Optimal nutrition in critically ill children

Determining nutritional requirements and prescribing nutrition

Developed by
The Asia Pacific – Middle East Consensus Working Group on Nutrition Therapy in the Paediatric Critical Care Environment

Supported by
Nestlé Nutrition Institute
Learning objectives

• To understand the rationale behind accurate determination of nutritional requirements of a critically ill child

• To understand how protein, carbohydrate, fat metabolism and energy requirements vary according to critical illness

• To understand the value of indirect calorimetry in calculating energy requirements

• To be aware of the predictive equations used to estimate energy requirements in the PICU

• To know the daily requirements for protein, carbohydrate and fat in critically ill children

• To be able to prescribe optimal EN or PN nutrition for PICU patients who have a range of conditions
Overview

1. Rationale for accurate calculation of nutritional requirements
2. Metabolic response to critical illness
3. Estimating energy requirements
   3.1 Indirect calorimetry (IC)
   3.2 Predictive equations
4. Nutrition prescription in the PICU: Enteral nutrition (EN)
   4.1. Protein metabolism and requirements
   4.2. Carbohydrate metabolism and requirements
   4.3. Lipid metabolism and requirements
   4.4. Other components
   4.5. EN formulas
5. Nutrition prescription in the PICU: Parenteral nutrition (PN)
6. Test your knowledge
Rationale for accurate calculation of nutritional requirements
Components of energy requirements

- Basal metabolic rate (BMR) or resting energy expenditure (REE)
- Growth rate (normal growth, or catch-up growth)
- Physical activity
- In sick children, stress due to illness or healing process is an additional factor affecting energy requirements; but often leads to overestimation of energy requirements in critically ill children

<table>
<thead>
<tr>
<th>Activity factors</th>
<th>Stress factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paralysed</td>
<td>Surgery 1.2–1.5</td>
</tr>
<tr>
<td>Confined to bed</td>
<td>Infection 1.2–1.6</td>
</tr>
<tr>
<td>Ambulatory</td>
<td>Trauma 1.1–1.8</td>
</tr>
</tbody>
</table>
Why is accurate energy estimation necessary?

- **To reduce mortality**
  - Negative energy balance is related to mortality

- **To prevent overfeeding**, which may result in:
  - Hyperglycaemia ➔ increased risk of secondary infection
  - Increased fat deposition, fatty liver
  - Increased ventilatory work following ↑ carbon dioxide production, which can prolong the need for mechanical ventilation

- **To prevent underfeeding**, which may result in:
  - Malnutrition
  - Impaired immunologic responses
  - Impaired growth

## Causes of overfeeding

| Failure to recognise the hypometabolic phase of metabolic stress response (overestimating energy expenditure) | Reliance on standardised formulae/equations for energy expenditure, which may be inaccurate, e.g. in the case of obese patients |
| Inaccurate weight of patient being used to calculate energy requirements | Over-estimating the degree of metabolic stress in the era of modern anaesthesia and surgery |

## Causes of underfeeding

| Inability to predict the hypermetabolic stress response (underestimating energy expenditure) |
| Inaccurate estimation of energy expenditure |
| Delay in detecting deteriorating nutritional status |
| Failure to deliver prescribed nutrients |

2 Metabolic response to critical illness
Metabolic stress response

Metabolic states during illness

- Stress response is lower in children (blue line) than in adults (orange and red lines).
- Energy requirements of critically ill children are less than in adults, and resting energy requirements plateau after the initial increase.

# Metabolic responses to critical illness

<table>
<thead>
<tr>
<th>Condition</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burns</td>
<td>Extreme hypermetabolism in early stages; protein requirements can double(^1,2)</td>
</tr>
<tr>
<td>Sepsis</td>
<td>Upregulated fat oxidation;(^3) increased energy requirements(^2)</td>
</tr>
<tr>
<td>Congenital heart disease</td>
<td>Increased EE, fluid restricted, may absorb nutrients poorly(^1)</td>
</tr>
<tr>
<td>Cardiac surgery</td>
<td>Risk of underfeeding because of fluid restriction,(^2) mosaic of hyper-, hypo- and normometabolic states post-surgery(^6)</td>
</tr>
<tr>
<td>Abdominal surgery (newborns)</td>
<td>Increase in REE at 4 hrs, followed by return to baseline after 12–24 hrs(^4)</td>
</tr>
<tr>
<td>Surgery in general</td>
<td>Hyperglycaemia response that is negatively correlated with age (12 hrs in neonates; 24–48 hrs in children)(^5)</td>
</tr>
<tr>
<td>Mechanical ventilation</td>
<td>REE may be reduced due to inactivity, absence of growth or decreased insensible fluid loss(^4)</td>
</tr>
</tbody>
</table>

