A Comprehensive Review of Resuscitation in Pediatric Critical Care: Optimizing Outcomes and Addressing Challenges

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Abstract

This literature review explores the critical role of fluid resuscitation in pediatric care, emphasizing its significance in managing acute conditions and enhancing patient outcomes. Pediatric patients undergoing emergency care demand meticulous fluid management, with early and precise administration holding the potential to improve survival rates and mitigate mortality risks. The human body's intricate fluid compartments, comprising intracellular and extracellular fluids, undergo age-dependent variations that influence total body water distribution. Maintaining fluid and electrolyte balance is crucial and tightly regulated by physiological mechanisms. In cases of critical illness, such as sepsis, trauma, or burns, pediatric patients may experience fluid loss, necessitating prompt intervention to prevent dehydration and kidney failure. This review delves into the distinctions between colloid and crystalloid solutions, highlighting crystalloids' frequent utilization due to their cost-effectiveness, wide availability, and comparable outcomes in various critical conditions. Crystalloids, predominantly isotonic to human plasma, play a vital role in expanding intravascular volume without disrupting ion concentrations or causing significant fluid shifts. The discussion extends to hypertonic solutions, like 3% saline, elucidating their potential for inducing osmotic effects and guiding their clinical indications. Additionally, buffer solutions, including lactate, acetate, and gluconate, are explored for their role in maintaining physiological plasma pH. The literature underscores the prevalence and recommendations for crystalloid use in the United States, emphasizing their "first-line" status in resuscitating critically ill pediatric patients. As fluid resuscitation continues to be a cornerstone in pediatric emergency care, this review aims to provide insights into optimizing fluid strategies, addressing challenges, and fostering a comprehensive understanding of the intricacies surrounding fluid management in pediatric critical care.

Keywords: Fluid resucitation, Pediatric, Treatment.

1. Introduction

Pediatric critical care poses unique challenges, necessitating a nuanced approach to resuscitation strategies. Among these, fluid resuscitation emerges as a pivotal aspect in managing acute conditions and influencing outcomes in critically ill children. As underscored by Cruz et al. (2020), sepsis, trauma, and burns can trigger serious health crises in pediatric patients, leading to fluid loss and requiring immediate intervention to avert complications such as dehydration and renal failure. The human body's intricate fluid compartments, intracellular and extracellular, undergo dynamic changes across different stages of life, influencing the distribution of total body water. Understanding these age-dependent variations is crucial for tailoring resuscitation strategies to the specific needs of pediatric patients. From infancy to adolescence, the percentage of total body water changes, ranging from 70% in infants to 60% in adults (Kight & Waseem, 2022).

In critical conditions, the importance of early and appropriate fluid resuscitation cannot be overstated. Research by Lewis et al. (2018) emphasizes the significance of crystalloids in this context. Crystalloids, characterized by small molecules, affordability, and ease of use, are frequently employed in pediatric care for their rapid applicability in fluid resuscitation. The selection between colloid and crystalloid solutions involves considerations such as cost-effectiveness, availability, and potential side effects, with crystalloids often emerging as a pragmatic choice. Crystalloids, mainly isotonic to human plasma, play a crucial role in expanding intravascular volume without disrupting ion concentrations or causing substantial fluid shifts between different bodily compartments. This makes them particularly well-suited for fluid resuscitation in pediatric emergencies. In the United States, the widespread use of crystalloids is evident, with over 200 million liters administered annually, as highlighted by Casey et al. (2019).

The cost-effectiveness and comparable efficacy of crystalloids position them as the "first line" for fluid resuscitation in common critical illnesses such as sepsis, hemorrhagic shock, and cardiac arrest. While crystalloids are integral to fluid resuscitation, understanding the nuances of hypertonic solutions adds depth to resuscitation strategies. Hypertonic solutions, like 3% saline, deviate from isotonicity and have higher solute concentrations than human serum. This disparity induces osmotic effects, influencing fluid shifts. The clinical indications for hypertonic solutions, particularly in cases of hyponatremia with neurological symptoms, underscore the tailored nature of fluid resuscitation approaches (Epstein & Waseem, 2022).

Additionally, the role of buffer solutions, metabolized in vivo into bicarbonate, adds another layer to fluid management. Lactate, acetate, and gluconate, commonly utilized buffer molecules, contribute to maintaining physiological plasma pH. This reflects the multifaceted nature of fluid resuscitation strategies, encompassing considerations of pH regulation in addition to volume expansion. In light of these complexities, this literature review aims to comprehensively explore fluid resuscitation in pediatric critical care, delving into the intricacies of crystalloids, hypertonic solutions, and buffer molecules. By synthesizing existing knowledge, the review seeks to offer insights into optimizing fluid strategies, addressing challenges, and fostering a holistic understanding of fluid management in the context of pediatric critical care. Through this exploration, we aim to contribute to the refinement of resuscitation protocols, ultimately improving outcomes for critically ill children.

