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RESEARCH ARTICLE

Energy expenditure measured by indirect calorimetry in a neuroscience intensive care unit: a retrospective observational study

Clarabella Liew[a*], Kok Wah Wong[b], Puay Shi Ng[b] and Yie Hui Lau[a]

[a]Department of Anaesthesiology, Intensive Care and Pain Medicine, Tan Tock Seng Hospital, Singapore
[b]Department of Nutrition and Dietetics, Tan Tock Seng Hospital, Singapore
**Correspondence: clarabella_liew@ttsh.com.sg*

Objectives: To compare indirect calorimetry (IC) readings with the Harris–Benedict equation (HBE) predictions of resting energy expenditure (REE) in intubated acute brain-injured patients in a tertiary hospital's Neuroscience Intensive Care Unit (ICU).
Design: A single-centre, retrospective study.
Setting: Neuroscience Intensive Care Unit at a tertiary hospital.
Subjects: All adult patients admitted to the Neuroscience Intensive Care Unit between June 1, 2020, and June 30, 2021, who had an IC reading.
Outcome measures: Comparison of the measured REE using IC and the predicted REE using the HBE modified for critically ill adults. Subgroup analysis based on body mass index (BMI) was also performed.
Results: A total of 108 patients had IC readings taken during the study period. There was a significant difference between the REE predicted by the HBE and the measured IC readings, with a mean difference of 465.3 kcal (95% CI 408.1–522.5, $p = 0.001$). A moderate positive correlation was observed (coefficient $r = 0.565$, $p < 0.001$). In patients with BMI ≥ 30 kg/m^2, the HBE significantly overestimated REE compared with IC readings ($p = 0.005$).
Conclusions: The Harris–Benedict equation tends to overestimate resting energy expenditure, especially in acute brain-injured patients with a BMI ≥ 30 kg/m^2. Utilising IC-directed nutrition therapy in intensive care units could help in delivering personalised caloric intake, reducing the risks of underfeeding or overfeeding.

Keywords indirect calorimetry, intensive care, neuroscience, nutrition

Introduction

Underfeeding or overfeeding patients persist in intensive care units (ICU) worldwide.[1] Among the key factors influencing the prevention of underfeeding and overfeeding in ICU is the precise determination of resting energy expenditure (REE). Indirect calorimetry (IC) improves the accuracy of nutritional assessment by providing real-time measurements based on the patient's oxygen consumption and carbon dioxide production. While IC is considered the gold standard to determine REE in critically ill patients, predictive equations are commonly used instead due to the lack of resources.[2]

Among numerous predictive equations that estimate REE, the Harris–Benedict equation is one of the most widely used predictive equations. It takes into account the patient's gender, weight, height, and age as well as activity and/or injury factors, which predicts total, free-living energy requirements.[3] In the absence of IC, predictive equations remain the best available alternative.

An earlier review by Morbitzer *et al*. concluded that while the predictive equations assessed in their study may produce similar REE to readings of IC as a group, there is significant variability individually, with prediction accuracy often falling outside the 10% range.[4] Fluctuating metabolic states in acute-brain injured patients make nutrition delivery challenging.[5] Providing optimal nutrition therapy in the ICU by knowing how much to provide, when to do so, and to whom remains unclear.

The study aims to compare the REE estimated by the Harris–Benedict equation against the measurements made by IC on intubated acute brain-injured patients in a Neuroscience Intensive Care Unit (NICU). We also explored the nutritional requirements by the body mass index (BMI) of the patients.

Materials and methods

This was a single-centre, retrospective, observational study approved by the National Healthcare Group Domain Specific Review Board (DSRB reference 2021/00916) and the requirement for written informed consent was waived.

The study included all adult patients aged at least 21 years old admitted to the NICU of Tan Tock Seng Hospital, a tertiary hospital with over 1500 acute beds in Singapore. The study took place over a 13-month period between June 1, 2020 and June 30, 2021 and included all intubated patients with an IC reading.