Metabolic stress response and optimal nutritional intake

• The hypermetabolic response in critically ill children is less pronounced than in adults

• Sustained protein breakdown may result in significant loss of lean body mass during critical illness

• Accurate assessment and delivery of energy to match the patient’s demand is an important goal
  – Intended under or overfeeding is associated with poor outcomes

Adequate protein and energy intake helps maintain protein balance and prevent lean body mass depletion in the PICU patient

3.1 Indirect calorimetry (IC)
Indirect calorimetry (IC)

- IC uses a metabolic cart to measure O₂ consumed and CO₂ exhaled, to determine resting energy expenditure (REE)

- Provides the respiratory quotient (RQ), which can help determine substrate use (fat, protein, mixed, carbohydrate or fat synthesis)

- Patients are measured under a hood that collects inhaled O₂ and exhaled CO₂
  - Ventilated/tracheostomised patients can be tested if there are no leaks and FIO₂ is not >60%

- IC is performed when the child is quiet, awake and calm

IC is the gold standard to measure REE, but is not always available in resource-limited settings
Using IC to measure REE

Measures **Respiratory Exchange Ratio**

\[ RQ = \frac{VCO_2}{VO_2} \]

when patient is in a calm steady state

**RESTING ENERGY EXPENDITURE (REE)**

*Weir equation*

\[ \text{REE (kcal/day)} = [\text{VO}_2 (3.94) + \text{VCO}_2 (1.11)] \times 1440 \text{ min} \]

RQ=respiratory quotient; VO₂=Oxygen consumption; VCO₂=CO₂ production
Interpreting respiratory quotient (RQ) values

<table>
<thead>
<tr>
<th>RQ</th>
<th>Clinical interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.85</td>
<td>Indicates under feeding</td>
</tr>
<tr>
<td>0.85–1.0</td>
<td>Indicates adequate feeding</td>
</tr>
<tr>
<td>&gt;1.0</td>
<td>Indicates overfeeding</td>
</tr>
</tbody>
</table>

Recommendations on IC

- IC is the **gold standard** for estimating resting energy requirements.

- In resource-limited settings, if it is not feasible to carry out IC in all patients, it should be targeted at patients who are at particular risk of metabolic instability (shown on the next slide).

- If IC is not available, resting energy requirements may be calculated using **predictive equations**.
PICU patients who are at risk of metabolic instability

- **Underweight** (BMI <5th percentile for age), at risk of overweight (BMI >85th percentile) or **overweight** (BMI >95th percentile)
- >10% **weight gain or loss** during ICU stay
- **Failure to meet prescribed caloric goals** consistently
- **Failure to wean**, or need to escalate respiratory support
- Need **muscle relaxants** for >7 days
- **Neurologic trauma** with evidence of dysautonomia
- **Oncologic** diagnoses (including stem cell or bone marrow transplant)
- **Thermal** injury
- Need **mechanical ventilator support for >7 days**
- Children suspected to be severely **hypermetabolic or hypometabolic**

3 Estimating energy requirements

3.2 Predictive equations
## Common predictive equations used to predict energy expenditure in PICU

<table>
<thead>
<tr>
<th>Name</th>
<th>Gender</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schofield</td>
<td></td>
<td>Go to slide</td>
</tr>
<tr>
<td>White (kJ/d)</td>
<td></td>
<td>17 x A[mo] + (48 x W) + (292 x body temp °C) - 9677</td>
</tr>
<tr>
<td>FAO/WHO/UNU</td>
<td></td>
<td>Go to slide</td>
</tr>
<tr>
<td>Harris-Benedict † (kcal/d)</td>
<td>M</td>
<td>66.4730 + (5.0033 x H) + (13.7516 x W) - (6.7550 x A)</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>655.0955 + (1.8496 x H) + (9.5634 x W) - (4.6756 x A)</td>
</tr>
</tbody>
</table>

† When using the Harris-Benedict equation in the clinical setting, the factors can be rounded to one decimal point.

