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Accurate Determination of Energy Needs in Hospitalized Patients

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ABSTRACT

Objective To evaluate the accuracy of seven predictive equations, including the Harris-Benedict and the Mifflin equations, against measured resting energy expenditure (REE) in hospitalized patients, including patients with obesity and critical illness.

Design A retrospective evaluation using the nutrition support service database of a patient cohort from a similar timeframe as those used to develop the Mifflin equations.

Subjects/setting All patients with an ordered nutrition assessment who underwent indirect calorimetry at our institution over a 1-year period were included.

Intervention Available data was applied to REE predictive equations, and results were compared to REE measurements.

Main outcome measures Accuracy was defined as predictions within 90% to 110% of the measured REE. Differences >10% or 250 kcal from REE were considered clinically unacceptable.

Statistical analyses performed Regression analysis was performed to identify variables that may predict accuracy. Limits-of-agreement analysis was carried out to describe the level of bias for each equation.

Results A total of 395 patients, mostly white (61%) and African American (36%), were included in this analysis. Mean age±standard deviation was 56±18 years (range 16 to 92 years) in this group, and mean body mass index was 24±5.6 (range 13 to 53). Measured REE was 1,617±355 kcal/day for the entire group, 1,790±397 kcal/day in the obese group (n=51), and 1,730±402 kcal/day in the critically ill group (n=141). The most accurate prediction was the Harris-Benedict equation when a factor of 1.1 was multiplied to the equation (Harris-Benedict 1.1), but only in 61% of all the patients, with significant under- and overpredictions. In the patients with obesity, the Harris-Benedict equation using actual weight was most accurate, but only in 62% of patients; and in the critically ill patients the Harris-Benedict 1.1 was most accurate, but only in 55% of patients. The bias was also lowest with Harris-Benedict 1.1 (mean error −9 kcal/day, range +403 to −421 kcal/day); but errors across all equations were clinically unacceptable.

Conclusions No equation accurately predicted REE in most hospitalized patients. Without a reliable predictive equation, only indirect calorimetry will provide accurate assessment of energy needs. Although indirect calorimetry is considered the standard for assessing REE in hospitalized patients, several predictive equations are commonly used in practice. Their accuracy in hospitalized patients has been questioned. This study evaluated several of these equations, and found that even the most accurate equation (the Harris-Benedict 1.1) was inaccurate in 39% of patients and had an unacceptably high error. Without knowing which patient's REE is being accurately predicted, indirect calorimetry may still be necessary in difficult to manage hospitalized patients.

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Accurate determination of energy needs in hospitalized patients is vital because underfeeding and overfeeding of energy are both associated with undesirable consequences. A number of predictive equations for resting energy expenditure (REE) have been developed from actual energy expenditure measurements using indirect calorimetry, and are mostly based on modest numbers of healthy nonhospitalized individuals. The accuracy of these equations in underrepresented groups, such as those who are elderly, obese, and US-residing ethnic minorities, has been questioned (1-5). Their accuracy in hospitalized patients has also been questioned, particularly for critically ill, malnourished, and elderly patients (6-8). Furthermore, any error in REE obtained from predictive equations risks being magnified by the application of activity and injury factors used to empirically account for altered needs in acutely ill patients (9).

The most accurate method for determining REE in hospitalized patients is indirect calorimetry (10). This method relies on the measurement of oxygen consumption and carbon dioxide production to calculate whole body energy catabolism over 24 hours. The cost of the calorimeter and personnel needed to perform indirect calorimetry has led to the widespread use of predictive equations in most inpatient settings (5). The Harris-Benedict (11) equations are most commonly used in clinical practice, although the Mifflin-St Jeor (12) equations may yield greater accuracy in healthy and in obese adults than do the Harris-Benedict equations (5). Additional predictive equations commonly used in practice include the Ireton-Jones equation as published in 1992 (13), the guideline from the American College of Chest Physicians (14), and the Ireton-Jones equation for obese individuals (15). Equations used specifically to predict REE in critically ill patients include both the Swinamer (16) and the Penn State (17) formulas. The objective of this study was to evaluate the accuracy of the Harris-Benedict, Mifflin-St Jeor, Ireton-Jones 1992, American College of Chest Physicians, and Ireton-Jones equations against measured REE in hospitalized patients, as well as the accuracy of the Swinamer and Penn State equations in critically ill hospitalized patients. An evaluation of actual and adjusted body weights in patients with obesity was also performed.

