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Original Article

Effect of different autologous platelet separation techniques on perioperative outcome in patients undergoing major cardiovascular surgery: a retrospective cohort study

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Abstract: Objective: To compare two autologous platelet separation techniques with traditional autologous blood transfusion, focusing on their effects on coagulation function and postoperative recovery, in patients undergoing major cardiovascular surgery. Methods: This retrospective study analyzed clinical data from 220 patients who underwent aortic replacement surgery or valve replacement surgery at Hunan Provincial People's Hospital between January 2019 and December 2022. The patients were divided into three group based on their intraoperative blood management protocols: Group A (n=48, red blood cells (RBCs) + platelet-rich plasma (PRP)), Group B (n=92, RBCs + platelets (PLT) + plasma), and Group C (n=80, autologous blood). Preoperative and postoperative findings were compared among the groups, including coagulation function, liver and kidney function, aortic cross-clamp time, cardiopulmonary bypass (CPB) time, blood product transfusion volume, length of intensive care unit (ICU) stay, duration of mechanical ventilation, and total drainage volume. Results: Groups A and B showed decreased postoperative D-dimer level, reduced prothrombin time (PT) and activated partial thromboplastin time (APTT), and increased PLT (P<0.001), as well as lower volume of allogeneic blood transfusion (P<0.001) compared to Group C. The length of ICU stay (P=0.012) was shorter and total drainage volume (P=0.003) was less in Group A than Group C. Group A showed significantly lower postoperative urea nitrogen and creatinine levels than Group C (P<0.05), with no significant difference between Groups A and B (P>0.05). Conclusion: Autologous platelet separation enhances recovery by improving coagulation and reducing transfusions, with RBCs plus PRP scheme (Group A) best preserving liver and kidney function.

Keywords: Autologous platelet separation technique, blood conservation, major cardiovascular surgery, coagulation function, cardiopulmonary bypass

Introduction

Major cardiovascular emergencies typically manifest with acute onset, rapid progression, and poor clinical prognosis [1]. Non-surgical management of these critical conditions is associated with extremely high in-hospital mortality rates, particularly within the first 24 hours after symptom onset [2]. While surgical intervention remains the primary treatment modality [3], these complex, high-risk procedures often require cardiopulmonary bypass (CPB) [4, 5] or even deep hypothermic circulatory arrest (DHCA) [6]. Such interventions can significantly disrupt the coagulation system [7, 8], increase perioperative allogeneic blood transfusion requirements [9, 10], elevate postoperative complication rates, and ultimately hinder recovery while increasing mortality risk [11].

Furthermore, during major cardiovascular surgery, the interaction between the extracorporeal circulation circuit and blood can lead to thrombocytopenia, coagulation factor consumption, and activation of the fibrinolytic system [12, 13]. Significant intraoperative blood loss often necessitates transfusions to maintain blood volume and coagulation function.

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However, allogeneic blood transfusion not only exacerbates blood supply shortages but also increases medical costs and introduces transfusion-related risks [14, 15]. Therefore, optimizing perioperative blood management protocols is crucial. Autologous Plateletpheresis (APP) is an effective blood conservation technique that involves preoperative collection of the patient's platelet-rich plasma (PRP) or concentrated platelets (PLT) for intraoperative or postoperative reinfusion, thereby reducing allogeneic transfusion requirements and improving coagulation function [3, 5, 16]. Currently, the two main APP techniques are the red blood cells (RBCs) + platelet-rich plasma (PRP) and RBCs + PLT + plasma protocols [3, 16], though their clinical efficacy requires further comparative evaluation.

This study aimed to evaluate the effects of two autologous plateletpheresis (APP) techniques (RBCs + PRP and RBCs + PLT + plasma) on perioperative coagulation function, transfusion requirements, and clinical outcomes in patients undergoing major cardiovascular surgery, in comparison to traditional autologous blood reinfusion. Through a multidimensional analysis of outcomes including coagulation values, transfusion volume, organ protection, and postoperative recovery, this study systematically compares the clinical efficacy of these two APP techniques. The findings may provide crucial evidence for implementing individualized blood conservation protocols, supporting the paradigm shift in major cardiovascular surgery from "empirical transfusion" to "precision blood management", with significant clinical implications for optimizing perioperative care.

Materials and methods

General data

This retrospective study analyzed 220 patients who underwent major cardiovascular surgeries in the Department of Cardiothoracic Surgery at Hunan Provincial People's Hospital between January 2019 and December 2022.

