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Original Article

Goal-directed fluid therapy improves volume loading and stabilizes hemodynamics in patients undergoing coronary artery bypass grafting

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Abstract: Objective: To investigate the effects of goal-directed fluid therapy (GDFT) on volume load and hemodynamics in patients undergoing coronary artery bypass grafting (CABG). Methods: This retrospective study analyzed data from 131 patients with coronary heart disease who underwent CABG between April 2020 and April 2023. Seventy-five patients who received GDFT were categorized as the observation group, while 56 patients who received routine liquid therapy served as the control group. Fluid intake and outflow, volume load, regional cerebral oxygen saturation (rSO_2), central venous blood oxygen saturation ($ScvO_2$), hemodynamic parameters, and blood lactic acid levels were measured at several time points: 30 min preoperatively (T0), 15 min after anesthesia induction (T1), 1 h intraoperatively (T2), 2 h intraoperatively (T3), and at the end of the operation (T4). Postoperative recovery and complication rates were also compared between the two groups. Results: There were no significant group differences in total fluid input, red blood cell infusion rate, autologous blood transfusion rate, and bleeding amount between the two groups (all *P>0.05*). However, the amount of Ringer's solution, and fluid intake/output were significantly lower compared to the control group (all *P<0.05*). Conversely, the observation group had higher hydroxyethyl starch input and greater urine output than the control group (*P<0.05*). The cardiac output (CO) in the observation group was remarkably higher than that in the control group at T2-T4 (*P<0.05*), while stroke volume variation (SVV) was lower in the observation group (*P<0.05*). The rSO_2 and $ScvO_2$ in the observation group were notably higher at T2 to T4 than those in the control group (*P<0.05*). There was no significant difference in mean arterial pressure (MAP) and heart rate (HR) between the two groups at each time point (*P>0.05*). The cardiac index (CI) was higher while the central venous pressure (CVP) was lower in the observation group at T2-T4 than those in the control group (both *P<0.05*). Blood lactate levels were significantly lower in the observation group at T2 to T4 (*P<0.05*). The duration of postoperative assisted ventilation, positive inotropic medication, ICU stay, and the overall hospital stay of the observation group were shorter than those in the control group (*P<0.05*), and the incidence of postoperative complications was significantly lower than that in the control group (*P<0.05*). Conclusion: GDFT improves cardiac function and reduces cardiac volume load in patients undergoing CABG. It helps stabilize intraoperative hemodynamics, reduces blood lactate levels, enhances oxygen supply to brain tissue (as reflected by improved rSO_2 and $ScvO_2$), and accelerates postoperative recovery. Additionally, it significantly lowers the incidence of postoperative complications.

Keywords: Target-directed fluid therapy, coronary artery bypass grafting, volume loading, hemodynamics

Introduction

Coronary artery bypass grafting (CABG) is the most effective treatment for coronary heart disease. However, preoperative cardiac insufficiency or varying degrees of myocardial damage can significantly affect cardiac function during the procedure. This may lead to heart failure, which increases perioperative, mid- and long-term mortality, severely affecting patient's quality of life [1]. Factors such as underlying health conditions, anesthesia drugs, and intraoperative drops in blood pressure can all reduce effective blood perfusion to multiple tissues, potentially causing ischemia and hypoxia [2, 3]. Brain tissue is particularly sensitive to ischemia and hypoxia, making patients undergoing CABG vulnerable to postoperative complications like delirium and cognitive impairment (POCD), which prolong hospital stays and recov-

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ery times [4, 5]. Therefore, maintaining stable hemodynamics during surgery, ensuring effective tissue perfusion, and providing adequate oxygen supply to organs are crucial for reducing perioperative complications and improving postoperative outcomes [6].

Goal-directed fluid therapy (GDFT) is an effective strategy for maintaining optimal perioperative circulation. An individualized fluid therapy program, guided by hemodynamic indices, maximizes cardiac output and helps maintain effective circulatory perfusion, ensuring proper oxygen supply to tissues and organs [7]. Studies have shown that GDFT offers significant advantages in CABG, reducing hospitalization duration, mortality and complications compared to traditional fluid management [8, 9]. However, variability in GDFT protocols used across studies makes comparisons challenging. In addition, the small sample size and short follow-up periods in these studies may limit the ability to fully assess the therapy's effectiveness. In this study, we aimed at investigating the effects of GDFT on volume load and hemodynamics in patients undergoing CABG.