General Equations

Harris-Benedict

Men $66.5+(13.8)(Wt^a)+(5)(Ht^b)-(6.8)(A^c)$

Women $655+(9.6)(Wt^a)+(1.8)(Ht^b)-(4.7)(A^c)$

Mifflin-St Jeor

Men $5+(10)(Wt^a)+(6.25)(Ht^b)-(5)(A^c)$

Women $-161+(10)(Wt^a)+(6.25)(Ht^b)-(5)(A^c)$

Ireton-Jones 1992

$1{,}925+(5)(Wt^a)-(10)(A^c)+(281)(G^d)+(292)(Tr^e)+(851)(B^f)$

American College of Chest Physicians

$(25)(Wt^a)$

Obesity

Ireton-Jones for obese individuals

$1{,}444+(606)(G^d)+(9)(Wt^a)-(12)(A^c)+(400)(V^g)$

Harris-Benedict (using adjusted body weight)

Hamwi×1.3

Men 48.2+(2.7)(in of height over 5 ft)

Women 45.5+(2.3)(in of height over 5 ft)

James×1.3

Men $(1.1013)(Wt^a)-(0.01281)(BMI^h)(Wt^a)$

Women $(1.07)(Wt^a)-(0.0148)(BMI^h)(Wt^a)$

Ventilated Patients

Swinamer

$-4{,}349+(945)(BSA^i)-(6.4)(A^c)+(108)(Temp^j)+(24.2)(RR^k)+(81.7)(TV^l)$

Penn State

$-6{,}433+(\text{Harris-Benedict})(0.85)+(V_E{}^m)(33)+(T_m{}^n)(175)$

Figure. Equations for predicting resting energy expenditure (kcal/d). [a]Weight (kg). [b]Height (cm). [c]Age (y). [d]Sex (1=man, 0=woman). [e]Trauma (1=present, 0=not present). [f]Burns (1=present, 0=not present). [g]Ventilated (1=present, 0=not present). [h]Body mass index (calculated as kg/m^2). [i]Body surface area (m^2). [j]Temperature (°C). [k]Respiratory rate (breaths per minute). [l]Tidal volume (L). [m]Minute ventilation (L/min). [n]Maximum temperature (°C).

METHODS

A retrospective evaluation of the nutrition support service REE database from 1991 was conducted. The project was approved by the Institutional Review Board of the University of Pennsylvania. This cohort reflects patients at a similar time to those used for the Mifflin-St Jeor equations. All patients for whom a nutrition assessment was ordered at the Hospital of the University of Pennsylvania that year underwent indirect calorimetry and were included in this study. If REE was measured multiple times on a given patient, only the first measure was considered. No diagnoses were excluded; however, any patients with an incomplete dataset were excluded.

Energy expenditure measurements were obtained by a single respiratory therapist using a strict protocol, under conditions typically seen with inpatients (18). REE was measured after a 30-minute rest, a minimum 2-hour fast (unless enteral or parenteral feedings were infusing continuously), with no movement by the patient in a thermoneutral environment. The Deltatrac metabolic cart (Sensormedics, Yorba Linda, CA) was allowed to warm up for 30 minutes in the patient's room before machine calibration against a test gas of 96% oxygen and 4% carbon dioxide. Steady state was achieved when the coefficient of variation for oxygen consumption and carbon dioxide production measures was 5% or less across 5 consecutive minutes.

Patient height in our database was a measured value when possible, or the value documented in the medical record at the time. Weight was measured using calibrated hospital scales in most patients. Body mass index (BMI) was calculated as kg/m^2. The last recorded temperature on a patient's vital signs record just before the REE measurement was documented. Also documented was whether or not the gas measure was collected by a canopy (for patients breathing room air) or through attachment to a mechanical ventilator circuit.

Patients were stratified for subsequent subset analysis according to three variables: by BMI as defined by the National Heart, Lung, and Blood Institute criteria (19) as underweight (BMI $<$18.5), desirable weight (BMI 18.5 to 24.9), overweight (BMI 25 to 29.9), and obese (BMI $\geq$30); by age tertiles; and by the method of REE gas collection (with a canopy or through a ventilator) as a reflection of patient acuity.

All REE predictions were calculated using actual body weight, with the series of tested equations shown in the Figure. For the entire cohort, the Harris-Benedict (11), the Mifflin-St Jeor (12), the Ireton-Jones 1992 (13), and the American College of Chest Physicians (14) REE predictions were calculated for each patient. In obese patients, the Ireton-Jones (15) and Harris-Benedict were calculated using actual weight and Harris-Benedict also using an adjusted body weight. The adjusted body weight was calculated using a lean weight based on either the Hamwi equation (20) or the James equation (21) multiplied by a factor of 1.3 (22). In addition, for the patients who were measured during mechanical ventilation while in an intensive care unit, the Swinamer (16) and Penn State (17) predictions were also determined.

