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Original article

Accuracy of predictive equations for the measurement of resting energy expenditure in older subjects

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SUMMARY

Background and aims: The measurement of resting energy expenditure (REE) is important to assess individual total energy requirements in older subjects. The validity of REE prediction equations in this population has not been thoroughly evaluated and therefore the main aim of this analysis was to assess the accuracy of REE prediction equations in older subjects.
Methods: Weight, height and body mass index (BMI) were measured. REE was measured by indirect calorimetry (IC) in 68 older subjects (age: 60–94 years, M/F: 13/55, BMI: 26.3 ± 5.0 kg/m^2). Measured REE was compared to 14 equations for the calculation of REE estimates. In addition, two novel approaches (Aggregate model and meta-regression equations) for the prediction of REE were evaluated. Paired *t* test and Bland–Altman method were used to assess the agreement of the equations.
Results: The average measured REE was 1298 ± 264 kcal/day. The equation with the smallest bias was proposed by Muller (Bias ± 2SD = +3 ± 294 kcal/day) whereas the Mifflin equation was associated with the largest error (Bias ± 2SD = −172 ± 282 kcal/day). The Aggregate, Muller, Harris–Benedict and Fredrix equations were characterised by a prediction within ±10% of measured REE in more than 60% of subjects. Of the four algorithms, only the Aggregate equation did not show a significant association of the measurement bias with age, BMI and gender.
Conclusions: The Aggregate algorithm was characterised by a higher, overall accuracy for the prediction of REE in older subjects and its use should be advocated in older subjects. However, due to the large variability of the estimates, the measurement of REE by IC is still recommended for an accurate assessment of individual REE.

1. Introduction

The measurement of individual total energy expenditure (TEE) is a critical component of diagnostic protocols for the assessment of nutritional status. Resting energy expenditure (REE) contributes to approximately 70% of the TEE and therefore is routinely used as the primary step to define total energy requirements after accounting for physical activity energy expenditure (PAEE) and thermic effect of food (TEF).[1] REE can be precisely measured using indirect calorimetric systems but the instruments are expensive and, as a result, the measurements are still confined to specialised settings. Predictive equations based on demographic (age, sex, ethnicity), anthropometric (weight, height) and body composition variables (fat free mass, fat mass) have been developed over the last century to allow simple and rapid calculations of REE.

However, new prediction equations are continuously developed using a variety of socio-demographic factors (age, ethnicity, BMI, gender) as predictors and applied in different physiological states (growth, menopause, physical activity level) and disease processes (acute and chronic diseases). Therefore, the growing number of equations makes difficult the selection of a specific equation that will work well in different contexts.

Ageing-related changes in body composition and cellular energy metabolism influence total energy expenditure and its subcomponents. The decrease in REE is mainly related to the progressive, reciprocal changes in higher (fat-free mass (FFM),

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decrease) and less metabolically active (fat mass (FM), increase) tissues, which appears to be due to a reduction in organ mass and specific metabolic rates of individual tissues.[2] Hence, REE predictions equations validated in young populations may not be applicable to older subjects, particularly to the very old (>80 y). The applications of these equations may lead to an increased measurement error, inaccurate estimation of energy requirements and, particularly in frail older individuals, development of inadequate nutritional interventions to maintain an optimal nutritional status. Three prediction equations have been specifically developed in geriatric populations but the association of the measurement bias with age has not been evaluated. In addition, two novel approaches have been recently proposed. Wells et al.[3] developed an "Aggregate" approach based on the hypothesis that pooling together independent REE estimates derived from different algorithms would improve accuracy and reduce error variability. The Aggregate approach showed greater accuracy compared to other prediction equations in a population of young women but the accuracy of this approach has not been evaluated in older subjects. Secondly, a new array of 20 algorithms taking into account weight, age (young, old), gender (male, female) and ethnicity (White Caucasian, African American, Asian, Hispanics) has been derived from a meta-regression of 47 algorithms published in the literature.[4] Neemalat et al. have recently evaluated the accuracy of REE predictive equations in hospitalised malnourished older patients and reported a proportional bias of predictive equations, with overestimation of low REE values and underestimation of high REE values.[5] The accuracy of the REE algorithms has not been tested in an independent sample of non-hospitalised older subjects.

The main aim of this study was to evaluate the accuracy of established (Harris–Benedict,[6] Owen,[7] Mifflin,[8] Bernstein, Muller,[9] Fredrix,[10] WHO,[1] EU,[11] Luhrmann,[12] De Lorenzo,[13] Korth,[14] Schofield[15]) and novel equations (Aggregate[3] and meta-regression[4]) for the measurement of REE in older subjects. We have also evaluated whether the bias of each individual equation is influenced by age, gender and BMI.

