TITLE: Indirect Calorimetry to Measure Energy Requirements: A Review of the Guidelines and Clinical Effectiveness

DATE: 02 February 2009

CONTEXT AND POLICY ISSUES:

Indirect calorimetry is the calculation of resting energy expenditure (REE) via the precise measurement of oxygen consumption (V\textsubscript{O\textsubscript{2}}) and carbon dioxide production (V\textsubscript{CO\textsubscript{2}}) from a patient’s inspired and expired gas concentrations and volumes using an instrument known as a metabolic cart or a hand-held indirect calorimeter.\textsuperscript{1-3} The measurements are converted to energy expenditure (kcal/day) by application of an equation (e.g. the Weir equation).\textsuperscript{1,2} which provides an individualized estimate of a patient’s daily caloric requirements. While there is consensus that nutritional support in critically ill patients improves nutritional outcomes (e.g., body weight), there is no agreement whether clinical outcomes (e.g., duration of mechanical ventilation, length of stay in the ICU or hospital, or mortality) are improved with nutritional support.\textsuperscript{4} Nonetheless, both under- and overfeeding are associated with negative consequences such as immunosuppression, poor wound healing, and compromised stress responses in the underfed, and lipogenesis, hyperglycemia, and exacerbation of respiratory failure in the overfed critically ill patient.\textsuperscript{5-8} Both under- and overfeeding are also associated with delayed liberation from mechanical ventilation.\textsuperscript{6,8}

Indirect calorimetry has long been considered to be the “gold standard” for measuring energy requirements in the clinical setting;\textsuperscript{6,7,9} however, routine use may be impractical due to the expense, calibration required, and need for specially trained personnel to operate the equipment and interpret the results.\textsuperscript{2,7} An alternative method for determining REE is the use of predictive mathematical equations, of which there are many.\textsuperscript{9} The most commonly used is the Harris-Benedict equation\textsuperscript{10} which was developed in 1919 and predicts REE based on an a patient’s sex, weight, height, and age. The Harris-Benedict equation was derived using data from healthy ambulatory subjects, therefore in subsequent years, the practice of applying activity and stress/injury factors to the equation to better approximate energy requirements in critically ill patients has become common practice.\textsuperscript{9,11} Another example is the Ireton-Jones equation, which...
uses patient variables similar to those in the Harris-Benedict equation, but also includes variables for trauma and burn injuries and distinguishes between mechanically ventilated and spontaneously breathing patients.\textsuperscript{12} The American College of Chest Physicians (ACCP) makes a standard recommendation to administer 25 kcal/kg usual body weight of total caloric requirements per day to all critically ill patients.\textsuperscript{13} In comparison to indirect calorimetry, predictive equations are readily accessible and do not require specialized instrumentation or trained personnel for their use; however, many are derived from population-based estimates. As a result, care must be taken to ensure that the subject characteristics (e.g., healthy versus ill, obese versus non-obese) upon which the equations are based do not dramatically differ from the patients to which the equations are being applied.\textsuperscript{6}

Indirect calorimetry is currently used in the ICU for over- or underweight patients to ensure adequate feeding. At times, a patient’s weight and energy requirements may be “guesstimated”; however, using indirect calorimetry would be more accurate and could potentially improve clinical outcomes. As a result, there is a need to review the evidence supporting clinical effectiveness of indirect calorimetry, and to identify guidelines for its use. This report will review the current evidence, focusing on the comparison of indirect calorimetry with predictive equations, for determination of the caloric requirements of critically ill adult patients treated in the ICU setting.

RESEARCH QUESTIONS:

1. What is the clinical effectiveness of indirect calorimetry to measure energy requirements and provide adequate feeding in adults in the intensive care unit?

2. What are the guidelines for measuring energy requirements?

METHODS:

A limited literature search was conducted on key health technology assessment resources, including PubMed, The Cochrane Library (Issue 4, 2008), University of York Centre for Reviews and Dissemination (CRD) databases, ECRI, Uptodate, EuroScan, international health technology agencies, and a focused Internet search. Database results include articles published between 2004 and January 2009, and are limited to English language publications only. No filters were applied to limit the retrieval by study type for the first research question; however, filters were applied to limit the retrieval to guidelines for the second research question.

HTIS reports are organized so that the higher quality evidence is presented first. Therefore, health technology assessments, systematic reviews, and meta-analyses are presented first. These are followed by randomized controlled trials (RCTs), observational studies, and evidence-based guidelines.

