6.1 Nutritional requirements in clinical practice

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> **Key points**
>
> ■ The determination of nutritional requirements requires a significant element of clinical judgment.
>
> ■ Irrespective of the method used, requirement calculations should be interpreted with care and used only as a starting point.
>
> ■ The requirements for a number of nutrients in illness and injury have yet to be established.

The aim of devising a nutritional prescription is to provide patients with their complete requirements either via a single route or any combination of oral, enteral or parenteral nutrition, while avoiding the known complications associated with both underfeeding and overfeeding (ASPEN, 2002; NICE, 2006). The estimation of nutritional requirements is an important part of patient assessment, yet no single, validated method for estimating requirements exists, and the evidence-base for all prediction methods currently in use is poor (Reeves & Capra, 2003). Practitioners need, therefore, to exercise a considerable degree of clinical judgment when determining the nutritional requirements of an individual.

All prescriptions for nutritional support should take account of the patient's needs for energy, protein, fluid, electrolytes, micronutrients and fibre (NICE, 2006). However, a number of factors complicate the determination of nutritional requirements in clinical practice (see Table 6.1.1) and should be considered prior to estimating the requirements of an individual. Even within a single disease, individual variation (e.g. due to age, co-morbidities, nutritional status, response to surgery or treatment) may make prognosis unpredictable. Furthermore, illness or injury does not have a consistent effect on energy expenditure, and this is also likely to be the case for other nutrients. Different treatment modalities, e.g. surgery, chemotherapy or pharmacological agents, may influence requirements in different ways, and the same treatment may have very different effects in individuals with the same disease. These differences in response to treatment may be due at least in part to genetic predispositions and environmental influences. The measurement and assay techniques used to assess nutrient status and determine nutritional requirements are not always fully described in the literature and may differ between studies (equipment, timing, protocols etc.), thus making comparisons difficult. Furthermore,

older studies may not be relevant to current practice due to advances in diagnostic procedures and management strategies, e.g. the advent in the late 1990s of highly active antiretroviral therapy (HAART) for the treatment of HIV infection. Irrespective of the route and likely duration, the aims and objectives of nutritional support should be clearly defined and documented at baseline, reviewed at each stage of the patient's illness and nutritional support amended accordingly, e.g. minimising losses in acute illness, nutritional repletion in the recovery phase (NICE, 2006).
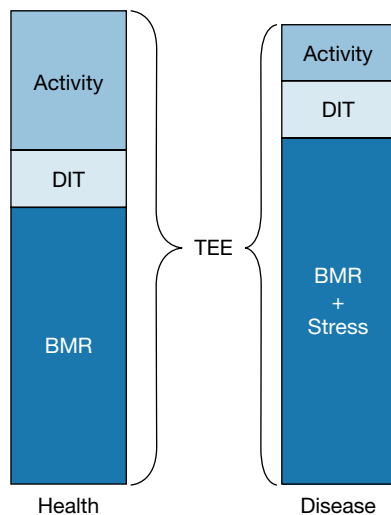
Energy

Basal metabolic rate and total energy expenditure

In healthy individuals, total energy expenditure (TEE) comprises basal metabolic rate (BMR), dietary-induced thermogenesis (DIT) (i.e. energy expended in the digestion, absorption and transport of nutrients), and physical activity (see Figure 6.1.1). Basal metabolic rate (BMR), i.e. the metabolic activity required to maintain life, comprises approximately 60% of TEE, and, in any individual, measured BMR is highly reproducible. The conditions essential for the measurement of BMR are:

- Post-absorptive (12-hour fast).
- Lying still at physical and mental rest (but not asleep).
- Thermo-neutral environment (27–29 °C).
- No stimulants such as tea, coffee or nicotine in the previous 12 hours.
- No heavy physical activity during the previous day.
- Validation gases must be calibrated to ensure measurements are accurate and reliable.
- Steady-state must be established, i.e. <10% difference in minute-to-minute oxygen (VO_2) and carbon dioxide (VCO_2) volume measurements over 5 minutes.

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Table 6.1.1 Factors affecting nutritional requirements in illness and injury

Nutritional requirements	Factors
Basal requirements	Age
	Sex
	Body weight
	Body composition (proportions of fat and muscle mass)
	Previous and current nutritional intake
	Ambient temperature
Goals of treatment	Diagnosis
	Prognosis
	Likely duration of nutritional support
Disease effects	Metabolic state (e.g. catabolic, normobolic or anabolic)
	Severity of illness
	Inflammatory response
	Gastrointestinal function
	Medical interventions (e.g. mechanical ventilation, radiotherapy, chemotherapy, hormone treatment or transplantation)
	Surgery
	Pharmacological interventions, e.g. sedation, oral steroid therapy
	Pain
	Psychological state
Activity	Mobility status, e.g. bed-bound, mobile on ward
	Level of consciousness
	Neuromuscular function

Figure 6.1.1 Energy expenditure in health and disease (source: The British Dietetic Association, 2013. Reproduced with permission from The British Dietetic Association, www.bda.uk.com)

If any of these criteria are not met, then the measurement is defined as resting energy expenditure (REE) or resting metabolic rate (RMR). The most accurate method for measuring energy expenditure is indirect calorimetry (Branson & Johannigman, 2004). However, in the clinical situation, it is rarely possible to measure BMR, owing to the exacting requirements listed earlier. Therefore, in sick or injured subjects, REE will comprise BMR plus the effect of any metabolic response to injury or disease. If the patient has not fasted, the REE measurement may also include some proportion of DIT. In some patients, such as those with involuntary movements due to neuromuscular dysfunction, an element of physical activity may also be included during measurements of REE. Conversely, if measurement conditions are strictly controlled, REE may not equate to total energy requirements, since neither activity nor DIT will be accounted for.

A large number of BMR prediction equations exist, although the most commonly cited are Harris-Benedict (Harris & Benedict, 1919) and Schofield (Schofield, 1985). More recently, the Henry (Oxford) equations (Henry, 2005) have been evaluated (Ramirez-Zea, 2005; SACN, 2011) and recommended as the most rigorously tested and applicable to modern healthy populations. The Henry equations were derived from a database of 10,552 BMR values in studies conducted from 1914 to 2005, including a larger cohort of elderly subjects than in previous databases. Only studies where conditions met strict criteria for BMR measurements were included. The vast majority of clinical studies compare measured energy expenditure with the Harris–Benedict equations, and only a small proportion compare with other equations.

