

REVIEW ARTICLE

Malnutrition in pediatric oncology critical care:
Mechanisms, assessment, and nutrition supportPeiyu Huang¹ and Zhixuan Deng^{2*}¹Department of Pediatric Intensive Care Unit, Shenzhen Children's Hospital, Shenzhen, China²Institute of Cell Biology, Hengyang Medical School, University of South China, Hengyang, Hunan, China

Abstract

Children with cancer who require pediatric intensive care encounter overlapping metabolic insults from cancer biology, anticancer treatment, and critical illness. These insults may produce a dynamic malnutrition phenotype characterized by impaired intake or absorption, rapid lean-mass loss, micronutrient and electrolyte depletion, and assessment confounded by inflammation and fluid shifts. In this narrative review, we conducted a systematic search on PubMed/MEDLINE through August 11, 2026 and prioritize evidence in the following order: pediatric oncology pediatric intensive care unit (PICU), general PICU, non-critical pediatric oncology or hematopoietic stem-cell transplantation, adult clinical, and preclinical studies. We propose an unvalidated triple-hit model and an evidence-informed decision framework. Serial measured weight should be interpreted with cumulative fluid balance and edema; bioelectrical impedance phase angle and the C-reactive protein-to-albumin ratio are prognostic or risk markers, while muscle ultrasound documents tissue trajectory but does not determine protein requirements. Enteral nutrition is preferred after adequate resuscitation when the gastrointestinal tract is usable. General PICU evidence, including the PEPaNIC trial, supports withholding routine supplemental parenteral nutrition during the first seven days, although applicability to pediatric oncology PICU populations remains unexplored. Universal energy and high-protein targets are not supported; prescriptions should reflect age, illness phase, measured energy expenditure when available, organ function, and refeeding risk. Direct evidence remains sparse, and the proposed framework requires prospective validation.

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Keywords: Pediatric oncology; Pediatric intensive care unit; Malnutrition; Enteral nutrition; Parenteral nutrition; Muscle ultrasound; Evidence-informed care

1. Introduction

Childhood cancer survival has improved with advances in risk-adapted chemotherapy, targeted therapy, immunotherapy, and supportive care.^{1,2} As survival improves, attention increasingly extends beyond tumor control to treatment tolerance, functional recovery, and survivorship. Frailty-like phenotypes—including reduced strength, impaired physical activity, and multisystem vulnerability—have been described in childhood cancer survivors, making nutrition and rehabilitation clinically relevant throughout the disease trajectory.³

Malnutrition is common during pediatric cancer treatment, although reported prevalence varies substantially with diagnosis, treatment phase, assessment method, and setting.⁴ Across heterogeneous oncology cohorts, undernutrition and early weight loss have been associated with infectious complications, treatment intolerance, and poorer survival; these associations should not be interpreted as proof that one nutrition intervention will reverse every outcome.⁵ Direct pediatric oncology critical-care evidence is much thinner. In a secondary analysis of 160 children with cancer admitted to intensive care, admission nutritional status was associated with clinical outcomes, but the observational design did not define an optimal feeding strategy.⁶

Admission to the pediatric intensive care unit (PICU) changes the nutrition problem. Children may have sepsis, multiple-organ dysfunction, postoperative complications, respiratory failure, neurologic deterioration, tumor lysis syndrome, or treatment toxicity. They may require vasoactive drugs, mechanical ventilation, extracorporeal membrane oxygenation (ECMO), or continuous renal replacement therapy (CRRT). These exposures alter substrate use, fluid balance, gastrointestinal perfusion, nutrient losses, mobility, and route feasibility. Consequently, strategies developed for stable oncology wards cannot be transferred directly to pediatric oncology critical care.

Hematologic malignancies and solid tumors also show different critical-illness phenotypes. In a multicenter cohort spanning 112 PICUs and 10,365 admissions, children with hematologic malignancies had greater illness severity, infection burden, intervention use, and mortality than those with solid tumors.⁷ More recent single-center data similarly show diagnosis-related differences in acute presentation.⁸ However, nutritional comparisons derive largely from non-PICU cohorts and are inconsistent: some studies found no clear diagnostic-group difference, whereas others reported more undernutrition in solid tumors and more overnutrition during treatment for acute lymphoblastic leukemia.^{9,10} Tumor type should therefore be treated as a risk modifier, not as a standalone determinant of energy, protein, or feeding route.

The infection phenotype deserves particular attention. Pediatric oncology patients may accumulate risk through prolonged or profound neutropenia, mucosal barrier injury, central venous access, corticosteroids or other immunosuppressants, hematopoietic stem cell transplantation (HSCT), graft-versus-host disease, and repeated hospitalization. In sepsis, inflammatory and organ dysfunction phenotypes are associated with different outcomes.¹¹ Infection can reduce appetite, provoke nausea and diarrhea, increase metabolic stress, and interrupt

feeding for procedures or instability. Repeated antimicrobial exposure may additionally contribute to taste disturbance, gastrointestinal intolerance, and microbiome disruption, but it can also be a marker of more severe infection.

This narrative review synthesizes mechanisms, assessment, and nutrition support relevant to pediatric oncology critical care. We propose a triple-hit model linking cancer biology, anticancer treatment, and critical illness; appraise dynamic assessment tools; examine phase-aware nutrition decisions; and address special scenarios. Both the model and decision pathway are evidence-informed author proposals, not validated protocols.

The intended audience includes intensivists, oncologists, transplant clinicians, dietitians, nurses, pharmacists, and rehabilitation specialists. The scope includes children receiving active anticancer treatment, children recovering from HSCT, and children with cancer-related complications who require PICU organ support. It does not replace tumor-specific protocols, antimicrobial guidelines, renal prescriptions, or transplant pathways. Instead, it identifies decisions that become unusually difficult when pre-existing nutritional vulnerability intersects with inflammation, fluid resuscitation, gastrointestinal injury, organ failure, and an imminent need to resume cancer therapy.

2. Methods

2.1. Literature identification

PubMed/MEDLINE was searched from database inception through August 11, 2026. The reproducible core query was: (child* OR pediatric* OR paediatric*) AND (cancer OR oncology OR leukemia OR lymphoma OR tumor OR tumour) AND (“pediatric intensive care” OR “paediatric intensive care” OR PICU) AND (nutrition OR malnutrition OR enteral OR parenteral OR body composition OR muscle). This query returned 188 records on the search date. Targeted supplementary searches combined pediatric terms with (i) oncology nutrition, (ii) general PICU nutrition assessment and support, and (iii) mucositis, gastrointestinal graft-versus-host disease, tumor lysis syndrome, sepsis, ECMO, or CRRT. Reference lists of relevant guidelines and reviews were also examined.