SUMMARY OF FINDINGS:

The literature search identified one systematic review, 14 observational studies, and three guidelines. No health technology assessments, meta-analyses, or RCTs were identified.
Health technology assessments
No health technology assessments were identified.

Systematic reviews and meta-analyses

Miles 2006,14 conducted a review of published studies in which REE was measured by indirect calorimetry and compared with basal energy expenditure (BEE) derived from the Harris-Benedict equation. Although REE is considered to be synonymous with BEE, for purposes of this review, REE was taken to be a measurement that is sometimes made during feeding or under fasting conditions. Although this appeared to be a systematic review, there was very limited information provided on the methodology used. Eligible studies included those published since 1980, with a minimum of 20 hospitalized patients, in which REE measured by indirect calorimetry was compared with BEE by the Harris-Benedict equation. Studies in patients with burns, head injuries, or fever were excluded. A total of 19 studies in 1256 patients were included; however, information on study selection, study design, or quality was not reported. Studies reported data from patients with the following diagnoses: 355 (28%) post-operative with a variety of surgical diagnoses, 329 (26%) trauma or sepsis, 226 (18%) cancer, 118 (9%) pneumonia or respiratory failure, 31 (2%) non-surgical cardiovascular conditions, and <2% miscellaneous diagnoses (e.g., bowel obstruction, pancreatitis). A diagnosis was not specified in 79 (6%) of patients. The mean REE/BEE ratio (which compares measured to predicted energy requirements) from the 19 studies ranged from 94% to 130% and averaged 113%. The mean REE/BEE ratio was significantly higher (117 ± 3%) in 11 studies in which measurement of REE was done during feeding than in five studies (105 ± 4%; p=0.047) in which the measurement was made during fasting. A relationship between severity of illness and REE/BEE was not consistently observed. It was concluded that administration of nutritional support increases REE, although this effect may be less if overfeeding is avoided. These findings suggest that BEE derived from the Harris-Benedict equation may underestimate energy requirements in patients receiving nutritional support.

No meta-analyses were identified.

Randomized controlled trials
No RCTs were identified.

Observational studies

A total of 14 observational studies were identified in which indirect calorimetry was compared with predictive equations for calculating REE for the nutritional support of critically ill, adult patients in the ICU setting. Details of these studies are provided in Appendix 1.

The majority of studies were small, prospective, or retrospective cross-sectional studies that compared the accuracy, precision, and bias of REE estimates derived from a variety of predictive equations with the measurement of REE by indirect calorimetry. None of the studies were randomized, blinded, included a control group, or investigated the effect of the methodology on clinical outcomes (e.g., duration of mechanical ventilation, length of stay in the ICU or hospital, or mortality). Patient populations were heterogeneous as age, patient size, disease state, or type of trauma varied considerably within studies given that inclusion criteria typically extended to all patients treated in the ICU within a specific period of time. In addition, REE was often measured or estimated in patients who were already receiving nutritional support and the contribution of calories from other sources (e.g., IV solutions, renal dialysate)
was not controlled for. In most studies, REE was determined at only one point in time, thus not factoring in the dynamic clinical status and fluctuating energy requirements of critically ill patients.

Eleven of the studies compared REE measured by indirect calorimetry with estimates derived from the Harris-Benedict equation (with and without activity and injury/stress factors applied). Five studies compared indirect calorimetry with the Ireton-Jones equation (including adjustments for obese patients) and four studies with the ACCP recommendation of 25 kcal/kg/day. Other studies compared indirect calorimetry with various other equations such as the Brandi, Swinamer, Penn State, Mifflin St. Jeor, Faisy, Fusco, Schofield, and Cunningham equations. Four studies specifically investigated REE in obese patients and one study in underweight patients. One study included patients on renal replacement therapy and one study included patients with cerebral injury undergoing hypothermia. One study compared total energy expenditure (TEE) by continuous (24 h/day for ≥ five days) indirect calorimetry with estimates from three predictive equations.

Although a number of studies reported correlations between REE derived from predictive equations and indirect calorimetry, when all identified studies are considered, the overall results are inconclusive as many studies reported conflicting results. For example, of the eleven studies that compared indirect calorimetry with the Harris-Benedict equation, four concluded that the Harris-Benedict equation (multiplied by activity or injury/stress factors) accurately predicted REE, whereas seven studies found the equation to be inaccurate. Five of the 14 studies concluded that indirect calorimetry remained the most accurate method of determining a patient’s energy needs.

