Efficacy and Safety of Early Post-ICU Admission Colloid Resuscitation with 5% Albumin Versus 4% Gelatin Following 30 mL/kg Crystalloid in Septic Shock Patients Upon General Surgical ICU Admission: A Retrospective Study

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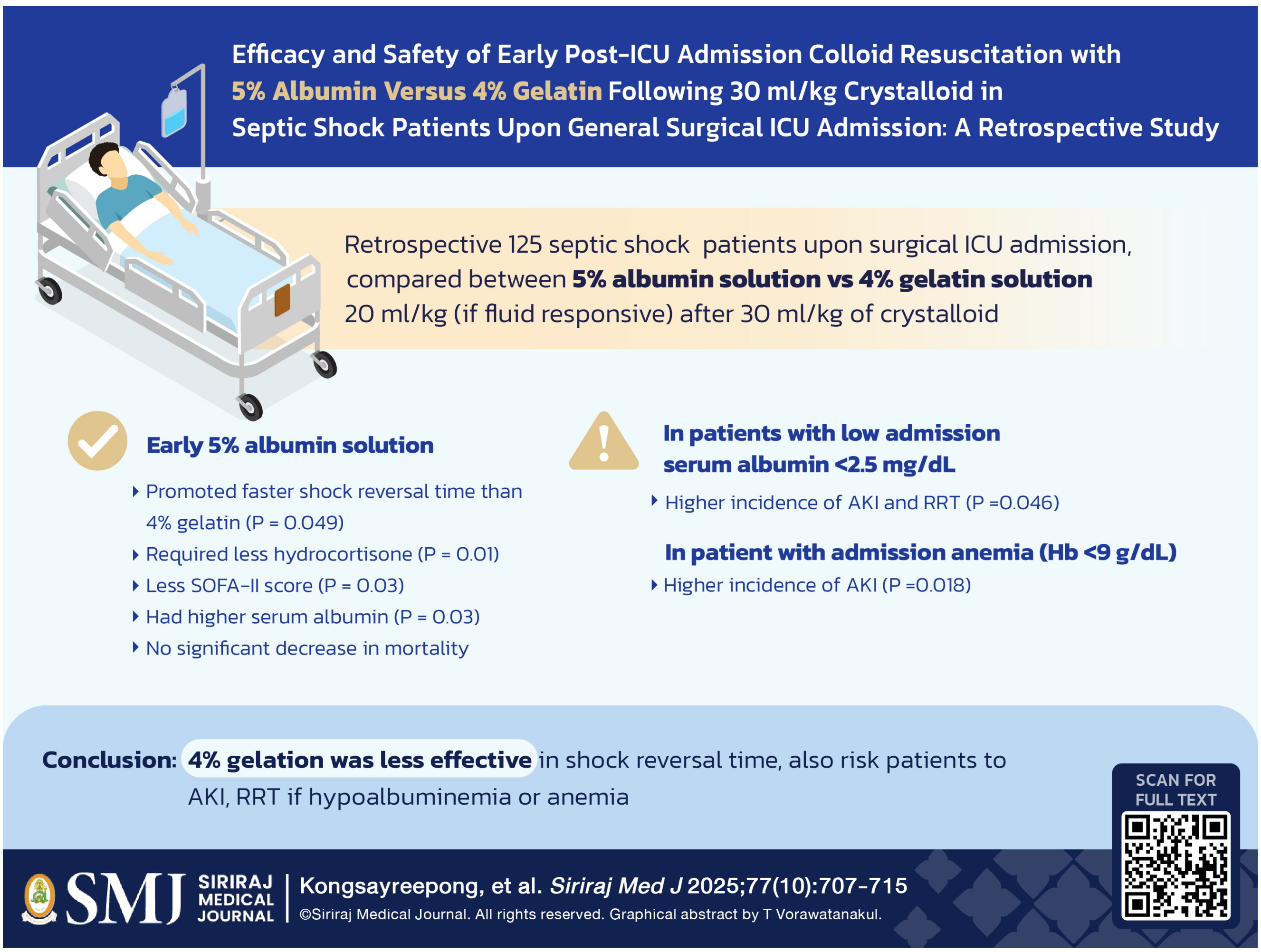

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ABSTRACT

Objective: To compare the efficacy and safety of early post-ICU admission colloid resuscitation with 5% albumin versus 4% gelatin after 30 ml/kg crystalloid solution in septic shock patients upon general surgical ICU admission at Thailand's largest tertiary reference center.

