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PEDIATRIC INTENSIVE CARE: MODERN APPROACHES TO THE MANAGEMENT OF CRITICALLY ILL CHILDREN

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ABSTRACT. Background: Pediatric Intensive Care Units (PICUs) play a decisive role in reducing childhood morbidity and mortality associated with acute life-threatening conditions, severe trauma, sepsis, and multi-organ dysfunction syndrome (MODS). Rapid advancements in organ support technologies, precision hemodynamic monitoring, and evidence-based clinical bundles have fundamentally transformed critical care pediatrics over the past decade.
Objective: This review systematically synthesizes contemporary evidence-based strategies for the management of critically ill children, focusing on early recognition of clinical deterioration, lung-protective respiratory support, precision fluid and hemodynamic resuscitation, pediatric sepsis protocols, neuroprotection, and family-centered post-intensive care rehabilitation.
Methods: A comprehensive analytical synthesis of international clinical practice guidelines (Surviving Sepsis Campaign, PALICC-2, European Resuscitation Council) and peer-reviewed clinical studies published between 2018 and 2026 was conducted, contextualized to regional emergency medical care delivery.
Results: Modern pediatric critical care prioritizes physiological precision over aggressive empirical intervention. Key mortality-reducing pillars include structured Pediatric Early Warning Systems (PEWS), early non-invasive respiratory support and low-tidal-volume mechanical ventilation (6–8 mL/kg predicted body weight), balanced crystalloid resuscitation guided by dynamic hemodynamic indices, bundle-driven antimicrobial administration within one hour of septic shock recognition, targeted temperature and intracranial pressure management, and early mobilization protocols.
Conclusion: Integrating standardized clinical bundles, bedside point-of-care ultrasonography (POCUS), and multidisciplinary team coordination substantially improves survival rates and long-term neurodevelopmental outcomes in critically ill pediatric patients.

Keywords: pediatric intensive care unit (PICU); critically ill children; pediatric sepsis; mechanical ventilation; hemodynamic monitoring; point-of-care ultrasound (POCUS); neuroprotection; multi-organ dysfunction syndrome.

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1. INTRODUCTION

Pediatric intensive care medicine represents one of the most dynamic and technically demanding disciplines within modern healthcare. Critically ill children exhibit distinct anatomical, physiological, immunological, and pharmacokinetic characteristics that fundamentally differentiate them from adult intensive care patients [1]. Infants and young children possess markedly higher basal metabolic rates, reduced functional residual capacity (FRC) in the lungs, lower glycogen reserves, and highly compliant chest walls, predisposing them to rapid hypoxemic decompensation and sudden cardiopulmonary arrest when compensatory mechanisms are exhausted [2].

Over the last two decades, the paradigm of Pediatric Intensive Care Unit (PICU) management has shifted from reactive, high-intensity rescue interventions toward proactive early detection, organ-protective support, and precision medicine [3]. In high-volume emergency medical centers—such as regional branches of the Republican Research Center of Emergency Medicine (RSHTYOIMFF)—patients admitted to pediatric resuscitation and intensive care departments frequently present with acute respiratory failure, septic shock, severe polytrauma, diabetic ketoacidosis, acute neurological emergencies, and toxicological exposures. Standardizing clinical workflows around internationally validated, evidence-based protocols is essential to minimizing preventable mortality and mitigating long-term Post-Intensive Care Syndrome in pediatrics (PICS-p) [4].

The objective of this scientific article is to provide a comprehensive, structured analysis of contemporary approaches to the management of critically ill children across core physiological domains, integrating current international guidelines with practical clinical implementation strategies.

2. MATERIALS AND METHODS

This study employs a narrative and analytical review methodology based on international consensus guidelines and high-impact clinical evidence published between 2018 and 2026. Primary guideline frameworks examined include the Pediatric Acute Lung Injury Consensus Conference (PALICC-2, 2023) [5], the Surviving Sepsis Campaign (SSC) International Guidelines for the Management of Septic Shock and Sepsis-Associated Organ Dysfunction in Children [6], the Brain Trauma Foundation Guidelines for the Management of Pediatric Severe Traumatic Brain Injury [7], and contemporary Point-of-Care Ultrasound (POCUS) consensus statements from the European Society of Paediatric and Neonatal Intensive Care (ESPNIC) [8].