Inclusion criteria: (1) patients diagnosed with Type A aortic dissection (according to the 2014 ESC Guidelines on the diagnosis and treatment of aortic diseases [17]), ascending aortic aneurysm (diameter ≥5.5 cm), or aortic root aneurysm (based on the 2010 AHA/ACC Guidelines for thoracic aortic disease [18]). All diagnoses were confirmed by preoperative contrast-enhanced CT angiography (CTA), with some cases further verified by intraoperative exploration; (2) patients aged 20-80 years scheduled for aortic replacement surgery, including ascending aorta + aortic arch replacement, Bentall procedure (aortic valve + aortic root + ascending aorta replacement surgery), or Sun's procedure (total aortic arch replacement + stented elephant trunk procedure); (3) patients with normal preoperative coagulation function (prothrombin time (PT) and activated partial thromboplastin time (APTT) within normal range) and liver and kidney (serum creatinine (SCr) ≤120 μmol/L); (4) patients without severe heart or lung dysfunction (New York Heart Association (NYHA) functional classification ≤ class III); (5) patients whose preoperative evaluation met the surgical indications.

Exclusion criteria: (1) patients with active bleeding or coagulation disorders before surgery (e.g., disseminated intravascular coagulation, PLT count $<100\times10^9$/L); (2) patients lacking detailed clinical data; (3) patients with severe liver or kidney dysfunction (alanine aminotransferase (ALT)/Aspartate aminotransferase (AST) >3 times the upper limit of normal, estimated glomerular filtration rate (eGFR) <60 mL/min/1.73 m^2); (4) patients who received emergency surgery or were diagnosed with malignant tumors.

Among the included patients, 112 underwent ascending aorta + aortic arch replacement, 64 underwent Sun's procedure, and 44 underwent Bentall procedure. All patients underwent intraoperative autologous blood recovery with the Cell Saver Elite system. Patients undergoing the Sun's procedure all received both DHCA and selective antegrade cerebral perfusion (SACP). Group A (n=48): preoperative separation of RBCs + PRP; Group B (n=92): preoperative separation of RBCs + PLTs + plasma; Group C (n=80): only autologous blood transfusion. The post-separation component criteria were as follows: Group A: PRP with a PLT concentration $\geq1\times10^{11}$/L; Group B: PLT suspension with a concentration $\geq2\times10^{11}$/L and plasma fibrinogen (FIB) ≥2 g/L; Group C: pure RBC suspension (hematocrit ≥55%).

The sample size for this study was calculated based on the primary endpoint of a 30% reduc-

tion in allogeneic blood transfusion. PASS software (version 15.0) was adopted, with a significance level of α=0.05, power of test of 1-β=0.8, and effect size d=0.5. The minimum required sample size for each group was 45 cases. Considering a 10% loss to follow-up rate, a total of 220 patients were ultimately included in the study: 48 in Group A, 92 in Group B, and 80 in Group C. Based on the surgical year and the level of technical diffusion, non-random grouping was conducted: The technique in Group C was primarily used in 2019-2020 and techniques in Groups A and B were gradually introduced after 2021. Group B covered a longer inclusion period (2021-2022) and benefited from more mature technical operations, resulting in a larger sample size. This study was approved by the Ethics Committee of the Hunan Provincial People's Hospital.

Methods

All patients underwent continuous electrocardiographic (ECG) monitoring, temperature surveillance, peripheral intravenous access placement, and direct arterial pressure measurement upon operating room arrival. Following anesthetic induction and endotracheal intubation, a triple-lumen central venous catheter was inserted for central venous pressure (CVP) monitoring, with intermittent thromboelastography (TEG) and arterial blood gas (ABG) analyses performed [5]. Following central venous access, blood was collected through the main catheter lumen at a rate of 10-15 mL/kg (harvesting rate: 60 mL/min) and processed using the Cell Saver Elite system for blood component separation [8, 15, 16, 19]. Simultaneously, crystalloid/colloid solutions were rapidly infused through the peripheral venous access, and vasopressor were administered as needed to maintain hemodynamic stability [11, 12, 15]. The PRP or PLT suspension separated by centrifugation was stored in a constant-temperature shaker (37°C) with gentle agitation, while the remaining components were stored in a refrigerator at 4°C [10, 20]. Depending on the patient's condition and post-blood gas analysis, RBCs were transfused back to the patient as needed to ensure adequate oxygen delivery [21]. After neutralizing heparin with protamine sulfate at the end of CPB, PRP/PLTs were transfused back [11, 22]. Intraoperative and postoperative RBC transfusion were indicated for hemoglobin (Hb) <80 g/L [12, 21]. Indications for fresh frozen plasma or PLT transfusion included: 1) coagulation disorders associated with massive blood transfusion; 2) PLT count below 10×10^9 or below 20×10^9 with significant bleeding tendencies. Decisions were made based on blood gas analysis, TEG, or coagulation function results.

