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Original Article

Ideal burn resuscitation: a step toward resolving the dilemma in acute flame burn management

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Abstract: Following severe burns, the predominant concern is significant fluid loss, for which balanced crystalloid solutions are widely recommended as the primary intravenous resuscitation fluids. However, current literature lacks a clear distinction among various buffered crystalloid types that might be most effective in the early resuscitation of burn patients. This retrospective study was conducted to identify the optimal resuscitation fluid for major burns and to assess the clinical outcomes associated with isotonic crystalloid solutions compared to hypotonic crystalloids, specifically in terms of urinary output, acid-base balance, and electrolyte stability. Conducted over one year at the Burn Care Center of the Pakistan Institute of Medical Sciences in Islamabad, the study involved 132 patients who were divided equally into two groups, each with 66 patients. Group A received isotonic crystalloids, while Group B was administered hypotonic crystalloids. The mean pre-infusion levels of sodium, potassium, bicarbonate, and pH were identical across both groups. Following infusion, sodium and chloride levels remained within normal ranges in the isotonic group. Among children under 12 years of age, none in the isotonic group exhibited a urine output below 1 ml/kg/h, while 22.7% of those in the hypotonic group had urine output below this threshold. In patients over 12 years, only one individual in the isotonic group presented a urine output of less than 0.5 ml/kg/h, compared to 19.7% of those in the hypotonic group. These findings indicate that isotonic crystalloids are superior to hypotonic crystalloids, demonstrating improved urinary output and better serum electrolyte balance in patients with severe burns.

Keywords: Burns, flame, isotonic, hypotonic, resuscitation, crystalloid

Introduction

The protocols for managing burn injuries are similar to those for any trauma injury, with an emphasis on the ABCs (airway, breathing, and circulation). Patients with significant burns require greater resuscitation volumes compared to those with other types of injuries. The most widely recognized formula, the Parkland formula, predicts a fluid resuscitation rate of 4 milliliters per kilogram of body weight per percentage of total body surface area (TBSA) burned within the first 24 hours. Alternatively, the Modified Brookes formula suggests a reduced volume of 2 milliliters per kilogram per percentage of TBSA burned. Urine output is used as a best monitoring tool for adjusting fluids, with target rates of 0.5-1.0 mL/kg/hour in adults and 1.0-1.5 mL/kg/hour in children [1].

The most common causes of mortality in untreated burns are burn shock and smoke inhalation injury. Before the implementation of resuscitation protocols, the LD50 burn size - defined as the burn size at which 50% of the population succumbs - was 30% TBSA. This threshold improved significantly with the advent of resuscitation protocols. Significant fluid administration is crucial for major burns, defined as those involving more than 20% TBSA, especially within the initial 24 hours post-injury [2].

To calculate fluid requirements, the burned area must first be estimated. Traditionally, the Lund and Browder burn chart has been used to determine the total body surface area (TBSA) affected by a burn. This chart illustrates how the proportion of body surface area varies with

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the child's age. According to an alternate guideline, the patient's palm represents 1% of their body surface area. The 'rule of nines' is another method used to quickly assess TBSA and used commonly to decide whether a patient requires transfer to a specialized burn center. Lactated Ringer's solution is preferred as initial resuscitation fluid, with frequent re-evaluation to prevent fluid overload and subsequent complications [3].

The critical aspect of resuscitation is correcting hypovolemic shock through intravascular volume replacement using intravenous crystalloids, supplemented with intravenous colloid solutions if needed [4]. Fluid infusion rates for burn resuscitation have been the focus of numerous studies. Although various resuscitation volumes (2/3/4 ml/kg/%TBSA) have been used previously, the consensus is to individualize fluid needs and initiate at lower volumes to prevent fluid overload and pulmonary complications [5]. Additionally, several studies have evaluated whether a hypertonic, hyperoncotic, or isotonic solution is superior for fluid resuscitation in burns [6]. Since its introduction in the 1970s, Ringer's solution has not been modified to provide an ideal fluid for burn resuscitation [7]. An increasing number of guidelines recommend using buffered crystalloid solutions as the initial intravenous resuscitation fluid. However, guidelines do not differentiate between various types of buffered solutions that work well in acute burn resuscitation [8]. The electrolyte composition of balanced crystalloid solutions, such as lactate- and acetate-based fluids, closely resembles that of plasma. Although Ringer's lactate is not pH-balanced or isotonic, newer solutions like Sterofundin and Plasmalyte address these issues and offer alternatives due to their balanced electrolytes and metabolic profiles. Ringer's lactate, however, remains the standard in acute burn resuscitation [9, 10]. This study was conducted to identify the ideal resuscitation fluid for severe flame burns and to compare urinary output, electrolyte levels, and acid-base changes following isotonic and hypotonic crystalloid infusion in acute burn resuscitation.

