Nutritional therapy in paediatric intensive care units: a consensus statement of the Section of Paediatric Anaesthesia and Intensive Therapy of the Polish Society of Anaesthesiology and Intensive Therapy, Polish Society of Neonatology and Polish Society for Clinical Nutrition of Children

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Abstract

Providing nutritional therapy via the gastrointestinal tract in patients in paediatric intensive care units (PICUs) is an effective method for delivering energy and other nutrients. In the event of contraindications to using this method, it is necessary to commence parenteral nutrition. In the present study, methods for nutritional treatments in critically ill children are presented, depending on the clinical situation.

Key words: enteral nutrition, parenteral nutrition, critically ill children, PICU
Malnutrition of patients treated in paediatric intensive care units (PICUs) is common and its incidence has not substantially changed in recent decades [1, 2]. The causes of malnutrition include concomitant severe underlying diseases, catabolic response to trauma (in the wide sense of the word), improper nutritional therapy and the fact that PICUs often admit children with exacerbated chronic diseases who are already malnourished [3, 4]. Nutritional therapy in PICUs is an integral part of the medical management aimed at saving lives and ensuring the recovery of severely ill children.

**METABOLIC RESPONSE TO TRAUMA**

The metabolic response to trauma was first described in adults by Sir David Cuthbertson in 1942 [5, 6]. The response involves the following three phases:

- **Ebb** — or early shock with reduced metabolism;
- **Flow** — with increased catabolism; and
- **Recovery** — or anabolic phase.

Intensivists are interested in the first two phases. In the ebb phase, stabilizing the patient’s condition is essential; nutritional therapy is contraindicated. In the “flow” phase, nutritional therapy should be initiated, provided that the patient is haemodynamically stable.

The metabolic response to surgical trauma in newborns during the postpartum period differs from that in older children, i.e., lower energy expenditure is observed, followed by the return to baseline values, with the “flow” phase omitted, which results from the secretion of endogenous opioids [7].

The metabolic response to trauma is a “hormone-cytokine storm,” which is characterized by:

- the increased secretion of catabolic hormones (adrenaline, glucagon, and cortisol); — the increased production of proinflammatory cytokines (tumor necrosis factor — TNF alpha, IL-1, IL-2, and IL-6); and
- the resistance of peripheral tissues to anabolic hormones (insulin and growth hormone).

The process results in:

- an enhanced breakdown of muscle proteins (including diaphragmatic, intercostal muscles and myocardium);
- a negative nitrogen balance; and
- a loss of fat-free body mass.

Amino acids formed during protein degradation in the muscles are used in the following two processes [8]:

- synthesis of acute phase proteins (C-reactive protein — CRP, procalcitonin, and alpa-1 antitrypsin) — the proteins indispensable for immune response and the repair of damaged tissues; and gluconeogenesis, which aims to supply glucose (fuel) to the brain, renal medulla, bone marrow cells, and erythrocytes.

The action of proinflammatory cytokines results in insulin resistance in the peripheral tissues, which leads to hyperglycaemia accompanied by hyperinsulinaemia. Moreover, adipose tissue metabolism changes — lipolysis increases with the secretion of free fatty acids (FFAs) and glycerol to the plasma, which are the additional sources of energy in the form of ketone bodies and glucose [9–12] (Fig. 1).

**ENERGY AND PROTEIN REQUIREMENTS**

Children are at an increased risk of malnutrition because their energy requirements are higher than those of adults, whereas their muscle mass and adipose tissue stores are smaller. Energy and protein requirements are strictly connected. Proteins cannot be formed without adequate

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**Figure 1. Metabolic response to trauma**
amounts of energy, and extra protein energy does not support anabolism without exogenous protein supply.

Total energy expenditure (TEE) in children consists of the following factors [13]:

— basal metabolic rate (BMR) — 40–75%;
— food-induced thermogenesis — 10%;
— energy used for activity — 10–20%; and
— energy required for body growth — 1–35%.

A child doubles his body weight during the first five months and triples it during the first year of life; thus, the highest energy expenditure for tissue growth is during infancy and systematically decreases, i.e.,

— during the first three months of life — 35% of TEE;
— up to 12 months of life — 5%;
— during the second year of life — 3%; and
— during adolescence — 1–2%.

The gold standard for the assessment of energy requirements in critically ill patients is to measure the real energy expenditure using indirect calorimetry [3]. Energy expenditure is calculated based on the oxygen volume used per unit of time (VO2) and the carbon dioxide volume produced per unit of time (VCO2). The limitations of using this method are the high costs of devices, false results in the presence of a leak around the endotracheal tube exceeding 10% and oxygen content in the breathing mixture > 60%. Indirect calorimetry is poorly available in everyday practice. However, measurements performed using this method have proven that energy requirements of critically ill children are comparable to BMR, which is related to limited physical activity, medications used and therapeutic procedures (analgesia, sedation, and mechanical ventilation). In practice, BMR is more commonly calculated using mathematical formulas, and the Schofield equations are considered to be the most reliable [14].

The Schofield equation for calculating BMR in the units of kcal day−1 varies according to gender and age.

For boys, the following equations are used:

< 3 years: \[0.167 \times W + 15.174 \times H − 617.6\]
3–10 years: \[19.59 \times W + 1.303 \times H + 414.9\]
10–18 years: \[16.25 \times W + 1.372 \times H + 515.5\]

For girls, the following equations are applied:

< 3 years: \[16.252 \times W + 10.232 \times H − 413.5\]
3–10 years: \[16.969 \times W + 1.618 \times H + 371.2\]
10–18 years: \[8.365 \times W + 4.65 \times H + 200.0\]

where W is body weight in kg, and H is height in cm.

The mean values of BMR are presented in Table 1.

The production of proteins requires suitable amounts of extra-protein energy. Approximately 120–150 kcal should be given per gram of nitrogen (or 19.2–24 kcal per gram of protein) in the form of carbohydrates and fats in the appropriate proportions, i.e., 60–70% and 30–40%. For the calculations, it should be assumed that 4 kcal is obtained from 1 gram of protein and carbohydrates and that 9 kcal is obtained from 1 gram of lipid. In the case of parenteral nutrition calculations, the conversion factors are different: 1 gram of glucose for 3.4 kcal and 1 gram of lipids for 10 kcal.