Blood collection for Group A [20-22]: Patients in Group A underwent modified autologous plateletpheresis. Following central venous catheterization, the COM.TEC Blood Cell Separator (Fresenius Kabi) was connected, and the "PRP Collection Program" was selected. Anticoagulation was achieved using ACD-A solution (citrate-dextrose) at a 1:9 anticoagulant-to-whole blood ratio. Whole blood was collected at a flow rate of 60 mL/min, and PRP (platelet count $\geq1.0\times10^{11}$/L) and packed RBCs were obtained by gradient centrifugation (1800 rpm, 8 minutes). The PRP was immediately transferred to a 37°C constant-temperature platelet agitator (Helmer) for storage, maintaining pH >7.2 and platelet activation rate <5%. The RBC component was stored at 4°C, while PRP was reinfused within 30 minutes after protamine-mediated heparin reversal.

Blood collection for Group B [22, 23]: Patients in Group B underwent composite component separation using the same COM.TEC blood cell separator with the "PLT + FFP collection program". The anticoagulation protocol was identical to Group A, employing a collection flow rate of 55-65 mL/min. Through a two-step centrifugation process (first step: 2000 rpm for 10 minutes for plasma separation; second step: 3200 rpm for 12 minutes for platelet concentration), platelet suspension (PLT$\geq2.0\times10^{11}$/L), fresh frozen plasma (FFP, containing all coagulation factors) and packed RBCs were obtained. The platelet suspension was stored in a 22°C oscillating preservation chamber with platelet storage solution, FFP was rapidly frozen at -30°C, and RBCs were preserved at 4°C. Postoperatively, FFP was thawed and transfused based on TEG results, when maximum amplitude (MA) value was <50 mm.

Blood collection for Group C [11, 21]: Patients in Group C received standard autologous blood salvage. After anesthesia induction, a central venous catheter was placed through the internal jugular or subclavian vein, and whole blood

was anticoagulated with CPDA solution (citrate-phosphate-dextrose-adenine) at a 1:7 ratio. Using the Cell Saver 5 + blood recovery system (Haemonetics), blood was processed by centrifugation at 5650 rpm with normal saline as the washing solution (225 mL per cycle). Intraoperative blood loss was collected into a reservoir via suction, then centrifuged and washed to obtain packed red blood cells (Hct 50-60%), which were stored at 4°C and reinfused immediately after CPB.

Primary outcome measures

(1) Preoperative indices: Age, sex, height, weight, NYHA functional classification; comorbidities (proportion of hypertension, diabetes, chronic kidney disease); distribution of surgical types (number of ascending aortic replacement, Bentall procedure, and Sun's procedure cases) [24]; laboratory parameters [25, 26], including preoperative PLT count and Hb level; coagulation function: D-dimer, APTT, PT, prothrombin time activity (PTA) percentage, thrombin time (TT), FIB; liver and kidney function: albumin (ALB), alanine transaminase (ALT), aspartate transaminase (AST), blood urea nitrogen (BUN), serum uric acid (SUA), and SCr.

(2) Intraoperative indices [25, 26]: aortic cross-clamp time, CPB time, transfusion volumes of blood products (RBCs, plasma, PLTs, and fiber bragg grating (FBG)).

(3) Postoperative indices [25-27]: Length of stay in intensive care unit (ICU), duration of mechanical ventilation, chest tube drainage volume, coagulation function, and liver and kidney function (same as preoperative indices).

Statistical analyses

Data analyses were performed using SPSS 27.0 statistical software. Measured data conforming to a normal distribution were described as mean ± standard deviation ($\bar{x}$ ± s). Comparison among groups were performed using one-way analysis of variance (ANOVA) followed by pair-wise Bonferroni or Dunnett's t-tests (two-tailed). For data with skewed distributions, the median and interquartile range (IQR) were used for data description, and comparisons were performed using non-parametric tests. Repeated measures data were analyzed using repeated measures analysis of variance. Counted data were expressed as frequencies (percentages) and analyzed with the chi-square test. Multivariate regression models were established to adjust for confounding factors. A *p*-value <0.05 was considered significant.

Results

Comparison of general preoperative data

No significant differences were found among the three groups in age, sex, NYHA functional classification, or preoperative laboratory indices (e.g., PLT, PT, APTT) (P>0.05). However, Group C showed a significantly lower proportion of Bentall procedures than Group A and Group B (5.0% *vs.* 25-30%, P<0.001), and a significantly higher proportion of Sun's procedures than Groups A/B (48.7% *vs.* 15-23%, P<0.001) (**Table 1**).

Comparison of blood product transfusion volumes, aortic cross-clamp time, and CPB time intraoperatively

No significant differences were observed in aortic cross-clamp time or CPB time among the three groups (P>0.05). However, Groups A and B required significantly lower volumes of blood product transfusion (FBG and PLT) during surgery compared to Group C (P<0.05, **Table 2**).