**Guidelines**

In 2006, the American Dietetic Association (ADA) published a critical illness evidence-based nutrition practice guideline. In developing the guideline, an ADA workgroup conducted a systematic review and also reviewed published meta-analyses. The strength of the evidence was graded according to a rating scheme. Recommendations were formulated by expert consensus and the strengths of the recommendations were also rated. The guideline was validated by external and internal peer review using the Appraisal of Guidelines for Research and Evaluation (AGREE) instrument as the evaluation tool. With regard to indirect calorimetry, the ADA recommends that for determination of resting metabolic rate, indirect calorimetry is the standard in critically ill patients since resting metabolic rate based on measurement is more accurate than estimation using predictive equations. The recommendation was rated as strong [meaning the workgroup believes that the benefits exceed the harms and that the quality of the supporting evidence is excellent/good (Grade I or II)] and imperative (meaning that the statement is broadly applicable to the target population without restraints on their pertinence). Recommendations are also made regarding use of appropriate and inappropriate predictive equations in non-obese and obese critically ill patients if indirect calorimetry is not feasible. In non-obese patients, the following equations (listed in order of accuracy according to the ADA) that are considered appropriate are: Penn State 2003a (79%), Swinamer (55%), and Ireton-Jones 1992 (52%). Inappropriate equations are the Harris-Benedict (with or without activity and stress factors), Ireton-Jones 1997, Fick method, and Mifflin St. Jeor equation. In obese patients, appropriate equations are the Ireton-Jones 1992, and Penn State 1998 equations. No inappropriate recommendations were identified for obese patients. The recommendations pertaining to non-obese and obese patients were rated as fair [meaning that the workgroup believes that the benefits exceed the harms but that the quality of the
evidence is not as strong (Grade II or III) and conditional [meaning that the recommendation contains conditional text (i.e., if/then terminology)].

In 2004, the American Association for Respiratory Care (AARC) issued a clinical practice guideline for metabolic measurement using indirect calorimetry during mechanical ventilation. No information about the guideline development process was provided and the recommendations were not graded or rated. The AARC recommends that metabolic measurement by indirect calorimetry be used in patients with known nutritional deficits or derangements where multiple nutritional risk and stress factors could considerably skew prediction by the Harris-Benedict equation such as:

- neurological trauma;
- paralysis;
- chronic obstructive pulmonary disease;
- acute pancreatitis;
- cancer with residual tumor burden;
- amputations;
- patients in whom height and weight cannot be accurately obtained;
- patients who fail to respond adequately to estimated nutrition needs; and
- patients who require long-term acute care.

Metabolic measurement by indirect calorimetry is also recommended in:

- patients who fail attempts at liberation from mechanical ventilation;
- to measure the $O_2$ cost of breathing and components of ventilation;
- when the need exists to assess $V_{O_2}$ in order to evaluate hemodynamic support of the mechanically ventilated patient;
- to measure cardiac output by the Fick method; and
- to determine the cause(s) of increased ventilatory requirements.

In 2003, Canadian clinical practice guidelines for nutrition support in mechanically ventilated, critically ill adult patients were issued. The guidelines were developed by a panel of experts comprised of epidemiologists, intensivists, surgeons, gastroenterologists, dietitians, nurses and pharmacists from across Canada. A systematic review of the evidence was conducted as well as meta-analyses of the data where possible. The strength of the evidence was graded and the strengths of the recommendations denoted by specific summary statements (e.g., strongly recommended, recommended, should be considered and no recommendation due to insufficient data). With regard to indirect calorimetry, the panel concluded that there were insufficient data to make a recommendation on the use of indirect calorimetry versus predictive equations for determining energy needs for enteral nutrition in critically ill patients.

**Limitations**

No health technology assessments and only one systematic review were identified from the defined literature search. The systematic review appeared to be of low quality as very limited information was provided about the methodology used (i.e., no details were given regarding the study selection process or the design and quality of included studies). Furthermore, the review was based on a heterogeneous population of hospitalized patients, not all of whom were treated in the ICU. No meta-analyses were identified from the literature search.

No prospective RCTs of indirect calorimetry were identified. As a result, there is no evidence identified that indirect calorimetry results in better clinical outcomes than alternate methods of
estimating nutritional requirements. In light of this, no conclusions can be drawn regarding the clinical effectiveness of indirect calorimetry.

