Original Research Article

Electrolyte imbalances and their impact on outcomes in critically ill children: a prospective study from North India

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ABSTRACT

Background: Electrolyte imbalances are frequent in critically ill children and significantly influence prognosis, yet pediatric data from North India remain scarce. To determine the prevalence of electrolyte imbalances in a tertiary care pediatric intensive care unit (PICU) and assess their associations with morbidity, mortality and clinical outcomes.
Methods: This prospective observational study included 196 children (1 month–18 years) admitted to a North Indian tertiary PICU over 18 months. Electrolyte levels were measured at admission and monitored daily. Associations between dyselectrolytemia and outcomes including ventilatory and inotropic needs, complications, length of stay and mortality were analyzed using chi-square tests.
Results: Electrolyte imbalance was observed in 58.2% of patients, with hyponatremia (52.6%) being most common, followed by hypocalcemia (13.8%) and hyperkalemia (7.1%). Dyselectrolytemia was significantly associated with prolonged PICU stay (p<0.0001), need for ventilation and inotropes (p<0.0001), complications (42.9%), MODS (11.2%) and higher mortality (p<0.0001). Seizures were the most frequent complication (20.4%). Mortality was highest with hyperkalemia (78.6%), followed by hypernatremia (57.1%) and hypokalemia (57.1%), whereas hyponatremia showed a non-significant trend. Overall mortality was 9.2%, lower than prior reports, possibly due to early monitoring and timely correction.
Conclusions: Electrolyte disturbances are common in PICU and strongly associated with adverse outcomes. Hyperkalemia and hypernatremia carry the greatest mortality risk. Early recognition and prompt correction of dyselectrolytemia may reduce morbidity and improve survival. Larger multicentre studies incorporating additional electrolytes such as magnesium and phosphate are warranted.

Keywords: Dyselectrolytemia, Electrolyte imbalance, Hyponatremia, Hyperkalemia, Hypocalcemia, Mortality, MODS, Pediatric intensive care

INTRODUCTION

Over the past few decades, advancements in pediatric intensive care, including enhanced monitoring, timely interventions and refined therapeutic strategies, have markedly improved morbidity and mortality outcomes in critically ill children.[1] Nevertheless, electrolyte imbalances remain one of the most prevalent yet underrecognized challenges in the PICU, significantly impacting prognosis, hospitalization duration and survival rates.[2] Critically ill pediatric patients are predisposed to disturbances in sodium, potassium, calcium, chloride and magnesium due to multifactorial causes such as systemic inflammation, renal dysfunction, aggressive fluid therapy, hormonal dysregulation and medications like diuretics.[3,4] These electrolytes are crucial regulators of neuromuscular excitability, acid–base homeostasis, cardiovascular function and cellular metabolism.[5] Even minor deviations can trigger severe

complications, seizures, arrhythmias, altered mental status or death.[3,6,7] Global reports estimate that dyselectrolytemia affects between 40% and 90% of PICU admissions, with hyponatremia, hypokalemia and hypocalcemia being most frequently documented.[3,8,9] Such imbalances also correlate with extended PICU stays and heightened healthcare resource utilization.[10] While international literature sheds light on the prevalence and implications of electrolyte disorders in critically ill children, there is a paucity of data from India, particularly North India, where unique disease patterns, resource constraints and patient demographics might influence the epidemiology and impact of these abnormalities.[11,12] Electrolyte imbalances in critically ill children are associated with an increased need for ventilatory and inotropic support, a higher incidence of complications and multiple organ dysfunction syndrome (MODS), prolonged PICU stay and an elevated risk of mortality.[3,13] Hyponatremia is the most common electrolyte abnormality in PICU worldwide (20–67%), followed by hypocalcemia (up to 58%), hypokalemia (30–40%), hypernatremia (9–38%) and hyperkalemia (7–10%).[3,14-16]

In PICU, hypernatremia has the highest mortality risk (35–38%), followed by hyponatremia (~32%), hyperkalemia (~30%) and hypokalemia (~24–25%), with sodium disturbances being the strongest predictors of death.[17,18] Early detection and correction of dyselectrolytemia are vital to reducing morbidity and mortality in this vulnerable population.[19,20] Region-specific evidence is essential to tailor effective monitoring and management protocols within similar healthcare settings. This study addresses that gap by assessing the prevalence of electrolyte imbalances in a North Indian tertiary PICU and examining their associations with morbidity, mortality, length of stay and need for ventilatory and inotropic support. By systematically evaluating these disturbances, we aim to generate evidence to guide timely recognition and management, thereby reducing avoidable complications and improving survival in pediatric critical care.