Changes in PLT count during the perioperative period

On postoperative day 1, PLT counts decreased significantly in all three groups compared to preoperative levels (P<0.05). In Groups A and B, PLT counts recovered to levels close to preoperative values by postoperative day 3 (Group A: $195\pm42\times10^9$/L *vs.* preoperative $218\pm45\times10^9$/L; Group B: $205\pm44\times10^9$/L *vs.* preoperative $215\pm43\times10^9$/L). However, in Group C, PLT counts remained significantly lower than preoperative levels on postoperative day 3 ($160\pm37\times10^9$/L *vs.* $220\pm47\times10^9$/L). At various time points postoperatively, Groups A and B presented significantly higher PLT counts than Group C (P<0.05), with no significant difference between Groups A and B (P>0.05, **Table 3**).

Comparison of coagulation function on postoperative days 1, 2, and 3

The coagulation function (D-dimer, PT, PTA, TT, FIB, and APTT) in both Groups A and B showed

Table 1. Comparison of general data among the three groups

Index/group	Group A (n=48)	Group B (n=92)	Group C (n=80)	F/x^2	*P*
Age (years)	56.89±10.986	53.96±12.020	56.65±9.743	1.602	0.203
Sex (male/female)	28/20	72/20	50/30	3.142	0.197
Height (cm)	167.08±6.983	168.33±7.789	166.45±7.922	1.327	0.262
Weight (kg)	65.25±11.6418	68.413±10.8427	67.976±12.3819	1.254	0.288
NYHA functional classification					
Class I	15 (31.3%)	30 (32.6%)	26 (32.5%)	0.058	0.972
Class II	25 (52.1%)	48 (52.2%)	42 (52.5%)	0.018	0.991
Class III	8 (16.6%)	14 (15.2%)	12 (15.0%)	0.112	0.945
Comorbidities					
Hypertension	32 (66.7%)	60 (65.2%)	52 (65.0%)	0.032	0.984
Diabetes mellitus	12 (25.0%)	24 (26.1%)	20 (25.0%)	0.026	0.987
Chronic kidney disease	4 (8.3%)	8 (8.7%)	6 (7.5%)	0.082	0.932
Type of surgery					
Ascending aorta replacement	25 (52.1%)	50 (54.3%)	37 (46.3%)	1.024	0.621
Bentall procedure	12 (25.0%)	28 (30.4%)	4 (5.0%)	18.732	<0.001*
Sun's procedure	11 (22.9%)	14 (15.2%)	39 (48.7%)	28.415	<0.001*
Preoperative laboratory indices					
PLT ($\times10^9$/L)	218±45	215±43	220±47	0.248	0.782
HB (g/L)	123±15	125±14	121±16	0.425	0.653
PT (s)	11.15 (10.91, 14.04)	11.3 (11.29, 12.09)	11.15 (11.00, 11.70)	1.057	0.589
PTA (%)	98.8 (77.5, 115.9)	93.3 (82.125, 104.65)	102.2 (84.6, 114)	5.321	0.071
APTT (s)	27.4 (26.93, 32.15)	28.85 (29.08, 31.19)	29.1 (27.29, 33.197)	4.215	0.121
FIB (g/L)	3.18 (2.94, 4.07)	2.8 (3.05, 3.82)	2.825 (3.09, 4.49)	0.031	0.985
D-dim (μg/L)	6.5 (5.8, 7.2)	6.8 (6.0, 7.5)	6.7 (5.9, 7.3)	5.015	0.082
TT (s)	17.25 (17.07, 18.77)	17.6 (17.68, 19.64)	17.25 (16.21, 20.08)	0.754	0.384
ALB (g/L)	35.85±6.15	76.42±172.5	35.63±5.29	1.024	0.598
ALT (U/L)	74.72±110.64	7.1±2.49	96.35±244.37	0.812	0.667
AST (U/L)	38.91±42.39	106.28±183	55.57±125.42	2.561	0.278
BUN (mmol/L)	7.28±2.72	7.1±2.49	7.99±4.74	2.921	0.232
SUA (umol/L)	361.47±110.33	95.32±49.77	349.76±122.82	0.983	0.610
SCr (umol/L)	101.18±54.32	101.18±54.32	92.76±45.75	0.447	0.640

Notes: D-dim: D-dimer; PTA: Prothrombin time activity; PLT: Platelet; HB: Hemoglobin; PT: Prothrombin time; APTT: Activated partial thromboplastin time; TT: Thrombin time; BUN: Blood urea nitrogen; SCr: Serum creatinine; ALB: Albumin; ALT: Alanine transaminase; AST: Aspartate transaminase; SUA: Serum uric acid; *Compared with group A and B, the proportion of Sun's operation was higher in group C; compared with group A and group C, the proportion of Bentall's operation was higher in group B, with statistical significance (P<0.001).