Evidence was structured across six operational pillars of modern PICU care: (1) early recognition and triage systems; (2) advanced respiratory support and lung-protective ventilation; (3) hemodynamic stabilization and bedside ultrasound; (4) sepsis and antimicrobial stewardship; (5) neurocritical care and sedation-analgesia bundles; and (6) metabolic support, early mobilization, and family-centered care.

3. RESULTS AND DISCUSSION

3.1. Early Recognition of Clinical Deterioration and Rapid Response Systems

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Unlike adults, who frequently exhibit early systemic hypotension during circulatory or respiratory compromise, children maintain normal arterial blood pressure through intense sympathetic vasoconstriction and compensatory tachycardia until up to 25–30% of circulating blood volume is lost [2]. Consequently, hypotension in a pediatric patient is a late, ominous sign of decompensated shock.

Modern pediatric emergency and intensive care systems rely on validated Pediatric Early Warning Systems (PEWS) combined with structured ABCDE (Airway, Breathing, Circulation, Disability, Exposure) assessments [9]. Integrating multiparametric scoring—incorporating respiratory rate, work of breathing, oxygen saturation (SpO2/FiO2 ratio), heart rate, capillary refill time, and neurological responsiveness (AVPU/GCS)—enables rapid escalation to PICU consultation before irreversible cellular hypoxia ensues. Implementation of dedicated Pediatric Rapid Response Teams (PRRTs) has been consistently associated with significant reductions in out-of-PICU cardiopulmonary arrests and overall hospital mortality [9].

3.2. Modern Respiratory Support and Lung-Protective Ventilation

Acute respiratory failure remains the leading cause of PICU admission globally. Contemporary respiratory management follows a tiered escalation strategy designed to avoid endotracheal intubation whenever safely achievable while preventing patient self-inflicted lung injury (P-SILI) and ventilator-induced lung injury (VILI) [5].

High-Flow Nasal Cannula (HFNC) oxygen therapy and Non-Invasive Ventilation (NIV), including CPAP and BiPAP, are widely utilized as first-line modalities in moderate bronchiolitis, pneumonia, and early hypoxemic respiratory failure. HFNC delivers heated, humidified gas flows (typically 1–2 L/kg/min) that wash out nasopharyngeal dead space, reduce inspiratory resistance, and generate modest positive distending airway pressure [10]. However, clinicians must closely monitor the ROX index or SpO2/FiO2 trends within the first 1–2 hours to prevent delayed intubation in non-responders.

When invasive mechanical ventilation is indicated for Pediatric Acute Respiratory Distress Syndrome (PARDS), strict adherence to PALICC-2 lung-protective principles is mandatory [5]: low tidal volumes (6–8 mL/kg of predicted body weight, and 4–6 mL/kg in severe PARDS), limitation of plateau pressure (<= 28 cmH2O) and driving pressure (< 15 cmH2O), individualized Positive End-Expiratory Pressure (PEEP) titration to optimize alveolar recruitment without hemodynamic compromise, and permissive hypercapnia (pH >= 7.20). In severe refractory hypoxemia, early prone positioning (12–16 hours/day), neuromuscular blockade during the first 24–48 hours, and timely referral for Venovenous Extracorporeal Membrane Oxygenation (VV-ECMO) represent established rescue pathways [5].

3.3. Hemodynamic Stabilization, Balanced Fluids, and Bedside POCUS

Fluid resuscitation in critically ill children has undergone substantial refinement following landmark clinical trials demonstrating that overly aggressive, unmonitored fluid boluses increase mortality due to endothelial glycocalyx degradation, interstitial edema, and prolonged mechanical ventilation [6, 11]. Current guidelines recommend administering isotonic balanced crystalloids (such as

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Ringer's lactate or Plasma-Lyte) rather than 0.9% normal saline, thereby reducing the risk of hyperchloremic metabolic acidosis and acute kidney injury [12].

