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Original article

Optimizing Preoperative Blood and Blood Component Preparation in Patients Undergoing Aortic Surgery at a University Hospital

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Abstract

Objective: This study evaluated the efficacy of preoperative blood preparation and transfusion practices for patients undergoing aortic surgery.

Material and Methods: This retrospective descriptive study included adult patients who underwent aortic surgery between 2018 and 2022. The focus was on preoperative blood preparation and transfusions within 24 hours. Optimal blood ordering was defined by established indices, including the crossmatch-to-transfusion (C/T) ratio (< 2.0), transfusion probability (%T > 30), and transfusion index (Ti > 0.5).

Results: A total of 504 patients were included. The average number of packed red cell units (PRC) prepared was 4.99, with an average of 2.34 units transfused. Only 1,180 of the 2,515 (46.93%) PRC units prepared were used. The overall C/T ratio, %T, and Ti were 2.13, 66.27%, and 2.34, respectively, reflecting inappropriate utilization and excessive preparation. However, most surgeries demonstrated appropriate blood use, except for the EVAR, TEVAR, and TAR procedures, which showed inappropriate blood preparation, with C/T ratios of 2.28, 3.43, and 2.85, respectively. Among elective surgeries, the C/T ratio, %T, and Ti were 2.61, 56.07%, and 1.6, respectively, indicating inappropriate blood use. In emergency surgeries, the C/T ratio, %T, and Ti were 1.76, 84.15%, and 3.63, respectively, indicating appropriate blood preparation.

Conclusion: Overall, preoperative PRC preparation in aortic surgery was demonstrated to be inappropriate. EVAR, TEVAR, and TAR procedures showed excessive PRC preparation. In contrast, PRC preparation for emergency aortic surgery was appropriate, while elective aortic surgery continued to reflect inappropriate utilization.

Keywords: Aortic surgery, blood transfusion, preoperative blood preparation

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Introduction

Aortic surgery is a high-risk, complex procedure frequently associated with significant blood loss, surgical bleeding, and coagulopathy—particularly in complex ascending and aortic arch surgeries, where deep hypothermic circulatory arrest (DHCA) with or without cerebral perfusion is often employed[1, 2]. DHCA has been linked to kidney injury, vasoconstriction, neurologic dysfunction, bleeding, and coagulopathy.[3, 4] These patients often require the administration of blood and blood products.

Effective blood management is critical in this setting, as it directly affects surgical outcomes and resource utilization. Traditionally, blood preparation for aortic surgery involves crossmatching large volumes of blood to ensure availability during the procedure. Although advancements in surgical techniques and blood conservation strategies have reduced actual transfusion rates,[2, 5] studies suggest that routine practices often exceed the true transfusion requirements.

The COVID-19 pandemic has intensified challenges in blood management, leading to a significant decline in global blood donations. The Thai Red Cross Society reported a reduction of more than 50% in donations, resulting in blood shortages that caused delays or cancellations of elective surgeries, including aortic procedures.[6]

A previous study conducted at Srinagarind Hospital and Queen Sirikit Heart Center of the Northeast (QSHC) reported a crossmatch-to-transfusion (C/T) ratio of 3.68 for endovascular procedures, compared to 2.06 for open repairs, indicating inappropriate blood preparation for certain surgical interventions.[7] This discrepancy increases the workload for blood bank staff, strains resources needed for other patients, and drives up healthcare costs.

To reduce unnecessary blood wastage, medical centers should adopt blood-conserving strategies such as a maximum surgical blood ordering schedule (MSBOS), which predicts expected transfusion needs based on procedure type and helps optimize blood preparation.[8, 9] This study evaluated the effectiveness of routine preoperative blood preparation and transfusion practices in patients undergoing aortic surgery at Srinagarind Hospital and Queen Sirikit Heart Center of the Northeast.

Materials and Methods

This retrospective descriptive study was approved by the Center for Ethics in Human Research, Khon Kaen University (HE 661322). Written informed consent was waived due to the retrospective and anonymous nature of the study. Data were collected at Khon Kaen

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University's Srinagarind Hospital and Queen Sirikit Heart Center of the Northeast (QSHC) from January 2018 to December 2022.