We excluded patients who were not intubated or classified as moribund and with an ICU stay of less than 48 hours from the analysis. The remaining exclusion criteria for the use of IC in the ICU were: known air leak syndromes such as pneumothorax, broncho-tracheal fistula or presence of a chest tube, fraction of inspired oxygen requirements ≥ 0.6 and those on renal replacement therapy, which could entail peritoneal dialysis, haemodialysis, or continuous renal replacement therapy. This reduced any potential bias caused by a brief ICU stay, inevitable mortality, and known factors that might affect the accuracy of IC measurements.

The IC readings were obtained by dietitians as part of their routine clinical work and were made possible by proprietary metabolic cart modules in the GE Healthcare Carescape™ R860 invasive ventilators (GE Healthcare, Chicago, IL, USA). The Harris–Benedict equation, modified for critically ill patients (Table 1), was computed backend by the team. A stress factor of 1.2 was chosen to maintain a consistent methodological approach across all patient groups and to avoid the introduction of additional variables. The ideal stress factor to use for critically ill patients is unknown, with disease-specific variability.[6,7] Height and weight were directly measured on admission and retrieved from patient records. The nutrition prescription for the patient relied solely on the IC readings. If no nutrition prescription was available at the time of initiation of feeding, the intensivist would prescribe feeding at their own discretion.

Demographic data collected include age, gender, height, admission weight, BMI, acute physiology, and chronic health evaluation (APACHE) II score, sequential organ failure assessment (SOFA) score, ICU admission diagnosis, timing of IC reading, length of ICU stay, and mortality outcome in the ICU. Further information collected on the day of the IC assessment included the presence of fever (temperature > 37.5°C), best Glasgow coma score (GCS), and Richmond agitation sedation score (RASS). In the 24-hour post-dietitian review, data on the calories administered and presence of blood sugar > 12 mmol/L were recorded.

Statistical analysis

Normality of the data was assessed using the Kolmogorov–Smirnov and Shapiro–Wilk tests in conjunction with histograms and Q–Q plots. Comparisons between data were made using paired *t*-tests and one-way ANOVA was used to compare between groups. The correlation between Harris–Benedict equation and IC was determined using Pearson's correlation coefficient. A *p*-value < 0.05 was considered statistically significant for the analyses. The statistical tests for this study were performed using IBM SPSS Statistics version 27 (IBM Corp, Armonk, NY, USA).

Results

There were 732 patients admitted during this study period, and 108 patients had an IC measurement. Patient demographics and characteristics and details of the ICU stay are summarised in Table 2.

The average time from admission to the ICU for an IC reading was 3.5 days. The average daily calories based on the Harris–Benedict equation and IC reading were 1 780.4 ± 355.5 kcal and 1 317.0 ± 251.1 kcal respectively. This translates to a daily caloric reading of 27.8 ± 2.6 kcal/kg and 20.9 ± 4.0 kcal/kg respectively. Twenty-four hours post-dietitian review, the average daily calories administered were 1 440.0 ± 1551.2 kcal and 18.5% of the patients had a blood sugar reading of >12 mmol/L.

Table 1: Predictive equation

Gender	Harris–Benedict equation x activity factor x stress factor
Male	[66.47 + (13.75 × weight in kg) + (5.00 × height in cm) − (6.76 × age)] × 1.1 × 1.2
Female	[655.10 + (9.56 × weight in kg) + (1.85 × height in cm) − (4.68 × age)] × 1.1 × 1.2

Analysis of the daily energy measurements comparing the Harris–Benedict equation with IC measurements demonstrated a significant difference of mean 465.3 kcal (95%CI 408.1–522.5, $p = 0.001$). There is a positive correlation between the Harris–Benedict equation and IC measurements with a moderate correlation coefficient $r = 0.565$ (*p*-value <0.001) (Figure 1).

In the subgroup analysis of patients ($n = 13$) with BMI ≥ 30 kg/m^2, estimated REE from the Harris–Benedict equation was 2 198.44 ± 132.03 kcal compared with an IC of 1439.08 ± 63.10 kcal. This was found to be significantly higher than the IC reading (*p*-value = 0.005) (Figure 2).

