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Original Article

Predicting resting energy expenditure (REE): Misapplying equations can lead to clinically significant errors

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SUMMARY

Background & Aims: Predicted REE is often the largest component of a nutritional prescription. While inaccuracy due to individual variability is well-known, prediction errors due to mis-applying equations have been largely ignored.

Methods: Size of error was determined for: A. Mis-quotation of the Harris-Benedict (HB) equation; B. Substitution of the Department of Health (DOH) basal metabolic rate (BMR) equation into REE equations developed from the Harris-Benedict (HB) equation; C. Using the HB equation in children; D. Using 'general' rather than disease-specific stress factors; and E. Double-inclusion of dietary-induced thermogenesis (DIT). Dietitians were surveyed to determine whether they could detect large errors.

Results: Errors were up to: A. 87%; B. 30%; C. 298%; D. 33%; E. 10%. Errors A–D were highly variable and dietitians could not accurately define error size.

Conclusions: Errors from misapplying equations can pass undetected by dietitians and are large enough to result in major complications if applied to nutritional support. Such errors will apply to new as well as current equations. Avoiding these errors when predicting REE for a range of individuals necessitates a complex array of equations; this may only be practical by using bedside software.

1. Introduction

The estimated energy requirement (EER) comprises BMR, metabolic stress, growth, activity and DIT. BMR is measured when awake at physical and mental rest in a thermoneutral environment, 10–12 h after the last meal, without having done strenuous physical exercise in the previous 24 h and without disease or fever. In contrast, REE includes BMR plus any metabolic stress from disease or injury when at complete rest for at least 30 min, in a post-absorptive state and thermoneutral environment. In acute disease BMR and DIT are relatively constant and activity and growth are often minimal or absent. REE is therefore the largest and most difficult component of EER to predict.

Estimation of energy expenditure is fundamental to planning nutritional support because underfeeding is associated with increased intensive care unit stay, complications and mortality[1,2] whereas overfeeding increases hyperglycemia, infection and liver dysfunction.[3,4] Unfortunately, estimating energy expenditure is prone to error.[5] Measurement is preferable but available to few patients. Even when indirect calorimetry is available to critically ill adults and children, clinical instability makes it impractical in 47% and 75%, respectively.[6,7] Thus prediction from equations is often the only practical alternative. Physiology-based equations improve prediction accuracy in mechanically ventilated patients,[5] but REE prediction for most patient groups has to be done by adding metabolic stress (a 'stress factor') to predicted BMR to account for the overall effect on REE.[8] Metabolic stress is expressed as: % predicted BMR = measured REE × 100/predicted BMR. For example, REE for major surgery is 106% of BMR (ie. a 6% stress factor).[9]

In a review of 500 publications on energy and nitrogen requirements in disease states[8] the most commonly used BMR equations ranked: Harris-Benedict[10] (HB) > Schofield[11] either using weight (S) or weight and height (SWH) > World Health Organisation.[12] However, dieticians in North America, Australia and the UK most commonly use HB, S and DOH equations, respectively. DOH is identical to S except for equations for over 60 y. Each equation was developed from regression analysis of BMR measured by indirect calorimetry. The HB equation was developed from a small database ($n = 239$) that excluded children, had few obese subjects and the measurement was not strictly basal. Independent variables used in the male and female HB equations include weight (kg), height (cm) and age (negatively weighted). In contrast, >7000 subjects were

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Non-standard abbreviations

DIT	Dietary-induced thermogenesis
DOH	Deparment of health
EER	Estimated energy requirement
HB	Harris-Benedict
PAL	Physical activity level
REE	Resting energy expenditure
S	Schofield
SWH	Schofield weight height
TEE	Total energy expenditure
Vm	Minute ventilation
WHO	World Health Organisation

used to develop the male and female series of age-banded equations using weight (DOH, S, WHO) or weight and height (SWH).[13,12] However, DOH, HB, S, SWH and WHO equations all lack subjects from the tropics and frequently overestimate measured BMR in a variety of populations.[14] More modern equations are recommended for estimating BMR in healthy individuals[14] and their use in developing REE equations would reduce the BMR component of prediction error. Future, physiology-based equations may reduce well-known errors from applying stress factors derived from groups to an individual or use of inaccurate parameters (eg. edematous weight),[5] but to date their use is mostly limited to mechanically ventilated patients. Unfortunately, current and future 'BMR_stress factor' equations will remain prone to mis-application. This paper describes five avoidable errors: A. Mis-quotation; B. Substituting the 'wrong' BMR equation; C. Mis-use in children; D. Using the 'wrong' stress factor and E. Double-inclusion of DIT. The likelihood that such errors could be identified was tested among dieticians.