In settings with advanced intensive care monitoring, fluid boluses of 10–20 mL/kg are administered incrementally over 15–20 minutes, with mandatory reassessment of perfusion markers (lactate clearance, capillary refill, urine output >= 1 mL/kg/h, mental status) and signs of fluid overload (hepatomegaly, pulmonary rales) after each bolus. When shock persists after 40–60 mL/kg of crystalloid resuscitation, early initiation of vasoactive infusions—primarily epinephrine for cold/low-cardiac-output shock or norepinephrine for warm/vasodilatory shock—is prioritized over continued fluid loading [6].

Bedside Point-of-Care Ultrasonography (POCUS) has emerged as an indispensable diagnostic and monitoring standard in modern PICUs [8]. Focused cardiac ultrasound (FoCUS) allows real-time evaluation of left and right ventricular contractility, pericardial effusion, and inferior vena cava (IVC) collapsibility, while lung ultrasound detects interstitial syndrome (B-lines), consolidation, and pneumothorax with higher sensitivity than portable chest radiography.

Table 1. Evolution of Clinical Paradigms in Pediatric Intensive Care Management

Clinical Domain	Traditional Empirical Approach	Modern Evidence-Based PICU Approach	Primary Clinical Benefit
Fluid Resuscitation	Rapid, large-volume 0.9% NaCl boluses (>60 mL/kg) without dynamic assessment	Incremental balanced crystalloids (10–20 mL/kg) guided by POCUS and lactate clearance	Prevents fluid overload, glycocalyx injury, and hyperchloremic acidosis [6, 12]
Mechanical Ventilation	High tidal volumes (10–12 mL/kg) targeting strict normocapnia	Low tidal volume (6–8 mL/kg PBW), driving pressure <15 cmH2O, permissive hypercapnia	Reduces barotrauma, volutrauma, and PARDS mortality [5]
Vasoactive Support	Dopamine as first-line vasopressor; delayed initiation until >60–80 mL/kg fluid	Early epinephrine or norepinephrine via peripheral or central access at 40–60 mL/kg	Faster reversal of myocardial dysfunction and shock [6]
Sedation & Delirium	Deep continuous sedation with benzodiazepines and prolonged immobilization	Goal-directed light sedation (SBS/COMFORT-B), dexmedetomidine, daily awakening	Decreases PICU delirium, ventilator days, and PICS-p [4, 14]

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Clinical Domain	Traditional Empirical Approach	Modern Evidence-Based PICU Approach	Primary Clinical Benefit
Nutritional Support	Delayed enteral feeding until full hemodynamic stability and bowel sounds	Early trophic enteral nutrition within 24–48 hours of admission	Preserves gut mucosal integrity and lowers nosocomial sepsis [15]

3.4. Pediatric Sepsis Bundles and Antimicrobial Stewardship

Pediatric sepsis remains a primary driver of preventable mortality worldwide, recently redefined through the Phoenix Sepsis Score criteria, which evaluate dysfunction across respiratory, cardiovascular, coagulation, and neurological organ systems [13]. Successful management hinges on time-critical execution of the 'Golden Hour' bundle [6]:

• Immediate Recognition and Vascular Access: Screening within 15 minutes of presentation and establishing intravenous or intraosseous (IO) access within 5 minutes if peripheral cannulation fails.

• Microbiological Sampling: Obtaining blood cultures (and site-specific cultures) prior to antibiotic initiation, without delaying therapy beyond 45 minutes.

• Broad-Spectrum Antimicrobial Administration: Administering empiric intravenous broad-spectrum antibiotics within 1 hour of septic shock recognition (and within 3 hours for sepsis-associated organ dysfunction without shock), tailored to local antibiograms and multidrug-resistant pathogen risks.

• Source Control and De-escalation: Urgent surgical or interventional drainage of infectious foci alongside daily antimicrobial stewardship reviews to de-escalate therapy once culture susceptibilities are confirmed.

