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Original Article

Effects of intraoperative cell salvage versus preoperative autologous blood donation on postoperative coagulation in cardiac surgery

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Abstract: Objective: To compare the effects of intraoperative cell salvage (ICS) and preoperative autologous blood donation (PABD) on postoperative coagulation and platelet function in patients undergoing cardiac surgery, and to explore the underlying mechanisms. Methods: A retrospective analysis was conducted on 212 patients who underwent either ICS (n = 127) or PABD (n = 85) between June 2022 and May 2025. Hematologic parameters (including platelet count), coagulation indices (prothrombin time [PT], activated partial thromboplastin time [APTT], fibrinogen, D-dimer) and platelet function (thromboelastography [TEG], platelet aggregation test, and platelet activation markers) were measured preoperatively and within 24 hours postoperatively. Results: Baseline characteristics and incidences of transfusion-related adverse reactions did not differ significantly between groups. Postoperatively, the ICS group showed significantly lower platelet counts, prolonged PT and APTT, reduced fibrinogen levels, and elevated D-dimer levels compared with the PABD group. TEG showed a longer reaction time (R) in the ICS group, indicating delayed thrombus formation. The platelet aggregation rate and activation marker expression were also more markedly impaired in the ICS group (both $P < 0.05$). Conclusion: ICS is associated with more pronounced platelet depletion and coagulation factor loss, likely due to mechanical shear stress and the washing process, whereas PABD better preserved hemostatic components. Both methods are safe, but PABD may be more suitable for patients at risk of coagulation disorders.

Keywords: Autologous blood transfusion, intraoperative cell salvage, preoperative autologous blood donation, coagulation, platelet function, cardiac surgery

Introduction

In cardiac surgery, effective perioperative blood management is crucial due to the high risk of intraoperative blood loss and associated transfusion requirements [1]. Cardiac procedures, such as coronary artery bypass grafting (CABG), valve replacement, and correction of congenital heart defects, often involve significant bleeding, necessitating effective strategies to maintain hemostasis while minimizing reliance on allogeneic blood products [2]. Autotransfusion has become a cornerstone of blood conservation within this field, offering a safer alternative to allogeneic transfusions by eliminating risks of immune reactions, infectious disease transmission, and alloimmunization [3]. Among the available autotransfusion approaches, intraoperative cell salvage (ICS) and preoperative autologous blood donation (PABD) are the two predominant techniques, each with distinct mechanisms and applications.

ICS involves collection, washing, and reinfusion of shed blood during surgery, making it particularly advantageous for procedures with unpredictable blood loss [4]. This technique is widely used in cardiac surgery to promptly restore red blood cell mass and reduce donor blood utilization [5]. However, the inherent centrifugation and washing processes of ICS may subject blood components to mechanical shear stress and heparin anticoagulation, potentially compromising platelet integrity and depleting plas-

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ma coagulation factors [6]. In contrast, PABD involves the preoperative collection and storage of a patient's own blood, typically 3-5 weeks before surgery, often with erythropoietin supplementation to maintain hematologic stability [7]. By preserving all blood components, PABD is theoretically superior in maintaining postoperative hemostasis [8]. However, it necessitates meticulous preoperative planning, is constrained by minimum hemoglobin levels, and is not suitable for emergency cases or patients with unstable cardiovascular conditions [9].

Current research on autotransfusion in cardiac surgery primarily focuses on comparing hemoglobin recovery and allogeneic transfusion rates between ICS and PABD, with limited attention to their differing impacts on coagulation-fibrinolysis kinetics and platelet function [10]. Although some studies suggest that ICS may increase the risk of coagulopathy due to platelet and coagulation factor loss, whereas PABD may preserve hemostatic stability by retaining all blood components, these findings remain fragmented and lack comprehensive validation using multidimensional assessments such as thromboelastography (TEG) [11-13]. Furthermore, few studies have systematically compared these two techniques across different types of cardiac surgery (e.g., CABG, valve surgery, and congenital heart defect repair), while controlling for preoperative coagulation status and the use of antiplatelet medications [14].

This study addresses these gaps by providing a comprehensive comparison of the effects of ICS and PABD on early postoperative coagulation parameters, platelet counts, and function in patients undergoing cardiac surgery. By integrating conventional coagulation assays, dynamic TEG monitoring, and platelet function tests, this study aims to elucidate the mechanisms underlying mechanical injury associated with ICS and the homeostatic preservation afforded by PABD. Incorporating a diverse cardiac surgery patient cohort and controlling for potential confounding factors, this study aims to establish evidence-based guidelines for personalized autotransfusion choices, particularly for patients at elevated risk of postoperative bleeding or thrombosis. Ultimately, this work seeks to refine perioperative blood management by clarifying the mechanistic differences between ICS and PABD in shaping the coagulation microenvironment, thereby optimizing hemostasis and reducing complications.

Materials and methods

Case selection

Inclusion criteria: (1) Patients undergoing CABG, cardiac valve replacement, or correction of congenital heart defects; (2) American Society of Anesthesiologists (ASA) classification II or III; (3) New York Heart Association (NYHA) classification I to III; (4) Indications for autotransfusion as defined by the American Association of Blood Banks (AABB) guidelines [15]: preoperative hemoglobin (Hb) ≥ 110 g/L, hematocrit (HCT) ≥ 0.33, platelet count (PLT) ≥ 100×10^9/L, normal platelet function, and no antiplatelet therapy within the previous 2 weeks; (5) Complete medical records with no missing data.

Exclusion criteria: (1) Preoperative coagulation disorders, severe hepatic or renal dysfunction, active infections, or hematogenous tumor metastasis; (2) Recent history of infection, blood transfusions, or severe blood-donation reactions (such as seizures); (3) Recent myocardial infarction, chronic heart failure, or severe hemodynamic instability.

A retrospective study was conducted on 212 cardiac surgery patients who underwent autologous blood transfusion at the first affiliated hospital of Naval Medical University between June 2022 and May 2025. Patients were assigned to either the ICS group or the PABD group according to clinical indications and the surgeon's judgment, with no crossover between the groups. Patient data, including demographic characteristics, surgical variables, hematologic and coagulation parameters, TEG, platelet aggregation and activation indices, postoperative bleeding, and transfusion-related adverse events, were retrieved from the institutional electronic medical record system.