Materials and Methods: This retrospective study included 125 adults with septic shock admitted to the ICU (September 2017-July 2018). After 30 mL/kg crystalloid, patients received 20 mL/kg of either 4% gelatin (Group G) or 5% albumin (Group A) if fluid responsive. The main efficacy was time to vasopressor discontinuation, and the main safety outcome was the incidence of acute kidney injury (AKI) per KDIGO criteria, within 72 hours of ICU admission. Other safety endpoints included allergic reactions, the need for renal replacement therapy (RRT), and 90-day mortality.

Results: Of 125 patients, 62 received gelatin and 63 albumin. Despite being older, having more severe baseline illness, higher proportion undergoing surgical drainage prior to ICU admission, and a greater incidence of intra-abdominal infections, Group A achieved faster vasopressor discontinuation (48 vs. 60 h; p=0.049), required less hydrocortisone (p=0.01), had lower SOFA-II scores (p=0.03), and higher serum albumin (p=0.03). In patients with hypoalbuminemia (<2.5 g/dL) or anemia (<9 g/dL), Group G was associated with higher AKI and RRT rates (p<0.05). No allergic reactions occurred, and ICU stay, hospital stay, and 90-day mortality were not different.

Conclusion: Early 4% gelatin was associated with slower shock reversal and higher AKI risk compared with 5% albumin in critically ill surgical patients, while hospital stay and 90-day mortality were not different.

Keywords: Early Colloid Resuscitation; 5% Albumin; 4% Gelatin; 30 mL/kg Crystalloid Solution; Surgical Septic Shock (Siriraj Med J 2025; 77: 707-715)

INTRODUCTION

Septic shock is the main etiology of mortality among critically ill surgical patients undergoing noncardiac procedures. This condition is characterized by peripheral vasodilation, vasoplegia, and hypovolemia. Fluid resuscitation is a principal intervention for septic shock.[1,2] Delayed or inadequate fluid therapy can result in severe microvascular alterations, heightened expression of pro-inflammatory mediators, and profound mitochondrial dysfunction, particularly within the first 3 hours of treatment.[3,4] In contrast, excessive fluid administration leading to a positive fluid balance has been correlated with poor outcomes.[5,6]

Human albumin solution is generally regarded as a safe colloid with multiple physiological benefits.[7] It tends to remain in circulation despite capillary leak during septic shock[8], making it a promising option for rescue after substantial crystalloid resuscitation. External albumin replacement, targeted to keep a serum albumin level of 3.0 mg/dL in patients with septic shock, has been shown to lower 90-day mortality, decrease daily net fluid balance, and reduce organ dysfunction.[8] However, its role in early septic shock resuscitation remains uncertain, especially concerning shock reversal time and mortality in surgical septic shock patients who often experience greater fluid losses.

A 4% gelatin solution, a synthetic colloid, offers a more cost-effective resuscitation fluid compared with albumin-based solutions and has been used for septic shock. Although it possesses a lower molecular weight, it carries a higher incidence of anaphylaxis, and some studies showed a higher likelihood of developing acute kidney injury (AKI).[9,10] Given the limited data on the safety and efficacy of gelatin in septic shock patients, it is still uncertain whether this solution should be advised for surgical patients with this condition.

The purpose of this study was to evaluate the effectiveness and safety of 5% albumin (Group A) compared with 4% gelatin (Group G) for early colloid resuscitation following 30 ml/kg of crystalloid resuscitation in septic shock patients upon admission to the general surgical intensive care unit (SICU). The main efficacy was time to vasopressor discontinuation, and the main safety outcome was the incidence of acute kidney injury (AKI) per KDIGO criteria, within 72 hours of ICU admission. Other safety endpoints included allergic reactions, the need for renal replacement therapy (RRT) and 90-day mortality.