Inflammatory state

In sick or injured individuals, TEE is influenced by many factors, and, in any individual patient, it may be lower, similar to or, in rare cases, higher than requirements in healthy populations (see Figure 6.1.1). In the majority of chronic conditions, BMR is usually normal or may be slightly increased. Since any metabolic-stress-induced increase in BMR is often accompanied by a decrease in physical activity, TEE in chronically ill individuals is usually normal or decreased (Kulstad & Schoeller, 2007; SACN, 2011).

Acute illness increases BMR above that predicted for healthy individuals of the same age and weight, usually by 0–40%, and, very rarely, up to 100%. Both the magnitude and duration of the increase are dependent on the presence of an inflammatory response, and thus assessment of patients' inflammatory states may assist in the determination of their energy requirements. To avoid the risk of overfeeding in acutely ill individuals, it might be prudent to include a stress factor in any estimate of energy requirements only while there is biochemical and clinical evidence of an inflammatory response, e.g. elevated C-reactive protein or white cell count, low serum albumin, poor appetite or oedema.

In the presence of an inflammatory response, weight gain and other clinical benefits are unlikely to be achieved with nutritional support alone (Streat et al., 1987), and the goal of nutritional support is usually to minimise losses while the patient is in this state. Aggressive nutritional support should only be considered when the patient is more able to utilise the nutrients provided, i.e.

during recovery (anabolic phase). A patient is likely to be moving into the recovery phase as oedema resolves and the parameters listed earlier return to the normal range.

Physical activity

Individuals requiring nutrition support range from paralysed and sedated, critically ill patients to fully mobile patients on the ward or in the community. To date, however, there is a relative lack of research on the effects of illness and injury on physical activity levels (Elia, 2005), although a recent report concluded that acute illness is usually accompanied by a decrease in physical activity that compensates for any increase in BMR (SACN, 2011). The energy expended in physical activity is lowest in the sickest patients, with sedated, ventilated patients usually expending <10% above BMR in physical activity. This can be highly variable, however, especially in agitated patients (Frankenfield, 2006). In hospitalised individuals, it is reasonable to assume that physical activity will be lower than habitual levels. For example, in pre-operative patients, activity accounts for 20% above BMR, while physical activity may decrease post-operatively to 5% BMR in the first few days, increasing to 15% BMR by days 9–12 (Kinney et al., 1968).

While it might be expected that physical activity will be increased in patients receiving active physiotherapy, moving painful or damaged limbs, or in those with abnormal neuromuscular function, this may not result in increased TEE as the patient compensates by resting or sleeping. For example, in patients with involuntary movements due to Parkinson's disease, TEE was not found to be increased due to a reduction in the energy expended in voluntary physical activity (Toth et al., 1997).

As patients recover from illness, or once they are discharged from hospital, the component of TEE that is most likely to change is the physical activity level, assuming there have been no effects on neurological or muscular function. In the community, some patients receiving nutritional support, irrespective of feeding route, may have similar activity levels as healthy individuals, whereas house-bound or nursing-home patients are likely to have physical activity levels similar to hospital patients. In the determination of energy requirements, regular assessment of habitual activity is important; however, the best method for assessing physical activity levels objectively in clinical practice has yet to be determined (Frankenfield & Ashcraft, 2011). Multiplication factors for physical activity do exist (Taylor, 2007), but are as variable and open to misinterpretation as stress factors, and thus a considerable degree of clinical judgement is required in their use.

Dietary-induced thermogenesis (DIT)

Dietary-induced thermogenesis (DIT) usually accounts for 8–10% of TEE, and, in healthy individuals, the main determinant of DIT is the energy content of the food, followed by the protein fraction (Benedict & Carpenter, 1918). The effects of injury and sepsis on DIT are unclear,

although evidence suggests the effects are similar to those in healthy individuals (Westerterp, 2004). While differences in DIT might be expected when comparing the parenteral with the enteral route, studies have so far failed to show a significant difference (Stokes & Hill, 1993). When enteral feed is given as a bolus, the effect on DIT is similar to that observed with food, i.e. an increase in TEE of 8–10% occurs. In contrast, the continuous infusion of nutrients does not significantly increase REE over fasting level (Heymsfield et al., 1987). In the determination of energy requirements, there is rarely a need to make a separate adjustment for DIT, as most prediction equations were derived from data collected from subjects who were receiving nutritional support during metabolic measurements. The effects of DIT are therefore already included in the equation.

Prediction methods

The most accurate methods for determining energy requirements are calorimetry and the doubly labelled water technique; however, these methods are generally too expensive and impractical for routine clinical use (Branson & Johannigman, 2004). In clinical practice, therefore, energy requirements are usually estimated using published prediction methods. Three main methods for estimating energy requirements exist, all of which use some combination of body weight, age or sex. The factorial method involves estimating BMR from prediction equations and then adding factors for metabolic stress, physical activity and DIT (e.g. Taylor, 2007; PENG, 2011). An alternative method has been proposed by other organisations (ASPEN, 2002; NICE, 2006) where requirements are based on energy values per kg body weight, adjusted for particular purposes, e.g. 25–30 kcal/kg body weight for bedridden patients (Table 6.1.2). A number of disease-specific regression equations have been derived, in particular for critical care (Frankenfield et al., 2005) and burns (Ireton-Jones et al., 1992).

All three methods are open to criticism, e.g. the current PENG (2011) guidelines involve calculating BMR using the Henry equations (Henry, 2005) and adding a factor (0–60%) to take account of metabolic stress, and adding another factor (10–25%) to take account of activity and diet-induced thermogenesis (DIT). All these steps have the potential to introduce error. All BMR prediction equations were derived for use in healthy populations, and their use in sick individuals could therefore be open to criticism. Furthermore, the data used to derive the stress factors is unclear, and there is considerable scope for misinterpretation by inexperienced practitioners. While there is a lack of evidence to support this method, the approach is easy to use and takes account of the main factors that impact on an individual's energy requirements, i.e. weight, age, gender, physical activity level and dietary-induced thermogenesis.

