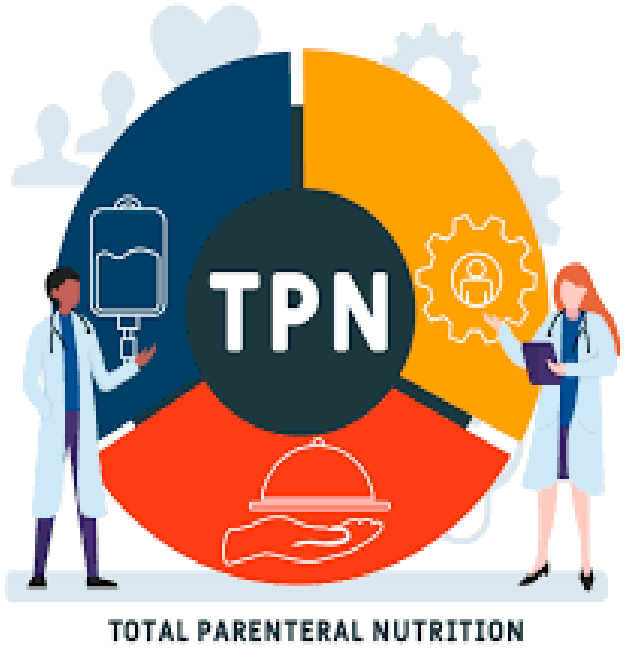
# Parenteral nutrition in pediatric critical care

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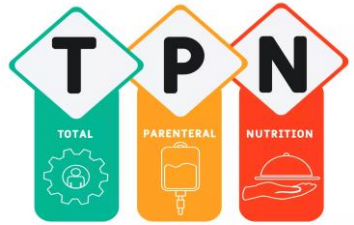
# Indications for PN in children

| Indications | |
|---|---|
| Partially functioning gastrointestinal tract | ▪ Cannot meet nutritional requirements after maximizing enteral support<br>▪ Burns<br>▪ Multi-organ failure<br>▪ Malabsorption (Short bowel syndrome , Chronic intractable diarrhea , Congenital small bowel malabsorptive syndromes such as congenital chloride diarrhea, tufting enteropathy, or microvillus inclusion disease , Pseudo-obstruction)<br>▪ Severe malnutrition with hypoproteinemia and bowel edema |
| Nonfunctional gastrointestinal tract | ▪ Paralytic ileus<br>▪ Small bowel ischemia<br>▪ Necrotizing enterocolitis<br>▪ Gastrointestinal surgery (Gastroschisis, omphalocele, gastrointestinal atresias (parenteral nutrition is indicated until the enteral route is functional and accessible) |

- **Observational studies have found that malnourishment and underfeeding due to macronutrient deficits are associated with delayed wound healing, reduced immune response, malabsorption, bacterial overgrowth and increased morbidity and mortality**

- **Overfeeding in its turn may lead to intestinal failure associated liver disease (IFALD), hyperglycemia and increased respiratory burden due to the increase in $CO_2$ production present by lipogenesis from carbohydrates**

**The role of parenteral nutrition in paediatric critical care, and its consequences on recovery, Renate D. Eveleens , Pediatric Medicine , Vol 3 (November 2020)**



**To understand the optimal role of PN during pediatric critical illness, the following two fundamental questions should be answered:**

- **What is the optimal timing of PN?**
- **What is the optimal dose and composition of PN?**

**The acute stress response to critical illness can be divided into three different phases:**

- **Acute** (characterized by requirement of (escalating) vital organ support. Phase when the patient requires vital organ support (sedation, mechanical ventilation, vasopressors, fluid resuscitation)

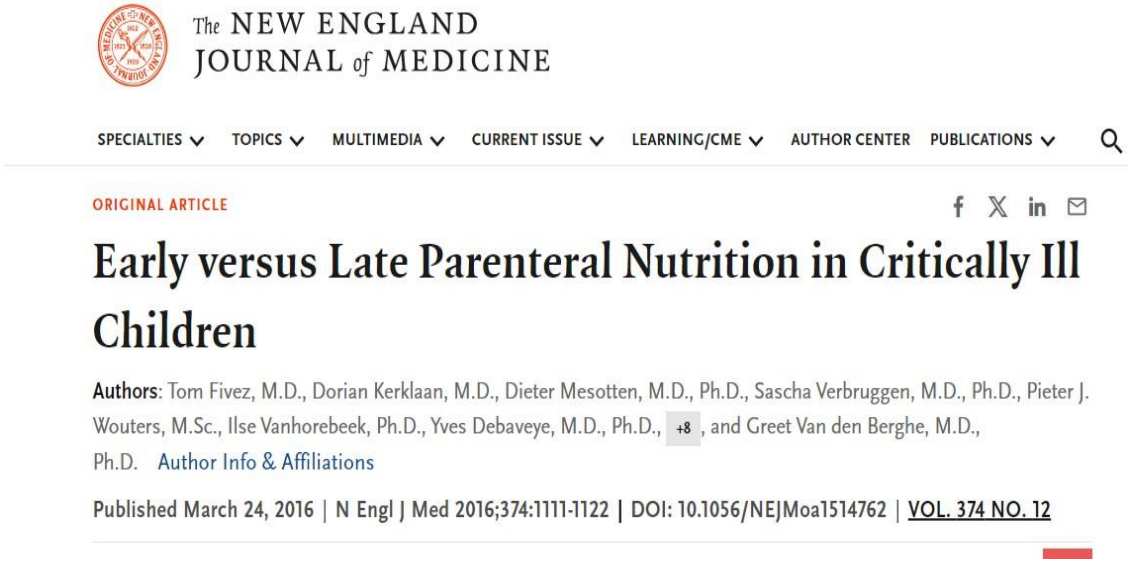
- **Stable** (Stabilization or weaning of vital organ support, while the different aspects of the stress response are not (completely) resolved)