Material and methods

Study Design: Retrospective Comparative analytical study.

Setting: Burn care center, PIMS, Islamabad.

Duration of Study: 1 year (9 May 2023-8 May 2024).

Sample Size: A total of 132 patients were involved in the study, with 66 patients in each group according to WHO sample size calculator, the sample size was determined and from study done by Sharifuddin et al. 2018 [11].

Sampling Technique: Non probability consecutive sampling was done.

Sample selection

Inclusion criteria: (1) Flame burn patients more than 20% TBSA. (2) All age groups. (3) No known co-morbids including diabetes, renal, hepatic, cardiac or respiratory diseases. (4) Admitted within first 4 hours of initial burn injury in Burn Care Center.

Exclusion criteria: (1) Minor burn patient less than 20% TBSA. (2) Scald, electric and other types of burns. (3) Pregnant females. (4) Patients with known diabetes, renal, hepatic, cardiac or respiratory diseases will be excluded. (5) Patients admitted after first 4 hours of initial burn injury in Burn Care Center.

Data collection procedure

This retrospective comparative study included 132 patients. Data collection commenced after obtaining approval from the Ethical Review Board and the Advanced Studies and Research Board (AS & RB) of Shaheed Zulfiqar Ali Bhutto Medical University. Informed consent was obtained from the immediate family members of patients who met the inclusion/exclusion criteria.

Patient selection: Patients were randomly divided into two equal groups, each containing 66 patients, for a total of 132. Patients admitted to ICU Beds 1-6 received isotonic crystalloid, while those admitted to ICU Beds 7-12 received hypotonic crystalloid during the study period. Group A: Patients received Isotonic Crystalloid (Sterofundin fluid). Group B: Patients received Hypotonic Crystalloid (Ringers lactate fluid).

The total burn surface area of patients was assessed using the Wallace Rule of Nines for adults and the Lund and Browder chart for children and infants.

Protocol for burn resuscitation: (1) Resuscitation in Adults: Resuscitation was carried out using the Modified Brooke formula (2 ml/kg/%TBSA burn) in both groups. The first half of the total fluid was administered in the first eight hours, and the second half over the following sixteen hours. (2) Resuscitation in Children: In addition to fluid requirement calculated by the Modified Brooke formula (2 ml/kg/%TBSA burn), children under 12 years of age received maintenance fluid (5% dextrose) according to the 4-2-1 rule: 4 ml/kg per hour for the first 10 kg of body weight, 2 ml/kg per hour for the second 10 kg, and 1 ml/kg per hour for any weight above 20 kg.

Patients in both groups were compared for urinary output, acid-base balance, and serum electrolytes at admission and after the completion of the initial 24-hour burn resuscitation. (1) Urinary output: Hourly urine monitoring was conducted for the first 24 hours of admission. Urine output was assessed using an indwelling urinary catheter and measured with an urometer. The target urine output for patients weighing less than 30 kg was 1 ml/kg/h, while the target for those weighing more than 30 kg was 0.5 ml/kg/h. Fluid resuscitation rates were adjusted if urine output was either below or above these targets. (2) Acid base balance: Arterial blood gas sampling was performed upon ICU admission and again after 24 hours of initial resuscitation. Blood pH and bicarbonate levels were measured to assess the acid-base balance. Normal blood pH: 7.35-7.45. Normal bicarbonate (HCO_3) level: 22-26 mEq/L. (3) Serum electrolytes: Sodium, potassium, and chloride levels were measured via blood tests upon ICU admission and after 24 hours of initial resuscitation. Normal sodium (Na) level: 135-145 mmol/L. Normal potassium (K) level: 3.6-5.5 mmol/L. Normal chloride (Cl) level: 96-106 mmol/L.