While easy to use and based on the parameter with the greatest influence on BMR, the second method (kcal/kg body weight) does not account for changes in energy expenditure with age, gender or metabolic state, and it is

Table 6.1.2 Guidelines for estimating nutritional requirements in stable patients

Energy (Per kg per day)	Protein (Per kg per day)	Micronutrients
25–35 kcal (105–147 kJ) (NICE, 2006)[a]	0.8–1.5 g (NICE, 2006)[a]	Provision of adequate electrolytes, minerals, micronutrients (allowing for any pre-existing deficits, excessive losses or increased demands) and fibre if appropriate (NICE, 2006)[a]
20–35 kcal (84–147 kJ) (ASPEN, 2002)[b]	0.8–2.0 g (ASPEN, 2002)[b]	Recommendations are made for specific nutrients based on route of administration. For enteral nutrition, recommendations are based on the RDA/AI levels, and for parenteral nutrition, recommendations were made on the assumption that patients had increased requirements (ASPEN, 2002)[b]

[a]For patients who are not severely ill or injured, nor at risk of re-feeding syndrome; [b]for unstressed adult patients with adequate organ function; RDA = recommended daily allowance; AI = adequate intake.

unclear for people who are obese whether requirements should be calculated using actual or ideal body weight. Their applicability for depleted individuals has also been questioned. Similarly, there are no defined criteria for when to use 20, 25, 30 or 35 kcal/kg/day.

Disease-specific equations are based on physiological variables that may change considerably over a short period of time, e.g. body temperature, heart rate and minute ventilation. While they may be more accurate in the specific population for which they were derived, these equations too are open to similar criticisms regarding validity, and currently there are no indications on how frequently requirements should be reviewed and amended in the light of any changes in these variables. Furthermore, it is yet to be determined if amending feeding regimens in response to changes in physiological variables results in beneficial outcomes.

The data used to derive all prediction methods is difficult to locate, and not one of the methods described in the preceding text has been fully validated (Reeves & Capra, 2003). Furthermore, while prediction methods may provide adequate estimates of requirements for groups of patients, they all have a poor predictive value for individuals. Regardless of the method used, all estimates of energy requirements should be interpreted with care and used as a starting point only. Since any one of a number of factors might vary during a patient's illness and recovery, requirements should be reviewed and re-calculated regularly to avoid either underfeeding or overfeeding (NICE, 2006). The importance of monitoring cannot be too highly emphasised.

Protein (Nitrogen)

In clinical practice, the determination of protein (nitrogen) requirements is complicated by the fact that protein homeostasis is in a state of constant flux. In the healthy individual, protein requirements are dependent to a varying degree on a number of factors, including recent and long-term protein and energy intakes, physical activity and the quality of the protein consumed (Calloway & Spector, 1955). A chronic lack of protein (and energy) results in the body adapting to starvation in order to preserve body protein stores. In illness or injury,

determination of protein requirements is further complicated by the metabolic state of the patient and the presence or absence of an inflammatory response. The maintenance of nitrogen balance depends on long-term and recent nitrogen and energy intakes and clinical state in injury or illness. As a result, it is very difficult to predict requirements in any one individual at any particular time.

In severe chronic illness, such as cancer, chronic respiratory failure or cardiac failure, the presence of cachexia may further complicate the picture (see Chapter 7.15.9, Cancer cachexia). Cachexia results in severe and specific loss of skeletal muscle mass, with relative preservation of visceral protein, as the body re-prioritises protein metabolism away from the peripheral tissues and towards the liver. This preferential loss of skeletal muscle mass occurs even during periods of poor dietary intake. In the short term, this response may be beneficial as protein stores are liberated to mount the immune response and promote healing. However, in the longer term, or if the loss of muscle mass is excessive, this is detrimental to the patient (WHO/FAO/UNU, 2007).

A recent systematic review concluded that a prescription consisting of 1.0–1.2 g protein/kg body weight/day is likely to provide sufficient protein for the majority of hospitalised patients (Ferrie *et al.*, 2013). In those who are metabolically stressed, however, requirements may be higher, although current recommendations suggest that provision of more than 1.5–2.0 g protein/kg/day is unlikely to be beneficial in terms of clinical outcome, and may indeed be detrimental, particularly in patients who have had a prolonged period of poor intake and are therefore at risk of re-feeding syndrome (NICE, 2006).

The largest nitrogen losses have been documented in sepsis, major trauma and burns (Ferrie *et al.*, 2013). In these conditions, nitrogen balance is almost impossible to achieve in the early catabolic phase post-injury, and currently there appears to be little to gain from providing nitrogen in excess of 1.5 g protein/kg body weight in the critically ill (NICE, 2006), although this is open to debate (Frankenfield, 2006).

In the past, guidelines for dietary protein have advised a similar intake for all adults, regardless of age. Evidence suggests, however, that older people may

require a higher protein intake than younger adults (Bauer *et al.*, 2013). This may be due in part to a declining anabolic response to protein intake in older people and to the fact that older people consume less protein than those who are younger (Kurpad & Vaz, 2000). In illness or following injury, older people may need to consume more protein to offset the impact of catabolism and/or the inflammatory response. The PROT-AGE guidelines (Bauer *et al.*, 2013) make recommendations for protein intake levels in older patients with specific diseases. The authors conclude that older adults who have an acute or chronic disease need more dietary protein (i.e. 1.2–1.5 g/kg body weight/day) than younger people, and older people with severe illness or injury or with severe malnutrition may need as much as 2.0 g/kg body weight/day. Older people with severe kidney disease who are not on dialysis are an exception to these recommendations. It must be recognised, however, that the evidence base for protein requirements in many clinical conditions in older people is lacking, and the PROT-AGE group did not conduct a systematic review in the preparation of their guidelines.

The repletion of protein stores is most likely to be effective once a patient is in the recovery (anabolic) phase, is able to mobilise, and when adequate amounts of energy are also provided (WHO/FAO/UNU, 2007).