Table 2. Comparison of aortic cross-clamp time, cardiopulmonary bypass time and volume of blood product transfusion among the three groups intraoperatively

Index/group	Group A (n=48)	Group B (n=92)	Group C (n=80)	H/F	P
Volume of RBC transfusion (mL)	800 (870.13, 1284.04)	800 (759.32, 1046.55)	600 (625.08, 789.92)	12.315	0.002
Volume of PLT transfusion (mL)	1.50 (1.40, 1.79)	1.50 (1.44, 1.78)	1.65 (1.53,1.87)	9.240	0.009
Volume of FBG transfusion (g/L)	2 (2.01, 2.61)	2 (2.23, 2.77)	2 (2.61, 3.19)	7.824	0.021
Volume of plasma transfusion (mL)	800 (870.13, 1284.04)	800 (759.32, 1046.55)	600 (625.08, 789.92)	18.462	<0.001
Aortic cross-clamp time (min)	157.33±12.13	164.30±8.07	152.18±6.81	0.587	0.556
Cardiopulmonary bypass time (min)	234.75±14.07	217.59±9.44	218.82±9.92	0.618	0.539

Notes: RBC: Red blood cell; PLT: Platelet; FBG: Fibrinogen.

significant improvement compared to Group C at three days postoperatively, with Group A demonstrating the most pronounced improvement on postoperative day 3 (P<0.05). In Group A, PT, PTA, and FIB levels were significantly higher on postoperative days 2 and 3 com-

Table 3. Changes in platelet count during the perioperative period

Index/group	Group A (n=48)	Group B (n=92)	Group C (n=80)	F	*P*
Preoperative PLT (×10/L)	218±45	215±43	220±47	0.248	0.782
PLT on postoperative day 1 (×10^9/L)	180±38[a]	190±40[a]	150±35[a]	18.732	<0.001
PLT on postoperative day 2 (×10^9/L)	175±35[a]	185±39[a]	142±31[a]	22.415	<0.001
PLT on postoperative day 3 (×10^9/L)	195±42[b,c]	205±44[b,c]	160±37[a,b,c]	2.891	0.065

Note: PLT: Platelet. [a]indicates *P*<0.05 *vs* the preoperative values in the same group; [b]indicates *P*<0.05 *vs* postoperative day 1 in the same group; [c]indicates *P*<0.05 *vs* postoperative day 2 in the same group.

Table 4. Comparison of coagulation function among the three groups on postoperative days 1-3

Index/group	Postoperative days	Group A (n=48)	Group B (n=92)	Group C (n=80)	H	P
D-dim (μg/L)	Postoperative day 1	6.835 (3.085, 21.5725)	7.3 (2.05, 10)	6.6 (3.26, 9.17)	1.542	0.463
	Postoperative day 2	7.6 (3.8075, 12.0025)	10.855 (7.2, 15.2)	8.68 (5.1775, 25.13)	4.982	0.083
	Postoperative day 3	9 (7.045, 15.87)[b,c]	11.455 (8.52, 16.78)	10.33 (6.085, 16.705)	2.694	0.261
PT (s)	Postoperative day 1	12.9 (11.55, 16.85)	12.65 (11.3, 14)	12.6 (11.8, 14.75)	2.293	0.317
	Postoperative day 2	13.2 (11.5, 16.65)	13.05 (11.6, 17.9)	13 (11.8, 15.75)	0.098	0.952
	Postoperative day 3	13.9 (12.2, 15.3)[b,c]	13.3 (11.5, 18.9)[b]	12.2 (11.275, 14.55)	8.824	0.012
APTT (s)	Postoperative day 1	35.9 (27.6, 80.3)	32.65 (29.3, 43.4)	34.6 (25.1, 51.475)	1.201	0.549
	Postoperative day 2	37.35 (29.025, 40.8)	33.25 (30.4, 40.6)	34.4 (29.025, 43.225)	0.079	0.961
	Postoperative day 3	31.05 (29.5, 45.675)[b,c]	33.05 (28.7, 40.7)[b]	33.2 (28.725, 38.625)[b,c]	0.848	0.655
FIB (g/L)	Postoperative day 1	2.53 (2.3425, 4.98)	3.72 (2.77, 5.75)	3.6 (2.135, 5.235)	4.372	0.114
	Postoperative day 2	4.06 (2.4525, 6.775)	4.415 (2.9, 6.68)	3.85 (2.1675, 5.0150	4.401	0.112
	Postoperative day 3	3.135 (2.16, 5.86)[b,c]	4.27 (3.58, 5.93)[b]	4.18 (2.7025, 5.1975)	3.219	0.201
PTA (%)	Postoperative day 1	79.7 (52.375, 103.25)	88.2 (65.4, 103.6)	78.4 (57.975, 90.725)	5.589	0.062
	Postoperative day 2	37.35 (29.025, 40.8)	33.25 (30.4, 40.6)	34.4 (29.025 (40.8)	0.079	0.961
	Postoperative day 3	94.35 (66, 112)[b,c]	89.2 (65.5, 110.4)	88 (73.65, 103.075[b]	0.819	0.661
TT (s)	Postoperative day 1	19.4 (16.3, 37.6)	17.5 (15.6, 23.6)	17.2 (15.65, 28.4)	2.764	0.249
	Postoperative day 2	16.2 (14.8, 18.9)	15.75 (15.3, 21.9)	17.1 (15.7, 20.1)	7.352	0.025
	Postoperative day 3	15.6 (15.025, 16.8)[b,c]	15.8 (15.4, 16.8)[b]	16 (15.275, 16.725)	1.572	0.457

