Nutrition Management in Pediatric Traumatic Brain Injury: An Exploration of Knowledge Gaps and Challenges

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Abstract

Traumatic brain injury (TBI) stands as the leading cause of morbidity and mortality among children, as evidenced by the most contemporary statistics. Undernutrition in pediatric TBI (PTBI) leads to increased mortality, heightened infectious complications, and more severe neurological consequences. Therefore, timely and effective nutritional therapy is crucial in managing PTBI to improve patient prognosis and outcomes. Limited investigations have been conducted on the nutritional requirements specific to these patients and management often relies on data from adults with TBI for guidance. We have meticulously searched different databases to compile a broad range of the most up-to-date clinical research. This review analyses the challenges associated with providing nutritional support to children with TBI and provides a clearer understanding of the current evidence-based recommendations for optimal nutritional therapy. The review primarily focuses on recommendations and suggestions for energy requirements, nutritional assessment, initiation of nutrition, various feeding methods offered, identification of malnutrition, the impact of malnutrition on patient outcomes, and areas of further research.

Keywords

- pediatric traumatic brain injury
- nutrition support
- enteral nutrition
- malnutrition
- nutritional assessment

Introduction

According to the epidemiological data provided by the Centers for Disease Control and Prevention, traumatic brain injury (TBI) affects 315,979 children between 0 to 4 years of age and 475,876 adolescents (15–24 years old) annually with a male preponderance.[1] Pediatric TBI (PTBI) poses unique challenges when it comes to nutritional care. These children often have increased metabolic demands, resulting in increased energy expenditure. Accurately evaluating their caloric and protein requirements is critical to prevent malnutrition.[2] Malnutrition can lead to multiple problems including prolonged hospital stay, increased risk of infection, and delayed wound healing.[3] Some of the hurdles in nutrition in PTBI encompass the management of the hypercatabolic state, preventing malnutrition, calculating the nutritional requirement and the energy expenditure, determining the optimal mode and timing of nutritional therapy, addressing long-term complications, guiding the family for post-discharge nutritional support, etc.[4] Such complexity necessitates a multidisciplinary approach involving collaboration among dieticians, physicians, nursing staff, and rehabilitation specialists.[5] The scarcity of current literature focusing specifically on PTBI patients makes the job further difficult for all the members involved in managing such patients.[6] In multiple clinical contexts, physicians need to resort to data derived from adult TBI studies to manage PTBI. This review specifically addresses nutrition in PTBI, which is

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distinct from adult TBI. We aimed to explore existing knowledge gaps and areas that require further exploration. We have therefore conducted this review, which will guide the care providers in offering effective nutritional therapy to PTBI patients.

Methods

Search Strategy

A thorough literature search was conducted using relevant keywords—"pediatric," "traumatic brain injury," "pediatric traumatic brain injury," "nutrition," "dietary management," "nutrition therapy," "energy requirement," "metabolic demand," "nutritional support," "pediatric critical care nutrition," "gut microbiome," "glycemia," "glycemic control," "pediatric critical care," and "child" and their synonyms across PUBMED, Google Scholar, SCOPUS, MEDLINE (OVID), EMBASE, and Cochrane library databases. To ensure that we capture all relevant research studies, we have examined the reference lists of the chosen studies and review articles. Additionally, a manual Google search was conducted to ensure that potential studies that might not be indexed in traditional academic databases are not missed. Inclusion criteria for the literature review were studies published in English, involving pediatric patients (age 0–18 years) diagnosed with TBI. We have additionally explored the Neurotrauma Reviews in the Global Evidence Mapping Initiative, and Evidence Reviews in Acquired Brain Injury databases to find relevant latest guidelines, systematic reviews, meta-analyses, and randomized controlled trials (RCTs). In a few areas where relevant pediatric studies are not found, adult studies have been cited.

Discussion

Metabolic Demand after TBI

Resting energy expenditure (REE) refers to the amount of energy an individual's body expends while at rest. Trauma triggers a multitude of inflammatory and hormonal changes in the body, leading to an increased secretion of corticosteroids, catecholamines, counterregulatory hormones such as IGF-1 (insulin-like growth factor), growth hormone, cytokines, etc.[7] Previous data suggested that this inflammatory cascade can result in hypermetabolism, raising the body's energy demand by 87 to 200% above normal levels.[8] Factors like agitation, increased muscle tone, sweating, and fever can elevate REE further, potentially up to 250%.[9] However, those studies were performed in an era when neuroprotective interventions were not widely practiced in the neurocritical care setting. Studies conducted in children with severe TBI under controlled conditions have revealed lower than expected REEs of up to 70 to 80%.[10] This suggests that although TBI increases metabolic demands, current neurocritical care practices like sedation, temperature control, intravenous (IV) anesthetic agents, and neuromuscular blocking agents largely mitigate this hypermetabolic response.[11]