A large number of observational studies comparing REE measured by indirect calorimetry with estimates derived from various predictive equations were identified. None of the studies assessed clinical outcomes such as duration of mechanical ventilation, length of stay in the ICU or hospital, or mortality, but rather reported on the accuracy, precision, and bias of predictive equations when compared with indirect calorimetry. The small sample sizes and heterogeneous nature of the patients studied makes interpretation of study results difficult. The studies were also limited by lack of randomization, blinding, and control groups and failure to account for known confounding variables (e.g., caloric contribution from nutritional support already administered, IV solutions, or renal replacement fluids). The majority of studies measured indirect calorimetry at one point in time and therefore did not account for the dynamic and fluctuating nature of the disease state or injury. Four of the studies were retrospective analyses, making validation of data and control of extraneous variables difficult.

The timeline for the literature search for this report encompassed only the last five years. As a result, there may be studies or reviews published prior to this that were not included.

CONCLUSIONS AND IMPLICATIONS FOR DECISION OR POLICY MAKING:

There was no evidence identified to support that indirect calorimetry has a direct impact on patient outcomes such as duration of mechanical ventilation, length of stay in the ICU or hospital, or on patient mortality. There were no prospective RCTs identified to show that use of indirect calorimetry in one group of patients resulted in improved outcomes relative to a control group in which an alternative method of estimating nutritional requirements was used. As a result, no conclusions can be made regarding the clinical effectiveness of indirect calorimetry. Furthermore, there is no consensus whether nutritional support of critically ill patients improves outcomes or whether accuracy in determining the nutritional support regimen in these patients improves outcomes and reduces complications.

Predictive equations are inherently inaccurate for use in critically ill patients as they are derived from different patient populations, there is subjectivity and variability associated with the application of activity and injury/stress factors, and they generally assume a linear relationship between total body weight and REE, which results in incorrect predictions in under- and overweight patients. The evidence to support the validity of predictive equations was recently systematically reviewed by Frankenfield *et al.*, 2008. The authors evaluated seven equations plus the Fick method and concluded that, based on the available validation studies, the Harris-Benedict, Ireton-Jones 1997, and Fick methods can be confidently eliminated from use in critically ill patients. The authors further concluded that other equations may be useful in critically ill non-obese and obese patients, but the strength of their conclusions is moderated due to limited and sometimes inconsistent data.

The only available evidence found to support use of indirect calorimetry in the ICU setting was from a number of small, prospective, and retrospective observational studies. These studies compared the accuracy, precision, and bias of various predictive equations with indirect calorimetry; however, the overall results were conflicting and inconclusive. No health technology assessments, meta-analyses, RCTs or economic evaluations of indirect calorimetry were identified.
Three clinical practice guidelines that dealt with nutritional support in critically ill patients were identified in which indirect calorimetry was specifically mentioned. Two of the guidelines supported the use of indirect calorimetry in critically ill patients, whereas the third guideline, which was Canadian-based, concluded that there were insufficient data to make a recommendation on the use of indirect calorimetry versus predictive equations for determining energy needs for enteral nutrition in critically ill patients.

Because indirect calorimetry directly measures REE and allows for the calculation of individualized caloric requirements, its potential value in critically ill patients cannot be overlooked. Accurate determination of REE is necessary in these patients to ensure energy needs are met and that the complications associated with under- or overfeeding are avoided. At present, indirect calorimetry is considered to be the “gold standard”; however, the lack of evidence, cost, availability of the instrumentation, and the need for specially trained personnel to operate the equipment and interpret the results may preclude its widespread use. In order to better inform decision or policy makers, well-designed, prospective RCTs that focus on clinical outcomes and economic evaluations that compare indirect calorimetry with alternative methods for determining energy requirements are required to provide evidence of clinical and cost effectiveness in critically ill patients treated in the ICU setting.