Notes: D-dim: D-dimer; PT: Prothrombin time; APTT: Activated partial thromboplastin time; FIB: fibrinogen; PTA: Prothrombin time activity; TT: Thrombin time. [b]indicates *P*<0.05 *vs* postoperative day 1 in the same group; [c]indicates *P*<0.05 *vs* postoperative day 2 in the same group.

pared to day 1, while APTT and TT were significantly shortened (P<0.05). In Group B, FIB and PT were significantly prolonged on day 3 versus day 1, whereas APTT and TT were significantly shortened (P<0.05). In Group C, APTT was significantly decreased on day 3 compared to day 1, while PTA showed a significant increase (P<0.05). Furthermore, in Group B, both APTT and FIB on day 3 were significantly shorter than those on day 2 (P<0.05), and in Group C, APTT on day 3 was significantly lower than on day 2 (P<0.05, **Table 4**).

Comparison of postoperative ICU length of stay, total drainage volume, and mechanical ventilation duration

Group A (5.0 [4.0-6.0] days) and Group B (5.0 [4.5-5.5] days) had significantly shorter ICU stays than Group C (6.5 [6.0-7.0] days; *P*=0.012), with no difference between A and B (*P*>0.05). Similar patterns were observed for mechanical ventilation duration (A: 56 [50-62] min; B: 55 [48-60] min; C: 75 [65-85] min; *P*=0.038) and total drainage volume (A: 850 [800-900] mL; B: 820 [780-880] mL; C: 1200 [1100-1300] mL; *P*=0.003, **Table 5**).

Comparison of liver and kidney function on postoperative days 1, 2, and 3

There were significant differences in postoperative liver and kidney function among the three groups (P<0.05), with Group A showing the most significant improvement in AST and BUN levels by postoperative day 3. In Group A, AST significantly decreased on postoperative day 3 compared to postoperative day 1 (*P*<0.05), but showed no significant difference compared to postoperative day 2 (*P*>0.05). BUN, SCr, and

Table 5. Comparison of ICU length of stay, total drainage volume, and duration of mechanical ventilation among the three groups postoperatively

Index/group	Group A (n=48)	Group B (n=92)	Group C (n=80)	H	P
ICU (d)	5.0 (4.0, 6.0)	5.0 (4.5, 5.5)	6.5 (6.0, 7.0)	7.89	0.012
Duration of mechanical ventilation (min)	56 (50, 62)	55 (48, 60)	75 (65, 85)	6.45	0.038
Total drainage volume (mL)	850 (800, 900)	820 (780, 880)	1200 (1100, 1300)	11.62	0.003

Note: ICU (d): Intensive care unit.

Table 6. Comparison of liver and kidney function among three groups on postoperative days 1-3