Because the objective was a clinically oriented narrative synthesis rather than an exhaustive estimate of intervention effects, records were selected iteratively for relevance and methodological contribution. Priority was given to randomized trials, guidelines, systematic reviews, multicenter cohorts, and studies reporting nutrition, body composition, organ support, or clinical outcomes. English-language full texts were used. The review was not preregistered, duplicate independent screening was not

performed, and no PRISMA flow diagram or quantitative meta-analysis was undertaken. These decisions should be considered when interpreting completeness and selection bias.

2.2. Evidence directness and synthesis

Evidence was interpreted using a prespecified directness hierarchy: (1) pediatric oncology PICU evidence; (2) general PICU evidence; (3) non-critical pediatric oncology or HSCT evidence; (4) adult clinical evidence; and (5) mechanistic or preclinical evidence. Study design and population directness are described in the text and tables. We did not perform formal Grading of Recommendations Assessment, Development and Evaluation (GRADE); therefore, labels such as low, indirect, or very low are descriptive, not formal certainty ratings. Where direct evidence was absent, recommendations are explicitly framed as conditional extrapolations or knowledge gaps.

For each high-risk clinical claim, we asked four questions: (i) whether the source population included children with cancer in a PICU; (ii) whether the evidence described association, prognosis, or an intervention; (iii) whether a numerical threshold was validated for children of different ages and sizes; and (iv) whether the proposed action could cause harm if generalized. This claim-level audit led us to remove unsupported universal calorie and protein targets, distinguish prognostic markers from nutrition-response measures, and separate ECMO from CRRT. The same wording and evidence boundaries were then synchronized across the abstract, main text, figures, tables, and reviewer responses.

3. Pathophysiological basis: A proposed triple-hit model

Malnutrition in pediatric oncology critical care can be conceptualized as three interacting insults: cancer-driven inflammation and metabolic rewiring, anticancer-treatment toxicity, and critical illness with organ support (Figure 1). These insults may converge through inflammatory, mitochondrial, gastrointestinal, neuroendocrine, muscular, and fluid-related pathways. The model explains why a child may simultaneously gain measured weight during resuscitation, lose lean tissue, exhibit hypoalbuminemia from inflammation, and remain catabolic despite apparently adequate calorie delivery. It is a hypothesis-generating structure rather than a validated causal model.

3.1. Cancer biology and cellular catabolism

Adult cancer-cachexia and preclinical studies identify a network rather than a single pathway. Tumor- and host-

derived tumor necrosis factor alpha (TNF- α), interleukin 1 beta (IL-1 β), and interleukin 6 (IL-6) can activate nuclear factor kappa B (NF- κ B) and signal transducer and activator of transcription 3 (STAT3), increasing ubiquitin-proteasome and autophagy-lysosome activity while suppressing muscle-protein synthesis. These mechanisms are biologically plausible in children, but most have not been demonstrated directly in pediatric oncology PICU cohorts.^{12,13}

Skeletal muscle is both a target and a metabolic organ. Cancer-associated inflammation, inactivity, glucocorticoids, and selected cytotoxic agents can increase proteolysis and impair myogenesis.^{14–16} Neuroendocrine stress adds cortisol, catecholamine, and glucagon signaling, insulin resistance, reduced insulin-like growth factor 1 activity, and a non-thyroidal-illness pattern. In critically ill children, endocrine changes correlate with inflammation and are not simply corrected by increasing calorie delivery.¹⁷

Reactive oxygen species (ROS) and mitochondrial dysfunction may reduce adenosine triphosphate production, disturb mitochondrial quality control, and amplify fatigue and muscle wasting. Evidence is strongest in adult cancer and experimental models.¹⁸ Organ cross-talk further complicates interpretation: intestinal barrier disruption can increase microbial-product exposure; hepatic acute-phase reprioritization lowers albumin synthesis; adipose lipolysis changes circulating substrates; renal dysfunction alters amino-acid and micronutrient handling; and cardiac or respiratory failure raises the cost of recovery. These processes can reinforce one another without establishing that a single biomarker identifies nutritional depletion.

The relative contribution of these pathways probably differs by diagnosis and treatment. A child with leukemia, prolonged neutropenia, corticosteroid exposure, and sepsis may have sustained immune and endocrine stress with repeated interruptions. A child with an abdominal solid tumor may have mechanical obstruction, surgery, radiation injury, or reduced absorptive surface. Central nervous system tumors can impair swallowing, consciousness, or endocrine axes, while thoracic disease can raise respiratory work. These are clinically useful phenotypes, but current evidence does not justify diagnosis-specific numeric feeding targets; the relevant variables must still be measured in the individual child.

3.2. Anticancer-treatment toxicity

Chemotherapy injures rapidly proliferating gastrointestinal epithelium, producing oral mucositis, esophagitis, enteritis, pain, nausea, diarrhea, malabsorption, and