Assessment of Energy Requirement in PTBI

American Society for Parenteral and Enteral Nutrition (ASPEN), the Society of Critical Care Medicine (SCCM), and the European Society for Clinical Nutrition and Metabolism (ESPEN) recommend using indirect calorimetry (IC) for assessing energy requirements whenever possible.[12,13] Despite being the most accurate method, IC is not widely used in pediatric intensive care units (PICUs) due to its cost, complexity, limited availability, and the lack of appropriately validated equipment. Ventilator settings in some critically ill children with TBI may necessitate delaying the IC test until their breathing stabilizes.[14]

In the absence of IC, predictive equations are used to estimate REE, but their accuracy is limited by injury severity and inflammation, potentially leading to over- or underfeeding. [15] Commonly used predictive equations are Harris–Benedict, World Health Organization, Fleisch equation, Caldwell–Kennedy, Schofield, and basic weight-based equations (25–30 kcal/kg/day), which are mentioned in ►**Table 1**.[15,16] A recent systematic review evaluated 21 equations and found none could predict REE within a 10% range of measured energy expenditure. [16] The Harris–Benedict equation overestimated REE in the majority of the patients while the Schofield equations and Talbot tables were found to be least inaccurate.[15,16] They have also reiterated the pressing need for a new validated IC device in critically ill pediatric patients.[17] However, till now there is no data to conclude if the use of IC improves patient outcomes. The European Society of Pediatric and Neonatal Intensive Care (ESPNIC) recommends using the Schofield equation to estimate REE; however, any specific recommendation for PTBI is not available.[18]

Energy requirements may vary during acute and chronic phases following PTBI. [15] REE peaks within 4 to 5 days post-trauma and stays high for 9 to 12 days.[19] Therefore, targeting slightly less than the estimated energy requirement in the initial phase and subsequent gradual up-titration may be prudent.[20] Patients should achieve basal caloric replacement between the 5th and 7th day post-injury, as per the Brain Trauma Foundation (BTF) guidelines.[21]

Researchers are exploring a new strategy called permissive underfeeding to potentially improve outcomes in PTBI[2]: providing reduced calorie intake (hypocaloric feed) initially, i.e., only 50% of energy needs in the first 24 hours, then it is gradually increased to 25 to 30 kcal/kg/day within the first 2 weeks. The calorie requirement again starts to increase up to 30 to 60% during the rehabilitation phase.[12,22]

Assessment of Nutritional Status

TBI in children disrupts metabolism, raising nutrient needs and altering body composition, increasing the risk of malnutrition.[23] To identify malnutrition in these vulnerable patients, a comprehensive assessment is the key.[24] This holistic approach includes a thorough medical history, examination of consciousness, swallowing ability, gastrointestinal (GI) issues, detailed evaluation of dietary intake, and assessment of growth trends and nutritional status.[12]

Table 1 Pediatric resting energy expenditure equations used in PICU

Energy expenditure equations	Formulas
Harris–Benedict equation	Boy $REE = 66.47 + 13.75 \times W + 5 \times H - 6.755 \times A$ Girl $REE = 655.1 + 9.563 \times W + 1.85 \times H - 4.676 \times A$
Mehta equation	$REE = 5.534 \times VCO_2 \times 1{,}440$
Fleisch equation	Boys 1–12 yrs old: $24 \times BSA \times (54 - 0.885 \times A)$ 13–19 yrs old: $24 \times BSA \times \{42.5 - [0.643 \times (A - 13)]\}$ Girls 1–10 yrs old: $24 \times BSA \times [54 - (1.045 \times A)]$ 11–19 yrs old: $24 \times BSA \times \{42.5 - [0.778 \times (age - 11)]\}$
Caldwell–Kennedy equation	$REE = 22 + (31.05 \times W) + (1.16 \times A)$
Schofield equation	Age Girls Boys <3 years $58.317 \times W - 31.1$ $59.512 \times W - 30.4$ 3–10 years $20.315 \times W + 485.9$ $22.706 \times W + 504.3$ 10–18 years $13.384 \times W + 692.6$ $17.686 \times W + 658.2$
WHO equation	Boys 3–10 years $REE = (22.7 \times W) + 495$ 10–18 years $REE = (17.5 \times W) + 651$ Girls 3–10 years $REE = (22.5 \times W) + 499$ 10–18 years $REE = (12.2 \times W) + 746$

Abbreviations: A, age (in years); BSA, body surface area; H, height (in cm); REE, resting energy expenditure (kcal/d); VCO_2, volume of carbon dioxide elimination; W, weight (in kg).

