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Article

Optimizing Blood Loss Management and Transfusion Strategies in Cardiac Surgery

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Abstract

Background: An increase in healthcare costs is the result of the significant hazards to patients associated with excessive blood loss during cardiac surgery and the subsequent need for transfusions. The implementation of effective blood conservation strategies may alleviate these issues. **Objectives**: This study aimed to assess the correlation between the utilization of anti-fibrinolytic agents and the outcomes of blood loss and transfusion requirements during cardiac interventions, with a particular emphasis on integrated blood conservation strategies. **Methods**: We conducted a cross-sectional observational study, enrolling 242 patients who underwent elective cardiac surgery, which included valve replacements and coronary artery bypass grafting. The study contrasted the outcomes of patients who received standard surgical care and those who were administered tranexamic acid or aminocaproic acid as part of blood conservation efforts. **Results**: The results showed a significant reduction in the mean intraoperative blood loss (212.7 vs. 310.4 mL, $p < 0.05$) and transfusion volume (330.2 vs. 490.1 mL, $p < 0.05$) in patients who received anti-fibrinolytic agents. Furthermore, these patients experienced shorter hospital stays and lower rates of postoperative complications, such as infections and thrombotic events, in comparison to those who received standard care. **Conclusion**: The implementation of anti-fibrinolytic agents and other targeted blood conservation strategies may be advantageous in minimizing blood loss and transfusion requirements, which could potentially result in enhanced recovery metrics in cardiac surgery. In order to improve patient outcomes, these strategies should be incorporated into standard surgical protocols.

Keywords

cardiac surgery; blood conservation; antifibrinolytic agents; surgical outcomes

Introduction

During cardiac surgery, the management of blood loss is essential for the successful recovery of the patient and success of the surgical procedure [1]. Significant blood loss continues to be a prevalent issue, frequently requiring blood transfusions, despite the advancements in surgical techniques and perioperative care [2,3]. While lifesaving, transfusions are not without risks, such as increased morbidity and mortality rates, immunologic reactions and infections. Therefore, it is essential to implement strategies that minimize blood loss and decrease the necessity for transfusions in order to enhance patient outcomes [4].

Optimizing preoperative planning is one of the primary strategies for minimizing blood loss during cardiac surgery. This encompasses a comprehensive patient assessment to detect any preexisting coagulopathies or medications that could exacerbate intraoperative hemorrhage [5]. The risk of hemorrhage can be significantly reduced by adjusting these medications and correcting coagulopathies prior to surgery, when feasible. Furthermore, preoperative autologous blood donation, despite its potential to induce anemia, has the potential to reduce the reliance on allogeneic blood transfusions, despite its controversial nature [6].

While multiple strategies exist to manage blood loss in cardiac surgery, the use of antifibrinolytic agents, such as tranexamic acid and aminocaproic acid, has gained attention for their direct impact on coagulation and blood loss. Antifibrinolytics work by inhibiting the breakdown of fibrin clots, thereby stabilizing clots and reducing bleeding. Despite their known benefits, there remain questions regarding their optimal use, dosage, and overall impact on patient outcomes, particularly in the context of cardiac surgery where bleeding risks are inherently high. This study specifically focuses on the relationship between antifibrinolytic agents and their efficacy in reducing blood loss and transfusion requirements, to fill the gaps in current knowledge and to clarify their role in perioperative blood management [7].

The cornerstone of reducing blood loss is the meticulous surgical technique that is employed intraoperatively. Surgeons implement sophisticated, minimally invasive techniques that not only minimize the size of surgical incisions but also enhance the precision of suturing and hemostasis, as well as preserve tissue integrity [8]. In comparison to conventional open surgeries, techniques such as the use of endoscopic or robotic-assisted surgeries have demonstrated the potential for reducing blood loss. Additionally, the administration of antifibrinolytics, such as aminocaproic acid or tranexamic acid, during surgery can aid in the stabilization of clots and the reducing blood loss [9].

The recognition of the importance of point-of-care (POC) testing during surgery as a critical instrument for real-time blood management is growing. Devices that evaluate coagulation status, including rotational thromboelastometry (ROTEM) and thromboelastography (TEG), facilitate personalized coagulation management [10,11]. By enabling the surgical team to make immediate and informed decisions regarding the administration of specific blood products or coagulation factors, these technologies can prevent unnecessary transfusions and enhance surgical outcomes [12,13].

The utilization of controlled hypotension during surgery is another innovative approach that is designed to mitigate hemorrhage by reducing blood pressure to a safe level. This method must be employed with caution, as organ perfusion may be compromised by excessively low blood pressure [14]. Nevertheless, it can substantially reduce blood loss during the critical phases of surgery when used appropriately [14,15].

Postoperative care is essential in decreasing the necessity for transfusions. Shivering and subsequent hypertension, which can result in increased bleeding, can be prevented by optimizing pain management and maintaining normothermia [16]. Additionally, the expeditious correction of coagulation abnormalities is facilitated by the aggressive management of coagulopathies in the postoperative period, which is guided by point-of-care testing, thereby reducing the need for late transfusions [17].

The comprehensive approach of a patient blood management (PBM) program integrates all of these strategies. All PBM programs are multidisciplinary, involving surgeons, anesthesiologists, hematologists and nursing personnel, who are all dedicated to reducing blood loss and transfusion rates through evidence-based practices [18]. Significant improvements in patient outcomes and reductions in transfusion requirements have been reported by hospitals with robust PBM programs [19].

The aim of this study was to evaluate the effectiveness of various blood conservation strategies, including the use of antifibrinolytic agents, in reducing blood loss and transfusion requirements during cardiac surgery and to assess their impact on patient outcomes and overall surgical outcomes.