All adult patients (aged >18 years) who underwent aortic surgery at Srinagarind Hospital and QSHC were included, regardless of whether the procedures were elective or emergent. Patients undergoing aortic surgery with additional procedures, such as valve replacement or coronary artery bypass grafting (CABG), were excluded. Patients with missing data were also omitted. The study focused on preoperative blood preparation, actual blood use on the day of surgery, and postoperative transfusion within 24 hours.

Throughout the study period, clinical and anesthetic management protocols remained standardized to minimize variability. The transfusion threshold for packed red cells (PRC) was consistently based on a restrictive strategy, typically triggered at a hemoglobin level of <8.0 g/dL, or < 10.0 g/dL in the presence of severe hemodynamic instability or active myocardial ischemia. Anesthetic management followed standard institutional practices tailored to each surgical approach. Intraoperative cell salvage was routinely utilized in all open repairs and complex endovascular cases to minimize allogeneic blood consumption. Importantly, no major changes in these institutional policies occurred during the data collection period.

After receiving Ethics Committee approval, medical records were retrospectively reviewed. Collected data included patient demographics (age, gender, American Society of Anesthesiologists (ASA) physical status, body weight, height), diagnosis, type of operation, preoperative hematocrit and coagulation profile, number of preoperative blood crossmatch units, intraoperative blood loss (mL), intraoperative blood transfusion (units), operative time, cardiopulmonary bypass time, lowest body temperature, use of DHCA, crystalloid volume (mL), colloid volume (mL), cell salvage volume (mL), postoperative hematocrit and coagulation profile, and 24-hour postoperative blood transfusion in the intensive care unit (ICU) (units).

To account for the substantial differences in anticipated bleeding risk and physiological demands, the recorded surgical procedures were stratified into three distinct subgroups for comparative and predictive analysis: Endovascular (e.g., EVAR, TEVAR), Simple Open (e.g., open abdominal or peripheral aneurysm repair), and Complex Open (e.g., Total Arch Replacement, Thoracoabdominal Repair).

The appropriateness of blood preparation was evaluated using three criteria: the C/T ratio, a widely accepted indicator for evaluating blood ordering practices which reflects the

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efficiency of crossmatching relative to actual transfusion; transfusion probability (%T), calculated as (number of patients transfused × 100) / number of patients crossmatched, indicating the likelihood of transfusion for a given procedure; and the transfusion index (Ti), calculated as the number of units transfused divided by the number of patients crossmatched, representing the average number of units used per case. Effective blood usage was defined as a C/T ratio < 2.0, Ti > 0.5, and %T > 30. [10, 11] The maximum surgical blood ordering schedule (MSBOS) was calculated using Mead's criterion: 1.5 × Ti.[12]

Blood preparation costs were calculated using the standard institutional fee of 450 Thai Baht (THB) per unit of packed red cells (PRC). This fee covers all blood bank processing, including ABO/Rh typing, antibody screening, crossmatching, and short-term storage. The cost of "unused blood" was defined as the total processing fees incurred for crossmatched units that were returned to the blood bank.

Sample Size Calculation

Based on a literature review examining the optimization of routine preoperative crossmatching for elective cardiothoracic surgery,[7] the calculated sample size for this study was 141 participants. Accounting for a 10% dropout rate, the final required sample size was determined to be 157 participants.

Statistical Analysis

All data were analyzed using STATA version 18. Categorical variables were presented as numbers and percentages (%) and analyzed using the Chi-square test or Fisher's exact test. Continuous variables were reported as mean ± standard deviation (SD) or median with interquartile range (IQR). Normality was assessed using the Shapiro-Wilk test. Normally distributed data were analyzed using an independent t-test, while non-normally distributed data were analyzed using the Mann-Whitney U test. To identify independent predictors of blood transfusion requirements, a multivariable logistic regression analysis was performed. Due to the high incidence of transfusion in certain surgical subgroups leading to near-perfect prediction, Firth's penalized likelihood logistic regression was utilized to reduce bias and provide stable adjusted odds ratios (aORs). A P-value <0.05 was considered statistically significant.

Results

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A total of 504 patients were enrolled in the study, including 321 elective surgeries and 183 emergency surgeries. Demographic and baseline characteristics are presented in **Table 1**. The overall median age was 69 years, with a male predominance (74.21%). The median weight was 60 kg, and the majority of patients were classified as ASA physical status III (67.66%). The median baseline hematocrit was 33.85%. Patients in the emergency group had significantly lower baseline hematocrit levels and prolonged coagulation times compared to the elective group. The median operative duration was 290 minutes. Ninety-seven patients (19.25%) underwent open aortic surgery using cardiopulmonary bypass, with an average bypass time of 211.32 ± 64.79 minutes. Surgeries were categorized into two groups: predominantly endovascular procedures (388 patients, 76.98%) and open aortic surgeries (116 patients, 23.02%). The most common procedure overall was endovascular surgery. Among open surgeries, the most frequently performed operation was total arch replacement with frozen elephant trunk (TAR with FET), accounting for 6.55% of cases.