Fluid

In health, fluid requirements are 25–35 mL/kg body weight. This is approximately 2000–3000 mL for individuals within the normal range for body mass index (BMI). The metabolic response to acute illness and injury results in changes in fluid and electrolyte balance, such that water and sodium are retained avidly. This often results in oedema in the early days of illness that may take up to 10 days to return to normal, or longer in the presence of sepsis or other complications. Recovery is accompanied by a return of the capacity to excrete any excess salt and water acquired during the acute phase.

In post-surgical patients, there is evidence that poor fluid management (usually administration of excess fluid sodium and chloride) is a common cause of oedema, prolonged ileus and other complications, and has an adverse effect on patient outcome (Lobo *et al.*, 2006). Patients are, therefore, extremely susceptible to errors in fluid prescription early after injury or surgery. The NICE (2013) guidelines provide recommendations for the safe use of intravenous therapy in hospitalised adults, and focus on assessment and monitoring as well as providing algorithms for fluid resuscitation, routine maintenance, and replacement and redistribution. The guideline committee recommends that food and fluids be provided orally or enterally, and that intravenous infusions be discontinued as soon as possible. In disease or following surgery, estimates of fluid requirements should take into account any losses resulting from pyrexia, drains, diarrhoea, burns, stomas and fistulae (see Figure 6.1.2), and all sources of fluids should be considered (including fluids given with some intravenous drugs) to minimise the risks of over-hydration, especially in patients receiving enteral or parenteral nutrition.

There is currently insufficient evidence to provide guidelines on sodium and fluid requirements in very thin or obese individuals, and therefore patients at the extremes of BMI should be monitored closely for signs of over-hydration or under-hydration, and fluid prescriptions adjusted accordingly.

Micronutrients

In the presence of illness or injury, micronutrient deficiencies may occur for a variety of reasons although blood measurements may not be reliable markers of micronutrient status (Shenkin, 2000):

- Inadequate (or imbalanced) intake.
- Increased metabolic rate and increased number of biochemical reactions.
- Adverse effects of treatment.
- Increased oxidative stress.
- Losses from fistulae, burns, diarrhoea, dialysis.

The effects of micronutrient deficiency are non-specific and insidious (e.g. muscle weakness, anorexia, depression), and are commonly associated with acute and chronic illness. Suboptimal levels may impair function before signs of deficiency become evident, and micronutrient deficiencies may therefore go undiagnosed in the presence of illness or injury.

In the absence of an adequate evidence base, recent guidelines for the provision of micronutrients to patients with acute or chronic illness (Arends *et al.*, 2006) are non-specific, in that they state that provision should be based on recommended daily allowance (RDA)/adequate intake (AI) levels (Table 6.1.2). While recognising that RDA/AI levels are recommended for healthy populations rather than sick individuals, in the absence of evidence, this pragmatic approach would appear to be justified. In some patients with long-term chronic conditions (e.g. cancer, multiple sclerosis, rheumatoid arthritis), excess micronutrient intake may be of concern, particularly in those utilising a number of non-prescription supplements. During assessment, the potential adverse effects of self-dosing of alternative medicines and/or vitamin and mineral supplements should always be considered.

With regard to nutritional support, most standard oral nutritional supplements and enteral feeds contain sufficient minerals and electrolytes to meet daily requirements for sodium, potassium, magnesium and phosphate (NICE, 2006), but only if the patient is receiving enough of the feed to meet all their energy needs. Since many patients are either receiving less than full nutrition from these products or have pre-existing deficits, high losses or increased demands, additional provision may be required. However, care is needed to avoid excessive provision in some patients, e.g. those with renal or liver impairment. Some specialised feeds are designed specifically to provide adequate electrolytes, vitamins and minerals in lower-energy provision, for patients with low total energy needs.
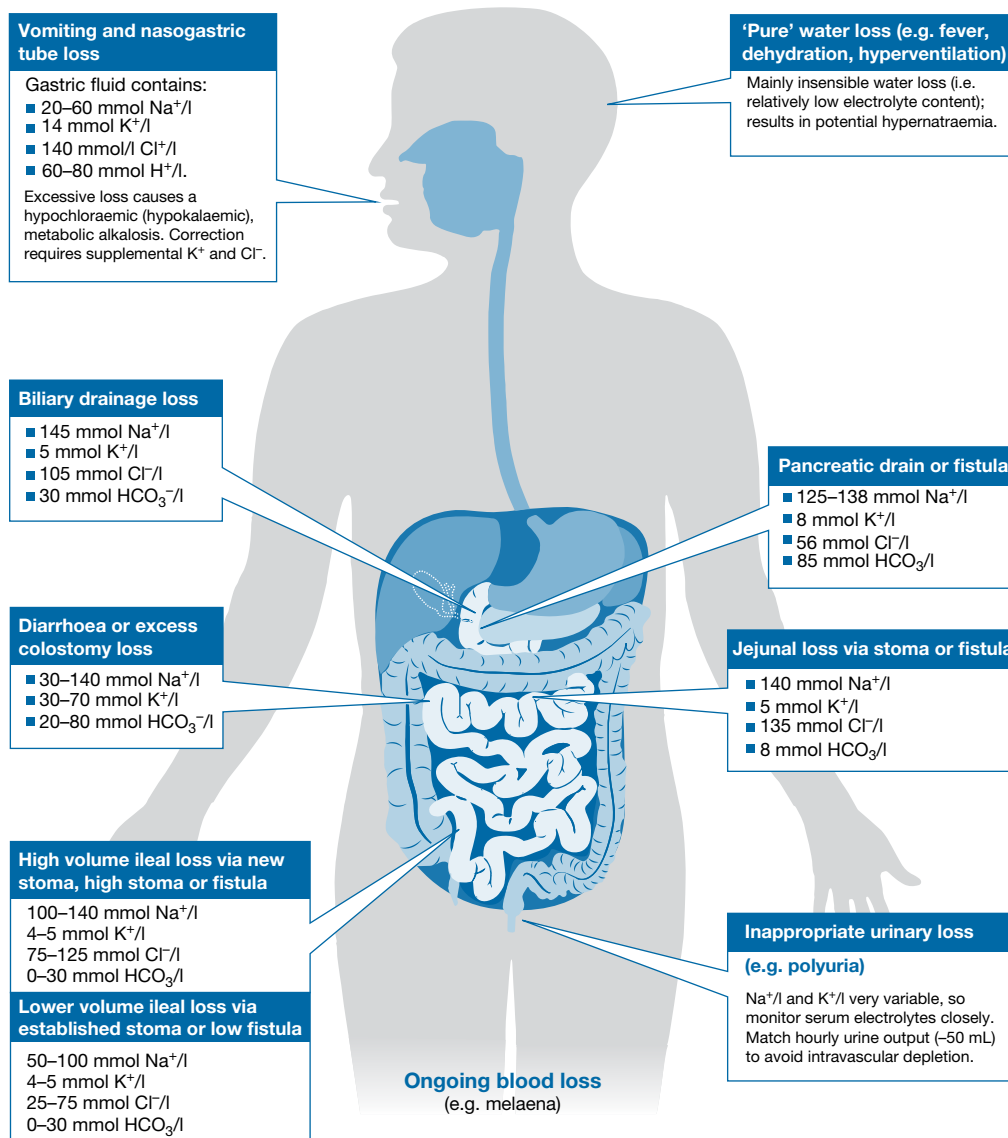
Vomiting and nasogastric tube loss