2. Review Content

2.1 Critical Illness in Children

Critical illness in children is a significant concern that disrupts the health and development of children, and can negatively impact family function and well-being (Crow et al., 2017). Diseases in children such as sepsis, pneumonia, diarrhea, and trauma are among the leading causes of death. In 2017, over 80% of the 6.64 million deaths worldwide in children and adolescents occurred in low- and middle-income countries (Kortz et al., 2022). Pediatric patients with critical illnesses are typically treated in a specialized unit within a hospital known as the pediatric intensive care unit. Patients in this unit require respiratory, hemodynamic, and organ support to achieve better outcomes compared to those treated in other hospital departments (Edae et al., 2022). A study by Dharmawati et al. (2017) conducted in the Emergency Care Unit of Dr. Soetomo Surabaya Hospital in 2011 revealed that the highest number of pediatric patients admitted were respiratory cases at 31%, oncology cases at 19.9%, diarrhea at 17.4%, seizures at 13.5%, neonatal cases at 8.4%, and dengue infections at 6.5%.

2.2 Epidemiology

A study by Demirkiran et al. (2021), conducted from 2014 to 2017 in three university hospital Pediatric Intensive Care Units (PICUs) in Turkey, included 7,961 patients, with a total of 887 (11.14%) meeting the consensus definition for chronic critical illness (CCI). In the United States, approximately 230,000 children are admitted to PICUs each year, and 97% of them survive critical illnesses (Nelson et al., 2019). According to Matsumoto et al. (2019), patients with prolonged PICU stays face a high risk of worsening conditions and death. A study by Ping Kirk et al. (2018) at a tertiary children's hospital in Singapore revealed that the mortality rate for patients with extended PICU stays was 20%, five times higher than the overall mortality rate in PICU patients (3.9%).

Extended care in the intensive care unit incurs significant costs and affects patients, families, and the country's economy (Toptas et al., 2018). Alsharari (2019) argued that families of patients in the intensive care unit may experience psychological crises, stress, and depression due to their family members' critical conditions with a high potential for mortality. This aligns with a study by Akbar et al. (2020) conducted at the Ulin Banjarmasin General Hospital PICU, indicating that families of patients experience burnout in the form of both physical and mental fatigue as manifestations of psychological pressure and stress. The psychological pressure experienced by families is caused by fear, anxiety, depression, and a sense of helplessness.

2.3 Demographics

Critical illness is a life-threatening condition that requires intensive and specialized care, along with comprehensive monitoring (Latief et al., 2016). Several studies indicate that the age group predominantly treated in pediatric intensive care units is under 5 years old (Dewi & Fatimatuzzuhroh, 2019). Another epidemiological study (Lanetzki et al., 2012) revealed that out of 433 patients treated in pediatric intensive care units in Israel, the age group of one to four years old was predominant. In 2016, the World Health Organization (WHO) reported a decrease in mortality rates for children under 5 years old, from 93 per 1000 births in 1990 to 41 per 1000 births in 2016. Additionally, it was found that the highest risk of death occurred during the child's first year of life (World Health Organization, 2018). According to Sudarmadji et al. (2016), patients under 5 years old are the most commonly admitted age group to intensive care units because their immune systems are mostly immature. The developmental phases of the immune system indicate that the younger the age, the less mature the immune system. Regarding gender, several studies show a higher prevalence of male patients among hospitalized critically ill children.

2.4 Sepsis in Children

Sepsis is defined as organ dysfunction caused by the host's dysregulated response to an infection, carrying a high potential for morbidity and mortality in children (Cruz et al., 2020). Sepsis is a medical emergency that illustrates the body's immune response to an infection, which can lead to organ dysfunction, ultimately progressing to death. Despite significant advancements in understanding the pathophysiology of this clinical syndrome, as well as improvements in hemodynamics, monitoring devices, and resuscitation measures, sepsis remains a leading cause of morbidity and mortality in critically ill patients (Gyawali et al., 2019).