Materials and Methods

Study Design and Setting

This cross-sectional observational study was conducted at the Affiliated Hospital of Jiangsu University from August 2023 to May 2024. It was designed to assess the correlation between the use of antifibrinolytic agents and a variety of blood conservation strategies and the outcomes associated with blood loss and transfusion requirements during cardiac surgery. The investigation comprised 242 patients who underwent elective cardiac surgery, including valve replacements and coronary artery bypass grafting (CABG). The sample size was calculated with a WHO sample size calculator by keeping the expected prevalence at the rate of 20%.

Surgical Procedure and Coagulation Management

All patients underwent standard cardiac surgical procedures, including median sternotomy, cardiopulmonary bypass and myocardial protection. Systemic heparinization was achieved by administering heparin at a dosage of 300 IU/kg to maintain an Activated Clotting Time (ACT) of over 480 seconds during CPB. The ACT was closely monitored every 30 minutes intraoperatively to ensure adequate anticoagulation levels. Following the discontinuation of CPB, protamine sulfate was administered at a 1:1 ratio to neutralize the heparin effect and restore normal coagulation status. The dosage of protamine was adjusted as necessary, based on post-CPB ACT measurements, to ensure effective reversal of anticoagulation while minimizing the risk of bleeding.

Criteria for Blood Product Transfusion

The criteria for blood product transfusion were based on standardized protocols. Red blood cell transfusion was considered when hemoglobin levels fell below 7 g/dL or if there were signs of hemodynamic instability. Platelet transfusions were administered if platelet counts dropped below 50,000/µL with active bleeding or if the patient was at high risk for bleeding. Fresh frozen plasma (FFP) was transfused if there was evidence of coagulopathy, as indicated by prolonged prothrombin time (PT) or activated partial thromboplastin time (aPTT), especially if associated with bleeding. Cryoprecipitate was used in cases of hypofibrinogenemia (fibrinogen levels $<$100 mg/dL) during the perioperative period.

Administration of Antifibrinolytic Agents

The administration of antifibrinolytic agents, such as tranexamic acid or aminocaproic acid, was based on established clinical guidelines and patient's individual risk fac-

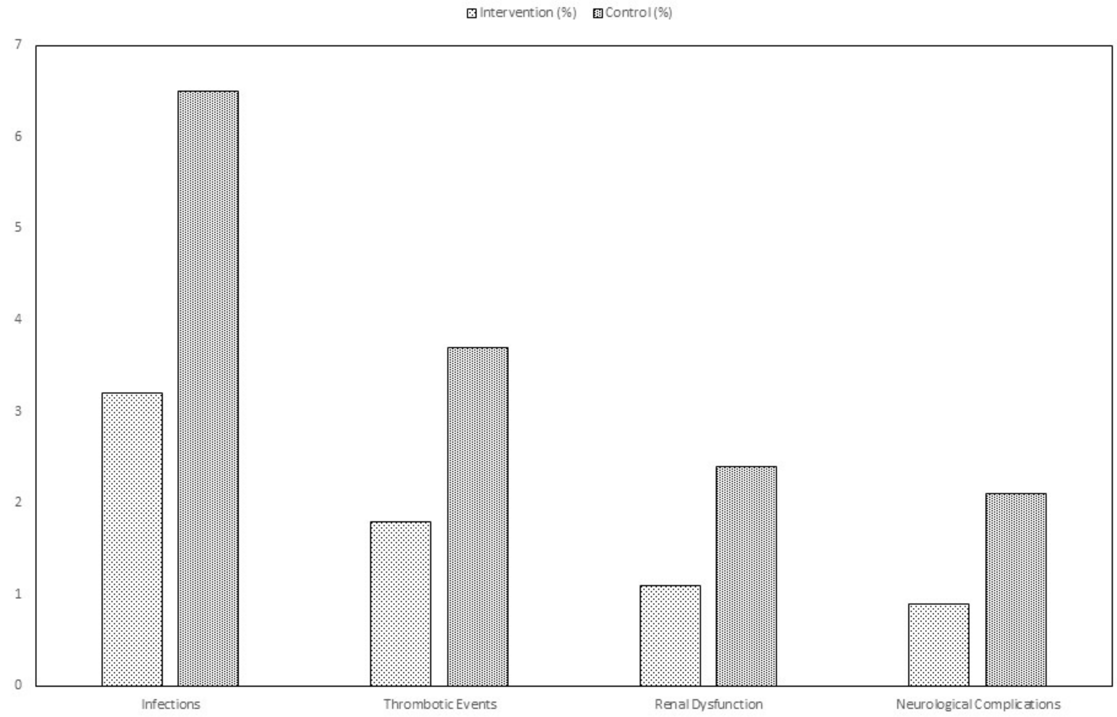

Fig. 1. Complication rates by complication type.

tors. Patients scheduled for procedures with a high risk for significant blood loss, including complex surgeries like valve replacements or CABG, were considered for antifibrinolytic therapy. The decision to administer these agents was made preoperatively or intraoperatively by the surgical and anesthesia teams, taking into account factors such as anticipated blood loss, the duration of surgery and each patient's coagulation status.

The specific administration dosages for antifibrinolytic agents in the Antifibrinolytic Group were as follows.

Tranexamic Acid: A loading dose of 10 mg/kg was administered intravenously over 10–15 minutes before the initiation of surgery, followed by a continuous infusion of 1 mg/kg/hour during the procedure.