M = male; F = female; A = age; H = height (m); W = weight (kg)

Schofield equation to estimate BMR (kcal/day) of PICU patient

<table>
<thead>
<tr>
<th>Age</th>
<th>Gender</th>
<th>Equation W</th>
<th>WH</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3 years</td>
<td>M</td>
<td>59.48W - 30.33</td>
<td>0.167W + 1517.4H - 617.6</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>58.29W - 31.05</td>
<td>16.252W + 1023.2H - 413.5</td>
</tr>
<tr>
<td>3–10 years</td>
<td>M</td>
<td>22.7W + 505</td>
<td>19.59W + 130.3H + 414.9</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>20.3W + 486</td>
<td>16.97W + 161.8H + 371.2</td>
</tr>
<tr>
<td>10–18 years</td>
<td>M</td>
<td>17.7W+ 659</td>
<td>16.25W + 137.2H + 515.5</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>13.4W+ 696</td>
<td>8.365W + 465H + 200</td>
</tr>
</tbody>
</table>

In critically ill children, use of actual weight (whether child is underweight or overweight) is recommended.

M = male; F= female; H = height (m); W = weight (kg)

### FAO/WHO/UNU equations to estimate REE (kcal/day)

<table>
<thead>
<tr>
<th>Name</th>
<th>Gender</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3 years</td>
<td>M</td>
<td>60.9W - 54</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>61W - 51</td>
</tr>
<tr>
<td>3–10 years</td>
<td>M</td>
<td>22.7W + 495</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>22.5W + 499</td>
</tr>
<tr>
<td>10–18 years</td>
<td>M</td>
<td>17.5W + 651</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>12.2W + 746</td>
</tr>
</tbody>
</table>

*M = male; F = female; W = weight (kg)*

Predictive equations: Which to use?

<table>
<thead>
<tr>
<th>Equation</th>
<th>Accuracy/Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAO/WHO/UNU</td>
<td>Evaluated/good accuracy in healthy children</td>
</tr>
<tr>
<td>Schofield</td>
<td>Not validated in children</td>
</tr>
<tr>
<td>Harris-Benedict</td>
<td>Not validated in infants &lt;2 months</td>
</tr>
<tr>
<td>White</td>
<td></td>
</tr>
</tbody>
</table>

- It is recommended to **use Schofield equation, without routine inclusion of stress factors**
  - Regular reassessment is necessary to ensure that appropriate nutrition is provided
  - Use the same equation for serial assessments

Research has shown that stress factors may overestimate EE in critically ill children

4 Nutritional prescription in the PICU

4.1 Protein metabolism and requirements
**Metabolism**

Chemical reactions enable the body to function as an integrated system.

**Two basic types of metabolism**

**Anabolism:** Substances are assembled

**Catabolism:** Substances are broken down

Protein metabolism is measured by nitrogen balance.
Proteins

- Proteins are in a constant state of flux and exist either as ‘complete’ proteins, or in the free amino acid pool
  - Protein breakdown provides free amino acids, which are channelled toward tissue repair, wound healing and the inflammatory response
  - In critically ill children, this may lead to substantial losses of lean body mass

Amino acid
Simplest form

Peptide
Chain of <99 amino acids

Protein
Chain of <100 amino acids

Sources of protein (4 kcal/g)

- Key sources of protein for nutritional therapy are:
  - Milk proteins: whey, casein
  - Soy proteins

- All proteins are not digested at the same rate:
  - Whey empties from the stomach more rapidly than casein because it remains liquid and does not form a curd in the acidic environment of the stomach
  - In the small intestine, whey is digested and absorbed faster than casein.
  - Hydrolysed proteins (peptides) are easier to digest and more readily absorbed

Influence of stress on protein absorption & metabolism

**Altered absorption**
- ↓ ability to absorb intact protein
- ↓ amino acid carriers in gut
  - 70% of protein absorbed as peptides

**Increased protein catabolism**
- ↑ protein requirements
- Loss of lean body mass
- Protein used by the body for energy and acute phase

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Essential to provide high-quality protein
Protein balance

• ‘Protein balance’ describes the status of protein metabolism within an individual
  – **Negative balance** is a marker for catabolism (degradation or breakdown)
  – **Positive balance** indicates anabolism (synthesis)

• Positive protein balance is a surrogate measure of lean body mass preservation

• Maintaining positive protein balance is an important goal of nutrition therapy in critically ill children
Protein requirements for critically ill children