Sepsis continues to be a major cause of morbidity and mortality in critically ill patients, even with the use of modern antibiotics and resuscitation therapy. Although there has been an overall improvement in sepsis outcomes, possibly due to an increased focus on early diagnosis and other improvements in supportive care, the mortality rate remains high. The diagnosis and definition of sepsis are crucial issues due to the diversity of

its disease processes. Despite ongoing efforts to advance understanding, sepsis and related terms remain challenging to define. A consensus conference in 1991 defined sepsis as a systemic inflammatory response syndrome (SIRS) to infection. The definitions of sepsis and septic shock were updated in 2001 to include thresholds for organ damage.

2.5 Resuscitation in Critically Ill Children

2.5.1 Cardiopulmonary Resuscitation (CPR)

Resuscitation in children and newborns involves a systematic procedure to achieve return of spontaneous circulation (ROSC), similar to cardiopulmonary resuscitation (CPR) in adults but with specific considerations in terms of differential diagnosis, drug doses, procedures, and advanced care that make this subject distinct (Ujevich & Pozun, 2022). Unlike adults, cardiac arrest in children is less likely to be a primary cardiac event. Early onset of effective and high-quality cardiopulmonary resuscitation (CPR) has the potential to improve survival. Children requiring resuscitation can be categorized into various groups, including pulseless arrest (likely due to asystole), pulseless electrical activity, or ventricular fibrillation/ventricular tachycardia without a pulse (Vega et al., 2022).

Most cardiac arrests in children are not caused by primary heart issues but rather secondary causes, often respiratory insufficiency. Therefore, the sequence for administering resuscitation is airway (A), breathing (B), circulation (C) (Ali & Bingham, 2018). Cardiac arrest contributes significantly to mortality and morbidity in the Pediatric Intensive Care Unit (PICU) (Mustafa et al., 2021). Each year, over 15,000 children receive CPR due to cardiac arrest while receiving hospital care in the United States. Approximately 80–90% survive such incidents, but the majority do not survive beyond hospital discharge (Morgan et al., 2021).

2.5.2 Fluid Resuscitation

Fluid resuscitation is crucial for children experiencing critical illness. When children are treated in the emergency department of a hospital, fluid management is vital during acute care. Early and appropriate fluid administration can improve outcomes and reduce mortality in pediatric patients. Water is essential for cellular homeostasis. The human body has two main fluid compartments: intracellular fluid and extracellular fluid. Two-thirds of the total body water is intracellular. Total body water varies with age: 70% in infants, 65% in children, and 60% in adults. The human body has a strict physiological control to regulate fluid and electrolyte balance (Kight & Waseem, 2022).

Patients with critical illness may lose fluids due to serious conditions such as infection (e.g., sepsis), trauma, or burns, requiring immediate additional fluids to prevent dehydration or kidney failure. Colloid or crystalloid solutions can be used to prevent this. Crystalloids have small molecules, are cost-effective, easy to use, and can be rapidly employed for fluid resuscitation but may increase edema (Lewis et al., 2018). Crystalloids are the most commonly given intravenous fluids because of their low cost, wide availability, and, in many cases, equivalent outcomes compared to colloid formulations. In the United States, over 200 million liters of crystalloid are administered annually, and crystalloids are recommended as the "first line" for fluid resuscitation in common critical illnesses such as sepsis, hemorrhagic shock, and cardiac arrest (Casey et al., 2019). Most widely available crystalloid solutions are isotonic to human plasma. These fluids approximate the concentration of various solutes found in plasma and do not exert an osmotic effect in vivo. Crystalloid fluids work to expand intravascular volume without disturbing ion concentration or causing significant fluid shifts between intracellular, intravascular, and interstitial spaces.

Hypertonic solutions, such as 3% saline, have a higher solute concentration than that found in human serum. This concentration difference causes the fluid to exert an osmotic effect and can lead to fluid shifts. Key indications include replacement of serum solutes, as in hyponatremia with neurological symptoms. Buffer solutions contain molecules metabolized in vivo into bicarbonate. These solutions are formulated to maintain a normal physiological plasma pH. Lactate, acetate, and gluconate are three commonly used molecules. Lactate and gluconate are metabolized in the liver into bicarbonate, while acetate is mostly metabolized peripherally by skeletal muscles (Epstein & Waseem, 2022).

3. Conclusion

In conclusion, effective fluid resuscitation is paramount in pediatric critical care, with crystalloids serving as a pragmatic choice for their affordability and rapid applicability. The nuances of hypertonic solutions and buffer molecules further enrich resuscitation strategies. This review underscores the need for tailored approaches, considering age-specific physiological variations. As fluid resuscitation remains central to pediatric emergency care, continued research and refinement of protocols are essential to optimize outcomes for critically ill children.

Acknowledgements

The authors would like to thank all the supervisors, enabling the successful implementation of this study.

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