The accuracy of these equations was defined as prediction values that fell within 90% to 110% of the measured REE. All other predictions falling outside this range were deemed inaccurate.

Descriptive statistics included mean±standard deviation REE values, and percent accuracy by patient subgroups. Pearson's correlation was used to compare measured REE to each predictive equation. Univariate and multivariate logistic regression was used to determine the odds of specific variables predicting accuracy of a given equation. The variables for logistic regression included age tertile (young and older tertile compared to middle-age tertile), race (African American compared to white), sex (women compared to men), BMI category (all other categories compared to desirable weight category), or ventilator status (ventilator compared to canopy measurement). Because the group of patients described as other race comprised only 10 members, logistic regression would not adequately describe their ability to predict equation accuracy, so they were dropped from the logistic regressions, but were included in all other statistical analyses. Data are presented as odds ratios, with *P* values, and 95% confidence intervals. The level of bias between the predicted and measured REE was evaluated using Bland-Altman limits of agreement analysis (23). A priori, an error of greater than 250 kcal or 10% difference from REE was considered clinically unacceptable. P values <0.05 were considered statistically significant. Statistical analyses were performed using SPSS (version 12.0, 2003, SPSS Inc, Chicago, IL).

RESULTS

Demographics

A total of 397 patients received at least one indirect calorimetry measurement of REE. Two patients were excluded for having missing height or weight. Of the remaining 395 patients, the mean age was 56±18 years (range 16 to 92 years). Whereas 61% were white, 36% were African American, and the remaining 3% were of Hispanic or Asian descent. The BMI values (13 to 53) covered all National Heart, Lung, and Blood Institute classifications, but the mean value fell in the desirable weight range (BMI 24±5.6). Most REE measures (64%) were taken using the canopy, but 141 patients (36%) were measured while on the ventilator in an intensive care unit. The diagnoses were typical for a tertiary medical center, that is, 40% surgical and 60% medical.

Energy Expenditure Values

The measured REE was 1,617±355 kcal/day (Table 1). The predicted REE by Harris-Benedict and by Mifflin-St Jeor equation was less than the measured REE (1,478±301 and 1,406±220 kcal/day, respectively), whereas the Ireton-Jones 1992 and American College of Chest Physicians predictions were greater than measured REE (1,920±341 and 1,764±444 kcal/day, respectively). When a factor of 1.1 was multiplied to the Harris-Benedict equation (Harris-Benedict 1.1) and the Mifflin-St Jeor equation, the percent of accurate predictions was improved with both equations, and REE was 1,626±331 and 1,546±242 kcal/day, respectively. For the subset of obese patients, the measured REE was 1,790±397 kcal/day. The Harris-Benedict prediction for these patients (using their actual body weight) was 1,771±375 kcal/day, and the Ireton-Jones predicted 2,079±474 kcal/day. Use of an adjusted body weight based on the Hamwi equation resulted in a prediction of only 1,554±317 kcal/day, and the James prediction was 1,602±263 kcal/day. For the mechanically ventilated patients, the measured REE was 1,730±402 kcal/day, the Swinamer and Penn State predictions were 1,696±360 and 1,536±327 kcal/day, respectively. This compares with 1,729±326 kcal/day using the Harris-Benedict 1.1 in this subgroup. All predictive equations were highly correlated with the measured REE, but no equation predicted more than 68% of the variance (data not shown). The high correlations are expected given the common source of data used therein.

Prediction Accuracy

Prediction accuracy for the entire group (Table 1) was 61% with Harris-Benedict 1.1. Maximum underprediction by the equations in the entire cohort ranged from 25% to 34%, with the Harris-Benedict 1.1 having the maximum underprediction of 34%. The maximal overprediction ranged from 62% to 109% of measured REE, and was least with the Harris-Benedict 1.1 equation. For the subgroup of obese patients, Harris-Benedict using current body weight predicted accurately more often (62%) than did Harris-Benedict using an adjusted weight (44% with Hamwi, 46% with James) or Ireton-Jones at 32%. For patients with obesity, the Harris-Benedict using actual weight had similar under- (26%) and overestimation (29%) errors. For the mechanically ventilated patients, Swinamer predicted accuracy in 45% while Penn State predicted accuracy in 43%; however, the Penn State equation prediction had considerably lower maximal under- (25%) and overpredictions (56%) than did Swinamer (33% and 116%, respectively).

Logistic Regression

For the entire group, both unadjusted and adjusted odds ratios for age, sex, race, BMI, and ventilator status are presented in Table 2. The Harris-Benedict 1.1, adjusted for age, sex, race, and ventilator status, predicted more accurately in overweight (1.8-fold odds) than desirable weight, but also predicted only half as accurately in underweight and obese persons. Adjusted for age, race, weight category, and ventilator status, the Mifflin-St Jeor equation multiplied by 1.1 predicted accurately 1.9-fold more often in men than women.