This study was approved by the ethics committee of the First Affiliated Hospital of Naval Medical University. All procedures adhered to the Helsinki declaration. Patient confidentiality was strictly protected, and all data were de-identified for research purposes only. The study protocol met the scientific and ethical require-

ments for human research as outlined by the world medical association's guidelines. Given the retrospective design, the Institutional Review Board (IRB) waived the requirement for written informed consent.

Intervening method

ICS

During surgery, an autologous blood recovery machine (Cell Saver® Elite®+, Haemonetics, USA) was used to collect and reinfuse the patient's shed blood. Intraoperative blood loss was aspirated into a reservoir using a negative-pressure suction device and mixed with heparinized saline to prevent coagulation. The anticoagulated blood in the reservoir was filtered to remove excess heparin and tissue debris. When approximately 800 ml of blood had accumulated, the blood recovery machine was activated to transfer the blood into a centrifuge bowl for automatic washing. Finally, the processed and concentrated red blood cells were subsequently collected into a reinfusion bag and returned to the patient within 2 hours.

PABD

Before blood collection, patients were intravenously infused with 500 ml of hydroxyethyl starch 130/0.4 sodium chloride solution (NMPA approval number: H20064330, Shouhe Jinhai Pharmaceutical Co., Ltd., Shandong, Qingdao) for volume expansion. Blood collection started after half of the infusion had been administered. Venous blood was drawn from the median cubital vein into a disposable blood bag containing a blood preservation solution (CPDA-1). The blood bag was placed on an electronic rocking blood collection scale to simultaneously record the collected volume and prevent coagulation. Vital signs and electrocardiogram (ECG) activity were closely observed during blood collection. If tachycardia or discomfort occurred, blood collection was immediately stopped, and appropriate measures were taken to address these symptoms. The volume for a single blood collection was set at 200 to 400 ml. For anticipated high intraoperative blood demand, multiple blood collections were allowed, provided the baseline Hb remained ≥ 13.0 g/dL with at least a 3-day interval between collections. Collected autologous blood was stored in a dedicated refrigerator at 4°C and reinfused intraoperatively after completion of cardiopulmonary bypass.

Data collection

Primary indicators (coagulation parameters)

Prothrombin time (PT), activated partial thromboplastin time (APTT), thrombin time (TT), fibrinogen (FIB), and D-dimer (D-D) were measured using an automated coagulation analyzer (CN-6000, Sysmex, Japan) in citrate-anticoagulated venous blood samples. These measurements were taken both preoperatively and within 24 hours postoperatively to evaluate the impact of autotransfusion on coagulation parameters.

Secondary indicators

Blood cell parameters: Red blood cell count (RBC), Hb, HCT, white blood cell count (WBC), and PLT were measured using an automated blood analyzer (CN-6000, Sysmex, Japan) in EDTA-anticoagulated blood samples. These measurements were taken both preoperatively and within 24 hours postoperatively to observe the effects of blood transfusion on hematologic parameters, particularly PLT. The normal range for platelets is typically between 100 and 300 × 10^9/L.

TEG: Before surgery and within 24 hours postoperatively, the entire process of platelet-fibrin interactions, was dynamically monitored using a TEG analyzer (DRNX-III, DingRun, China). TEG parameters, including reaction time (R), clot formation time (K), maximum amplitude (MA), and α-angle, were measured to evaluate the effects of transfusion on coagulation kinetics and platelet function.

Platelet aggregation test: Platelet aggregation was measured using a 700 Aggregometer (Chrono-Log Corporation, USA) before surgery and within 24 hours after surgery. Aggregation responses were induced by adenosine diphosphate (ADP, 5 μM), collagen (2 μg/mL), and epinephrine (10 μM). Under normal conditions, the aggregation rates induced by ADP, collagen, and epinephrine are 60-75%, 60-75%, and 45-60%, respectively.

Platelet activation markers: Before surgery and within 24 hours after surgery, platelet surface

P-selectin (CD62P) and lysosomal-associated membrane glycoprotein (CD63) expression were measured using flow cytometry (CytoFLEX SRT, Beckman Coulter, USA). Platelets were labeled with PE-conjugated anti-human CD62P (ab234221, Abcam plc) and FITC-conjugated anti-human CD63 (ab18235, Abcam plc), each diluted 1:10 in phosphate-buffered saline (PBS). Samples were incubated for 30 minutes at room temperature in the dark. First, the platelets were gated using forward scatter (FSC) and side scatter (SSC). Then, in a dual-parameter scatter plot of CD62P-PE and CD63-FITC, the percentage of positive cells was calculated. Plasma levels of platelet factor 4 (PF4) were measured using an enzyme-linked immunosorbent assay kit (EHPF4; Thermo Fisher, USA) to assess in vivo platelet activation. Normal reference values were < 5% for CD62P positivity, < 2% for CD63 positivity, and PF4 < 10 IU/mL.

Postoperative bleeding outcomes: Postoperative bleeding outcomes included 24-hour thoracic drainage volume, 24-hour transfusion rate, rate of secondary thoracotomy, and a reduction in Hb levels within 48 hours postoperatively. The Hb reduction within 48 hours postoperatively was calculated as the difference between the preoperative Hb (24 hours before surgery) and the Hb concentration 48 hours postoperatively.

Statistical analysis

All data were analyzed using IBM SPSS 29.0 statistical software (IBM Corp., Armonk, NY, USA). The Shapiro-Wilk test was applied to assess the normality of continuous variables. As all variables followed a normal distribution, parametric tests were used. Sensitivity analyses using nonparametric tests yielded consistent results.

Categorical data were presented as frequencies and percentages (n (%)), and between-group differences were assessed using the chi-square (χ^2) test. Continuous variables were presented as means ± standard deviations (M ± SD). Between-group comparisons were performed using independent-samples t-tests, and within-group comparisons using paired t-tests. A *P* value < 0.05 was considered statistically significant.

Given the exploratory design and interdependence among outcome variables, no formal correction for multiple comparisons was applied to avoid excessive Type II error inflation. However, results were interpreted in light of multiple testing, emphasizing effect sizes and clinical relevance in the overall interpretation.

Result

Basic characteristics

A comparison of demographic and clinical characteristics between the ICS group (n = 127) and the PABD group (n = 85) showed no significant differences across most parameters (**Table 1**). Gender distribution, age, body mass index (BMI), education level, marital status, comorbid hypertension, comorbid diabetes, comorbid cerebrovascular disease, ASA classification, NYHA classification, left ventricular ejection fraction (LVEF), left ventricular end-diastolic diameter (LVDd), and left atrial diameter (LAD) were all comparable between the two groups (all P > 0.05). These findings indicate that baseline clinical characteristics were well balanced, minimizing potential confounding influences on subsequent analyses.

