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ORIGINAL RESEARCH

Effects of restrictive fluid resuscitation on the clinical efficacy of treating traumatic hemorrhagic shock combined with traumatic coagulopathy

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Abstract

This study aims to assess the clinical efficacy of limited fluid resuscitation on traumatic hemorrhagic shock combined with traumatic coagulopathy. A cohort of 120 patients with traumatic hemorrhagic shock complicated with traumatic coagulopathy at admission were divided into two groups based on their emergency fluid resuscitation: the study group (received restrictive fluid resuscitation) and the control group (received conventional fluid resuscitation). Then, the incidence of complications, coagulation parameters, blood gas parameters and electrolyte parameters between the two groups were compared. The incidence of complications in the study group was 6.67%, which was significantly lower than the 20.00% observed in the control group ($p < 0.05$). Before resuscitation, there was no significant difference in coagulation parameters, blood gas parameters and electrolyte parameters between the two groups ($p > 0.05$), and in both groups, before and after resuscitation, the coagulation parameters after resuscitation were higher than those before resuscitation, blood gas parameters were lower than those before resuscitation, Mg^{2+}, Cl^{-} and Na^{+} levels were higher than those before resuscitation, K^{+} was lower than that before resuscitation, and the difference had statistical significance ($p < 0.05$). After resuscitation, the coagulation parameters in the study group were significantly lower than those in the control group, the BL (Blood Lactic Acid) and $PaCO_2$ (partial pressure of carbon dioxide in arterial blood) levels in the study group were lower than those in the control group, the BE (base excess) and PaO_2 levels were higher than those in the control group, and the differences were statistically significant ($p < 0.05$). However, after resuscitation, we found no significant difference in electrolyte parameters between both groups ($p > 0.05$). Restrictive fluid resuscitation was found to significantly enhance coagulation and blood gas function, stabilize water and electrolyte balance and reduce complications in traumatic hemorrhagic shock patients complicated with traumatic coagulopathy. These findings hold substantial clinical significance and merit further exploration.

Keywords

Restrictive fluid resuscitation; Traumatic hemorrhagic shock; Traumatic coagulation; Clinical efficacy

1. Introduction

In recent years, there has been a significant increase in the incidence of injuries caused by external factors, often resulting in traumatic blood loss and, in severe cases, hemorrhagic shock [1]. A direct correlation has been reported between the rate of blood loss over time in patients with traumatic blood loss and the severity of hemorrhagic shock [2]. As blood loss escalates, it can compromise the normal perfusion of bodily organs and tissues, leading to inadequate blood supply and a reduction in the release of coagulation factors, which can precipitate traumatic coagulation disorders, thereby posing a serious threat to patients' life. The clinical management of this condition primarily revolves around the timely initiation of rapid hemostasis, which serves to maintain proper blood perfusion in organ tissues, thereby playing a crucial protective role in preserving the functionality of these vital organs [3].

Studies have demonstrated that approximately 85% of patients suffering from traumatic hemorrhagic shock also present with traumatic coagulation [4]. The optimal window for rescuing patients with traumatic hemorrhagic shock combined with traumatic coagulopathy is within the first hour after the onset of shock. Timely blood transfusion is administered to restore normal organ perfusion, rebalance the internal environment, maintain the body's compensatory mechanisms,

and prevent ischemia-reperfusion injuries. Traditionally, clinical practice relies heavily on fluid resuscitation to normalize water-electrolyte levels, maintain vital signs and prevent shock [5]. However, this approach often led to adverse events due to factors such as irregular infusion rates, challenges in maintaining normal body temperature and the potential to exacerbate metabolic acidosis, which could impact treatment efficacy and prognosis [6]. In this regard, restrictive fluid resuscitation represents an optimized approach on the basis of conventional treatment. It prioritizes strict control over infusion rates and volumes during fluid administration to rapidly restore vital signs, effectively addresses issues associated with conventional treatment, accelerates toxic substance metabolism, mitigates acidosis and ensures a safe resuscitation process [7–10].