In the subset of obese patients (Table 3), logistic regression did not detect differences in prediction accuracy by any variable tested, for any of the four equation formats compared. For the subset of ventilated patients (Table 4),

Table 1. Accuracy of resting energy expenditure (REE) predictions in hospitalized patients					
Patient group	**Measured REE (kcal/d) mean±SD**	**Predicted REE (kcal/d) mean±SD[a]**	**Accurate predictions (%)**	**Maximum underprediction (%)**	**Maximum overprediction (%)**
All patients (n=395)	1,617±355				
HB[b]		1,478±301	43	28	78
HB multiplied by a factor of 1.1		1,626±331	61	34	62
MSJ[c]		1,406±220	35	25	83
MSJ multiplied by a factor of 1.1		1,546±242	58	32	66
IJ92[d]		1,920±341	28	29	93
ACCP[e]		1,764±444	43	32	109
Obese patients (n=51)	1,790±397				
HB_{CBW}[f]		1,771±375	62	26	29
IJO[g]		2,079±474	32	35	15
HB_{ABW}[h] [Hamwi]		1,554±317	44	19	59
HB_{ABW}[h] [James]		1,602±263	46	14	46
Ventilated patients (n=141)	1,730±402				
SWN[i]		1,696±360	45	33	116
PSU[j]		1,536±327	43	25	56
HB multiplied by a factor of 1.1		1,729±326	55	34	62

[a]SD=standard deviation.
[b]HB=Harris-Benedict equation.
[c]MSJ=Mifflin-St Jeor equation.
[d]IJ92=Ireton-Jones 1992 equation.
[e]ACCP=American College of Chest Physicians.
[f]CBW=current body weight used.
[g]IJ=Ireton-Jones obesity equation.
[h]ABW=adjusted body weight used.
[i]SWN=Swinamer equation.
[j]PSU=Penn State University 2004 equation.

using the Penn State equation, adjusted for age, race, and weight status, the odds of accurate prediction were almost 2.8 times greater in men than in women. Adjusted for age, sex, and race, the Penn State equation was four times as likely to predict accurately in the desirable weight as in the patients with obesity.

Bias and Precision

Bland-Altman limits of agreement analysis was undertaken to determine the extent of error with each predictive equation compared to the measured REE. For the entire patient group, the bias was lowest with the Harris-Benedict 1.1 predictive equation (mean error −9 kcal/day); however, the extent of error could be between +403 kcal and −421 kcal daily. For the subset of obese patients, the mean error was least using Harris-Benedict with current body weight (+47 kcal/day) but the error could be 534 kcal above or 440 kcal below this mean. For the ventilated patients, Harris-Benedict 1.1 had the lowest bias (−0.3 kcal/day) but the error range was +501 to −501 kcal/day. The errors across all equations were greater than the 250 kcal maximum stated a priori.

DISCUSSION

Overview

None of the equations accurately predicted REE in most hospitalized patients regardless of age, sex, race, BMI, or ventilator status. Even with the most accurate overall prediction equation (Harris-Benedict 1.1), 39% of patients' energy expenditures were still predicted inaccurately with an error that could be as great as 400 kcal above or below the measured REE—an error that would result in weight change if applied to energy delivery. For patients with obesity, the Harris-Benedict equation predicted accurately in more patients (62%) than any other equation, although the mean error was 47 kcal, with limits of agreement between +534 and −440 kcal. For the patients receiving mechanical ventilator support, the Harris-Benedict 1.1 predicted accurately more often than other equations, but its mean bias was −0.3 kcal/day with a large error range (±500 kcal). Altogether, these findings underscore the urgency for measuring REE in clinical situations where accurate knowledge of energy needs is vital.

Inaccuracy: Rationale and Consequence

It may be argued that inaccurate predictions are to be expected when equations developed long ago (eg, the Harris-Benedict) or based on data from healthy volunteers (eg, Harris-Benedict and Mifflin-St Jeor) are applied to ill hospitalized patients. The Harris-Benedict equation represents REE as developed from 239 mostly normal weight, white men and women evaluated in the first 2 decades of the 20th century (11). The poor resemblance of those healthy samples to hospitalized patients seen currently includes a greater diversity in body composition, obesity, and race. The Mifflin-St Jeor equation was derived in a group of 498 healthy subjects, 47% of

Table 2. Subgroup analysis of predictive equation accuracy relative to measured resting energy expenditure in hospitalized patients