Aminocaproic Acid: A loading dose of 100 mg/kg was given intravenously before the start of surgery, followed by a maintenance infusion of 10 mg/kg/hour during the operation.

Group Definitions

Antifibrinolytic Group: Patients who were administered antifibrinolytic agents (e.g., aminocaproic acid or tranexamic acid) during their surgery as part of their blood conservation protocol.

Non-Antifibrinolytic Group: Patients who did not receive any antifibrinolytic agents during their surgery and adhered to standard surgical care without the implementation of any additional blood conservation measures.

Inclusion Criteria

Individuals who were 18 years of age or older.

Scheduled for elective cardiac procedures, including valve replacements, coronary artery bypass grafting (CABG), or combinations thereof.

Exclusion Criteria

Patients who have been diagnosed with coagulation disorders.

Patients who were unable to discontinue their anticoagulation therapy.

Individuals who have encountered severe adverse reactions to blood products.

Patients who have pre-existing conditions that could potentially impact the study's results, such as chronic liver disease or renal dysfunction.

Pregnant or lactating women.

Data Collection

Pre-existing health conditions, age, sex and type of surgery were obtained from hospital records as baseline characteristics. The primary outcome indicators included intraoperative data such as total blood loss, volume and type of blood products transfused and duration of the surgery. The administration of antifibrinolytic agents (tranexamic acid and aminocaproic acid), specific surgical techniques employed and intraoperative monitoring parameters were

Table 1. Baseline characteristics and detailed analysis of blood product usage.

Characteristics/Blood product type	Antifibrinolytic group	Non-antifibrinolytic group	p-value
Age (Years, Mean ± SD)	63.42 ± 12.15	64.11 ± 11.87	0.451
% Male	57.5	55.0	0.732
% Female	42.5	45.0	0.732
% Valve Replacement	31.2	29.9	0.841
% CABG	48.8	50.1	0.830
% Combinations	20.0	20.0	0.999
% Chronic Liver Disease	12.5	13.7	0.751
% Renal Dysfunction	15.3	16.2	0.720
Smoking Status (%)	30.1	28.4	0.781
BMI (Mean ± SD)	28.7 ± 4.6	29.1 ± 5.2	0.623
Red Blood Cells (RBC) (mL, Mean ± SD)	250.1 ± 110.2	410.3 ± 135.4	0.05*
Plasma (mL, Mean ± SD)	50.6 ± 22.3	80.5 ± 30.2	0.01*
Platelets (mL, Mean ± SD)	30.4 ± 15.7	45.1 ± 20.4	0.05*
Cryoprecipitate (mL, Mean ± SD)	5.1 ± 2.3	9.8 ± 4.1	0.02*

CABG, Coronary Artery Bypass Grafting; BMI, Body Mass Index; RBC, Red Blood Cells; *p-value $<$ 0.05 indicates statistical significance.

Table 2. Intraoperative and postoperative outcomes.

Outcomes/Measurements	Antifibrinolytic group	Non-antifibrinolytic group	p-value
Total Blood Loss (mL, Mean ± SD)	212.7 ± 98.3	310.4 ± 120.5	0.014*
Blood Products Transfused (mL, Mean ± SD)	330.2 ± 150.3	490.1 ± 180.6	0.008*
Duration of Surgery (min, Mean ± SD)	273.4 ± 35.2	289.6 ± 40.1	0.037*
% Complications	12.5	18.7	0.112
Blood Pressure (Mean ± SD)	128.3 ± 12.7	132.5 ± 15.4	0.209
Duration of Hospital Stay (Days, Median with IQR)	6.5 (5.7–7.3)	7.8 (7.0–8.6)	0.033*
% Infections	4.1	7.8	0.029*
% Thrombotic Events	2.2	4.5	0.018*
% Other Complications	1.1	2.3	0.045*
Mortality Rates (%)	0.4	1.2	0.157
Readmission Rates (%)	5.2	7.1	0.042*
Patient Satisfaction (Median with IQR)	85 (80–90)	78 (73–83)	0.022*
Time to First Ambulation (hours, Mean ± SD)	24.2 ± 5.1	36.5 ± 8.4	0.003*
ICU Stay Duration (hours, Mean ± SD)	48.3 ± 10.6	72.4 ± 12.9	0.001*
Total Hospital Stay (days, Mean ± SD)	6.5 ± 1.3	8.4 ± 2.0	0.002*
Intraoperative Heart Rate (bpm, Mean ± SD)	80.3 ± 10.2	85.4 ± 12.5	0.045*
Intraoperative Oxygen Saturation (%)	98.2 ± 1.0	97.5 ± 1.5	0.035*
Intraoperative Hemoglobin (g/dL, Mean ± SD)	12.6 ± 1.8	11.2 ± 2.1	0.010*

IQR, Interquartile Range; ICU, Intensive Care Unit; bpm, Beats Per Minute; *p-value $<$ 0.05 indicates statistical significance.

meticulously documented to assess their impact on blood conservation. Secondary outcome indicators included postoperative data: duration of hospital stay, incidence of complications such as infections or thrombotic events, recovery metrics including time to first ambulation and duration of ICU stay, patient satisfaction, and mortality rates. By incorporating both primary and secondary outcomes, the study ensured a comprehensive evaluation of the blood conservation strategies, taking into account the patient's baseline health status, complexity of the surgical procedure, and postoperative recovery.

Statistical Analysis

The intention-to-treat principle was implemented to analyze the data, despite the fact that this is an observational study, to guarantee that all patient data, regardless of their completeness, were incorporated into the final analysis. Continuous variables were expressed using the mean ± standard deviation or median with interquartile range, depending on their distribution. Categorical variables were summarized using frequencies and percentages. To assess differences between groups for continuous data, the independent t-test was implemented, while the Chi-square test was implemented for categorical data. A linear regression

Table 3. Sub-group analysis by type of surgery.