2. Methods

2.1. Subjects

Subjects were recruited consecutively among patients who attended the International Center for the Assessment of Nutritional Status (ICANS, University of Milan) for body composition evaluation between 2009 and 2010. Eligible for the study were white Caucasian subjects of both genders fulfilling the following criteria: 1) age ≥60 years; 2) body mass index (BMI) ≤50 kg/m^2; 3) absence of significant cardiovascular or pulmonary diseases, uncontrolled metabolic disease (diabetes, anaemia or thyroid disease), cancer or inflammatory conditions, any use of drugs (corticosteroids, hormones, etc.) that might interfere with REE 4) absence of weight loss or gain (>5 kg) in the last year and 5) no treatment with special diets. All measurements were performed, in the same morning, in 84 subjects, including seven smokers, after an overnight fast. Sixteen subjects were excluded from the final analysis due to: 1) a respiratory quotient outside the expected physiological range (0.71–1.00) (11 subjects), BMI less than 18.0 kg/m^2 (3 subjects) and measured REE greater than ±3SD (2 subjects). Sixty-eight subjects (Male/Female: 13/55) were included in the final analysis. The higher prevalence of female subjects is representative of the higher number of female subjects attending our outpatient nutritional clinic. The study procedures were approved by the local Ethical Committee and all subjects gave informed consent. The STROBE statement for cross-sectional studies[16] has been adopted to provide detailed information on the study design and sample characteristics.

2.2. Measurements

2.2.1. Anthropometry

Measurements were collected by the same operator, according to standardised procedures.[17] Body weight (WT, Kg) and Height (HT, cm) were measured to the nearest 0.1 kg and 0.5 cm, respectively. BMI was calculated using the formula: BMI (Kg/m^2) = WT (Kg)/HT^2 (m).

2.2.2. Measured REE

An open-circuit ventilated-hood system indirect calorimetry was used (Sensor Medics 29, Anaheim, CA, USA). Resting VO_2 and VCO_2 measurements were taken in the early morning, after an overnight fast, under standardised conditions, with the person lying awake and emotionally undisturbed, completely at rest and comfortably supine on a bed, their head under a transparent ventilated canopy, in a thermally neutral environment (24–26 °C), and after at least 8 h of sleep. Respiratory gas samples were taken by a ventilated hood system, every minute for 30–40 min and the data collected during the first 5–10 min were discarded, as recommended by Isbell et al.[18] This allowed the subjects to acclimatize to the canopy and instrument noise. The calorimeter was calibrated daily before starting the tests, using a two-point calibration method based on two separate mixtures of known gas content. The flow rate was calibrated with a 3-liter syringe, according to the calorimeter manufacturer's instructions. The average of the last 20 min of measurements was used to determine 24 h REE according to standard abbreviated Weir equation.[19]

2.2.3. Predicted REE

The measured REE was then compared to the following published REE prediction equations: 1) Harris–Benedict,[6] 2) Owen,[7] 3) Mifflin,[8] 4) Bernstein,[20] 5) World Health Organization (WHO),[21] 6) Fredrix,[10] 7) Livingston,[22] 8) Muller,[9] 9) Luhrmann,[12] 10) Schofield,[15] 11) European Community,[11] 12) Henry,[23] 13) Korth,[14] 14) De Lorenzo.[13] In addition two recent computational approaches based on meta-regression of data from 47 published studies and on the calculation of the Aggregate estimates of REE were also evaluated. The first approach[4] provides meta-regression equations with different independent factors, including those that only rely on a subset of easily measured covariates (weight, age, height, gender and race). This procedure incorporates the coefficients or slopes of previously developed equations into a single slope. The latter approach[3] is based on the assumption that the REE predictions are independent of one another; that the individual predictions are based on different underlying assumptions and that these independent predictions are then aggregated. Under these conditions, the error will not be correlated across the predictions, but will rather be randomly distributed across them and hence tend to cancel out, increasing the accuracy of the REE Aggregate prediction. The algorithm of each equation for the prediction of REE is reported in Table 1. The difference between measured and predicted REE (ΔREE) was expressed in absolute values (kcal/day, mean bias) and percentage (%, relative bias). Relative Bias (%) was calculated as: $(\Delta REE_{Mean\ Bias})/REE_{Measured}$ *100. A measurement was considered inaccurate when the relative bias was greater than ±10% of measured REE; the number of subjects with an inaccurate prediction was calculated together with the maximal overestimation (MOE) and maximal underestimation (MUE) for REE. The association between age, BMI and gender with REE estimates was evaluated to indicate whether these factors had a significant influence on the measurement bias.

2.2.4. Statistical analysis

The data are reported as mean ± SD. The Bland–Altman method was used to evaluate the agreement between measured and