- **Recovery** (Clinical mobilization with normalization of neuro-endocrine, immunologic and metabolic alterations, characterized by a patient who is mobilizing)

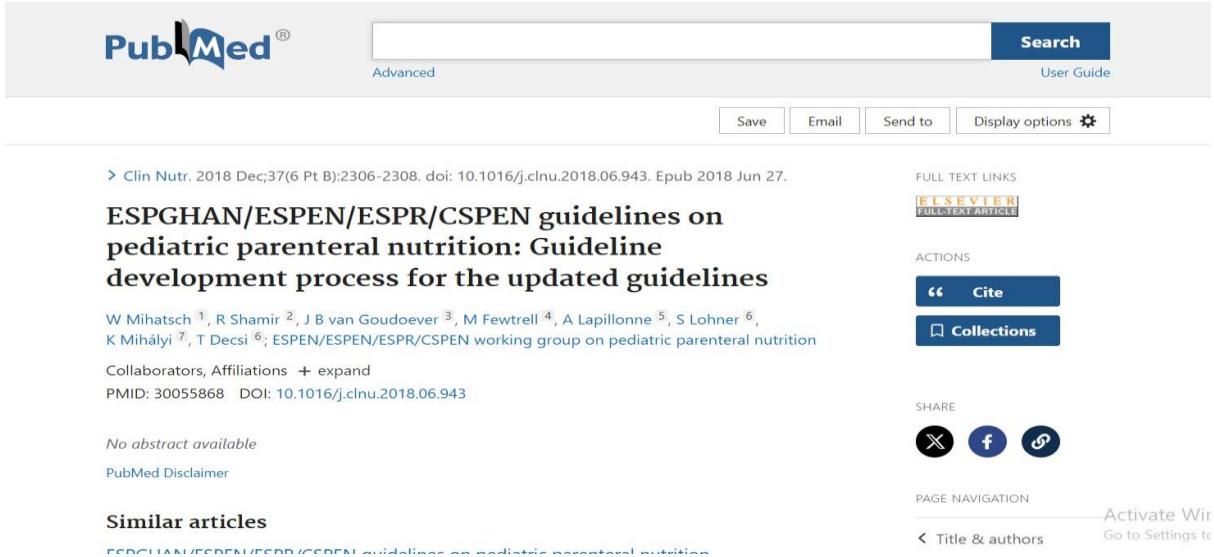
- **Nutritional goals differ throughout the different phases of the disease**

# Timing of PN : 1) Acute phase

- **This large multicentre RCT involving 1,440 critically ill children showed that withholding supplemental PN for 7 days (Late PN), as compared with initiating PN within 24 hours after admission (early PN) , improved short-term outcome such as new acquired infections , the time on a ventilator and the length of stay in the PICU and the hospital**



**(ESPGHAN/ESPEN/ESPR/CSPEN) have updated their guidelines and recommend considering withholding parenteral macronutrients during the first week of pediatric critical illness, while continuing to provide micronutrients**



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Clin Nutr. 2018 Dec;37(6 Pt B):2306-2308. doi: 10.1016/j.clnu.2018.06.943. Epub 2018 Jun 27.

ESPGHAN/ESPEN/ESPR/CSPEN guidelines on pediatric parenteral nutrition: Guideline development process for the updated guidelines

W Mihatsch [1], R Shamir [2], J B van Goudoever [3], M Fewtrell [4], A Lapillonne [5], S Lohner [6], K Mihályi [7], T Decsi [6]; ESPEN/ESPEN/ESPR/CSPEN working group on pediatric parenteral nutrition

Collaborators, Affiliations + expand

PMID: 30055868 DOI: 10.1016/j.clnu.2018.06.943

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## 2) Stable and recovery phase

- **During the stable and recovery phases, PN should focus on allowing normal or even catch up growth and successful provision is usually monitored through anthropometric measurements, muscle strength and function and tissue repair (e.g., wound healing)**

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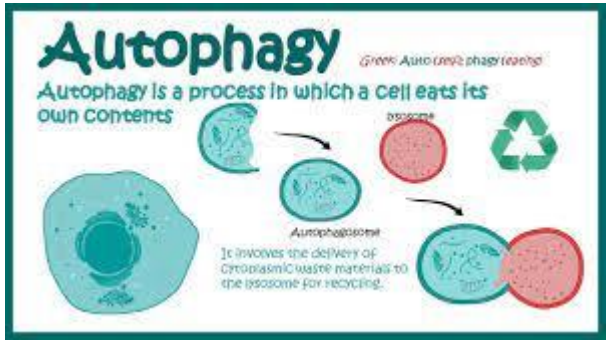
## Autophagy

- **The leading explanation behind the counter-intuitive finding of the PEPaNIC RCT is the consequence of early and high nutritional intake to suppress the fasting response, which induces ketosis and activates autophagy**

- **Autophagy is an evolutionary conserved intracellular degradation process and it is crucial for maintaining cellular integrity and function**

- **This becomes even more important during acute stress, as children suffer from extensive cell and organ damage, leading to organ failure and muscle weakness**



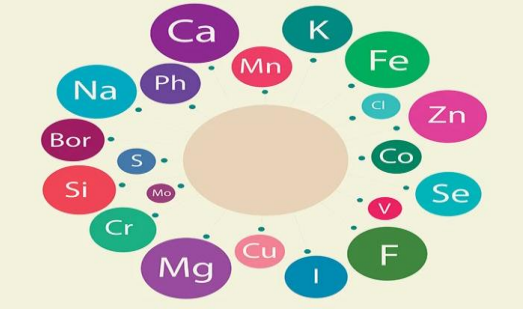
- **This process was confirmed by a study in adults establishing that early PN did not prevent muscle wasting and even increased adipose tissue deposition in the muscle**