Similarly, no significant differences were observed in surgical characteristics between the two groups (**Table 2**). There were no significant differences in the types of surgeries performed, including CABG, cardiac valve replacement, and congenital heart defect repair (P = 0.746). Additionally, there were no significant differences in operative time (P = 0.493), cardiopulmonary bypass time (P = 0.366), intraoperative blood loss (P = 0.217), and transfusion volume (P = 0.644) between the two groups. These results indicate that the operative and intraoperative parameters were equivalent, supporting their comparability in further outcome analyses.

Blood cell and coagulation parameters

Preoperative comparisons of blood cells showed no significant differences between the two groups in most indices, including RBC, Hb, HCT, WBC, and PLT (all P > 0.05; **Figure 1**). Similarly, coagulation parameters including PT, APTT, TT, FIB, and D-D, also showed no significant differences between groups (all P > 0.05, **Figure 2**). These results indicate that baseline

Table 1. Comparison of demographic characteristics between the two groups

Parameter	ICS group (n = 127)	PABD group (n = 85)	t/X^2	P
Gender [n (%)]			0.855	0.355
Male	65 (51.18%)	38 (44.71%)		
Female	62 (48.82%)	47 (55.29%)		
Age (years)	53.24 ± 8.63	52.85 ± 8.49	0.325	0.745
BMI (kg/m^2)	22.61 ± 2.08	22.59 ± 2.13	0.059	0.953
Educational level [n (%)]			1.064	0.587
Primary and below	23 (18.11%)	12 (14.12%)		
Junior high school	75 (59.06%)	56 (65.88%)		
High school	29 (22.83%)	17 (20.00%)		
Marital status [n (%)]			0.050	0.975
Married	95 (74.80%)	63 (74.12%)		
Unmarried	8 (6.30%)	5 (5.88%)		
Divorced	24 (18.90%)	17 (20.00%)		
Combined hypertension [n (%)]	27 (21.26%)	19 (22.35%)	0.036	0.850
Combined diabetes [n (%)]	3 (2.36%)	4 (4.71%)	0.296	0.587
Combined cerebrovascular disease [n (%)]	5 (3.94%)	4 (4.71%)	0	1.000
ASA grade [n (%)]			0.045	0.833
II	46 (36.22%)	32 (37.65%)		
III	81 (63.78%)	53 (62.35%)		
NY-HA grade [n (%)]			0.075	0.963
I	3 (2.36%)	2 (2.35%)		
II	44 (34.65%)	31 (36.47%)		
III	80 (62.99%)	52 (61.18%)		
LVEF (%)	59.36 ± 7.52	58.64 ± 8.23	0.652	0.515
LVDd (mm)	53.61 ± 8.26	54.06 ± 8.43	0.379	0.705
LAD (mm)	47.29 ± 9.58	47.21 ± 8.86	0.063	0.950

ICS: intraoperative cell salvage; PABD: preoperative autologous blood donation; BMI: body mass index; ASA: American society of anesthesiologists; NY-HA: New York heart association; LVEF: left ventricular ejection fraction; LVDd: left ventricular diameter in diastole; LAD: left atrial diameter.

Table 2. Comparison of surgery-related factors between the two groups

Parameter	ICS group (n = 127)	PABD group (n = 85)	t/X^2	P
Types of surgeries [n (%)]			0.586	0.746
CABG	25 (19.69%)	15 (17.65%)		
Cardiac valve replacement	71 (55.91%)	52 (61.18%)		
Orthodontic surgery for congenital heart disease	31 (24.41%)	18 (21.18%)		
Operative time (min)	176.85 ± 21.63	178.96 ± 22.45	0.687	0.493
Extracorporeal circulation time (min)	66.59 ± 13.74	68.31 ± 13.25	0.906	0.366
Blood loss volume (mL)	1075.26 ± 83.41	1061.35 ± 75.38	1.237	0.217
Blood transfusion volume (mL)	591.34 ± 102.14	584.76 ± 100.32	0.463	0.644

ICS: intraoperative cell salvage; PABD: preoperative autologous blood donation; CABG: coronary artery bypass grafting.

hematologic and coagulation profiles were well balanced between groups, supporting their comparability in further clinical evaluations. Significant within-group changes were observed in all parameters before and after surgery (all $P < 0.05$).

A comparison of blood cell parameters within 24 hours postoperatively between the two groups revealed several notable differences. While RBC count, Hb levels, HCT percentages, and WBC count did not differ significantly between groups (all $P > 0.05$), postoperative