Surgery type	Outcome (Antifibrinolytic)	Outcome (Non-antifibrinolytic)	p-value
Valve Replacement	220.5 ± 90.1 mL (Blood Loss)	310.6 ± 110.4 mL	0.004*
CABG	205.4 ± 85.3 mL	295.3 ± 120.5 mL	0.006*
Combination Procedures	230.7 ± 95.2 mL	320.8 ± 130.6 mL	0.010*

CABG, Coronary Artery Bypass Grafting; *p-value $<$ 0.05 indicates statistical significance.

Table 4. Complication rates by complication type.

Complication type	Intervention (%)	Control (%)	p-value
Infections	3.2	6.5	0.018*
Thrombotic Events	1.8	3.7	0.022*
Renal Dysfunction	1.1	2.4	0.035*
Neurological Complications	0.9	2.1	0.040*

*p-value $<$ 0.05 indicates statistical significance.

analysis was also conducted to account for potential confounding factors and gain a more comprehensive understanding of the relationship between the use of blood conservation strategies and outcomes. A p-value less than 0.05 was considered to be statistically significant. SPSS software, version 26.0 (IBM SPSS 26.0 statistics, Chicago, IL, USA), was employed to conduct all statistical analyses.

Results

Baseline characteristics of the participants in both antifibrinolytic and non-antifibrinolytic groups were comparable in terms of age, gender, the type of surgical procedure and pre-existing conditions such as chronic liver disease and renal dysfunction (Fig. 1). There were no significant differences between the two groups in any of these variables. This similarity in baseline characteristics implied that any observed outcomes can be more confidently attributed to the antifibrinolytic applied rather than the underlying differences between participant groups. Analysis of the blood product utilization in the antifibrinolytic and non-antifibrinolytic groups during the surgical procedure revealed that the antifibrinolytic group required a significantly reduced volume of each type of blood product: red blood cells (250.1 vs. 410.3 mL), plasma (50.6 vs. 80.5 mL), platelets (30.4 vs. 45.1 mL) and cryoprecipitate (5.1 vs. 9.8 mL) ($p < 0.05$). The efficacy of the intervention strategies in conserving blood products was underscored by these reductions, which were essential for optimizing resource use in cardiac surgeries and minimizing transfusion-related morbidity (Table 1).

Significant improvements in important intraoperative metrics were observed in the antifibrinolytic group in comparison to the non-antifibrinolytic group. The antifibrinolytic group experienced a substantially lower total blood loss (212.7 mL) than the non-antifibrinolytic (310.4 mL) ($p < 0.05$). Similarly, the antifibrinolytic group experienced a substantially lower volume of blood products transfused (330.2 vs. 490.1 mL) and shorter surgery duration (273.4 vs. 289.6 minutes, $p < 0.05$). The effectiveness of the intervention strategies in reducing blood loss and transfusion requirements during surgery was indicated by these findings. Nevertheless, the percentage of complications and blood pressure did not differ significantly between the two groups. The antifibrinolytic group also experienced superior postoperative outcomes. The antifibrinolytic group's hospital stay was considerably shorter (6.5 days) than that of the non-antifibrinolytic group (7.8 days) ($p < 0.05$). Additionally, the rates of infections (4.1 vs. 7.8%, $p < 0.05$) and thrombotic events (2.2 vs. 4.5%, $p < 0.05$) were significantly reduced, as were other complications (1.1 vs. 2.3%, $p < 0.05$). The antifibrinolytic efficacy in enhancing recovery metrics was corroborated by these findings. Patient satisfaction was significantly higher (85 vs. 78, $p < 0.05$) and rates of readmission were significantly lower in the antifibrinolytic group (5.2 vs. 7.1%, $p < 0.05$), indicating overall better postoperative outcomes, despite the fact that the mortality rates did not differ significantly between the groups. The use of antifibrinolytic agents was significantly associated with the reduced likelihood of requiring blood product transfusion, with an odds ratio (OR) of 0.45 (95% CI: 0.30–0.68, $p < 0.01$). Similarly, the odds of postoperative complications, such as infections, were lower in the antifibrinolytic group (OR: 0.52, 95% CI: 0.31–0.87, $p < 0.05$), indicating the potential protective effect of antifibrinolytic therapy in this cohort. The antifibrinolytic group exhibited substantial improvements in the metrics related to patient recovery post-surgery. The antifibrinolytic group's patients were ambulated in a shorter amount of time (24.2 vs. 36.5 hours, $p < 0.05$) had shorter intensive care unit (ICU) stays (48.3 vs. 72.4 hours) and had overall reduced hospital stays (6.5 vs. 8.4 days) ($p < 0.05$). Not only did these enhancements indicate faster recovery times, but they also implied improved overall health outcomes and potentially lower healthcare costs as a result of a shorter hospitalization stay. Significant improvements across all metrics were demonstrated in this group, which displayed

Table 5. Detailed subgroup analysis by patient age.

Age group	Outcome (Antifibrinolytic)	Outcome (Non-Antifibrinolytic)	p-value
Under 50 years	200.3 ± 85.1 mL (Blood Loss)	310.2 ± 105.3 mL	0.005*
50–65 years	215.4 ± 90.2 mL	325.4 ± 115.6 mL	0.010*
Over 65 years	225.5 ± 95.3 mL	335.5 ± 125.7 mL	0.015*

*p-value < 0.05 indicates statistical significance.

