Assessing Hypermetabolism and Hypometabolism in the Postoperative Critically Ill Patient*

Charles Weissman, M.D.; and Marcia Kemper, B.A., C.R.T.T.

To determine whether a patient is hypermetabolic or hypometabolic, measured resting energy expenditure is compared with estimated (or predicted) energy expenditure. The latter is calculated using equations derived from measurements made in groups of healthy individuals. Body weight or body surface area are among the variables used in these equations. Yet, in critically ill patients, body weight often rises because of fluid resuscitation. This study examined the difference between using preoperative, postoperative, and ideal body weights on the determination of hypermetabolism and hypometabolism in mechanically ventilated, critically ill patients. When the elevated postoperative weights were used instead of the preoperative ones to predict energy expenditure, the degree of hypermetabolism was underestimated. Subtracting the weight of the cumulative net fluid balance from the postoperative weight was found to accurately reflect preoperative weight. The influence of various predictive equations on the magnitude of hypermetabolism was also explored. In conclusion, it is important, when determining hypermetabolism or hypometabolism, to consider the influence of the specific predictive equation used and the effect of resuscitation fluid.

Assessing the altered metabolic homeostasis in critically ill patients involves examining a variety of parameters, including energy and nitrogen balance and the utilization of substrates such as protein, carbohydrates, and lipids. Measuring metabolic rate helps to determine caloric requirements and whether the patient is hypermetabolic or hypometabolic. To determine the patient's metabolic state, measured values are compared with estimated (or predicted) resting energy expenditure. The latter is calculated using equations derived from measurements made in large groups of healthy subjects. Height, body weight, age, and body surface area are the variables used in these equations. Yet, in the critically ill patient, pre-illness weights are often unavailable and/or the patient is unable to report his usual weight. Also, body weight is often increased by the fluid infused for hemodynamic resuscitation. Using the actual body weight to predict energy expenditure may thus result in an artificially inflated prediction that may interfere with the accuracy of the determinations of hypermetabolism or hypometabolism.

Patients undergoing major elective abdominal, vascular, or thoracic surgery serve as good subjects for assessing the effects of fluid resuscitation on the determination of hypermetabolism and hypometabolism since preoperative weights are often available. This study quantitated the influence of peroperative body weight change on predicted energy expenditure and on the subsequent calculation of metabolic state. This was performed using preoperative, postoperative, and ideal body weights. In addition, the degree of hypermetabolism and hypometabolism calculated using various predictive equations was examined.

Methods

Patients admitted to the Surgery-Anesthesiology Intensive Care Unit of the Columbia-Presbyterian Medical Center for mechanical ventilation following major elective abdominal, vascular, or thoracic surgery were included in this study. Only patients who had been weighed prior to surgery were studied. On the morning following surgery, they were again weighed and had their resting energy expenditure calculated from measurements of oxygen consumption and carbon dioxide production. In addition, their ideal body weights were determined using the 1975 National Academy of Science RDA (recommended daily allowance) tables.

Resting Energy Expenditure

Resting energy expenditure was calculated from measurements of oxygen consumption and carbon dioxide production (obtained with a Datex Deltrac, Sensor Medics, Yorba Linda, Calif.). This instrument has been validated in vivo with a lung simulator and found to be accurate to within ±5 percent of expected values. The instrument was calibrated before each measurement session with a gas mixture of 96 percent O₂ and 4 percent CO₂. All patients were being mechanically ventilated (using Bear II, III, Bear Medical Systems, Riverside, Calif., or Puritan-Bennett 7200, Puritan-Bennett, Carlsbad, Calif.) ventilators. To ensure a stable inspiratory oxygen concentration, the air and oxygen intakes of the ventilators were attached to a single oxygen blender (Bennett AO-1 oxygen blender). Inspired oxygen concentrations ranged from 35 to 50 percent. During each measurement session, a log of the patient's activity state was kept, being at rest was defined as lying motionless with eyes open, responsive to surrounding events. The oxygen consumption and carbon dioxide production values from the resting periods were then used to calculate resting energy expenditure (REE) with the Weir equation.