### Table 1. BMR according to body weight (based on the Schofield equation)

<table>
<thead>
<tr>
<th>b.w.</th>
<th>kcal day−1</th>
<th>b.w.</th>
<th>kcal day−1</th>
<th>b.w.</th>
<th>kcal day−1</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg</td>
<td>1–12 months</td>
<td>kg</td>
<td>1–3 years</td>
<td>kg</td>
<td>4–18 years</td>
</tr>
<tr>
<td>3.5</td>
<td>202</td>
<td>9.0</td>
<td>528</td>
<td>15</td>
<td>859</td>
</tr>
<tr>
<td>4.0</td>
<td>228</td>
<td>9.5</td>
<td>547</td>
<td>20</td>
<td>953</td>
</tr>
<tr>
<td>4.5</td>
<td>252</td>
<td>10.0</td>
<td>566</td>
<td>25</td>
<td>1046</td>
</tr>
<tr>
<td>5.0</td>
<td>278</td>
<td>10.5</td>
<td>586</td>
<td>30</td>
<td>1139</td>
</tr>
<tr>
<td>5.5</td>
<td>305</td>
<td>11.0</td>
<td>605</td>
<td>35</td>
<td>1231</td>
</tr>
<tr>
<td>6.0</td>
<td>331</td>
<td>11.5</td>
<td>624</td>
<td>40</td>
<td>1325</td>
</tr>
<tr>
<td>6.5</td>
<td>358</td>
<td>12.0</td>
<td>643</td>
<td>45</td>
<td>1418</td>
</tr>
<tr>
<td>7.0</td>
<td>384</td>
<td>12.5</td>
<td>662</td>
<td>50</td>
<td>1512</td>
</tr>
<tr>
<td>7.5</td>
<td>410</td>
<td>13.0</td>
<td>682</td>
<td>55</td>
<td>1606</td>
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<tr>
<td>8.0</td>
<td>437</td>
<td>13.5</td>
<td>701</td>
<td>60</td>
<td>1699</td>
</tr>
<tr>
<td>8.5</td>
<td>463</td>
<td>14.0</td>
<td>720</td>
<td>65</td>
<td>1793</td>
</tr>
<tr>
<td>9.0</td>
<td>490</td>
<td>14.5</td>
<td>739</td>
<td>70</td>
<td>1886</td>
</tr>
<tr>
<td>9.5</td>
<td>514</td>
<td>15.0</td>
<td>758</td>
<td>75</td>
<td>1980</td>
</tr>
<tr>
<td>10.0</td>
<td>540</td>
<td>15.5</td>
<td>778</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.5</td>
<td>566</td>
<td>16.0</td>
<td>797</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.0</td>
<td>593</td>
<td>16.5</td>
<td>816</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The value of BMR should be a point of departure to determine the energy requirements of children during their PICU stay. The metabolic condition should be carefully monitored; each change in the general condition can induce changes in energy requirements, e.g., discontinuation of mechanical ventilation requires the supply of additional energy associated with the work of respiratory muscles; deepening sedation, analgesia or muscle relaxation are likely used to reduce energy expenditure (Table 2).

The following children have the highest risk of metabolic disorders:

1. those who are undernourished with body mass index (BMI) < 5th percentile, overnourished with BMI > 85th percentile, or obese with BMI > 95th percentile;
2. those whose body weight increased or decreased by 10% during their PICU stay;
3. those in whom the nutritional objective cannot be accomplished;
4. those who require muscle relaxation for > 7 days;
5. those who experience difficult weaning from mechanical ventilation;
6. those with cerebrocranial trauma;
7. those with a high likelihood of hypermetabolism (status epilepticus, hyperthermia, and systemic inflammatory response syndrome) or hypometabolism (hypothermia, hypothyroidism, and coma);
8. those with oncologic diseases or after bone marrow transplantation;
9. those with burn diseases;
10. those who require mechanical ventilation for > 7 days; and
11. those who stay in the PICU for > 4 weeks.

### Table 2. BMR in intubated and extubated children

<table>
<thead>
<tr>
<th>Age in years</th>
<th>Intubated (kcal kg⁻¹ day⁻¹)</th>
<th>After extubation (kcal kg⁻¹ day⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–1</td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>2–7</td>
<td>60–70</td>
<td>70–80</td>
</tr>
<tr>
<td>8–12</td>
<td>50–60</td>
<td>60–70</td>
</tr>
<tr>
<td>13–18</td>
<td>40–50</td>
<td>50–60</td>
</tr>
</tbody>
</table>

**PROTEIN**

Protein turnover is substantially higher in critically ill patients due to an enhancement of protein synthesis and degradation. Muscle protein is primarily degraded, including the diaphragm muscles, intercostal muscles, and myocardium. Protein degradation is accompanied by the formation of acute phase proteins connected with the immune system and is involved in wound healing. The synthesis of structural proteins is reduced. The degradation of proteins outweighs their synthesis, which results in a negative nitrogen balance. The increased supply of proteins cannot prevent muscle degradation, just as glucose supply does not prevent gluconeogenesis; however, nutritional therapy favourably affects protein synthesis because the muscle mass can be preserved or restored [8].

Critically ill children, even those similar in age, do not constitute a uniform group of patients. Various diseases (sepsis, trauma, burns) can cause hospitalizations; the severity of organ failure varies. According to several data, the degree of protein degradation correlates with the severity of the child’s condition, assessed by the Paediatric Risk of Mortality (PRISM) and the Therapeutic Intervention Scoring System (TISS), albeit the correlation with the type of disease is weaker [8, 15, 16]. There is a consensus that critically ill children require an increased supply of protein; however, the recommendations for this group differ. According to the American Society for Parenteral and Enteral Nutrition (ASPEN), the following amounts are recommended: ages 0−2 years, 2.3 g kg⁻¹ day⁻¹; ages 2−13 years, 1.5−2 g kg⁻¹ day⁻¹; and ages 13−18 years, 15 g kg⁻¹ day⁻¹. The guidelines of the European Society for Paediatric Gastroenterology, Hepatology and Nutrition (ESPGHAN) state that the supply of proteins up to 3 g kg⁻¹ day⁻¹ is beneficial in critically ill children aged 3−12 years [17].

The European Society for Clinical Nutrition and Metabolism (ESPEN) recommends the protein supply of 2.0−3.0 g kg⁻¹ day⁻¹ in children with burns [17].

Verbruggen compared the effect of amino acid supply of 1.5 g kg⁻¹ and 3.0 g kg⁻¹ in children aged 14−17 years [18] and observed not only improved nitrogen balance (thanks to the increased formation of proteins) in the latter group but also increased insulin resistance and lipolysis. The degradation of muscle proteins remained unchanged, irrespective of the amount of amino acids supplied. The author emphasised the potential toxicity of excessive amino acid supply.

Nitrogen balance is the difference between the amount of nitrogen supplied in the form of exogenous protein and the amount of nitrogen excreted from the organism. A negative nitrogen balance suggests the predominance of catabolic processes; a positive nitrogen balance indicates anabolism, whereas a zero balance shows equilibrium between the supply and degradation of body proteins. Nitrogen is excreted with urine in the form of urea nitrogen residue, creatinine, ammonia, uric acid and hippuric acid, as well as with faeces, desquamated epidermis, nails and hair. For practical reasons, the daily excretion of nitrogen with urine can be determined using a shortened method [8, 16] as shown below:

\[
\text{Nitrogen balance} = \text{daily nitrogen supply} - \text{amount of urea nitrogen excreted daily} \times 1.25.
\]

1 gram of nitrogen is contained in:

- 6.25 g of protein;
Parenteral nutrition is indicated when feeding via the gastrointestinal (GI) tract is impossible or the total energy requirements cannot be exclusively provided by enteral nutrition [19]. Total parenteral nutrition, whenever possible, should be replaced by feeding through the GI tract as quickly as possible [3, 17, 19]. The most common type of nutrition in critically ill patients is mixed nutrition, i.e., parenteral and enteral.