- **These studies open perspectives for therapies that activate autophagy during critical illness**

- **Although still controversial, possible endeavors can lie within pharmacological agents inducing autophagy**

- **For instance, an animal experiment found that stimulation of autophagy in the kidney with rapamycin correlated with protection of renal function**

## Parenteral micronutrients




- **Micronutrients, consisting of vitamins, trace elements and electrolytes, are considered to have an important role in body metabolism, immune response and tissue function, and are therefore essential during critical illness**

- **While the current guidelines on PN in critically ill children recommended to consider withholding PN for the first week of admission, they advise to maintain supplementation of micronutrients during this time window**

- **The ESPGHAN/ESPEN guidelines recommend to provide micronutrients daily because this prohibits adverse reactions from transient high levels, except from vitamin K which can be provided weekly without harmful side effects**

# Dose of parenteral macronutrients

## ❑ Energy

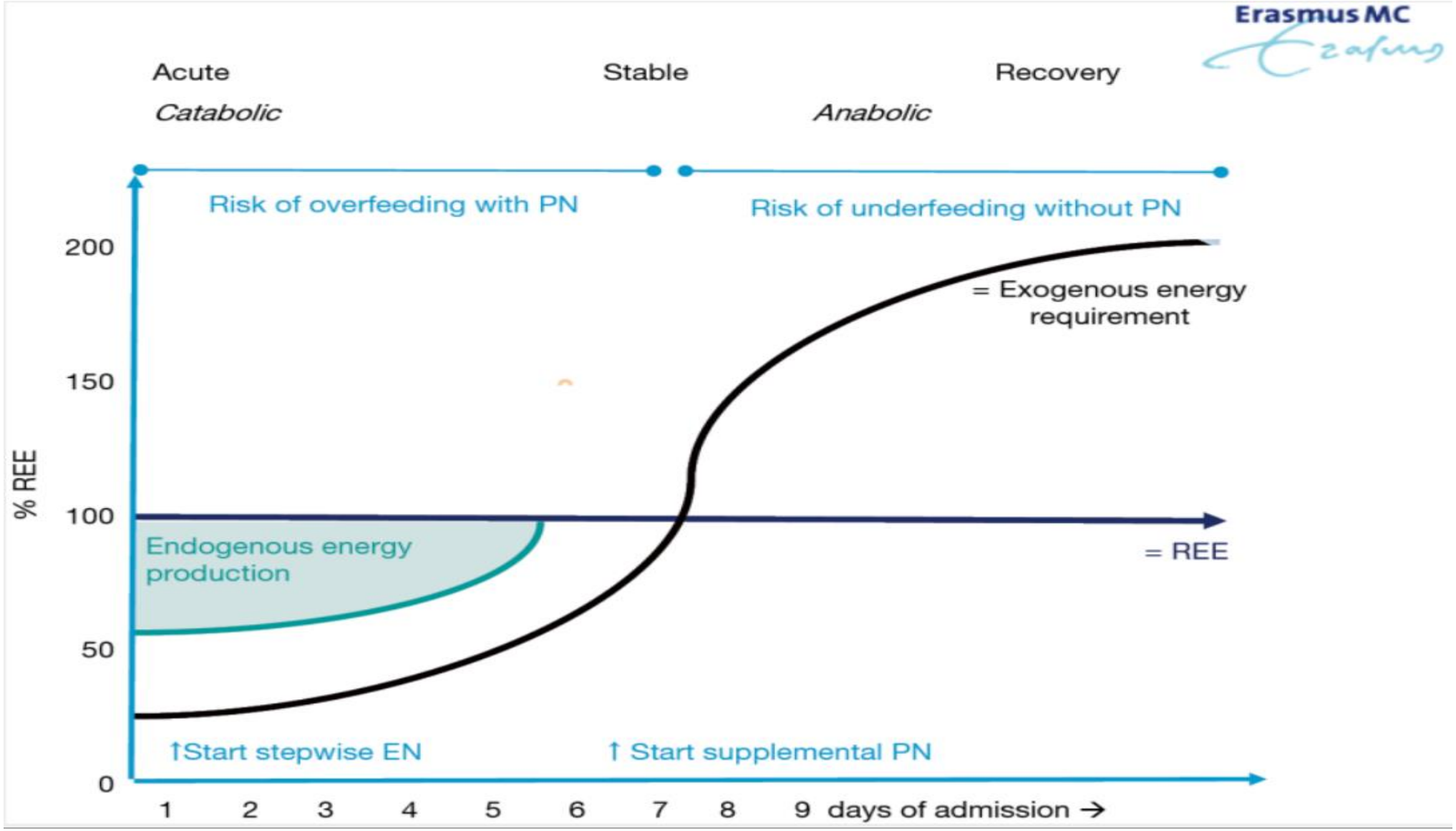
- **The actual energy requirement of the child will depend on many factors including medication, need for mechanical ventilation, temperature, (lack of) physical activity and on the phase of the disease**

- **During the acute phase, endogenous energy production accounts for a substantial proportion of energy requirement (up to 75%) irrespective of the energy provision via exogenous source**
- **Therefore, the energy requirement from EN or PN can be much lower than the calculated or measured resting energy expenditure (REE) (*Figure 1*)**

- **During the recovery phase the focus shifts from acute interventions to optimizing activity, tissue repair and physical and neurocognitive development. There is an increasing demand in energy during this phase to allow normal development of the child and even to catch up growth**

## *Figure 1* : Dynamic energy need during the different phases of critical illness

**REE, resting energy expenditure**



# Energy

- **Energy requirements vary with age, weight, and numerous other individual patient factors including fever, activity level, underlying disease, and ambient temperature**