Subgroup	Statistical measure	HB[a]	HB 1.1[b]	MSJ[c]	MSJ 1.1[d]	IJ92[e]	ACCP[f]
Age (y)[g]	OR[h] (*P* value)	1.21 (0.023)	0.98 (0.791)	1.12 (0.188)	1.01 (0.861)	0.68 (0.000)	0.99 (0.904)
16-49 (n=131)	Adjusted OR	1.95	1.12	1.54	0.95	0.30	0.99
	95% CI[i]	(1.14-3.32)	(0.66-1.88)	(0.87-2.67)	(0.57-1.60)	(0.15-0.59)	(0.57-1.70)
	P value	0.014	0.678	0.141	0.851	0.000	0.957
50-67 (n=130)	—	—	—	—	—	—	—
68-92 (n=134)	Adjusted OR	1.61	1.57	2.34	0.99	0.68	0.48
	95% CI	(0.96-2.70)	(0.93-2.65)	(1.36-4.01)	(0.60-1.64)	(0.40-1.16)	(0.28-0.82)
	P value	0.070	0.090	0.002	0.975	0.154	0.007
Sex[j]	OR (*P* value)	1.85 (0.003)	1.15 (0.496)	0.60 (0.018)	0.55 (0.004)	0.93 (0.742)	0.59 (0.011)
Male (n=221)	—	—	—	—	—	—	—
Female (n=174)	Adjusted OR	1.83	1.09	0.51	0.52	0.71	0.60
	95% CI	(1.18-2.83)	(0.70-1.70)	(0.32-0.81)	(0.34-0.80)	(0.43-1.17)	(0.38-0.96)
	P value	0.007	0.709	0.004	0.003	0.180	0.032
Race[k]	OR (*P* value)	1.18 (0.118)	1.03 (0.815)	1.01 (0.960)	1.04 (0.742)	0.84 (0.152)	0.84 (0.103)
White (n=242)	—	—	—	—	—	—	—
African American (n=143)	Adjusted OR	1.33	1.15	1.06	1.15	0.92	0.67
	95% CI	(0.86-2.06)	(0.73-1.79)	(0.67-1.68)	(0.74-1.77)	(0.55-1.53)	(0.42-1.07)
	P value	0.205	0.553	0.795	0.537	0.74	0.092
Weight category[l]	OR (*P* value)	1.03 (0.683)	0.99 (0.904)	0.94 (0.427)	1.15 (0.074)	0.98 (0.838)	0.80 (0.005)
Under (n=50)	Adjusted OR	0.83	0.54	0.67	1.75	0.33	0.47
	95% CI	(0.42-1.64)	(0.28-1.04)	(0.33-1.38)	(0.88-3.48)	(0.11-0.99)	(0.24-0.92)
	P value	0.593	0.064	0.279	0.113	0.049	0.028
Desirable (n=196)	—						
Over (n=98)	Adjusted OR	1.61	1.87	0.94	1.17	3.16	0.40
	95% CI	(0.97-2.67)	(1.088-3.23)	(0.55-1.60)	(0.71-1.94)	(1.81-5.50)	(0.24-0.68)
	P value	0.068	0.026	0.805	0.536	0.000	0.001
Obese (n=51)	Adjusted OR	2.27	0.46	2.59	1.00	2.65	0.09
	95% CI	(1.17-4.39)	(0.24-0.88)	(1.33-5.04)	(0.53-1.90)	(1.31-5.34)	(0.03-0.23)
	P value	0.015	0.019	0.005	0.994	0.006	0.000
Ventilator status[m]	OR (*P* value)	1.04 (0.839)	0.70 (0.100)	1.18 (0.457)	0.96 (0.827)	0.75 (0.220)	0.62 (0.029)
Canopy (n=254)	—						
Ventilator (n=141)	Adjusted OR	1.01	0.65	0.95	0.87	0.57	0.55
	95% CI	(0.64-1.59)	(0.41-1.03)	(0.59-1.51)	(0.56-1.36)	(0.34-0.95)	(0.34-0.90)
	P value	0.979	0.066	0.818	0.533	0.032	0.016

[a]HB=Harris-Benedict equation.
[b]HB 1.1=Harris-Benedict equation multiplied by a factor of 1.1.
[c]MSJ=Mifflin-St Jeor equation.
[d]MSJ 1.1=Mifflin-St Jeor equation multiplied by a factor of 1.1.
[e]IJ92=Ireton-Jones 1992 equation.
[f]ACCP=American College of Chest Physicians equation.
[g]Compared to the middle-aged group.
[h]OR=odds ratio.
[i]CI=confidence interval.
[j]Compared to males.
[k]Compared to the white group.
[l]Compared to the desirable weight group.
[m]Compared to the canopy group.