MATERIALS AND METHODS

Study design and participants

This retrospective study, approved by the Siriraj

Ethics Committee (COA no. Si 500/2017), involved 125 consecutive surgical patients over 18 years old diagnosed with septic shock upon admission to the general surgical ICU. (ICU Siamitra and ICU Salad-Sumang, Department of Anesthesiology, Siriraj Hospital, Mahidol University, Bangkok, Thailand; Thailand's largest national tertiary referral center from September 2017 to July 2018. All patients obtained blood cultures and cultures from infection sites and received appropriate antibiotics. Each patient received an initial fluid resuscitation of 30 mL/kg of crystalloids before receiving either a 5% albumin solution (Group A) or a 4% gelatin solution (Group G) at a dose of 20 mL/kg. Patients were included only if they remained fluid responsive. The attending physician managed subsequent fluid administration after the colloid infusion as per the septic shock protocol practice in our ICU. Norepinephrine (NE) was the primary vasopressor used, which was initiated after 30 mL/kg crystalloid if MAP remained <65 mmHg and titrated to maintain MAP >65 mmHg. Shock reversal time was defined as the duration (in hours) from NE initiation to discontinuation.

Inclusion and exclusion criteria

Patients were included in this study if they were over 18 years old, diagnosed with septic shock upon general surgical ICU admission. The exclusion criteria were patients who underwent cardiothoracic, neurosurgical, traumatic, or transplant procedures. Additional exclusion criteria included prior administration of fresh frozen plasma or other synthetic colloids or received both 5% albumin and 4% gelatin, chronic kidney disease stage IV or V, end-stage renal disease, requirement of RRT before ICU admission, use of hemoperfusion or extracorporeal membrane oxygenation (ECMO), or an ICU stay shorter 3 days.

Collected data

Baseline data included demographics, comorbidities (stroke, hypertension, coronary artery disease, chronic obstructive pulmonary disease, diabetes mellitus, chronic kidney disease, immunocompromised status, and cancer), and initial laboratory results (hemoglobin, serum creatinine, albumin, and lactate levels). The use of potentially nephrotoxic medications (gentamicin, vancomycin, amphotericin B, polymyxin, cyclosporine A, intravenous contrast dye, nonsteroidal anti-inflammatory drugs, and COX-2 inhibitors) was recorded. Surgical details (type of procedure) and infection sites were also documented.

Over the first 3 ICU days, hemoglobin, serum creatinine, albumin, lactate, and liver function tests were measured. Fluid administration (including type and amount), blood or blood component use, total intake and output, and fluid balance were recorded. The type and duration of vasopressor or inotropic support were noted, along with APACHE II and SOFA II scores. RRT use, ventilator support, duration of stay in the ICU and hospital, and all-cause mortality in 28 and 90 days were likewise collected.

Operational definitions

Septic shock was diagnosed according to the Third International Consensus Definitions for Sepsis and Septic Shock (Sepsis–3).[11] Chronic kidney disease and AKI were classified based on KDIGO criteria.[12,13] Time to reverse shock was measured in hours, from the initiation of vasopressors until they were discontinued. Fluid balance was the total fluid intake minus the total fluid output.

Statistical analysis

According to previous reports, the incidence of AKI was 69%[10] in 4% gelatin solution and 44% in 5% albumin solution.[14] Based on these data, we calculated a required sample size of 62 patients per group, presuming a two-sided type I error of 0.05 and a power of 80%. For univariate analysis, the chi-square test was used to assess associations between categorical variables and the outcome of interest. We reported crude odds ratios with 95% confidence intervals to show the strength of these associations. An unpaired t-test was employed for normally distributed quantitative data, and a Mann-Whitney test for non-normally distributed data. For multivariable analysis, we performed an unconditional multiple logistic regression to assess the independent effect of each risk factor, adjusting for potential confounders. We then reported adjusted odds ratios with 95% confidence intervals, along with the p-value for statistical significance. All statistical analyses were conducted using IBM SPSS Statistics, version 21 (IBM Corp, Armonk, NY, USA). A two-sided p-value of < 0.05 was considered statistically significant.

RESULTS

Baseline characteristics

We enrolled 63 patients in Group A and 62 patients in Group G. Demographic data and ICU information are summarized in Table 1. Group G was significantly younger and had higher rates of pneumonia as the primary infection. These patients also demonstrated more frequent use of hydrocortisone (77.4% vs 57.1%, p=0.01) and higher SOFA-II scores on day 1 (8.8±3.0 vs 7.7±2.6, p=0.03). In contrast, Group A had a significantly higher

TABLE 1. Demographic and baseline characteristics of the patients in the albumin and gelatin groups.