- **Guidelines from the American Society for Parenteral and Enteral Nutrition outline the following age- and weight-based energy requirements**

- **Term infants <6 months – 85 to 105 kcal/kg/day**
- **≥6 to 12 months – 80 to 100 kcal/kg/day**
- **≥1 to 7 years – 75 to 90 kcal/kg/day**
- **≥7 to 12 years – 50 to 75 kcal/kg/day**
- **≥12 to 18 years – 30 to 50 kcal/kg/day**

| Increased energy requirements | Decreased energy requirements |
|---|---|
| Trauma | Immobility |
| Surgery | Mechanical ventilation |
| Sepsis | Extracorporeal membrane oxygenation (ECMO) |
| Burns | Medical sedation/paralysis |
| Tumors | |
| Seizures | |
| Hypertonia | |
| Spinal cord injury | |

- A number of alternative methods can be used to estimate basal energy needs such as the Harris-Benedict Equation or the Schofield Equation
- These methods are estimates more appropriate for adults For children and adolescents, they must be adjusted based on weight and clinical status

- Indirect calorimetry

Schofield Equation

Males

SCHOFIELD EQUATION: BASAL METABOLIC RATE

Weight (kg)

Height (cm)

Calculate Clear Form

<3 years

3-10 years

10-18 years

18-30 years

Schofield Equation for Males

| Age | W=weight in kg; H=height in cm. |
|---|---|
| < 3 years | 0.167W + 15.174H - 617.6 |
| 3-10 years | 19.59W + 1.303H + 414.9 |
| 10-18 years | 16.25W + 1.372H + 515.5 |
| 18-30 years | 15.057W - 0.1H + 705.8 |

Females

SCHOFIELD EQUATION: BASAL METABOLIC RATE

Weight (kg)

Height (cm)

Calculate Clear Form

<3 years

3-10 years

10-18 years

18-30 years

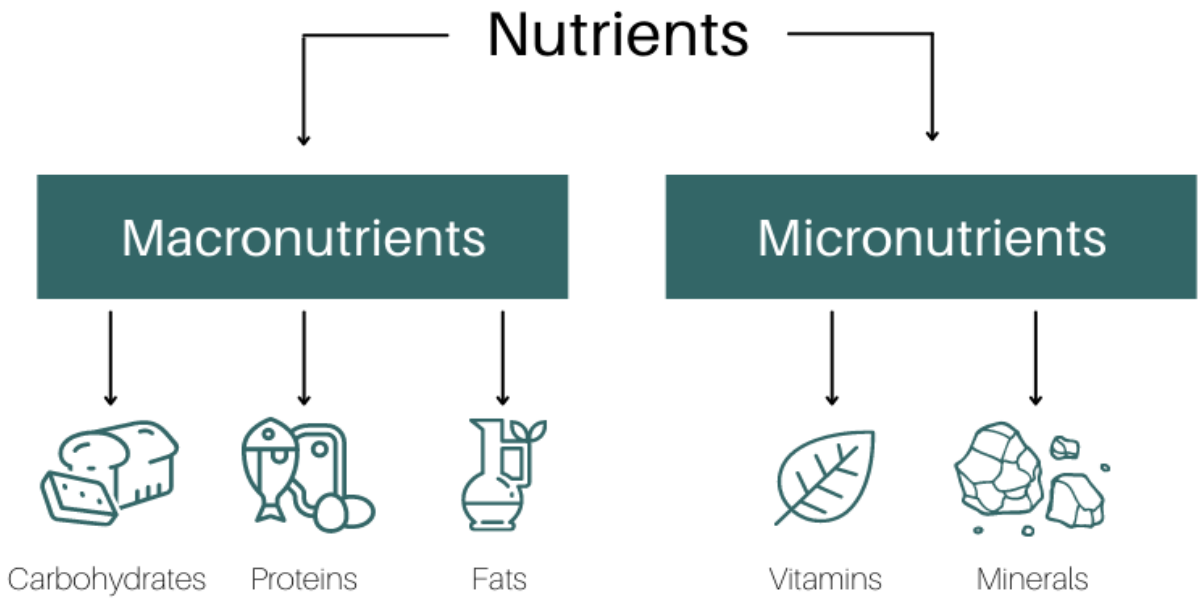
Schofield Equation for Females

## Parenteral macronutrients

- ✓Carbohydrates
- ✓Amino acids
- ✓Lipids

## Parenteral micronutrients

- ✓Vitamins
- ✓Trace elements
- ✓Electrolytes



# Carbohydrates

- Carbohydrates or glucose are one of the main and preferred energy sources during health and during critical illness

- Plasma glucose levels are a balance between glucose utilization and exogenous glucose intake and endogenous glucose production (glycogenolysis and gluconeogenesis)

- During critical illness glucose metabolism is affected due to insulin resistance and β-cell dysfunction, which increases the risk of developing hyperglycaemia

- Due to the restricted glucose utilisation in the acute phase lower doses are advised during this acute phase compared to the stable phase

# Consequences of overfeeding with glucose

- ✓Excessive glucose intake should be avoided because it may be responsible for hyperglycemia, causes increased lipogenesis and fat tissue deposition together with subsequent liver steatosis and enhanced production of VLDL triglycerides by the liver, and may cause increased $CO_2$ production and minute ventilation , hyperosmolarity , and osmotic diuresis

- The glucose concentration must be carefully advanced in a malnourished patient to reduce the risk of refeeding syndrome, and serum phosphorus, potassium, calcium, and magnesium should be closely monitored

- Glucose intake does not lower protein catabolism in the acute phase of critical illness

## Recommended doses per phase and weight are presented for children from 28 days to 18 years

| | Acute phase | Stable phase | Recovery phase |
|---|---|---|---|
| 28 d–10 kg | 2–4 (2.9–5.8) | 4–6 (5.8–8.6) | 6–10 (8.6–14) |
| 11–30 kg | 1.5–2.5 (3.6–2.9) | 2–4 (2.8–5.8) | 3–6 (4.3–8.6) |
| 31–45 kg | 1–1.5 (1.4–2.2) | 1.5–3 (2.2–4.3) | 3–4 (4.3–5.8) |
| > 45 kg | 0.5–1 (0.7–1.4) | 1–2(1.4–2.9) | 2–3 (2.9–4.3) |

Acute phase = resuscitation phase when the patient requires vital organ support (sedation, mechanical ventilation, vasopressors, fluid resuscitation).
Stable phase = patient is stable on, or can be weaned, from this vital support.
Recovery phase = patient who is mobilizing.