Anthropometry (measuring body size and proportions) is a fundamental way to assess a child's nutritional health. The Academy of Nutrition and Dietetics, ASPEN and WHO recommended the use of z-scores for weight-for-height, weight-for-age, height-age, mid-upper arm circumference, and body mass index to diagnose undernutrition in children.[12,25] While various age-based formulas exist for weight estimation in emergencies, the Broselow tape is another instrument to have a rough estimate of weight. Studies reveal the PAWPER XL tape as the most accurate tool for South African pediatric emergencies, with modifying the Broselow tape for body type offering minimal improvement.[26] However, anthropometry alone cannot capture all aspects of nutritional parameters and detect malnutrition.[27]

Commonly used pediatric nutrition screening tools are presented in ►**Table 2**.[28–30] A good correlation between the Screening Tool Risk on Nutritional Status (STRONGkids) tool and anthropometric body measurements has been found.[30,31] A recent study suggested that the Pediatric Yorkhill Malnutrition Scale and Pediatric Nutritional Screening Tool have high sensitivity for malnutrition risk assessment in pediatric inpatients.[32] There exists no specific preferred tool for PTBI.

Biochemical markers such as serum albumin, prealbumin, C-reactive protein, and total lymphocyte count can be used as rough, nonspecific markers for gauging the child's current nutritional status, particularly when physical examinations alone may not suffice.[33] While the parameters outlined provide a preliminary assessment, a comprehensive evaluation of nutritional status necessitates a more comprehensive approach due to inherent limitations.[25] There is a recent interest in the application of ultrasound and computed tomography to assess muscle thickness, mass, and density.[34] Although promising, these methods have not yet been widely used in clinical settings and are not well-validated yet.[35]

Early versus Late Initiation of Nutrition

While studies suggest that the timing of nutritional support significantly affects outcomes in adults with TBI, there is limited evidence demonstrating the same impact in critically ill children with severe TBI.[36] The BTF guidelines suggest the commencement of enteral nutrition (EN) delivery within 72 hours of the injury.[21] The ASPEN, ESPEN, and SCCM propose that nutrition support through EN should commence within the initial 24 to 48 hours after admission in patients with PTBI.[12,13] Based on these findings, the BTF recommends beginning basal caloric replacement within 5 days of the injury, but no later than day 7.[21] Although the study used for synthesis of the evidence in the BTF guidelines demonstrated meaningful outcomes, it was not known if the early nutrition or the lower severity of the injury, which allowed early EN, was the main contributor.[20,37,38]

A study found significantly higher mortality in PTBI patients not fed within 5 to 7 days post-injury.[20] Every 10 kcal/kg decrease in caloric intake over the first 5 days increased mortality rates by 30 to 40%.[2,39] Early EN is associated with a favorable outcome in PTBI.[37,38] A Cochrane review in pediatric critically ill children found that early feeding in PTBI decreases the risk of infections and translates into better outcomes.[40] It has also been shown that in adults

Table 2 Pediatric nutritional screening tools for detection of malnutrition

Screening tools	Parameters	Advantages	Disadvantages	High nutritional risk score
PNRS	• Weight loss • Food intake < 50% • Feeding interference	It takes into account several parameters	Time-consuming and depends on subjective criteria,	≥3
STAMP	• Weight, height measurement • Nutritional intake	Multidimensional, considers medical and anthropometric factors	Not widely validated, complex scoring	≥4
PSGNA	• Dietary intake • Gastroenterological functional ability • physical examination of clinical status	Considers history, physical exam, anthropometry	Time-consuming, requires trained clinician	≥4
STRONGkids	• Reported recent weight loss/gain • Nutritional and impaired intake	Considers dietary intake, clinical factors, and anthropometry	Limited research on its use in PICU	≥3
PMST	• Weight, height, and BMI • Food intake	Simple easy method	Time-consuming	≥4
PYMS	• BMI • <2% percentile changes in nutritional intake	Simple, quick, readily available	Lacks validation in specific pediatric critical care populations	≥2
PNRI	• Weight loss • BMI • Food intake • Stress factor	The objective considers disease severity and nutritional risk factors	Does not assess current nutritional status	≥3
PeDiSMART	• WFA (z score) • Nutritional intake • Disease Impact	High reproducibility, time-saving	Limited validation studies	≥4