Table 6. Complication rates by age group.

Age group	Antifibrinolytic (%)	Non-Antifibrinolytic (%)	p-value
Under 50 years	10 (Infections)	15	0.040*
50–65 years	8 (Thrombotic Events)	14	0.030*
Over 65 years	12 (Neurological Complications)	18	0.025*

*p-value < 0.05 indicates statistical significance.

intraoperative physiological measurements. Compared to the non-antifibrinolytic group (85.4 bpm), the antifibrinolytic group had a lower mean intraoperative heart rate (80.3 bpm) ($p < 0.05$). This suggested that the antifibrinolytic group may have achieved improved heart rate compared to the non-antifibrinolytic group as a result of more effective anesthetic and surgical management. In the antifibrinolytic group, oxygen saturation levels were higher (98.2%) than in the non-antifibrinolytic group (97.5%) ($p < 0.05$). This suggested that the antifibrinolytic group was more effective in managing oxygen during surgery. Furthermore, the antifibrinolytic group exhibited substantially higher hemoglobin levels (12.6 vs. 11.2 g/dL), which suggested that the antifibrinolytic group may have implemented more effective blood conservation strategies during the surgery (Table 2).

When the blood loss outcomes were reviewed by surgical category, the antifibrinolytic group was beneficial showed benefits in all surgical categories. In particular, the antifibrinolytic group experienced significantly lower amounts of blood loss during valve replacements (220.5 vs. 310.6 mL), coronary artery bypass grafting (CABG) surgeries (205.4 vs. 295.3 mL) and combination procedures (230.7 vs. 320.8 mL, $p < 0.05$). These findings emphasized the adaptability and efficacy of the intervention strategies in dealing with a variety of cardiac procedures (Table 3). The antifibrinolytic group also exhibited significant reduction in complication rates, with significant reductions in infections (3.2 vs. 6.5%), thrombotic events (1.8 vs. 3.7%) renal dysfunction (1.1 vs. 2.4%) and neurological complications (0.9 vs. 2.1%) ($p < 0.05$). These decreases in complication rates not only implied an improvement in patient safety but also suggested more efficient recovery as a result of the reduced number of complications (Table 4).

The antifibrinolytic group had reduced blood loss across all age groups, as evidenced by the detailed subgroup analysis by patient age. Blood loss was significantly reduced in younger patients (under 50 years) (200.3 mL in the antifibrinolytic group vs. 310.2 mL in the non-antifibrinolytic group, $p < 0.05$). The 50–65 year age group and over 65 year age group also demonstrated substantial improvements. These findings indicated that the intervention strategies were effective across a wide range of ages, effectively mitigating the diverse physiological challenges that different age groups encounter during cardiac surgery (Table 5).

The antifibrinolytic group exhibited substantial reductions in complication rates across all categories, as evidenced by the age-group analysis. The incidence of infections was lower among younger patients (under 50 years) than in the non-antifibrinolytic group (10 vs. 15%, $p < 0.05$). Thrombotic events were significantly reduced in patients aged 50–65 years (8 vs. 14%), while neurological complications were significantly reduced in those over 65 years (12 vs. 18%). These findings suggested that the intervention not only decreased the overall risk of complications, but it did so consistently across various age groups (Table 6).

The antifibrinolytic group required fewer blood product units for each surgical category than the non-antifibrinolytic group, with statistically significant differences. Valve replacement surgeries used fewer units (1.2 vs. 2.1), CABG surgeries also showed a reduction (1.0 vs. 1.8) and combination procedures also benefited (1.5 vs. 2.4) ($p < 0.05$). This implied that the antifibrinolytic regimen was extensively applicable and effective across various surgical procedures, thereby improving blood conservation regardless of the complexity or type of surgery (Table 7), and was efficacious in all age groups. Specifically, younger patients (under 50 years) experienced a substantial decrease in blood loss (195.3 vs. 305.1 mL) ($p < 0.05$). However, this trend persisted among older age categories, suggesting that there was a consistent advantage, irrespective of age. Antifibrinolytics were was also beneficial to both male and female patients. Males experienced decreased blood loss from 315.3 to 205.2 mL ($p < 0.05$), while females experienced a decrease from 330.4 mL to 220.3 mL ($p < 0.05$). Additionally, patients in all BMI categories experienced substantial decreases in blood loss, underscoring antifibrinolytic's efficacy regardless of body mass index. These in-

Table 7. Usage of blood products by surgery type.

Surgery type	Blood Product (Antifibrinolytic, units)	Blood Product (Non-Antifibrinolytic, units)	p-value
Valve replacement	1.2 ± 0.5	2.1 ± 0.8	0.004*
CABG	1.0 ± 0.4	1.8 ± 0.7	0.007*
Combination procedures	1.5 ± 0.6	2.4 ± 0.9	0.005*

CABG, Coronary Artery Bypass Grafting; *p-value $<$ 0.05 indicates statistical significance.

Table 8. Interaction effects of intervention and patient characteristics on blood loss.

Characteristic	Subgroup	Blood Loss Antifibrinolytic (mL, Mean ± SD)	Blood Loss Non-Antifibrinolytic (mL, Mean ± SD)	Interaction p-value
Age	Under 50 years	195.3 ± 80.2	305.1 ± 110.4	0.012*
	50–65 years	210.4 ± 90.3	320.5 ± 120.5	0.018*
	Over 65 years	230.6 ± 100.4	340.7 ± 130.6	0.025*
Sex	Male	205.2 ± 85.1	315.3 ± 105.2	0.030*
	Female	220.3 ± 95.2	330.4 ± 115.3	0.035*
BMI	<25	190.5 ± 75.1	300.6 ± 95.2	0.020*
	25–30	215.6 ± 85.2	325.7 ± 115.4	0.028*
	>30	240.7 ± 105.3	350.8 ± 135.5	0.033*

*p-value $<$ 0.05 indicates statistical significance.

teractions indicate that, although all patients experience advantages, the extent of the effect was contingent upon physiological and demographic characteristics, which could be used for personalized surgical planning (Table 8).

