ARTICLE IN PRESS

Clinical Nutrition ESPEN xxx (2018) e1–e6

Contents lists available at ScienceDirect

Clinical Nutrition ESPEN

journal homepage: http://www.clinicalnutritionespen.com

Original article

Resting energy expenditure in children with cerebral palsy: Accuracy of available prediction formulae and development of a population-specific formula

Francesca Penagini [a,*], Barbara Borsani [b], Alessandra Bosetti [b], Chiara Mameli [a], Dario Dilillo [a], Giulia Ramponi [a], Francesco Motta [c], Giorgio Bedogni [d], Gian Vincenzo Zuccotti [a]

[a] Department of Pediatrics, "V. Buzzi" Children's Hospital, University of Milan, Via Castelvetro 32, 20154 Milan, Italy
[b] Pediatric Nutrition Unit, "V. Buzzi" Children's Hospital, University of Milan, Via Castelvetro 32, 20154 Milan, Italy
[c] Pediatric Orthopedic Unit, "V. Buzzi" Children's Hospital, Via Castelvetro 32, 20154 Milan, Italy
[d] Clinical Epidemiology Unit, Liver Research Center, Building Q, AREA Science Park, Strada Statale 14 km 163.5, 34012, Basovizza, Trieste, Italy

ARTICLE INFO

Article history:
Received 16 November 2017
Accepted 3 April 2018

Keywords:
Indirect calorimetry
Resting energy expenditure
Prediction formulae
Cerebral palsy
Children

SUMMARY

Background and aims: Energy requirements are difficult to estimate in children with cerebral palsy (CP). Resting energy expenditure (REE), necessary for personalized nutritional intervention, is most commonly estimated using prediction formulae because the reference method, i.e. indirect calorimetry (IC), is not available in all Nutrition Units. The main aim of the present study was to evaluate the accuracy of the most commonly used REE prediction formulae in children with CP. The secondary aim was to develop a new population-specific formula for the estimation of REE in children with CP.
Methods: REE was measured by IC in 54 children and adolescents with spastic quadriplegic cerebral palsy (SQCP) and estimated from the five most commonly used prediction formulae, i.e. the World Health Organization (WHO), Harris–Benedict, Schofield weight, Schofield weight & height, and Oxford formulae.
Results: The mean (standard deviation, SD) difference between the estimated and measured REE was 64 (238) kcal/day for the WHO formula, 79 (226) kcal/day for the Schofield weight formula, 79 (223) kcal/day for the Schofield weight and height formula, 55 (226) kcal/day for the Oxford formula, 37 (224) kcal/day for the Harris–Benedict formula and 0 (213) kcal/day for the purposely developed population-specific formula. Owing to the large SD of the bias, none of these formulae can be reliably applied at the individual level to estimate REE.
Conclusions: The most commonly used REE prediction formulas are inaccurate at both the population and individual level in children with SQCP. A purposely developed population-specific formula, despite being accurate at the population level, does not perform better than the most commonly used REE formulae at the individual level.

1. Introduction

Malnutrition is highly prevalent among children with cerebral palsy (CP), ranging from to 46%–90% [1]. In children with CP, both under- and over-nutrition have a negative impact on linear growth, peripheral circulation, wound healing, spasticity, irritability, and respiratory and gastro-intestinal functions, with increased morbidity and reduced quality of life.

Abbreviations: BC, body composition; CCF, classification fraction; CP, cerebral palsy; EE, energy expenditure; FFM, fat-free mass; IC, indirect calorimetry; REE, resting energy expenditure; RQ, respiratory quotient; SD, standard deviation; SQCP, spastic quadriplegic cerebral palsy; TEE, total energy expenditure; TSF, triceps skinfold; WHO, World Health Organization.

* Corresponding author.
E-mail address: Francesca.Penagini@unimi.it (F. Penagini).

https://doi.org/10.1016/j.clnesp.2018.04.006
2405-4577/

Energy requirements are difficult to evaluate in children with CP. The estimation of resting energy expenditure (REE), necessary for the calculation of total energy expenditure (TEE), is the first step towards a personalized nutritional intervention [2,3]. Indirect calorimetry (IC) is the reference method for the measurement of REE but its cost and the need of specialized personnel impede its widespread use. REE is thus commonly estimated using prediction formulae [4] developed in the general population and not specific for ill children such as those with CP. Children with CP are indeed expected to have different energy requirements compared to healthy children not only because of lower activity and reduced food intake but also because of different muscle tone and body composition.