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REFERENCES:


### APPENDICES:

**Appendix 1: Details of Observational Studies**

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<td>Alexander et al. 2004&lt;sup&gt;2&lt;/sup&gt; Retrospective cross-sectional study</td>
<td>Critically ill, mechanically ventilated adult ICU patients (n=76)</td>
<td>IC vs. H-B equation with and without an activity factor of 1.2, Ireton-Jones equation and ACCP recommendation (25 kcal/kg TBW)</td>
<td>REE</td>
<td>Based on calculation of mean prediction errors and mean squared prediction errors associated with REE relative to IC, H-B x 1.2 was found to be unbiased and precise. Ireton-Jones was precise but biased, ACCP and H-B without an activity factor were both biased and imprecise</td>
<td>The H-B equation x an activity factor of 1.2 is suitable for predicting REE and can be used in the absence of IC in patients with REE values &lt; 2650 total kcal/day.</td>
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<td>Basile-Filho et al. 2008&lt;sup&gt;25&lt;/sup&gt; Prospective cross-sectional study</td>
<td>Mechanically ventilated adult ICU patients with septic shock (n=15)</td>
<td>IC vs. Brandi and Liggett equations using V0&lt;sub&gt;2&lt;/sub&gt; consumption obtained by Fick's method</td>
<td>REE</td>
<td>Differences in mean REE were +8.7% (IC vs. Brandi; p&lt;0.05) and -22.7% (IC vs. Liggett; p&gt;0.05). Correlation coefficients were r=0.80 between IC and Brandi and r=0.58 between IC and Liggett.</td>
<td>REE can be calculated by obtaining V0&lt;sub&gt;2&lt;/sub&gt; and using the Brandi equation for septic patients under mechanical ventilation.</td>
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<td>Boullata et al. 2007&lt;sup&gt;13&lt;/sup&gt; Retrospective database analysis</td>
<td>All hospital in-patients with an ordered nutrition assessment (n=395) which included 141 (36%) critically ill, ventilated ICU patients</td>
<td>IC vs. H-B, Mifflin-St. Jeor, Ireton-Jones 1992 equations and ACCP recommendation (25 kcal/kg). In obese patients, the Ireton-Jones equation for obese individuals and the H-B equation using adjusted body weight were also determined. In ventilated patients, the Swinamer and Penn State equations were determined.</td>
<td>REE Accuracy defined as predictions within 90% to 110% of measured REE. Differences &gt;10% or 250 kcal from REE were considered not clinically acceptable.</td>
<td>The H-B equation x 1.1 was the most accurate, but only in 61% of patients, and was associated with under- and over-predictions. In ICU patients, the H-B equation x 1.1 was most accurate, but only in 55% of patients. Bias was lowest with H-B x 1.1, but errors &gt; 250 kcal occurred across all equations.</td>
<td>No equation accurately predicted REE. The most accurate equation (H-B x 1.1) compared to IC was inaccurate in 39% of patients and had an unacceptably high error &gt; 250 kcal. Without a reliable predictive equation, only IC will provide accurate assessment of energy needs.</td>
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<td>Campbell et al. 2005&lt;sup&gt;16&lt;/sup&gt; Retrospective nutrition care plan analysis</td>
<td>Critically ill, severely underweight adult male ICU patients (n=42) Of these, n=37 were mechanically ventilated</td>
<td>IC vs. H-B equation in patients &lt;90% IBW (n=42) using CBW and IBW. For patients &lt; 85% IBW (n=31) an experimental equation using adjusted body weight ([CBW+IBW]/2) was compared with IC. In mechanically ventilated patients (n=37), the Ireton-Jones equation was compared with IC.</td>
<td>REE</td>
<td>Average caloric need for all patients was 31.2 ± 6.0 kcal/kg CBW. REE from H-B using CBW, IBW or adjusted body weight was SS different than IC (p&lt;0.05). Compared to IC, the Ireton-Jones equation was NS different (p&gt;0.05) but it overestimated energy needs (109.3% ± 16.8%). In contrast, H-B using CBW (77.0% ± 11.6%) or IBW (90.9 ± 16.1%) underestimated energy needs. All equations were SS correlated with IC (r&gt;0.5; p&lt;0.05).</td>
<td>IC remains the best method of determining a patient’s energy needs.</td>
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<td>Davis et al. 2006&lt;sup&gt;17&lt;/sup&gt; Prospective cross-sectional study</td>
<td>Critically ill, mechanically ventilated, surgery and trauma adult ICU patients (n=59)</td>