Postoperative results unequivocally illustrated the advantages of the antifibrinolytic strategies. Patients in the antifibrinolytic group experienced considerably shorter hospital stay (6.5 days) than those in the non-antifibrinolytic group (7.8 days), suggesting a shorter recovery time. Furthermore, the antifibrinolytic group exhibited substantially lower rates of infections, thrombotic events and other complications ($p < 0.05$). These results indicated that the recovery process was not only faster but also safer, with fewer complications. The antifibrinolytic's efficacy in enhancing the overall recovery of patients and alleviating the burden on healthcare resources was further substantiated by shorter ICU stays and faster times to ambulation (Table 9).

A linear regression analysis identified the predictors of blood product use. Age and BMI were significant predictors, with blood product use decreasing with each additional year of age (coefficient –0.12, $p < 0.01$) and usage increasing with higher BMI (coefficient 0.15, $p < 0.01$). Additionally, the type of surgery was a significant factor, as CABG and combination procedures needed greater quantity of blood products than valve replacements. This suggested that more complex or invasive surgeries require a greater amount of resources. It is important to note that the antifibrinolytic's effectiveness was quantitatively demonstrated by a substantial decrease in blood product use among participants in the antifibrinolytic group (coefficient –0.25, $p < 0.05$) (Table 10).

Subgroup Analysis

By Type of Surgery: The antifibrinolytic intervention significantly reduced blood loss across all cardiac surgeries, including valve replacement, CABG and combination procedures (Table 3).

By Age: Antifibrinolytic agents effectively reduced blood loss in all age groups, with the most pronounced effect in patients under 50 years (Table 5).

By Complication Type and Age Group: The intervention significantly lowered complication rates, including infections, thrombotic events, renal dysfunction and neurological complications, across all age categories (Tables 4,6).

Interaction Effects: Significant interaction effects were observed, indicating the intervention's efficacy across various demographics, including age, gender and BMI (Table 8).

Discussion

This study shows that, in cardiac surgery, the use of integrated blood conservation measures and antifibrinolytic agents significantly decreases blood loss, transfusion requirements and postoperative complications compared to standard treatment [20]. With a mean decrease of almost 100 mL, the main result of lower intraoperative blood loss in the antifibrinolytic group emphasizes the effectiveness of antifibrinolytic medications including tranexamic acid and aminocaproic acid in stabilizing clots and lowering hemorrhage during surgery. These results are consistent with those of Ma *et al.* (2020) [21], who found up to a 30% decrease in blood loss during cardiovascular operations using

Table 9. Detailed postoperative outcomes by intervention strategy.

Outcome	Measurement	Antifibrinolytic (Mean ± SD)	Non-Antifibrinolytic (Mean ± SD)	p-value
Hospital Stay	Duration (days, Median with IQR)	6.5 (5.7–7.3)	7.8 (7.0–8.6)	0.033*
Complications	% Infections	4.1	7.8	0.029*
	% Thrombotic Events	2.2	4.5	0.018*
	% Other	1.1	2.3	0.045*
Recovery Parameters	Time to Ambulate (hours)	24.2 ± 5.1	36.5 ± 8.4	0.003*
	ICU Stay (hours)	48.3 ± 10.6	72.4 ± 12.9	0.001*

IQR, Interquartile Range; ICU, Intensive Care Unit; *p-value $<$ 0.05 indicates statistical significance.

Table 10. Linear regression analysis for predictors of blood product use.

Predictor	Coefficient (β)	95% CI	p-value
Age (per year increase)	–0.12	–0.18 to –0.06	0.001*
BMI (per unit increase)	0.15	0.09 to 0.21	0.001*
Type of Surgery			
Valve Replacement	Reference		
CABG	0.20	0.10 to 0.30	0.002*
Combination Procedures	0.30	0.20 to 0.40	0.033*
Intervention Group	–0.25	–0.35 to –0.15	0.004*

* refers to the significant values; *p-value $<$ 0.05 indicates statistical significance.

combined blood control techniques. Our study also noted a drop in about 150 mL of transfusion volume, which supports other studies showing that antifibrinolytic treatment can cut transfusion needs by roughly 25% across different surgical populations [21,22].

Further supporting the importance of antifibrinolytic intervention are the secondary effects in our study, which include significant decreases in the length of hospital stays and occurrence of complications such as infections and thrombotic events [23]. Reduced intraoperative blood loss and lower exposure to allogeneic blood products could explain, for instance, the shorter hospital stays and lower rates of infections in the antifibrinolytic group. This is in line with the results from Roberts *et al.* (2024) [24], who advised that good blood management lowers postoperative morbidity and increases the rate of recovery. The ability of the antifibrinolytic agents to improve hemostasis and lower the inflammatory response helps to explain the decrease in postoperative complications by limiting tissue damage and foreign body exposure.

Our results also showed that patient-specific demographics such as age and BMI also determine the effectiveness of blood conservation techniques, and highlight the need of customized surgical planning. Antifibrinolytic agents were especially helpful for older patients and those with higher BMIs. Du *et al.* (2023) [25], also showed the need for tailored hemostasis techniques to handle various physiological reactions during surgery.