	Albumin group (n=63)	Gelatin group (n=62)	*p*-value
Age (years) (mean ± SD)	68 ± 12	57 ± 15	< 0.01*
Male (n%)	36 (57.1)	32 (51.6)	0.59
Body mass index (kg/m^2) (mean ± SD)	23.1 ± 5.2	23.0 ± 4.2	0.94
Diabetes mellitus, n (%)	16 (25.4)	20 (32.3)	0.43
Previous stroke, n (%)	13 (20.6)	4 (6.5)	0.03*
Hypertension, n (%)	32 (51.6)	25 (40.3)	0.28
Coronary artery disease, n (%)	8 (12.7)	6 (9.7)	0.78
Chronic obstructive pulmonary disease, n (%)	2 (3.2)	2 (3.2)	0.98
Chronic kidney disease (eGFR<60 mL/min/1.73 m^2), n (%)	14 (22.2)	10 (16.1)	0.49
Immunocompromised, n (%)	12 (19.0)	18 (29.0)	0.21
Cancer, n (%)	18 (28.6)	12 (19.4)	0.29
Received nephrotoxic drug, n (%)	13 (20.6)	12 (19.4)	0.99
Received radio contrast, n (%)	14 (22.2)	7 (11.3)	0.15
Baseline serum creatinine (mg/dL) (in the past 3 months) (mean ± SD)	0.91 ± 0.32	0.86 ± 0.28	0.43
Had an operation for infection drainage before admission to the ICU, n (%)	33 (52.4%)	12 (19.4%)	<0.01*
Source of infection			
Intra-abdominal infection, n (%)	33 (52.4)	16 (25.8)	0.03*
Pneumonia, n (%)	9 (14.3)	16 (25.8)	0.02*
Urinary tract infection (n%)	8 (12.7)	10 (16.1)	0.53

Data are presented as the frequency of n (%), mean ± standard deviation (SD). * $p<0.05$ is considered significant.
Abbreviations: Kg, kilogram; m, meter; eGFR, estimated glomerular filtration rate; mg, milligram; dL, deciliter; ICU, Intensive care unit.

rate of underlying stroke and more intra-abdominal infections. More patients in Group A underwent surgery for infection source control and required higher volumes of packed red blood cell transfusions. Additionally, Group A had a significantly higher average albumin level during the first 72 hours (2.60 ± 0.45 vs 2.35 ± 0.53 mg/dL, $p = 0.03$) (Table 2).

Primary outcome

As shown in Table 3, Group A had a significantly faster shock reversal time than Group G. The median time was 48 hours (range 30-84) for Group A versus 60 hours (range 42-99) for Group G ($p = 0.049$).

Secondary outcomes

No allergic reactions were observed in both groups. Additionally, no statistically significant differences were noted between groups in the incidence of AKI, requirement for RRT, SOFA scores at 72 hours, respiratory support-free days, duration of stay in the ICU, and all-cause mortality in 90 days (Table 3).

TABLE 2. Intensive care unit admission characteristics and clinical parameters in the first 72 hours in albumin and gelatin groups.