3.5. Neurocritical Care, Analgesia-Sedation, and Delirium Prevention

In critically ill children presenting with severe traumatic brain injury (TBI), status epilepticus, central nervous system infections, or post-cardiac arrest encephalopathy, preventing secondary brain injury is paramount [7]. Modern pediatric neuroprotection emphasizes maintaining cerebral perfusion pressure (CPP >= 40–50 mmHg depending on age), keeping intracranial pressure (ICP) < 20 mmHg, ensuring strict normothermia (actively preventing hyperthermia > 37.5°C), maintaining normoglycemia, and utilizing hyperosmolar therapy (3% hypertonic saline) for acute intracranial hypertension [7].

Furthermore, the ICU Liberation (ABCDEF) bundle adapted for pediatrics emphasizes minimizing benzodiazepine exposure, which strongly correlates with pediatric delirium and prolonged mechanical ventilation [14]. Alpha-2 adrenergic agonists (such as dexmedetomidine) combined with validated pain (FLACC, NRS) and sedation scales (State Behavioral Scale, COMFORT-B) promote cooperative sedation, preserve respiratory drive, and facilitate earlier extubation.

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3.6. Metabolic Support, Early Mobilization, and Family-Centered Care

Critical illness triggers a profound neuroendocrine stress response characterized by protein catabolism, insulin resistance, and micronutrient depletion. Current nutritional guidelines advocate initiating early enteral nutrition within 24–48 hours of PICU admission once initial hemodynamic resuscitation is achieved, targeting at least two-thirds of prescribed energy and protein goals (1.5–2.0 g/kg/day of protein) within the first week [15].

Equally vital is addressing Post-Intensive Care Syndrome in pediatrics (PICS-p), which encompasses physical weakness, neurocognitive impairment, and psychological trauma affecting both the child and caregivers [4]. Early structured physical rehabilitation, age-appropriate cognitive stimulation, and open family presence during clinical rounds significantly accelerate functional recovery and reduce parental anxiety.

Table 2. Summary of Core Physiological and Therapeutic Targets in Modern PICU Practice

Organ System / Domain	Monitoring Parameter	Recommended Clinical Target	Reference Standard
Respiratory (PARDS)	Tidal Volume / Driving Pressure / SpO2	Vt 6–8 mL/kg PBW; ΔP < 15 cmH2O; SpO2 92–97% (mild/mod) or 88–92% (severe)	PALICC-2 Guidelines (2023) [5]
Cardiovascular / Shock	MAP / Lactate / Capillary Refill	MAP > 5th–50th percentile for age; lactate trend falling (>10–20%/2h); CRT <= 2 sec	Surviving Sepsis Campaign [6]
Neurocritical Care	ICP / CPP / Core Temperature	ICP < 20 mmHg; CPP >= 40–50 mmHg; Core Temp 36.0–37.5°C (avoid fever)	Brain Trauma Foundation [7]
Renal & Fluid Balance	Urine Output / Cumulative Fluid Overload	Urine output >= 1.0 mL/kg/h; cumulative fluid overload < 10% body weight	KDIGO / ESPNIC Consensus [8, 12]
Metabolic & Nutrition	Blood Glucose / Enteral Initiation	Blood glucose 4.4–10.0 mmol/L (80–180 mg/dL); enteral start within 24–48 h	ASPEN / SCCM Pediatric Guidelines [15]

4. CONCLUSION

Modern pediatric intensive care has evolved into a highly integrated, physiology-driven specialty where survival is no longer the sole benchmark of success; preserving intact neurodevelopmental and

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functional quality of life is equally imperative. Implementing structured Pediatric Early Warning Systems, lung-protective mechanical ventilation, balanced and ultrasound-guided hemodynamic resuscitation, rapid sepsis bundles, and delirium-sparing sedation protocols significantly lowers mortality and ICU length of stay.

For regional emergency medical centers such as the Fergana Branch of the Republican Research Center of Emergency Medicine (RSHTYOIMFF), continuous investment in multidisciplinary simulation training, point-of-care diagnostic technologies, and standardized clinical pathways remains the cornerstone of delivering world-class critical care to severely ill and injured children.

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