Predicting energy expenditure in sepsis: Harris–Benedict and Schofield equations versus the Weir derivation

Ashwin Subramaniam, Michelle McPhee and Ramesh Nagappan

ABSTRACT

Background: Given the difficulties of using indirect calorimetry in many intensive care units, clinicians routinely employ predictive equations (the Harris–Benedict equation [HBE] and Schofield equation are commonly used) to estimate energy expenditure in critically ill patients. Some extrapolate CO_2 production ($\dot{V}CO_2$) and O_2 consumption ($\dot{V}O_2$) by the Weir derivation to estimate energy expenditure. These derivative methods have not been compared with predictive equations.

Objective: To compare prediction of energy expenditure by the HBE and Schofield equation with energy expenditure as estimated by the Weir derivation in a cohort of critically ill patients.

Methods: Between June 2009 and May 2010, we conducted a prospective single-centre study of 60 mechanically ventilated patients with sepsis of varying severity in the ICU of a metropolitan hospital. Three groups of patients were compared: those with systemic inflammatory response syndrome (SIRS), severe sepsis and septic shock. The HBE and Schofield equation are age-based, weight-determined, sex-specific derivations that may incorporate stress and/or activity factors. Total energy expenditure (TEE) values calculated from these equations (TEE_{HBE} and TEE_{SCH}, respectively) were compared with the measured energy expenditure (MEE) calculated by the Weir derivation. We derived $\dot{V}CO_2$ from end-tidal CO_2 and deduced $\dot{V}O_2$ assuming a respiratory quotient of 0.8381.

Results: Mean (± SD) APACHE II score for the 60 patients was 25.7 ± 8.4. All patients received nutrition (51 enteral, eight parenteral and one combined) in addition to standard management for sepsis and multiorgan supportive therapy. Overall, 45 patients required inotropes and four received continuous renal replacement therapy. TEE derived from both predictive equations correlated well with MEE derived from the Weir equation (mean TEE_{HBE}, 7810.7 ± 1669.2 kJ/day; mean TEE_{SCH}, 8029.1 ± 1418.6 kJ/day; mean MEE, 7660.8 ± 2092.2 kJ/day), being within 8% of each other. Better correlations between TEE and MEE were observed in patients with APACHE II scores < 25 (vs those with scores ⩾ 25) and patients with SIRS or severe sepsis (vs those with septic shock).

Conclusion: In a cohort of patients with sepsis, TEE values calculated by the HBE and Schofield equation matched reasonably well with MEE values derived from the Weir equation. Correlation was better in patients with less severe sepsis (SIRS and severe sepsis and APACHE II score < 25). Our results suggest that predictive equations have sufficient validity for ongoing regular use in clinical practice.

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Optimal nutrition is a routine aspect of integral intensive care therapy. Previous studies have shown that adequate nutrition support during critical illness facilitates early weaning from mechanical ventilation, enhances wound healing, shortens the post-intensive-care period of recovery, reduces the length of hospital stay, decreases the incidence of pressure ulcers and reduces mortality.[1-6]

Measuring total energy expenditure (TEE) by direct calorimetry, based on regression equations of doubly labelled water, is complex and unrealistic in day-to-day practice in many intensive care units. Metabolic rate can be estimated indirectly in the ICU by using a metabolic cart (indirect calorimeter); extrapolating numbers computed from pulmonary artery catheter measurements using the Fick equation; or employing various equations based on body size, degree of injury/illness, or degree of inflammatory response. However, indirect calorimetry, considered as the practical "gold standard",[7-11] is time-consuming and expensive

Abbreviations

APACHE	Acute Physiology and Chronic Health Evaluation
$ETCO_2$	End-tidal CO_2 concentration
$FECO_2$	Fraction of CO_2 in mixed expired gas
HBE	Harris–Benedict equation
MEE	Measured energy expenditure (as predicted by the Weir derivation)
REE	Resting energy expenditure
RQ	Respiratory quotient
SIRS	Systemic inflammatory response syndrome
SOFA	Sequential Organ Failure Assessment
TEE	Total energy expenditure
TEE_{HBE}	TEE calculated by the Harris–Benedict equation
TEE_{SCH}	TEE calculated by the Schofield equation
$\dot{V}CO_2$	Volume of CO_2 eliminated in expired air
$\dot{V}O_2$	Oxygen consumption

Table 1. Comparison of the Weir derivation with the Harris–Benedict and Schofield equations, the most commonly employed predictive equations for estimation of energy expenditure

Weir derivation (kJ/day)	$(3.493 \times \dot{V}O_2) + (1.11 \times \dot{V}CO_2) \times 1440 \times 4.2$ $\dot{V}O_2 = \dot{V}CO_2/RQ$		
	Age (years)	Men	Women
Schofield equation (kJ/day)	10–17	$(74 \times W) + 2754$	$(56 \times W) + 2898$
	18–25	$(63 \times W) + 2896$	$(62 \times W) + 2036$
	30–59	$(48 \times W) + 3653$	$(34 \times W) + 3538$
	60–74	$(49.9 \times W) + 2930$	$(38.6 \times W) +2875$
	⩾ 75	$(35 \times W) + 3434$	$(41 \times W) +2610$
Harris–Benedict equation (kcal/day)*		$66.5 + (13.8 \times W) + (5.0 \times H) – (6.8 \times A)$	$655.1 + (9.6 \times W) + (1.8 \times H) – (4.7 \times A)$

A = age. H = height. RQ = respiratory quotient. $\dot{V}CO_2$ = volume of CO_2 eliminated in expired air. $\dot{V}O_2$ = oxygen consumption. W = weight.
* 1 kcal = 4.2 kJ.

and requires trained personnel. Hence it is not feasible to use it in daily patient management.[8,11,12]

Clinical dietitians routinely employ predictive equations to estimate energy expenditure. Though predictive equations are derived mainly from non-critically ill patients,[13] these equations are practical and time-effective and guide the prescription of appropriate energy support in the critically ill. Many of these equations only estimate the resting energy expenditure (REE), which accounts for 75%–100% of the TEE in the critically ill patient.[14] Various stress and activity factors[15-17] are applied to estimate TEE in the critically ill. A patient's anthropometry is factored into most such equations. Given the practical difficulty of measuring weight and height accurately in ICU patients, dietitians use approximations of height and weight.