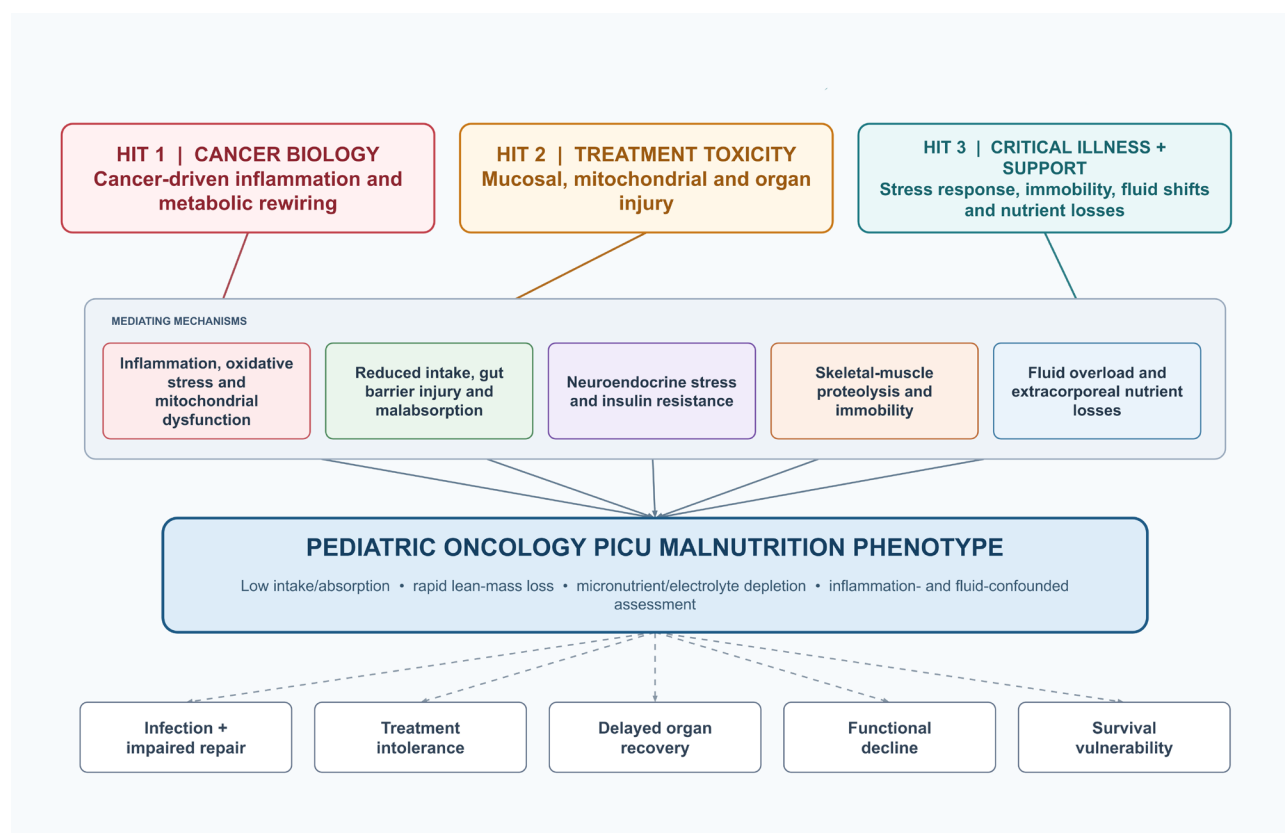


Figure 1. Proposed triple-hit model of malnutrition in pediatric oncology critical care. Cancer biology, anticancer-treatment toxicity, and critical illness with organ support interact through inflammatory, mitochondrial, gastrointestinal, neuroendocrine, muscular, and fluid-related mechanisms. These processes converge on a pediatric oncology PICU malnutrition phenotype characterized by impaired intake or absorption, rapid lean mass loss, micronutrient and electrolyte depletion, and inflammation- or fluid-confounded assessment. The phenotype may contribute to infection and impaired repair, treatment intolerance, delayed organ recovery, functional decline, and survival vulnerability. Solid arrows denote the proposed mechanistic sequence; dashed arrows denote hypothesized downstream consequences. The model integrates general PICU, non-critical pediatric oncology, adult, and preclinical evidence and requires prospective validation.

Abbreviation: PICU: Pediatric intensive care unit.

occasionally protein-losing enteropathy.^{19,20} Radiotherapy can cause site-specific toxicity: abdominal or pelvic exposure may lead to enteritis, fibrosis, bleeding, or strictures, whereas head, neck, or thoracic exposure can impair taste, swallowing, and esophageal function.^{21,22} Treatment-associated hepatic, pancreatic, cardiac, renal, and neuromuscular injury can further restrict route or composition.

HSCT adds a temporal sequence of conditioning injury, microbiome disturbance, inflammation, and immunosuppression. Nutrition support is often required during this period, but route decisions change as mucosal integrity and graft-versus-host disease evolve.²³ Gastrointestinal graft-versus-host disease (GI-GVHD) can cause diarrhea, bleeding, protein loss, pain, and malabsorption; pediatric evaluation should integrate stool

output relative to body size with symptoms and functional absorption.²⁴ Microbiome associations with GI-GVHD outcomes are clinically relevant but do not prove that a particular formula or supplement modifies risk.²⁵

3.3. Infection, critical illness, and the PICU environment

Uncontrolled or recurrent infection can sustain anorexia, inflammation, insulin resistance, and protein breakdown. Fever and neutropenia guidelines emphasize risk-adapted antimicrobial management in pediatric cancer and HSCT populations.²⁶ Broad-spectrum antibiotic exposure has been associated with graft-versus-host disease in pediatric transplantation cohorts, plausibly through microbiome disruption, although confounding by indication is substantial.²⁷ Nutrition assessment should

therefore record infection burden, neutropenia, mucosal injury, antimicrobial exposure, appetite, gastrointestinal symptoms, and procedure-related interruptions rather than attributing all deterioration to one drug class.

Critical illness itself produces variable energy expenditure, endogenous substrate production, insulin resistance, and accelerated proteolysis.^{28,29} Some children are hypometabolic and others hypermetabolic; repeated measurement by indirect calorimetry may reveal trajectories that prediction equations cannot. Persistent hypermetabolism has been associated with muscle wasting and energy deficit, but the available ICU evidence is not oncology-specific.³⁰ A subset progresses toward persistent inflammation, immunosuppression, and catabolism, a syndrome described in adult and pediatric critical care literature but insufficiently characterized in pediatric oncology.^{31,32}

Mechanical ventilation, sedation, neuromuscular blockade, and bed rest reduce muscle loading and may accelerate functional decline. ECMO and CRRT add fluid, circuit, and nutrient-loss considerations. Repeated fasting for procedures, airway management, hemodynamic concern, or imaging can create a cumulative nutrient deficit. In a prospective PICU study, children spent a large proportion of admission without nutrition support and received only part of estimated energy and protein needs.³³ A 2026 meta-analysis confirmed that enteral-feeding interruption is common in critically ill children.³⁴ Duration and intensity of ventilation, extracorporeal support, immobility, and interruption should therefore be documented as dynamic risk modifiers.

4. Nutrition assessment: From static markers to dynamic context

Assessment should combine anthropometry, intake, fluid balance, inflammatory burden, organ support, body-composition trajectory, and function (Table 1). No single measure diagnoses nutritional response in this setting. Laboratory and device-derived measurements should change the quality of multidisciplinary reassessment, not generate an automatic energy or protein prescription.

4.1. Conventional measures and fluid confounding

Serum albumin, prealbumin, and related visceral proteins are unreliable as stand-alone nutrition markers during critical illness. Inflammation redistributes hepatic synthesis toward acute-phase proteins, capillary leak changes distribution, and organ dysfunction alters clearance.³⁵ In a prospective PICU study, changes in prealbumin and retinol-binding protein tracked C-reactive protein (CRP) more closely than changes in energy or protein delivery.³⁶

These tests may inform illness context but should not be labeled feeding-response biomarkers.

Measured body weight remains essential, but it must be interpreted alongside cumulative fluid balance, edema, and diuretic exposure. Fluid accumulation is common and associated with adverse pediatric critical-care outcomes.^{37,38} When reported, percent fluid accumulation can be estimated as $100 \times \text{cumulative fluid balance in liters} / \text{admission weight in kilograms}$. Both numerator and denominator are error-prone: intake/output records are incomplete, admission weight may already be fluid-affected, and one liter cannot always be treated as one kilogram of freely removable water. The term fluid-corrected weight should therefore be avoided unless a transparent, validated method is available.