Data analysis

Data were entered and analyzed using the Statistical Package for Social Sciences (SPSS V-20). Means and standard deviations were computed for quantitative variables such as total burn surface area, urinary output, pH, bicarbonate levels, and levels of sodium, potassium, and chloride. Frequencies with percentages were presented for qualitative variables such as age (grouped), gender, degree of burn, TBSA, and resuscitation fluids administered. An independent samples t-test was applied to compare electrolyte and acid-base outcomes between groups at admission and after 24 hours of fluid resuscitation. The chi-square test was used to compare urine output after 24 hours of resuscitation in both groups and to assess urine output by age group. A p-value < 0.05 was considered significant.

Results

This study included 132 patients, with 66 patients in each group (A and B, respectively). Participants were added to the study according to the inclusion criteria. No subjects were lost or dropped out at any point during the study. The following are the findings of the study.

Patient outcomes

Patient outcomes were compared using the independent samples t-test, as shown in **Table 1**. In both groups, more than 60% of patients were over 12 years of age, and the majority of flame burn patients were male. Weight, depth, degree of burns, TBSA, and the volume of resuscitation fluid given within 24 hours were equally comparable between both groups.

Pre-infusion values of electrolytes and acid-base balance at admission

The mean pre-infusion values of sodium, potassium, bicarbonate, and pH were the same in both groups (p-value > 0.05), as shown in **Table 2**.

Post-infusion values of electrolytes and acid-base balance after 24-hour resuscitation

Post-infusion sodium and chloride levels were within the normal range in the isotonic group (p-value > 0.05); whereas they were lower in the hypotonic group. There was no significant difference between mean potassium, bicarbonate, and pH levels in either group (p-value > 0.05), as shown in **Table 3** and **Figure 1**.

Urine output after 24-hour resuscitation in both groups

95% of patients had a urine output greater than 0.5 ml/kg/h in the isotonic group, whereas 80% of patients in the hypotonic group had a

Table 1. Patient outcomes

Variables	Isotonic group (n=66), Mean (SD)	Hypotonic group (n=66), Mean (SD)	*P*-value
Age	< 12 years (39.4%) > 12 years (60.6%) 20.26 (15.5)	< 12 years (31.8%) > 12 years (68.2%) 19.7 (11.7)	0.810
Gender	Male (54.5%) Female (45.5%) 1.45 (0.5)	Male (51.5%) Female (48.5%) 1.48 (0.5)	0.730
Weight	< 30 kg (39.4%) > 30 kg (60.6%) 5.47 (3.1)	< 30 kg (30.3%) > 30 kg (69.7%) 6.18 (3)	0.172
Depth and degree of burn	Second degree deep and third degree (87.9%) Third degree (12.1%) 3 (0.45)	Second degree deep and third degree (93.9%) Third degree (6.1) 3 (0.35)	0.516
TBSA	< 50% (60.6%) > 50% (39.4%) 6.5 (3.6)	< 50% (56.1%) > 50% (43.9%) 6 (2.9)	0.418
Resuscitation fluid given in 24 hours	< 10000 ml (89.4%) > 10000 ml (10.6%) 9.3 (7.7)	< 10000 ml (89.4%) > 10000 ml (10.6%) 10.2 (7.1)	0.530

*P < 0.05 indicates statistical significance.

Table 2. Values of electrolytes and acid base at admission

Variables (mmol/L)	Isotonic group (n=66), Mean (SD)	Hypotonic group (n=66), Mean (SD)	*P*-value
Sodium, Na^+	131 (2.39)	130.2 (2.79)	0.920
Potassium, K^+	3.9 (0.43)	3.9 (0.67)	0.878
Chloride, Cl^-	92 (3.36)	96.5 (2.72)	0.000*
Bicarbonate, HCO_3^-	21 (2)	21 (2)	1.000
pH	7.3 (0.06)	7.3 (0.06)	0.947

*P < 0.05 indicates statistical significance.

Table 3. Values of electrolytes and acid base post 24 hour resuscitation

Variables (mmol/L)	Isotonic group (n=66), Mean (SD)	Hypotonic group (n=66), Mean (SD)	*P*-value
Sodium, Na^+	138.7 (2)	128.1 (3.3)	0.000*
Potassium, K^+	3.8 (0.3)	3.5 (0.39)	0.000*
Chloride, Cl^-	99.5 (1.9)	90.9 (3.1)	0.000*
Bicarbonate, HCO_3^-	21.2 (1.9)	21.1 (2)	0.863
pH	7.31 (0.05)	7.3 (0.06)	0.290

*P < 0.05 indicates statistical significance.

urine output greater than 0.5 ml/kg/h (*p*-value < 0.05), as shown in **Table 4** and **Figure 2**.