Parenteral nutrition can be provided through central or peripheral venous access. In the latter case, osmolarity of fluids cannot exceed 625 mOsm L⁻¹, which corresponds to a 12.0% glucose solution. Moreover, in newborns, the umbilical vessels, vein and artery can be used for this purpose over a period of several days after birth. It is recommended that the umbilical vein catheters be inserted into the lumen of the inferior vena cava, whereas umbilical artery catheters be inserted high into the aorta. The catheter tip should be located above the renal vessels.

**WATER**

Daily water requirements should always be considered while planning the nutrition of a particular patient. These requirements change with age and maturity; the highest requirements are in the neonatal period (high content of extracellular water, high indiscernible losses), and the requirements gradually decrease until maturity (Table 3).

In newborns, the supply of water is initially 60–80 mL kg⁻¹ day⁻¹ on the first day of life and is increased by approximately 20 mL kg⁻¹ day⁻¹ to approximately 150 mL kg⁻¹ day⁻¹. Daily water requirements can be calculated using the following rule:

- children with body mass > 10 kg — 100 mL kg⁻¹;
- children with body mass 10–20 kg — 1000 mL + 50 mL per each kg > 10 kg; and
- children with body mass > 20 kg — 1500 mL + 20 mL kg⁻¹ per kg > 20 kg.

Daily water requirements increase during fever, hyperventilation, and in hypermetabolism at increased loss from the digestive system (vomiting and diarrhea). During kidney and heart failure, fluid requirements are limited.

**CARBOHYDRATES**

Carbohydrates are the primary source of energy and should provide 40–60% of the energy requirement in children. It should be remembered that an excessive supply of glucose inhibits oxidation of fats, stimulates lipogenesis, increases fat accumulation in the tissues leading to hepatic steatosis, hyperglycaemia and other conditions; moreover, it stimulates the excessive production of CO₂, which increases the respiratory work and is a risk factor of infections [20–22].

In older critically ill children, the supply of glucose should not exceed 5–7 g kg⁻¹ day⁻¹. Early in their illness, these children develop insulin resistance in response to stress. In children with burns, the capacity to oxidase glucose decreases to 5 mg kg⁻¹ min⁻¹ [23, 24]. The supply of glucose in infants should not exceed 17 g kg⁻¹ day⁻¹, and glucose in small children should not exceed 10–12 g kg⁻¹ day⁻¹ [19]. In newborns, during the first day of life, the supply is initially 5–8 mg kg⁻¹ min⁻¹ (8–10 grams of glucose per kg body weight a day), and it is increased during the week to achieve approximately 16 kg⁻¹ day⁻¹.

**CAUTION:** The ability of glucose oxygenation of extremely low body weight (ELBW) newborns may necessitate the supply of glucose below 12 g kg⁻¹ day⁻¹. Similar to infants, the supply of glucose in a dose higher than 17 g kg⁻¹ day⁻¹ is not recommended.

In parenterally fed children, when the glucose concentration in serum exceeds 180 mg dL⁻¹, the infusion of insulin should be considered in an initial dose of 0.01–0.1 IU kg⁻¹ h⁻¹. The dose is modified according to regularly monitored glycaemia [25, 26]. In all of the treated patients, the glucose concentration should likely be maintained at < 180 mg dL⁻¹, and hypoglycaemia should be avoided [27].
**AMINO ACIDS**

The typically higher protein requirement is associated with catabolism caused by the severe disease in critically ill children compared to that estimated for healthy children [8]. In infants and children after the severe course of surgery, the processes of protein degradation increase by 25%. In patients with sepsis, in burn disease (posttraumatic or during extracorporeal membrane oxygenation (ECMO) therapy), the protein requirement can reach 4 g kg⁻¹ day⁻¹. In such cases, evaluating the nitrogen balance and nitrogen losses with urine can be helpful [3]. A parenteral supply of amino acids of 3 g kg⁻¹ day⁻¹ is frequently recommended in severely ill children.

Parenterally fed children have slightly lower protein requirements compared to enterally fed children.

The daily dose of amino acids depends on the child’s maturity. Extremely immature newborns with body weight < 1,000 g receive 3 g kg⁻¹ during the first day of life; subsequently, the provision of amino acids is increased to 4 g kg⁻¹ day⁻¹ to promote proper growth after birth and to supplement residual energy stores because the adipose tissue in these children constitutes only 1% of their body weight. Moreover, such a supply of amino acids allows limiting hyperglycaemia in extremely immature children because it stimulates the release of endogenous insulin. In such cases, the plasma concentration of phosphorus should be additionally monitored because insulin enhances the incorporation of phosphorus together with protein into the cells, which can lead to reduced concentrations of this component, e.g., in the leucocytes. This unfavourable phenomenon impairs their phagocytic and bactericidal activity, thus increasing the risk of sepsis. The supply of amino acids in full-term newborns starts with 1.5 g kg⁻¹ day⁻¹ and is increased to 3 g kg⁻¹ day⁻¹.

**CAUTION:** at such doses, the concentration of urine nitrogen can transiently increase in preterm newborns and should not exceed 50 mg dL⁻¹ [28].

**LIPIDS OR LIPIDS**

Lipids are a high-energy substrate. In critically ill children, the oxidation of fats is accelerated; therefore, free fatty acids are the major source of energy in children in metabolic stress. An increased supply of glucose (carbohydrates) in this group of patients leads to inhibition of fat oxidation and enhances lipogenesis [8].

The parenteral supply of lipids should provide 25–40% of extra-protein energy requirements [19]. The use of lipid emulsions reduces the production of CO₂. The supply of 0.1 g of linoleic acid effectively prevents the deficit of free fatty acids. There is no evidence that gradual increments in the supply of lipids increase their tolerance, although such practices are commonly used in intensive care units. Generally, the supply of lipids does not exceed 3 g kg⁻¹ day⁻¹ in infants and 1.5–2 g kg⁻¹ day⁻¹ in older children. Lipids should be simultaneously administered with the nutritional formula (simultaneously or separately). Heparin does not improve the assimilability of intravenous fats and should thus be added to the infusion of lipids.

In patients receiving fat emulsions, the plasma concentration of triglycerides should be periodically monitored. A decrease in lipid doses should be considered when the concentration of triglycerides exceeds 250 mg dL⁻¹ in infants and 400 mg dL⁻¹ in older children.