METHODS

Study design and setting

This was a prospective, observational study conducted in the PICU of the Hind Institute of Medical Sciences, Sitapur, Uttar Pradesh, India, over 18 months from July 2023 to January 2025. The study was approved by the Institutional Ethics Committee (IHEC-HIMSA/MD/MS-22/RD-12/07-23). Written informed consent was obtained from the parents or guardians of all participants and assent was obtained from older children when applicable.

Study population

All critically ill children aged 1 month to 18 years admitted to the PICU during the study period were eligible.

Inclusion criteria

Children aged 1 month–18 years admitted to PICU with critical illness.

Exclusion criteria

Children with congenital anomalies, chronic renal insufficiency or malignancy. Children with recent blood transfusion (within 3 months). Children with known HIV infection.

Sample size and sampling

The sample size was calculated using Cochran's formula for proportion,

$$n = Z^2 \times p \times (1-p)/d^2,$$

where Z=1.96 (for 95% confidence level), p=anticipated prevalence of electrolyte imbalance in PICU patients=85% based on previous research and d=0.05 (absolute allowable error).[3,21] The estimated sample size was 196 patients, who were selected using a random sampling method.

Operational definitions

Electrolyte imbalance (Dyselectrolytemia)

Electrolyte imbalance was defined as sodium levels outside 135–145 millimole per decilitre (mmol/l), potassium levels outside 3.5–5.0 mmol/l or ionized calcium levels below 1.11 mmol/l or above 1.35 mmol/l.[3,22,23]

Hyponatremia: Serum sodium level of <135 mmol/l.[3,22]

Hypernatremia: Serum sodium level of >145 mmol/l.[3,22]

Hypokalemia: Serum potassium level of <3.5 mmol/l.[3,22]

Hyperkalemia: Serum potassium level of >5.0 mmol/l.[3,23]

Hypocalcemia: Ionized calcium below 1.11 mmol/l.[24]

Hypercalcemia: Ionized calcium above 1.35 mmol/l.[24]

MODS

Defined as the presence of dysfunction in two or more organ systems (respiratory, cardiovascular, renal, hematologic, hepatic or neurologic) occurring simultaneously or sequentially in a critically ill child.[25]

Acute kidney injury

It is defined by the kidney disease improving global outcomes (KDIGO) criteria as an abrupt decline in

kidney function, indicated by an increase in serum creatinine of $\geq$0.3 mg/dl within 48 hours, a rise to $\geq$1.5 times the baseline within seven days or urine output less than 0.5 ml/kg/hour for at least six hours.[26]

Ventilator-associated pneumonia

Pneumonia that develops in a child after $\geq$48 hours of endotracheal intubation and mechanical ventilation, characterized by new or progressive pulmonary infiltrates on chest imaging along with clinical features such as fever, leucocytosis or leukopenia, purulent tracheal secretions and worsening oxygenation.[27]

Data collection

At admission, a detailed history and clinical examination were performed for all patients. Demographic data, diagnosis and system involvement were recorded. Venous blood samples (2–3 ml) were collected under aseptic precautions at admission and subsequently every 24 hours or earlier if clinically indicated. The levels of serum sodium, potassium and ionized calcium were measured using an ion-selective electrode (ISE) analyser. Additional investigations included complete blood count, renal and liver function tests and imaging as clinically indicated.

The clinical parameters recorded included the need for ventilatory support (both non-invasive and invasive), requirement for inotropic support, length of PICU stay categorized as<7 days or $\geq$7 days (based on observed distribution) and duration of ventilatory support categorized as $\leq$3 days versus>3 days. Additional parameters noted were the occurrence of complications such as seizures, VAP and AKI, as well as the development of MODS. The outcome of each patient, either discharge or death, was also documented.
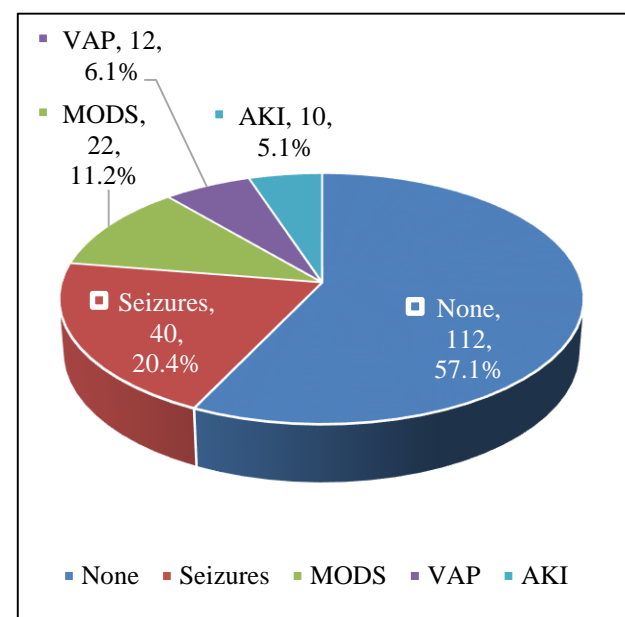
Statistical analysis