Weir showed that the metabolic rate calculated from respiratory gas exchange measurements is, to a close approximation, proportional to the difference in percentage oxygen content between inspired and exhaled air.[18] This principle is employed in indirect calorimetry,[19] which determines the caloric expenditure using oxygen consumption ($\dot{V}O_2$) and the volume of CO_2 eliminated in expired air ($\dot{V}CO_2$). Continuous end-tidal CO_2 ($ETCO_2$) measurements may be used to derive $\dot{V}CO_2$ from the equation:

$$\dot{V}CO_2 = \dot{V} \times FECO_2,$$

where $\dot{V}$ is the expired gas volume and $FECO_2$ is the fraction of CO_2 in mixed expired gas. Modern ventilators can estimate $\dot{V}CO_2$ in real time. Such a method is independent of anthropometric measurements, and factors in individual variables such as severity of sepsis, fever, and medications.[20-23]

A few studies have compared TEE estimations by various predictive equations[24-27] with measured indirect calorimetry in critically ill mechanically ventilated patients. One such study evaluated the relationship between oxygen consumption and resting energy expenditure in critically ill patients with infectious and non-infectious causes of systemic inflammatory response syndrome (SIRS).[28] The host response to sepsis is highly variable, with some patients being hypometabolic.[29]

To our knowledge, no studies to date have compared predictive equations with the Weir derivation. Predictive equations have a high chance of under- or overestimating the energy expenditure in patients with sepsis. Although the Weir derivation has been validated in a few clinical situations,[30,31] its validity in patients with sepsis has not been evaluated.

The purpose of our study was to compare values of TEE predicted by the Weir derivation (here referred to as the "measured energy expenditure" [MEE]) with estimates of TEE

Table 2. A-priori calculation was performed for all 60 patients with sepsis based on *t* tests comparing TEE estimated using the predictive equations with MEE calculated from the Weir derivation*

Comparing method	H_0: no correlation *P* value (*F* test)	Method	Minimum difference regarded as significant
HBE estimation	0.0853	Equal variance	697.2 kJ/day
Schofield equation estimation	0.0199	Unequal variance	671.1 kJ/day

H_0 = null hypothesis. HBE = Harris–Benedict equation. MEE = measured energy expenditure. TEE = total energy expenditure.
* The concept of unknown variance was used to do the a-priori calculation, as we did not know the population variance. A folded *F* test was performed for both methods. The equal variance method was used to estimate the minimum difference required to reject the null hypothesis for the HBE, as the H_0 (no correlation) *P* value was > 0.05, whereas the unequal variance method was used for Schofield equation.

calculated by the Harris–Benedict equation[32] (TEE_{HBE}) and the Schofield equation[33] (TEE_{SCH}). Given that catabolism increases with worsening sepsis, we hypothesised that the Weir derivation may be superior to predictive equations for estimating energy expenditure in critically ill patients with sepsis.

Methods

Study design and setting

We conducted a prospective, single-centre study from June 2009 to May 2010 in a multidisciplinary ICU in a large metropolitan hospital where TEE assessment is performed as part of routine patient care. We assessed patients with varying severity of sepsis by comparing TEE_{HBE}[32] and TEE_{SCH}[33] with MEE. We analysed our study subjects in three cohorts: (a) a SIRS group, (b) a severe sepsis group, and (c) a septic shock group.

Inclusion criteria

Patients were included in our study if they were aged ⩾ 18 years, had an admitting diagnosis of sepsis requiring mechanical ventilation, had an expected ICU length of stay of > 48 hours, and received nutrition. Patients were excluded if they were under 18 years of age or moribund. Also excluded were patients who had active malignancy or burns; those with $PaO_2/FiO_2 < 100$ or who required $FiO_2 > 0.80$ to obtain $SpO_2 > 90\%$; and those with massive pulmonary embolism or cardiogenic shock (cardiac index < 2.2).

Predictive equations

For each patient, TEE was estimated using the Harris–Benedict and Schofield equations (Table 1). A range of stress factors (between 1.1 and 1.6), in accordance with the dietitian's usual practice, was factored into the calculated basal metabolic rate. Activity factors were not applied to our patients. TEE was calculated using the actual, healthy body weight, if known, or the ideal body weight as estimated from current weight (in patients with a body mass index [BMI] < 25 kg/m²) or from body weight adjusted using the Hamwi equation[34] (in patients with BMI > 25 kg/m²). The actual height, if known, was used; otherwise it was estimated using the length of the ulna.[35]

Weir derivation

TEE values estimated using the predictive equations were compared with $ETCO_2$-determined MEE values using the Weir derivation:

$$MEE = [(\dot{V}O_2 \times 3.941) + (\dot{V}CO_2 \times 1.11)] \times 1440 \times 4.2 \text{ kJ/day}$$

We assumed a respiratory quotient (RQ) of 0.8381 for all patients and calculated $\dot{V}O_2$ from the formula:

$$\dot{V}O_2 = \dot{V}CO_2/RQ.$$

Table 3. Baseline characteristics of the patients (*n* = 60)