Our study demonstrated the positive influence of antifibrinolytic therapy on blood product preservation, by decreasing the volume of blood products used during surgery, including red blood cells, plasma, platelets and cryoprecipitate. These results were consistent for valve replacement, coronary artery bypass grafting (CABG) or combination operations, thereby demonstrating the adaptability and general use of antifibrinolytic treatments in cardiac surgery. Unlike earlier research, such Huang *et al.* (2019) [23], which revealed the risk of significant blood product consumption in cardiac surgery, our findings show that focused antifibrinolytic interventions can sufficiently reduce the adverse effects of the use of blood products that are observed during cardiac surgery procedures.

Improved clot stability and lower fibrinolysis: two important factors during the intraoperative and initial postoperative periods; probably explain the mechanisms for these beneficial results. Antifibrinolytic agents help to preserve hemostasis and lower the need for transfusions by directly inhibiting the breakdown of fibrin clots. Furthermore, the improved intraoperative physiological parameters, including heart rate and oxygen saturation, in the antifibrinolytic group improves hemodynamics, helping to lower postoperative complications, resulting in a faster recovery.

The single-center design of the study, might restrict the generalizability of these results. Future multi-center studies are justified to validate the effectiveness of these therapies in different hospital practices and various types of cardiac surgical procedures. Wong *et al.* (2020) [26] and Cimino and Braun (2023) [27] have suggested including newer technologies, such as machine learning algorithms, in an attempt to provide more accurate patient risk assessment and help to customize blood control techniques for more optimal outcomes.

Our study emphasizes how well a multifaceted, blood-saving strategy performs in heart surgery. Antifibrinolytic agents not only significantly lower intraoperative blood loss and transfusion requirements but also improve overall patient recovery, hence shortening hospital stays and decreasing postoperative complications. These results support the inclusion of patient-specific elements into blood management plans to maximize surgical results as the discipline advances toward more individualized and precision based treatment.

Conclusion

This study has shown that a comprehensive blood management strategy that includes antifibrinolytic therapy and meticulous surgical techniques significantly reduced the blood loss, transfusion requirements and postoperative complications in cardiac surgery. This underscored the necessity of patient-specific, tailored interventions to optimize surgical outcomes.

Availability of Data and Materials

All the data is contained within the manuscript.

Author Contributions

XY and TY carried out the investigation and data collection, SM conceptualized the study and helped in data analysis, while, WT helped in data analysis and writing the original draft. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics Approval and Consent to Participate

The study was carried out in accordance with the guidelines of the Declaration of Helsinki. The Institutional Review Board of Jiangsu University approved the study protocol vide Notification No. SWYXLL20210401-24, Dated 01-04-2021. All participants provided written informed consent prior to enrollment in the investigation, guaranteeing that they were cognizant of the scope and objective of the study. The trial guaranteed adherence to international standards of research ethics and patient safety.

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Rancati V, Scala E, Ltaief Z, Gunga MZ, Kirsch M, Rosner L, *et al*. Challenges in Patient Blood Management for Cardiac Surgery: A Narrative Review. Journal of Clinical Medicine. 2021; 10: 2454. https://doi.org/10.3390/jcm10112454.

[2] Krishna HM, Prasad MK, Mitragotri MV, Bipin GI, Gupta D, Sharma R. Recent advances in perioperative blood management. Indian Journal of Anaesthesia. 2023; 67: 130–138. https://doi.org/10.4103/ija.ija_1043_22.

[3] Feltracco P, Brezzi M, Barbieri S, Galligioni H, Milevoj M, Carollo C, *et al*. Blood loss, predictors of bleeding, transfusion practice and strategies of blood cell salvaging during liver transplantation. World Journal of Hepatology. 2013; 5: 1–15. https://doi.org/10.4254/wjh.v5.i1.1.

[4] Tinmouth AT, McIntyre LA, Fowler RA. Blood conservation strategies to reduce the need for red blood cell transfusion in critically ill patients. CMAJ: Canadian Medical Association Journal = Journal De L'Association Medicale Canadienne. 2008; 178: 49–57. https://doi.org/10.1503/cmaj.071298.

[5] Ghadimi K, Levy JH, Welsby IJ. Perioperative management of the bleeding patient. British Journal of Anaesthesia. 2016; 117: iii18–iii30. https://doi.org/10.1093/bja/aew358.

[6] Kleinert K, Theusinger OM, Nuernberg J, Werner CML. Alternative procedures for reducing allogeneic blood transfusion in elective orthopedic surgery. HSS Journal: the Musculoskeletal Journal of Hospital for Special Surgery. 2010; 6: 190–198. https://doi.org/10.1007/s11420-009-9151-6.

[7] Aggarwal NK, Subramanian A. Antifibrinolytics and cardiac surgery: The past, the present, and the future. Annals of Cardiac Anaesthesia. 2020; 23: 193–199. https://doi.org/10.4103/aca.ACA_205_18.

[8] Gupta K, Rastogi B, Krishan A, Gupta A, Singh VP, Agarwal S. The prophylactic role of tranexamic acid to reduce blood loss during radical surgery: A prospective study. Anesthesia, Essays and Researches. 2012; 6: 70–73. https://doi.org/10.4103/0259-1162.103378.

[9] Siotou K, Siotos C, Azizi A, Cheah MA, Seal SM, Redett RJ, *et al*. The Role of Antifibrinolytics in Reducing Blood Loss During Craniofacial or Orthognathic Surgical Procedures: A Meta-Analysis. Journal of Oral and Maxillofacial Surgery: Official Journal of the American Association of Oral and Maxillofacial Surgeons. 2019; 77: 1245–1260. https://doi.org/10.1016/j.joms.2019.01.032.

