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2. Energy

METHODS

Literature Search

Medline search, Pub-Med search.

Timeframe: publications from 1990–2003, in addition relevant publications from 1978 were considered.

Type of publications: original papers, meta-analyses, experts' recommendations, overviews.

Key Words: Energy expenditure, total parenteral nutrition, intensive care, critical care, prematurity, equations.

Language: English, French.

Key Words: Energy expenditure, resting energy expenditure, diet induced thermogenesis.

ENERGY IN PAEDIATRIC PARENTERAL NUTRITION (PN)

Introduction

Energy supply should aim at covering the nutritional needs of the patient (basal metabolic rate, physical activity, growth and correction of pre-existing malnutrition) including the support of anabolic functions (1). Excessive energy intake may result in hyperglycaemia, increased fat deposition, fatty liver and other complications (2). Underfeeding, on the other hand, may result in malnutrition, impaired immunologic responses and impaired growth (3). In general, infants require more calories when fed enterally than when fed parenterally. Energy supply can be divided into protein and non protein (carbohydrate and lipid) calories (see specific chapters on lipids, carbohydrates and amino acids). On a theoretical basis, energy needs can be calculated based on non protein calories as protein needs are calculated only for new tissue deposition, as well as for tissue renewal and not as an energy source. However, since the recommendations for energy needs in children usually include the protein contribution to energy expenditure, most of the statements in this chapter will include proteins as well as carbohydrates and lipids for assessment of energy needs.

This chapter provides a short overview on energy, but is not a substitution for a Nutrition Textbook. Some theoretical issues in energy supply will be mentioned but the intention is to provide a practical approach for clinical practice. In general, the total caloric requirements can either be estimated or directly measured. Measurement of energy expenditure is not routinely done and different equations were suggested for estimating energy needs. These equations (see below) can serve only as guidelines when commencing PN. Further aspects need to be taken into account according to clinical parameters:

1. Weight gain in regard to the target growth and required catch-up growth (see below).
2. Recommended intake of the different macronutrients (see specific chapters on lipids, carbohydrates and protein).
3. Tolerance to PN administration i.e. hyperglycaemia, hypertriglyceridaemia, liver enzyme abnormalities, cholestasis, tolerance of cyclic administration etc.

Components of Energy Needs

Total energy needs of a healthy individual are the sum of different components which can be divided into 4 main sub-groups: Basal metabolic rate (BMR), diet induced thermogenesis (DIT), physical activity (PA) and growth. Energy needs may be affected by nutritional status, underlying diseases, energy intake, energy losses, age and gender. No effect of gender on different components of daily energy expenditure was found in free-living prepubertal children (4). On the other hand, Goran et al (1991) found that fat free mass, gender and fat mass are important determinants of total energy expenditure (TEE) in prepubertal children (5). During puberty and adolescence, energy expenditure is affected by gender, body composition and season, but not by the stage of puberty (6).

Basal Metabolic Rate

Basal metabolic rate (BMR) is the amount of energy needed for maintaining vital processes of the body not including activity and food processing. It is measured in a recumbent position, in a thermo-neutral environment after 12 to 18 hours fast, just when the individual has awakened before starting daily activities. In practice, resting energy expenditure (REE) is usually measured instead of BMR. REE is similarly measured at rest in a thermo-neutral environment, after 8–12 hours fast and not immediately after awakening. REE doesn't differ by more than 10% from BMR (7). Sleeping energy expenditure, a component of BMR was shown to be equal to REE $\times$ 0.9 (8). BMR may be increased in conditions such as inflammation, fever, chronic disease (i.e. cardiac, pulmonary), or can decrease in response to low energy intake.

TABLE 2.1. *Equations for calculating REE and BMR (kcal/day) in infants from 0–3 years**

Source	Gender	Equation
WHO	male	REE = 60.9 × Wt − 54
	female	REE = 61 × Wt − 51
Schofield (W)	male	BMR = 59.48 × Wt − 30.33
	female	BMR = 58.29 × Wt − 31.05
Schofield (WH)	male	BMR = 0.167 × Wt + 1517.4 × Ht − 617.6
	female	BMR = 16.25 × Wt + 1023.2 × Ht − 413.5
Harris-Benedict	male	REE = 66.47 + 13.75 × Wt + 5.0 × Ht − 6.76 × age
	female	REE = 655.10 + 9.56 × Wt + 1.85 × Ht − 4.68 × age

*Wt = body weight in kilograms; Ht = Length in meters.

Diet Induced Thermogenesis

Diet induced thermogenesis (DIT) reflects the amount of energy needed for food digestion, absorption and part of synthesis and can, therefore, be affected by the route of substrate administration (oral, enteral or parenteral). DIT usually accounts for about 10% of daily energy needs. In orally fed healthy adult subjects the time of food consumption may affect DIT (9). During PN, DIT and the respiratory quotient are affected by the mode of PN administration (continuously vs. cyclic) (10–12).