Methods

Selection of clinical data

This retrospective study involved 131 patients with coronary heart disease who underwent CABG from April 2020 to April 2023. Among these, 75 patients who received GDFT were classified into the observation group, and the other 56 that were treated with routine fluid therapy were assigned into the control group. The study was approved by the Ethics Committee of The First Affiliated Hospital of Hebei North University. The research process is shown in **Figure 1**.

Inclusion criteria: (1) Patient met the diagnostic criteria for coronary heart disease and indications for CABG. (2) Patient's ASA classification was Class II to III. (3) Patients aged between 50 to 80. (4) Patients with the New York Heart Association (NYHA) classification of II to III. (5) Patients with complete clinical profile.

Exclusion criteria: (1) Patients with concomitant malignant tumors. (2) Patients with autoimmune diseases. (3) Patients with hematological disorders. (4) Patients with mental illness or cognitive impairment. (5) Patients with arrhythmia. (6) Patients who had received vasoactive drugs within 1 month before surgery. (7) HIV positivity. (8) Patients with combined dysfunction of the liver, kidneys, lungs or other vital organs. (9) Patients with acute or chronic systemic infections.

Surgical methods

All procedures were off-pump CABG performed by the same surgical team. Hemodynamic parameters were monitored using Vigileo during surgery. In the control group, fluid infusion volume was determined based on the routine 4/2/1 rule. The timing and dosage of infusion were adjusted according to the patients' blood pressure and central venous pressure. In the observation group, fluid therapy was given based on a 2 ml/(kg-h) infusion of Ringer's solution, with stroke volume variation (SVV) and cardiac index (CI) used as goal-directed targets. If SVV>12%, patients received 3 ml/kg of Hydroxyethyl starch as a rapid infusion within 10 minutes, which could be repeated until SVV was ≤12%. If SVV was ≤12%, and either arterial blood pressure was ≤65 mmHg or 20% below baseline, and CI was ≥2.5 L/(min-m^2), patients were given 40 to 80 μg of intravenous phenylephrine, which could be repeated until the arterial blood pressure was ≥65 mmHg or was maintained within ±20% of baseline. If SVV was ≤12%, arterial blood pressure was ≤65 mmHg or ±20% below baseline, and CI was <2.5 L/(min-m^2), patients were given pumped dobutamine at a dose of 2.0 to 10 μg/(kg-min) to achieve a CI≥2.5 L/(min-m^2). During the procedure, the heart rate was kept at 50-80 beats/min. Intravenous atropine (0.25 mg) was administered if the heart rate fell below 45 beats/min, whereas intravenous esmolol (0.4 mg/kg) was given if the heart rate exceeded 80 beats/min.

Indicators of results

Primary indicators: (1) Postoperative recovery and incidence of complications: The duration of assisted ventilation, positive inotropic medication and ICU stay, total hospital stay, complication rates, and 30-day morbidity and mortality were recorded and compared between the two groups. (2) Volume load indicators: Volume loading indices, including cardiac output (CO) and SVV were recorded and compared between the two groups at the following time points: 30 min preoperatively (T0), 15 min after anesthe-