Herein, we designed this present study to explore the clinical effectiveness of restrictive fluid resuscitation on patients with traumatic hemorrhagic shock combined with traumatic coagulopathy admitted to our hospital.

2. Materials and methods

2.1 Patients and grouping

A total of 120 patients diagnosed with traumatic hemorrhagic shock complicated with traumatic coagulopathy were enrolled and categorically divided into two groups (n = 60 patients/group): the study group, who underwent restrictive fluid resuscitation, and the control group, who received conventional fluid resuscitation (Table 1).

In the study group, there were 31 male and 29 female patients, with an average age of 53.15 (±5.36) years. The interval between injury and rescue averaged 48.20 (±4.51) minutes, and the injuries ranged from falls from heights, traffic accidents and external violent attacks, which accounted for 21, 25 and 14 cases, respectively. Hemorrhagic shock grading revealed 11, 39 and 10 cases in grades I, II and III, respectively.

The control group comprised 32 male and 28 female patients, with an average age of 53.18 (±5.31) years. The time elapsed from injury to rescue averaged 48.70 (±4.48) minutes, and the causes of injury included falls from heights, traffic accidents and external violent attacks in 18, 27 and 15 cases, respectively. In addition, the hemorrhagic shock grading indicated that there were 13, 36 and 11 cases classified as grade I, II and III, respectively. Importantly, no significant differences in baseline data were observed between the two groups ($p > 0.05$).

2.2 Inclusion and exclusion criteria

The study inclusion criteria were: (1) meeting the relevant diagnostic criteria in the Expert Consensus on Diagnosis and Hygiene Emergency Treatment of Acute Traumatic Coagulopathy and Coagulopathy (2016); (2) survival time ≥1 d after rescue; (3) having complete medical records and data that would not affect data analysis, and; (4) provided signed informed consent.

Patients with the following criteria were excluded: (1) severe heart, liver and kidney dysfunction; (2) non-traumatic hemorrhagic shock; (3) severe craniocerebral hemorrhage and injury; (4) recent use of anticoagulant drugs; (5) cerebral thrombosis, and; (6) withdrew during the study.

2.3 Method

In this study, selected patients were diligently monitored for vital signs, closely observed for any changes, and assessed for limb function and immobilization before commencing treatment. Arteriovenous blood samples were obtained to assess pertinent indicators, including blood gas parameters, troponin levels, complete blood counts, and coagulation parameters, in addition to monitoring hemodynamic parameters. Venous access was established to facilitate fluid replacement therapy, primarily involving blood transfusion and the infusion of hemostatic agents.

Specifically, the control group received conventional fluid resuscitation, adhering to the principles of rapid, adequate and early fluid replacement to achieve a systolic blood pressure ≥90 mmHg. In contrast, the study group underwent restrictive fluid resuscitation, wherein fluid (both blood and intravenous fluids) was administered following a strict regimen of initial rapid infusion, followed by controlled infusion rates, with the volume adjusted according to the patient's condition. Preoperative procedures were conducted to ensure patients' vital signs stability, including maintaining systolic blood pressure, central venous pressure, and mean arterial pressure in the ranges of

TABLE 1. Comparison of clinical data between the two groups.

Parameters	n	Gender (n, %)		Age (yr)	Time from injury to rescue (min)	Hemorrhagic shock grade (n, %)			Causes of injury (n, %)		
		Male	Female			Grade I	Grade II	Grade III	Fall from Height	Traffic Accident	External Force Strike
Study group	60	31	29	53.15 ± 5.36	48.20 ± 4.51	11	39	10	21	25	14
Control group	60	32	28	53.18 ± 5.31	48.70 ± 4.48	13	36	11	18	27	15
χ^2 value	—	0.033		0.031	0.609	0.334			0.342		
p value	—	0.855		0.976	0.544	0.846			0.843		

70–80 mmHg, >2.18 mmHg and 50–60 mmHg, respectively.