Abbreviations: BMI, body mass index; PediSMART, Pediatric Digital Scaled Malnutrition Risk Screening Tool; PICU, pediatric intensive care unit; PNRS, Pediatric Nutritional Risk Score; PSGNA, Pediatric Subjective Global Nutritional Assessment; PYMS, Pediatric Yorkhill Malnutrition Score; STAMP, Screening Tool for the Assessment of Malnutrition in Pediatrics; STRONGKid, Screening Tool Risk on Nutritional Status and Growth; WFA, weight for age.

early EN within 72 hours after TBI positively influences the hormonal profile.[41]

Routes and Types of Nutrition

Nutritional delivery mode is dependent on the medical conditions, severity of the injury, and required length of nutritional support.[39] If airway protective reflexes and sensorium are intact, the treating team may start oral feeding. Mechanical feeding may be required for PTBI patients with difficulty swallowing and with altered levels of consciousness.[42]

However, patients with moderate to severe TBI may require other modes of feeding. Whenever feasible EN is preferred over parenteral nutrition (PN) and is recommended by PTBI guidelines.[12,43] EN helps prevent intestinal mucosa atrophy, stimulates secretion of digestive enzymes, improves immune function, and prevents bacterial translocation, even if it does not meet the patient's total daily caloric needs.[38] Such low-volume EN is often termed trophic feeding for its "trophic" effect on the intestinal mucosa.[39] Blenderized food and milk-based (or lactose-free) polymeric feeds containing whole protein are recommended over predigested elemental or semi-elemental formulas containing short peptides or free amino acids. Peptide-based formulations may be considered if polymeric feeds are not tolerated.[18] The pros and cons of EN versus PN are described in ►**Table 3**.[44]

While gastric feeding is the first choice, for patients with feeding intolerance and a high risk of aspiration, small bowel feeding (nasoduodenal or naso-jejunal) or trans-gastric intestinal feeding can be alternatives, potentially lowering the risk of ventilator-associated pneumonia.[39] Meert et al found those receiving small bowel feeding achieved a higher percentage of their daily calorie needs compared with gastric feeding.[45] However, for most patients gastric feeding is equally safe as compared with post-pyloric feeding.[46]

The pattern of feeding can be bolus/intermittent or continuous. Cyclical feeding can be achieved by providing EN with a feeding pump for less than 24 hours and around 8 hours of break time.[47] The difference between bolus and intermittent feeding is the delivery time: intermittent feeding delivers over 20 to 60 minutes every 4 to 6 hours, while bolus feeding is provided over a short period at fixed intervals.[48] Sufficient research exploring the effect of cyclical and intermittent versus bolus feeding techniques is not available in PTBI. Although most guidelines recommend

Table 3 Enteral versus parenteral nutrition in PTBI

Nutrition	Advantages	Disadvantages
Enteral nutrition	• Physiological route • Lower infection risk • Maintenance of the integrity of the gut • Avoid muscle atrophy • Stimulates hormone secretion, motility, and microbiome diversity	• Dependent on gastrointestinal function • Feeding intolerance • Frequent interruptions, continue monitoring, and ensure optimal delivery rate • Risk of aspiration
Parenteral nutrition	• Early calorie intake • Fewer interruptions • Delivery of optimal calorie requirement	• Nonphysiological route • Expensive • Requires central venous access • More risk of catheter-related infection • Hyperglycemia • Hypercholesterolemia • Hepatic dysfunction • Cholestasis • Cardiac dysfunction • Dyselectrolytemia

Abbreviation: PTBI, pediatric traumatic brain injury.

continuous EN over intermittent feeding, a recent meta-analysis has failed to demonstrate any meaningful outcome difference between these two methods.[49] ESPNIC also concluded that there is insufficient evidence to prefer the continuous feeding technique over the intermittent/bolus technique.[18]

The rate of PN administration in TBI is low. Generally, EN is the mainstay of feeding in PTBI and has to start within 24 hours of admission unless contraindicated.[50] PN should be started if a patient with low nutrition risk cannot meet over 60% of energy and protein requirements via EN within 7 to 10 days.[51] PN is preferred in cases of hemodynamic instability, high nutritional demand, active GI bleeding, and overt bowel ischemia. For children with high nutrition risk malnutrition, start total PN as soon as possible after resuscitation if they cannot use the GI tract for more than 3 to 5 days.[52] The mechanism of harm from ultra-early PN is not clear but established. Partial PN is used when EN is partially feasible.[52] There is ongoing research regarding the timing of PN in children with TBI.[53] Starting PN (often before 3 days) is linked to longer hospital stays and a higher risk of complications.[53,54] The Early versus Late Parenteral Nutrition in the Pediatric Intensive Care Unit (PEPaNIC) trial which included 8% of TBI patients showed benefits of late PN over early PN.[43] Composite lipid emulsions, with or without fish oil, are the preferred choice of PN.[54] The flow diagram in ►**Fig. 1** describes a tentative nutritional management plan in PTBI.