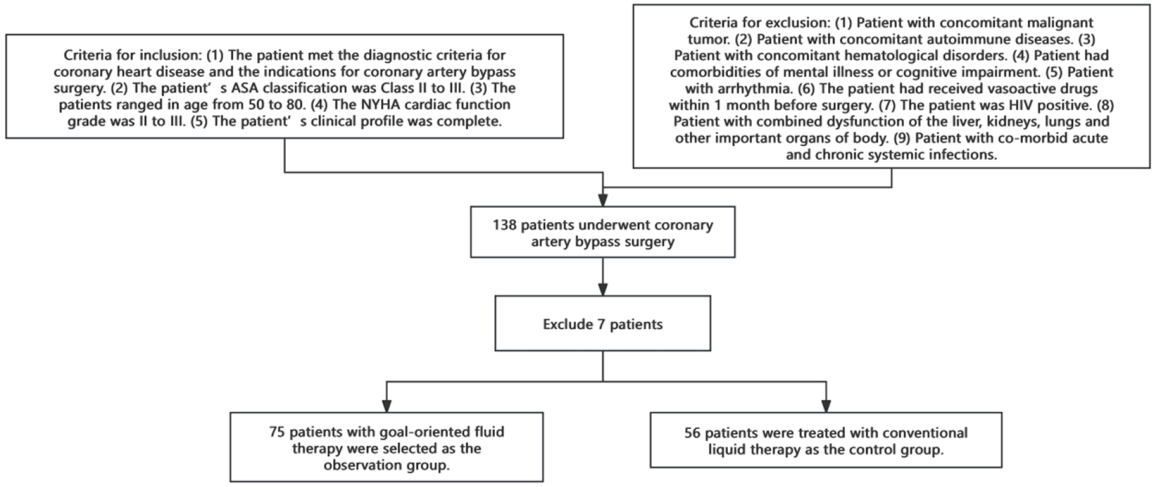

Figure 1. Study flow chart.

sia induction (T1), 1 h intraoperatively (T2), 2 h intraoperatively (T3), and at the end of the operation (T4). (3) Hemodynamic indicators: Changes in hemodynamic parameters, including mean arterial pressure (MAP), heart rate (HR), CI, central venous pressure (CVP) at T0-T4 were recorded and compared between the two groups.

Secondary indicators: (1) Regional cerebral oxygen saturation (rSO_2) and central venous oxygen saturation ($ScvO_2$): The rSO_2 and $ScvO_2$ at T0-T4 were recorded and compared between the two groups. (2) Blood lactate: The radial artery lactate levels at T0-T4 were measured using a rapid blood gas analyzer in both groups. (3) Fluid intake and output: Fluid intake and output, including Ringer's solution, Hydroxyethyl starch, autologous blood, and allogeneic red blood cell infusion volumes, were recorded and compared between the two groups. The total fluid volume was calculated as the sum of all infusions. Outflow = total amount of fluids infused intraoperatively - (bleeding + urine output).

Statistical analysis

SPSS 27.0 was used for statistical analysis. The t-test was used for comparison of measurement data (mean ± SD), while the χ^2 test was used for comparison of count data (n, %). Multifactorial logistic regression was used to identify the factors affecting the occurrence of complications. A *P*-value of <0.05 was considered statistically significant.

Results

Comparison of baseline information between the two groups

There were no significant differences between the two groups in terms of gender, age, BMI, duration of surgery, NYHA classification, ASA classification, underlying diseases, fasting blood glucose, white blood cell count, hemoglobin, and platelet count (all *P>0.05*) (**Table 1**).

Comparison of fluid intake and output

There were no significant differences between the two groups in terms of total fluid input, the proportion of patients receiving red blood cell transfusion, the proportion of patients undergoing autologous blood transfusion, or the amount of blood loss (*P>0.05*). However, the amount of Ringer's solution and total fluid intake/output in the observation group was apparently lower than those in the control group (*P<0.05*), whereas the amount of Hydroxyethyl starch input and urine output were remarkably higher than those of the control group (*P<0.05*) (**Table 2**).

Comparison of volume loading

The CO level in the observation group was remarkably higher while SVV was significantly lower compared to the control group at T2-T4 (both *P<0.05*) (**Table 3**).

Table 1. Comparison of baseline data between the two groups

Clinical data	Observation group (n=75)	Control group (n=56)	t/χ^2	*P*
Gender				
Male	41	32	0.080	0.778
Female	34	24		
Age (years, $\bar{x}\pm s$)	64.38±7.26	64.97±8.34	0.432	0.667
BMI (kg/m^2, $\bar{x}\pm s$)	25.10±2.16	25.31±2.27	0.539	0.591
Length of surgery (min, $\bar{x}\pm s$)	168.39±30.52	161±28.50	1.410	0.161
NYHA Classification				
II	33	29	0.780	0.377
III	42	27		
ASA Classification				
II	46	38	0.593	0.441
III	29	18		
Hypertension [n (%)]	41 (54.67)	35 (62.50)	0.808	0.369
Diabetes [n (%)]	38 (50.67)	36 (64.29)	2.419	0.120
Hypertriglyceridemia [n (%)]	19 (25.33)	17 (30.36)	0.406	0.524
Fasting blood glucose (FBG) (mmol/, $\bar{x}\pm s$)	6.38±1.29	6.41±0.96	0.146	0.884
White blood cell count (×10^9/L, $\bar{x}\pm s$)	7.84±2.10	7.95±1.77	0.317	0.752
Hemoglobin (g/L, $\bar{x}\pm s$)	145.62±30.65	150.36±34.28	0.832	0.407
Platelet count (×10^9/L, $\bar{x}\pm s$)	165.65±38.50	172.31±44.21	0.919	0.360

Note: BMI: body mass index. NYHA: New York Heart Association. ASA: American society of Anesthesiologists.