Characteristic	Mean ± SD or *n* (%)
Age (years)	64.8 ± 16.6
Sex	
Male	36 (60%)
Female	24 (40%)
Type of patient	
Medical	46 (77%)
Surgical	14 (23%)
Type of sepsis	
SIRS	15 (25%)
Severe sepsis	20 (33%)
Septic shock	25 (42%)
APACHE II score	25.7 ± 8.4
APACHE III score	89.7 ± 37.5
SOFA score	9.12 ± 2.93
Source of sepsis	
Chest	43 (72%)
Abdomen	13 (22%)
Urine	3 (5%)
Blood	1 (2%)
Comorbidities*	
Hypertension	16 (15%)
Ischaemic heart disease (IHD)†	15 (14%)
Chronic obstructive lung disease	14 (14%)
Hypercholesterolaemia	10 (13%)
Dysrhythmia‡	8 (8%)
Diabetes mellitus	8 (8%)
Epilepsy	7 (7%)
Peripheral vascular disease	6 (6%)
Congestive cardiac failure	5 (5%)
Asthma	4 (4%)
Obstructive sleep apnoea	4 (4%)
Chronic renal impairment	4 (4%)
Metabolic syndrome	4 (4%)
Venous thromboembolism	4 (4%)
ICU length of stay (days)	9.1 ± 9.1
Hospital length of stay (days)	22.3 ± 22.5
Mortality rate	13 (22%)
Time to nutrition commencement (hours)	29.5 ± 16.9
Time to dietitian review (hours)	45.9 ± 27

APACHE = Acute Physiology and Chronic Health Evaluation. ICU = intensive care unit. SIRS = systemic inflammatory response syndrome. SOFA = Sequential Organ Failure Assessment. * Values add up to > 100% because patients could have more than one condition. † Nine patients had stable IHD; six had active disease leading to sepsis secondary to aspiration pneumonia. ‡ Atrial fibrillation was the most common dysrhythmia; one patient had paroxysmal supraventricular tachycardia.

Table 4. Metabolic and anthropometric variables (*n* = 60)

Variable	Mean ± SD
Height (cm)	170 ± 10
Weight (kg)	74.2 ± 17.6
Body mass index (kg/m^2)	26.7 ± 7.7
Maximum heart rate (beats/min)	121 ± 26
Minimum heart rate (beats/min)	83 ± 22
Maximum temperature (°C)	38.2 ± 0.9
Minimum temperature (°C)	36.1 ± 1.2
pH	7.37 ± 0.09
$PaCO_2$ (mmHg)	45.2 ± 11.8
PaO_2 (mmHg)	93.2 ± 22
Minute ventilation (L/min)	7.8 ± 2.1
VCO_2 (mL/min)	221.7 ± 60.5
VO_2 (mL/min)*	265 ± 72
$ETCO_2$ (mL/min)	37.4 ± 10.8
MEE derived from Weir equation (kJ/day)	7660.8 ± 2092.2
TEE derived from Harris–Benedict equation (kJ/day)	7810.7 ± 1669.2
TEE derived from Schofield equation (kJ/day)	8029.1 ± 1418.6

$ETCO_2$ = end-tidal CO_2 concentration. TEE = total energy expenditure. $\dot{V}CO_2$ = volume of CO_2 eliminated in expired air. $\dot{V}O_2$ = oxygen consumption. * $\dot{V}O_2$ calculation was based on an assumed respiratory quotient of 0.8381.

Measurements

Acute Physiology and Chronic Health Evaluation (APACHE) II and III scores were calculated for each patient at ICU admission, and the Sequential Organ Failure Assessment (SOFA) score was calculated at the peak of a patient's illness. $ETCO_2$-derived $\dot{V}CO_2$ (Evita, Dräger, Pittsburgh, PA, USA) measurements were done before nutrition was commenced. The predictive equations were calculated by a single dietitian who was blinded to the results of the MEE derived by the Weir method, and the investigator who calculated the MEE by the Weir method was blinded to the results of the predictive equations.

Statistics

Continuous variables were summarised using mean, standard deviation, median and range, and categorical variables were summarised using proportions (counts and percentages). Data on demographics (sex, age) and other baseline characteristics (APACHE II and III scores, type of sepsis and SOFA score) were recorded. Bland–Altman plots[36] were constructed to compare the two estimating equations. The strength of the correlation between the two estimation methods (predictive equations v Weir derivation) was quantified by the Karl Pearson correlation coefficient (r) or the coefficient of determination (R^2). A-priori calculation was performed for the 60 patients based on t tests comparing TEE_{HBE} and TEE_{SCH} values with MEE values. Differences of 697.2 kJ/day between MEE and TEE_{HBE} and 671.1 kJ/day between MEE and TEE_{SCH} were considered to be statistically significant (Table 2).

Ethics approval

The Eastern Health Human Research Ethics Committee granted ethics approval for our study, and the need for informed consent was waived.

Results

Patient demographics

Descriptive and demographic characteristics of the 60 patients are summarised in Table 3. Metabolic and anthropometric data and TEE values calculated with predictive equations are summarised in Table 4.

Thirteen patients died either in the ICU or in hospital. Noradrenaline was administered in 45 patients, adrenaline was used as a second agent in nine patients and vasopressin in three patients. Twenty-two patients had renal impairment (defined as estimated glomerular filtration rate < 60 mL/min, based on the MDRD formula) and four of these patients required continuous renal replacement therapy.