Throughout the resuscitation process, we maintained mixed or central venous oxygen saturation at or above 70% (the recovery endpoint). For fluid resuscitation, both groups received electrolyte injections (Sichuan Kelun Pharmaceutical Co., Ltd., approval number: State medical permit number H20113475, strength: 1000 mL).

2.4 Outcome measures

(1) Analysis of complication incidence: The incidence of complications, such as pulmonary infection, disseminated intravascular coagulation and multiple organ dysfunction syndrome, was assessed in both study groups.

(2) Evaluation of coagulation parameters: These were compared between the two groups before and after resuscitation. Venous blood samples were collected in the morning (between 8:00–10:00), with patients instructed to fast prior to blood collection and maintain a fasting state. Briefly, a 5 mL venous blood sample was obtained, and the supernatants were isolated and stored in a cold environment until analysis. An automated coagulometer (SYSMEX Corporation, Japan, Kobe City, Hyogo Prefecture; model: CA-1500) was used for measuring thrombin time (TT), activated partial thromboplastin time (APTT), and prothrombin time (PT).

(3) Assessment of blood gas parameters: These were compared between the two groups before and after resuscitation, following the same blood sample collection procedure as described in (2). Briefly, an arterial blood gas analyzer (Siemens AG, Germany, Munich, Bavaria; model: RP405) was utilized to measure key indicators, such as blood lactate (BL), base excess (BE), arterial partial pressure of carbon dioxide ($PaCO_2$), and arterial partial pressure of oxygen (PaO_2).

(4) Electrolyte parameter analysis: Evaluation of electrolyte parameters before and after resuscitation was conducted in both groups, using the same blood sample collection method as detailed in (2). An automatic analyzer (BadeBehring Company, USA, Vermont; model: Archiyectc 16000) was used to assess magnesium ion (Mg^{2+}), chloride ion (Cl^-), sodium ion (Na^+), and potassium ion (K^+). The testing kit was supplied by BadeBehring.

2.5 Statistical methods

Data analysis was performed using SPSS 27.0 (International Business Machines Corporation, Armonk, NY, USA). Measurement data that adhered to a normal distribution are presented as mean (±standard deviation; ($\bar{x} \pm$ SD)), while measurement data not conforming to a normal distribution are shown as median (interquartile range: M (Q1, Q3)). For comparisons, *t*-tests were used for data with a normal distribution, whereas the rank sum test was used for data without a normal distribution. Enumeration data are expressed as counts and percentages (n (%)), with the comparison between groups conducted using the χ^2 test. A significance level of $p < 0.05$ was used to determine statistical significance.

3. Results

3.1 Comparison of complication rates between both groups

The incidence of complications in the study group was 6.67%, significantly lower than the 20.00% observed in the control group ($p < 0.05$). The detailed results are presented in Table 2.

3.2 Comparison of coagulation parameters between both groups

Before resuscitation, there were no significant differences in coagulation indicators between the two groups ($p > 0.05$). However, after resuscitation, coagulation indicators in both groups were significantly higher compared to before resuscitation ($p < 0.05$). Furthermore, post-resuscitation coagulation indicators in the study group were significantly lower than those in the control group ($p < 0.05$), as shown in Table 3.

3.3 Comparison of blood gas parameters between both groups

Before resuscitation, there were no significant differences in blood gas parameters between the two groups ($p > 0.05$), while after resuscitation, the blood gas parameters were significantly lower than before resuscitation in both groups ($p < 0.05$). In addition, after resuscitation, the study group exhibited lower levels of BL and $PaCO_2$ compared to the control group while also displaying significantly higher levels of BE and PaO_2 than the control group ($p < 0.05$) (Table 4).