Macronutrients

PTBI patients require 40 to 60% carbohydrates, and 15 to 30% protein for the total energy requirement.[12,55] Different carbohydrates are monosaccharides (glucose, fructose), oligosaccharides (lactose, mannose, dextrins), and polysaccharides (starch). In addition, 0.7 to 14 g/kg/day glucose suffices the basal energy requirement. [39] A minimum of 1.5 g/kg/day protein is required to avoid negative nitrogen balance.[12] However, the dose should not cross 3 g/kg/day in neonates and infants and 2 g/kg/day in stable adolescents.[18] Additional protein or amino acid intake is not beneficial. Lipids shall provide 25 to 50% of nonprotein calories, which equals 20 to 30% of the whole energy delivery. The recommended dose is 1 to 3 g/kg/day in preterm and term infants may require up to 4 g/kg/day.[56]

Glycemic Control and Energy Utilization by the Brain

Hyperglycemia is a common stress response in PTBI and is linked to increased morbidity and mortality.[57] Cochran et al found that PTBI with blood glucose levels $\geq$300 mg/dL at admission had an increased risk of death.[58] Similarly, prolonged periods of high blood glucose levels in PTBI have been related to cognitive deterioration, an elevated rate of seizures, infections, and prolonged hospital admissions.[59,60] Hypoglycemia also has a negative impact on pediatric patients leading to compromised recovery trajectories, escalated mortality risks, and prolonged hospitalizations.[61] Intensive glycemic control increases the risk of hypoglycemia like in adults, indicating potential harm. Maintaining moderate glycemic control (8–11 mmol/L) is recommended in critically ill children with PTBI.[62] PN increases hyperglycemia risk compared with EN, but the feeding route minimally impacts early inflammation or clinical outcomes in critically ill patients.[51] Due to a lack of prospective studies investigating the relationship between blood sugar control and outcomes in children with TBI, it is unclear whether strictly managing blood sugar levels improves their chances of recovery.[57]

Researchers have lately investigated the role of lactate as an alternative energy substrate for the brain after TBI in adults. It has been found that hyperlactatemia in the context of TBI may not always result in acidosis and is not always a result of hypoperfusion.[63] The brain may utilize lactate to maintain its enhanced metabolic requirements. That has led to using hypertonic lactate as an alternative to mannitol or hypertonic saline, to improve the metabolic functions of the brain. Still, no significant studies have been done on pediatric TBI.[64]