Table 2. Comparison of fluid intake and output between the two groups

Indicators observed	Observation group (n=75)	Control group (n=56)	t/χ^2	*P*
Total liquid input (ml, $\bar{x}\pm s$)	1568.36±372.06	1618.56±503.45	0.657	0.513
Ringer's solution (ml, $\bar{x}\pm s$)	450.69±201.84	677.20±183.60	6.602	<0.0001
Hydroxyethyl starch (ml, $\bar{x}\pm s$)	901.42±217.36	683.42±156.47	6.371	<0.0001
Red blood cell infusion [n (%)]	17 (22.67)	12 (21.43)	0.029	0.866
Autologous blood transfusion [n (%)]	45 (60.00)	33 (58.93)	0.015	0.902
Urine output (ml, $\bar{x}\pm s$)	683.02±197.64	524.79±154.30	4.965	<0.0001
Hemorrhage (ml, $\bar{x}\pm s$)	410.36±110.25	403.62±104.53	0.354	0.724
Fluid intake and output (ml, $\bar{x}\pm s$)	474.98±129.67	690.15±172.36	8.157	<0.0001

Comparison of rSO_2 and $ScvO_2$ at different time points

The rSO_2 and $ScvO_2$ levels in the observation group were notably higher than those in control group at T2 to T4 (all *P<0.05*) (**Table 4**).

Comparison of hemodynamics at different time points

There were no significant differences in MAP or HR between the two groups at each time point (*P>0.05*). However, the CI in the observation group at T2-T4 was significantly higher than that in the control group (*P<0.05*), while the CVP was significantly lower than that in the control group (*P<0.05*) (**Table 5**).

Comparison of blood lactate levels

At T2 to T4, the level of blood lactate in the observation group was significantly lower than that in control group (*P<0.05*) (**Table 6**).

Table 3. Comparison of volume loading between the two groups

Indicator	Group	T0	T1	T2	T3	T4
CO (min/L)	Observation group (n=75)	5.91±1.24	5.62±1.17	4.39±0.69*	4.38±0.75*	5.29±1.16*
	Control group (n=56)	6.03±1.07	5.70±1.19	3.86±0.52	3.59±0.61	4.01±0.97
	t	0.581	0.384	4.815	6.448	6.692
	P	0.563	0.701	0.000	0.000	0.000
SVV (%)	Observation group (n=75)	12.79±2.06	12.29±1.64	11.06±1.83*	10.27±1.39*	7.64±1.30*
	Control group (n=56)	12.57±1.98	12.18±1.70	13.98±2.16	14.83±1.99	9.48±1.16
	t	0.615	0.374	8.361	15.439	8.387
	P	0.540	0.709	0.000	0.000	0.000

Note: *P<0.05 vs. control group. CO: cardiac output. SVV: stroke volume variability.

Table 4. Comparison of rSO_2 and $ScvO_2$ at different time points between the two groups

Indicator	Group	T0	T1	T2	T3	T4
rSO_2	Observation group (n=75)	70.85±6.12	85.61±6.97	83.64±6.50*	83.75±7.27*	81.25±7.43*
	Control group (n=56)	69.73±7.33	83.96±7.05	77.21±5.94	72.29±7.11	73.16±6.98
	t	0.952	1.334	5.809	9.010	6.326
	P	0.343	0.185	0.000	0.000	0.000
$ScvO_2$	Observation group (n=75)	55.64±5.36	58.82±7.31	67.82±7.18*	71.68±6.95*	76.83±8.12*
	Control group (n=56)	56.10±6.14	57.68±6.99	59.62±5.93	60.67±5.84	65.87±6.86
	t	0.457	0.900	6.955	9.591	8.157
	P	0.649	0.370	0.000	0.000	0.000

Note: *P<0.05 vs. control group. rSO_2: regional cerebral oxygen saturation. $ScvO_2$: central venous oxygen saturation.