Growth charts, weight-for-height, body mass index (BMI)-for-age, mid-upper-arm circumference, recent weight change, and dietary history remain foundational for identifying pediatric undernutrition.³⁹ Acute lean mass loss may nevertheless precede visible anthropometric change. Serial measured weight should be obtained when feasible under standardized conditions and interpreted with a fluid narrative rather than mathematically converted into a presumed euvoletic body composition.

4.2. Critical-care-specific tools

Bioelectrical impedance analysis (BIA) estimates electrical properties of tissue; phase angle (PhA) has been proposed as a composite marker related to membrane integrity and body composition.⁴⁰ In a prospective cohort of 205 critically ill children, a low admission PhA was associated with mortality and longer PICU stay.⁴¹ The reported cutoff was study-, device-, age-, and population-specific. Edema and rapid fluid shifts can distort measurement. PhA should therefore be described as an adjunctive prognostic or risk-stratification marker, not a validated measure of response to feeding.

The CRP-to-albumin ratio (CAR) similarly reflects inflammation and severity rather than nutrient reserve. In retrospective and prospective general PICU cohorts, higher CAR was associated with mortality and with the Pediatric Risk of Mortality III (PRISM III) score.^{42,43} CAR may support risk communication, but changing CAR cannot be assumed to represent successful or unsuccessful nutrition therapy.

Bedside skeletal-muscle ultrasound can document serial change in quadriceps or other standardized sites. General PICU cohorts show substantial early muscle loss, particularly among mechanically ventilated children.^{44–46} A 2025 systematic review estimated an approximately 9% pooled decline in quadriceps thickness during the first

week, but observational data did not establish that higher protein or energy delivery prevents this loss.⁴⁷ Ultrasound can trigger review of intake, inflammation, mobilization, edema, and rehabilitation; it cannot identify a required protein dose.

Handgrip strength can complement recovery assessment in older, awake, cooperative children. Lower values in hospitalized pediatric populations correlate with poorer anthropometry and longer stay, but evidence is highly indirect to oncology PICU care.⁴⁸ The measure is not feasible during shock, deep sedation, paralysis, or severe weakness and should not be used as an acute feeding target.

4.3. Reassessment at clinical transitions

A fixed day 1, 3, and 7 schedule is not validated for this population. A more defensible approach is to obtain a baseline assessment within the first 24 hours when feasible, reassess during hemodynamic or fluid-status changes, and repeat standardized measurements at major clinical transitions: initiation or escalation of organ support, stabilization, substantial diuresis, prolonged interruption, route change, mobilization, PICU transfer, and discharge. Daily review during instability should focus on delivered

intake, interruptions, electrolytes, glucose, fluid balance, perfusion, gastrointestinal findings, and refeeding risk; device-dependent measurements can be repeated only when conditions are comparable.

The purpose of reassessment is to identify trajectory and reversible barriers. A rising weight during positive fluid balance does not demonstrate tissue gain; a falling weight during diuresis does not prove worsening malnutrition; a lower PhA during edema does not independently justify parenteral nutrition; and muscle loss does not automatically mandate a universal high-protein prescription. Each signal should lead to integrated review of illness phase, delivery versus prescription, fluid exposure, organ function, inflammation, medications, and mobility.

Implementation should also account for measurement quality. Weight should be obtained on the same calibrated bed or scale where possible; ultrasound should use a defined site, limb position, pressure, and operator-training process; BIA should record device and fluid state; and functional testing should document age, cooperation, sedation, pain, and dominant-hand status. Trends collected under incomparable conditions may create false precision. A useful bedside note records not only the value but also

Table 1. Candidate dynamic assessment tools in pediatric oncology critical care: intended roles, limitations, and evidence directness

Tool	Population/Design	Intended role	Key limitations	Evidence level/ Directness	References
BIA phase angle (PhA)	Single prospective general PICU cohort, <i>n</i> = 205; measured within 72 h	Adjunctive prognostic risk stratification; serial use remains investigational	Affected by age, device, disease spectrum, edema, and fluid shifts; not validated as a measure of nutritional response	Low; indirect to pediatric oncology PICU	41
CRP-to-albumin ratio (CAR)	Retrospective general PICU cohort, <i>n</i> = 8,000; prospective cohort, <i>n</i> = 102	Describes inflammatory or severity burden and support prognostic stratification	Combines an acute-phase reactant with a negative acute-phase protein; does not measure nutrition reserve or response to feeding	Low; indirect	42,43
Bedside skeletal-muscle ultrasound	Observational general PICU and mechanically ventilated cohorts	Standardized serial documentation of muscle thickness or cross-sectional area	Operator-, site-, device-, and edema-dependent; pediatric references incomplete; does not identify a required protein dose	Low; indirect	44–46
Handgrip strength	Hospitalized pediatric reference and outcome data; not oncology PICU	Recovery- or discharge-phase functional assessment in awake, cooperative children	Not feasible in young children, shock, deep sedation, paralysis, or severe weakness; not an acute feeding target	Very low; highly indirect	48
Serial measured weight interpreted with cumulative fluid balance	Pediatric critical-care fluid-overload reviews; no validated nutrition-correction equation	Identifies fluid-related distortion of weight trajectory and trigger complementary assessment	Balance records and admission weight are error-prone; weight change does not equal lean-mass change or set energy/protein prescriptions	Low for fluid-outcome association; very low for nutrition prescription	37,38

Note: Evidence level/directness is a descriptive assessment of study design and applicability and is not a formal GRADE rating. None of these tools has been validated to diagnose nutritional response or determine energy or protein targets in pediatric oncology PICU patients. Abbreviations: BIA: Bioelectrical impedance analysis; CRP: C-reactive protein; PhA: Phase angle; PICU: Pediatric intensive care unit.

whether edema, dressings, drains, positioning, or device changes limit comparison.

5. Nutrition support across physiologic phases

Nutrition support should be phase-aware, age-aware, and responsive to physiology rather than tied to fixed calendar cutoffs (Figure 2). Enteral nutrition (EN) is preferred when the gastrointestinal tract is usable after adequate resuscitation. Parenteral nutrition (PN) is reserved for situations in which EN is contraindicated or persistently inadequate after reversible barriers have been addressed. The proposed framework is a decision scaffold, not an established pediatric oncology PICU protocol.