Although there is no evidence that the supply of fat emulsions in children diagnosed with acute respiratory failure, with or without pulmonary hypertension, can deteriorate the respiratory efficiency, excessive supply of lipids should be avoided. Furthermore, the complete withdrawal of their supply carries the risk for deficiency of free fatty acids.

In parenteral nutrition of children, only 20% solutions of fat emulsions are used (1 mL contains a double energy dose at preserved normoosmolality), except for the supply of 10% fish oil emulsions (10% Omegaven®).

There are no studies that explicitly demonstrate special benefits of individual fat emulsions in children. The above information also involves preparations of potential immunomodulating effects. However, using fish oil preparations containing omega-3 fatty acids (at present, Smoofflipid® is available on the market) significantly reduces the incidence of cholestasis and hepatic complications, dependent on parenteral nutrition in children, including the group of newborns [29]. Preterm newborns, especially those with ELBW (< 1,500 g), are particularly vulnerable to fat deficiencies because they have several times lower fatty tissue stores compared to full-term newborns (approximately 1% vs. 18% of body weight). In these preterm babies, the 2- to 3-day limitation of fat supply leads to the clinical condition called essential fatty acid deficiency. To prevent this condition, preterm newborns should receive lipids during the first day of life (30). The total supply of lipids should be approximately 3–4 g kg⁻¹ b.w. per day. Initially, the supplementation can be initiated with 1.0–1.5 g kg⁻¹ day⁻¹ and can increase by 1.0 g kg⁻¹ day⁻¹. It has been recently demonstrated that the supply of fat emulsions containing fish oil (docosahexaenoic acid [DHA]) reduces the risk of severe forms of retinopathy, significantly reduces the incidence of cholestasis and alleviates the clinical course of the diseases, whose essential pathomechanism is excessive inflammatory response [31, 32].

**ELECTROLYTES**

In parenteral nutrition, the supply of electrolytes, such as sodium and potassium (Na, K), calcium (Ca), magnesium (Mg) and phosphates (P), should be considered [19] (Table 4).
The use of organic preparations of Ca and P enables us to preserve the chemical stability of the nutritional formula. A growing newborn should receive 1.3–3 mmol Ca kg\(^{-1}\) day\(^{-1}\), 1.0–2.3 mmol P kg\(^{-1}\) day\(^{-1}\) and 0.2–0.3 mmol Mg kg\(^{-1}\) day\(^{-1}\). Table 5 presents the guidelines on the supply of energy substrates, electrolytes, calcium and phosphorus in parenteral nutrition.

**VITAMINS, TRACE ELEMENTS AND OTHER SUPPLEMENTS**

During parenteral nutrition therapy, the supplementation of vitamins should be considered. Using vitamin preparations, likely oxygen-, light- or heat-induced degradation of vitamins, should be considered. Trace elements should always be added to the nutritional formulas [19]. However, the medical literature lacks explicit data regarding the dosages of individual trace elements. Therefore, dosing should be based on the manufacturer’s recommendations. There are no data demonstrating the benefits associated with the use of glutamine and arginine in parenteral nutrition in children [3]. The addition of carnitine for parenteral nutrition should be individually considered in several infants [19].

The currently accepted management for the use of vitamins in newborns is the supply of Soluvit N® (Fresenius Kabi) and Vitalipid N Infant® (Fresenius Kabi) in fat emulsion. Soluvit N® is used in the volume of 1 mL solution kg\(^{-1}\) day\(^{-1}\). Vitalipid N Infant® is administered in the amount of 4 mL solution kg\(^{-1}\) day\(^{-1}\) in newborns whose body weight does not exceed 2,500 g. The supply of trace elements in newborns can be initiated after birth. The zinc requirement in preterm newborns is 400 µg kg\(^{-1}\) day\(^{-1}\), and an appropriate preparation must be obtained (e.g., via target importation) because the zinc content in Peditrace® is suitable for older infants.

In newborns with cholestatic jaundice, considerable caution should be exercised and the usefulness of manganese and copper supply should always be considered because these elements are excreted with the bile. The excessive concentrations of these elements in the liver can cause toxic damage to hepatocytes. Moreover, kidney failure impairs the secretion of selenium, molybdenum, zinc and chromium.

An important component of mixtures containing trace elements is iodine. According to the ESPGHAN recommendations, parenterally fed newborns should receive 1 µg iodine kg\(^{-1}\) day\(^{-1}\).

In newborns with hepatic failure, the supply of trace elements should be abandoned. Table 6 lists the preparations used for parenteral nutrition.

**INTRAVENOUS ACCESSES**

While planning partial parenteral nutrition aimed to supplement the energy balance in a short time, peripheral catheters can be successfully inserted. A prerequisite of safety during their use is low osmolality of the formula (e.g., in adults, use < 850 mOsmol L\(^{-1}\)). Formulas of higher osmolality must be administered through central vascular catheters, whose tips should be placed at the border of the right atrium and superior or inferior vena cava. Catheter placement that is too deep is likely to cause arrhythmias at any age, starting from the neonatal period. Thus, radiologic verification of the catheter tip position is always required [33].

### Table 4. Daily electrolyte requirements in individual age groups

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Infants (mmol kg(^{-1}) day(^{-1}))</th>
<th>Children &gt; 1 year of age (mmol kg(^{-1}) day(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>2–3</td>
<td>1–3</td>
</tr>
<tr>
<td>K</td>
<td>1–3</td>
<td>1–3</td>
</tr>
<tr>
<td>Mg</td>
<td>0.1–0.2</td>
<td>0.15</td>
</tr>
<tr>
<td>Ca</td>
<td>0.6–0.8</td>
<td>0.2–0.4</td>
</tr>
<tr>
<td>P</td>
<td>0.6–0.7</td>
<td>0.3–0.4</td>
</tr>
</tbody>
</table>

### Table 5. Fluids, energy substrates, amino acids, minerals and electrolytes in parenteral nutrition of infants and children in intensive care

<table>
<thead>
<tr>
<th>Component</th>
<th>Infants (mL kg(^{-1}) day(^{-1}))</th>
<th>Children aged 2–3 years (mL kg(^{-1}) day(^{-1}))</th>
<th>Children aged 4–7 years (mL kg(^{-1}) day(^{-1}))</th>
<th>Children aged 8–12 years (mL kg(^{-1}) day(^{-1}))</th>
<th>Children aged 13–18 years (mL kg(^{-1}) day(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluids</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amino acids (g kg(^{-1}) day(^{-1}))</td>
<td>3.0</td>
<td>2.5–3.0</td>
<td>2.5–3.0</td>
<td>2.5–3.0</td>
<td>2.5–3.0</td>
</tr>
<tr>
<td>Glucose (g kg(^{-1}) day(^{-1}))</td>
<td>10–17</td>
<td>10–12</td>
<td>10–12</td>
<td>7–10</td>
<td>5–7</td>
</tr>
<tr>
<td>Lipids (g kg(^{-1}) day(^{-1}))</td>
<td>2.0–3.0</td>
<td>2.0–2.5</td>
<td>2.0–2.5</td>
<td>2.0–2.5</td>
<td>1.5–2.0</td>
</tr>
<tr>
<td>Na (mmol kg(^{-1}) day(^{-1}))*</td>
<td>1.0–3.0</td>
<td>1.0–1.5</td>
<td>1.0–1.5</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>K (mmol kg(^{-1}) day(^{-1}))*</td>
<td>1.0–3.0</td>
<td>1.0–1.5</td>
<td>1.0–1.5</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Ca (mmol kg(^{-1}) day(^{-1}))*</td>
<td>0.6–0.8</td>
<td>0.2–0.4</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>P (mmol kg(^{-1}) day(^{-1}))*</td>
<td>0.6–0.7</td>
<td>0.3–0.4</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Mg (mmol kg(^{-1}) day(^{-1}))*</td>
<td>0.2–0.5</td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