Urine output after 24-hour resuscitation according to age

No children (< 12 years) in the isotonic group had a urine output of < 1 ml/kg/h, whereas 22.7% of children in the hypotonic group had a urine output of < 1 ml/kg/h (*p*-value < 0.05), as shown in **Table 5**.

Discussion

This is novel research, as no such study has been conducted in Pakistan so far comparing crystalloid fluids in major burns during acute 24-hour resuscitation. Additionally, burns are a significant issue in undeveloped countries, so not many studies regarding fluid comparisons in major burns have been conducted in developed countries either. There are many studies and meta-analyses comparing different types of crystalloid fluids in settings other than burns. Regarding the distribution of age, gender, TBSA, and total volume of fluid provided in both groups, the current study's data show no discernible variations. Our objective included comparing the urinary outcomes, acid-base balance, and electrolyte status of patients in both groups, which we will discuss one by one.

Electrolytes

The mean pre-infusion values of sodium, potassium, bicarbonate, and pH were the same in both groups (*p*-value > 0.05). However, post-infusion sodium and chloride were within the normal range in the isotonic group (*p*-value < 0.05), showing an improvement in the electro-

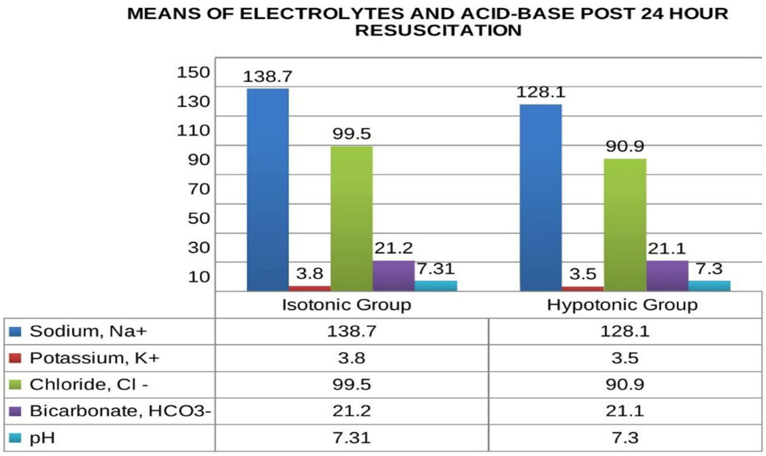

Figure 1. Values of electrolytes and acid-base post 24 hour resuscitation in both groups.

Table 4. Urine Output post 24 hour resuscitation in both groups

Urine Output per Kg per hours (ml)	Isotonic group (n=66)	Hypotonic group
< 0.5 ml/kg/hr	1 (1.5%)	13 (19.7%)
0.5 ml/kg/hr	33 (50%)	47 (71.2%)
1.0 ml/kg/hr	30 (45%)	6 (9.1%)
> 1.0 ml/kg/hr	2 (3%)	0 (0%)
P-value	0.000*	0.000*

*P < 0.05 indicates statistical significance.

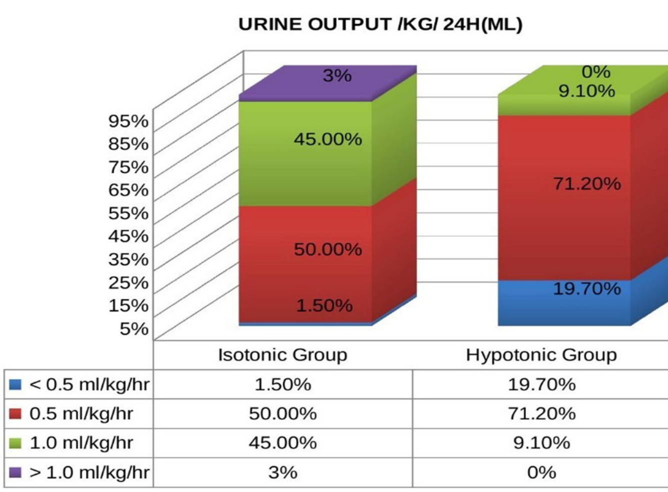

Figure 2. Urine Output post 24 hour resuscitation in both groups.

lyte status of patients after infusion with isotonic crystalloid compared to hypotonic crystalloid, confirming our hypothesis and highlighting the fact that Ringer's lactate is hypotonic. Several studies support our findings, including:

(1) In a study done by Torres, S.F., et al. (2019) [12], they documented that, compared to children who received hypotonic fluids, iatrogenic hyponatremia was less likely to occur with isotonic solutions in pediatric hospital patients receiving exclusive parenteral hydration over a 24-hour period. Although in their study they compared 0.45% normal saline plus dextrose with 0.9% normal saline plus dextrose, the sodium concentration is similar to the isotonic fluid we used in our study.