3.4 Comparison of electrolyte indicators between both groups

Before resuscitation, there were no significant differences in electrolyte parameters between the two groups ($p > 0.05$). However, both before and after resuscitation, the levels of Mg^{2+}, Cl^- and Na^+ were higher after resuscitation than before resuscitation, while K^+ levels were lower after resuscitation in both groups, and no significant differences in electrolyte parameters were observed between the two groups after resuscitation ($p > 0.05$) (Table 5).

4. Discussion

Traumatic hemorrhagic shock, a condition characterized by blood and fluid loss following trauma, leads to microcirculatory hypoperfusion, often resulting in pathological alterations such as metabolic disturbances and multiple organ dysfunction. Clinical manifestations include negative mood, pallor and shortness of breath, and the condition can progress to multiple organ failure [10–12]. The primary approach to clinical management of this condition depends on early and timely fluid replacement, continuous monitoring of vital signs, rapid restoration of normal blood circulation to achieve and maintain normal blood pressure, provision of essential nutritional support, and enhancement of microcirculation [10]. Treatment initiated within the first hour post-trauma enables the rapid replenishment of effective circulating blood volume to provide anti-shock effects. Conventional fluid resuscitation has been a fundamental component of clinical management to rapidly restore blood pressure and overall bodily indices by

TABLE 2. Comparison of complication rates between both groups (n, %).

Parameters	n	Lung infection	Disseminated intravascular coagulation	Multiple organ dysfunction syndrome	Incidence
Study group	60	2 (3.33)	1 (1.67)	1 (1.67)	4 (6.67)
Control group	60	6 (10.00)	2 (3.33)	4 (6.67)	12 (20.00)
χ^2 value					4.615
p value					0.032

TABLE 3. Comparison of coagulation parameters between both groups ($\bar{x} \pm$ SD).

Parameters	Study group (n = 60)	Control group (n = 60)	*t* value	*p* value
TT				
Pre-resuscitation	10.47 ± 1.46	10.23 ± 1.15	1.000	0.319
Post-resuscitation	13.58 ± 1.29	16.27 ± 1.58	10.215	<0.001
t value	12.365	23.941		
p value	<0.001	<0.001		
APTT				
Pre-resuscitation	27.26 ± 2.68	27.11 ± 2.61	0.311	0.757
Post-resuscitation	31.28 ± 3.23	35.72 ± 3.48	7.244	<0.001
t value	7.419	15.332		
p value	<0.001	<0.001		
PT				
Pre-resuscitation	8.98 ± 0.87	8.73 ± 0.81	1.629	0.106
Post-resuscitation	10.82 ± 1.11	11.69 ± 1.18	4.160	<0.001
t value	10.106	17.643		
p value	<0.001	<0.001		

TT: thrombin time; APTT: activated partial thromboplastin time; PT: prothrombin time.

adhering to early, extensive and rapid treatment principles. Nonetheless, the infusion rate depends on various factors, increasing the risk of complications such as reduced body temperature and metabolic acidosis. Thus, the selection of effective treatment options becomes critically significant [12].

Restrictive fluid resuscitation offers several distinct advantages. It is characterized by a shorter treatment duration, the ability to promptly prevent bleeding, and the capacity to tailor fluid infusion rates according to the patient's specific conditions. This approach enhances blood volume by establishing osmotic pressure gradients both within and outside blood vessels while maintaining lower blood pressure levels and simultaneously restoring normal blood volume, thereby promoting efficient patient resuscitation. By assessing the patient's disease severity and employing a targeted approach to fluid infusion, restrictive fluid resuscitation ensures the rationality of the infusion process, ultimately improving blood volume, enhancing cardiac function, and contributing to favorable prognoses [9]. Its primary benefits are summarized as follows [7–10]: ① Restrictive fluid resuscitation primarily focuses on modulating blood pressure levels, maintaining them at lower levels to ensure the body maintains normal blood volume. It also effectively controls the rate of fluid replacement, achieving the desired resuscitation outcome. ② This approach speeds up the process of hemostasis, reducing the time required for blood clotting. The selection of fluid infusion methods is comprehensive and tailored, which aids in reducing complications such as vascular coagulation and acute respiratory distress. ③ Restrictive fluid resuscitation can rapidly adjust blood volume, protecting myocardial function and supporting cardiac health.