*under control of laboratory examinations
Parenteral nutrition for > 2 weeks may require surgical insertion of a tunnelled central catheter. Compared to the surgical method, the percutaneous insertion of the central venous catheter can be associated with a three-fold increase in the risk of thrombosis, especially when the catheter is inserted into the left subclavian vein [34]. The likely cause of this complication is mechanical damage to the vessel during the cannula insertion, particularly during the widening of the opening in the vessel and during catheter insertion, which activates the clotting cascade. Thrombi usually develop within several days after the catheter has been inserted. Prospective studies have revealed that deep vein thrombosis develops in 12–28% of the children [35, 36]; in infants, this risk is higher, i.e., 44% [37]. Therefore, thrombosis in children with central venous catheters has been increasingly considered to be a significant problem, especially because none of the methods used has been demonstrated to provide full protection, except for the removal of cannulas as soon as possible. The choice of a proper cannula size is essential and should be adjusted to the vein diameter rather than the needs of the medical personnel. Slow blood flow over the long vessel segment when the cannulas are inserted into the inferior vena cava, particularly at coexisting increased intra-abdominal pressure, is a contraindication for choosing this vein and indicates the necessity to cannulate the jugular or subclavian vein.

A different group of patients includes children with severe congenital heart defects whose circulatory efficiency depends on the optimal heart function. In this group, the risk of thrombosis associated with catheter insertion into the superior vena cava can lead to the formation of collateral circulation, which prevents additional stages of surgical treatment.

The site of central vein cannulation in children is irrelevant to the risk of infections. Unlike adults, there was no correlation between the cannula insertion into the femoral vein, and there was a higher incidence of catheter-related infections [38]. Moreover, no relation was demonstrated between the cannula insertion into the femoral vein and the increased incidence of infectious complications, irrespective of whether the catheter was inserted in the emergency department, PICU or operating theatre [39]. Medical personnel training is crucial for the prevention of catheter-related infections [40]. Ultrasound used during the insertion of central venous catheters contributes to an increased efficacy of proper catheter insertion and reduces the number of complications associated with arterial and pleural cavity puncture [41].

**THROMBOEMBOLIC COMPLICATIONS**

Thromboembolic complications are less common in infants and children than in adults; however, since the 1990s,
their increasing incidence in the paediatric population has been observed. Apart from the predisposing factors involving severe concomitant diseases (e.g., neoplasms, heart defects, severe sepsis, and trauma), the risk is substantially increased by advanced methods of treatment, among which central catheters are the major cause of thrombosis at a young age [42, 43]. However, current guidelines do not recommend the use of antithrombotic agents in children with central venous catheters because there are no data confirming the efficacy and safety of this type of management [44].

An indicator that the central catheter properly functioning is its dual patency capability, i.e., the ability to administer fluids via the central catheter without resistance and to aspirate blood. Lack of catheter patency is likely to result from external compression, dislocation of the proximal catheter tip, presence of deposits within the catheter lumen (e.g., medications or nutrients), or a thrombus in the catheter lumen on the external surface of the catheter or in the vessels.

The factors increasing the risk of thromboembolic complications directly related to the central catheter include the time in which the intravascular cannula remains in place exceeding 6 days, presence of the cannula in the femoral veins, and the supply of fluids and hyperosmotic nutritional formulas [45, 46]. Other factors are prematurity, immobilization, injuries, generalised infections, congenital heart defects, thrombophilias, autoimmune and neoplastic diseases, and nephrotic syndrome [42].

The objective of therapeutic management in patients with parental nutrition is the quick restoration of catheter and vessel patency by using one of the two pharmacological methods, i.e., anticoagulative or thrombolytic therapy. Because there are no guidelines for children, the suggested treatment, based on the data regarding the adult population, for the most part requires a meticulous interpretation of the results, knowledge of pharmacokinetic differences of the paediatric population and individualization of therapy. The recommended management for central venous catheter-related thrombotic complications involves diagnosis and Doppler and imaging monitoring, as well as the monitoring of laboratory examinations. The laboratory examinations used include activated partial thromboplastin time (APTT), prothrombin time (PT), concentration of D-dimers and fibrinogen, platelet count and anti-Xa activity. We propose the following pharmacological management, depending on the thrombus location [42, 47–49]:

1. Thrombus adherent to the catheter tip, perimural or ballotable:
   - unfractionated heparin (UFH) IV: 50–75 IU kg⁻¹ for 10 min., followed by a continuous infusion 15 IU kg⁻¹ h⁻¹ (< 1 year old) or 25 IU kg⁻¹ h⁻¹ (> 1 year old), with APTT monitored (providing its two- to three-fold prolongation);
   - low molecular weight heparin (LMWH) SC — after UFH therapy:
     - nadroparin (Fragiparine 100 IU kg⁻¹ = 0.1 mL × 10 kg⁻¹ 2 × day);
     - enoxaparin (Clexane) 1 IU kg⁻¹ every 12 h (1.5 mg kg⁻¹ < 2 months).
   - The thrombus must be observed for 24 h; removal of the catheter and insertion of a new catheter should be considered.

2. Thrombus obliterating the vessel lumen:
   - alteplase (plasminogen activator) 0.5–2 mg in 2 mL, evaluation of catheter patency after 30 min.; when no effects are found, further waiting up to 120 min.; if still no effect is observed, the entire management can be repeated. After restoration of the central catheter patency, an intravenous infusion of UFH should be initiated in a dose of 10 IU kg⁻¹ h⁻¹. The solution should be prepared in such a way that the recommended hourly dose is contained in the minimum volume of 1 mL (minimum flow, 1 mL h⁻¹).

Despite the lack of indications for routine antithrombotic prevention in critically ill children, the prevention in question is recommended when at least two risk factors coexist, particularly in older children. The recommended prophylactic dosage of antithrombotic drugs is presented in Table 7.

The treatment of thromboembolic complications in critically ill children causes numerous difficulties because of the lack of acceptable guidelines, the differences in pharmacokinetics of medications (higher doses in newborns and infants) and the limited medication indications (the summary of product characteristics) in the group of youngest patients.