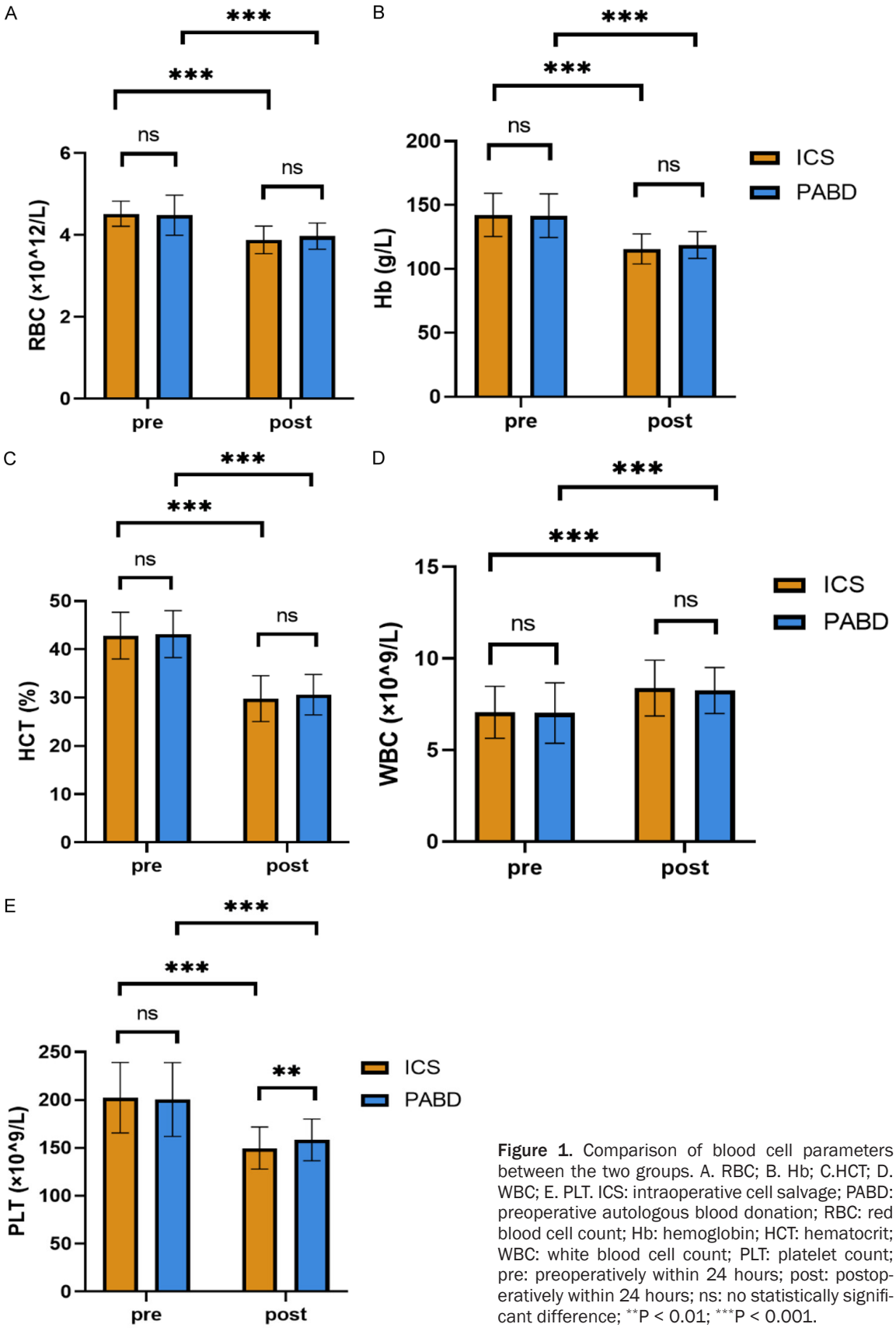

Figure 1. Comparison of blood cell parameters between the two groups. A. RBC; B. Hb; C.HCT; D. WBC; E. PLT. ICS: intraoperative cell salvage; PABD: preoperative autologous blood donation; RBC: red blood cell count; Hb: hemoglobin; HCT: hematocrit; WBC: white blood cell count; PLT: platelet count; pre: preoperatively within 24 hours; post: postoperatively within 24 hours; ns: no statistically significant difference; $^{**}P < 0.01$; $^{***}P < 0.001$.

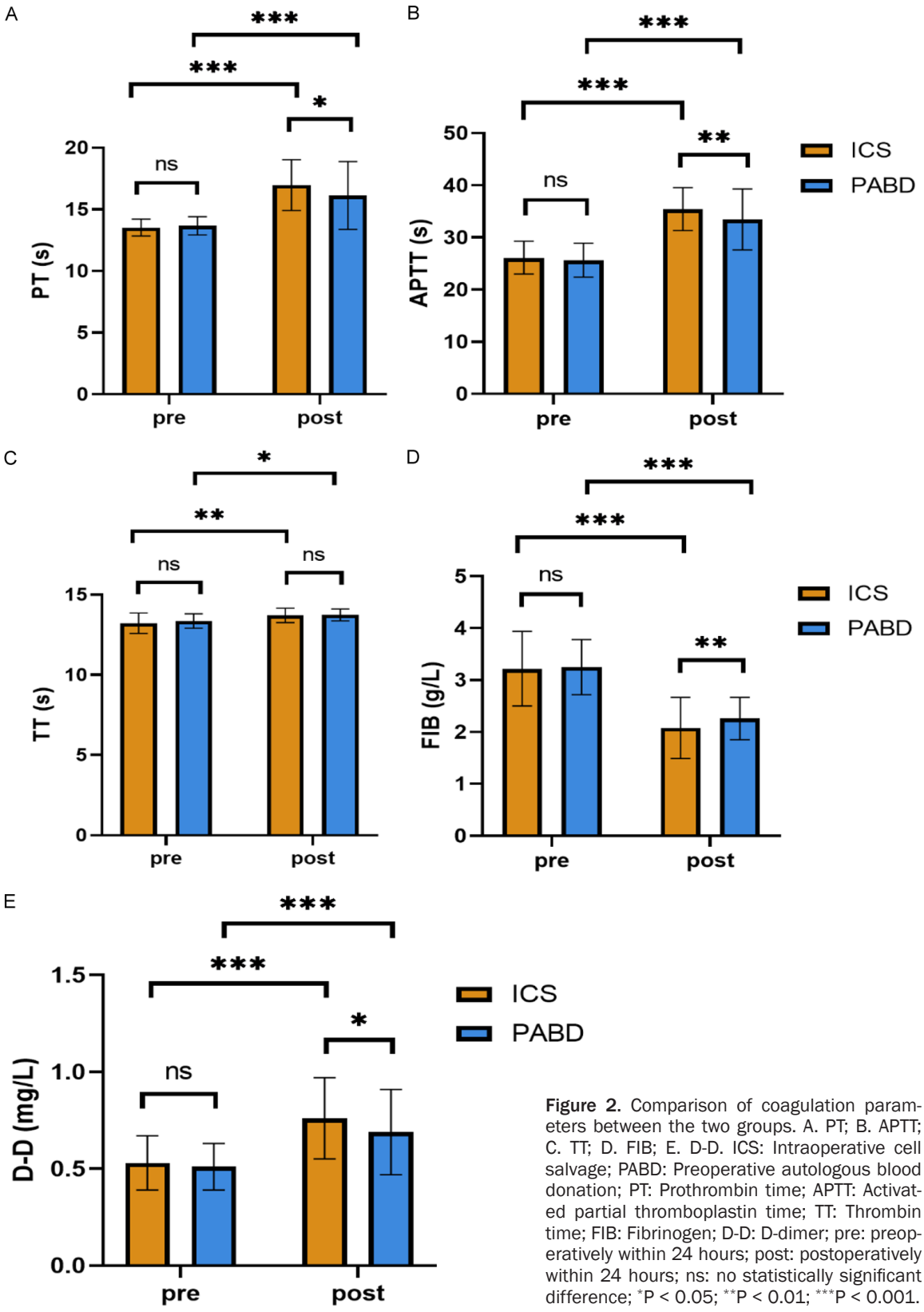

Figure 2. Comparison of coagulation parameters between the two groups. A. PT; B. APTT; C. TT; D. FIB; E. D-D. ICS: Intraoperative cell salvage; PABD: Preoperative autologous blood donation; PT: Prothrombin time; APTT: Activated partial thromboplastin time; TT: Thrombin time; FIB: Fibrinogen; D-D: D-dimer; pre: preoperatively within 24 hours; post: postoperatively within 24 hours; ns: no statistically significant difference; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

PLT count was significantly lower in the ICS group compared to the PABD group (P = 0.005, **Figure 1**), indicating more pronounced platelet depletion following ICS.