EN protein requirements are age-dependent in children

<table>
<thead>
<tr>
<th>Age</th>
<th>A.S.P.E.N. recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–2 years</td>
<td>2–3 g/kg/day</td>
</tr>
<tr>
<td>2–13 years</td>
<td>1.5–2 g/kg/day</td>
</tr>
<tr>
<td>13–18 years</td>
<td>1.5 g/kg/day</td>
</tr>
</tbody>
</table>

The minimum recommended daily protein intake for critically ill children is 1.5 g/kg body weight/day

Managing protein requirements

- Protein needs can be determined by measuring urinary nitrogen excretion
- Protein retention can be increased by using a balanced glucose/fat solution
- Increasing protein intake cannot reverse protein breakdown, but it can improve nitrogen balance by enhancing protein synthesis

4 Nutritional prescription in the PICU: EN

4.2 Carbohydrate metabolism and requirements
Carbohydrates (4 kcal/g)

Monosaccharides
- Glucose
- Fructose
- Galactose

Disaccharides
- Glucose + Fructose = Sucrose
- Glucose + Glucose = Maltose
- Glucose + Galactose = Lactose

Oligosaccharides (3–10 monosaccharide units):
- Maltodextrin

Polysaccharides (10+ monosaccharide units linked to form long complex chains)
- Starch, fibre
Carbohydrates: Functions and metabolism

- **Primary source of energy** for many organs
  - Primary source for CNS/brain and red blood cells
  - Brain requires constant supply of glucose to meet its energy needs
- In fasting conditions, the liver and kidneys convert *glycogen to glucose* (primarily from liver and skeletal muscle)
- During prolonged fasting:
  - Hepatic glycogen stores will be depleted within a few hours
  - Gluconeogenesis is stimulated to maintain normoglycaemia
- **Fibre**
  - Important for maintenance of normal bowel function
Types of dietary fibre

**Soluble**
- Pectin
- Gum
- Mucilages
- Hemicellulose A
- Inner pea fibre

**Dietary fibre**

**Insoluble**
- Lignin
- Cellulose
- Hemicellulose-B
- Inner pea fibre
- Outer pea fibre

**Prebiotics**
- Inulin
- Fructo-oligosaccharides
- Oligofructose
- Acacia gum
Carbohydrate metabolism in critically ill children

• Glucose intolerance and insulin resistance can result from hormonal and metabolic challenges\(^1\)
  – Hyperglycaemia and hypoglycaemia are prevalent in the PICU.\(^1\)

• In critically ill children, carbohydrate is utilised poorly, and fat is preferentially used for oxidation\(^2\)

• During the metabolic response, carbohydrate turnover is increased, with a significant increase in glucose oxidation and gluconeogenesis\(^3\)

Glucose production and availability is a priority of nutritional therapy

4.3 Lipid metabolism and requirements
Fat (9 kcal/g)

- Fats (lipids) exist as fatty acids, triglycerides, sterols, phospholipids
- 95% of dietary fat is triglycerides
  - Glycerol backbone + 3 fatty acids
# Fat types and sources

| **Short chain fatty acids (SCFA)** | • 2–4 carbons in length  
• Fermentation product of prebiotics, energy source for the gut wall |
| --- | --- |
| **Medium chain triglycerides (MCT)** | • 6–12 carbons in length  
• Do not require bile salts or pancreatic lipase for digestion ➔ more rapidly digested and absorbed than LCT  
• Rapid source of energy |
| **Long chain triglycerides (LCT)** | • >14 carbons in length  
• Major energy source in diet  
• Essential fatty acids are LCT  
• Ensure absorption of fat-soluble vitamins |
| **Fish oil** | • Supplies long-chain fatty acids with strong anti-inflammatory properties (EPA and DHA) |

**EPA** = eicosapentaenoic acid; **DHA** = docosahexaenoic acid
Omega-3 & omega-6 fatty acids can affect immune & inflammatory responses

**Omega-3 Fatty Acids**
Sources: Fish Oil (Marine Oil) – Canola Oil
- Linoleic acid (EFA)
- Eicosapentaenoic acid (EPA) OR Docosahexaenoic acid (DHA)
- LESS inflammatory & immune enhancing

**Omega-6 Fatty Acids**
Sources: Safflower Oil, Corn Oil, Sunflower Oil, Soybean Oil, Cottonseed Oil
- Linoleic acid (EFA)
- Arachadonic acid
- MORE (Pro) inflammatory & immune suppressing

Changing the amount of omega-6 to omega-3 can modulate the inflammation and the immune response of the body.
Fat metabolism in critically ill children

- **Fat metabolism is increased** by illness, surgery and trauma.