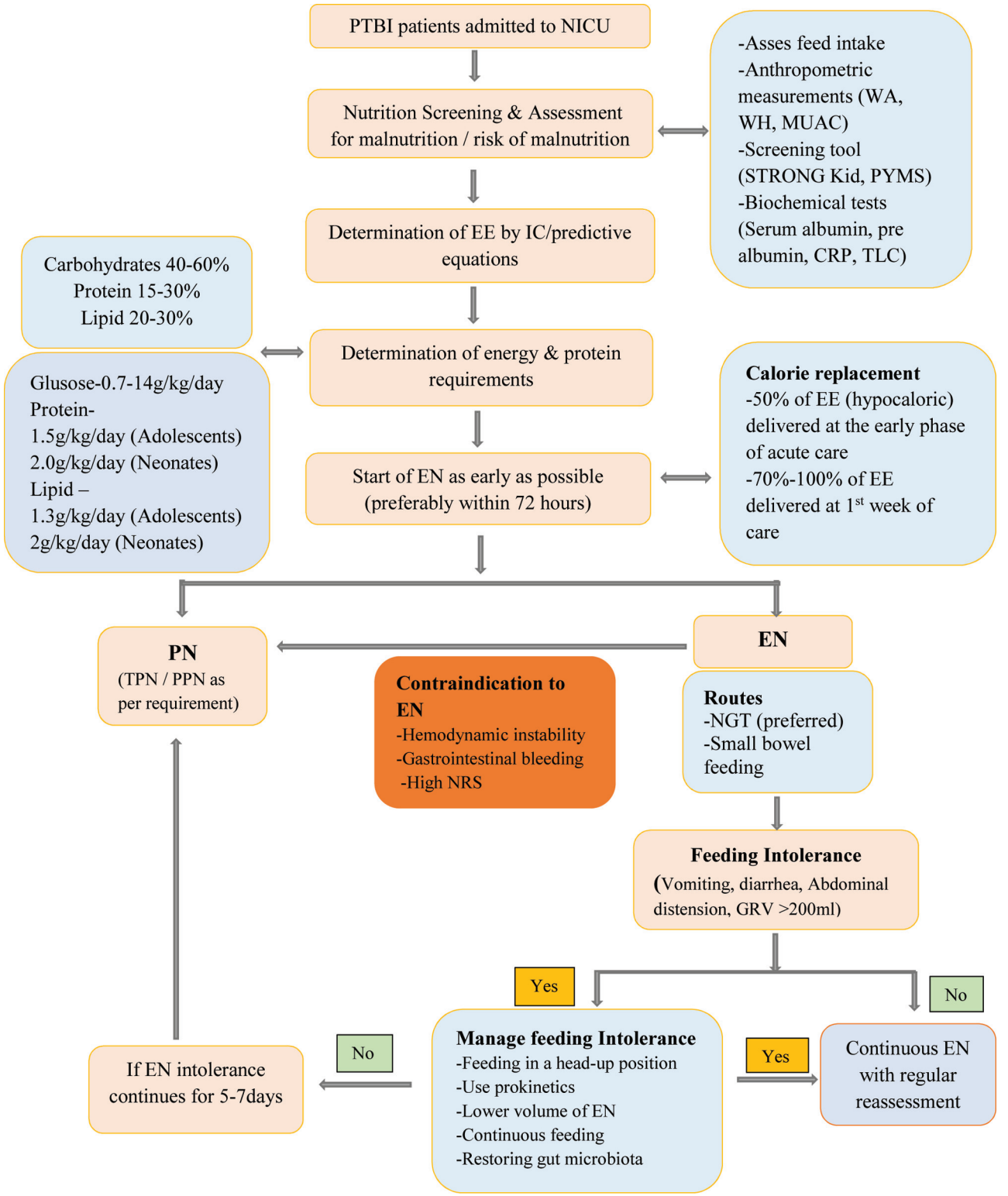

Fig. 1 **Nutrition management in PTBI.** CRP, C-reactive protein; EE, energy expenditure; EN, enteral nutrition; GRV, gastric residual volume; IC, indirect calorimetry; MUAC, measuring mid-upper arm circumference; NGT, nasogastric tube; NICU, neuro-intensive care unit; NRS, nutritional risk score; PN, parenteral nutrition; PPN, partial PN; PTBI, pediatric traumatic brain injury; PYMS, Pediatric Yorkhill Malnutrition Screening; STRONGKids, Screening Tool Risk On Nutritional Status and Growth; TLC, total leukocyte count; TPN, total PN; weight for age; weight for height; WA, Weight for age; WH, Weight for height.

Role of Immunonutrition

Immunonutrition, also known as immune-enhancing nutrition therapy, incorporates specific supplements like arginine, glutamine, omega-3 fatty acids, nucleotides, and antioxidants like copper, selenium, zinc, B vitamins, vitamin C, and vitamin E in regular diet.[65] The role of immunonutrition in PTBI has been reported sparingly. There are few RCTs in PTBI, comparing the role of immunonutrition with a normal diet.[63,66] Immunonutrition was found to improve various nutrition and inflammatory indices in children with severe head injury; however, it was not associated with additional advantages in morbidity or mortality.[63] Conflicting results exist, with some trials linking immunonutrition to increased mortality in severe sepsis cases. Immunonutrition might increase colonization and infection rates in critically ill PTBI and has highlighted the need for age-specific formulas.[66]

Guidelines for managing severe TBI do not universally recommend immune nutrients. Pediatric TBI guidelines also advise against their use.[21] A very recent pilot RCT has shown some evidence that branched-chain amino acid supplementation may have a beneficial role in PTBI.[67] A proposed meta-analysis is underway which may clarify its efficacy, safety, and relevance in PTBI.[68]

Barriers to Early Nutritional Therapy

Providing adequate EN proves challenging for children with severe TBI. These patients are more likely to experience delays in starting EN, often leading to insufficient deliveries of essential macronutrients during their stay in the PICU.[69] Several factors directly connected to the secondary complications, such as cognitive impairments, difficulty swallowing, coordination problems, or diminished consciousness, are potential causes that complicate safe oral intake. [2] A lower Glasgow Coma Scale score and higher Injury Severity Score are independently associated with delayed initiation of EN.[38] Different reasons for delay in nutrition are presented in ►**Table 4**.[70,71]