2. Methodology

The error in each mis-applied equation was determined as a percentage of the correctly applied equation in a series of 'theoretical patients'. The HB equation is seriously mis-quoted in the literature when the decimal place of the female or male constant is moved from 655 and 65.5 to 66.5 and 665, respectively or the height measure in 'cm' is changed to meters.[15] The error as %HB was found from: (HB mis-quote − HB) × 100/HB, using a range of age (20–95 y), height (10th, 50th and 90th height centiles)[16] and BMI (18, 22 and 30). In addition, UK guidelines substitute the DOH equation into REE equations mostly developed from the HB equation.[17] The %HB error was calculated from: (DOH − HB) × 100/HB, using the above age, height and BMI ranges. The effect of this error on REE was then examined by multiplying the minimum and maximum errors by a range of hypo- or hypermetabolic stress factors: Error as %HB × stress factor.

Potential errors in using the HB equation in children were plotted as %SWH (developed for children) from 1 month to 25 y using standard weights and heights for age and sex[13]: (HB − SWH) × 100/SWH. Gender differences were calculated from: male HB BMR × 100/female HB BMR. The error of applying a 'general' REE equation, developed from patients with heterogenous disease, to an individual was estimated as %BMR: 'general' − 'disease-specific' REE. Lastly, the error of double-counting DIT is defined.

If dietitians mis-apply equations but detect and investigate large errors, mis-application might not be a problem. To determine whether the above errors would be obvious in practice, North Bristol NHS Trust acute-care dietitians were asked to 'best guess' error size (%: ≤10, ≤20, ≤30, ≤40, ≤50, >50) for 30 mis-applied BMR calculations. For each calculation the dietitian was given the age (0.08–75 y), gender, weight (4–94 kg), height (55–186 cm) and the BMR (474–2289 Kcal/d) and warned of how the equation had been mis-applied:

- HB wrongly used instead of SWH equations.
- Decimal point mistake (in published literature) in the HB equation.
- Incorrect units mistake (in published literature) in the HB equation.
- S equations used in place of HB when the stress factor was developed from the HB equation.

Systematic bias between actual and estimated errors was tested using the General Linear Squares model (Stata® 6.0, StataCorp, Texas).

3. Results

3.1. Mis-quoting the HB equation

Mis-placing the constant decimal place to 65.5 in females and 665 in males results in a 34–65% underestimate and 26–62% overestimate, respectively. Using height in meters instead of 'cm' underestimates BMR by 18–31% in females and 40–87% in males. However, rounding the original equations from 4 decimal places to 1 is clinically acceptable because the error is <1%.

3.2. Substituting BMR equations

When DOH is substituted for HB (Figs. 1–3), BMR prediction is rarely comparable (ie. 100%HB), systematically increases with age, excepting the 60–75 y DOH equation nadir, and is higher at BMI 18 > 22 > 30 and in males > females. There is no consistent pattern in DOH BMR, as a percentage of HB, over a range of age, sex, height and weight. Multiplying the minimum and maximum BMR errors by stress factors developed for HB can exaggerate overall REE error (Fig. 4). Underestimation increases if a BMR underestimate coincides with a hypometabolic (<90%BMR) stress factor. Overestimation increases if a BMR overestimate coincides with a hypermetabolic (>110%BMR) stress factor. For example, when DOH predicts BMR to be 130%HB and the REE for head injury was measured as 154%HB, REE will equal: 1.3 × 142 = 185%HB, equivalent to a 43% overestimate. Conversely the overall error would be reduced by combination of a BMR underestimate with a hypermetabolic stress factor or an overestimate with a hypometabolic stress factor. An incidental finding is that moving to a higher age-banded DOH equation 'estimates' an artifactual fall in BMR; up to 8% moving from <60 y to >60 y.

3.3. Differences in BMR over age and between genders

As a percentage of SWH, female HB falls from 398% to 130% between 0 and 2.5 y, then from 123% to 110% between 3 y and 8.5 y after which it remains between 99% and 106% (Fig. 5). For males the differences were smaller with HB falling from 185% to 90% from age 0 to 2.5 y, reaching its nadir of 86–93% between 3 y and 7.5 y and 93–97% when >7.5 y. The difference between female and male HB predictions falls from 213% to 40%SWH from age 0 to 2.5 y, 36%–18% from 3 y to 7.5 y after which the difference was 5–15%.

3.4. Using the 'wrong' stress factor and double-counting DIT

Differences between 'general' and disease-specific REE prediction are very variable depending on the disease-type, stage or treatment (Table 1). Variance of disease-specific REE prediction is