- The use of fat is **reduced in early stages** of critical illness, leading to ↑plasma triglycerides and ↓metabolism of intravenous fats (lipids).

- Fat breakdown (lipolysis) is enhanced to provide free fatty acids for energy and glycerol for gluconeogenesis.

- **Essential fatty acid deficiency** can result from the increased demand for fat and the limited fat stores in a critically ill child.

- Increasing glucose in feeds does not decrease glycerol clearance or reduce lipid recycling.
Carbohydrate and lipid requirements for critically ill children

Reasonable first-line goals (depending on the age of the child):

**Carbohydrate**
- Approximately 50–60% of total energy intake

**Lipid**
- 30–40% of total energy intake

4 Nutritional prescription in the PICU: EN

4.4 Other components
Considerations for fluid requirements

### Increased fluid needs:
- Fever
- Hyperventilation
- GI losses (high output diarrhoea, fistulae)

### Conditions requiring fluid restrictions:
- Cardiac (congestive heart failure)
- Respiratory (pulmonary oedema)
- End Stage Renal Disease
- Liver (ascites)

### Daily fluid requirements (A.S.P.E.N. 2010)

<table>
<thead>
<tr>
<th>Body weight</th>
<th>Daily fluid requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10 kg</td>
<td>100 mL/kg</td>
</tr>
<tr>
<td>10–20 kg</td>
<td>1000 mL + 50 mL/kg for each kg &gt;10 kg</td>
</tr>
<tr>
<td>&gt;20 kg</td>
<td>1500 mL + 20 mL/kg for each kg &gt;20 kg</td>
</tr>
</tbody>
</table>
Prokinetics

Abnormal gastric motility is common in critically ill patients and prevents achievement of nutritional goals.

There is insufficient evidence to recommend the use of prokinetic medications or motility agents for EN intolerance or to facilitate enteral access device placement in critically ill pediatric patients.
Prebiotics and probiotics

- **Probiotics** are viable microorganisms (bacteria or yeast) that are used as dietary supplements to alter the microflora of the host, with the potential for beneficial health effects.

- **Prebiotics** are nondigestible soluble dietary fibres (e.g., inulin, fructooligosaccharides), which selectively stimulate the growth/activity of beneficial bacteria in the gut to improve the health of the host.

- **Synbiotic** formulations contain both pre- and probiotics.

Tolerability and safety have been shown, but there is still not enough evidence to recommend the routine use of prebiotics, probiotics, or synbiotics in critically ill children.

Micronutrients

• Micronutrients are essential to the diet and are needed for the maintenance of normal health

• A balanced micronutrient solution should be included in the diet of all critically ill patients

• Daily requirements vary with age, gender, course and type of illness and recommended intakes vary by geography

• Detailed information about micronutrient requirements in the critically ill child can be found in Goday PS, Mehta NM. Pediatric Critical Care Nutrition. McGraw-Hill Education. 2014, pp 59–68
Nutritional prescription in the PICU: EN

4.5 EN formulas
# Considerations for formula selection

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutritional goals</td>
<td>What are long-term requirements of the patient? Will EN be short- or long-term?</td>
</tr>
<tr>
<td>Current nutritional status</td>
<td>In severe malnutrition, gut function is compromised due to the gut wall becoming oedematous</td>
</tr>
<tr>
<td>Age</td>
<td>Consider nutritional requirements, nutritional status</td>
</tr>
<tr>
<td>Biochemistry/Laboratory measurements</td>
<td>Very low albumin can be a predictor of oedema in the gut; pre-albumin can be used as an indicator of nutritional status; CRP can be a measure of inflammatory status</td>
</tr>
</tbody>
</table>
# Types of EN formula