whom were defined as obese (12). Measurements were obtained for subjects in the current cohort during the same time frame as subjects studied for the Mifflin-St Jeor equation. The original Harris-Benedict and Mifflin-St Jeor papers describe the correlation between the respective predictive equations and measured REE (r^2=0.53 and 0.71, respectively) (11,12). This is not much different from how the Harris-Benedict and Mifflin-St Jeor equations performed with the current data (r^2=0.67 and 0.68, respectively); however, the original publications do not describe the extent of error. The accuracy and extent of error provides more clinically useful information on predictive equations than does the measure of correlation. The Ireton-Jones 1992, American College of Chest

Table 3. Subgroup analysis of predictive equation accuracy relative to measured resting energy expenditure in obese hospitalized patients					
Subgroup	**Statistical measure**	**HB^{a}_{CBW}[b]**	**IJO[c]**	**HB_{ABW}[d] [Hamwi]**	**HB_{ABW} [James]**
Age (y)[e]	OR[f] (*P* value)	1.63 (0.057)	1.10 (0.8)	1.20 (0.427)	0.91 (0.682)
16-45 (n=17)	Adjusted OR	4.52	1.31	2.44	1.00
	95% CI[g]	(0.89-23.01)	(0.25-6.79)	(0.56-10.72)	(0.23-4.35)
	P value	0.069	0.75	0.238	0.995
46-65 (n=17)	—	—	—	—	—
66-86 (n=16)	Adjusted OR	4.55	0.80	2.93	4.42
	95% CI	(0.91-22.90)	(0.18-3.62)	(0.66-13.08)	(0.96-20.34)
	P value	0.066	0.78	0.159	0.057
Sex[h]	OR (*P* value)	0.50 (0.268)	0.73 (0.63)	10.48 (0.220)	0.55 (0.312)
Male (n=32)	—	—	—	—	—
Female (n=18)	Adjusted OR	0.33	0.48	0.53	0.53
	95% CI	(0.07-1.51)	(0.12-2.01)	(0.15-1.90)	(0.14-1.97)
	P value	0.151	0.31	0.333	0.340
Race[i]	OR (*P* value)	1.69 (0.117)	1.09 (0.77)	0.89 (0.703)	1.00 (0.990)
White (32)	—	—	—	—	—
African American (n=17)	Adjusted OR	4.47	0.83	0.90	1.56
	95% CI	(0.91-21.92)	(0.22-3.13)	(0.24-3.32)	(0.41-5.94)
	P value	0.065	0.78	0.871	0.515
Ventilator status[j]	OR (*P* value)	1.29 (0.666)	0.54 (0.32)	1.86 (0.285)	1.59 (0.420)
Canopy (n=27)	—	—	—	—	—
Ventilator (n=23)	Adjusted OR	1.08	0.38	1.24	1.01
	95% CI	(0.26-4.40)	(0.09-1.66)	(0.35-4.35)	(0.28-3.73)
	P value	0.916	0.19	0.736	0.986

[a]HB=Harris-Benedict equation.
[b]CBW=current body weight.
[c]IJO=Ireton-Jones obesity equation.
[d]ABW=adjusted body weight.
[e]Compared to the middle-aged group.
[f]OR=odds ratio.
[g]CI=confidence interval.
[h]Compared to males.
[i]Compared to the white group.
[j]Compared to the canopy group.

Physicians, Swinamer, and Penn State equations were in fact developed from hospitalized patient data sets (13,14,16,17), but their accuracy in predicting REE is actually considerably below that of Harris-Benedict 1.1 based on these findings. It is possible that the original Harris-Benedict equation particularly with the 1.1 factor, which often overestimates REE in healthy adults, may by chance better match the degree of hypermetabolism seen in hospitalized patients.

An error may be less concerning with a healthy population, but in seriously ill patients, major errors can translate into complications, including underfeeding and overfeeding patients, when the data are applied to energy delivery (24). Underfeeding risks further unintentional and even iatrogenic weight loss in patients who, in this data set had a baseline BMI as low as 13, or weight gain in those with BMI up to 53. None of the factors we evaluated (ie, age, race, sex, BMI category, or ventilator status) adequately predicted which patients would suffer inaccurate predictions from most equations. It is, therefore, impossible to distinguish in practice which individual patient will have inaccurate predictions from each equation. In the years since these data were collected, both patient adiposity and patient acuity have only worsened. For this reason, the findings from this study may actually understate the poor accuracy of these equations in current practice.