(2) In a study done by Amer, B.E., et al. (2024) [13], a meta-analysis of 33 randomized controlled trials, they compared isotonic and hypotonic fluids for hyponatremia and found that isotonic maintenance fluids given intravenously significantly reduced moderate hyponatremia at both the 24-hour time points (P < 0.00001; strong evidence) and beyond 24 hours (P < 0.00001; strong evidence). Our study shows similar findings in acute burn patients - both adults and children - who received isotonic fluids and maintained normal sodium and chloride serum levels after 24 hours of resuscitation.

(3) In a study done by Karageorgos, S.A., et al. (2018) [14], they documented that pediatric patients receiving hypotonic fluids had an increased risk of developing hospital-acquired hyponatremia compared to those receiving isotonic fluids, without a statistically significant change in other serum electrolyte levels.

(4) In a study done by Akinsola, B., et al. (2021) [15], the use of isotonic fluids increased according to The American Academy of Pediatrics

Table 5. Urine Output post 24 hour resuscitation in both groups as per Age

Urine Output per Kg per hours (ml)	Isotonic group (n=66)		Hypotonic group	
	< 12 years	> 12 years	< 12 years	> 12 years
< 0.5 ml/kg/hr	0 (0%)	1 (1.5%)	0 (0%)	13 (19.7%)
0.5 ml/kg/hr	0 (0%)	33 (50%)	15 (22.7%)	32 (48.5%)
1.0 ml/kg/hr	24 (36.4%)	6 (9.1)	6 (9.1%)	0 (0%)
> 1.0 ml/kg/hr	2 (3%)	0 (0%)	0 (0%)	0 (0%)
P-value	0.000*		0.008*	

*P < 0.05 indicates statistical significance.

(AAP) clinical practice guideline (CPG) regarding maintenance intravenous fluids in pediatric emergency settings, and the incidence of hyponatremia was reduced after the intervention (*p*-value < 0.05). Similarly, in our study, we found hyponatremia in patients who received conventional Ringer's lactate.

Acid-base balance

In our study, we found no significant difference between the mean bicarbonate and pH values in both groups (*p*-value > 0.05). There are some studies that found no change in acid-base balance with the use of Sterofundin fluid as isotonic crystalloids and Ringer's lactate fluid as hypotonic crystalloids, although these studies were not conducted in burn injury patients, but the study variables were the same. These studies include:

(1) In a study done by Hasyizan M. Hassan., et al. (2018) [16], they stated that in pediatric surgical patients undergoing surgery lasting less than three hours, Sterofundin was not found to be superior to Ringer's lactate solution in terms of electrolytes and acid-base balance. Though our study showed an improvement in electrolyte status with Sterofundin, no improvement was noted in terms of the acid-base status of the patients.

(2) In a study done by Pratap, R., et al. (2018) [17], they also discovered no statistically significant variation in pH, bicarbonate, sodium, or potassium at admission and at different time periods between the two groups using Sterofundin fluid compared to Ringer's (*p*-value > 0.05). They studied trauma and post-surgical patients who experienced hypotension when admitted to the intensive care unit. They also found low serum lactate levels with the use of Sterofundin fluid, as lactate is a major buffer in Ringer's fluid. Our study, with the exception of normal sodium levels, also showed similar results.

(3) In a study done by Rawat, N., et al. (2020) [18], they documented that administering balanced salt solutions - Ringer's lactate or acetate-containing balanced salt solution - in critically ill patients with metabolic acidosis, acetate-containing balanced salt solutions conferred no advantage in the time or extent of correction of metabolic acidosis, which is similar to our study findings.

There are some studies that found an improvement in acid-base balance with the use of Sterofundin fluid as an isotonic crystalloid and Ringer's lactate fluid as a hypotonic crystalloid, although these studies were also not conducted in burn injury patients, but the study variables are the same.