Details of nutrition commencement

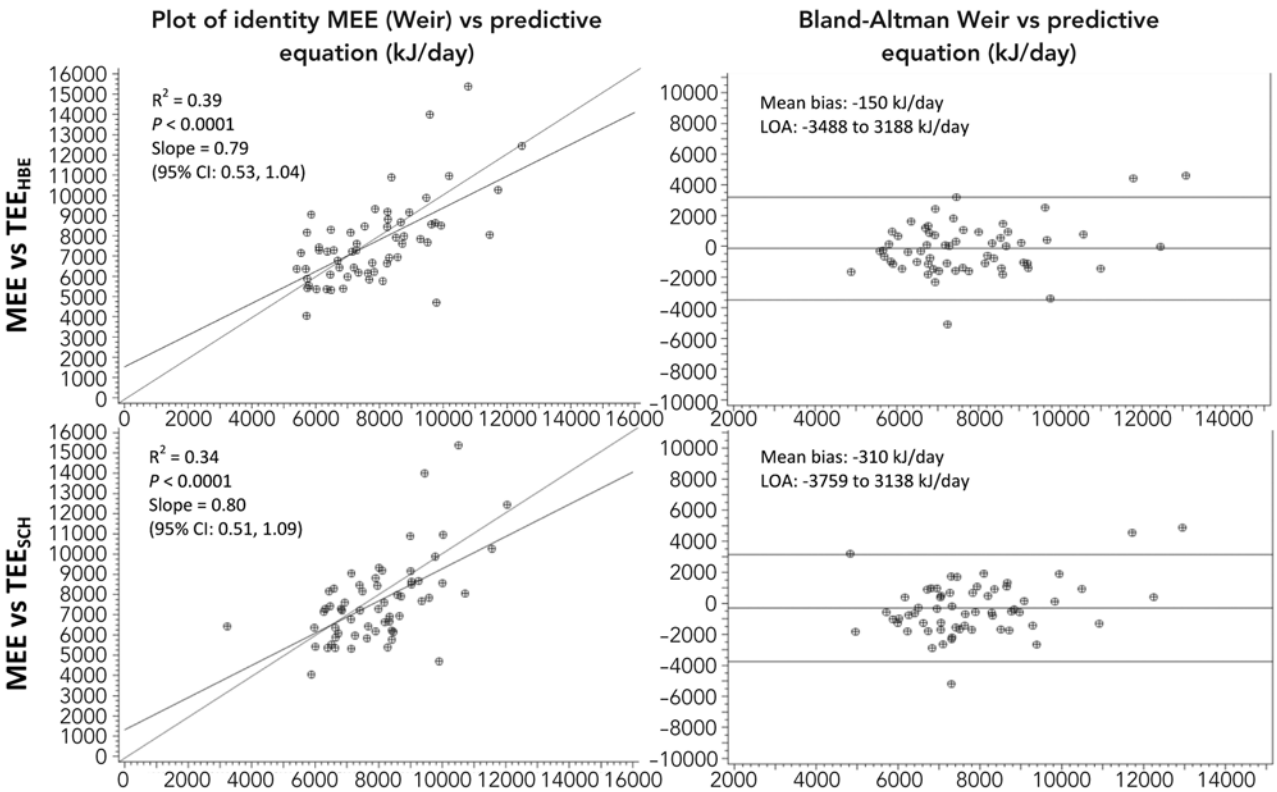
The mean (± SD) time to nutrition commencement was 29.5 ± 16.9 hours (median, 24 hours). Fifty-one patients received enteral nutrition, eight received parenteral nutrition, and one received both. The first measurement of a patient's VCO_2 using $ETCO_2$ was obtained soon after the patient was deemed eligible for enteral or parenteral nutrition. Fifty-nine of the enterally fed patients received their targeted dose.

Comparison of predictive equations with estimated energy expenditure

The mean and median differences between TEE derived by the Weir method (MEE) and TEE derived from the predictive equations (TEE_{HBE} and TEE_{SCH}) are illustrated in Figure 1. Analysis of the data based on the null hypothesis (that all three measurements of TEE had a common mean) strongly supported the assumption of equal means (ie, estimates using the predictive equations were not significantly different from the mean MEE values as measured by Weir's method).

$ETCO_2$-derived MEE values correlated well with TEE_{HBE} (R^2 = 0.39 for MEE [mean Bland–Altman bias of –149.9 kJ/

Figure 1. Comparison of MEE predicted by the Weir derivation with TEE_{HBE} and TEE_{SCH}: (a) scatter plots, looking at correlation (left); and (b) Bland–Altman plots, looking at level of agreement and bias (right)*



LOA = limits of agreement. MEE = measured energy expenditure (as predicted by the Weir derivation). R^2 = Coefficient of determination. TEE = total energy expenditure. TEE_{HBE} = TEE calculated by the Harris–Benedict equation. TEE_{SCH} = TEE calculated by the Schofield equation.

* In the scatter plots, predictive equation values are plotted on the x axis and Weir derivation values on the y axis. In the Bland Altman plots, the averages of Weir derivation (MEE) and predictive equation (TEE) values are plotted on the x axis and the differences between Weir derivation (MEE) and predictive equation (TEE) values on the y axis.

day]) and with TEE_{SCH} (R^2 = 0.34 [mean Bland–Altman bias of –310 kJ/day]).

In patients with less severe sepsis (the SIRS group), MEE values were higher than TEE values, but in more seriously ill patients (the severe sepsis and septic shock groups), MEE values were lower than TEE values. Although MEE values were higher than TEE values in the SIRS group by a mean difference of 518 kJ/day (HBE) and 331 kJ/day (Schofield equation), there was reasonably good correlation between MEE and TEE (r = 0.68 [HBE] and 0.70 [Schofield equation]) (Table 5, Figure 2). In the severe sepsis group, correlation between MEE and TEE_{HBE} was very high (r = 0.90), and there was also reasonably good correlation between MEE and TEE_{SCH} (r = 0.76). On the other hand, in patients with septic shock, there was poor agreement between MEE and TEE_{HBE} (r = 0.43) and TEE_{SCH} (r = 0.44).