Table 5. Comparison of hemodynamic parameters between the two groups

Indicator	Group	T0	T1	T2	T3	T4
MAP (mmHg)	Observation group (n=75)	76.25±8.12	78.31±6.97	80.21±5.98	79.65±5.84	79.12±5.43
	Control group (n=56)	75.98±7.53	78.02±7.14	79.32±6.73	80.87±7.36	78.67±7.95
	t	0.194	0.233	0.799	1.058	0.385
	P	0.846	0.816	0.426	0.292	0.701
HR (times/min)	Observation group (n=75)	85.96±8.36	82.04±7.29	77.68±8.36	75.06±7.95	80.65±7.21
	Control group (n=56)	84.75±7.94	80.98±8.36	78.91±7.95	76.85±8.33	79.56±6.42
	t	0.837	0.773	0.851	1.249	0.897
	P	0.404	0.441	0.397	0.214	0.372
CI [L/(min·m^2)]	Observation group (n=75)	2.98±0.36	3.17±0.33	3.51±0.41*	3.57±0.42*	3.48±0.40*
	Control group (n=56)	2.95±0.42	3.09±0.41	3.06±0.37	3.08±0.40	2.94±0.33
	t	0.439	1.237	6.476	6.741	8.225
	P	0.661	0.218	0.000	0.000	0.000
CVP (cmH_2O)	Observation group (n=75)	6.72±1.06	7.16±1.21	7.26±1.19*	9.36±1.33*	8.96±1.17*
	Control group (n=56)	6.67±1.09	7.23±1.26	8.06±1.25	11.95±2.16	12.97±2.36
	t	0.264	0.322	3.725	8.461	12.773
	P	0.792	0.748	0.000	0.000	0.000

Note: *P<0.05 vs. control group. MAP: Mean arterial pressure. HR: Heart rate. CI: cardiac index. CVP: Central venous pressure.

Comparison of postoperative recovery and complications

The duration of postoperative assisted ventilation, positive inotropic medication, ICU stay, and overall hospital stay were significantly shorter in the observation group compared to the control group (*P<0.05*). Additionally, the incidence of postoperative complications in the observation group was significantly lower

Table 6. Comparison of blood lactate levels between the two groups

Indicator	Group	T0	T1	T2	T3	T4
CO (min/L)	Observation group (n=75)	2.27±0.42	3.94±0.46	4.36±0.62*	4.60±0.98*	2.56±0.43*
	Control group (n=56)	2.36±0.45	4.03±0.52	5.69±0.77	6.75±1.20	5.24±0.73
	t	1.177	1.048	10.947	11.279	26.286
	P	0.241	0.297	0.000	0.000	0.000

Note: *P<0.05 vs. control group. CO: cardiac output.

Table 7. Comparison of postoperative recovery and complications between the two groups

Indicators	Observation group (n=75)	Control group (n=56)	t/χ^2	*P*
Duration of assisted ventilation (h, $\bar{x}\pm s$)	21.36±4.15	25.53±3.67	5.974	<0.0001
Duration of positive inotropic drug use (d, $\bar{x}\pm s$)	3.64±0.72	4.36±0.85	5.240	<0.0001
Length of ICU stay (d, $\bar{x}\pm s$)	3.67±0.61	4.59±0.77	7.629	<0.0001
Overall length of hospitalization (d, $\bar{x}\pm s$)	7.26±1.34	9.36±1.65	8.034	<0.0001
Complications	8 (10.67)	17 (30.36)	8.050	0.005
Delirium	2	6	-	-
Acute pulmonary edema	0	2	-	-
Acute renal insufficiency	1	1	-	-
Deep vein thrombosis	3	5	-	-
Cognitive dysfunction	2	3	-	-
30-day mortality [n (%)]	0	0	-	-

Table 8. Multivariate logistic regression analysis of factors affecting the occurrence of complications

Key factors	B	S.E.	χ^2	*P*	OR	95% CI	
Goal-directed fluid therapy	1.793	0.517	12.028	0.001	6.007	2.181	16.549
Fluid intake and output	1.662	0.498	11.138	0.001	5.270	1.986	13.986
CVP (T4)	1.427	0.638	5.003	0.025	4.166	1.193	14.548
SVV (T3)	1.529	0.72	4.510	0.034	4.614	1.125	18.920

Note: CVP: Central venous pressure. SVV: stroke volume variability.

than that in the control group (*P<0.05*) (**Table 7**).

Multifactor logistic regression analysis of factors affecting the occurrence of complications

The factors affecting the occurrence of complications in patients were analyzed using multifactorial logistic regression. The results revealed that GDFT was a significant factor influencing the occurrence of complications (*P<0.05*), as shown in **Table 8**.