Through comparative analysis, this study revealed a lower incidence of complications in the study group, suggesting that the restrictive fluid resuscitation protocol is associated with reduced complications and enhanced safety, minimizing the disruption of the internal environment, which may be closely related to the regimen's restrictions on infusion volume and speed, thereby helping maintain a dynamic equilibrium between the body's coagulation and fibrinolytic systems and ultimately reducing blood loss [13, 14].

In the human coagulation system, essential indicators for accurately assessing coagulation function include TT, PT and APTT, and their levels closely correlate with coagulation performance [15]. In this study, our observations revealed a reduction in TT, APTT and PT indicators in both study groups, with a greater reduction observed in the study group compared to the control group, indicating that restrictive fluid resuscitation therapy plays a role in ensuring adequate blood perfusion

TABLE 4. Comparison of blood gas parameters between both groups ($\bar{x} \pm SD$).

Parameters	Study group (n = 60)	Control group (n = 60)	*t* value	*p* value
BL (mmol/L)				
Pre-resuscitation	2.89 ± 0.21	2.97 ± 0.26	1.854	0.066
Post-resuscitation	0.97 ± 0.09	1.74 ± 0.14	35.837	<0.001
t value	65.094	32.264		
p value	<0.001	<0.001		
BE (mmol/L)				
Pre-resuscitation	−2.69 ± 0.27	−2.71 ± 0.22	0.445	0.657
Post-resuscitation	−3.58 ± 0.38	−6.89 ± 0.62	35.258	<0.001
t value	14.789	48.274		
p value	<0.001	<0.001		
$PaCO_2$ (mmHg)				
Pre-resuscitation	33.58 ± 3.61	33.23 ± 3.25	0.558	0.578
Post-resuscitation	27.18 ± 2.71	30.81 ± 2.26	7.968	<0.001
t value	10.982	4.735		
p value	<0.001	<0.001		
PaO_2 (mmHg)				
Pre-resuscitation	94.97 ± 9.19	94.37 ± 9.45	0.353	0.725
Post-resuscitation	91.59 ± 9.01	84.57 ± 8.39	4.417	<0.001
t value	2.034	6.007		
p value	0.044	<0.001		

BL: blood lactate; BE: base excess; $PaCO_2$: arterial partial pressure of carbon dioxide; PaO_2: arterial partial pressure of oxygen.

to vital organs while mitigating coagulation dysfunction during rapid fluid replacement, thereby maintaining blood volume equilibrium, stabilizing the internal environment, and reducing the occurrence of disseminated intravascular coagulation. This favorable outcome is primarily attributable to the early-stage application of restrictive fluid resuscitation in patients with this condition. By controlling the infusion rate and volume, excessive fluid administration is avoided, reducing the risk of rebleeding and facilitating the restoration of normal microcirculation and accelerating coagulation function recovery.