5.1. Energy estimation and refeeding risk

Indirect calorimetry is preferred when available because energy expenditure varies across age, diagnosis, organ support, sedation, fever, and illness phase. General Society of Critical Care Medicine/American Society for Parenteral and Enteral Nutrition (SCCM/ASPEN) and European Society of Paediatric and Neonatal Intensive Care (ESPNIC) guidance advises avoiding delivery above measured resting energy expenditure during the acute phase.^{29,50} When indirect calorimetry is unavailable, an age-appropriate predictive equation without an arbitrary stress factor is preferable to a universal kcal/kg target. Total energy assessment should include nutrition, intravenous dextrose, and lipid-based medications where relevant. Components of pediatric total energy expenditure change with growth and recovery, further limiting one-size-fits-all targets.⁵¹

Refeeding risk should be assessed before rapid advancement in children with severe undernutrition, substantial recent weight loss, prolonged negligible intake, or low phosphate, potassium, or magnesium. The ASPEN consensus recommends thiamine and close electrolyte monitoring, accounting for intravenous glucose, and cautious initiation. For high-risk children, a practical starting point is approximately 40%–50% of the age- and size-appropriate goal, followed by stepwise advancement according to electrolyte and clinical response; the consensus also describes pediatric glucose infusion guidance rather than a universal kcal/kg threshold.⁵² If electrolytes fall precipitously, energy—particularly dextrose—should be reduced or paused while deficits are corrected. Protein should not be automatically restricted solely because refeeding risk is present.

Energy accounting should distinguish prescribed nutrition from non-nutrition substrates. Dextrose-containing maintenance fluids, drug carriers, and

dialysis solutions may contribute carbohydrate; propofol contributes lipid calories when used; and citrate contributes energy only when delivered and metabolized systemically. Conversely, heparin, saline, and most medication volumes do not provide calories. Counting these sources can prevent inadvertent excess, but aggressively replacing every shortfall in the acute phase can also overfeed. Daily totals should therefore be interpreted against measured expenditure, carbon-dioxide production, glucose control, triglycerides, hepatic function, and the trajectory of organ support rather than a single percentage goal.

5.2. Protein and muscle trajectory

General PICU guidance suggests a minimum protein delivery of approximately 1.5 g/kg/day when feasible, but evidence quality is limited and the recommendation is not oncology-specific.⁵⁰ Age, premorbid status, renal and hepatic function, CRRT losses, gastrointestinal losses, nitrogen tolerance, and phase of illness should inform progression. Universal prescriptions of 2–3 g/kg/day are not supported for pediatric oncology critical care.

Protein delivery should not be equated with reversal of catabolism. The systematic review linking intake and muscle change included heterogeneous observational cohorts and could not establish that higher delivery prevented muscle loss.⁴⁷ When ultrasound or function worsens, clinicians should examine actual versus prescribed delivery, interruptions, inflammation, corticosteroid exposure, renal replacement, pain, sedation, and mobilization. Increasing protein density may be reasonable in selected recovery-phase children, but it should be a monitored intervention rather than a reflex response to one measurement.

5.3. Enteral and parenteral routes

Enteral nutrition (EN) should be attempted or continued when perfusion is adequate, abdominal findings are reassuring, and there is no dominant contraindication such as bowel ischemia, obstruction, uncontrolled bleeding, or perforation. Normal bowel sounds and full gastric tolerance are not prerequisites. Gastric feeding is usually simplest; post-pyloric access may be considered for persistent gastric intolerance or aspiration risk when distal absorption is plausible. Evidence comparing routes in cancer populations is heterogeneous and largely outside pediatric critical care.⁵³ General PICU studies associate earlier EN with favorable process outcomes, but residual confounding limits causal interpretation.⁵⁴

The PEPaNIC randomized trial materially changes discussion of early supplemental PN. Among 1,440 critically ill children, withholding supplemental PN through day 7 and initiating it on day 8 if still required, compared with

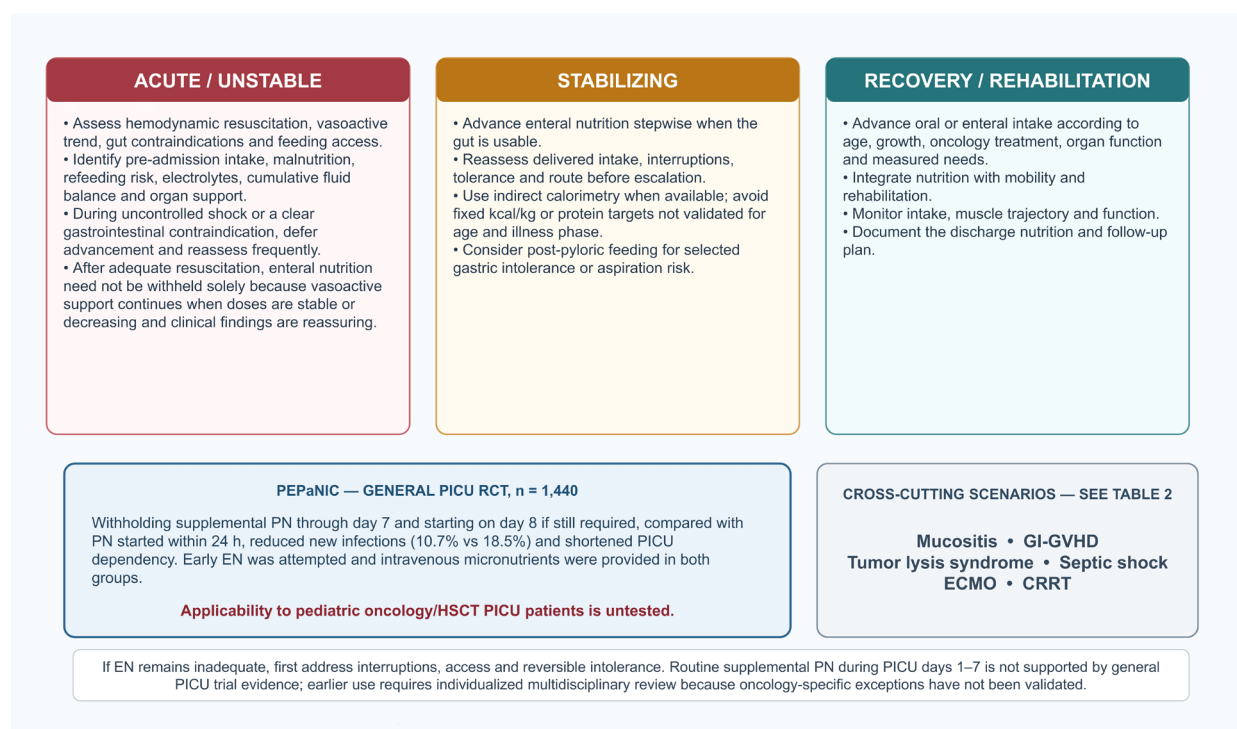


Figure 2. Proposed evidence-informed nutrition framework across phases of pediatric oncology critical care. The framework is a decision scaffold rather than a validated protocol; transitions are determined by physiology, gastrointestinal usability, organ support, and recovery rather than fixed calendar cutoffs. In the general PICU PEPaNIC randomized trial ($n = 1,440$), withholding supplemental PN through day 7 and starting on day 8, if still required, reduced new infections (10.7% versus 18.5%) and shortened PICU dependency compared with PN started within 24 hours.⁴⁹ Applicability to pediatric oncology and HSCT PICU populations remains untested.