Gastric fluid contains:
- 20–60 mmol Na^+/l
- 14 mmol K^+/l
- 140 mmol/l Cl^+/l
- 60–80 mmol H^+/l.

Excessive loss causes a hypochloraemic (hypokalaemic), metabolic alkalosis. Correction requires supplemental K^+ and Cl^-.

'Pure' water loss (e.g. fever, dehydration, hyperventilation)

Mainly insensible water loss (i.e. relatively low electrolyte content); results in potential hypernatraemia.

Biliary drainage loss
- 145 mmol Na^+/l
- 5 mmol K^+/l
- 105 mmol Cl^-/l
- 30 mmol HCO_3^-/l

Pancreatic drain or fistula
- 125–138 mmol Na^+/l
- 8 mmol K^+/l
- 56 mmol Cl^-/l
- 85 mmol HCO_3/l

Diarrhoea or excess colostomy loss
- 30–140 mmol Na^+/l
- 30–70 mmol K^+/l
- 20–80 mmol HCO_3^-/l

Jejunal loss via stoma or fistula
- 140 mmol Na^+/l
- 5 mmol K^+/l
- 135 mmol Cl^-/l
- 8 mmol HCO_3/l

High volume ileal loss via new stoma, high stoma or fistula

100–140 mmol Na^+/l
4–5 mmol K^+/l
75–125 mmol Cl^-/l
0–30 mmol HCO_3/l

Lower volume ileal loss via established stoma or low fistula

50–100 mmol Na^+/l
4–5 mmol K^+/l
25–75 mmol Cl^-/l
0–30 mmol HCO_3/l

Inappropriate urinary loss

(e.g. polyuria)

Na^+/l and K^+/l very variable, so monitor serum electrolytes closely. Match hourly urine output (–50 mL) to avoid intravascular depletion.

Ongoing blood loss
(e.g. melaena)

Figure 6.1.2 Ongoing fluid losses (© NICE, 2013 Diagram of Ongoing Loss. Available from https://www.nice.org.uk/guidance/cg174/resources/diagram-of-ongoing-losses-191664109.

Pre-mixed parenteral nutrition bags contain very variable amounts of electrolytes and minerals, and care is needed to avoid giving PN with either inadequate or excessive electrolyte and/or mineral content (NICE, 2006). As with electrolytes and minerals, most standard oral and enteral feeds contain enough vitamins and trace elements to ensure that needs are met if patients are taking enough feed to meet their daily energy needs. However, when this is not the case, further balanced micronutrient supplementation may be required, especially in those with pre-existing deficits, poor absorption, increased demands or high losses (NICE, 2006). Premixed PN bags invariably contain inadequate levels of some micronutrients, and therefore need additions to be made prior to administration. The provision of PN without adequate micronutrient content must be avoided.

Special considerations

Estimating energy and protein requirements in obese patients

The factor that has the greatest influence on BMR is actual body weight (Horgan & Stubbs, 2003). However, some clinicians have recommended the use of adjusted weights to calculate BMR from prediction equations in subjects at the extremes of BMI. Regardless of BMI, rapid weight loss is associated with increased complications and poor outcome in hospitalised patients (NICE, 2006), and weight loss should therefore not be a nutritional goal during acute illness or following injury, even in the obese. Figure 6.1.3 shows how changes in weight and body composition affect BMR. The excess body weight in obese individuals largely comprises tissue with a low metabolic rate, and some clinicians have
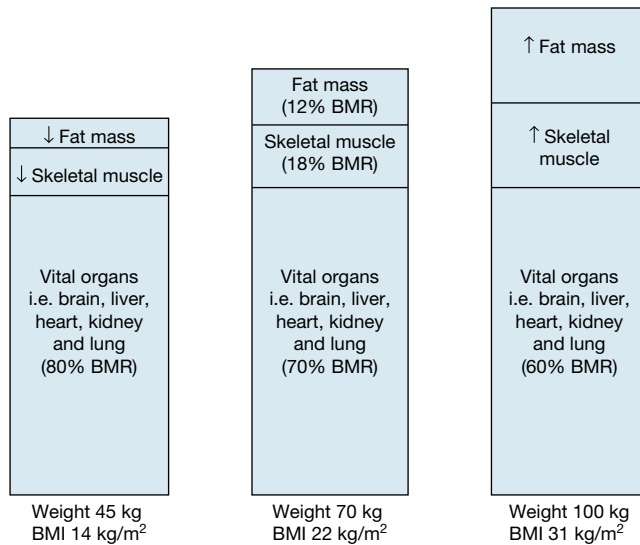
Figure 6.1.3 Effects of changes in body composition on basal metabolic rate (BMR)

therefore recommended adjusting weight downwards to calculate BMR, e.g. 25% adjusted weight=actual body weight×0.25+ideal body weight (Ireton-Jones, 2005). Other authors, however, recommend the use of actual body weight (Krenitsky, 2005), since BMR prediction equations were derived from data on individuals across the range of BMI, and actual rather than adjusted body weight was used to develop the equations. As there is no good evidence to support the use of adjusted body weight or specific cut-offs, clinical judgment is required to minimise the risks of overestimating or underestimating energy requirements in obese individuals (BMI>30 kg/m²). In clinical practice, actual body weight should be used to estimate BMR in obese individuals (Frankenfield & Ashcraft, 2011), but the assignment of stress factors should be undertaken with caution (PENG, 2011). Alternatively, energy requirements can be calculated using 19–21 kcal/kg actual body weight (Glynn *et al.*, 1999). However, it may be beneficial in some conditions (e.g. cancer of the breast and prostate) to aim for weight loss once a full recovery has been made in order to aid mobility and reduce the risk of recurrence (World Cancer Research Fund, 2007).