Table 2: Patient demographics and characteristics

Characteristic	No. of patients, $n = 108$ (%)	Mean (SD)
Age, years		61.1 (15.5)
Height, cm		162.0 (17.7)
Weight, kg		64.5 (14.2)
BMI, kg/m^2, *n* (%)		24.1 (4.7)
BMI <30	95 (88.0)	
BMI ≥30	13 (12.0)	
Male gender	65 (60.2)	
APACHE II score		18.6 (6.0)
SOFA score		5.6 (2.9)
ICU admission diagnosis		
Subarachnoid aneurysmal haemorrhage	17 (15.7)	
Intracerebral haemorrhage	40 (37.0)	
Traumatic brain injury	14 (13.0)	
Sepsis	9 (8.3)	
Elective postoperative	2 (1.9)	
Status epilepticus	6 (5.6)	
Others	20 (18.5)	
Days from admission to IC reading		3.5 (2.5)
At the time of IC reading		
Presence of fever (T > 37.5°C)	38 (35.2)	
Best Glasgow coma score		6 (2.3)
Richmond agitation sedation score		−4 (1.2)
Daily calories based on the Harris–Benedict equation, kcal		1780.4 (355.5)
Daily calories based on the Harris–Benedict equation, kcal/kg		27.8 (2.6)
Daily calories based on IC reading, kcal		1317.0 (251.1)
Daily calories based on IC reading, kcal/kg		20.9 (4.0)
Daily protein prescribed, g		75.0 (15.2)
24-hour post-dietitian review		
Daily calories received, kcal		1440 (1551.2)
Blood sugar > 12 mmol/L	20 (18.5)	
Length of ICU stay, days (median IQR)		10.0 (6–16)
Mortality	11 (10.2)	

BMI: body mass index, APACHE II: Acute Physiology And Chronic Health Evaluation, SOFA: Sequential Organ Failure Assessment, ICU: intensive care unit, IC: indirect calorimetry, IQR: interquartile range.

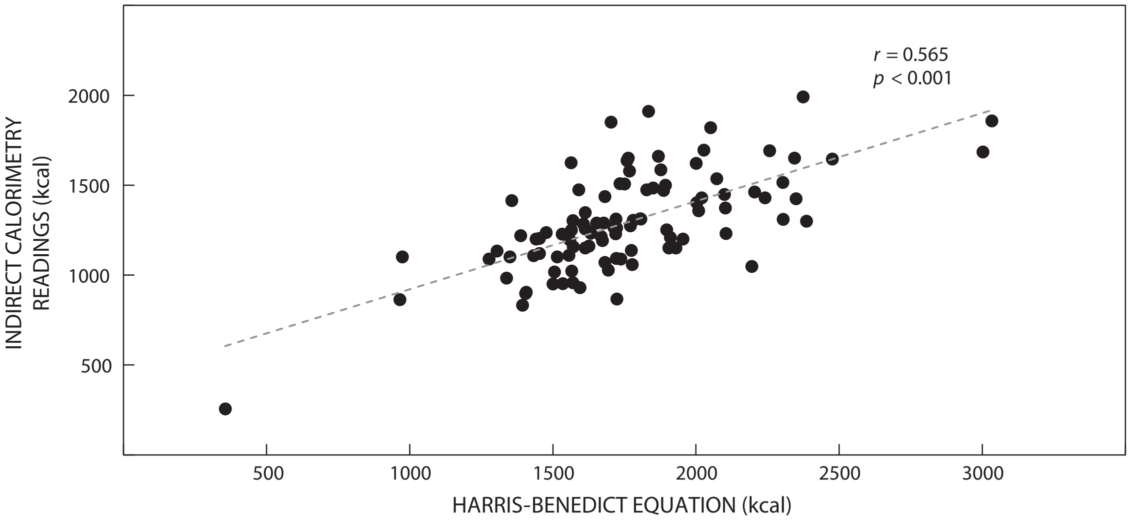

Figure 1: Comparing the Estimated Resting Energy Expenditure from the Harris–Benedict Equation to Measured Resting Energy Expenditure from Indirect Calorimetry.