Abbreviations: CRRT: Continuous renal replacement therapy; ECMO: Extracorporeal membrane oxygenation; EN: Enteral nutrition; GI-GVHD: Gastrointestinal graft-versus-host disease; HSCT: Hematopoietic stem-cell transplantation; PICU: Pediatric intensive care unit; PN: Parenteral nutrition.

PN started within 24 h, reduced new infections (10.7% versus 18.5%) and shortened PICU dependency. Early EN was attempted and intravenous micronutrients were supplied in both groups.⁴⁹ A secondary analysis of 289 undernourished children did not demonstrate benefit from early PN, although subgroup analysis cannot define every high-risk exception.⁵⁵ ESPNIC guidance consequently supports considering withholding supplemental PN during the first PICU week while providing indicated glucose, electrolytes, vitamins, and trace elements.²⁹

PEPaNIC did not test a pediatric oncology- or HSCT-specific strategy. Therefore, the evidence does not justify presenting children with cancer as a proven exception, nor does it exclude rare individualized indications. During PICU days 1–7, supplemental PN should not be started solely to close a calculated energy deficit. If EN remains inadequate, the team should first address fasting, access, symptoms, fluid limits, and reversible intolerance. Any earlier PN should follow explicit multidisciplinary review of baseline malnutrition, anticipated gastrointestinal

failure, treatment trajectory, and catheter risk; from day 8 onward, the indication can be reassessed if adequate EN remains unachievable.

When PN is used, the prescription should be treated as a monitored therapy rather than a default route. Central-line infection risk, glucose, triglycerides, hepatic and renal function, fluid and electrolyte load, compatibility with anticancer drugs, micronutrient provision, and the continuing opportunity for enteral exposure should be reviewed. Combined EN and PN may be reasonable after the first week when EN remains insufficient, but the combined total—not each route in isolation—must be compared with the individualized goal. The route should be reassessed at every major clinical transition so that temporary PN does not persist after gastrointestinal function recovers.

5.4. Immunonutrition and evidence boundaries

Formulas or supplements containing arginine, glutamine, omega-3 fatty acids, selenium, zinc, or nucleotide

combinations are often grouped as immunonutrition. Evidence of benefit is most developed in adult perioperative populations and cannot be generalized to children with shock, neutropenia, mucosal barrier injury, renal replacement, or active sepsis. Pediatric oncology trials are small, diagnosis-specific, and frequently outside intensive care. Routine immunonutrition is therefore not supported for pediatric oncology PICU patients. A nutrient may still be indicated to treat a documented deficiency or a defined non-PICU indication, but that is different from prescribing an immune-modulating formula to all patients.

The safety question is as important as efficacy. Renal or hepatic dysfunction may alter clearance; CRRT may increase loss of selected water-soluble compounds; and mucosal injury may change absorption. Biomarkers such as inflammation or low serum micronutrient concentration can also be redistributed during critical illness and should not automatically trigger high-dose replacement. Future trials should specify formulation, dose, baseline status, organ support, interaction with chemotherapy, infection outcomes, and adverse events rather than treating immunonutrition as one uniform intervention.

5.5. Multidisciplinary nutrition and rehabilitation

Pediatric oncology consensus supports standardized screening and individualized escalation outside the PICU, but direct evidence for critical-care prescriptions is limited.⁵⁶ A nutrition support team intervention has been associated with fewer fasting days in pediatric cancer care, and international recommendations emphasize coordinated dietetic practice.^{57,58} In the PICU, nutrition rounds should record delivered energy and protein, interruption reasons, route, safety barriers, fluid context, and the next recovery goal.

Nutrition and rehabilitation should be synchronized. Protein delivery alone is unlikely to restore function if a child remains immobilized after shock resolves, while mobilization may be limited by inadequate intake, anemia, pain, nausea, or electrolyte disturbance. Recovery plans should integrate physiotherapy, symptom control, oral or tube-feeding progression, muscle and functional monitoring, upcoming anticancer therapy, and transfer of responsibility to the oncology ward or outpatient team.

6. Special clinical scenarios

Selected scenarios require changes in route, composition, or monitoring (Table 2). These recommendations are conditional because direct pediatric oncology PICU evidence is absent for most decisions. Diagnoses frequently overlap; physiology, gastrointestinal function, perfusion, electrolyte trajectory, fluid constraints, and organ support

should guide the sequence of decisions.

For overlapping scenarios, the plan should identify explicit pause-and-reassess triggers rather than rely on diagnosis alone. Worsening perfusion, escalating vasoactive support, new gastrointestinal bleeding, suspected ischemia or obstruction, uncontrolled vomiting, rapidly rising abdominal distension, severe electrolyte deterioration, or a catheter complication may justify temporary change. These triggers are clinical safeguards, not validated numeric cutoffs. Their purpose is to prevent both unsafe persistence and premature abandonment of EN while the dominant physiology changes.

6.1. Severe mucositis

Severe mucositis can reduce intake through pain, dysphagia, nausea, vomiting, bleeding, and infection risk. The essential distinction is between oral intolerance and intestinal failure. Oral pain alone should prompt analgesia, mucosal care, and alternative access rather than automatic PN. Gastric or post-pyloric EN may remain feasible when the distal gastrointestinal tract is functional. PN may be necessary for obstruction, uncontrolled bleeding, ileus, severe malabsorption, or prolonged intolerance that prevents adequate EN. Pediatric trials of glutamine for mucositis have produced inconsistent findings, so routine use cannot be recommended.^{56,59,60}

6.2. Gastrointestinal graft-versus-host disease

GI-GVHD assessment should combine stool output relative to body size with frequency, pain, bleeding, ileus, absorption, protein loss, and electrolyte loss. An adult-derived absolute threshold of 500 mL/day is inappropriate as a universal pediatric cutoff. Pediatric guidance supports preserving or reintroducing EN as tolerated; semi-elemental formulas may be considered during recovery, while PN is appropriate when severe malabsorption or intestinal failure prevents adequate EN.^{24,61} Protein delivery should be individualized to age, losses, renal function, and tolerance; the literature does not validate a universal 1.8–2.5 g/kg/day target in pediatric GI-GVHD.⁶²