\[
\text{Energy expenditure (Kcal/day)} = (3.9 \text{ VO}_2 + 1.1 \text{ VCO}_2) \times 1.44
\]

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Table 1—Weights and Measured Resting Energy Expenditure (REE)*

<table>
<thead>
<tr>
<th></th>
<th>Preoperative Weight, kg</th>
<th>Postoperative Weight, kg</th>
<th>Ideal (1975) Weight, kg</th>
<th>Measured REE, Kcal/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>All (N = 30)</td>
<td>69.2 ± 13.5</td>
<td>74.2 ± 12.4</td>
<td>69.8 ± 9.0</td>
<td>1540 ± 320</td>
</tr>
<tr>
<td>Male (N = 17)</td>
<td>73.4 ± 11.6</td>
<td>76.9 ± 9.5</td>
<td>76.0 ± 6.9</td>
<td>1624 ± 257</td>
</tr>
<tr>
<td>Female (N = 13)</td>
<td>63.8 ± 13.8</td>
<td>70.7 ± 14.6</td>
<td>61.5 ± 2.6</td>
<td>1414 ± 376</td>
</tr>
</tbody>
</table>

*Values are mean ± SD.

In 21 patients, the perioperative fluid balance was calculated from the beginning of surgery until the time of REE measurement.

**Predicted energy expenditure**

Energy expenditure was predicted using a number of commonly used equations. These included the following:

(1) The Harris-Benedict equation.
   
   Male subjects: REE = 66.47 + 13.75(W) + 5.0033(H) + 6.755(A)
   
   Female subjects:
   
   REE = 655.1 + 9.65(W) + 1.8496(H) - 4.6759(A), where
   
   W = body weight (kg), A = age (years), and H = height (cm).

(2) The equations of Boothby, as derived by Staats et al.:

   Male subjects: (20 to 74 years old) c/BSA/hr = 43.66 - 0.1329(A)
   
   Female subjects: (20 to 74 years old) c/BSA/hr = 38.65 - 0.909(A)
   
   BSA = 0.00718 x W0.43 x H0.72, where
   
   c = basal metabolic requirements,
   
   BMR (kcal/24 hour) = (c/BSA/hr) x BSA x 24, and
   
   BSA = body surface area.

(3) The equations of Owen.

   Nonathletic men: RMR = 787 + 10.2(W);
   
   Nonathletic women: RMR = 575 + 7.8(W).

(4) The equations of Quebbeman et al.:

   Male subjects: REE = 798(BSA) + 137
   
   Female subjects: REE = 544(BSA) + 414

**Data Analysis**

The estimated REE was calculated with the predictive equations using preoperative, postoperative, and ideal body weights. The ratio, measured REE/estimated REE, was calculated for each estimated REE. Also, the estimated preoperative weight was determined by subtracting the weight of the net postoperative fluid balance from the postoperative weight.

Statistical analysis was performed using repeated measures analysis of variance with the Tukey post hoc test. Linear regression analysis was used to examine the relationship between measured and predicted REE. All values are mean ± SD. This study was approved by the Institutional Review Board of the Columbia-Presbyterian Medical Center.

**RESULTS**

Thirty patients, 17 male and 13 female, were studied. They ranged in age from 56 to 88 years (average, 68 ± 9 years). All except four had undergone major abdominal (abdominal aortic aneurysm repair, nine; radical nephrectomy, three; pancreatic abscess drainage, two; radical cystectomy, two; colectomy, two; gastrectomy, three; abdominal hysterectomy, one) or thoracic (esophagogastrectomy, one, pneumonectomy, one, repair of aortic dissection, one, pulmonary lobectomy, one) elective surgery. The four patients had undergone peripheral lower extremity vascular bypass surgery.