Protein

Since protein requirements are, to a large extent, determined by lean body mass, there is an argument for using an adjustment to the actual body weight to calculate protein requirements in obese patients, or to use ideal rather than actual body weight, although original work relating to this suggestion is difficult to locate.

Re-feeding syndrome

There are several published regimens for managing patients at risk of re-feeding syndrome. The lack of randomised controlled trials in this area, however, means that management is based on consensus and expert opinion rather than evidence (Khan *et al.*, 2011). Irrespective of which regimen is employed, the common principles are to prevent re-feeding syndrome by cautious re-introduction of energy and correction of biochemical abnormalities. While some authors recommend the correction of biochemical abnormalities prior to the introduction of energy and other macronutrients (Crook *et al.*, 2001), others recommend that both can occur in tandem without deleterious effects to the patient (NICE, 2006). There are currently no published randomised trial data to support either view. It is likely that the problems associated with re-feeding are less likely to arise with oral nutrition support, since starvation is usually accompanied by a loss of appetite. However, care should be taken in the prescription of oral nutrition supplements, particularly in the area of eating disorders (NICE, 2006). Underweight individuals tend to lose muscle and fat stores while preserving tissues with a high metabolic rate, i.e. brain, liver, heart and kidney. On a body weight basis, their metabolic rate is about 25% higher than in normal-weight individuals, and some clinicians have used this as a rationale to use ideal or usual body weight instead of actual body weight when calculating BMR. For a full discussion on the management of severely depleted individuals, please see a report recently published by the Royal College of Psychiatrists and the Royal College of Physicians (MARSIPAN, 2010) (also see Chapter 6.4 in this book, Enteral nutrition).

Estimating requirements for patients with abnormal fluid status

Oedema and ascites increase body weight without increasing metabolically active tissue. In the presence of over-hydration, therefore, dry weight should be measured after paracentesis, drainage of ascites or dialysis, and used to calculate BMR. In those patients where excess fluid cannot be removed, consider using the last recorded weight prior to developing ascites or oedema, or estimating dry weight using the following equation:

$$\text{Estimated dry weight} = \text{actual body weight} - (\text{weight of ascites} + \text{weight of oedema})$$

Estimating energy requirements for critically ill patients

In comparison with other clinical populations, there are considerably more studies measuring the energy expenditure of critically ill patients. The evidence-base for protein provision in critically ill patients is more limited, however, and there is even lesser evidence for micronutrient provision.

Reported energy requirements for Intensive Therapy Unit (critical care) (ITU) patients vary considerably, in part owing to the heterogeneity of the different ITU populations studied, and also due to differences in definitions of critical illness and/or the presence of sepsis. In addition to the factors that affect energy expenditure in general (e.g. age, gender and weight), the determination of

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energy requirements in ITU patients is complicated by a number of additional metabolic and management factors including hyperglycaemia, the presence or absence of sedation, ventilation mode, and/or the fraction of inspired oxygen. In the ITU setting, the estimation of an individual patient's energy requirements can be particularly challenging.

In bed-bound, artificially ventilated patients, BMR is frequently increased. However, TEE is not usually elevated, mainly because of minimal physical activity and/or sedation (SACN, 2011). In the most acutely ill patients (e.g. severe burns), however, TEE may be transiently elevated above normal (Bessey & Wilmore, 1988). For a full discussion of nutritional requirements in critically ill patients, see Chapter 7.17.1 in this book, Critical care.

References

ASPEN Board of Directors and the Clinical Guidelines Task Force. (2002) Guidelines for the use of parenteral and enteral nutrition in adult and paediatric patients. *JPEN J. Parenter. Enteral Nutr.* 26(1 Suppl): 1SA–138SA.

Arends J, Bodoky G, Bozzetti F, *et al.* (2006) ESPEN guidelines on enteral nutrition: non-surgical oncology. *Clin. Nutr.* 25: 245–259.

Bandini LG, Puelzl-Quinn H, Morelli JA, *et al.* (1995) Estimation of energy requirements in persons with severe central nervous system impairment. *J. Pediatr.* 126(5 Pt 1): 828–832.

Bauer JM, Biolo G, Cedeholm T *et al.* (2013) Evidence-based Recommendations for Optimal Dietary Protein Intake in Older People: A Position Paper From the PROT-AGE Study Group. *J. Am. Medical Directors Association* 14(8): 542–559.

Benedict FG, Carpenter TM. (1918) *Food Ingestion and Energy Transformation with Special Reference to the Stimulating Effects of Nutrients*. Pub. No. 261. Carnegie Institution of Washington.

Bessey PQ, Wilmore DW. (1988) The burned patient. In *Nutrition and Metabolism in Patient Care*. London: W.B. Saunders, pp. 672–700.

Boullata J, Williams J, Cottrell F, *et al.* (2007) Accurate determination of energy needs in hospitalized patients. *J. Am. Diet. Assoc.* 107: 393–401.

Brandi LS, Bertolini R, Santini L, *et al.* (1999) Effects of ventilator resetting on indirect calorimetry measurement in the critically ill surgical patient. *Crit. Care Med.* 27(3): 531–539.

Branson RD, Johannigman JA. (2004) The measurement of energy expenditure. *Nutrition in Clinical Practice* 19:622–636.

British Artificial Nutrition Survey. (2010) *Artificial Nutrition Support in the UK 2000–2009*. Redditch, Worcs: The British Association for Parenteral and Enteral Nutrition (ISBN: 978-1-899467-61-7).