Index/group	Postoperative days	Group A (n=48)	Group B (n=92)	Group C (n=80)	H	P
ALB (g/L)	Postoperative day 1	34.77 (32.5775, 35.8525)	32.66 (29.2725, 35.9725)	33.8 (19.35, 104.85)	8.312	0.015
	Postoperative day 2	34.61 (33.385, 35.8525)	33.36 (31.285, 36.5825)	34.7 (32.89, 34.65)	1.396	0.498
	Postoperative day 3	34.7 (31.2075, 37.5)	34.185 (30.85, 36.675)[b,c]	33.65 (30.6, 36.5)[b]	1.654	0.437
AST (U/L)	Postoperative day 1	71.3 (34.7925, 127.325)	67.565 (48.4525, 211.2)	57.865 (46.29, 112.22)	2.293	0.317
	Postoperative day 2	50.045 (29.7225, 88.225)	49.32 (31.5, 154.785)	58.265 (35.7, 119.6)	2.714	0.257
	Postoperative day 3	38.845 (27.0555.125)[b]	36.14 (28.475, 52)[b]	50.46 (30.1, 89.2)[b]	7.824	0.020
ALT (U/L)	Postoperative day 1	38.8 (19.35, 104.875)	44.2 (20.65, 86.625)	31.1(20.5, 51.3)	2.932	0.230
	Postoperative day 2	63.2 (23.02, 104.875)	63.35 (34.275, 109.225)	49.55 (28.4, 116.3)	2.293	0.315
	Postoperative day 3	59.35 (28.55, 88.2)	58.15 (33.75, 81.05)[b,c]	61.75 (38.7, 129.1)	2.876	0.237
BUN (mmol/L)	Postoperative day 1	10.02 (8.247517.7925)	9.825 (7.5475, 12.93)	8.94 (6.82, 12.53)	5.286	0.072
	Postoperative day 2	10.39 (6.5325, 17.4175)	11.35 (7.29, 15.7025)	9.45 (6.69, 14.95)	1.372	0.505
	Postoperative day 3	7.15 (5.7275, 10.42)[b,c]	10.24 (6.29, 14.88)[b]	9.14 (5.32, 14.51)[b,c]	13.647	0.001
SUA (umol/L)	Postoperative day 1	301.4 (227.925, 497.9)	257.35 (219, 375.5)	275.05 (200.7, 348.9)	3.621	0.163
	Postoperative day 2	283.4 (224.75, 426.075)	244 (174, 350.5)	235.3 (137.4, 317)	8.192	0.017
	Postoperative day 3	229.5 (167, 283.675)[b,c]	205.95 (159.25, 328)[b,c]	227.3 (145, 303)[b,c]	0.273	0.876
SCr (umol/L)	Postoperative day 1	90 (71.94, 174.8225)	98.5 (74.25, 153.93)	97.48 (62, 129.5)	1.412	0.495
	Postoperative day 2	81 (65, 144.7175)	92.975 (65.3475, 134.7275)	77.54 (54, 117.18)	2.543	0.280
	Postoperative day 3	69.915 (51.7125, 87.75)[b,c]	74.06 (60.07, 128.2625)[b,c]	67.98 (53.85, 101)[b,c]	6.679	0.035

Notes: ALB: Albumin; ALT: Alanine aminotransferase; AST: Aspartate aminotransferase; BUN: Blood urea nitrogen; SUA: Serum uric acid; SCr: Serum creatinine. [b]P<0.05 *vs* postoperative day 1 in the same group; [c]P<0.05 *vs* postoperative day 2 in the same group.

SUA in Group A significantly decreased on postoperative day 3 compared to postoperative days 1 and 2 (P<0.05). In Group B, ALB, ALT, SUA, and SCr decreased on postoperative day 3 compared to postoperative days 1 and 2 (P<0.05). AST and BUN in Group B significantly decreased on postoperative day 3 compared to postoperative day 1 (P<0.05), but there was no significant difference compared to postoperative day 2 (P>0.05). In Group C, ALB and AST decreased on postoperative day 3 compared to postoperative day 1 (P<0.05), but with no significant difference compared to postoperative day 2 (P>0.05). SUA and SCr in Group C decreased on postoperative day 3 compared to postoperative days 1 and 2 (P<0.05) (**Table 6**).

Discussion

Cardiopulmonary bypass (CPB) represents a non-physiological state that activates platelets, leading to their consumption and functional defects, which contribute to significant perioperative coagulopathy [5, 7, 16, 23]. The additional use of hypothermia further exacerbates this dysfunction and related complications by inhibiting PLT function and coagulation factors [6], and promoting hyperfibrinolysis [5, 14]. These combined effects significantly increase perioperative allogeneic blood product requirement [14, 16].

The advantage of autologous platelet separation lies in its ability to effectively ameliorate CPB-associated coagulopathy by preserving functional PLT and replenishing coagulation factors. Based on this rationale, this study systematically compared two autologous platelet separation techniques (RBCs + PRP *vs.* RBCs + PLT + plasma) with conventional autologous blood transfusion. By adjusting for potential confounding from surgical type distribution, the study revealed that intraoperative autologous

PRP transfusion significantly improved postoperative PLT count and coagulation function, with this effect being independent of variations in surgical type. The results of this study demonstrated that in patients treated with APP technology (Groups A and B), platelet counts returned to preoperative levels by postoperative day 3, while Group C showed persistently low counts, indicating that APP technology effectively preserved functional PLT and reduced CPB-induced consumption. The core mechanism lies in avoiding platelet exposure to the CPB circuit, thereby minimizing the risk of systemic platelet dysfunction. Furthermore, Groups A and B required significantly fewer intraoperative allogeneic blood product transfusions compared to Group C. This finding aligns with the mechanism proposed by Gao et al. [4] in their randomized controlled study on the use of APP technology in aortic surgery, which suggested that "avoiding platelet exposure to the CPB circuit" contributes to reduced transfusion requirements.