<table>
<thead>
<tr>
<th>Type</th>
<th>Details</th>
</tr>
</thead>
</table>
| Polymeric (intact protein/standard formula) | • Provide 1–2 kcal/mL, may or may not contain fibre  
• Require that patients can absorb intact macronutrients |
| Semi-elemental (peptide-based/hydrolysed)  | • Provide 1–1.5 kcal/mL  
• Contain pre-digested macronutrients (such as small peptides and MCT), making it easier for a partially dysfunctional GI tract to absorb them |
| Elemental (amino acid-based)              | • Provide 1–1.5 kcal/mL  
• Contain 100% free amino acids with variable amount of MCT, making it easier for a severely impaired GI tract to absorb them |
| Modular                                   | • Vary in energy content  
• Contain single macronutrients (protein, glucose polymers, or lipids) |
| Disease-specific                          | • Vary in protein, carbohydrate, lipid and vitamin and mineral content  
• For patients with disease-specific conditions such as renal impairment, hepatic disease, diabetes, and pulmonary disease, etc. |
When to use which formula

**Paediatrics**
- 'Junior' formula

**Normal GI function**
- Intact protein* formula

**Patient's condition**
- Peptide-based** formula
  - OR elemental*** formula

**Allergies**
- Elemental*** OR extensively hydrolysed formula

**Disease**
- Disease-specific formula

* Polymeric or standard formula; ** Semi-elemental formula, ***Amino acid formula
## Examples of EN formulas for use in PICU (0–12 months)

<table>
<thead>
<tr>
<th>Normal Gut Function</th>
<th>Impaired Gut Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expressed breast milk</td>
<td>Expressed breast milk</td>
</tr>
<tr>
<td>Standard infant formula or follow-on formula (&gt;6 month)</td>
<td>Lactose-free formula</td>
</tr>
<tr>
<td>± Fortifiers:</td>
<td>Semi-elemental (peptide-based/hydrolysed)</td>
</tr>
<tr>
<td>• Formula</td>
<td>Extensively hydrolysed formula</td>
</tr>
<tr>
<td>• Carbohydrate powder</td>
<td>Elemental formula</td>
</tr>
<tr>
<td>• Fat</td>
<td><em>(All formulas above can be fortified)</em></td>
</tr>
</tbody>
</table>

Modular feed if above formulas not well tolerated.
*(If used, will require individual manipulation and careful monitoring)*
## Examples of EN formulas for use in PICU [1–6 years (8–20 kg)]

<table>
<thead>
<tr>
<th>Normal Gut Function</th>
<th>Impaired Gut Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard paediatric formulas (with or without fibre)</td>
<td>Hydrolysed paediatric formula (1 kcal/ml; may be concentrated up to 1.5 kcal/ml)</td>
</tr>
<tr>
<td>• 1–1.5 kcal/mL</td>
<td>Elemental paediatric formula (kcal/ml)</td>
</tr>
</tbody>
</table>
Examples of EN formulas for use in PICU [>6 years (>20 kg)]

<table>
<thead>
<tr>
<th>Normal Gut Function</th>
<th>Impaired Gut Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paediatric formula may still be appropriate</td>
<td>Hydrolysed paediatric formula (1 kcal/ml)</td>
</tr>
<tr>
<td>Standard adult formula (with/without fibre):</td>
<td>Elemental paediatric formula (1 kcal/ml)</td>
</tr>
<tr>
<td>• 1–2 kcal/mL</td>
<td>Adult semi-elemental / elemental formula (1 kcal/ml)</td>
</tr>
</tbody>
</table>
Examples of EN formulas for use in PICU [Liver/metabolic/renal disease]

• Metabolic
  – PKU, MSUD-specific feeds are available

• Renal
  – Low-to-moderate protein, low phosphate and potassium (pre-dialysis)
  – Moderate-to-high protein, low phosphate, normal potassium (on dialysis)

• Liver
  – 80% MCT, whole protein
  – 50% MCT, hydrolysed protein

• Chylothorax
  – High proportion of fat as MCT
Nutrition prescription in the PICU: Parenteral nutrition (PN)
PN macro/micronutrient intake

• Parenteral nutrition involves the infusion of an intravenous nutrition formula into the bloodstream
  – Total Parenteral Nutrition (TPN) means that the infusion is providing the patient’s complete nutritional requirements
  – Sometimes PN is needed to support inadequate EN intake
• PN comprises a mixture of amino acids, carbohydrates and fat, as well as electrolytes and micronutrients
• Fluid and energy requirements are an important consideration
• Energy delivery must be individually adjusted to energy expenditure
## Protein requirements for PN