The postoperative, preoperative, and ideal body weights, as well as the measured REE, are shown in Table 1. In all patients there was an increase in body weight. Metabolic rate predicted using the Harris-Benedict, Quebbeman, Staats, and Owen equations can be found in Table 2. The correlation between measured and predicted REEs, using the various equations, ranged from r = 0.48 to 0.50 using the graph:

**Figure 1.** The ratios of measured to predicted resting energy expenditure, using preoperative and postoperative body weights. Values are mean ± SE.
Table 3—Weight of Patients in Whom Fluid Balance Was Calculated (N = 21)

<table>
<thead>
<tr>
<th></th>
<th>Preoperative Weight, kg</th>
<th>Postoperative Weight, kg</th>
<th>Postoperative Weight Minus Net Fluid Balance, kg</th>
<th>Measured REE, kcal/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>67.6 ± 14.4</td>
<td>72.9 ± 13.4</td>
<td>67.2 ± 13.0</td>
<td>1,572 ± 329</td>
</tr>
<tr>
<td>Male</td>
<td>71.8 ± 11.9</td>
<td>76.8 ± 10.3</td>
<td>71.6 ± 10.4</td>
<td>1,645 ± 280</td>
</tr>
<tr>
<td>Female</td>
<td>62.9 ± 15.3</td>
<td>68.6 ± 15.0</td>
<td>62.4 ± 13.9</td>
<td>1,386 ± 318</td>
</tr>
</tbody>
</table>

postoperative weight and r = 0.53 to 0.62 using the preoperative weight. The correlation coefficient for the Harris-Benedict equation was 0.57 using the postoperative and 0.62 for the preoperative weight. The ratios of measured to predicted REEs can be found in Figure 1.

Fluid intake and output data were available in 21 of the patients studied. Subtracting the weight of the net fluid balance from the postoperative weight provided good estimates of the preoperative weight (Table 3) and REE (Table 4).

The influence of a 1-kg increase in body weight on predicted energy expenditure is shown in Figure 2. The increase in predicted energy expenditure with increasing weight was dependent on the patient’s sex and the equation employed.

**Discussion**

This study demonstrates the problems encountered when determining hypermetabolism or hypometabolism by comparing measured with estimated REE in critically ill patients. The particular equation and/or the weight used in the calculation influences the predicted energy expenditure and thus, the estimate of hypermetabolism or hypometabolism. Weight, inflated by resuscitation fluid, increases the predicted REE and reduces the apparent degree of hypermetabolism and increases the apparent degree of hypometabolism. It is important to realize that the increase in metabolic rate following elective surgery ranges from 7 percent after cholecystectomy to 10 to 20 percent after more extensive surgery.11 This is consistent with the present data, wherein the ratio of measured to predicted (Harris-Benedict) REE was 1.11 ± 0.21 using preoperative weights and 1.06 ± 0.21 using postoperative weights. This confirms the previous observations that elective major surgery results in only a modest rise in energy expenditure.

Hypermetabolism and hypometabolism can be evaluated in two ways. One can compare the metabolic rate in the healthy or preoperative individual with that following an intervention such as surgery.13 In the clinical arena, however, there is often no opportunity to measure preillness or preprocedure metabolic rate. Therefore, hypermetabolism and hypometabolism is determined by comparing the measured with predicted metabolic rates. As this study points out, this latter method is problematic, especially in the critically ill patient. The specific predictive equation can influence the apparent degree of hypermetabolism (Fig 2). The Harris-Benedict equation predicted lower energy expenditures than the other equations, while the Quebbeman equation predicted the highest expenditures. This is not unexpected, since the Quebbeman equation was derived from metabolic rates measured in surgical patients. In contrast, the other equations were derived from studies performed on healthy subjects. The Harris-Benedict and the basis of the Staats equation (the work of Boothby) were published in 1919, ie, in the early part of the 20th century.8 They thus reflect the body habitus and weights of people of that era. The Owen equation is based on measurements made during the 1980s. It predicts higher metabolic rates than the Harris-Benedict equations, likely because modern Americans are taller and heavier. The Harris-Benedict equations are also the only ones that account for age. This is important since basal metabolic rate decreases with age, due to an increase in body fat and decline in lean body mass.14-16 The Harris-Benedict equation is still the most commonly used predictive equation for determining hypermetabolism and hypometabolism, as revealed by a review of the literature.17-34 In some articles,31,30,31,32,33,34 the nomograms of Fleisch35 and Clifton

Table 4—Measured/Predicted Resting Energy Expenditure (N = 21): Predicted Resting Energy Expenditure Using the Following Weight