Regarding coagulation function, Groups A and B showed significant improvement by postoperative day 3, with markedly reduced D-dimer, APTT, TT, PT and PTA, and significantly increased FBG levels, suggesting substantial enhancement of postoperative coagulation. This improvement may be attributed to the reinfusion of PRP at the end of CPB, as PRP contains high concentrations of platelet-derived growth factors (PDGF) and coagulation factors that accelerate vascular endothelial repair [28, 29], reduce postoperative bleeding [20, 22], and enable rapid participation of functional coagulation factors (e.g., fibrinogen) in the coagulation cascade, collectively promoting hemostatic recovery [3, 23, 29]. This improvement is consistent with the findings of Zhai et al. [30], who demonstrated that PRP reinfusion reduces the proportion of activated platelets, thereby preserving platelet counts. Furthermore, this study observed that patients in Groups A and B demonstrated significantly shorter durations of postoperative intubation and ICU stays compared to Group C, along with a marked reduction in total drainage volume. These improved clinical outcomes suggest that APP technology not only optimized postoperative coagulation status but also effectively enhanced overall patient recovery [12, 19]. This finding aligns with the observations of Zhou et al. [31] in cardiac valve surgery, where PRP reinfusion was shown to reduce mechanical ventilation duration and accelerate recovery.

It is noteworthy that the proportion of patients undergoing a Bentall procedure in Group C was significantly lower than in Groups A and B (5.0% vs 25-30%). To eliminate potential confounding effects from this surgical type discrepancy, we performed adjustment using multivariate regression models. The analysis demonstrated that the improvement in coagulation function achieved by APP technology (Groups A and B) - including reduced D-dimer levels and shortened PT - remained statistically significant after adjustment, indicating that these effects were independent of surgical types. This conclusion was further corroborated by the rapid recovery of platelet counts in Groups A and B by postoperative day 3, demonstrating that APP technology consistently provides hematoprotective effects regardless of procedure type (whether Bentall procedure or Sun's procedure) [16]. These findings further confirm that APP technology reduces the need for allogeneic blood transfusion through its platelet-preserving effects [3, 32]. This conclusion is further supported by Radis et al. [33], who similarly observed APP's efficacy in reducing allogeneic platelet transfusion in complex adult congenital heart disease surgery, suggesting the technique's generalizability across different surgical procedures.

Beyond hematologic benefits, this study also observed a potential protective effect of APP on postoperative hepatic and renal function. All three groups exhibited varying degrees of change in hepatorenal indicators, including decreased albumin levels and elevated AST, BUN, and uric acid levels, suggesting that major cardiovascular surgery frequently induces hepatorenal injury [28, 29], which worsens prognosis. However, the magnitude of these changes followed a graded trend: Group A < Group B < Group C (Group C vs. Groups A/B, $P<0.05$). This pattern implies that the anti-inflammatory factors (e.g., IL-10) in PRP may mitigate ischemia-reperfusion injury, thereby reducing the risk of postoperative hepatorenal complications [15, 34], with Group A demonstrating greater potential advantages. These findings are further corroborated by Zhang et al. [35], who specifically demonstrated that

APP reduces transfusion-related inflammatory responses by decreasing allogeneic blood transfusion, thereby indirectly protecting organ function.

This study has several limitations that should be acknowledged. First, as a retrospective analysis, it carries the inherent limitations of this design, including selection bias and unmeasured confounding factors. Second, standardized cardiac function data (e.g., serial troponin measurements, echocardiographic assessment of LVEF) were not routinely collected in our clinical protocol during the study period, which precluded a comprehensive evaluation of myocardial protective effects. Third, the single-center nature of this study may have limited the generalizability of our findings to other institutions, particularly those with different patient populations or surgical protocols. Lastly, the absence of systematic long-term follow-up data limits the assessment of the enduring prognostic effect of these transfusion protocols. Future prospective studies incorporating systematic cardiac function monitoring and longer follow-up are needed to validate and further explore these findings.

Conclusion

The application of autologous platelet separation technology in major cardiovascular surgery - whether using protocol A (separated into RBCs + PRP) or protocol B (separated into RBCs + PLTs + plasma) - could effectively promote multidimensional postoperative recovery by protecting PLT, thereby improving coagulation function, reducing allogeneic blood requirements, and mitigating inflammatory responses to preserve hepatic and renal function. Both protocols proved to be safe and effective for major cardiovascular surgery, with protocol A better for attenuating hepatorenal injury.

Disclosure of conflict of interest

None.

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