<table>
<thead>
<tr>
<th></th>
<th>Older children</th>
<th>Infants</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Start</strong></td>
<td>1 g/kg/day</td>
<td>1 g/kg/day</td>
</tr>
<tr>
<td><strong>Advance by</strong></td>
<td>0.5 g/kg/day</td>
<td>1 g/kg/day</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>1.5 g/kg/day</td>
<td>3.0–3.5 g/kg/day</td>
</tr>
</tbody>
</table>

Carbohydrate requirements for PN

- Glucose is the carbohydrate of choice and should provide 40–60% of total calorie intake
- Glucose (dextrose) component is in a water solution, usually expressed as % (weight per volume of total solution)
- If glucose intake exceeds energy needs, there is a risk of hyperglycaemia
  - Net lipogenesis occurs at glucose intakes of more than 18 g/kg/day in infants (12.5 mg/kg/min)
  - Calculate glucose infusion rates (5–7% concentration) to maintain normoglycaemia at around 5–7.5 mg/g/min
  - Higher ranges ➔ hyperglycaemia and lipogenesis
  - Lower ranges ➔ risk of hypoglycaemia

## Carbohydrate aims for PN

<table>
<thead>
<tr>
<th></th>
<th>Older children</th>
<th>Infants</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Start</strong></td>
<td>3–5 g/kg/day</td>
<td>2–3 g/kg/day</td>
</tr>
<tr>
<td><strong>Advance by</strong></td>
<td>2–3 g/kg/day</td>
<td>2–3 g/kg/day</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>12 g/kg/day</td>
<td>12–16 g/kg/day</td>
</tr>
</tbody>
</table>

Lipid requirements for PN

• Generally provide **30–40% of total calorie** intake

• Commercially available solutions reduce risk of EFA deficiency, improve protein use, and do not significantly increase CO\textsubscript{2} production or metabolic rate

• PN preparations with **increased omega-3 and omega-6** fatty acid content are metabolised better and provide **anti-inflammatory and immunomodulatory** effects

• Lipid emulsion has a **low osmolality**; adding it to a PN formulation will lower osmolality of the resulting solution (hence peripheral PN formulations are high in fat)

### Lipid requirements for PN

<table>
<thead>
<tr>
<th></th>
<th>Older children</th>
<th>Infants</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Start</strong></td>
<td>1 g/kg/day</td>
<td></td>
</tr>
<tr>
<td><strong>Advance by</strong></td>
<td>0.5 g/kg/day</td>
<td>1 g/kg/day</td>
</tr>
<tr>
<td><strong>Goal</strong></td>
<td>2 g/kg/day</td>
<td>3 g/kg/day</td>
</tr>
</tbody>
</table>

*Use 20% lipid solutions in infants and children (E.g. for 20% lipid, 1 g/kg provides 10 kcal/kg or 42 kj/kg)*

PN formulas

• Use a standard commercially available PN formulation
  – Has the advantage of being sterile
  – Meets the needs of most individuals
  – Cheaper than custom-made

• Alternately, PN formulas can be custom-made to precisely meet the patient’s individual requirements for macronutrients, micronutrients and electrolytes
Module summary

- Adequate intake of protein and energy maintains protein balance and prevents lean body mass depletion caused by metabolic stress
- Accurate assessment, and delivery of energy to match the patient’s needs, are vital
- IC is the gold standard method of calculating energy needs; predictive equations can also be used
Module summary

- Nutritional requirements that should be provided via EN are:
  - **Protein**: 1.5 g/kg (minimum recommended daily intake)
  - **Carbohydrate**: approximately 50–60% of total energy intake
  - **Fat**: 30–40% of total energy intake

- PN comprises a mixture of amino acids, carbohydrates, fat, electrolytes and micronutrients
  - As with EN, protein and energy delivery must be adjusted to the patient’s requirements
6 Test your knowledge
1. During critical illness, the metabolic stress response initially causes resting metabolism (energy requirements) to:

A. Increase
B. Decrease
1. During critical illness, the metabolic stress response initially causes resting metabolism (energy requirements) to:

• Answer:
  A. Increase

Because of the metabolic stress response, significant increases in resting energy expenditure (REE) are observed for several weeks after burns and major trauma, before they return to the normal state as the patient recovers. The energy requirements of critically ill children are less than those in adults, and resting energy requirements plateau relatively soon (1–2 weeks) after the initial increase.
Test your knowledge

2. For estimating energy requirements in critically ill children, stress factors must always be included

A  True
B  False
2. For estimating energy requirements in critically ill children, stress factors must always be included.