<td>IC vs. H-B with an activity and stress factor of 1.5 and weight-based calculations (30 kcal/kg)</td>
<td>REE</td>
<td>REE calculated using the H-B equation x 1.5 or 30 kcal/kg adjusted body weight were NS different from IC (p&gt;0.05). Either 30 kcal/kg adjusted body weight or the H-B equation x 1.5 adequately predicts nutritional requirements of critically ill patients.</td>
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<td>Frankenfield et al. 2008&lt;sup&gt;18&lt;/sup&gt; Prospective cross-sectional study</td>
<td>Critically ill, mechanically ventilated adult ICU patients (n=202) Patients were subgrouped by age and obesity status.</td>
<td>IC vs. Penn State, Faisy, Brandi, Swinamer, Ireton-Jones, Mifflin St. Jeor, Mifflin St. Jeor x 1.25, H-B, H-B x 1.25, H-B using adjusted weight for obese patients and each of the adjusted weight versions of H-B x 1.25 equations. (1.25 is a stress factor)</td>
<td>RMR</td>
<td>Accuracy rates compared to IC ranged from 67% for the Penn State to 18% for the weight-adjusted H-B (without x 1.25) equations. The Penn State was the only unbiased and precise equation across all subgroups. The Penn State equation provides the most accurate assessment of metabolic rate in critically ill patients if IC is unavailable.</td>
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<td>Hoher et al. 2008\textsuperscript{19} Prospective cross-sectional study</td>
<td>Critically ill, adult ICU patients undergoing assisted or controlled mechanical ventilation (n=100)</td>
<td>IC vs. H-B equation multiplied by (injury factors depending upon patient’s diagnosis) and either multiplied or not by an activity factor of 1.1</td>
<td>TEE for two modes of ventilation (assisted or controlled)</td>
<td>Controlled: H-B overestimated IC by 8.2% (P=0.012) when multiplied by injury and activity factors and underestimated IC by 2.6% (P=0.399) without the activity factor. Assisted: H-B underestimated IC by 10.7% (P=0.001) when not multiplied by the activity factor and by 0.75% with the activity factor (P=0.829). H-B positively correlated with IC for both controlled (r=0.374; p&lt;0.001) and assisted (r=0.281; p=0.005) ventilation.</td>
<td>A 10% activity factor should only be applied to assisted ventilation as multiplication by an activity factor may lead to overfeeding of patients on controlled ventilation.</td>
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<td>Marson et al. 2003\textsuperscript{30} Prospective cross-sectional study</td>
<td>Critically ill, mechanically-ventilated adult ICU patients (n=14)</td>
<td>IC vs. calculation by Fick’s Method</td>
<td>O\textsubscript{2} consumption index at four sequential 30 minute periods (T1, T2, T3 and T4).</td>
<td>Good correlation between IC and Fick’s Method (r=0.77). NS differences were observed between the two methods at T1 (p=0.10) and T3 (p=0.14) and SS differences at T2 (p=0.03) and T4 (P=0.01)</td>
<td>IC can be used for O\textsubscript{2} consumption analysis in critically ill patients and is as efficient as Fick’s Method with the benefit of being noninvasive.</td>
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<td>Reid 2007\textsuperscript{24} Prospective cohort study</td>
<td>Critically ill, mechanically ventilated adult ICU patients (n=27)</td>
<td>Continuous (24 h/day for ≥ 5 days) IC vs. H-B x 1.3, Schofield x 1.3 and Ireton-Jones equations and ACCP recommendation (25 kcal/kg/day). (1.3 is a stress factor)</td>
<td>TEE</td>
<td>Agreement between 24 h TEE and prediction equations was poor (all p ≥ 0.0015). Estimates between 80-110% of TEE values were: H-B (66%), Schofield (66%) and ACCP (65%), which would result in underfeeding in 16%, 15% and 22% of patients and overfeeding in 18%, 19% and 13% of patients respectively.</td>
<td>Limits of agreement between different predictive equations and TEE values were unacceptably wide. Prediction equations may result in significant under or overfeeding in the clinical setting.</td>
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<td>Saur et al. 2008&lt;sup&gt;20&lt;/sup&gt; Prospective pilot study</td>
<td>Mechanically ventilated, adult, acute cerebral injury patients undergoing mild hypothermia (n=5)</td>
<td>IC vs. H-B equation (if needed H-B was further multiplied by an activity factor)</td>
<td>REE</td>