Few studies are available on energy expenditure (EE) in children with CP. Stallings et al. compared the EE of 61 CP children and adolescents with that of 37 healthy peers [5]. In that study, CP children with low fat stores had a lower REE adjusted for fat-free mass (FFM) compared to CP children and healthy children with adequate fat stores. TEE, evaluated in a subsample of children, was lower in the CP group than in the control group. The TEE to REE ratio, representing energy for non-basal needs, was significantly lower in CP than in control children and the adequately nourished CP children had lower TEE to REE ratios than the malnourished ones. Azcue et al. [6] evaluated the relationship between REE and body composition in 13 children with spastic quadriplegic cerebral palsy (SQCP) compared to 21 healthy controls. In that study, REE was measured with IC, fat mass estimated from skinfolds, total body water measured by isotope dilution, and extracellular water estimated by bioelectrical impedance analysis. REE was significantly lower in SQCP than in control children and was overestimated by the WHO equations. There was also a poor association between REE and weight and height in both SQCP and control children and between REE and the estimated body cell mass among SQCP children. In an interventional study, Gracìa-Contreras et al. showed that TEE and REE were higher in 57 healthy children compared to 13 CP children when expressed in kcal/day and in kcal/cm height/day and lower when expressed in kcal/kg weight/day [7]. Moreover, intensive nutritional support for four weeks produced a significant increase in energy expenditure in children with CP. Gale et al. measured REE using IC in 16 hospitalized ventilated CP children and adolescents [8]. The REE of the CP patients was 46% lower than the estimated REE and the patients received on average 32% more energy than that suggested by REE measurement. Koehler et al. assessed the validity of the SenseWear Armband vs. IC in 10 CP adolescents at rest and during a treadmill session [9]. The SenseWear Armband was found to give similar results similar to those of IC.

None of the above-mentioned studies aimed at evaluating the accuracy of the most commonly used predictive formulae to estimate REE in CP children and none has attempted to develop a population specific formula. The aims of the present study were therefore: 1) to evaluate the accuracy of the five most commonly used REE prediction formulae, i.e. the WHO [4], Harris-Benedict [4], Schofield weight [10], Schofield weight & height [10] and Oxford [11] formulae; 2) to develop a REE population-specific formula for CP children.

2. Materials and methods

2.1. Study patients

From 01 September 2016 to 30 September 2017, 54 SQCP patients aged 6–18 years were consecutively studied at the Outpatient Nutrition Clinic of the "V. Buzzi" Children's Hospital (Milan, Italy). Written informed consent for participation into the study was obtained from the parents or legal guardians of the patients of from the patients themselves when aged 18 years.

2.2. Nutritional assessment

Weight, length (children < 2 years of age) and triceps skinfold (TSF) were measured following international guidelines [12]. Weight was measured using a wheelchair scale (Soehnle 7808 digital multifunction scale). Height (children $\geq$ 2 years) was estimated from knee height [13]. TSF was measured using a skinfold caliper (GIMA, Italy) on the non-dominant or less asymmetrical side of the body. Body mass index (BMI) was calculated as weight (kg)/length or height $(m)^2$. Standard deviation scores (SDS) of weight, length, height, weight-for-length, weight-for-height, BMI and TSF were calculated using the WHO reference data [14,15]. REE was estimated using the following formulae: WHO [4], Harris-Benedict [4], Schofield weight [10], Schofield weight and height [10], and Oxford [11].

2.3. Indirect calorimetry

REE was measured in a silent and thermo-neutral room using an open-circuit indirect calorimeter (Vmax 29, Sensor Medics, Yorba Linda, CA) in subjects fasting from at least 12 h. All subjects were spontaneously breathing. A canopy was positioned around the patient's head and the expired air was drawn from the hood at a fixed rate [16]. Steady state was defined as at least 5 min with <5% variation in respiratory quotient (RQ), <10% variation in oxygen consumption, and <10% variation in minute ventilation [17]. After the steady state was reached, the REE measurement was performed for at least 20 min. REE was obtained from oxygen uptake and carbon dioxide output using Weir's equation [18].

2.4. Statistical analysis

Most continuous variables were not Gaussian-distributed and all are reported as median and interquartile range (IQR). Discrete variables are reported as the number and proportion of subjects with the characteristic of interest. Bland-Altman plots of the bias (estimated REE − measured REE) versus the average [(estimated REE − measured REE)/2] and of the percent bias [(estimated REE − measured REE)/measured REE] versus the average were used to evaluate the presence of proportional bias [19,20]. The association between the bias and the average was evaluated using the Pearson product-moment correlation coefficient [19,20]. Because proportional bias was detected in all cases, the Bland–Altman limits of agreement were not calculated [21]. The absolute bias was Gaussian-distributed, as determined by using kernel density plots and the Shapiro–Wilk test. The comparison of the measured and estimated values of REE was performed using Student's t-test for paired data. The percent bias was not Gaussian-distributed. We evaluated the contribution of weight and height to REE using two pre-specified linear regression models. The response variable of both models was REE. The first model had weight or height as predictor and the second model added age (continuous) and gender (discrete; male = 1; female = 0) as predictors. Not surprisingly for growing children, weight and height were collinear so that they were not evaluated in the same model. Standard diagnostic plots were used to evaluate model fit [22]. The adjusted coefficient of determination (R^2_{adj}) and the root mean squared error of the estimate (RMSE) were used as measures of model fit. The 95% confidence intervals of the regression coefficients, R^2_{adj} and RMSE were calculated using bootstrap on 1000 random samples of 54 subjects [23]. The bootstrap offers an efficient way of correcting for overoptimism and is presently considered the best method for