(1) In a study done by Shariffuddin, et al. (2018) [11], they found no significant change in electrolytes but found improved acid-base status in patients using Sterofundin fluid compared to Ringer's lactate (*p*-value < 0.05).

(2) In a study done by Klein-Richers, U., et al. (2022) [19], they found a significant change in the acid-base status of patients using both acetate- and lactate-containing fluids (*p*-value < 0.05). These findings are contrary to our results.

Urine output

In both adult and pediatric burn care, urine production is considered the ultimate aim of resuscitation. The target is 1 ml/kg per hour for children under 30 kg in weight, and 0.5 ml/kg per hour for children above 30 kg.

In our study, no children (< 12 years) in the isotonic group had a urine output of < 1 ml/kg/h, whereas 22.7% of the children in the hypotonic group had a urine output of < 1 ml/kg/h (p-value < 0.05). Additionally, in our study, only one adult patient (> 12 years) in the isotonic group had a urine output of < 0.5 ml/kg/h, whereas 19.7% of the adult patients in the hypotonic group had a urine output of less than 0.5 ml/kg/h (p-value < 0.05).

In review done by Boehm, D. and Menke, H. (2021) [20], they state that for goal-directed resuscitation, urine output remains the most important measure. However, if adequate tissue perfusion and oxygen delivery are the ultimate goals, urine output is not always a reliable metric, even though it can be used as a readily available indicator for appropriate resuscitation. Furthermore, oliguria or anuria is not limited to hypovolemia; they can also indicate other conditions. For instance, oliguria frequently occurs as intra-abdominal pressure rises, as seen in abdominal compartment syndrome. In reality, urine output should not be the sole factor used to guide resuscitation. Nonetheless, the American Burn Association continues to recommend it, and it remains one of the most commonly used parameters.

In our study, we found improved urine output with Sterofundin or isotonic fluids. Similar findings were noted in a study by Chaussard, M., et al. (2020) [21], in which they observed improved urine output in burn patients using Plasmalyte, an isotonic crystalloid like Sterofundin.

The mechanism by which isotonic fluids increased urine output in our study's burn patients remains unclear. It could be due to improvements in serum electrolytes, especially sodium and chloride levels, post-resuscitation, as observed in our study. Improved urine output was also reported in a study by Adwaney, A., et al. (2017) [22], where patients in the 0.9% saline group did not produce as much urine as those in the Plasma-Lyte group. However, in their study, the enhanced diuresis was linked to a larger fluid volume administered, and the study involved patients undergoing renal transplants, which was not the case in our study, as both groups received the same amount of resuscitation fluids, and the patients had burn injuries.

However, increased urine output with isotonic fluids is not observed in all studies. In a study by Rossman, H.M., et al. (2017) [23], no difference in urine output was found between Sterofundin and Normal Saline in managing patients with Diabetic Ketoacidosis.

Regarding restoring plasma volume in the intravascular compartment during the first day after a burn, there is currently no consensus on the ideal type or composition of fluid to be used - whether isotonic crystalloids, hypertonic solutions, or colloids. Researchers continue to explore the issue of choosing an appropriate burn resuscitation fluid [24]. Although our study found isotonic fluid to be superior compared to hypotonic fluid in the initial 24-hour acute burn resuscitation, further studies are needed to address this issue more definitively.

Conclusion

This study supports the superiority of isotonic crystalloids compared to hypotonic crystalloids, showing better urinary output and electrolyte balance in burn victims. However, with a limited sample size, there was a noticeable variation in outcomes among patients treated with isotonic fluids. As this is a pilot study, it paves the way for more clinical trials in the future. This study can serve as a foundation for further research to obtain significant outcomes, potentially altering our current approach to acute resuscitation in burn patients and helping to resolve this ongoing dilemma.

Limitations and recommendation

(1) There is a scarcity of literature comparing isotonic crystalloids with conventional hypotonic crystalloids (Ringer's lactate) in burn patients.

(2) No advanced monitoring tools, such as the Pulse Pressure Variation (PPV) algorithm or the Global End-Diastolic Volume Index (GEDVI) algorithm, were used to monitor resuscitation endpoints due to the research being conducted in a resource-limited setting.

(3) Large multi-center studies need to be conducted in burn centers across the globe using isotonic crystalloids to support our findings and further resolve the dilemma of identifying the best resuscitation fluid for acute burn resuscitation.

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Disclosure of conflict of interest

None.

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