Activity

Activity is the amount of energy spent for daily movements and physical activity. In older children, activity accounts for a large proportion of total energy expenditure. TEE of a hospitalized child lying in bed, on the other hand, is reduced. In contrast to most adults the activity of children on home parenteral nutrition, who can attend school, is not reduced (13).

To account for energy needs related to activity, different metabolic constants were suggested for multiplication of BMR (i.e. EE = BMR × constant). In patients on PN the more applicable constants are: × 1.0 for sleeping, × 1.2 for lying awake and for sitting quietly, and × 1.4–1.5 for standing quietly or sitting activities (14). Generally 1.1 or 1.2 are the constants used for patients.

Growth

The rapid changes in organ maturation and the higher growth velocity during the first 2 years of life and later on during adolescence imposes extra caloric needs as compared to adults. The energy needed to maintain accelerated growth represents 30–35% of the energy requirements in term neonates and is greater in preterm infants. Energy cost for 1gr of tissue deposition ranges between 4.9 kcal/g in premature infants and 6.4 kcal/g in adults recovering from anorexia nervosa (14). In patients fed parenterally over longer periods of time, growth and body composition should be assessed on a regular basis, and caloric intake adapted to allow normal growth.

Catch-Up Growth

Children recovering from malnutrition need extra calories to correct their growth deficits (weight, height). In such cases energy needs may be calculated based on the 50th percentile of weight and height for the actual age, rather than the present weight. This difference will provide extra calories (above daily needs) to achieve catch-up growth. Alternatively, calculation may be based on the actual weight multiplied by 1.2–1.5, or even by 1.5 to 2 times in severe cases of failure to thrive, to provide the extra calories needed for catch up growth. Further caloric needs should be adjusted according to weight and height gain.

Special Considerations

Energy needs are affected by the underlying disease and current nutritional status and should be met accordingly (1). Some diseases have been shown to increase or

TABLE 2.2. *Equations for calculating REE and BMR (kcal/day) in children from 3–10 years**

Source	Gender	Equation
WHO	male	REE = 22.7 × Wt + 495
	female	REE = 22.4 × Wt + 499
Schofield (W)	male	BMR = 22.7 × Wt + 505
	female	BMR = 20.3 × Wt + 486
Schofield-(WH)	male	BMR = 19.6 × Wt + 130.3 × Ht + 414.9
	female	BMR = 16.97 × Wt + 161.8 × Ht + 371.2
Harris-Benedict	male	REE = 66.47 + 13.75 × Wt + 5.0 × Ht − 6.76 × age
	female	REE = 655.10 + 9.56 × Wt + 1.85 × Ht − 4.68 × age

TABLE 2.3. *Equations for calculating REE and BMR (kcal/day) in children from 10–18 years**

Source	Gender	Equation
WHO	male	REE = 12.2 × Wt + 746
	female	REE = 17.5 × Wt + 651
Schofield (W)	male	BMR = 13.4 × Wt + 693
	female	BMR = 17.7 × Wt + 659
Schofield (WH)	male	BMR = 16.25 × Wt + 137.2 × Ht + 515.5
	female	BMR = 8.365 × Wt + 465 × Ht + 200
Harris-Benedict	male	REE = 66.47 + 13.75 × Wt + 5.0 × Ht − 6.76 × age
	female	REE = 655.10 + 9.56 × Wt + 1.85 × Ht − 4.68 × age

decrease energy needs, and some of these situations are discussed below.

ESTIMATING ENERGY NEEDS

Energy needs can be either measured or calculated based on acceptable equations. The best way to assess energy needs in children is to measure total energy expenditure or alternatively REE (15). Previous estimation of energy needs were based mainly on body size (i.e. weight, height, body surface area) (16), but it has been suggested that prediction of energy needs should be based on fat free mass, to account for differences in body composition (17) or even on organ tissue mass basis (18). Daily energy requirements are usually estimated by adding the increased energy expenditure associated with activity, stress, disease state, injury and growth to the calculated basal metabolic rate of healthy children (14). The differences in actual energy needs versus calculated needs based on general equations arise from the special status of the patient, i.e.: reduced physical activity during illness, energy losses from ostomies, malabsorption, diarrhoea, underlying disease or inflammation, infection, impaired body composition (decreased lean body mass due to increased catabolism) and different energy routes of supplementation (oral, enteral feeding, continuous vs. intermittent feeding and PN). In addition, the total energy expenditure of a child who is hospitalized and lying in bed is reduced.

As most of the children in need of PN suffer from one or more of the above, the estimated energy needs based on current equations may be incorrect.