Table 3. Comparison of TEG parameters between the two groups

Parameter	ICS group (n = 127)	PABD group (n = 85)	T	P
Preoperatively within 24 hours				
R (min)	4.52 ± 0.69	4.58 ± 0.71	0.654	0.514
K time (min)	2.04 ± 0.11	2.02 ± 0.13	1.431	0.154
MA (mm)	62.36 ± 5.42	63.07 ± 5.16	0.948	0.344
Alpha angle (°)	59.61 ± 4.23	59.37 ± 3.68	0.417	0.677
Postoperatively within 24 hours				
R (min)	5.51 ± 1.32*	5.18 ± 0.97*	2.131	0.034
K time (min)	2.17 ± 0.16*	2.13 ± 0.15*	1.628	0.105
MA (mm)	61.25 ± 5.63*	62.38 ± 4.74*	1.523	0.129
Alpha angle (°)	58.19 ± 3.75*	58.64 ± 3.52*	0.877	0.382

ICS: intraoperative cell salvage; PABD: preoperative autologous blood donation; TEG: thromboelastography; R: reaction time; MA: maximum amplitude; *P < 0.05 compared to preoperatively within 24 hours.

Table 4. Comparison of platelet aggregation parameters between the two groups

Parameter	ICS group (n = 127)	PABD group (n = 85)	T	P
Preoperatively within 24 hours				
ADP induced aggregation rate (%)	69.65 ± 3.82	70.16 ± 2.17	1.231	0.220
Collagen induced aggregation rate (%)	65.73 ± 3.37	66.32 ± 2.94	1.324	0.187
Adrenaline induced aggregation rate (%)	47.86 ± 5.95	48.29 ± 5.12	0.552	0.582
Postoperatively within 24 hours				
ADP induced aggregation rate (%)	60.78 ± 5.75*	62.53 ± 2.22*	3.105	0.002
Collagen induced aggregation rate (%)	59.72 ± 4.97*	61.15 ± 1.56*	3.026	0.003
Adrenaline induced aggregation rate (%)	42.47 ± 6.38*	45.25 ± 6.17*	3.159	0.002

ICS: intraoperative cell salvage; PABD: preoperative autologous blood donation; ADP: adenosine diphosphate; *P < 0.05 compared to preoperatively within 24 hours.

Postoperative coagulation profiles demonstrated further distinctions. While TT did not differ significantly between the two groups (P = 0.594), PT (P = 0.016) and APTT (P = 0.008) were significantly prolonged in the ICS group compared with the PABD group. FIB levels were significantly reduced (P = 0.009), whereas D-D levels were significantly elevated (P = 0.017) in the ICS group (**Figure 2**). These findings suggest that ICS was associated with greater postoperative impairment of coagulation function, characterized by delayed clotting and increased fibrinolytic activity, whereas PABD better preserved hemostatic balance.

TEG

Comparison of preoperative TEG parameters between the ICS group and the PABD group showed no remarkable differences in R time, K time, MA, or alpha angle (all P > 0.05). Significant within-group differences were observed in all TEG indices before and after surgery (all P < 0.05; **Table 3**). Postoperatively, only R time demonstrated significant differences between groups, with significantly longer time in the ICS group compared to the PABD group (P = 0.034). These findings suggest that postoperative thrombus initiation was delayed in the ICS group.

Platelet aggregation test

As shown in **Table 4**, there were no significant differences in preoperative ADP-induced aggregation, collagen-induced aggregation, or epinephrine-induced aggregation (all P > 0.05). However, within 24 hours postoperatively, significant differences were observed in all three types of aggregation rates: ADP-induced (P = 0.002), collagen-induced (P = 0.003), and epinephrine-induced (P = 0.002). There were significant within-group changes in all indices before and after treatment (all P < 0.05). These findings indicate that while baseline platelet aggregation was comparable, postoperative

Table 5. Comparison of platelet activation markers between the two groups

Parameter	ICS group (n = 127)	PABD group (n = 85)	t	P
Preoperatively within 24 hours				
CD62P+ rate (%)	4.31 ± 0.23	4.35 ± 0.31	0.989	0.324
CD63+ rate (%)	1.58 ± 0.12	1.61 ± 0.19	1.153	0.251
PF4 (IU/mL)	8.86 ± 0.64	8.93 ± 0.57	0.858	0.392
Postoperatively within 24 hours				
CD62P+ rate (%)	8.95 ± 2.16*	8.31 ± 1.25*	2.700	0.008
CD63+ rate (%)	2.43 ± 0.54*	2.24 ± 0.48*	2.683	0.008
PF4 (IU/mL)	16.64 ± 4.22*	15.21 ± 3.35*	2.735	0.007

ICS: intraoperative cell salvage; PABD: preoperative autologous blood donation; CD62P, P-selectin; CD63, lysosomal integration membrane glycoprotein; PF4, platelet factor 4; *P < 0.05 compared to preoperatively within 24 hours.

Table 6. Comparison of bleeding events between the two groups

Parameter	ICS group (n = 127)	PABD group (n = 85)	t/X^2	P
Postoperative 24-hour thoracic drainage volume (mL)	415.35 ± 124.73	371.52 ± 106.81	2.653	0.009
Postoperative 24-hour transfusion rate [n (%)]	41 (32.28%)	16 (18.82%)	4.693	0.030
Secondary thoracotomy rate [n (%)]	6 (4.72%)	1 (1.18%)	1.050	0.305
Postoperative 48-hour Hb decrease (g/L^10^{-1})	31.73 ± 9.21	28.35 ± 8.56	2.696	0.008

ICS: intraoperative cell salvage; PABD: preoperative autologous blood donation; Hb: hemoglobin.

platelet reactivity was significantly reduced in the ICS group, suggesting greater impairment of platelet function after ICS.