## The units are mg/kg/min (g/kg per day)

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✓**It is important to maintain normal plasma levels of glucose as hyper and hypoglycaemia are both associated with impaired outcomes and carbohydrate tolerance should be controlled through glycemic monitoring**

**(<8 mmol/L in critically ill; <10 mmol/L sepsis or traumatic brain injury)**

- **Hyperglycaemia >8 mmol/L (145 mg/dL) should be avoided in pediatric ICU patients because of increased morbidity and mortality**

- **In PICU, repetitive blood glucose levels >10 mmol/L (180 mg/dL) should be treated with continuous insulin infusion**

➢**Repetitive and/or prolonged hypoglycaemia ≤2.5 mmol/L (45 mg/dL) should be avoided in all ICU patients**

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# Carbohydrates

- **Glucose is the only source of carbohydrate in PN and provides 40 to 60 percent of total calories, or 60 to 75 percent of nonprotein calories**

- **It is provided in a monohydrous form (dextrose monohydrate), which has a caloric concentration of 3.4 kcal/g , somewhat less than the concentration of carbohydrate calories in food (4 kcal/g)**

## Grams glucose = Energy (kcals) from carbohydrates ÷ 3.4 kcal/g

- **Concentrations greater than 12.5 percent must not be used in a peripheral vein, because the high osmolality can damage veins**

- **Central lines can accommodate a maximum concentration of 25 percent glucose**

- **Adequate quantities of glucose are important because at glucose infusions <2 mg/kg/min, body fat is mobilized for energy and ketosis occurs**

# Amino acids

**Amino acid dose requirement is lower via PN than EN due to the bypass of the utilization by the gastro-intestinal tract**

## The ESPGHAN/ESPEN/ESPR/CPNN guidelines

- **Withholding parenteral nutrition, including amino acids, for 1 week in critically ill children while providing micronutrients can be considered**

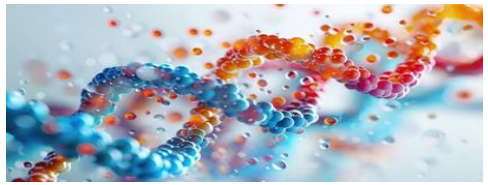
- ✓ **A secondary analysis from the PEPaNIC study showed that during the acute phase higher doses of parenteral administered amino acids was negatively associated with PICU length of stay, new acquired infections and duration of mechanical ventilation**

**After the acute phase muscle wasting often continues due to immobilization and undernourishment**

**Therefore, the ESPGHAN/ESPEN guidelines advise from day 8 onwards to provide a minimum amino acid intake of 1.0 g/kg/d should be administered in stable infants and children from 1 month to 3 years to avoid a negative nitrogen balance**

- **In stable children aged 3-12 years an amino acid intake of 1.0- 2.0 g/kg per day may be considered**

**ESPGHAN/ESPEN/ESPR/CSPEN guidelines on pediatric parenteral nutrition: Amino acids**



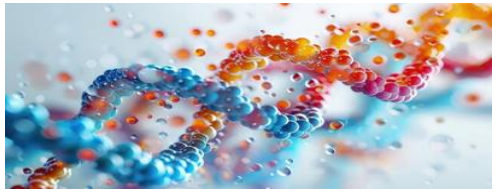
# Parenteral amino acid supply considered adequate for stable patients (g/kg/d)

**Table 3**
Parenteral amino acid supply considered adequate for stable patients (g/kg/d).

| | |
|---|---|
| Preterm infants | |
| First day of life | 1.5–2.5 |
| From day 2 onwards | 2.5–3.5 |
| Term infants[a] | 1.5–3.0 |
| 2nd month–3rd year[a] | –2.5 |
| 3rd–18th year[a] | –2.0 |

[a] Critically ill patients may benefit from withholding parenteral nutrition while providing micronutrients during the first week of hospital admission.

ESPGHAN/ESPEN/ESPR/CSPEN guidelines on pediatric parenteral nutrition: Amino acids



- **There is little evidence regarding specific amino acids administration during critical illness**

- **Both essential and nonessential amino acids are provided in standard solutions**

- **“Pediatric" amino acid solutions contain a higher concentration of essential amino acids and lower quantities of nonessential amino acids, so that the infants' plasma amino acid patterns mimic those of healthy, breastfed neonates**

- **Whether these solutions are beneficial to older infants and children is not known, but there is some evidence that they are associated with a decreased risk of cholestatic liver disease**

- **Cysteine – Tyrosine - Taurine**

- **Methionine – Phenylalanine**

## Cysteine

- **precursor to the antioxidant glutathione**
- ***N*-Acetylcysteine is a derivative of cysteine wherein an acetyl group is attached to the nitrogen atom**