Burge JC, Goon A, Choban PS, *et al.* (1994) Efficacy of hypocaloric total parenteral nutrition in hospitalized obese patients: A prospective, double-blind randomised trial. *JPEN J. Parenter. Enteral Nutr.* 18(3): 203–207.

Calloway DH, Spector H. (1955) Nitrogen utilization during caloric restriction. II. The effect of variation in nitrogen intake. *J. Nutr.* 56(4): 545–554.

Choban PS, Burge JC, Scales D, *et al.* (1997) Hypoenergetic nutrition support in hospitalized obese patients: a simplified method for clinical application. *Am. J. Clin. Nutr.* 66(546): 550.

Committee on the Medical Aspects of Food (COMA). (1991) *Dietary Reference Values for Food Energy and Nutrients for the United Kingdom*. London: Department of Health, HMSO, 41.

Crook MA, Hally V, Panteli JV. (2001) The importance of the refeeding syndrome. *Nutrition* 17(7–8): 632–637.

Dickerson RN, Brown RO, Gervasio JG, *et al.* (1999) Measured energy expenditure of tube-fed patients with severe neurodevelopmental disabilities. *J. Am. Coll. Nutr.* 18(1): 61–68.

Dickerson RN, Brown RO, Hanna DL, *et al.* (2003) Energy requirements of non-ambulatory, tube-fed adult patients with cerebral palsy and chronic hypothermia. *Nutrition* 19(9): 741–746.

Dickerson RN, Brown RO, Hanna DL, *et al.* (2002) Effect of upper extremity posturing on measured resting energy expenditure of nonambulatory tube-fed adult patients with severe neurodevelopmental disabilities. *JPEN J. Parenter. Enteral Nutr.* 26(5): 278–284.

Dvir D, Cohen J, Singer P. (2006) Computerized energy balance and complications in critically ill patients: an observational study. *Clin. Nutr.* 25(1): 37–44.

Elia M. (2005) Insights into energy requirements in disease. *Public Health Nutr.* 8(7A): 1037–1052.

European Society for Parenteral and Enteral Nutrition (ESPEN). (2007) Guidelines on adult enteral nutrition. *Br. J. Nutr.* 98: 253–259.

Faisy C, Guerot E, Diehl J-L, *et al.* (2003) Assessment of resting energy expenditure in mechanically ventilated patients. *Am. J. Clin. Nutr.* 78: 241–249.

Ferrie S, Rand S, Palmer S. (2013) Back to basics: estimating protein requirements for adult hospital patients. A systematic review of randomised controlled trials. *Food Nutr. Sci.* 4: 201–214. 10.4236/fns.2013.42028

Frankenfield D. (2006) Energy expenditure and protein requirements after traumatic injury. *Nutrition in Clinical Practice* 21(5): 430–437.

Frankenfield DC, Roth-Yousy L, Compher C. (2005) Comparison of predictive equations for resting metabolic rate in healthy nonobese and obese adults: a systematic review. *J. Am. Diet. Assoc.* 105(5): 775–789.

Frankenfield DC, Ashcraft CM. (2011) Estimating energy needs in nutrition support patients. *JPEN J. Parenter. Enteral Nutr.* 35(5): 563–570.

Glynn CC, Greene GW, Winkler MF, *et al.* (1999) Predictive versus measured energy expenditure using limits of agreement analysis in hospitalised, obese patients. *JPEN J. Parenter. Enteral Nutr.* 23:147–154.

Harris JA, Benedict FG. (1919) *Biometric Studies of Basal Metabolism in Man*. Washington DC: Carnegie Institute of Washington, Publication No. 297.

Henry CJK. (2005) Basal metabolic rate studies in humans: measurement and development of new equations. *Public Health Nutr.* 8(7A): 1133–1152.

Heymsfield SB, Casper K, Funfar J. (1987) Physiologic response and clinical implications of nutrition support. *Am. J. Cardiology* 60(12): 75G–81G.

Horgan GW, Stubbs J. (2003) Predicting basal metabolic rate in the obese is difficult. *Eur. J. Clin. Nutr.* 57(2): 335–340.

Ibrahim EH, Mehringer L, Prentice D, *et al.* (2002) Early versus late enteral feeding of mechanically ventilated patients: results of a clinical trial. *JPEN J. Parenter. Enteral Nutr.* 26(3): 174–181.

Ireton-Jones CS, Turner WW, Liepa GU, *et al.* (1992) Equations for the estimation of energy expenditure in patients with burns with special reference to ventilatory status. *J. Burn Care Rehabil.* 13: 330–333.

Ireton-Jones CS, Jones JD. (2002) Improved equations for predicting energy expenditure in patients: the Ireton-Jones equations. *Nutr. Clin. Pract.* 17(1): 29–31.

Ireton-Jones CS. (2005) Adjusted body weight, con: why adjust body weight in energy-expenditure calculations? *Nutr. Clin. Pract.* 20: 474–479.

Johnson RK, Hildreth HG, Contompasis SH, *et al.* (1997) Total energy expenditure in adults with cerebral palsy as assessed by doubly labeled water. *J. Am. Diet. Assoc.* 97(9): 966–970.

Kan MN, Chang HH, Sheu WF, *et al.* (2003) Estimation of energy requirements for mechanically ventilated, critically ill patients using nutritional status. *Crit. Care.* 7(5): R108–R115.

Khan LUR, Ahmed J, Khan S, *et al.* (2011) Refeeding syndrome: a literature review. *Gastroenterol. Res. Pract.* Article ID 410971.

Kinney JM, Long CL, Gump FE, Duke JH Jr. (1968) Tissue composition of weight loss in surgical patients. I. Elective operation. *Annals of Surgery* 168(3): 459–474.

Krenitsky J. (2005) Adjusted body weight, pro: evidence to support the use of adjusted body weight in calculating calorie requirements. *Nutr. Clin. Pract.* 20: 468–473.

Krishnan JA, Parce PB, Martinez A, *et al.* (2003) Caloric intake in medical ICU patients: consistency of care with guidelines and relationship to clinical outcomes. *Chest.* 124: 297–305.