Obesity

Both the Harris-Benedict and Mifflin-St Jeor equations were considered in a recent systematic review of predictive equations for use in healthy adults with and without obesity (5). Predictive equations became less accurate when applied to obese, but otherwise healthy, adults and incurred a greater range of errors (5). The Mifflin-St Jeor equation performed better than the Harris-Benedict equation in obese but otherwise healthy adults (prediction accuracy 70% vs 38% to 64%, respectively), with maximum over- and underestimates exceeding 10% with either equation (5). The Harris-Benedict equation is five times more likely to overpredict than underpredict REE regardless of BMI, whereas the Mifflin-St Jeor equation is more than twice as likely to underpredict REE in obese subjects (25). In one study of obese outpatients (mean BMI 38.9), REE was accurately predicted in 59% using the Harris-Benedict equations, with near equal proportions under- and overpredicted (22). The

Table 4. Subgroup analysis of predictive equation accuracy relative to measured resting energy expenditure in hospitalized patients receiving ventilator support

Subgroup	Statistical measure	SWN[a]	PSU[b]	HB 1.1[c]
Age (y)[d]	OR[e] (*P* value)	0.96 (0.737)	1.18 (0.230)	0.76 (0.19)
16-45 (n=45)	Adjusted OR	0.89	1.91	0.47
	95% CI[f]	(0.38-2.11)	(0.77-4.75)	(0.18-1.22)
	P value	0.791	0.165	0.12
46-65 (n=47)	—	—	—	—
66-86 (n=49)	Adjusted OR	1.09	2.12	1.04
	95% CI	(0.46-2.54)	(0.84-5.36)	(0.43-2.49)
	P value	0.852	0.111	0.94
Sex[g]	OR (*P* value)	0.91 (0.787)	0.36 (0.010)	1.13 (0.75)
Male (n=96)	—	—	—	—
Female (n=45)	Adjusted OR	0.89	0.36	0.83
	95% CI	(0.42-1.87)	(0.16-0.81)	(0.38-1.78)
	P value	0.757	0.013	0.63
Race[h]	OR (*P* value)	0.90 (0.525)	1.05 (0.779)	0.95 (0.88)
White (n=82)	—			
African American (n=57)	Adjusted OR	0.92	1.09	1.35
	95% CI	(0.44-1.95)	(0.49-2.42)	(0.62-2.92)
	P value	(0.832)	(0.834)	(0.45)
Body weight[i]	OR (*P* value)	1.16 (0.311)	0.77 (0.094)	1.03 (0.87)
Under (n=8)	Adjusted OR	0.95	0.24	2.17
	95% CI	(0.20-4.46)	(0.04-1.38)	(0.39-11.92)
	P value	0.948	0.110	0.37
Desirable (n=69)	—	—	—	—
Over (n=41)	Adjusted OR	2.10	0.61	1.27
	95% CI	(0.95-4.66)	(0.27-1.39)	(0.27-6.07)
	P value	0.068	0.238	0.76
Obese (n=33)	Adjusted OR	1.79	0.24	0.48
	95% CI	(0.67-4.75)	(0.08-0.75)	(0.09-2.45)
	P value	0.243	0.014	0.37

[a]SWN=Swinamer equation.
[b]PSU=Penn State University 2004 equation.
[c]HB 1.1=Harris-Benedict equation multiplied by a factor of 1.1.
[d]Compared to the middle-aged group.
[e]OR=odds ratio.
[f]CI=confidence interval.
[g]Compared to males.
[h]Compared to the white group.
[i]Compared to the normal-weight group.

Harris-Benedict equation accurately predicted REE in 62% of obese patients (mean BMI 35.1) in our study, also with near equal portions under- and overpredicted, despite the fact that these patients were hospitalized.

When estimating REE with the Harris-Benedict equation in patients with obesity, use of actual body weight has been reported to significantly overpredict (39% accurate), while use of ideal body weight significantly underpredicts (13% accurate) measured REE (26). Although this has led many to use an adjusted body weight for patients with obesity, we found that actual body weight performed more accurately than did an adjusted body weight in the Harris-Benedict equation.

According to 2003-2004 National Health and Nutrition Examination Survey data collected in nonhospitalized individuals, more than 32% of American adults are classified as obese and nearly 5% have severe obesity (27). These current rates reflect an increase in obesity prevalence from 23% and severe obesity from 2.9% in 1988 through 1994 (the time frame reflected in the current data set) (27). In addition, the prevalence of individuals with a BMI ≥50 increased by fivefold, compared to only a doubling of the rate in those with BMI ≥30 seen during roughly the same time period (1986 through 2000) (28,29). Clearly, these data suggest significant risk of poor estimation of energy need in this obese group using any of the equations tested.