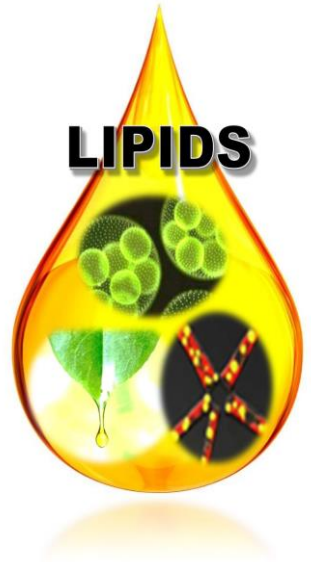
# Amino acid solution for parenteral nutrition of preterm & term newborns, infants and young children

- ✓Higher concentration of essential amino acids and lower quantities of nonessential amino acids
- ✓Taurine , Cysteine & tyrosine that are not synthesized in sufficient amounts
- ✓Low contents of methionine & phenylalanine due to their limited degradation rate

## Protein needs also depend on severity of illness

- Stress factors such as , thermal injury, surgery, trauma, and stomal losses increase protein requirements
- Urinary excretion of nitrogen related to steroids, diuretics, or primary kidney disease also can increase the protein requirement
- Protein may need to be reduced in conditions such as kidney disease, hepatic failure, and inborn errors of metabolism

# Lipids




- **Parenteral lipid provision should be a fundamental part of PN in critically ill children during stable and recovery phase**
- **Normally, lipid intake accounts for 25–50% of the non-protein caloric intake in parenterally fed patients**
- **In children, parenteral lipid intake should be limited to a maximum of 3 g/kg/day**

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- **Intravenous lipid emulsions (ILEs) are an indispensable part of PN as a noncarbohydrate source of energy delivered as an iso-osmolar solution in a low volume**

**(2.0 kcal/mL with 20% ILEs, or 1.1 kcal/mL with 10% ILEs due to the higher relative content of glycerol)**

- **Lipids provide essential fatty acids (EFAs) and help with the delivery of the lipid soluble vitamins A, D, E, and K . ( EFAs; primarily linoleic and linolenic acids)**

- **Pure soybean oil (SO) based ILEs (SO ILEs) have been widely used for several decades in adults, children, and neonates. More recent ILEs were also vegetable oil-based ILEs until the newest ILEs with fish oil (FO) became available**

## Formulations – Several types of intravenous lipid emulsions are available

### Soybean oil-based lipid emulsion (eg, Intralipid)


- ✓This is the most common form of ILE used in the United States and most other countries
- ✓It is are rich in omega-6 fatty acids, which have the advantage of supplying EFAs
- ✓However, accumulating evidence suggests that soy-based ILE also may be associated with increased inflammation and liver injury, especially in infants on total parenteral nutrition (TPN), in a pattern known as intestinal failure-associated liver disease (IFALD) or PN-associated liver disease

# Fish oil-based lipid emulsion (Omegaven)

- ✓This type of ILE contains **omega-3 fatty acids**, which have **anti-inflammatory properties**

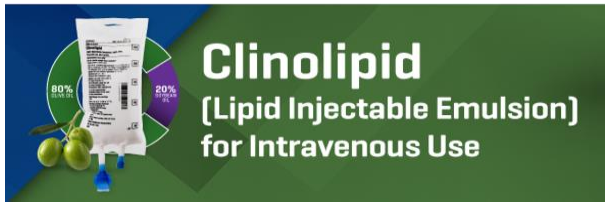

- ✓Preliminary evidence suggests that fish oil-based ILE may be **useful for treating infants with IFALD**
- ✓However, fish oil-based ILE provides **minimal amounts of EFA**, so patients are at risk for developing EFA deficiency and should be monitored

## Soybean, medium-chain triglyceride, olive, and fish oil lipid emulsion (SMOFLipid)

- ✓**This composite ILE was developed in an effort to delay the progression of IFALD, but evidence for efficacy is mixed and there are risks for EFA deficiency**


## Olive and soybean oil-based lipid emulsion (Clinolipid)

- ✓**This mixture of olive and soy oils (4:1) was approved in the United States for pediatric use in 2024 after randomized trials in 179 children, including 140 term and preterm neonates . Growth and biochemical parameters were similar to the comparator (a soy-based lipid emulsion)**
- ✓**Because the median treatment was 15 days or less, data are insufficient to determine the risk of EFA deficiency, so monitoring is advised**



# Monitoring

- **The provided dosage of lipids should not exceed the capacity for lipid clearance and should be lowered in case of hyperlipidaemia**

- **Reduction of the dosage of ILEs can be considered if serum or plasma triglyceride concentrations during infusion > 3 mmol/L (265 mg/dL) in infants or 4.5 mmol/L (400 mg/dL) in older children**

- **ESPGHAN/ESPEN/ESPR/CSPEN guidelines on pediatric parenteral nutrition: Lipids**

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# Carnitine

- **Carnitine is not present in PN solutions, yet it is necessary for transport and metabolism of long-chain fatty acids**

- **Carnitine supplementation may be considered in pediatric patients expected to receive PN for more than 4 weeks or in premature infants on an individual basis (dose of 2 to 5 mg/kg/day)**


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# Prevention of intestinal failure associated liver disease (IFALD)

- **In preterm infants, newborns and older children on short term PN, pure soybean oil (SO) ILEs may provide less balanced nutrition than composite ILEs**

- **For PN lasting longer than a few days, pure SO ILEs should no longer be used and composite ILEs with or without fish oil (FO) should be the first-choice treatment**