Discussion

Non-corporeal coronary artery bypass grafting (CABG), compared with conventional CABG, has been shown to reduce postoperative neurological complications and the need for intraoperative blood transfusion [10, 11]. Currently, an increasing number of patients are undergoing CABG with non-corporeal circulation. However, some patients experience perioperative complications, which prolong ICU stays and hospitalization, ultimately increasing the burden on medical resources [12].

Our study investigating the pathophysiologic mechanisms of hemodynamic alterations in patients undergoing CABG with non-corporeal circulation has highlighted the crucial role of volume management. Perioperative volume therapy remains one of the most controversial aspects of treatment for these patients. Several

factors contribute to this debate: 1) Surgical procedures are performed while the heart is beating, and hemodynamic changes are inevitable. Factors such as pericardial traction during surgery can alter heart pump function; 2) In patients with coronary artery disease, the hardening of blood vessels impairs the ability to regulate blood pressure; 3) Preoperative fasting and fluid restriction often lead to hypovolemia, placing the body in a state of chronic negative volume balance; 4) Anesthetic drugs and anesthesia methods can, to varying extents, induce a "vasodilator effect", leading to insufficient circulating blood volume and impaired cardiac pump function; 5) Intraoperative fluid loss and stress response make it difficult to accurately assess volume status; 6) Surgeons usually require limited rehydration to avoid fluid overload during surgery and to facilitate the operation, while anesthesiologists advocate for adequate rehydration to maintain steady hemodynamics [13-16].

Fluid therapy targeting SVV has been shown to reduce postoperative complications and length of stay in cardiac surgery. However, factors such as open-chest surgery, arrhythmia, and peripheral vascular disease may reduce the reliability of SVV in predicting fluid response [17-19]. While the use of CI-targeted mentoring strategies in cardiac surgery has proven effective in reducing 30-day postoperative morbidity rates, this approach still lacks comprehensive safety profiles and it requires the adjunctive use of positive inotropic drugs to prevent cardiac dysfunction [20-22]. Therefore, a combination of SVV and CI as infusion targets was adopted in this study. The results showed that after adopting goal-oriented liquid management, the infusion volume of crystalloid fluid decreased significantly, while the infusion volume of Hydroxyethyl starch increased significantly. Although the total volume of fluids administered did not change significantly, intraoperative urine output increased, leading to a reduction in the positive fluid balance. Furthermore, intraoperative CO, rSO_2, $ScvO_2$, and CI from T2 to T4 in observation group were higher than those in control group, while SVV, CVP, and blood lactate levels were lower than those in control group. These findings align with previous studies [23-25], suggesting that GDFT can effectively improve perioperative cardiac function in patients.

Additionally, reports have shown that GDFT improves intraoperative metabolism and cerebral perfusion, contributing to a reduction in postoperative cognitive dysfunction [26-28]. The significantly higher intraoperative rSO_2 and $ScvO_2$ in the observation group indicate that GDFT can improve cerebral oxygenation. This improvement is closely linked to better cardiac volume load and hemodynamics, which help mitigate ischemic and hypoxic damage to brain tissue, thus reducing the incidence of postoperative cognitive dysfunction [29, 30]. Moreover, the lower blood lactate levels observed in the observation group further suggest that this treatment regimen effectively improves tissue perfusion, protects vascular endothelial function, and maintains hemodynamic stability.

The duration of postoperative ventilation, inotropic drug use, ICU stay, and total hospital stay in the observation group were remarkably shorter than those in the control group, and the incidence of postoperative complications was notably lower. These findings are consistent with those reported by other scholars [31-33], who have shown that goal-oriented fluid therapy promotes postoperative rehabilitation of patients and effectively reduces the incidence of perioperative complications. This may be attributed to improved intraoperative cardiac volume loading, the maintenance of hemodynamic stability, and better cerebral tissue perfusion.

Overall, this study provides helpful insight for the field, yet the results may be influenced by the small sample size, which could introduce potential bias. Future studies with a larger sample size will be necessary to obtain more reliable clinical results. In conclusion, goal-oriented fluid therapy is effective in improving perioperative cardiac function and cardiac volume loading in patients undergoing CABG. At the same time, it helps lower blood lactic acid levels, stabilizes intraoperative hemodynamics, enhances rSO_2 and $ScvO_2$, improves brain tissue oxygenation, promotes postoperative recovery, and reduces the incidence of complications.

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Disclosure of conflict of interest

None.

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