	Albumin group (n=63)	Gelatin group (n=62)	*p*-value
Admitted hemoglobin (g/dL) (mean ± SD)	10.7 ± 2.4	10.7 ± 2.5	0.90
Admitted serum albumin (mg/dL) (mean ± SD)	2.6 ± 0.6	2.5 ± 0.6	0.26
Admitted serum creatinine (mg/dL) (median [interquartile range])	1.5 (1.0 - 2.1)	1.6 (0.9 - 2.3)	0.89
Average serum albumin (in the first 72 hours) (mg/dL) (mean ± SD)	2.60 ± 0.45	2.35 ± 0.53	0.03*
Average serum lactate (in the first 72 hours) (mg/dL) (median [interquartile range])	3.9 (2.9 - 5.7)	4.5 (2.75 - 8.5)	0.41
Need ventilator support, n (%)	55 (87.3)	48 (77.4)	0.16
Received hydrocortisone, n (%)	36 (57.1)	48 (77.4)	0.01*
APCHE II score day 1 (mean ± SD)	20.6 ± 6.0	21.4 ± 6.2	0.31
SOFA II score day 1 (mean ± SD)	7.7 ± 2.6	8.8 ± 3.0	0.03*
SOFA II score day 3 (median [interquartile range])	6 (0 - 18)	6 (0 - 18)	0.81
Fluid balance			
Fluid balance day 1 (liter) (mean ± SD)	5.3 ± 2.4	5.2 ± 1.6	0.65
Fluid balance day 2 (liter) (mean ± SD)	2.3 ± 1.7	2.3 ± 1.9	0.98
Fluid balance day 3 (liter) (mean ± SD)	1.0 (-2.3 - 1.87)	2.1 (0.4 - 2.0)	0.28
Net fluid in 3 days (liters) (mean ± SD)	8.5 ± 3.7	8.9 ± 3.9	0.56
Transfusion in the first 3 days			
Pack red cell (ml) (median [interquartile range])	366 (0 - 849)	254 (0 - 605)	0.07
Fresh frozen plasma (ml) (median [interquartile range])	303 (0 - 933)	438 (0 - 963)	0.90
Platelet (ml) (median [interquartile range])	0 (0 - 209)	0 (0 - 257)	0.22

Data are presented as the frequency of n (%), mean ± standard deviation (SD), and median (interquartile range). * $p<0.05$ is considered significant.

Abbreviations: g, gram; mg, milligram; dL, deciliter; ml, milliliter

Subgroup analysis

In the subgroup analysis (Table 4), based on admission serum albumin <2.5, ≥2.5 mg/dL) revealed that Group G resulted in a statistically higher percentage of AKI (KDIGO-1, p=0.046; KDIGO-2, *p*=0.046; KDIGO-3, *p*=0.045) and RRT (*p*=0.048). Similarly, based on admission hemoglobin levels, the G group also revealed a statistically significantly higher percentage of AKI (KDIGO-1, *p*=0.018) when compared to those with levels<9 g/dL. Also, Group G tended to be a predictor of AKI from multivariable logistic regression analysis for factors independently associated with acute kidney injury (Table 5). However, the result did not reach a statistically significant.

TABLE 3. Primary and secondary outcomes of this study.

	Albumin group (n=63)	Gelatin group (n=62)	*p*-value
Shock reversal time (hours) (median [interquartile range])	48 (30-84)	60 (42-99)	0.049*
AKI within 72 hours, n (%)	31 (49.2)	32 (51.6)	0.78
KDIGO I, n (%)	10 (15.9)	7 (11.3)	0.45
KDIGO II, n (%)	6 (9.5)	6 (9.7)	0.97
KDIGO III, n (%)	15 (23.8)	19 (30.6)	0.39
RRT, n (%)	10 (15.9)	13 (21.0)	0.46
RRT free day (days) (median [interquartile range])	28 (15 - 28)	28 (20.5 - 28)	0.68
90-day mortality, n (%)	17 (27.0)	17 (27.4)	0.95
SOFA II score day 3 (median [interquartile range])	6 (0 - 18)	6 (0 - 18)	0.81
Ventilator-free day (days) (median [interquartile range])	20 (0 - 25)	21 (3 - 26.5)	0.17
ICU length of stay (days) (median [interquartile range])	8 (5 - 13)	7 (4 - 12)	0.11
Hospital length of stay (days) (median [interquartile range])	15 (10 - 29)	15 (9.7 - 28.2)	0.54

Data are presented as the frequency of n (%), median [interquartile range]; *$p<0.05$ is considered significant.
Abbreviations: AKI, acute kidney injury; ICU, intensive care unit; RRT, renal replacement therapy

TABLE 4. Relationship between serum albumin and hemoglobin levels on day-1, and acute kidney injury and renal replacement therapy in the first 72 hours.