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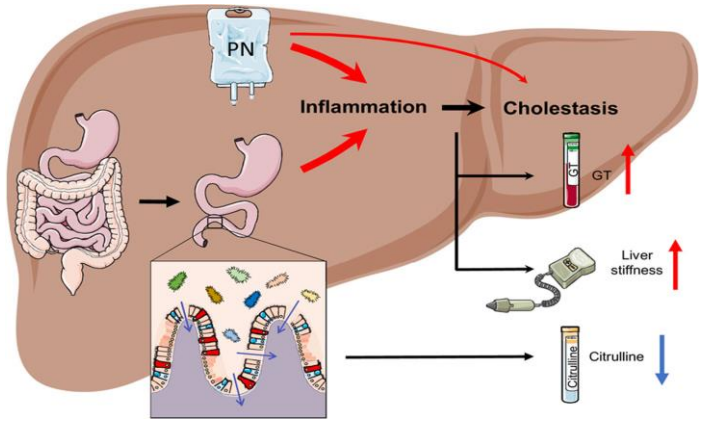
# IFALD

- **Intestinal failure associated liver disease (IFALD), also called parenteral nutrition associated liver disease (PNALD) or parenteral nutrition related cholestasis or reflects an heterogeneous liver injury consisting of cholestasis , steatosis, fibrosis and even cirrhosis**
- **The most common figure in pediatric patients is cholestasis**

## Patients at highest risk include :

➢ **Premature infants, infants with long term bowel rest, loss of entero-hepatic cycle (ileal resection, enterostomy ) or repeated sepsis, and infants with short bowel syndrome**

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# Management of intestinal failure associated liver disease( IFALD)

- As part of measures to reverse IFALD in pediatric patients, a discontinuation of SO ILE, a reduction of other ILE dosage and/or the use of composite ILE with FO, should be considered along with the treatment and management of other risk factors

- The use of pure FO ILE is not recommended for general use in pediatric patients but may be used for short-term rescue treatment in patients with progression to severe IFALD, based on case reports

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- A rare syndrome of clinical decompensation (including acute respiratory distress, metabolic acidosis, and death) has been associated with rapid ILE infusions, especially in infants

- This risk is minimized by gradual advancement to target rates and intermittent monitoring of triglycerides

- ILE infusion should be started slowly . Care should be taken to avoid more rapid infusions, even for a few hours

# Electrolytes

- **Electrolytes are essential and must be provided in PN**
- **Requirements for sodium, potassium, calcium, magnesium and phosphorus are included as a separate component of the PN prescription**
- **Calcium to phosphorus ratio in PN should be close to a 1:1 molar ratio**

**Daily electrolyte and mineral requirements for parenteral nutrition in pediatric patients**

| Electrolyte | Preterm neonates | Infants/children | Adolescent |
|---|---|---|---|
| Sodium | 2 to 5 mEq/kg (2 to 5 mmol/kg) | 2 to 5 mEq/kg (2 to 5 mmol/kg) | 1 to 2 mEq/kg (1 to 2 mmol/kg) |
| Potassium | 2 to 4 mEq/kg (2 to 4 mmol/kg) | 2 to 4 mEq/kg (2 to 4 mmol/kg) | 1 to 2 mEq/kg (1 to 2 mmol/kg) |
| Calcium* | 2 to 4 mEq/kg (1 to 2 mmol/kg)¶ | 0.5 to 4 mEq/kg (0.25 to 2 mmol/kg)¶ | 10 to 20 mEq (5 to 10 mmol)¶ |
| Phosphorus* | 1 to 2 mmol/kg | 0.5 to 2 mmol/kg | 10 to 40 mmol |
| Magnesium | 0.3 to 0.5 mEq/kg (0.15 to 0.25 mmol/kg) | 0.3 to 0.5 mEq/kg (0.15 to 0.25 mmol/kg) | 10 to 30 mEq (5 to 15 mmol) |
| Acetate$^{\Delta}$ | As needed | As needed | As needed |
| Chloride$^{\Delta}$ | As needed | As needed | As needed |

# Iron and trace minerals

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**Table 1**
Estimated parenteral requirements of iron and trace minerals (μg/kg/d).

| Mineral | Preterm | 0–3 mo | 3–12 mo | 1–18 y | Max dose |
|---|---|---|---|---|---|
| Iron | 200–250 | 50–100 | 50–100 | 50–100 | 5 mg/d |
| Zinc | 400–500 | 250 | 100 | 50 | 5 mg/d |
| Copper | 40 | 20 | 20 | 20 | 0,5 mg/d |
| Iodine | 1–10 | 1 | 1 | 1 | |
| Selenium | 7 | 2–3 | 2–3 | 2–3 | 100 μg/d |
| Manganese | ≤1 | ≤1 | ≤1 | ≤1 | 50 μg/d |
| Molybdenum | 1 | 0.25 | 0.25 | 0.25 | 5 μg/d |
| Chromium | – | – | – | – | 5 μg/d |

# Iron


- In patients receiving PN, iron supplementation should preferentially be given enterally rather than parenterally, if tolerated
- Routine provision of iron in parenteral nutrition should not be given for short term PN (<3 weeks)
- Patients receiving long-term PN, who cannot maintain adequate iron status using enteral iron supplements, should receive parenteral iron supplementation
- Parenteral iron can be given daily added to PN solution or as intermittent, separate infusions

- ESPGHAN/ESPEN/ESPR/CSPEN guidelines on pediatric parenteral nutrition: Iron and trace minerals

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- **If given daily, and assuming no enteral iron supplementation, routine parenteral iron supplements should be given at a dose of 200 - 250 mg/kg/day in preterm infants and 50 - 100 mg/kg per day up to a maximum dose of 5 mg/day in infants and children**

- **Iron status (at least ferritin and hemoglobin) should be monitored regularly in patients on long-term PN in order to prevent iron deficiency and iron overload**


## Copper

- Plasma Cu and ceruloplasmin should be monitored in patients on long term PN, especially if they develop PN associated liver disease or if they have high gastrointestinal fluid losses


## Zinc

- Zn status (serum Zn, alkaline phosphatase) should be periodically monitored in patients on long-term PN and more often in those with high gastrointestinal fluid output (usually ileostomy losses or diarrhea), who may have significantly higher Zn requirements