**INFECTIOUS COMPLICATIONS**

Central venous catheters, especially those used for parenteral nutrition, can be a source of central line-associated blood stream infections (CLA-BSIs) [50]. The crucial risk factors are directly related to the central venous line (CVL) and microorganisms present on the patient’s skin (30%) or hands of the medical personnel (60%) [51]. The pathogens predominantly include skin-colonising bacteria: *Staphylococcus epidermidis* (*S. epidermidis*), *Staphylococcus aureus* (*S. aureus*), *Enterococcus spp.*, *Acinetobacter spp.*, Klebsiella spp., and fungi, e.g., *Candida spp.* [52]. The extremely important CLA-BSI risk factors are the time the catheter remains in place and the number of catheters [53, 54]. The preventative strategy of CVL-associated infections necessitates the observation of patients to detect any clinical and laboratory symptoms of generalised infection (fever, CRP, procalcitonin, and positive blood cultures) and local symptoms. General recommendations and management rules are consistent with the
guidelines of the Surviving Sepsis Campaign, considering the individual patient-related factors and microbiological differences of a given intensive care unit and hospital [55].

When a CVL-associated infection is suspected, after identification of the responsible pathogen, empiric antibiotic therapy can be considered, including likely microbiological factors [56]:

1) Gram (+) strains (84%): coagulase-negative methicillin-resistant (MRCONS) S. epidermidis or methicillin-resistant S. aureus (MRSA): vancomycin, teicoplanin; 
2) Gram (−) strains (12%): e.g., Pseudomonas aeruginosa, Acinetobacter baumannii, Klebsiella pneumoniae, Escherichia coli, Enterobacter cloacae: third- or fourth-generation cephalosporins (aminoglycosides can be added), carbapenems; and 
3) Fungi: azoles, in cases of septic shock and haemodynamic instability, echinocandins.

Once its infection has been confirmed, the central venous catheter should be removed. The antibiotic lock therapy (the antibiotic dissolved in the volume of 0.9% NaCl corresponding to the catheter lumen volume, usually 1 mL) should be provided. The antibiotics applied include amikacin (15 mg), gentamicin (10 mg), or vancomycin (50 mg). The antibiotic lock should dwell for 3 days, and the medication should be changed every 24 h; moreover, a 70% ethyl alcohol (from the hospital pharmacy) lock can be beneficial. However, the dose of ethanol should not exceed the catheter lumen volume because of the risk of thrombosis.

In empiric antibiotic therapy, amikacin with vancomycin is used; once the culture results are known, the target antibiotic therapy is applied. An indication for permanent catheter removal is a fungal infection or bacterial infection without improvement after local and systemic antibiotic therapy.

Central venous catheter-related infections are a serious complication, which can substantially complicate the treatment of critically ill children, including parenteral nutrition, and lead to severe consequences, even death [57]. Therefore, system-associated strategies are crucial for the prevention of catheter-related infections, primarily by educating the healthcare workers, increasing their awareness, and observing the currently accepted procedures [58].

### ENTRAL NUTRITION

Enteral nutrition (EN) is the preferred method of supplying nutrients to critically ill children with preserved functions of the gastrointestinal tract [3, 59]. Early initiation of EN reduces the incidence of infectious complications, limits the PICU and hospital stays, and reduces mortality [59–61]. The cells of GI mucosa are nourished with substrates from the intestinal lumen. To maintain the physiological functions of the mucosa, trophic supply is required, which is defined as the supply of a nutrient in the amount of 0.5–1 mL kg⁻¹ h⁻¹ [62, 63].

Enteral nutrition, i.e., physiological nutrition, has many advantages [59, 61, 64], including:
- preserved integrity and immune activity of the intestinal epithelium (production of IgA and T lymphocytes — 70% of the body’s lymphocytes are associated with the GI cell membranes);
- prevention of bacterial translocation;
- improvement of blood flow in the mesenteric vessels;
- reduction in the number of infections;
- prevention of GI mucosal atrophy;
- maintenance of GI hormonal activity; and
- lower costs, compared to parenteral nutrition.

EN indications include the following:
- a functional GI tract (even partially); and
- no likelihood of oral feeding.

**Table 7. Prophylactic doses of antithrombotic drugs**

<table>
<thead>
<tr>
<th>Drug</th>
<th>Initial dose</th>
<th>Maintenance therapy</th>
<th>Monitoring parameters</th>
<th>Monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfractionated heparin (UFH)</td>
<td>50–100 IU kg⁻¹ i.v. for 10 min.</td>
<td>28 IU kg⁻¹ h⁻¹ (infants)</td>
<td>aPTT 60–85 sec. 1.5–2.5-fold increase in aPTT, compared to the baseline value</td>
<td>aPTT 4 h after the initial dose and in each case of infusion rate changes</td>
</tr>
<tr>
<td>Enoxaparin</td>
<td>–</td>
<td>1.5 mg kg⁻¹ s.c. every 12 h (infants)</td>
<td>Anti-FXa 0.5–1.0 U mL⁻¹</td>
<td>Monitoring every 4–6 h</td>
</tr>
<tr>
<td>Dalteparin</td>
<td>–</td>
<td>100 IU kg⁻¹ s.c. every 24 h or 200 IU kg⁻¹ every 24 h</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

APTT — activated partial thromboplastin time; s.c. — subcutaneous; i.v. — intravenous
The supply of catecholamines at the stable circulatory system is not a contraindication for enteral nutrition [65]. EN can be conducted using appropriate accesses, which are divided into temporary and long-term accesses [3, 59, 61]. A temporary access is defined as

— naso/orogastric tube; and
— naso/orointestinal tube that is introduced past the pylorus to the duodenum or jejunum, past the ligament of Treitz.

Implantation of the latter may require fluoroscopy or endoscopy. If the child must undergo laparotomy, the tube should be intraoperatively inserted into the jejunum under visual control.

Special indications for tube insertion beyond the pylorus are necessary in patients at high risk for aspiration, distension, delayed gastric emptying and massive gastroesophageal reflux, particularly after surgical GI procedures. Another tube should be simultaneously inserted into the stomach to decompress the retained gastric content and to evacuate air [39, 64]. In both cases, the tube location should be radiologically confirmed, although auscultation is also acceptable when the tubes are inserted into the stomach.

Polyurethane or silicone tubes are recommended, which can remain in the GI tract for up to 6 weeks. Tubes consisting of vinyl polychloride are more rigid and increase the risk of gastric mucosa damage and therefore should be replaced every day. To increase the patient's safety and avoid mistakes during nutrition, the “safe nutrition” equipment is recommended, i.e., with the tips of tubes, syringes or lines to nutritional pumps incompatible with the tips used for intravenous therapy. The equipment is always coloured violet or red.

A long-term access is used in PICU's patients whose access was provided before treatment in the intensive care unit. However, the placement of such accesses can be considered in children with poor prognosis of return to oral feeding within 6 weeks after PICU admission.