Measuring Energy Needs

Different techniques are available for short and long-term measurement of energy expenditure:

BMR and REE can be studied by an open circuit indirect calorimetry.

Total energy expenditure (**TEE**) can be estimated by stable isotope techniques ($^{2}H_2^{18}O$ Doubly labelled water) and bicarbonate (^{13}C) (19) as well as by heart rate monitoring (20,21). Physical activity can be estimated by activity monitoring (22).

Calculating Daily Energy Needs

Different equations have been developed to calculate REE, BMR and TEE. These predicting equations were based on various studies that took place during the first 80 years of the 20th century. Of these, the WHO equations (WHO 1985), (Schofield (1985) and Harris Benedict (1919) equations are mostly used (14,23,24) (Tables 2.1–2.3). The main predictor for each component of energy expenditure is body weight (25) while height also accounts for some of the variability in energy needs. Apart from special considerations which will be discussed below, in most cases there is little need to provide more than 110–120% of energy expenditure to most of the hospitalized patients (7). This is not the case in patients on home parenteral nutrition where a recent study measuring total daily energy expenditure under free-conditions in stable subjects did not find any difference from healthy controls (13).

Some studies have recently suggested that the above currently used equations provide an inadequate estimation of REE in different age groups. Duro et al found that the 3 above equations (WHO, Schofield-W and Schofield-WH) underestimate REE in healthy infants <3 year old (25). Thompson et al measured healthy infants (0.43 ± 0.27 years) and found that all the equations overestimated REE. The worst estimation in this age group was obtained by using the H-B equations ((26) (LOE 2++)). These equations are specifically inadequate in children with altered growth and body composition (27). In cases like failure to thrive, the Schofield -WH was found to be the best predicting equation (28). When the WHO equation was used for estimating energy needs in healthy subjects of 2–12 years of age, the equation overestimated the measure of REE by $105 \pm 12\%$ (27). Overestimation by the H-B equations was also found in adult subjects (29). In another study

TABLE 2.4. *Parenteral energy needs*

Age (yr)	Kilocalories/kg body weight per day
Pre-term	110–120
0–1	90–100
1–7	75–90
7–12	60–75
12–18	30–60

which compared predicted to actual measurements in 7.8–16.6 years healthy controls, the Schofield -WH equation showed the best agreement with actual measurement (30). In a study of 199 subjects aged 5–16 years both the Schofield WHO and were comparable to the measured resting values, with the Schofield equations providing the best estimates (31). In various illnesses and related malnutrition, these prediction equations were not accurately estimating actual REE requirements ((27) (LOE 2++)). Of the four equations the Schofield equation using both weight and height measurements was the best at predicting REE. Nevertheless, all of these equations have been established in normal children and should be used with caution in sick children treated with PN. Average daily parenteral energy intakes per kg bodyweight considered adequate for a major proportion of patients are shown in Table 4.

Recommendation

- Reasonable values for energy expenditure can be derived from formulae, e.g. Schofield. However, in individual patients measurement of REE may be useful. REE may be measured rather than calculated to estimate caloric needs due to a different individual variability and over or underestimation by the predicting equations. **GOR D**

Special Considerations

Premature Infants

Early nutrition support is advocated in extremely low birth weight and very low birth weight infants because of limited nutritional stores (32). A recent randomized controlled study compared the effect of PN on the first day of life as compared to PN started in the first few days and being advanced more slowly. Better growth was found with early PN (33). Energy intake affects nitrogen balance; minimal energy requirements are met with 50–60 kcal/kg per day, but 100–120 kcal/kg/d facilitate maximal protein accretion (34). A newborn infant receiving PN needs fewer calories (90–100 kcal/kg per day) than a newborn fed enterally because there is no energy lost in the stools and there is less thermogenesis (35).

In premature infants after surgery, one study of post surgical sick premature neonates did not find an increase in energy expenditure (36). However, in extremely low birth weight infants (ELBW), using doubly labelled water technique to measure energy expenditure, Carr et al found that ELBW (<1000 g birth-weight) with minimal respiratory disease but requiring mechanical ventilation appear to have significantly increased rates of energy expenditure (85 kcal/kg per day) in early postnatal life (37). Since foetal life energy accretion is approx. 24 kcal/kg per day between 24–48 weeks of gestation (38), an energy balance (energy intake-energy expenditure) of approximately 25 kcal/kg per day represents a reasonable goal for these small premature infants. Thus, on a theoretical basis sick children with high energy expenditure (85 kcal/kg per day) would require at least 85 + 25 = 110 kcal/kg per day to grow. Moreover, using the same doubly labelled water technique, it has been shown that ELBW infants may require even more energy intake at 3 to 5 weeks of age, when their measured EE ranges between 86–94 kcal/kg per day (39).