## Iodine

- **Patients on long-term PN should be regularly monitored for iodine status by measuring at least thyroid hormone concentrations**

➢ **Iodine is generally not included in PN; it is not provided in most trace element solutions or added to the PN**

➢ **If serum TSH is elevated, then iodine status can be evaluated by measurement of either 24-hour urinary iodine or spot urinary iodine (and creatinine)**

## Manganese

- **Blood Mn concentrations should be monitored regularly in patients on long term PN**
- **If the patient develops cholestasis, blood concentrations of Mn should be determined and parenteral Mn should discontinued**

➢ **Manganese can accumulate in patients with liver disease because it is normally excreted in bile**

## Selenium

- **Plasma Se should be monitored regularly in long term PN and in patients with renal failure**

➢ **Selenium is not included in some standard packages of trace elements, so patients on long-term PN ( for two months or more) need a trace element preparation that includes selenium**

## Chromium

- **Cr contaminates PN solutions to a degree that satisfies requirements; therefore, additional supplementation of Cr is considered unnecessary and Cr intake from PN should not exceed 5 mg/day**

# Vitamins

- ✓Infants and children receiving PN should receive parenteral vitamins
- ✓Whenever possible water and lipid soluble vitamins should be added to the lipid emulsion or a mixture containing lipids to increase vitamin stability
- ✓Vitamins should be administered daily, if possible
- ✓Lipid-soluble vitamins should be given simultaneously to lipid emulsions; an exception is vitamin K, which can be given weekly. Intermittent substitution twice or three times a week has a hypothetical risk of adverse effects from transient high levels

# Recommended doses for parenteral supply of fat soluble and water soluble vitamins for preterm infants, infants and children

**Table 1**
Recommended doses for parenteral supply of fat soluble and water soluble vitamins for preterm infants, infants and children.

| | Preterm infants | Infants – 12 months | Children and adolescents 1–18 years |
|---|---|---|---|
| Vitamin A[a] | 700–1500 IU/kg/d (227–455 ug/kg/d) | 150–300 ug/kg/d or 2300 IU/d (697 ug/d) | 150 ug/d |
| Vitamin D[b] | 200–1000 IU/d or 80–400 IU/kg/d | 400 IU/d or 40–150 IU/kg/d | 400–600 IU/d |
| Vitamin E[c] | 2.8–3.5 mg/kg/d or 2.8–3.5 IU/kg/d | 2.8–3.5 mg/kg/d or 2.8–3.5 IU/kg/d | 11 mg/d or 11 IU/d |
| Vitamin K | 10 ug/kg/d (recommended, but currently not possible)[d] | 10 ug/kg/d (recommended, but currently not possible)[d] | 200 ug/d |
| Vitamin C | 15–25 mg/kg/d | 15–25 mg/kg/d | 80 mg/d |
| Thiamine | 0.35–0.50 mg/kg/d | 0.35–0.50 mg/kg/d | 1.2 mg/d |
| Riboflavin | 0.15–0.2 mg/kg/d | 0.15–0.2 mg/kg/d | 1.4 mg/d |
| Pyridoxine | 0.15–0.2 mg/kg/d | 0.15–0.2 mg/kg/d | 1.0 mg/d |
| Niacin | 4–6.8 mg/kg/d | 4–6.8 mg/kg/d | 17 mg/d |
| Vitamin B12 | 0.3 ug/kg/d | 0.3 ug/kg/d | 1 ug/d |
| Pantothenic acid | 2.5 mg/kg/d | 2.5 mg/kg/d | 5 mg/d |
| Biotin | 5-8 ug/kg/d | 5-8 ug/kg/d | 20 ug/d |
| Folic acid | 56 µg/kg/d | 56 µg/kg/d | 140 µg/d |

**ESPGHAN/ESPEN/ESPR/CSPEN guidelines on pediatric parenteral nutrition: Vitamins**

ESPGHAN
European Society for Paediatric Gastroenterology, Hepatology and Nutrition

- **Pediatric patients receiving long-term PN should be monitored periodically for vitamin D deficiency**

- **In patients with 25(OH) vitamin D serum concentrations < 50 nmol/L, additional supplementation with vitamin D should be provided**.

## Aluminum is a contaminant of PN solutions

- Since crystalline amino acids have replaced protein hydrolysates, aluminum contamination has decreased. However, it remains a concern.

- Some components of PN including calcium gluconate and phosphate salts, still include significant amounts of aluminum

- There is no consensus to define "safe" levels of parenteral aluminum intake

- Intakes of less than 4 to 5 micrograms/kg/day were recommended by the US Food and Drug Administration in 2004

## Central and peripheral venous access

- PN can be administered through a peripheral or a central vein
- The choice of central versus peripheral venous access depends on the anticipated duration of the nutrition therapy

- The maximum osmolality that can be delivered via a peripheral vein is 900 mOsm/L, and this constraint limits the amount of nutrients that can be provided by a peripheral IV

- Given this osmolality restriction, it is usually impossible to supply all of the required nutrients with peripheral PN, and central venous access will be required to meet the child's full nutritional needs
- Therefore, if an infant or child is likely to need parenteral nutritional support for more than two weeks, a central venous catheter should be placed to meet the nutrition needs of the patient

# When extra caution should be used

- PN, whether provided peripherally or centrally, should only be used in patients who are hemodynamically stable and are able to tolerate the necessary fluid
- PN should be used with particular caution for children with electrolyte imbalance, renal or hepatic compromise, metabolic acidosis, or alkalosis
- Acid-base and electrolyte abnormalities should be corrected prior to starting PN, or corrected by infusions through a separate intravenous line

# Take home message

**Withholding parenteral macronutrients during the first week of pediatric critical illness, while continuing to provide micronutrients**