The data were arranged in Microsoft Excel and then analyzed using SPSS software, version 26. Continuous data were presented as the mean along with the standard deviation (SD), while categorical data were given as counts and percentages. Associations between electrolyte imbalances and clinical outcomes were analyzed using the chi-square test. Additional subgroup analyses were performed to assess the relationship between specific electrolyte abnormalities (hyponatremia, hypernatremia, hypokalemia, hyperkalemia and hypocalcemia) and mortality. A p value<0.05 was considered statistically significant.

RESULTS

The mean age of participants was 7.26 (5.04) years. The mean sodium, potassium and calcium levels were 134.56 (6.44), 3.91 (0.60) and 1.1 (0.14) mmol/l, respectively. The mean duration of stay in PICU and the mean duration of ventilatory support were 8.99 (4.41) and 4.68 (1.82) days, respectively. Among 196 children admitted to the PICU, most were<10 years (64.3%) and male (56.6%), with electrolyte imbalance in 58.2%. Infection/sepsis (35.7%) and CNS (32.7%) were the leading systems involved; 47.4% required ventilation, 54.1% needed inotropes and overall mortality was 9.2% (Table 1). Seizures were the most frequent complication, occurring in 40 patients (20.4%). MODS was noted in 22 patients (11.2%), followed by VAP in 12 (6.1%) and AKI in 10 (5.1%) (Figure 1). Hyponatremia was the most common electrolyte disturbance (52.6%), followed by hypocalcemia (13.8%) and hyperkalemia (7.1%), while other abnormalities were less frequent (Table 2).

Figure 1: Complications among PICU Patients (n=196).

Table 1: Baseline demographic, clinical and outcome characteristics of children admitted to the PICU (n=196)*.

Parameters	Categories	Number	%
Age (in years)	<10	126	64.3
	>=10	70	35.7
Sex	Female	85	43.4
	Male	111	56.6
Electrolyte imbalance	No	82	41.8
	Yes	114	58.2

Continued.

Parameters	Categories	Number	%
Primary systems involved	Infection/Sepsis	70	35.7
	CNS	64	32.7
	Respiratory	30	15.3
	GIT	18	9.2
	Trauma	6	3.1
	Haematology	3	1.5
	Renal	3	1.5
	CVS	2	1.0
Duration of stay in PICU	<7	83	42.3
	>=7	113	57.7
Need for ventilation	No	103	52.6
	Yes	93	47.4
Duration of ventilation (Days)	<=3	54	27.6
	>3	142	72.4
Need for an inotrope	No	90	45.9
	Yes	106	54.1
MODS	No	174	88.8
	Yes	22	11.2
Complications	No	112	57.1
	Yes	84	42.9
Outcome	Death	18	9.2
	Discharged	178	90.8

*CNS=Central Nervous System; CVS=Cardiovascular System; GIT=Gastrointestinal Tract; PICU=Pediatric Intensive Care Unit; MODS=Multiple Organ Dysfunction Syndrome.

Table 2: Types of electrolyte abnormalities observed in children admitted to the PICU (n=196)*.

Type of electrolyte imbalance	Category	Number	%
Hyponatremia	No	93	47.4
	Yes	103	52.6
Hypernatremia	No	189	96.4
	Yes	7	3.6
Hypokalemia	No	189	96.4
	Yes	7	3.6
Hyperkalemia	No	182	92.9
	Yes	14	7.1
Hypocalcemia	No	169	86.2
	Yes	27	13.8

Table 3: Association of patient characteristics and clinical outcomes with electrolyte imbalance in children admitted to the PICU (n=196)*.