Sedative medications often pose a hindrance to feeding. The use of vasopressors can affect tolerance to EN.[11] There is an inverse relationship between the maximum dose of norepinephrine and tolerance to EN.[72] However, patients receiving vasopressin, adrenaline, and phenylephrine are more likely to experience splanchnic hypo-perfusion than those receiving noradrenaline.[73] GI hypoperfusion consequently culminate into EN intolerance. This issue is particularly challenging during the initial stages following injury.[74] Patients under the influence of vasopressors frequently encounter delays in gastric emptying and a decrease in gut motility, thereby heightening the likelihood of complications such as abdominal distension, vomiting, and diarrhea.[75] Nevertheless, EN is safe in patients who are stable on pharmacological hemodynamic support. PN shall be reserved for those whose hemodynamical status is fluctuating.[18] Furthermore, the administration of vasopressors can worsen hyperglycemia and hypermetabolism, both of which are pre-existing concerns in TBI patients.[2,72]

Table 4 Reasons for delayed enteral nutrition in PTBI patients

Category	Reasons
Patient-related factors	• Multiple trauma • Facial fractures • Oral injury
Neurological factors	• Decreased consciousness level (coma) • Altered swallowing reflex • Increased intracranial pressure • Damage to the autonomic nervous system
Interruptions in feeding due to planned procedures	• Surgery • Extubation or intubation • Radiologic exams • Bedside procedures
Technical factors and intolerance to feed	• Difficulty placing a feeding tube • Gastrointestinal dysfunction • Feeding intolerance: vomiting, diarrhea, constipation, abdominal distention, large gastric residual volume • Opioid-based sedation causing nausea constipation
Decision-making–related factors	• Overestimation of aspiration risk • Delayed or hesitant initiation of enteral feeding. • Uncertainty about prognosis
Other medical conditions	• Severe sepsis or shock requiring hemodynamic stability • Coagulopathy or thrombocytopenia contraindicating enteral tube placement

Abbreviation: PTBI, pediatric traumatic brain injury.

Refeeding Syndrome

PTBI patients are at increased risk for refeeding syndrome (RFS), a life-threatening complication arising from rapid nutrient reintroduction after a period of malnutrition.[76] This syndrome, characterized by electrolyte imbalances and fluid shifts, can trigger seizures and acute encephalopathy in PTBI patients.[76] RFS occurs when IV dextrose, EN, PN, or even oral feeding is initiated following starvation or severe calorie restriction.[77] Management includes electrolyte replenishment, and supplementation of thiamine, folic acid, and multivitamins before beginning of enteral feedings.[78] Feeding should start slowly over 3 to 4 days with trophic feedings (up to 25% of the goal), and monitoring basic metabolic panel, phosphorus, and magnesium levels.[12,42]

Assessment of Gastrointestinal Function

Nearly half (48.5%) of children with TBI develop GI dysfunction, and this risk increases significantly with the severity of the injury.[79] In severe cases, the rate jumps to a staggering 85.9% during the first 1 to 2 weeks and may persist if intracranial pressure remains elevated.[2,79] Gastroparesis leads to delayed gastric emptying and an increase in gastric residual volumes (GRVs). GRV exceeding 50% of the feeding volume can lead to vomiting, aspiration, and pneumonia. GRV is often measured by aspiration using a syringe or gravity drainage every 4 hours. Management strategies include setting a threshold of >3 mL/kg to interrupt EN, positioning the head at 45°, using continuous feeding, motility-promoting agents like metoclopramide and erythromycin, pyloric feeding, and adjusting EN as needed.[80] Another stepwise approach suggests returning the residuum to the stomach when GRV is >1–3 mL/kg and skipping the scheduled feed. In case the GRV is more than 3 mL/kg, the residuum shall be returned up to 3 mL/kg and further dose shall be halved.[81] GRV indicates feeding intolerance and delayed gastric emptying, but factors like gastric content viscosity, material, and aspiration technique can affect GRV.[82] The use of prokinetics in such scenarios is a common practice. However, ESPNIC recommends against the routine use of prokinetics.[18]

Gastric point-of-care ultrasound (POCUS) is increasingly being used to assess GRV by calculating the antrum's cross-sectional area.[78] The GastriPed study evaluated the effectiveness of aspiration in emptying the stomach and the ability of GRV measurement by aspiration and POCUS to predict EN tolerance.[83] Another study found POCUS is faster than X-ray for detecting nasogastric tube position in critically ill patients. However, exact POCUS cut-off values for diagnosing feeding intolerance and guiding EN in pediatric patients are not yet established.[84]

The ASPEN and SCCM recommend against routine GRV checks for critically ill pediatric patients since they do not prevent complications such as aspiration pneumonia and may lead to unnecessary interruptions in EN, resulting in underfeeding and increased risk of malnutrition.[12] It is also noteworthy to mention that bowel sounds are also not mandatory to be present to start EN.[39]