The predictive equations were also compared with MEE based on the severity of illness (APACHE II score < 25 vs ⩾ 25). MEE and predicted TEE were both lower in patients with APACHE II scores ⩾ 25 (mean MEE, 7190.6 ± 2063 kJ/day) than in patients with APACHE II scores < 25 (mean MEE, 8235.5 ± 2017.8 kJ/day). A stronger correlation between MEE and TEE was observed in patients with APACHE II scores < 25 than in those with APACHE II scores ⩾ 25. The $ETCO_2$-derived MEE correlated moderately well with TEE_{HBE} (R^2 = 0.58; r = 0.76), with a mean Bland–Altman bias of –200 kJ/day. The correlation between MEE and TEE_{SCH} was relatively weak (R^2 = 0.40; r = 0.63), with a mean Bland–Altman bias of –144 kJ/day.

Discussion

Critically ill patients are extremely diverse, ranging from hypometabolic to hypermetabolic.[29] In addition, confounding issues such as obesity, fever, cachexia, oedema, some medications, and multiple surgical or metabolic insults

Table 5. Comparison of MEE with TEE_{HBE} and TEE_{SCH}, by type of sepsis

Variable	SIRS (*n* = 15)	Severe sepsis (*n* = 20)	Septic shock (*n* = 25)
Weir derivation			
MEE (kJ/day) (mean ± SD)	7945.4 (± 2330.2)	7682.1 (± 1920.7)	7473 (± 2141.3)
Harris–Benedict equation			
TEE_{HBE} (kJ/day) (mean ± SD)	7426.9 (± 1587.4)	8138.4 (± 1839.4)	7778.7 (± 1586.8)
Relationship between mean MEE and mean TEE_{HBE}*	MEE > TEE_{HBE}	MEE < TEE_{HBE}	MEE < TEE_{HBE}
P (mean MEE v mean TEE_{HBE})†	0.48	0.45	0.57
Difference between median MEE and median TEE_{HBE}‡	404.5	– 370.5	– 455.5
Correlation coefficient (*r*)	0.68	0.90	0.43
Coefficient of determination (R^2)	0.47	0.81	0.18
Schofield equation			
TEE_{SCH} (kJ/day) (mean ± SD)	7613.5 (± 1249.4)	8123.4 (± 1996.6)	8063.3 (± 1285.8)
Relationship between mean MEE and mean TEE_{SCH}*	MEE > TEE_{SCH}	MEE < TEE_{SCH}	MEE < TEE_{SCH}
P (mean MEE v mean TEE_{SCH})†	0.63	0.48	0.24
Difference between median MEE and median TEE_{SCH}‡	150.4	– 591.5	– 761
Correlation coefficient (*r*)	0.70	0.76	0.44
Coefficient of determination (R^2)	0.49	0.58	0.19

MEE = Measured energy expenditure (as predicted by the Weir derivation). SIRS = systemic inflammatory response syndrome. TEE = total energy expenditure. TEE_{HBE} = TEE calculated by the Harris–Benedict equation. TEE_{SCH} = TEE calculated by the Schofield equation.
* In less severely ill patients (the SIRS group), MEE was less than TEE, while the opposite relationship was observed between MEE and TEE in more seriously ill patients (the severe sepsis and septic shock groups). There was a strong correlation between MEE and TEE in the severe sepsis group (especially with TEE_{HBE}). † *P* value for the difference between two means was calculated using a two-sample *t* test. Analysis of the data strongly supported the null hypothesis that all three measurements of TEE had a common mean (ie, that there was no significant difference between the methods). ‡ As the values were dispersed, to avoid bias we compared median values as well as mean values.

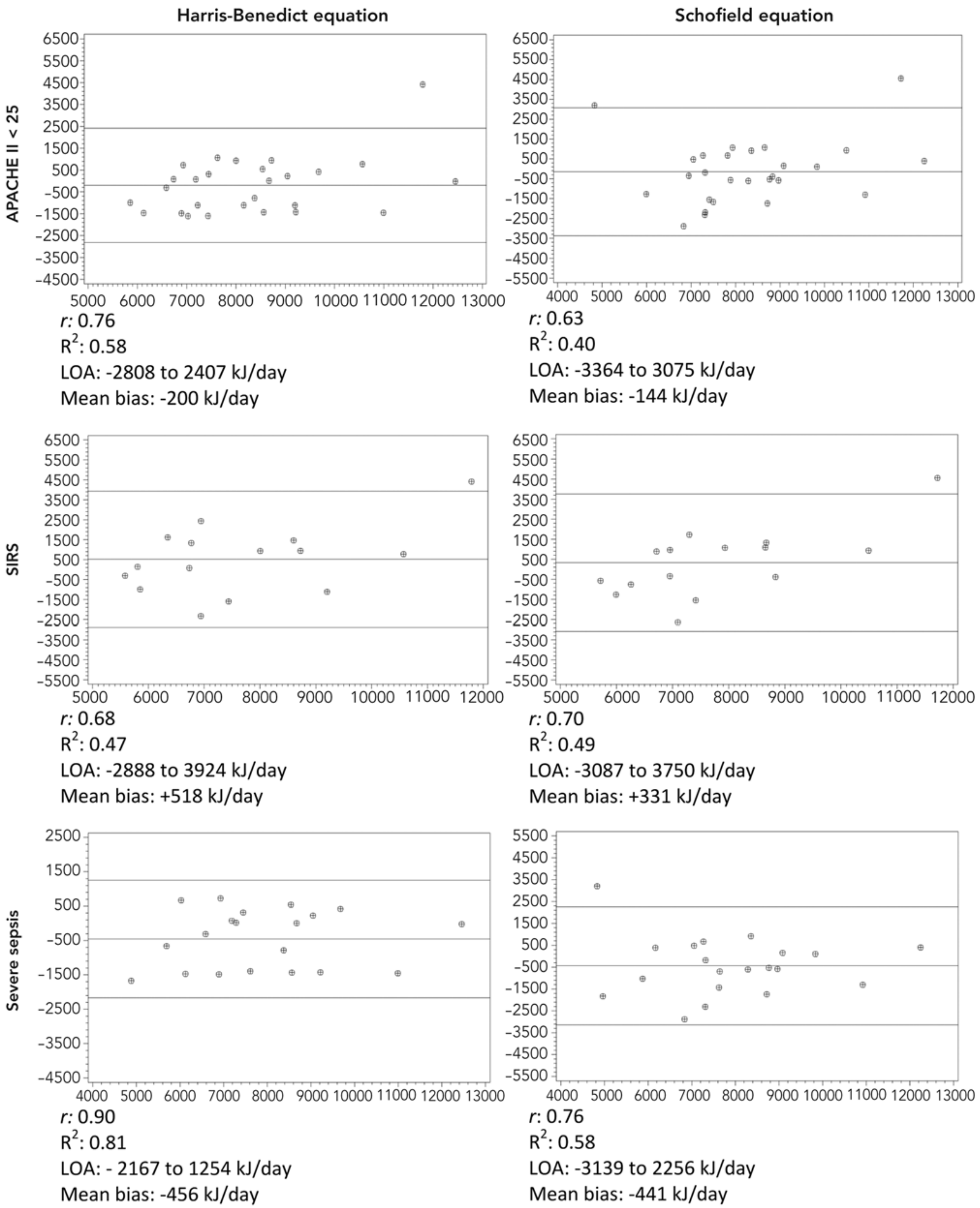
increase the difficulty of nutritional assessment and application of predictive equations.