6.3. Tumor lysis syndrome

During unstable tumor lysis syndrome, hydration, urate-lowering therapy, electrolyte monitoring, and renal management take priority. Potassium and phosphate should not be added routinely to intravenous fluids during active hyperkalemia or hyperphosphatemia. However, available evidence does not support routine fasting or a low-phosphate formula as standard nutrition therapy.⁶³ Nutrition can continue or resume when clinically safe; persistent severe electrolyte abnormalities may require individualized formula or electrolyte modification with

Table 2. Evidence-informed nutrition considerations in selected pediatric oncology PICU scenarios

Scenario	Evidence-informed considerations	Statements to avoid / Limitations	Evidence level/ Directness	References
Severe mucositis	Treat pain, nausea, and bleeding risk; preserve oral or gastric EN when tolerated. Consider post-pyloric access when gastric feeding is unsafe or poorly tolerated and the distal gut is usable. Use PN for intestinal failure, obstruction, uncontrolled bleeding, or prolonged severe intolerance preventing adequate EN.	Oral pain alone is not an indication for PN. Routine glutamine use is not supported.	Pediatric oncology consensus and small trials; low and indirect to PICU	56,59,60
GI-GVHD enteropathy	Assess stool output relative to body size together with bleeding, pain, ileus, absorption, protein loss, and electrolyte loss. Continue or reintroduce EN as tolerated; consider semi-elemental formulas during recovery. Use PN when severe malabsorption or intestinal failure prevents adequate EN.	Do not use an absolute 500 mL/day pediatric cutoff or a universal 1.8–2.5 g/kg/day protein target.	Pediatric position paper plus adult and HSCT evidence; very low or indirect	24,61,62
Tumor lysis syndrome	Prioritize hydration, urate lowering, electrolyte management, and renal support. Continue or resume nutrition when clinically safe; adapt potassium and phosphate load case-by-case with oncology, nephrology, and dietetic input.	No evidence supports routine fasting or a low-phosphate formula as standard TLS nutrition therapy.	Pathophysiology and expert guidance; very low	63
Septic shock	After adequate resuscitation, EN need not be withheld solely because vasoactive drugs continue when doses are stable or decreasing and perfusion and abdominal findings are reassuring. Reassess frequently and apply general PICU PN timing evidence.	No validated catecholamine or lactate threshold; direct oncology evidence absent.	Pediatric guideline; conditional and indirect to oncology	49,64,65
ECMO	Consider EN after stabilization; monitor delivery, interruptions, fluid limits, and tolerance. Count only energy-bearing non-nutrition substrates such as dextrose or propofol lipid.	Heparin provides no calories. No validated ECMO-specific energy or protein target.	Pediatric guideline and observational evidence; very low	66
CRRT	Monitor amino-acid, electrolyte, water-soluble vitamin, and trace-element losses. Individualize energy, protein, and replacement by age, status, effluent dose, laboratory trends, and nitrogen tolerance.	Do not apply a universal high-protein target or automatic micronutrient regimen; deficiency and accumulation are both possible.	Consensus, reviews, and small observational studies; very low	67–69

Note: Recommendations are conditional and should not be interpreted as a pediatric oncology PICU protocol. Evidence level/directness is descriptive rather than a formal GRADE rating. Direct evidence in pediatric oncology critical care is absent for most scenarios.

Abbreviations: CRRT: Continuous renal replacement therapy; ECMO: Extracorporeal membrane oxygenation; EN: Enteral nutrition; GI-GVHD: Gastrointestinal graft-versus-host disease; HSCT: Hematopoietic stem-cell transplantation; PICU: Pediatric intensive care unit; PN: Parenteral nutrition; TLS: Tumor lysis syndrome.

oncology, nephrology, pharmacy, and dietetic input. Fluid-exposed weight must be interpreted in the context of cumulative balance.

6.4. Septic shock

During uncontrolled shock, escalating vasoactive support, or suspected gastrointestinal ischemia, feed advancement should be deferred and frequently reassessed. The 2020 pediatric sepsis guideline suggested that, after adequate resuscitation, EN need not be withheld solely because vasoactive therapy continues when doses are stable or decreasing and perfusion and abdominal findings are reassuring.⁶⁴ The 2026 guideline update did not generate new oncology-specific nutrition evidence; current practice therefore still depends on general pediatric critical-care guidance and clinical assessment.⁶⁵ No fixed catecholamine or lactate threshold has been validated.

Routine supplemental PN during the first seven days should follow the general PICU evidence described above.

6.5. Extracorporeal membrane oxygenation

Extracorporeal membrane oxygenation (ECMO) should be considered separately from renal replacement. Pediatric ECMO guidance supports assessing EN after stabilization while monitoring fluid limits, interruption, tolerance, and delivered intake.⁶⁶ Energy-bearing intravenous dextrose and lipid emulsions, including the lipid vehicle of propofol when used, should be counted. Heparin provides no calories. Citrate contribution depends on the anticoagulation regimen and systemic metabolism and should not be assumed. No validated ECMO-specific energy or protein target exists for pediatric oncology patients.

6.6. Continuous renal replacement therapy

Continuous renal replacement therapy (CRRT) can remove amino acids, water-soluble vitamins, trace elements, and electrolytes. Recommendations for pediatric acute kidney injury advise individualizing nutrition according to age, premorbid status, effluent dose, laboratory trends, nitrogen tolerance, and recovery phase.⁶⁷ Reviews describe amino acid losses that may reach a clinically important fraction of delivery, but pediatric data are small and heterogeneous.⁶⁸ Micronutrient replacement should be guided by duration, modality, losses, laboratory feasibility, and risk of both deficiency and accumulation; automatic high-dose supplementation or a universal high protein prescription is not supported.⁶⁹

7. Evidence base and limitations

The principal limitation is directness. Most intervention evidence comes from general PICU trials; much of the oncology literature involves stable ward or outpatient populations; GI-GVHD evidence often derives from HSCT cohorts outside intensive care; and many mechanistic claims originate from adult cachexia or preclinical models. Even direct pediatric oncology PICU studies are predominantly retrospective or observational. The evidence-directness labels in this review describe applicability but do not constitute formal GRADE ratings.

The narrative method introduces additional limitations. Only PubMed/MEDLINE was searched systematically; supplementary searches were targeted rather than exhaustive; duplicate screening and formal risk-of-bias assessment were not performed; and English-language selection may have excluded relevant evidence. Publication through August 11, 2026, means that recently indexed evidence may be incompletely represented. The figures synthesize the literature but have not been prospectively tested as prediction tools or treatment algorithms.