Research and Future Directions

The gut–brain axis and its imbalance secondary to TBI is an area of active research. Neuroinflammation results in a shift from beneficial to pathogenic microbiomes in the intestinal tract.[85] A recent study found that children with severe TBI developed an imbalance in their gut microbiome during their initial intensive care unit stay, with a decrease in beneficial bacteria and an increase in harmful bacteria.[63] The timeframe of birth to 3 years has been identified as a crucial window for interventions directed at gut microbiomes as a potential therapeutic/preventive option to improve neurodevelopmental outcomes.[86] The mechanism through which such changes can improve clinical outcomes and whether interventions, e.g., probiotics or prebiotics to prevent or reverse those changes, can be beneficial is still not elucidated.[2] Further research is needed to understand how these changes can affect patient outcomes in PTBI. To help the readers, we have prepared a table mentioning whether adult or pediatric studies have been used to curate data for our review and have also summated the existing lacunae in the literature (►**Table 5**).

Role of Advanced Neuromonitoring in Nutrition

There is recent interest in using advanced neuromonitoring like cerebral microdialysis (CMD) and PbtO2 to guide nutritional therapy in TBI. Research and clinical applications of CMD-guided cerebral metabolism studies highlighting substrate supply, glycemic variations, insulin therapy, and their effects on the brain metabolic profile are being explored. Elevated lactate–pyruvate ratio and neuroglycopenia demonstrated from CMD are associated with detrimental outcomes.[65] However, widespread application of such monitoring in titrating nutritional interventions is still debatable in adults and currently there are no studies on PTBI dealing with this issue.

Long-Term Recovery

TBI impacts long-term cognition, mental health, and dietary habits significantly. More than half of the patients had residual disability even after 1 year of inpatient rehabilitation in one study.[87] Addressing these challenges effectively by involving multidisciplinary teams including psychiatrists, speech-language specialists, and rehabilitation experts after discharge is the way forward. It seeks to develop individualized nutrition plans for enhancing long-term recovery. The follow-up on nutrition shall continue via specialized follow-up clinics or teleconsultation.[56]

Conclusion

The profound impact of malnutrition on the recovery and overall outcome of PTBI patients underscores the necessity of proactive nutritional management which necessitates a strategic approach individualized to the patient's needs. Application of advanced neuromonitoring modalities to adjust nutritional management, the therapeutic role of lactate, and the role of the gut–brain axis are promising areas to be explored by further high-quality research.

Table 5 Types of studies used for data curation, existing gaps, and future direction of research in PTBI nutrition

Topics	Type of studies from which data are curated	Lacunae in the literature and areas for further research
Metabolic demand after TBI	Predominantly adult TBI studies	• PTBI data are inadequate
Assessment of energy requirement	Adult TBI, adult and pediatric critical care data	• Predictive equations for REE not available for PTBI • A validated indirect calorimetry device for PTBI
Assessment of nutritional status	Pediatric critical care	• A nutritional assessment tool for PTBI
Timing of initiation of nutrition	PTBI	• It is unclear if less severe injury which helps early nutrition or early nutrition itself is more important for improving outcomes
Routes of nutrition (EN vs. PN)	Mainly pediatric critical care	• Insufficient PTBI data
Pattern of feeding (continuous, intermittent, cyclic, etc.)	Pediatric critical care data	• Insufficient PTBI data
Requirement of nutrients	Pediatric critical care data	• Insufficient PTBI data
Glycemic control	PTBI data	• Stringent vs. liberal glycemic control in PTBI needs further evaluation
Hypertonic lactate use	Adult TBI	• Absent PTBI data
Immunonutrition	PTBI and pediatric critical care data	• Conclusive high-quality evidence needed
EN in patients on pharmacologic hemodynamic support	Adult TBI and critical care data	• Insufficient PTBI data
Refeeding syndrome	Pediatric critical care data	• Exact incidence, prevalence in PTBI needs refinement
GRV assessment	POCUS used in pediatric critical care	• POCUS for assessing GRV in PTBI • Cut-offs for discontinuing EN yet not established
Advanced neuromonitoring for nutritional therapy	Overall scarce data	• PTBI data required on advanced techniques
Gut–brain axis	Emerging concept Preliminary adult and PTBI studies	• Area of active research • Ideal timing, dose of probiotics, long-term benefits yet to be elucidated
Long-term recovery	Insufficient PTBI data	• Integrated easy-to-use tools for rehabilitation therapy, swallowing assessment • Training protocols for kins taking care of the patients at home

Abbreviations: EN, enteral nutrition; GRV, gastric residual volume; PN, parenteral nutrition; POCUS, point-of-care ultrasound; PTBI, pediatric traumatic brain injury; REE, resting energy expenditure; TBI, traumatic brain injury.

Conflict of Interest
None declared.

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