The types of long-term accesses are as follows:
— percutaneous endoscopic gastrostomy (PEG) using an open or laparoscopic method; and
— percutaneous endoscopic gastrostomy-percutaneous endoscopic jejunostomy (PEG-PEJ).

The most recent guidelines recommended the initiation of enteral nutrition as early as possible, i.e., within 24 h after PICU admission, and the supply of at least 25% of energy requirements within 48 h [60, 66].

Despite the generally known guidelines, proper assessment of protein-energy requirements and lack of absolute contraindications, the provision of nutritional needs still encounters many difficulties and can be insufficient in critically ill children.

The factors limiting the supply of nutrients through the GI tract include the following:

- fasting before procedures (64), such as
  — intubation or extubation;
  — surgical procedures, changes of dressings requiring general anaesthesia;
  — bedside procedures requiring sedation; and
  — diagnostic radiology procedures.
- fluid restrictions;
- delay or difficulties in gaining access to the GI tract, tube dislocation or obstruction;
- impaired function of the GI tract, such as
  — disorders of absorption, vomiting, diarrhoea or constipation;
  — bowel obstruction caused by opioids or postoperative condition;
  — increased risk of gastric content aspiration;
  — withdrawal of enteral nutrition due to intolerance;
  — gastric retention; and
  — flatulence, increased circumference of the abdominal cavity, patient’s discomfort;
- mistakes in implementation and continuation of enteral nutrition.

Several causes mentioned above can be eliminated by organizing a hospital nutrition team and implementing the individually formulated nutritional protocols. Figure 2 presents the suggested protocol based on the available literature data [59, 67].

In several patients, the symptoms of enteral nutrition intolerance were observed. The management in such patients is described in Table 8.

In newborns after the period of parenteral nutrition, enteral nutrition should be gradually restored yet as quickly as possible. However, gradually decreasing parenteral nutrition should be initiated when the enteral supply tolerance exceeds the volume of 50 mL kg⁻¹ day⁻¹. A gradual reduction involves all of the nutrients, including fats. Parenteral nutrition can cease when the newborn tolerates the oral supply in a volume exceeding 100−120 mL kg⁻¹ day⁻¹. The appropriate nutrition for newborns treated in PICUs is breast milk (maternal or from the maternal milk bank) or commercial formulas.

In the event of enteral nutrition intolerance, the following prokinetics are recommended:

- erythromycin, 3−7 mg kg⁻¹ day⁻¹ in four divided doses (intravenously or via the GI route); and
- metoclopramide, 0.5 mg kg⁻¹ day⁻¹ in 2−4 divided doses.

Combined therapy, with a simultaneous supply of both prokinetics, is recommended. Monotherapy, with both metoclopramide and erythromycin, causes rapid development of tachyphylaxis, reducing the effectiveness of treatment from the achieved intended effect in approximately 80% of the patients on day one of therapy to approximately 30%
of the patients on day 7. Combined therapy enables us to achieve efficacy in nearly 100% of the patients on day one and to maintain efficacy in 60% of the patients on day 7 [68–70]. Diarrhoea developing during treatment with prokinetics is not associated with Clostridium difficile infection and quickly subsides when the therapy is stopped (although its incidence is high, in approximately 40% of the patients) [71]. Considering the inferior efficacy of metoclopramide in patients with craniocerebral trauma [72] and the reports demonstrating that the medication increases intracranial pressure, the agent is contraindicated in this group of patients [73]. Erythromycin is contraindicated for patients with

Figure 2. Enteral nutrition scheme
myasthenia [74]. Prokinetic agents are not recommended for newborns.

While planning surgical procedures in patients treated in PICUs, the enteral nutrition rules should be observed:
— children endotracheally intubated, when the procedure does not involve airways and is not associated with the exchange of the endotracheal or tracheostomy tube, should be fed until transferred to the operating room;
— children without endotracheal intubation, when fed through the nasointestinal tube, should receive nutrition until their transfer to the operating room; in any other case, nutrition should be discontinued according to standard anaesthetic management. The accepted rule is 2-4-6, i.e., the interval between feeding and anaesthesia should be 2 hours for water and clear liquids, 4 hours for breast milk, and 6 hours for milk formulas, commercial diets and solid foods.

In planning extubation, the same management should be applied; and after extubation, enteral nutrition should be withheld for the time necessary to observe the patient’s respiratory efficiency. Nutrition via the intestinal tube, when well tolerated, requires withholding only for the duration of the procedure.

When enteral nutrition is impossible or insufficient, i.e., does not provide 85% of the protein-energy requirement in newborns and infants and 70% in older children, supplementary parenteral nutrition should be introduced in an amount that corrects the requirement [65]. In all of the cases without absolute contraindications, the trophic supply should be maintained (0.5–1 mL kg⁻¹ h⁻¹). During nutritional therapy in patients requiring intensive care, the actual accomplishment of the nutritional goal should be evaluated every day and compared with the intended objective. The requirement should be re-evaluated at least once a week and a cumulative protein-energy deficit should be calculated [59].

Enteral nutrition preparations vary in energy densities:
— normocaloric diets contain 0.7–1 kcal in 1 mL; and
— hypercaloric diets contain 1.5 kcal in ≥1 mL.

The commercial polymeric diets contain intact protein. The only preparation in this group available for infants is Infatrini®; for older children, the diets of various manufacturers are available.

Oligometric diets contain hydrolysed protein (the only preparation available for infants is Infatrini Peptisorb®). Elementary diets contain amino acids. Commercial diets are usually low-lactose and gluten-free.

The carbohydrate component of diets is primarily based on complex sugars (maltodextrines). The fat component can be modified by adding medium-chain triglycerides (MCTs). According to the worldwide recommendations and recent study findings, modern diets are composed of essential fatty acids, long-chain polyunsaturated omega-3 and omega-6 fatty acids.

Commercial diets are balanced in terms of the content of trace elements and vitamins. They are dedicated for patients with various organ disorders (hepatic, renal, and respiratory failure) and their composition varies according to the metabolic profile of disorders. Moreover, commercial preparations differ according to the dietary fibre content, e.g., residue-free, low-residue and rich-residue. In all of the cases, diets should be adjusted to the patient’s age.

**REFEEDING SYNDROME (RS) AND RECOMMENDATIONS FOR NUTRITIONAL THERAPY IN CASES OF SEVERE MALNUTRITION**

The refeeding syndrome is a life-threatening condition resulting from quick and improper composition-related supply of energy in severely debilitated patients with low serum concentrations of intracellular ions (potassium, phosphorus, and magnesium) and systemic fluid shifts. Hypophosphataemia, hypomagnesaemia and hypokalaemia are accompanied by disorders of glucose metabolism and deficiency of vitamins (particularly of thiamine, vitamin B₁) and trace elements. The symptomatic refeeding syndrome is most commonly irreversible and fatal.