	Type	n	KDIGO-1 n (%)	*p*-value	KDIGO-2 n (%)	*p*-value	KDIGO-3 n (%)	*p*-value	RRT n (%)	*p*-value
Serum albumin d-1 < 2.5 mg/dL	Gr. A	23	9 (39.1)	**0.046***	6 (26.1)	**0.046***	4 (17.4)	**0.045***	4 (17.4)	**0.048***
	Gr. G	30	20 (66.7)		16 (53.3)		13 (43.3)		10 (33.3)	
Serum albumin d-1 ≥ 2.5 mg/dL	Gr. A	40	22 (55.0)	0.139	15 (37.5)	0.402	11 (27.5)	0.385	6 (15.0)	0.548
	Gr. G	32	12 (37.5)		9 (28.1)		6 (18.8)		3 (9.4)	
Hemoglobin d-1 < 9 g/dL	Gr. A	15	6 (40.0)	**0.018***	5 (33.3)	0.200	5 (33.3)	0.552	5 (33.3)	0.201
	Gr. G	16	13 (81.3)		56.3%		43.8%		6 (37.5	
Hemoglobin d-1 ≥ 9 g/dL	Gr. A	48	52.1%	0.295	33.3%	0.882	20.8%	0.548	5 (10.4)	0.158
	Gr G	46	41.3%		34.8%		26.1%		7 (15.2)	

Data are presented as n (%); * $p<0.05$ is considered significant.
Abbreviations: g, gram; mg, milligram; dL, deciliter; ml, milliliter; Gr. A, albumin group; Gr. G, gelatin group; RRT, Renal Replacement Therapy; d-1, day one after day of admission in the intensive care unit

TABLE 5. Multivariable logistic regression analysis for factors independently associated with acute kidney injury.

	Adj OR (95% CI)	*p*-value
BMI	1.12 (1.02, 1.24)	0.019
APACHE II day 1	1.17 (1.07, 1.28)	0.001
CKD	1.64 (0.54, 4.96)	0.379
Amount of fluid/kg	1.00 (1.00, 1.01)	0.450
Gelatin	1.19 (0.50, 2.81)	0.700
Admitted serum albumin	0.69 (0.34, 1.37)	0.284
Average Hemoglobin in the first 72 hours	0.81 (0.60, 1.09)	0.160

Data are presented as adjusted odds ratios with 95% confidence intervals; $p<0.05$ is considered significant.
Abbreviations: mg, milligram; dL, deciliter; g, gram; adj OR, Gr A., group A; Gr G., group G; adj OR, adjusted odds ratio; BMI, body mass index; CKD, chronic kidney disease; Hb, hemoglobin; day 1, day after day of admission in the intensive care unit

DISCUSSION

Given the goal of early septic shock resuscitation is to reduce time to shock reversal, prevent organ dysfunction, and improve survival, a key challenge lies in identifying a safe and effective colloid that can minimize reliance on high-dose crystalloid fluid, particularly in surgical septic shock patients who typically sustain greater fluid losses. Gelatin is one of the colloids used for fluid resuscitation; however, previous studies have suggested a higher risk of AKI[9,10], and data on its safety and efficacy in surgical septic shock patients remain limited. Despite the study by Tongyoo S et al., which showed a significantly higher 28-day mortality rate in critically ill medical patients with refractory septic shock.[15]

Findings from this study indicate that a 4% gelatin solution is less effective than a 5% albumin solution. Patients receiving the gelatin solution had a significantly longer shock reversal time (60 [42-99] vs 48 [30-84], p=0.049). This reduced effectiveness may stem from gelatin's lower molecular weight of approximately 4,000 Da, in contrast to albumin's much higher molecular weight (commonly cited as approximately 66 kDa). The smaller molecular size of gelatin leads to lower oncotic pressure and diminished volume expansion.[9,14] By comparison, albumin exerts higher oncotic pressure and appears to remain longer in the circulation during septic shock. The ALBIOS trial[8] supports the use of albumin by demonstrating higher serum albumin levels in patients receiving exogenous albumin, similar to this study, where Group A had higher average serum albumin in the first 72 hours (p=0.03).

Despite the higher incidence of intra-abdominal infections and greater need for surgical interventions in the albumin group, these patients required less hydrocortisone, had lower SOFA scores on day 1, and showed a trend toward lower fluid balance by day 3. In addition, the higher efficacy of 5% albumin was also observed, even with the lesser use of hydrocortisone compared to the gelatin solution in this study.