Platelet activation markers

As shown in **Table 5**, there were no significant differences in preoperative rates of CD62P+, CD63+, or levels of PF4 (all P > 0.05). However, within 24 hours postoperatively, significant differences were observed: the rates of CD62P+ (P = 0.008) CD63+ (P = 0.008), and PF4 (P = 0.007) were significantly elevated in the ICS group compared with the PABD group. Significant within-group differences were also observed for each marker before and after surgery (all P < 0.05). These findings indicate that while baseline platelet activation was comparable, postoperative expression of CD62P, CD63, and PF4 was significantly higher in the ICS group, suggesting increased platelet activation following intraoperative cell salvage.

Postoperative bleeding events

Comparisons of postoperative bleeding events between the two groups (**Table 6**) revealed that the ICS group demonstrated significantly higher 24-hour thoracic drainage volume (P = 0.009) and 24-hour transfusion rate (P = 0.030), as well as greater hemoglobin decline within postoperative 48 hours (P = 0.008) compared with the PABD group, further supporting increased bleeding tendency in the ICS group. However, the secondary thoracotomy rate did not differ significantly between groups (P = 0.305).

Adverse transfusion reactions

There were no significant difference in overall incidence of postoperative transfusion-related adverse reactions between the two groups (P = 0.590; **Table 7**), including rash (P = 0.724), chest tightness (P = 0.312), shiver (P = 1.000), fever (P = 0.603).

Discussion

This study systematically compared the effects of ICS and PABD on postoperative coagulation and platelet function in patients undergoing cardiac surgery. The baseline demographics, surgical characteristics, and preoperative hematological parameters were comparable between the two groups, ensuring the validity of subsequent comparisons. Key results include significantly lower platelet counts, prolonged coagulation times, reduced fibrinogen levels, and elevated D-dimer levels in the ICS group,

Table 7. Comparison of transfusion-related adverse reactions between the two groups (postoperatively within 24 hours)

Parameter	ICS group (n = 127)	PABD group (n = 85)	X^2	P
Rash [n (%)]	1 (0.79%)	2 (2.35%)	0.124	0.724
Chest tightness [n (%)]	0 (0%)	2 (2.35%)	1.024	0.312
Shiver [n (%)]	1 (0.79%)	1 (1.18%)	0	1.000
Fever [n (%)]	6 (4.72%)	2 (2.35%)	0.271	0.603
Total incidence rate [n (%)]	8 (6.30%)	7 (8.24%)	0.290	0.590

ICS: intraoperative cell salvage; PABD: preoperative autologous blood donation.

indicating more pronounced hemostatic disturbances compared with PABD. These differences are likely attributed to mechanical injury during the blood recovery process, as the centrifugation and washing procedures in ICS expose blood components to shear stress, leading to platelet activation, aggregation, and subsequent consumption or destruction [16]. Platelets are highly vulnerable to such mechanical forces, which could explain the reduced postoperative platelet counts in the ICS group [17].

Regarding coagulation parameters, the ICS group showed significantly prolonged PT and APTT, reduced FIB levels, and elevated D-D levels postoperatively, collectively indicating more pronounced coagulation disturbances in the ICS group. The prolongation of PT and APTT suggests impairment of both the extrinsic and intrinsic coagulation pathways, likely caused by the loss of coagulation factors during the washing phase of cell salvage, which removes plasma components including fibrinogen and clotting factors [18]. This observation contrasts with the report by Lee et al. [19] on liver transplantation, where no coagulopathy was observed after intraoperative blood salvage (IBSA). The discrepancy could be explained by baseline coagulopathy of liver-transplant patients, which could mask procedure-related alterations. The reduction in FIB levels further supports this mechanism, as ICS prioritizes red blood cell recovery while discarding most plasma constituents [20]. In contrast, PABD reinfuses autologous whole blood collected preoperatively, thereby preserving native coagulation factors and minimizing dilution effects [21]. The elevated D-D levels in the ICS group likely reflect enhanced fibrinolysis or microvascular thrombosis secondary to intraoperative tissue injury and depletion of clotting factors. Collectively, these alterations were clinically manifested as higher postoperative chest-tube drainage and blood transfusions requirements in the ICS group, suggesting that platelet and coagulation factor depletion during ICS may exacerbate postoperative bleeding risk in cardiac surgery patients.

The TEG findings further elucidate the coagulation kinetics, with the prolonged R time in the ICS group indicating delayed thrombus formation. This reflects the duration required for initial clot formation, directly resulting from the depletion of coagulation factors during the mechanical washing process in ICS, which removes plasma containing fibrinogen and clotting factors such as factor V and VIII [22]. The preservation of K time, MA, and α-angle in both groups suggests that while clot formation was delayed in the ICS group, the subsequent processes of fibrin network development and platelet-fibrin interactions remain intact. This indicates that the primary impact of ICS on coagulation lies in the early activation of the coagulation cascade rather than in downstream platelet aggregation or fibrin polymerization.

Platelet function tests confirmed this, showing significantly lower ADP-, collagen-, and epinephrine-induced platelet aggregation rates in the ICS group. This functional impairment may be caused by multiple mechanisms: (1) mechanical shear stress during centrifugation disrupts the integrity of platelet membranes; (2) heparin exposure during the anticoagulation process interferes with receptor-mediated platelet activation; and (3) excessive activation-induced depletion exhausts active platelets [23-25]. The similarity in preoperative aggregation rates between groups confirms that the observed defects were iatrogenic rather than intrinsic. Such reductions in platelet aggregation-a key determinant of primary hemostasis-combined

with the lower platelet count observed in the ICS group, likely exacerbate the risk of postoperative bleeding.