Several apparent bedside metrics remain uncertain. CAR and PhA are mainly prognostic or severity markers; ultrasound documents muscle trajectory but not cause or protein need; cumulative fluid balance is itself imprecise; and delivered energy or protein does not reveal why a deficit occurred. A framework can improve visibility and consistency, but it cannot substitute for validated pediatric oncology-specific thresholds.

8. Future research priorities

Prospective multicenter registries should characterize nutrition phenotypes by malignancy type, treatment stage, infection burden, organ support, fluid trajectory, and baseline nutritional status. Minimal datasets should include route, measured and delivered intake, interruption

causes, indirect calorimetry where feasible, weight with fluid context, standardized muscle ultrasound, functional outcomes, and oncology-treatment interruption.

Pragmatic trials should test questions that remain unresolved after PEPaNIC: (i) whether selected pediatric oncology or HSCT subgroups benefit from different PN timing; (ii) how age- and phase-specific protein strategies affect function rather than nitrogen delivery alone; and (iii) whether nutrition combined with early rehabilitation improves muscle recovery. Trials should prespecify safety outcomes, infection, feeding intolerance, organ support duration, treatment tolerance, length of PICU stay, survival, and patient-centered function.

Consensus definitions are also required. Malnutrition, sarcopenia, refeeding risk, feeding intolerance, fluid-contextualized weight change, and nutrition rehabilitation are measured inconsistently. Harmonized definitions and evidence directness reporting would make cohorts comparable and prevent unvalidated pragmatic suggestions from being interpreted as protocols.

Implementation science should accompany efficacy research. Studies should report whether indirect calorimetry, dietetic staffing, post-pyloric access, standardized ultrasound, rehabilitation, and micronutrient monitoring are available, because a theoretically optimal recommendation may be infeasible in many units. Low-resource and high-resource settings may require different operational pathways while preserving the same principles of physiologic safety, transparent evidence limits, and reassessment of modifiable delivery barriers.

9. Conclusion

Malnutrition in pediatric oncology critical care reflects interacting cancer, treatment, and critical-illness processes. Assessment should be multidimensional: serial measured weight interpreted with cumulative fluid balance, standard anthropometry and intake history, inflammatory context, organ-support exposure, muscle trajectory, and function when feasible. CAR and PhA should remain risk markers, and muscle ultrasound should remain a trajectory measure—not automatic determinants of energy or protein prescriptions.

The most defensible current strategy is enteral-first after adequate resuscitation when the gastrointestinal tract is usable, cautious advancement for refeeding risk, measured energy expenditure when available, and integration of nutrition with rehabilitation. General PICU evidence supports withholding routine supplemental PN during the first seven days, but oncology-specific applicability and exceptions remain insufficiently tested. The proposed

triple-hit model and phase-aware framework can organize decisions and research; they require prospective validation before being treated as a pediatric oncology PICU protocol.

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Author contributions

Conceptualization: Peiyu Huang

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Ethics approval and consent to participate

Not applicable. This narrative review analyzed published literature and involved no new human participants, animal experiments, or identifiable patient data.

Consent for publication

Not applicable.

Availability of data

No new datasets were generated or analyzed. The reproducible PubMed search string and evidence-directness framework are provided in the Appendix, and all evidence cited is available in the published literature.

Further disclosure

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Appendix

Supplementary methods: Reproducible PubMed/MEDLINE search

Search date: August 11, 2026. Coverage: database inception through the search date. No date restriction was added other than the search-end date. The synthesis used English-language full text.

Core query (188 records on the search date):

(child* OR pediatric* OR paediatric*) AND (cancer OR oncology OR leukemia OR lymphoma OR tumor OR tumour) AND ("pediatric intensive care" OR "paediatric intensive care" OR PICU) AND (nutrition OR malnutrition OR enteral OR parenteral OR body composition OR muscle)

Targeted supplementary concepts

Pediatric oncology nutrition: nutrition, malnutrition, cachexia, sarcopenia, micronutrient, enteral, parenteral.

General PICU assessment/support: indirect calorimetry, phase angle, muscle ultrasound, CRP-to-albumin ratio, enteral nutrition, parenteral nutrition.

Special scenarios: mucositis, graft-versus-host disease, tumor lysis syndrome, sepsis, septic shock, ECMO, and CRRT, combined with nutrition, feeding, micronutrient, or protein terms.

Reference list screening of relevant guidelines, systematic reviews, and position papers.

Selection and synthesis limitations

Selection was purposive and iterative for a narrative review. Duplicate screening, preregistration, formal risk-of-bias assessment, PRISMA flow reporting, formal GRADE, and quantitative pooling were not performed. The broad targeted queries were used to identify domain-specific evidence; their record counts should not be interpreted as a systematic-review screening flow.

Table A1. Evidence-directness framework

Tier	Population/Source	How it is used	Primary limitation
1	Pediatric oncology PICU	Direct description of population, risk, or outcome	Predominantly observational; few nutrition interventions
2	General pediatric PICU	Intervention and critical-care guidance, including PEPaNIC	Oncology and HSCT subgroups not specifically validated
3	Non-critical pediatric oncology or HSCT	Diagnosis/Treatment-related nutritional phenotype and special scenarios	Different physiology and organ-support exposure
4	Adult clinical	Mechanistic or special-scenario context when pediatric evidence absent	Age, growth, disease, and treatment differences
5	Preclinical/Mechanistic	Biological plausibility and hypothesis generation	Cannot establish bedside effect or prescription

Table A2. High-risk claim audit

Claim/domain	Final wording	Directness	Key source(s)
Early supplemental PN	Withhold routine supplemental PN through PICU day 7; reassess from day 8 if EN remains inadequate; oncology applicability untested.	Tier 2	PEPaNIC; ESPNIC
Energy target	Use indirect calorimetry when available; otherwise, an age-appropriate equation without arbitrary stress factors.	Tier 2	SCCM/ASPEN; ESPNIC
Protein target	General PICU minimum guidance is not oncology-specific; no universal 2–3 g/kg/day target.	Tier 2	SCCM/ASPEN; muscle review
CAR/PhA	Prognostic or risk markers, not feeding-response measures.	Tier 2	General PICU cohorts

(Cont'd...)

Table A2. (Continued)

Claim/domain	Final wording	Directness	Key source(s)
Muscle ultrasound	Documents trajectory; does not determine a protein dose.	Tier 2	General PICU cohorts/ review
GI-GVHD	Use weight-contextualized stool output and clinical absorption; no absolute 500 mL/day cutoff.	Tier 3/4	ESPGHAN; adult review
TLS	No validated TLS-specific feeding regimen; do not prescribe routine fasting or low-phosphate formula.	Tier 4/5	Disease-primer/expert evidence
ECMO/CRRT	Discuss separately; heparin has no calories; CRRT losses require individualized replacement.	Tier 2	ELSO; PRNT