Parameters	Categories	Electrolyte imbalance		Chi-square test (χ^2)	P value
		No	Yes		
Age (in years)	<10	54 (42.9)	72 (57.1)	0.151	0.698
	>=10	28 (40.0)	42 (60.0)		
Sex	Female	35 (41.2)	50 (58.8)	0.027	0.870
	Male	47 (42.3)	64 (57.7)		
Primary systems involved	Infection/Sepsis	51 (72.9)	19 (27.1)	59.303	<0.0001
	CNS	11 (17.2)	53 (82.8)		
	Respiratory	13 (43.3)	17 (56.7)		
	GIT	2 (11.1)	16 (88.9)		
	Trauma	0 (0.0)	6 (100.0)		
	Haematology	3 (100.0)	0 (0.0)		
	Renal	1 (33.3)	2 (66.7)		
	CVS	1 (50.0)	1 (50.0)		

Parameters	Categories	Electrolyte imbalance		Chi-square test (χ^2)	P value
		No	Yes		
Duration of stay in PICU (days)	<7	58 (69.9)	25 (30.1)	46.526	<0.0001
	≥7	24 (21.2)	89 (78.8)		
Need for ventilation	No	74 (71.8)	29 (28.2)	80.330	<0.0001
	Yes	8 (8.6)	85 (91.4)		
Duration of ventilation (days)	≤3	40 (74.1)	14 (25.9)	31.833	<0.0001
	>3	42 (29.6)	100 (70.4)		
Need for an inotrope	No	64 (71.1)	26 (28.9)	58.609	<0.0001
	Yes	18 (17.0)	88 (83.0)		
MODS	No	80 (46.0)	94 (54.0)	10.920	<0.001
	Yes	2 (9.1)	20 (90.9)		
Complications	No	66 (58.9)	46 (41.1)	31.374	<0.0001
	Yes	16 (19.0)	68 (81.0)		
Outcome	Death	0 (0.0)	18 (100.0)	14.257	<0.0001
	Discharged	82 (46.1)	96 (53.9)		

*CNS=Central Nervous System; CVS=Cardiovascular System; GIT=Gastrointestinal Tract; MODS=Multiple Organ Dysfunction Syndrome; PICU=Pediatric Intensive Care Unit.

Table 4: Association between electrolyte imbalances and mortality in children admitted to the PICU (n=196).

Type of electrolyte imbalance	Category	Death	Discharged	Chi-Square test (χ^2)	P value
Hyponatremia	No	5	88	3.076	0.079
	Yes	13	90		
Hypernatremia	No	14	175	20.020	<0.0001
	Yes	4	3		
Hypokalemia	No	14	175	20.020	<0.0001
	Yes	4	3		
Hyperkalemia	No	7	175	87.036	<0.0001
	Yes	11	3		
Hypocalcemia	No	15	154	0.139	0.709
	Yes	3	24		

Electrolyte imbalance was significantly associated with the primary system involved, particularly CNS, gastrointestinal, respiratory and trauma cases, longer PICU stay, need for ventilation, prolonged ventilation (≥7 days), inotrope use, MODS, complications and mortality (all p<0.001), but showed no significant association with age or sex (Table 3). Mortality was significantly associated with hypernatremia, hypokalemia and hyperkalemia (all p<0.0001), with the highest risk observed in hyperkalemia (11 deaths vs. 3 discharges). Hyponatremia showed a trend toward higher mortality but did not reach statistical significance (p=0.079), while hypocalcemia was not significantly associated with outcome (Table 4).

DISCUSSION

In this prospective study from a North Indian tertiary care PICU, electrolyte imbalances were observed in 58.2% of critically ill children, with hyponatremia (52.6%) being the most common abnormality, followed by hypocalcemia (13.8%) and hyperkalemia (7.1%). These findings align with previous reports showing that hyponatremia is the predominant electrolyte disturbance in PICUs worldwide, affecting 20–67% of children, while hypernatremia is less common (9–38%).[3,14-16] The prevalence in our cohort is comparable to studies from Pakistan and India that reported dyselectrolytemia in 40-85% of PICU admissions.[9,10,13] In terms of demographic distribution, most of our patients were under 10 years of age (64.3%). This observation is consistent with Agarwal et al and Suryawanshi et al who reported that younger children are more susceptible to electrolyte disturbances due to immature renal function and higher fluid turnover.[4,12] No significant gender differences were observed in our study, which agrees with the findings of Bamnawat et al, who also documented similar rates of dyselectrolytemia among boys and girls.[11] With respect to the primary system involved, infections and CNS diseases accounted for the majority of admissions in our cohort. This mirrors the results of Hassan et al and Jadhav et al where sepsis and neurological illnesses were predominant in children with electrolyte abnormalities.[9,19] Electrolyte disturbances in CNS conditions, particularly seizures, have been emphasized by Sharma et al and Chagantipati et al supporting our observation that neurological involvement predisposed to higher rates of dyselectrolytemia and complications.[6,7] Authors found significant associations between electrolyte imbalance and key clinical outcomes, including prolonged PICU