Notably, the extent of the reduction in platelet aggregation aligns closely with the elevation of platelet activation markers, reinforcing the mechanistic link between mechanical trauma and platelet dysfunction. The elevated platelet activation markers (CD62P, CD63, PF4) in the ICS group further confirm that mechanical stress during ICS triggers platelet activation, leading to dysfunction and depletion. The translocation of CD62P and CD63 to the platelet surface indicates activation, while the elevated PF4 level reflects α-granule release during degranulation [19]. These markers not only confirm platelet activation but also suggest that ICS-induced platelet injury may lead to secondary microvascular thrombosis or enhanced fibrinolysis, as evidenced by concomitant rise in D-dimer levels [26]. In contrast, the preservation of these markers in the PABD group highlights its advantage in maintaining platelet homeostasis, likely because pre-collected whole blood is not exposed to the inherent mechanical stress in ICS. Overall, these findings indicate that ICS imposes a dual burden on platelets: mechanical destruction reduces their count, while activation impairs their functional capacity, whereas PABD preserves both platelet count and reactivity through the reinfusion of intact autologous blood components. These findings from conventional coagulation assays, TEG, and platelet function tests collectively provide a multidimensional understanding of how ICS and PABD differentially impact hemostasis.

Clinically, these results provide a rationale for the individualized selection of autologous transfusion strategies in cardiac surgery. PABD, due to its preservation of coagulation factors and platelets, is preferred for patients at high risk of coagulopathy, such as those with preexisting hemostatic disorders or prolonged cardiopulmonary bypass times. However, its use is constrained by preoperative planning, hemoglobin thresholds, and the exclusion of emergency cases [27]. In contrast, ICS offers greater flexibility and can be used intraoperatively to rapidly recover and reinfuse lost blood, making it particularly valuable when preoperative blood donation is not feasible [28]. Notably, although ICS is associated with losses of platelets and coagulation factors, it remains a safe option when combined with close perioperative coagulation monitoring and appropriate hemostatic interventions, such as timely administration of platelet concentrates or fibrinogen [29]. The comparable safety of both methods further supports their clinical utility, with the choice depending on balancing coagulation protection against surgical feasibility.

The clinical value of this study lies in its comprehensive assessment of how different autologous transfusion methods affect coagulation and platelet function through an integrated analysis of conventional coagulation indices, TEG, and platelet function tests, providing a multidimensional evaluation framework for clinical practice. The findings emphasize the importance of personalized transfusion strategies in cardiac surgery, guiding clinicians to consider individual patient risks and surgical characteristics for the selection between ICS and PABD [30]. For instance, in elective cardiac surgeries with adequate preoperative preparation time, PABD can be prioritized for patients at risk of coagulopathy to maintain hemostatic stability; whereas in emergency surgeries or situations with unpredictable blood loss, ICS can serve as an effective blood conservation measure when supplemented by close monitoring of postoperative coagulation function and timely supplementation of deficient blood components [31].

This study has several limitations that should be acknowledged. Its retrospective design and non-randomized patient allocation based on surgeon preference may have introduced selection bias and potential confounding factors. Future studies should consider propensity score matching (PSM) or multivariate regression analysis to address these potential biases. Moreover, according to our inclusion criteria, this cohort selectively comprised cardiac surgery patients not receiving antiplatelet therapy. Consequently, the coronary artery bypass grafting (CABG) patients represent a specific subgroup that had discontinued antiplatelet treatment, which may limit the generalizability of our findings to all CABG patients, particularly those requiring uninterrupted therapy. Additionally, this study only evaluated a single postoperative time point (within 24 hours), which limits our understanding of long-term out-

comes. Incorporating multiple postoperative assessments or longitudinal follow-up would provide more comprehensive insights into coagulation and platelet function recovery. The short-term focus also precluded detailed exploration of mechanisms such as platelet microparticle generation or coagulation factor alterations in salvaged blood. Future prospective studies with larger sample sizes and extended observation periods are warranted to validate and expand upon these findings.

Conclusion

In conclusion, while both ICS and PABD are safe autotransfusion strategies, ICS is associated with a more pronounced decline in platelet count and depletion of coagulation factors, likely due to mechanical shear and washing-related plasma removal, whereas PABD better preserves hemostatic components through whole blood reinfusion. Clinicians should weigh these factors when choosing an autologous transfusion strategy, particularly for patients at risk of coagulopathy, and maintain vigilant perioperative monitoring for early detection and management of hemostatic dysfunction.

Disclosure of conflict of interest

None.

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References

[1] Feng Z, Liao QX, Xie JB, Chen JF, Qiu ML and Li X. Utility of methylene blue mixed with autologous blood in preoperative localization of pulmonary nodules and masses. Open Life Sci 2023; 18: 20220645.

[2] Itano H, Akiyama T and Yoshihara M. Clinical efficacy of intraoperative Cell Saver autologous blood salvage in emergency surgery for massive hemothorax. Indian J Thorac Cardiovasc Surg 2023; 39: 359-366.

[3] Boer W, van Tornout M, Brusseleers M, Strauven M, de Vooght P, Vander Laenen M, Hoste E and Jorens PG. The effects of differing anticoagulant regimes on blood quality after cell salvage in coronary artery bypass grafting (CABG): a pilot study. J Cardiothorac Surg 2023; 18: 116.

[4] van Klarenbosch J, van den Heuvel ER, van Oeveren W and de Vries AJ. Does intraoperative cell salvage reduce postoperative infection rates in cardiac surgery? J Cardiothorac Vasc Anesth 2020; 34: 1457-1463.

[5] Mekhail A, Clayton N, Rhadakrishnan K, Blakey A and Galvin S. Utilizing retrograde autologous priming for blood conservation in cardiac surgery. ANZ J Surg 2023; 93: 2406-2410.

[6] Surcel C, Dotzauer R, Mirvald C, Popa C, Olariu C, Baston C, Harza M, Gangu C, Tsaur I and Sinescu I. Current role of intraoperative cell salvage techniques in the management of renal tumors with level III and IV inferior vena cava thrombus extension. Ther Adv Urol 2024; 16: 17562872241229248.

[7] Lei B, Guo M, Deng X, He S, Lu X, Wang Y and Wang L. Intraoperative cell salvage as an effective intervention for postpartum hemorrhage-evidence from a prospective randomized controlled trial. Front Immunol 2022; 13: 953334.

[8] Morimoto T, Ichinomiya T, Murata H, Sekino M and Hara T. Management of combined cardiac surgery using cardiopulmonary bypass with acute normovolemic hemodilution in a jehovah's witness: a case report. Cureus 2023; 15: e33442.

[9] Uramatsu M, Maeda H, Mishima S, Takahashi M, Wada J, Amano K, Barach P and Miki T. Serious hazards of transfusion: evaluating the dangers of a wrong patient autologous salvaged blood in cardiac surgery. J Cardiothorac Surg 2022; 17: 182.