- **Answer:**
  B. False

The use of stress factors resulted in overestimations of REE, and hence these should not routinely be included in the Schofield equation when calculating REE for PICU patients, to avoid the risk of overfeeding.
Test your knowledge

3. Which one of the statements listed below with regards to estimating energy and protein requirements is true?

A. In a patient admitted with severe burns, daily protein requirements can double

B. REE is independent of physical activity levels

C. In a neonate who has just had abdominal surgery, REE is elevated for 36 hours

D. REE is always increased in mechanically ventilated patients
3. Which one of the statements listed below with regards to estimating energy and protein requirements is true?

• Answer:
  
  A. In a patient admitted with severe burns, daily protein requirements can double.

Energy and nutritional requirements vary according to the type of critical illness in the PICU patient. Protein ‘turnover’ can double in patients with severe burns because a high protein turnover allows immediate synthesis of proteins required for tissue repair. REE is dependent on growth rate and physical activity. In neonates who have undergone abdominal surgery, REE is elevated for 4 hours, followed by a return to baseline after 24 hours. In mechanically ventilated patients, REE may be reduced due to inactivity, absence of growth and decreased insensible fluid loss.
4. Which predictive equation will usually yield the most accurate energy requirement estimation for PICU patients?

A. White equation in infants aged <2 months
B. Schofield equation with stress factors
C. Schofield equation without stress factors
D. Harris-Benedict equation
4. Which predictive equation will usually yield the most accurate energy requirement estimation for PICU patients?

- **Answer:**
  
  C. Schofield equation without stress factors

Most predictive equations are derived from healthy non-hospitalised individuals. Hence, they do not always accurately predict REE in critically ill PICU patients because of the large heterogeneity regarding age, weight, muscle mass, level of growth and maturity, diagnosis, and severity of illness. The White equation has not been validated in infants younger than 2 months. According to the Asia Pacific – Middle East Consensus Working Group on Nutrition Therapy in the Paediatric Critical Care Environment; the Schofield equation tends to be the most commonly used in PICUs in Asia Pacific, and is the most accurate. Because the use of stress factors resulted in overestimations of REE, these should not routinely be included in the Schofield equation when calculating REE for PICU patients, to avoid the risk of overfeeding. The WHO equation does not include stress factors but these may be applied.
Test your knowledge

5. What are the estimated daily protein requirements for a 7-year-old PICU patient on EN according to ASPEN guidelines?

A. 1.0 g/kg/day
B. 1.5–2 g/kg/day
C. 2–3 g/kg/day
D. 3–4 g/kg/day
5. What are the daily protein requirements for a 7-year-old PICU patient on EN?

• Answer:

  B. 1.5–2 g/kg/day

• EN protein requirements are age-dependent in children. The minimum recommended daily protein intake for critically ill children is 1.5g/kg body weight. For children aged 2–13 years, the American Society for Parenteral and Enteral Nutrition (A.S.P.E.N.)’s pediatric critical care nutrition guidelines state that the daily protein requirement is 1.5–2 g/kg/day.
Test your knowledge

6. Which type of EN formula is recommended for a PICU patient age >1 year old with impaired gut function? (Select all that apply)

- Standard infant formula
- Elemental (amino acid based) infant formula
- Hydrolysed (peptide based) pediatric formula
- Low-to-moderate protein, low phosphate, low potassium formula
6. Which type of EN formula is recommended for a PICU patient age >1 year old with impaired gut function? (Select all that apply)

- Answer:

  C. Hydrolysed (peptide based) pediatric formula

Hydrolysed (peptide based) formulas provide partially digested protein that is more easily absorbed, and are also suitable in this case. Standard formulas provide intact protein and requires normal GI functions for digestion and absorption. Infant formulas targeted at children aged <1 year contain lower energy and protein compared to pediatric formulas.
Test your knowledge

7. What is the minimum recommended daily protein intake for critically ill children?

A. 1.0 g/kg body weight/day
B. 1.5 g/kg body weight/day
C. 2.0 g/kg body weight/day
D. 3.0 g/kg body weight/day
7. What is the minimum recommended daily protein intake for critically ill children?

- Answer:

  B. 1.5 g/kg body weight/day

The recommended protein intake for critically ill children is a minimum of 1.5 g/kg body weight/day, higher for younger children and infants based on recommendations for daily protein requirements in the pediatric critical care nutrition guidelines from A.S.P.E.N.

Reference