Patient Acuity

The patients who required mechanical ventilation reflect greater patient acuity, although no disease severity scores were available. Increased acuity may be associated with increased oxygen consumption and hence REE, thus broadening the gap between predictive equations derived from healthy individuals and measured values—so poor predictive accuracy is not unexpected. Mechanical ventilator support was not associated with greater likelihood of accurate prediction of REE by any equation tested in our study, suggesting that this intervening factor did not describe an important difference between patients. The Harris-Benedict 1.1 equation actually predicted REE more accurately (in 55%) than either Swinamer or Penn State in these 141 critically ill patients, with a smaller error (Table 1)—but logistic regression did not identify any factors predictive of greater measurement accuracy.

The Harris-Benedict equation with an appropriate factor applied has been recommended over several other predictive equations for short-term use in the absence of indirect calorimetry in nonobese acutely ill patients (30); however, the potential error obtained from this equation was not described. We find the error associated with Harris-Benedict 1.1 in more than one third of patients to be high enough to result in unintentional weight change if applied to energy delivery. A previous study performed only in mechanically ventilated patients concurred that predictive equations did not accurately estimate REE (r^2=0.53) (31). With a regression equation using body weight, height, temperature, and minute ventilation, the authors obtained a slightly stronger correlation (r^2=0.61), but almost 40% of their patients were not predicted well from this equation.

Both acuity levels and sedation may influence REE measures. In a cohort of 46 critically ill patients (mean Acute Physiology and Chronic Health Evaluation II score of 18) the ratio of the REE to the Harris-Benedict prediction was 1.25 (32). In a retrospective evaluation of 76 mechanically ventilated, critically ill adult patients, Harris-Benedict multiplied by a factor of 1.2 was the least biased compared to Harris-Benedict, Ireton-Jones, and American College of Chest Physicians against measured REE (33). Their mean error when using the Harris-Benedict equation multiplied by 1.2 was −78 kcal/day, with a precision of 16.1%. Despite the significant acuity of the mechanically ventilated, critically ill patients in this study, the measured REE was 22.7±4.8 kcal/kg, compared with about 27 kcal/kg in the study by Alexander and colleagues (33). This lower REE from our study may in part be explained by the recognized increase in patient acuity during the past 10 years. Another may be the more widespread use of sedation, analgesia, and neuromuscular blockade at the time, a factor not documented for these patients. Critically ill patients today are less likely to be pharmacologically paralyzed, and more likely to receive closely managed sedation and analgesia. These medication regimens can have a significant influence on REE and need to be accounted for in future protocols (34). In a recent prospective clinical evaluation of postoperative patients in an intensive care unit who were receiving mechanical ventilation with sedation and analgesia, there was a statistically significant decrease in oxygen consumption and REE noted with increasing depth of sedation (35). In a prospective clinical observation of patients with severe head injury controlled for level of sedation/analgesia, body temperature was the major determinant of REE, and sepsis increases REE independently of fever (36).

The dynamic clinical status in critically ill patients may also influence the ability of equations to accurately predict REE, likely varying at different stages of the disease process. REE has been shown to be approximately 35 kcal/kg in critically ill patients with multiple injuries, or about 42 kcal/kg in those with sepsis and to be correlated with injury and septic severity scores (37). REE has been described as increasing progressively during the first week after the onset of major trauma or severe sepsis, peaking well above predicted values during the second week. Mean energy expenditure has been reported at 47 kcal/kg (week 1) and then 59 kcal/kg (week 2) in trauma, or 25 kcal/kg (week 1) and then 31 kcal/kg (week 2) in patients with sepsis in 1999 (38). By contrast, in a prospective study of 26 multiple trauma patients, continuous indirect calorimetry measurements did not correlate with various acuity scores, and the Harris-Benedict equation with adjustments for trauma did not accurately predict REE, with a mean error of +239 kcal/day, but with limits of agreement between −363 kcal/day to +941 kcal/day (39). In this patient group, where the time of REE measurement relative to date of injury or sepsis was not documented, predictive equations did not agree with measured REE.

CONCLUSION

Indirect calorimetry remains the gold standard for assessment of REE in hospitalized patients. Based on the data presented, the most accurate predictive equation (Harris-Benedict 1.1) did not accurately predict measured REE in 39% of patients, and the error was high. For patients with obesity, using Harris-Benedict with current weight but no added factor improves accuracy somewhat, but the errors are still large. Because it is impossible to know which patients are being predicted inaccurately, measuring REE by indirect calorimetry is indicated, and can provide considerably more accurate assessment of energy needs. A clearer understanding of all the factors that influence REE in hospitalized patients and the degree to which they each do so in various subgroups, may lead to better predictive equations. Given the resources required to measure REE in hospitalized patients, an accurate predictive equation would be welcome.

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