[10] Narula J, Saxena R and Bindal S. Bombay blood group for pediatric cardiac surgery in the era of a pandemic: newer challenges call for desperate measures! Ann Card Anaesth 2023; 26: 343-345.

[11] Qi J, Hu Y, Niu X, Dong Y, Zhang X, Xu N, Chen Z, Li W, Tian Y and Sun C. Efficacy of preoperative autologous blood donation for surgical treatment of thoracic spinal stenosis: a propensity-matched cohort study. Orthop Surg 2024; 16: 3068-3077.

[12] Zhou Y, Chen T, Yang C, Liu J, Yang X, Zhang B and Jin Z. Risk factors associated with positive bacterial culture in salvaged red blood cells during cardiac surgery and postoperative infection incidence: a prospective cohort study. Front Med (Lausanne) 2023; 10: 1099351.

[13] Ko SH, Nan Z, Soh S, Shim JK, Lee HW, Kwak YL and Song JW. Effect of retrograde autologous priming on coagulation assessed by rotation thromboelastometry in patients undergoing valvular cardiac surgery. J Cardiothorac Vasc Anesth 2024; 38: 939-945.

[14] Wilkinson KL, Kimber C, Allana A, Dorée C, Champaneria R, Brunskill SJ and Murphy MF.

Red blood cell transfusion management for people undergoing cardiac surgery for congenital heart disease. Cochrane Database Syst Rev 2025; 3: CD009752.

[15] Carson JL, Grossman BJ, Kleinman S, Tinmouth AT, Marques MB, Fung MK, Holcomb JB, Illoh O, Kaplan LJ, Katz LM, Rao SV, Roback JD, Shander A, Tobian AA, Weinstein R, Swinton McLaughlin LG and Djulbegovic B. Red blood cell transfusion: a clinical practice guideline from the AABB*. Ann Intern Med 2012; 157: 49-58.

[16] Li J, Xia Y, Jin S, Dong H, Zhao P, Jiang H and Hu R. Effects of acute normovolemic hemodilution on allogeneic blood transfusion & coagulation in orthognathic surgery: a randomized study. Transfusion 2023; 63: 125-133.

[17] Flores-Mendoza H, Shehata N, Murji A, Allen LM, Kingdom JC, Windrim RC, Carvalho JCA, Ravi Chandran A, Papalia N and Hobson SR. Use of intraoperative red cell salvage in the contemporary management of placenta accreta spectrum disorders. Can J Anaesth 2023; 70: 1544-1546.

[18] Yoon U, Bartoszko J, Bezinover D, Biancofiore G, Forkin KT, Rahman S, Spiro M, Raptis DA and Kang Y. Intraoperative transfusion management, antifibrinolytic therapy, coagulation monitoring and the impact on short-term outcomes after liver transplantation-a systematic review of the literature and expert panel recommendations. Clin Transplant 2022; 36: e14637.

[19] Lee J, Park S, Lee JG, Choo S and Koo BN. Efficacy of intraoperative blood salvage and autotransfusion in living-donor liver transplantation: a retrospective cohort study. Korean J Anesthesiol 2024; 77: 345-352.

[20] Aykut K, Albayrak G, Cetin Y, Ciftci N and Ciftci S. Coronary artery bypass surgery without blood transfusion; is it possible? Niger J Clin Pract 2021; 24: 59-63.

[21] Singab H, Gamal MA, Refaey R and Al-Taher W. Effect of retrograde autologous blood priming of cardiopulmonary bypass on hemodynamic parameters and pulmonary mechanics in pediatric cardiac surgery: a randomized clinical study. Semin Thorac Cardiovasc Surg 2021; 33: 505-512.

[22] Kiser KA, Tanaka A, Sandhu HK, Miller CC, 3rd, Leonard SD, Safi HJ and Estrera AL. Extensive cell salvage and postoperative outcomes following thoracoabdominal and descending aortic repair. J Thorac Cardiovasc Surg 2022; 163: 914-921, e911.

[23] Mansour A, Beurton A, Godier A, Rozec B, Zlotnik D, Nedelec F, Gaussem P, Fiore M, Boissier E, Nesseler N and Ouattara A. Combined platelet and red blood cell recovery during on-pump cardiac surgery using same™ by i-sep autotransfusion device: a first-in-human noncomparative study (i-transep study). Anesthesiology 2023; 139: 287-297.

[24] Morinaga M, Yoshitani K, Ogata S, Fukushima S and Matsuda H. Association between intraoperative blood salvage and coagulation disorder after cardiopulmonary bypass. JA Clin Rep 2024; 10: 5.

[25] Stoneham MD, Barbosa A, Maher K, Douglass P, Desborough MJR and Von Kier S. Intraoperative cell salvage using swab wash and serial thromboelastography in elective abdominal aortic aneurysm surgery involving massive blood loss. Br J Haematol 2023; 200: 652-659.

[26] Deng Y, Luo X and Xu X. The value of coagulation-related indicators combined with vascular ultrasound parameters in the risk assessment of deep vein thrombosis after secondary traumatic fracture surgery. Ann Ital Chir 2024; 95: 206-212.

[27] Roets M, Sturgess D, Tran T, Obeysekera M, Perros A, Tung JP, Flower R, van Zundert A and Dean M. Intraoperative cell salvage: the impact on immune cell numbers. PLoS One 2023; 18: e0289177.

[28] Walton TJ, Huntley D, Whitehouse SL, Davies J, Wilson MJ, Hubble MJW, Howell JR and Kassam AM. Intraoperative cell salvage in revision hip arthroplasty. Bone Joint J 2023; 105-B: 1038-1044.

[29] Bai Y, Su Y, Wang J, Yao N, Duan L, Liu T and Guo J. Effects of blood components of preoperative autologous blood donation on functions of myelopoietic stem cells. Hematology 2023; 28: 2240666.

[30] Del Fante C, Masiello F, Vaglio S, Lombardini L, Coluzzi S, Rondinelli MB, Ciceri F, Pupella S and De Angelis V. A survey on preoperative autologous blood donation policy in bone marrow stem cell donors in Italy. Blood Transfus 2023; 21: 337-344.

[31] You LW, Wu MD, Yao N, Li ZZ, Zhou X and Guo JR. An experimental study on the effect of preoperative autologous blood donation on bone marrow hematopoiesis and hematopoietic stem cells. J Physiol Pharmacol 2022; 73.