Although the HBE can accurately predict (within 14%) the energy need in a healthy population, it has been shown to be unreliable when applied to critically ill patients.[11,14,37-39] Nevertheless, it is commonly used in ICUs.[40] We chose to analyse only the HBE multiplied by the stress factor, in accordance with standard Australian practice, which often excludes an activity factor. We did not use correction factors suggested by Long and colleagues[41] for the HBE (multiplying by 1.6 for severe infection), as a recent review did not show any benefit.[11] Our second equation, the Schofield equation, is the most commonly used by Australian dietitians,[40] and is preferred because it does not require an often estimated value for height.

In our study, the mean MEE was 25.2 ± 5.6 kcal/kg/day, which is similar to the energy targets suggested in recent recommendations.[42,43] TEE derived from both predictive equations correlated well with the Weir derivation (MEE). With worsening severity of illness, the correlation between MEE and the TEE_{HBE} and TEE_{SCH} weakened: the median difference between MEE and TEE_{SCH} was –591.5 kJ/day in patients with severe sepsis and 761 kJ/day in those with septic shock. This was possibly due to the loss of fat-free mass and consequent decline in energy expenditure,[44] which is not factored in by the predictive equations. This leads to a risk of overfeeding if energy prescription is purely based on predictive equations derived from routine weight measurements. Both predictive equations overestimated the energy expenditure compared with the Weir derivation: 5.4% for HBE and 8.1% for Schofield.

Intuitively, one would expect a greater difference between MEE (based on the Weir derivation) and TEE (based on predicted equations) in patients with septic shock or with higher APACHE II scores, who are likely to exhibit hypercatabolism. The hypermetabolic response to severe sepsis is appropriate, as it provides extra energy and substrates necessary for synthesis of acute-phase proteins, replication of immune cells and wound healing.[45] However, in our study, there was a stronger correlation between MEE and TEE in patients with SIRS and severe sepsis than patients with septic shock. Our findings are concordant

Figure 2. Bland–Altman plots for subgroups of patients for whom there was good correlation between MEE and TEE



APACHE = Acute Physiology and Chronic Health Evaluation. LOA = limits of agreement. MEE = measured energy expenditure (as predicted by the Weir derivation). r = Karl Pearson correlation coefficient. R^2 = coefficient of determination. SIRS = systemic inflammatory response syndrome. TEE = total energy expenditure.

with previously reported observations by Kreymann and colleagues[46] and Houtchens and Westenskow.[47] In a study of patients with varying severity of sepsis, Kreymann and colleagues found that REE measured by indirect calorimetry was lowest in those with septic shock.[46] Impairment of peripheral oxygen consumption is the prime reason for multiorgan failure.[48] Despite hyperdynamic circulation, total body $\dot{V}O_2$ and hence REE have been proven to be normal, slightly increased or even subnormal in patients with septic shock.[47] The reasons why Kreymann colleagues' study[46] and our study did not show a wider variation between Weir MEE and predictive TEE are not entirely clear.

We recognise the limitations of our study. Firstly, we did not validate the $ETCO_2$-derived MEE with the gold standard (indirect calorimetry). Secondly, we assumed an RQ of 0.8381 for all patients. An RQ of 0.8 is the most commonly accepted value, albeit in non-critically ill patients. Thus the $\dot{V}O_2$ was a derived value in our study, as the use of Swan–Ganz catheters in non-cardiac critically ill patients[49,50] is uncommon. A recent review suggested that by assuming an RQ of 0.8381, the largest expected error is an underestimation of 25% for an RQ of 1.2 or an overestimation of 19% for an RQ of 0.67.[51] Thirdly, the variations and errors associated with anthropometric assessment in all patients (but notably in obese patients) were an additional factor in our study, as the height and weight were estimated in many patients. Finally, we did not include burns and trauma patients, as care of these patients is regionalised in Victoria's health system and our ICU does not manage these patients. Importantly, burns and trauma patients are more likely to be hypercatabolic, so it would be interesting to repeat our study in patients with burns and trauma.