<table>
<thead>
<tr>
<th></th>
<th>Preoperative Weight, kg</th>
<th>Postoperative Weight, kg</th>
<th>Postoperative Weight Minus Net Fluid Balance, kg</th>
<th>Ideal Body Weight, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harris-Benedict</td>
<td>1.11 ± 0.13</td>
<td>1.05 ± 0.13</td>
<td>1.11 ± 0.14</td>
<td>1.07 ± 0.20</td>
</tr>
<tr>
<td>Quebbeman</td>
<td>1.00 ± 0.15</td>
<td>0.97 ± 0.15</td>
<td>1.00 ± 0.16</td>
<td>0.99 ± 0.20</td>
</tr>
<tr>
<td>Staats</td>
<td>1.05 ± 0.13</td>
<td>1.01 ± 0.13</td>
<td>1.05 ± 0.14</td>
<td>1.02 ± 0.19</td>
</tr>
<tr>
<td>Owens</td>
<td>1.03 ± 0.16</td>
<td>0.99 ± 0.16</td>
<td>1.01 ± 0.16</td>
<td>0.99 ± 0.21</td>
</tr>
</tbody>
</table>

Assessing Hypermetabolism and Hypometabolism (Weissman, Kemper)
et al.,36 Boothby et al.,36 and the equations of Quebbeman et al.51 and Kleiber (cited by Bartlett et al.52) were used. In a few articles, no method of prediction was mentioned.25,28 The weight used in the prediction was not mentioned in many articles.15,25,29-34 Presumably, it was the weight at time of study. When the weight was specified,7,8,17,27-29,30 it was the one taken at the time of the metabolic measurement or the patient's "usual body weight."40

Some investigators have used ideal body weight in their predictive equations.41 These "ideal," "desirable," and "recommended" weights have been developed by the life insurance industry to identify weights associated with the lowest mortality rates.42 The best known of these tables were issued by the Metropolitan Life Insurance Company in 1959 and 1985. The ideal weights for a given height and frame differ, depending on the table used. For example, in the present study, the weights from the 1975 RDA table were used. They are lower than those from the 1989 table. It is thus important to realize that predicted metabolic rate, using ideal weight, is useful only to predict the "ideal" metabolic rate, which does not appear to have much clinical utility.41

Critical illness, in general, and following surgery, in particular, results in increases in body weight secondary to fluid resuscitation. The weight changes following uncomplicated major abdominal surgery are dynamic, with an initial increase over the first 36 to 48 hours followed by a decrease over the next several days. In patients with complications and/or sepsis, the increase in body water may persist for days or weeks. The effect of increased body water on body weight is demonstrated in the present study. The short-term increase in total body water—a metabolically inactive substance—due to perioperative fluid resuscitation resulted in the predictive equations underestimating the degree of hypermetabolism. Correcting body weight for net fluid may be a way to reduce the influence of fluid resuscitation on the prediction of REE (Tables 3 and 4). Ideally, lean body (or fat free) mass should be used when predicting energy expenditure,1 since cellular composition (ie, fat:muscle proportions) determines metabolic rate. The larger the muscle mass, the greater the energy expended. Two patients with similar body weights may thus have different amounts of metabolically active tissue.14

Currently, measurements of lean body mass are not in routine clinical use, although estimations of total body potassium43,44 and bioimpedence45 are used in the investigative setting. Therefore, weight or body surface are used in predictive equations. The use of the body surface area (derived again from weight) has been used to reduce the problems associated with weight. Owen3 indicated that 50 to 75 percent of the individual differences in resting energy production could be accounted for by changes in body surface area. Lean body mass accounts for 60 to 85 percent of individual differences in REE in normal adult subjects.3 The other differences may be due to familial traits independent of body size and composition,46-48 such as genetically determined differences in skeletal muscle metabolism.40

In conclusion, hypermetabolism and hypometabolism are usually determined by comparing measured with predicted REE. This study points out the problems with such an approach, namely that, depending on which predictive equation is used and the degree of acute body weight change (especially that due to resuscitation fluid), the apparent degree of hypermetabolism or hypometabolism will change. Correcting body weight for the cumulative fluid balance may provide a more reliable estimate of usual body weight and reduce the underestimation of hypermetabolism.