Regarding secondary outcomes, no allergic reactions were observed in this study. There was no statistically significant difference in AKI, RRT, or duration of stay in the ICU and hospital between groups. In the subgroup analysis (Table 4) based on admission serum albumin levels (<2.5, ≥2.5 mg/dL), it was shown that Group G, who were admitted with serum albumin levels <2.5 mg/dL had a significantly higher percentage of AKI (KDIGO 1-3) and RRT. Similarly, Group G patients who were admitted with hemoglobin levels <9 g/dL showed a significantly higher percentage of AKI (KDIGO-1). This result was different from Tongyoo S, et al study that showed more RRT incidence[15], however our result was analyzed from subgroup analysis and, given the small sample size in both Group A and Group B, this result should be interpreted with caution, as it is only for exploratory analysis. A larger sample size is needed to confirm this finding. We can use the data to develop a new multivariable logistic regression analysis model by adding the admission albumin group (<2.5, ≥2.5 mg/dL) and the admission hemoglobin group (<9 g/dL, ≥9 g/dL), as well as the interaction between Group G and AKI. This will give a more precise answer about gelatin as a predictor of AKI. Unfortunately, the final version of this data is unavailable.

In septic shock patients with low serum albumin levels (<2.5 mg/dL), indicating reduced oncotic pressure, this study found that resuscitation with 4% gelatin was associated with a significantly higher incidence of AKI across KDIGO stages 1-3, as well as an increased need for RRT. Furthermore, patients who developed hemodilution (hemoglobin <9 g/dL) also showed a significantly higher incidence of AKI (KDIGO stage 1) when treated with gelatin. These findings align with previous research by Bayer et al.[10], which identified 4% gelatin as a risk factor for AKI and increased RRT use in septic patients compared to crystalloids. Similarly, a meta-analysis by Moeller et al[9]. reported an association between gelatin use and AKI, with a risk ratio of 1.35 (95% CI: 0.58–3.14) in the context of hypovolemia resuscitation. Therefore, the use of gelatin should be approached with caution in patients with sepsis and septic shock, particularly those presenting with hypoalbuminemia or significant hemodilution.

The results of this study showed that the albumin group required more packed red blood cell (PRC) transfusions due to a higher number of surgeries. Nevertheless, there were no significant differences in the volumes of transfused fresh frozen plasma (FFP) and platelets when compared to the 5% albumin solution. Therefore, despite the presence of surgical septic shock, our study found that 4% gelatin did not demonstrate any difference in bleeding complications compared to the 5% albumin solution.

This study did give significant information of the lower effectiveness of 4% gelatin as a resuscitation colloid in addition to crystalloid in surgical septic shock. This gelatin potentially adds the risk of AKI and the need for RRT in patients with low serum albumin levels and hemodilution. This study had several limitations, including being a retrospective study, a small sample size, and unbalanced baseline characteristics (Group A was significantly older, and more patients underwent operations for infection drainage before admission to the ICU, and a higher incidence of intraabdominal infections that led to greater fluid loss).

CONCLUSION

This observational study suggests that early administration of 4% gelatin is less effective for shock resuscitation than the 5% albumin solution. Moreover, 4% gelatin is linked to a greater incidence of AKI and RRT in patients with low oncotic pressure, as well as a higher incidence of AKI in cases of hemodilution. No allergic reactions or bleeding complications were significantly associated with the use of the colloid solutions studied. A large, randomized controlled trial is needed to determine the effectiveness and safety of 4% gelatin in treating surgical septic shock.

Data availability statement

This study's information came from ICU Siamitra and ICU Salad–Sumang of the Department of Anesthesiology, Siriraj Hospital, Mahidol University database from September 2017 to July 2018. However, the ICU's confidential information cannot be shared openly; instead, the detailed data were kept in the researcher's pool data file with a security code. This manuscript was also edited with CHT GPT 4 Pro for more concise reporting of the information.

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Conflict of Interest

The authors do not have any conflict of interest associated with this study.

Registration Number of Clinical Trial

This study was registered to the US clinical number NCT01363635 and NCT01361477.

Author Contributions

Conceptualization and methodology, S.K., S.T.; Investigation, S.K., N.P., and S.T.; Formal analysis, S.K., N.P.; Visualization and writing – original draft, S.K., N.P.; Writing –review and editing, S.K.; Funding acquisition, S.K.; Supervision, S.K., S.T.

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Use of Artificial Intelligence

This manuscript was also edited by Mr. David Park and ChatGPT-4 Pro for more concise reporting of the information.

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