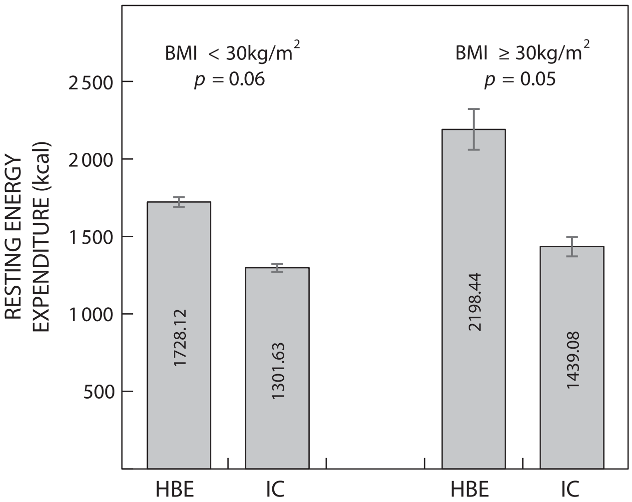

Figure 2: Comparing the Estimated Resting Energy Expenditure from the Harris–Benedict Equation to measured Resting Energy Expenditure on Indirect Calorimetry with BMI cut-off of 30 kg/m^2.

Discussion

This is the largest review performed in Singapore that compares REE measured by IC against the Harris–Benedict equation based on an IC-guided nutrition therapy. This study found that there is a significant difference of 465.3kcal with a moderate correlation coefficient of $r = 0.565$ when comparing the Harris–Benedict equation against IC. This is consistent with the current literature, which reports the inaccuracies of predictive equations and explains the recommendation by ASPEN and ESPEN for IC-guided nutrition therapy.[8,9]

Foley and colleagues in a systematic review showed that IC readings ranged from 87% to 200% of the predicted value in the first 30 days for patients with traumatic brain injury.[10] In the TICACOS study, the authors reported a significant day-to-day variation in measured REE by IC, though the mean REE was comparable between the IC-guided and the control groups.[11] This underscores the clinical difficulties in prescribing optimal nutritional therapy to acute brain-injured patients. IC readings are not performed continuously to determine the REE and in our institution repeat assessments are done only when there is a change in the clinical status.

In our study, 18.5% of the patients had a blood sugar reading of > 12 mmol/l 24 hours post-dietitian review. We believe that this could have been due to the reduction of cerebral metabolism and oxygen consumption in therapeutic sedation and possible undiagnosed diabetes in the Asian community. Using the Harris–Benedict equation to guide nutritional targets, with its association with overfeeding, may make glucose control more challenging. Furthermore, hyperglycaemia is associated with worse neurological outcomes.[12]

Among those with BMI $\geq$ 30 kg/m^2, the predicted REE from the Harris–Benedict equation was 2 198.44 ± 132.03 kcal compared with an IC of 1 439.08 ± 63.10kcal (p-value = 0.005). The extracted weights applied may have contributed to an overestimation, as the predictive equations were originally developed based on data from healthy, non-obese patients. Consequently, reliance on these predictive equations may lead to inaccurate nutritional delivery. An IC reading can be tailored to patients' nutritional needs with precision to meet their specific metabolic demands.

Limitations

Our study has some limitations as a retrospective observational study. First, selection bias may have resulted as only patients who had an IC reading were analysed and the use of a uniform stress factor may not fully account for the variability in energy demands based on the severity of head injury. Second, the data quality was dependent on the input by the clinical team and any missing data were excluded from the dataset. Third, we did not look into patient outcomes such as mortality. While the Harris–Benedict equation was selected in this study for comparative purposes, it is important to note that the ESPEN guidelines recommend weight-based energy requirements of 20–25 kcal/kg in the early phase of ICU care as an alternative when IC is unavailable. These can be worked on in future larger prospective studies. Lastly, the patient population is focused on critically ill acute brain-injured patients, which may limit the generalizability of the findings to the general intensive care population.

Conclusion

The Harris–Benedict equation overestimates REE, especially in critically ill acute brain-injured patients with BMI $\geq$ 30 kg/m^2.

With IC-directed nutrition therapy, intensive care units will be able to deliver personalised calories to minimise the likelihood of under or overfeeding.

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ORCID

Clarabella Liew http://orcid.org/0009-0008-2393-0581

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