Administering extensive fluid replacement to patients with traumatic hemorrhagic shock can lead to increased blood loss, decreased blood concentration, and impaired coagulation function. This approach can also reduce oxygen delivery to the body and diminish overall metabolic capacity. During this phase, lactate levels rise, contributing to metabolic acidosis, which, in turn, results in decreased PaO_2 levels and increased $PaCO_2$ levels [16]. The BE index level accurately reflects acid-base balance and disturbances, while the BL index level provides insight into peripheral tissue perfusion and cellular oxygen content. When oxygen levels drop and acidosis ensues, the BE index level decreases while the BL index level increases [17]. In this study, it was observed that the levels of BL, BE, $PaCO_2$ and PaO_2 significantly improved in the study group, indicating that restrictive fluid resuscitation can restore blood gas parameter levels and mitigate the risk of acidosis, which could be likely due to the treatment's effective control of fluid replacement rates and volumes, preventing complications associated with abnormal fluid replacement and ensuring adequate fluid replacement in the early stages. Additionally, it accelerates the return of normal metabolism, increases tissue oxygen content, and restores normal oxygen supply [18]. Collectively, these findings indicate that restrictive fluid resuscitation can restore organ tissue blood flow, alleviate pressure and strain on the body and facilitate a quicker recovery, aligning with existing literature [16–18].

In this study, the post-resuscitation analysis revealed no significant differences in the levels of Mg^{2+}, Cl^-, Na^+ and K^+ between both study groups. These findings indicate that resuscitation fluids were able to maintain the body's normal electrolyte balance, and the chosen resuscitation method did not influence electrolyte levels. Restrictive fluid resuscitation effectively achieved the expected resuscitation outcomes.

5. Research limitations and future perspectives

This study had several limitations. For instance, the number of cases was limited and all were derived from a single institution. In addition, although some experts advocate for early cessation of bleeding, rapid restoration of the body's required blood volume and the maintenance of a state of hypoperfusion to improve patient prognosis [19, 20], further research is required to determine the optimal timing and duration of restrictive fluid

TABLE 5. Comparison of electrolyte indicators between both groups ($\bar{x} \pm$ SD, mmol/L).

Parameters	Study group (n = 60)	Control group (n = 60)	*t* value	*p* value
Mg^{2+}				
Pre-resuscitation	0.42 ± 0.04	0.43 ± 0.03	1.549	0.124
Post-resuscitation	0.71 ± 0.06	0.73 ± 0.05	1.984	0.050
t value	31.151	39.853		
p value	<0.001	<0.001		
Cl^-				
Pre-resuscitation	103.58 ± 10.14	103.67 ± 10.23	0.048	0.961
Post-resuscitation	107.59 ± 10.22	107.67 ± 10.37	0.043	0.966
t value	2.158	2.127		
p value	0.033	0.036		
Na^+				
Pre-resuscitation	134.56 ± 13.78	134.28 ± 13.48	0.113	0.911
Post-resuscitation	140.69 ± 14.55	140.81 ± 14.29	0.046	0.964
t value	2.369	2.575		
p value	0.019	0.011		
K^+				
Pre-resuscitation	4.87 ± 0.41	4.79 ± 0.43	1.043	0.299
Post-resuscitation	3.72 ± 0.39	3.64 ± 0.37	1.153	0.251
t value	15.742	15.703		
p value	<0.001	<0.001		

Mg^{2+}: magnesium ion; Cl^-: chloride ion; Na^+: sodium ion; K^+: potassium ion.

resuscitation in the treatment of patients with this condition.

6. Conclusions

In summary, restrictive fluid resuscitation in patients with traumatic hemorrhagic shock combined with traumatic coagulopathy can significantly improve coagulation function and blood gas parameters, as well as effectively stabilizing water and electrolyte balance and reducing the incidence of complications, thereby holding substantial clinical value for potential widespread adoption.

AVAILABILITY OF DATA AND MATERIALS

The authors declare that all data supporting the findings of this study are available within the paper and any raw data can be obtained from the corresponding author upon request.

AUTHOR CONTRIBUTIONS

XZW, LP, HBX, LJN and CY—designed the study and carried them out; supervised the data collection, analyzed the data, interpreted the data, prepared the manuscript for publication and reviewed the draft of the manuscript. All authors have read and approved the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Ethical approval was obtained from the Ethics Committee of the Second Affiliated Hospital of Soochow University (JD-LK-2020-122-03). Written informed consent was obtained from a legally authorized representative(s) for anonymized patient information to be published in this article.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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