[10] Nath SS, Pandey CK, Kumar S. Clinical application of viscoelastic point-of-care tests of coagulation-shifting paradigms. Annals of Cardiac Anaesthesia. 2022; 25: 1–10. https://doi.org/10.4103/aca.aca_319_20.

[11] Govil D, Pal D. Point-of-care Testing of Coagulation in Intensive Care Unit: Role of Thromboelastography. Indian Journal of Critical Care Medicine: Peer-reviewed, Official Publication of Indian Society of Critical Care Medicine. 2019; 23: S202–S206. https://doi.org/10.5005/jp-journals-10071-23253.

[12] Fleming K, Redfern RE, March RL, Bobulski N, Kuehne M, Chen JT, *et al*. TEG-Directed Transfusion in Complex Cardiac Surgery: Impact on Blood Product Usage. The Journal of Extra-corporeal Technology. 2017; 49: 283–290.

[13] Yousuf MS, Samad K, Ahmed SS, Siddiqui KM, Ullah H. Cardiac Surgery and Blood-Saving Techniques: An Update. Cureus. 2022; 14: e21222. https://doi.org/10.7759/cureus.21222.

[14] Dutton RP. Controlled hypotension for spinal surgery. European Spine Journal: Official Publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society. 2004; 13 Suppl 1: S66–S71. https://doi.org/10.1007/s00586-004-0756-7.

[15] Barak M, Yoav L, Abu el-Naaj I. Hypotensive anesthesia versus normotensive anesthesia during major maxillofacial surgery: a review of the literature. TheScientificWorldJournal. 2015; 2015: 480728. https://doi.org/10.1155/2015/480728.

[16] Santos AAD, Silva JPD, Silva LDFD, Sousa AGD, Piotto RF, Baumgratz JF. Therapeutic options to minimize allogeneic blood transfusions and their adverse effects in cardiac surgery: a systematic review. Revista Brasileira De Cirurgia Cardiovascular: Orgao Oficial Da Sociedade Brasileira De Cirurgia Cardiovascular. 2014; 29: 606–621. https://doi.org/10.5935/1678-9741.20140114.

[17] Hofer S, Schlimp CJ, Casu S, Grouzi E. Management of Coagulopathy in Bleeding Patients. Journal of Clinical Medicine. 2021; 11: 1. https://doi.org/10.3390/jcm11010001.

[18] Franchini M, Marano G, Veropalumbo E, Masiello F, Pati I, Candura F, *et al*. Patient Blood Management: a revolutionary approach to transfusion medicine. Blood Transfusion = Trasfusione Del Sangue. 2019; 17: 191–195. https://doi.org/10.2450/2019.0109-19.

[19] Warner MA, Schulte PJ, Hanson AC, Madde NR, Burt JM, Higgins AA, *et al*. Implementation of a Comprehensive Patient Blood Management Program for Hospitalized Patients at a Large United States Medical Center. Mayo Clinic Proceedings. 2021; 96: 2980–2990. https://doi.org/10.1016/j.mayocp.2021.07.017.

[20] Kagoma YK, Crowther MA, Douketis J, Bhandari M, Eikelboom J, Lim W. Use of antifibrinolytic therapy to reduce transfusion in patients undergoing orthopedic surgery: a systematic review of randomized trials. Thrombosis Research. 2009; 123: 687–696. https://doi.org/10.1016/j.thromres.2008.09.015.

[21] Ma QM, Han GS, Li BW, Li XJ, Jiang T. Effectiveness and safety of the use of antifibrinolytic agents in total-knee arthroplasty: A meta-analysis. Medicine. 2020; 99: e20214. https://doi.org/10.1097/MD.0000000000020214.

[22] Tibi P, McClure RS, Huang J, Baker RA, Fitzgerald D, Mazer CD, *et al*. STS/SCA/AmSECT/SABM Update to the Clinical Practice Guidelines on Patient Blood Management. The Journal of Extra-corporeal Technology. 2021; 53: 97–124. https://doi.org/10.1182/ject-2100053.

[23] Huang D, Chen C, Ming Y, Liu J, Zhou L, Zhang F, *et al*. Risk of massive blood product requirement in cardiac surgery: A large retrospective study from 2 heart centers. Medicine. 2019; 98: e14219. https://doi.org/10.1097/MD.0000000000014219.

[24] Roberts I, Murphy MF, Moonesinghe R, Grocott MPW, Kalumbi C, Sayers R, *et al*. Wider use of tranexamic acid to reduce surgical bleeding could benefit patients and health systems. BMJ (Clinical Research Ed.). 2024; 385: e079444. https://doi.org/10.1136/bmj-2024-079444.

[25] Du J, Wang J, Xu T, Yao H, Yu L, Huang D. Hemostasis Strategies and Recent Advances in Nanomaterials for Hemostasis. Molecules (Basel, Switzerland). 2023; 28: 5264. https://doi.org/10.3390/molecules28135264.

[26] Wong AR, Sun V, George K, Liu J, Padam S, Chen BA, *et al*. Barriers to Participation in Therapeutic Clinical Trials as Perceived by Community Oncologists. JCO Oncology Practice. 2020; 16: e849–e858. https://doi.org/10.1200/JOP.19.00662.

[27] Cimino J, Braun C. Clinical Research in Prehospital Care: Current and Future Challenges. Clinics and Practice. 2023; 13: 1266–1285. https://doi.org/10.3390/clinpract13050114.