---

**Table 8. Management of enteral nutrition intolerance**

**Gastric nutrition:**

Gastric retention should be measured before each bolus or every 4 h in the case of continuous infusion. The symptoms of intolerance are retentions of:
— 5 mL kg⁻¹ or
— over 50% of volume of the portion administered or
— 200 mL (in children with b.w. > 40 kg)
— 200% of hour volume administered in continuous infusion

**Intestinal nutrition**

Abdominal circumference, flatulence and vomiting should be evaluated

When abdominal circumference increases on two successive measurements and vomiting occurred twice, nutrition should be withheld and evaluation repeated after 4 h

**Diarrhoea**

More than 4 loose stools day⁻¹

Discontinue laxatives increasing the stool volume or containing sorbitol

Pay attention to diet osmolarity

Consider the change of diet or withhold nutrition until diarrhoea subsides

Diagnostic testing for *Clostridium difficile*

**Constipation:**

Lack of faeces 48 h after introduction of nutrition
Nutritional therapy in patients at risk of RS involves gradual increases in energy supply accompanied by supplementation of electrolyte and phosphate deficiencies [75]. The therapy without simultaneous supply of phosphates substantially increases the risk of RS symptoms (Table 9).

To prevent RS in severely undernourished patients, the following rules should be followed:
- avoid aggressive nutrition therapy, especially when phosphate and electrolyte deficiencies have not been corrected;
- supplement electrolytes, even when the baseline values are normal;
- supplement thiamine; and
- thoroughly monitor therapy.

**MANAGEMENT RECOMMENDATIONS FOR NUTRITIONAL THERAPY IN CASE OF SEVERE MALNUTRITION**

The goal of initial treatment is to improve peripheral perfusion by supplying colloids, e.g., albumins (2 g kg⁻¹ day⁻¹), i.e., 10 mL 20% albumin kg⁻¹ day⁻¹; from treatment day 2, the supply can be reduced to 1 kg⁻¹ day⁻¹, with osmolarity and serum albumin concentrations controlled) and crystalloids. The initial parenteral supply of fluids in hypovolaemia in chronic malnutrition should be spread over 6−8 hours as follows:
- infancy: 60 mL kg⁻¹ within 8 hours; and
- post-infancy period: 40 mL kg⁻¹ within 6−8 hours.

The supply of electrolytes is presented in Table 10.

On treatment day 1, 50% of the basal energy requirement should be provided. Special attention should be paid to initial energy supply in patients with anorexia nervosa because their resting energy expenditure is lower than that calculated according to age and body weight. Therefore, the supply of energy in this group of patients should be started with 10 kcal kg⁻¹ day⁻¹ [76].

Basal energy requirements are as follows:
- newborns: 60 kcal kg⁻¹ day⁻¹;
- 2–12 months: 50–60 kcal kg⁻¹ day⁻¹; and
- > 12 months: 30–40 kcal kg⁻¹ day⁻¹.

In severe malnutrition cases, parenteral nutrition is recommended during the first three days. When enteral nutrition is likely, trophic nutrition in the amount of 10–20 kcal kg⁻¹ day⁻¹ is simultaneously provided with parenteral nutrition.

The correction of protein deficiencies-supply of nitrogen in the form of amino acids is as follows:
- 1 g kg⁻¹ day⁻¹ — treatment day 1;
- increased by 0.5 g kg⁻¹ day⁻¹ — on successive days; and
- target dose: 2−2.5 g kg⁻¹ day⁻¹.

The supply of lipids is as follows:
- treatment day 1 — 0.5 g kg⁻¹ day⁻¹; and
- on successive days, it is recommended to increase lipids gradually to the dose of:
  - 3.0 g kg⁻¹ day⁻¹ — infants;
  - 2.0 g kg⁻¹ day⁻¹ — older children; and
  - 1.5 g kg⁻¹ day⁻¹ — teenagers.

The supply of thiamine is as follows:
- oral 30–100 mg day⁻¹ for 5–7 days; and
- IM, SC, IV in a dose of 50–100 mg, even 200 mg day⁻¹ for the first 3−5 days of therapy.

Additionally, the following are required: supplementation of trace elements—zinc, selenium, manganese (paren-
Table 10. Recommended electrolyte supply in nutrition therapy for severe malnutrition (supply of electrolytes should be provided under ionogram control)

<table>
<thead>
<tr>
<th>Electrolytes</th>
<th>Dosage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium*</td>
<td>during the first 8–12 hours of therapy — 7 mmol kg(^{-1})</td>
</tr>
<tr>
<td></td>
<td>after 12 h — the dose can be repeated or modified according to sodium concentration of serum and urine</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.2–0.3 mmol kg(^{-1}) 8h(^{-1}) — lack of diuresis</td>
</tr>
<tr>
<td></td>
<td>0.5–1.0 mmol kg(^{-1}) 8h(^{-1}) — after initial hydration— at diuresis present; the dose should be modified according to serum concentration of potassium</td>
</tr>
<tr>
<td></td>
<td>0.7–0.8 mmol kg(^{-1}) for the next 12 h</td>
</tr>
<tr>
<td>Phosphates</td>
<td>0.8–1.2 mmol kg(^{-1}) day(^{-1}) in infants (treatment day 1)</td>
</tr>
<tr>
<td></td>
<td>0.4–0.8 mmol kg(^{-1}) day(^{-1}) in the post-infancy period (treatment day 1), on successive days–doses dependent on serum concentration</td>
</tr>
<tr>
<td>Calcium**</td>
<td>1 mmol kg(^{-1}) day(^{-1}) at the concentration below the norm</td>
</tr>
<tr>
<td></td>
<td>0.6–0.8 mmol kg(^{-1}) day(^{-1}) at normal or slightly reduced concentration in infants</td>
</tr>
<tr>
<td></td>
<td>0.2–0.4 mmol kg(^{-1}) day(^{-1}) at normal or slightly reduced concentration in the post-infancy period</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.4–0.8 mmol kg(^{-1}) day(^{-1})</td>
</tr>
</tbody>
</table>

* Sodium supply has to be added up from all fluids used (1 mL NaHCO\(_3\) = 1.00 mmol Na; 1 mL 0.9% NaCl — 0.33 mmol Na; 1 mL 10% NaCl — 1.70 mmol Na)

** Dosing depends on the baseline concentration

The management of RS is based on the generally available guidelines and recommendations [77–80].

SUMMARY

The guidelines for nutritional therapy in paediatric intensive care facilitate the choice of treatment methods and suggest the most modern and safe management options adjusted to the patients’ clinical situations. The Polish Society for Clinical Nutrition, the Section of Paediatric Anaesthesia and Intensive Therapy of the Polish Society of Anaesthesiology and Intensive Therapy and Polish Society of Neonatology cooperated in formulating “the principles” to improve the quality of therapy in severely ill children. Our “principles” are complementary to the 2011 recommendations regarding enteral nutrition in adults requiring treatment in intensive care units [81].

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References

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