Intensive Care Unit (ICU)

In critically ill ventilated children, within-day variations in energy expenditure measurements are uncommon and a single 30-minute energy measurement can be an acceptable guide. Between-day variation on the other hand can, however, be large (40). Several studies did not observe hyper-metabolism in critically ill children and most of the recent data suggest that the predicting equations overestimate or nearly estimate the actual REE. Moreover, some studies found that measured EE was lower than predicted and was associated with a higher mortality risk (41). Using stress factors added to the predicted equations grossly overestimated the energy expenditure (42). It was suggested, therefore, to use only predicting equations without "stress factors" when calculating energy needs (42–44). In a study that found increased REE, the measurement was done alongside PN administration and was 20% higher than the predicted by the Talbot's tables (45). Similar results were obtained for the H-B equations with a stress factor of 1.3 (46). The catabolic process in critically ill subjects inhibits growth, thus reducing energy requirements on one hand, while increasing basal energy expenditure on the other (47).

A combined measurement of energy expenditure along with nitrogen balance or RQ may help in tailoring the right formulation (48).

White et al recently suggested a new formula for estimating energy expenditure in ICU patients with a close correlation between predicted and measured EE (R2 = 0.867) (44):

$$
\begin{aligned}
\text{EE (kcal/d)} = [&(17 \times \text{age in months}) \\
&+ (48 \times \text{weight in kg}) \\
&+ (292 \times \text{body temperature in °C}) \\
&- 9677] \times 0.239
\end{aligned}
$$

This group has found that EE increased with time relative to the injury insult, which emphasizes the importance of serial measurements of EE in these patients. The changes were ascribed to the "ebb" and "flow" phases of the metabolic stress process. Resumption of anabolic (growth) metabolism may also contribute significantly to this phenomenon (47).

Post-Operative

Most of the studies indicate that major operations such as abdominal surgery are not accompanied by increased EE (49). REE peaks 2–4 hours after surgery and returns to baseline levels by 12–24 hours (50). The increase in postoperative REE is directly related to the severity of the operation and is greater in premature babies and in infants >48 hours of age. Because the increase in REE is of short duration and involves temporary metabolic changes there is no necessity to increase the energy intake of infants who have an uncomplicated operation (35). Pierro et al developed an equation for predicting basal energy requirements of stable surgical infants of less than 12 months (51).

$$\begin{aligned}\text{REE (cal/min)} &= -74.436 \\ &+ (34.661 \times \text{weight in kg}) \\ &+ (0.496 \times \text{rate in beats/min}) \\ &+ (0.178 \times \text{in days})\end{aligned}$$

Statement

- There is no support for increased energy needs after uncomplicated surgery. **LOE 2++**

Head Injury

REE is significantly increased after head injury (52,53). Energy expenditure varied markedly between and within children (mean 97% of predicted, range 60–137%) and was significantly lower in the children with poor outcome (52). Neuromuscular blockade (54) and hypothermia (55) reduce it to the predicted values.

Burn Injury

Recent studies suggest that previous studies overestimated energy needs (56). Goran et al (1991) compared measured REE to the predicted values based on Harris-Benedict equations and found that the energy required to ensure that 95% of patients achieve energy balance is approximately 2 × predicted REE (57).

Hematopoietic Transplantation

Measured energy expenditure post transplantation is significantly lower than the predicted by WHO equations (58) or Schofield equations (59).

Medications

Few studies have indicated changes in energy expenditure in response to different medications. Treatment with beta-blockers was found to reverse catabolism and attenuate hypermetabolism in children with burns (60).

Recommendations

- Reasonable parenteral energy supply can be estimated from calculated resting energy expenditure multiplied by a factor reflecting additional needs including physical activity, and from monitoring weight change. **GOR D**. Therefore, parenterally fed patients should be regularly weighed, usually on a daily basis during acute disease phases and in unstable patients. **GOR D**
- For calculating REE, WHO and especially Schofield (WH) equations should be used for children less than 10 years of age. For children aged 10 years and older, Harris Benedict, WHO and Schofield equations can be used. **GOR B**
- Measurement of resting energy expenditure by indirect calorimetry, and estimation of total energy expenditure from heart rate monitoring, might be used in selected patients to provide additional information. However, their general use is not recommended because of lack of data on outcome. **GOR D**
- Energy intake should be adapted in patients with disease states that increase resting energy expenditure, such as pulmonary (e.g. cystic fibrosis) and cardiac (e.g. some congenital heart disease) disorders. **GOR B**
- In most parenterally fed hospital patients energy needs are met by 100–120% of resting energy expenditure. **GOR D**
- Patients who are underweight and need to regain weight may need 130 to 150% of REE. **GOR D**
- Energy intake should not be increased after uncomplicated surgery. **GOR B**
- Total parenteral energy needs (including protein) of stable patients may be roughly estimated using Table 2.4. **GOR D**

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