<td>Reduction in temperature and REE correlated (r=0.82; p&lt;0.001) from 30.5 to 38.3°C. Average REE measured by IC was 16.7% (95% CI: 12.8, 20.6) below values calculated by the H-B equation.</td>
<td>The hypothermia-induced reduction in oxygen requirement recorded by IC is considerably below that calculated by the H-B equation.</td>
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<td>Savard et al. 2008&lt;sup&gt;21&lt;/sup&gt; Prospective cross sectional study</td>
<td>Critically ill, mechanically ventilated adult ICU patients (n=45)</td>
<td>IC vs. H-B (original and corrected for stress factors), Swinamer, Fusco, Ireton-Jones equations and the author’s own equation (Faisy equation)</td>
<td>REE</td>
<td>REE calculated via the Faisy equation correlated the strongest with IC ($r^2=0.62$; $p&lt;0.0001$) compared to the H-B equation alone ($r^2=0.41$) or with stress correction factors ($r^2=0.18$), the Swinamer ($r^2=0.41$), Fusco ($r^2=0.38$) or Ireton-Jones ($r^2=0.39$) equations; all $p&lt;0.0001$</td>
<td>The Faisy equation based on static (height), less stable (weight) and dynamic biometric variables (temperature and minute ventilation) provided precise and unbiased REE estimations in mechanically ventilated patients.</td>
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<td>Scheinkestel et al. 2003&lt;sup&gt;26&lt;/sup&gt; Prospective cross sectional study</td>
<td>Critically ill, mechanically ventilated patients requiring continuous renal replacement therapy for renal failure, adult ICU patients (n=50)</td>
<td>IC (measured in 68% of patients) vs. Schofield equation adjusted by stress factors</td>
<td>REE</td>
<td>If the predicted REE &lt; 2500, the Schofield equation underestimated IC by an average of 19%. If &gt;2500, the Schofield equation overestimated REE on average by 6%. The relationship was SS ($p=0.025$).</td>
<td>A metabolic cart (IC) can improve the accuracy of energy provision.</td>
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<td>Stucky et al. 2008&lt;br&gt;Retrospective chart review</td>
<td>Obese (BMI $&gt; 30$ kg/m$^2$) trauma and burn adult ICU patients (n=28)</td>
<td>IC vs. H-B, Cunningham and Diabetic prediction equations with and without an injury factor of 1.2.</td>
<td>REE</td>
<td>Average REE measured by IC was $21.37 \pm 5.26$ (trauma) and $21.81 \pm 3.35$ (burn) kcal/kg/day. All three equations underestimated REE in both populations (all $P&lt;0.05$) with the Cunningham &gt; Diabetic &gt; Harris Benedict equations being most biased. Cunningham underestimated REE and H-B and Diabetic equations overestimated REE if the injury factor is included.</td>
<td>Measured average REE in obese trauma and burn patients is significantly less than current guidelines. A hypocaloric regimen should be considered for these patients.</td>
</tr>
<tr>
<td>Zauner et al. 2006&lt;br&gt;Prospective cross sectional study</td>
<td>Critically ill, adult ICU patients (n=100) classified by BMI into normal weight (BMI 18.5-24.9 kg/m$^2$), pre-obese (BMI 25-29.9 kg/m$^2$), obese (BMI 30-34.9 kg/m$^2$) and morbidly obese (BMI $&gt; 35$ kg/m$^2$)</td>
<td>IC vs. H-B equation, ACCP equation (25 kcal/kg TBW) and 25 kcal/kg IBW</td>
<td>REE</td>
<td>REE (adjusted for TBW) by IC was $24.8 \pm 5.5$ kcal/kg (normal weight), $22.0 \pm 3.7$ kcal/kg (pre-obese), $20.4 \pm 2.6$ kcal/kg (obese) and $16.3 \pm 2.3$ kcal/kg (morbidly obese) ($p&lt;0.01$). The H-B equation underestimated REE measured by IC in normal weight and pre-obese patients. The 25 kcal/kg TBW equation over- and 25 kcal/kg IBW under-estimated measured REE in pre-obese, obese and morbidly obese patients, although the difference between IC and 25 kcal/kg IBW was NS in morbidly obese patients ($p=0.07$).</td>
<td>Predictive equations were not able to estimate REE measured by IC adequately in all patients. REE adjusted for TBW decreased with increasing BMI, thus a BMI group-specific adaptation should be applied.</td>
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</table>

ACCP=American College of Chest Physicians; BMI=body mass index; CBW=current body weight; H-B=Harris-Benedict equation; IBW=ideal body weight; IC=indirect calorimetry; ICU=intensive care unit; NS=not statistically significant; REE=resting energy expenditure; RMR=resting metabolic rate; SS=statistically significant; TEE=total energy expenditure; TBW=total body weight