We believe that $ETCO_2$-derived MEE could facilitate routine energy estimation and allow daily assessment, factoring in the dynamic nature of energy balance in a critically ill patient. Many modern ventilators allow continuous assessment of $\dot{V}CO_2$. This allows more accurate energy expenditure estimation in the nutritional support of critically ill patients.

As indirect calorimetry still remains the gold standard for measuring energy expenditure, further research is warranted to validate the results of our study, directly comparing Weir-determined MEE and predictive equation-derived TEE with indirect calorimetry measurements. Once validated with indirect calorimetry, the $ETCO_2$-derived MEE could be studied in other hypercatabolic patients, such as those with trauma and burns or those with inherently high energy expenditure. It is possible that a subgroup of critically ill patients, yet to be defined, would benefit from a more real-time Weir-derived MEE that is based on dynamic changes in a critically ill patient compared with a one-off estimation from predictive equations made early in the course of the illness.

Conclusion

The Harris–Benedict, Schofield and Weir derivations have not been comparatively validated in patients with sepsis and hypercatabolism. In our study, TEE derived from both predictive equations correlated well with MEE predicted by the Weir derivation. Better correlations were observed in patients with APACHE II scores < 25 and patients who had severe sepsis. Although intuitively one would expect a higher $\dot{V}CO_2$ in patients with severe sepsis and septic shock (due to hypercatabolism), in our study of 60 patients, $\dot{V}CO_2$-derived MEE was actually lower than TEE estimates derived from both the predictive equations in these patients. We believe that Weir-derived MEE could facilitate daily assessment, factoring in the dynamic nature of energy balance in critically ill patients. As indirect calorimetry still remains the "gold standard", further research is warranted to validate the results of derived equations.

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Author details

Ashwin Subramaniam, Intensive Care Senior Registrar[1]
Michelle McPhee, Accredited Practising Dietitian[1]
Ramesh Nagappan, Senior Intensive Care Specialist,[1] Associate Professor,[2] and Director of Medicine[3]

1 Intensive Care Unit, Box Hill Hospital, Melbourne, VIC, Australia.
2 Faculty of Medicine, Monash University, Melbourne, VIC, Australia.
3 Maroondah Hospital, Melbourne, VIC, Australia.

a.subramaniam@alfred.org.au; catchdrash@yahoo.com

References

1 Bassili HR, Deitel M. Effect of nutritional support on weaning patients off mechanical ventilators. *JPEN J Parenter Enteral Nutr* 1981; 5: 161-3.
2 Wray CJ, Mammen JM, Hasselgren PO. Catabolic response to stress and potential benefits of nutrition support. *Nutrition* 2002; 18: 971-7.
3 Larca L, Greenbaum DM. Effectiveness of intensive nutritional regimes in patients who fail to wean from mechanical ventilation. *Crit Care Med* 1982; 10: 297-300.
4 Askanazi J, Weissman C, Rosenbaum SH, et al. Nutrition and the respiratory system. *Crit Care Med* 1982; 10: 163-72.
5 Mechanick JI, Brett EM. Nutrition support of the chronically critically ill patient. *Crit Care Clin* 2002; 18: 597-618.
6 Villet S, Chiolero RL, Bollmann MD, et al. Negative impact of hypocaloric feeding and energy balance on clinical outcome in ICU patients. *Clin Nutr* 2005; 24: 502-9.
7 Coss-Bu JA, Jefferson LS, Walding D, et al. Resting energy expenditure and nitrogen balance in critically ill pediatric patients on mechanical ventilation. *Nutrition* 1998; 14: 649-52.

8 Flancbaum L, Choban PS, Sambucco S, et al. Comparison of indirect calorimetry, the Fick method, and prediction equations in estimating the energy requirements of critically ill patients. *Am J Clin Nutr* 1999; 69: 461-6.

9 Jéquier E, Felber JP. Indirect calorimetry. *Baillieres Clin Endocrinol Metab* 1987; 1: 911-35.

10 Soares MJ, Sheela ML, Kurpad AV, et al. The influence of different methods on basal metabolic rate measurements in human subjects. *Am J Clin Nutr* 1989; 50: 731-6.

11 Frankenfield D, Hise M, Malone A, et al. Prediction of resting metabolic rate in critically ill adult patients: results of a systematic review of the evidence. *J Am Diet Assoc* 2007; 107: 1552-61.

12 Mifflin MD, St Jeor ST, Hill LA, et al. A new predictive equation for resting energy expenditure in healthy individuals. *Am J Clin Nutr* 1990; 51: 241-7.

13 Reeves MM, Capra S. Predicting energy requirements in the clinical setting: are current methods evidence based? *Nutr Rev* 2003; 61: 143-51.

14 Walker RN, Heuberger RA. Predictive equations for energy needs for the critically ill. *Respir Care* 2009; 54: 509-21.

15 Elia M. Insights into energy requirements in disease. *Public Health Nutr* 2005; 8: 1037-52.

16 Barak N, Wall-Alonso E, Sitrin MD. Evaluation of stress factors and body weight adjustments currently used to estimate energy expenditure in hospitalized patients. *JPEN J Parenter Enteral Nutr* 2002; 26: 231-8.

17 Swinamer DL, Grace MG, Hamilton SM, et al. Predictive equation for assessing energy expenditure in mechanically ventilated critically ill patients. *Crit Care Med* 1990; 18: 657-61.

18 Weir JB. New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol* 1949; 109: 1-9.

19 Cunningham JJ. Calculation of energy expenditure from indirect calorimetry: assessment of the Weir equation. *Nutrition* 1990; 6: 222-3.

20 Swinamer DL, Phang PT, Jones RL, et al. Twenty-four hour energy expenditure in critically ill patients. *Crit Care Med* 1987; 15: 637-43.