stay, increased need for mechanical ventilation and inotropes, development of complications, MODS and mortality. Similar associations have been highlighted by Naseem et al and Kumari et al who reported that sodium and potassium disturbances correlated with extended PICU stays, higher complication rates and worse prognoses.[3,13] Naseem et al's study also noted that electrolyte abnormalities were strongly linked with the requirement of ventilation and poor outcomes.[20]

The strong relationship between dyselectrolytemia and intensive care needs in our study is further supported by Sahu et al and Al-Sofyani et al who showed that sodium and potassium abnormalities significantly increased the requirement for ventilation and prolonged PICU stay.[10,14] Likewise, Khairunnisa et al reported that potassium imbalances correlated with severe illness and greater dependence on inotropes and mechanical ventilation, reinforcing that electrolyte disturbances act as both contributors to and markers of disease severity.[8]

Seizures were the most frequent complication in our cohort (20.4%), consistent with earlier reports that sodium and calcium disturbances predispose to neurological manifestations.[6,7] MODS occurred in 11.2% of children, which parallels findings from Weiss et al, who underscored the role of dyselectrolytemia in aggravating multiorgan dysfunction.[25] Regarding mortality, our results showed the highest risk in hyperkalemia (78.6%), followed by hypernatremia (57.1%) and hypokalemia (57.1%), while hyponatremia (12.6%) showed a trend but did not reach statistical significance.

This contrasts with global literature where sodium abnormalities, particularly hypernatremia, are reported as the strongest predictors of death, with mortality rates of 35–38% for hypernatremia and 32% for hyponatremia.[17,18] The discrepancy may reflect regional variations in disease profiles, fluid therapy and management practices. Cummings et al also emphasized that potassium abnormalities, though less frequent, can be life-threatening due to their arrhythmogenic potential, supporting our finding of high mortality in hyperkalemia.[15] The overall mortality in our cohort was 9.2%, which is lower than some previously published reports (14–20%), possibly due to timely monitoring, early correction of dyselectrolytemia and availability of advanced critical care facilities in our center.[2,9,13] From a policy perspective, electrolyte monitoring in critically ill children aligns with the objectives of India's child health programs, including the National Health Mission (NHM) and the Rashtriya Bal Swasthya Karyakram (RBSK), which emphasize early detection and timely management of childhood illnesses.[28] Although these programs focus primarily on screening and preventive care, integration of standardized electrolyte monitoring protocols into pediatric critical care services could reduce avoidable morbidity and mortality. Routine monitoring of fluids and electrolytes in critically ill children is recommended by both the Indian Academy of Pediatrics (IAP) and the World Health Organization (WHO) as part of essential care bundles.[29]

The study highlights that electrolyte imbalances are common yet modifiable risk factors in the PICU. Regular monitoring and timely correction of sodium, potassium and calcium abnormalities can reduce morbidity, prevent complications and improve survival. We recommend structured protocols, staff training and rapid diagnostic support, integrated with government health initiatives, to strengthen pediatric critical care in resource-limited settings.

However, this study has limitations. We focused only on sodium, potassium and calcium, while other electrolytes such as magnesium and phosphate were not assessed due to resource constraints and limited availability of routine testing in our setting, despite their recognized impact on outcomes. Being a single-center study, the findings may not be generalizable across diverse healthcare settings in India. Larger multicentre studies are needed to validate these results and guide standardized protocols.

CONCLUSION

Electrolyte disturbances were highly prevalent among critically ill children in our PICU, with hyponatremia being the most common abnormality. These imbalances were significantly associated with prolonged PICU stay, increased need for ventilatory and inotropic support, higher complication rates and mortality, with hyperkalemia and hypernatremia carrying the greatest risk of death. As electrolyte abnormalities represent potentially modifiable factors, their early recognition and timely correction are essential to improving outcomes. Future multicentre studies including a wider range of electrolytes, such as magnesium and phosphate, are warranted to provide a more comprehensive understanding and to guide standardized management protocols in pediatric critical care.

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