Kulstad R, Schoeller DA. (2007). The energetic of wasting diseases. *Curr. Opin. Clin. Nutr. Metab. Care.*10(4): 488–493.

Kurpad AV, Vaz M. (2000) Protein and amino acid requirements in the elderly. *Eur. J. Clin. Nutr.* 54: S131–S142.

Lobo DN, Macafee DAL, Allison SP. (2006) How perioperative fluid balance influences postoperative outcomes. *Best Pract. Res. Clin. Anaesthesiol.* 20(3): 439–455.

McCrory MA, Kim HR, Wright NC, *et al.* (1998) Energy expenditure, physical activity, and body composition of ambulatory adults with hereditary neuromuscular disease. *Am. J. Clin. Nutr.* 67: 1162–1169.

Martin MM, Doig GS, Heyland DK, *et al.* (2004) Multicentre, cluster-randomized clinical trial of algorithms for critical-care enteral and parenteral therapy (ACCEPT). *CMAJ.* 170(2): 197–204.

Mehanna HM, Moledina J, Travis J. (2008) Refeeding syndrome: what it is, and how to prevent and treat it. *BMJ.* 336(7659): 1495–1498.

Miller MD, Daniels LA, Bannerman E, *et al.* (2005) Resting energy expenditure measured longitudinally following hip fracture compared to predictive equations: is an injury adjustment required? *Br. J. Nutr.* 94(6): 976–982.

NICE. (2006) *Nutrition support in adults: Oral nutrition support, enteral tube feeding and parenteral nutrition. Clinical Guideline* 32. Available at https://www.nice.org.uk/guidance/cg32. Accessed 4 October 2017.

NICE. (2013) Intravenous fluid therapy in adults in hospital. Clinical guideline [CG174]. Available at https://www.nice.org.uk/Guidance/CG174. Accessed 10 October 2018.

NICE. (2017) *Intravenous fluid therapy in adults in hospital Clinical guideline [CG174].* Available at https://www.nice.org.uk/guidance/cg174. Accessed 1 October 2017.

Patino JF, de Pimiento SE, Vergara A, *et al.* (1999) Hypocaloric support in the critically ill. *World J. Surg.* 23(6): 553–559.

Ramirez-Zea M. (2005). Validation of three predictive equations for basal metabolic rate in adults. *Public Health Nutr.* 8(7A): 1213–1228.

Reeves MM, Capra S. (2003) Predicting energy requirements in the clinical setting: are current methods evidence based? *Nutr. Rev.* 61(4): 143–151.

Royal College of Psychiatrists and the Royal College of Physicians. (2010) Report from the MARSIPAN group. MARSIPAN: Management of Really Sick Patients with Anorexia Nervosa. College Report CR162.

SACN. (2011). *Dietary Recommendations for Energy.* Available at https://www.gov.uk/government/uploads/system/uploads/ attachment_data/file/339317/SACN_Dietary_Reference_Values_ for_Energy.pdf. Accessed 4 October 2017.

Schofield WN. (1985). Predicting basal metabolic rate, new standards and review of previous work. *Hum. Nutr. Clin. Nutr.* 39: 5–41.

Shenkin A. (2000) Micronutrients in the severely-injured patient. *Proc. Nutr. Soc.* 59: 451–456.

Stanga Z, Brunner A, Leuenberger M, *et al.* (2008) Nutrition in clinical practice – the refeeding syndrome: illustrative cases and guidelines for prevention and treatment. *Eur. J. Clin. Nutr.* 62(6): 687–694.

Stokes MA, Hill GL. (1993) Total energy expenditure in patients with Crohn's disease: measurement by the combined body scan technique. *J. Parenter. Enteral Nutr.* 17(1): 3–7.

Streat SJ, Beddoe AH, Hill GL. (1987) Aggressive nutritional support does not prevent protein loss despite fat gain in septic intensive care patients. *J. Trauma* 27: 262–266.

Swinamer DL, Grace MG, Hamilton SM, *et al.* (1990) Predictive equation for assessing energy expenditure in mechanically ventilated critically ill patients. *Crit. Care Med.* 18: 657–661.

Taylor SJ. (2007) *Energy and Nitrogen Requirements in Disease States.* London: Smith-Gordon.

Todorovic V, Micklewright A, On behalf of the Parenteral and Enteral Nutrition Group of the British Dietetic Association (PENG). (2011) *A Pocket Guide to Clinical Nutrition.* Birmingham: BDA.

Toth MJ, Fishman PS, Poehlman ET. (1997) Free-living daily energy expenditure in patients with Parkinson's disease. *Neurology.* 48(1): 88–91.

Villet S, Chiolero RL, Bollmann MD, *et al.* (2005) Negative impact of hypocaloric feeding and energy balance on clinical outcome in ICU patients. *Clin. Nutr.* 24(4): 502–509.

Weekes CE. (2007) Controversies in the determination of energy requirements. *Proc. Nutr. Soc.* 66: 367–377.

Weekes CE. (2011) Nutritional requirements in cancer. In: Shaw C (ed) *Nutrition and Cancer.* UK: Blackwell Publishing Ltd.

Westerterp KR. (2004) Diet induced thermogenesis. *Nutr. Metab. (Lond).* 1(1): 5.

Westerterp KR. (2017) Doubly labelled water assessment of energy expenditure: principle, practice, and promise. *Eur. J. App. Physiol.* 117: 1277–1285. doi 10.1007/s00421-017-3641-x.

WHO/FAO/UNU Expert Consultation. (2007) Protein and amino acid requirements in human nutrition, Joint WHO/FAO/UNU Expert Consultation, *World Health Organization Technical Report Series 935*, World Health Organization.

World Cancer Research Fund. (2018) *Food, Nutrition, Physical Activity, and the Prevention of Cancer: A Global Perspective.* Washington DC: AICR. Available at www. https://www.wcrf.org/ dietandcancer. Accessed 10 October 2018.

Zauner A, Schneeweiss B, Kneidinger N, *et al.* (2006) Weight-adjusted resting energy expenditure is not constant in critically ill patients. *Intensive Care Med.* 32(3): 428–443.

SECTION 6