21 Gariballa S, Forster S. Energy expenditure of acutely ill hospitalised patients. *Nutr J* 2006; 5: 9.

22 Dempsey DT, Guenter P, Mullen JL, et al. Energy expenditure in acute trauma to the head with and without barbiturate therapy. *Surg Gynecol Obstet* 1985; 160: 128-34.

23 Wilmore DW, Long JM, Mason AD Jr, et al. Catecholamines: mediator of the hypermetabolic response to thermal injury. *Ann Surg* 1974; 180: 653-69.

24 Frankenfield D, Smith JS, Cooney RN. Validation of 2 approaches to predicting resting metabolic rate in critically ill patients. *JPEN J Parenter Enteral Nutr* 2004; 28: 259-64.

25 Cheng CH, Chen CH, Wong Y, et al. Measured versus estimated energy expenditure in mechanically ventilated critically ill patients. *Clin Nutr* 2002; 21: 165-72.

26 Frankenfield DC, Coleman A, Alam S, et al. Analysis of estimation methods for resting metabolic rate in critically ill adults. *JPEN J Parenter Enteral Nutr* 2009; 33: 27-36.

27 Faisy C, Guerot E, Diehl JL, et al. Assessment of resting energy expenditure in mechanically ventilated patients. *Am J Clin Nutr* 2003; 78: 241-9.

28 Moriyama S, Okamoto K, Tabira Y, et al. Evaluation of oxygen consumption and resting energy expenditure in critically ill patients with systemic inflammatory response syndrome. *Crit Care Med* 1999; 27: 2133-6.

29 Kao CC, Guntupalli KK, Bandi V, et al. Whole body CO_2 production as an index of the metabolic response to sepsis. *Shock* 2009; 32: 23-8.

30 Mansell PI, Macdonald IA. Reappraisal of the Weir equation for calculation of metabolic rate. *Am J Physiol* 1990; 258: R1347-54.

31 Turell DJ, Alexander JK. Experimental evaluation of Weir's formula for estimating metabolic rate in man. *J Appl Physiol* 1964; 19: 946-8.

32 Harris JA, Benedict FG. A biometric study of basal metabolism in man. Washington: Carnegie Institute of Washington, 1919. (CIW Publication no. 279.)

33 Schofield WN. Predicting basal metabolic rate, new standards and review of previous work. *Hum Nutr Clin Nutr* 1985; 39 Suppl 1: 5S-41S.

34 Hamwi GJ. Therapy: changing dietary concepts. In: Danowski TS, editor. Diabetes mellitus: diagnosis and treatment. Vol. 1. New York: American Diabetes Association, 1964.

35 Mohanty SP, Babu SS, Nair NS. The use of arm span as a predictor of height: a study of South Indian women. *J Orthop Surg (Hong Kong)* 2001; 9: 19-23.

36 Bland JM, Altman DG. Measuring agreement in method comparison studies. *Stat Methods Med Res* 1999; 8: 135-60.

37 Sherman MS, Pillai A, Jackson A, et al. Standard equations are not accurate in assessing resting energy expenditure in patients with amyotrophic lateral sclerosis. *JPEN J Parenter Enteral Nutr* 2004; 28: 442-6.

38 Headley JM. Indirect calorimetry: a trend toward continuous metabolic assessment. *AACN Clin Issues* 2003; 14: 155-67; quiz 266.

39 Reid CL. Poor agreement between continuous measurements of energy expenditure and routinely used prediction equations in intensive care unit patients. *Clin Nutr* 2007; 26: 649-57.

40 Reeves MM, Capra S. Variation in the application of methods used for predicting energy requirements in acutely ill adult patients: a survey of practice. *Eur J Clin Nutr* 2003; 57: 1530-5.

41 Long CL, Schaffel N, Geiger JW, et al. Metabolic response to injury and illness: estimation of energy and protein needs from indirect calorimetry and nitrogen balance. *JPEN J Parenter Enteral Nutr* 1979; 3: 452-6.

42 Kreymann KG, Berger MM, Deutz NE, et al. ESPEN guidelines on enteral nutrition: intensive care. *Clin Nutr* 2006; 25: 210-23.

43 Cerra FB, Benitez MR, Blackburn GL, et al. Applied nutrition in ICU patients. A consensus statement of the American College of Chest Physicians. *Chest* 1997; 111: 769-78.

44 Wang Z, Heshka S, Heymsfield SB, et al. A cellular-level approach to predicting resting energy expenditure across the adult years. *Am J Clin Nutr* 2005; 81: 799-806.

45 Biolo G, Toigo G, Ciocchi B, et al. Metabolic response to injury and sepsis: changes in protein metabolism. *Nutrition* 1997; 13: 52S-7S.

46 Kreymann G, Grosser S, Buggisch P, et al. Oxygen consumption and resting metabolic rate in sepsis, sepsis syndrome, and septic shock. *Crit Care Med* 1993; 21: 1012-9.

47 Houtchens BA, Westenskow DR. Oxygen consumption in septic shock: collective review. *Circ Shock* 1984; 13: 361-84.

48 Mirhashemi S, Messmer K, Arfors KE, et al. Microcirculatory effects of normovolemic hemodilution in skeletal muscle. *Int J Microcirc Clin Exp* 1987; 6: 359-69.

49 Peters SG, Afessa B, Decker PA, et al. Increased risk associated with pulmonary artery catheterization in the medical intensive care unit. *J Crit Care* 2003; 18: 166-71.

50 Wiener RS, Welch HG. Trends in the use of the pulmonary artery catheter in the United States, 1993–2004. *JAMA* 2007; 298: 423-9.

51 McArthur CD. AARC clinical practice guideline. Metabolic measurements using indirect calorimetry during mechanical ventilation — 2004 revision and update. *Respir Care* 2004; 46: 1073-9. ❑