Table 1 Demographic and baseline characteristics of the patients who underwent aortic surgery (n= 504)

Table 2 presents the data on blood and blood component preparation for all patients undergoing aortic surgery. Among these patients, 334 patients (66.27%) required transfusions during surgery or within 24 hours postoperatively. A total of 2,515 units of PRC were prepared, with 1,180 units (46.93%) transfused. Similarly, 2,343 units of fresh frozen plasma (FFP) were prepared, with 694 units (29.62%) transfused. The average number of PRC units prepared per case was 4.99, while the average number transfused was 2.34, as shown in **Figure 1**. The calculated C/T ratios were 2.13 for PRC and 3.38 for FFP, indicating inappropriate utilization. In contrast, the C/T ratios for platelets and cryoprecipitate were 1.52 and 0.7, respectively, reflecting appropriate usage.

Table 2 Blood component utilization indices in patients undergoing aortic surgery (n=504)

Figure 1 Average number of blood and blood components crossmatched and transfused (units per case)

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PRC preparation for open aortic surgeries was generally appropriate, with a C/T ratio of 1.62, %T of 97.41, and Ti of 5.27 **(Table 3).** However, total arch replacement (TAR) showed higher values, with a C/T ratio of 2.85, %T of 100, and Ti of 3.42, indicating over-preparation despite universal transfusion. On average, 8.52 units of PRC were prepared per open surgery case, with 61.84% of the prepared units actually transfused. In contrast, excessive blood preparation was observed across all endovascular procedures, with a C/T ratio of 2.68, %T of 56.96, and Ti of 1.47. An average of 3.94 PRC units were prepared per case, with a transfusion rate of 37.26%. Among elective surgeries, the C/T ratio, %T, and Ti were 2.61, 56.07%, and 1.6, respectively, indicating inappropriate blood use. For emergency surgeries, the overall C/T ratio was 1.76, indicating appropriate blood use, except in TAR and TEVAR procedures **(Table 4)**.

Table 3 PRC utilization indices in adult aortic surgery categorized by type of operation

Table 4 PRC utilization indices in adult aortic surgery categorized by elective and emergency procedures

This study demonstrates that, based on the C/T ratio, %T, and Ti, the surgeries with appropriate indications for blood reservation include aortic arch replacement, ascending aortic replacement, hemiarch replacement, open aneurysmorrhaphy, partial arch replacement, thoracoabdominal aortic replacement, and total arch replacement with frozen elephant trunk.

To address procedural heterogeneity and varying bleeding risks, preoperative blood utilization was stratified by surgical approach, procedural complexity, and urgency status (**Table 5**). The analysis revealed significant differences across all subgroups. Open aortic surgeries required significantly more prepared blood compared to endovascular procedures (mean 8.52 ± 2.25 vs. 3.94 ± 2.17 units; $p < 0.001$). Furthermore, the use of CPB or DHCA was associated with substantially higher blood demand than procedures without CPB (mean 8.70 ± 2.21 vs. 4.11 ± 2.30 units; $p < 0.001$).

Table 5 Stratified analysis of blood utilization by procedural complexity and urgency status

Importantly, the utilization indices highlighted distinct patterns of appropriateness. Blood preparation for open surgeries, procedures requiring CPB/DHCA, and emergency cases

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demonstrated appropriate utilization, with C/T ratios of 1.62, 1.80, and 1.76, respectively, and high transfusion probabilities (%T > 80%). In contrast, endovascular approaches (C/T ratio = 2.68) and elective procedures (C/T ratio = 2.61) consistently demonstrated over-preparation.

Based on the standard institutional processing fee of 450 THB per unit, the total cost of PRC preparation for all aortic surgeries (2,515 units) was 1,131,750 THB. Of this, 531,000 THB corresponded to the processing cost of the 1,180 units that were actually transfused, accounting for only 46.92% of the total financial expenditure. Consequently, the cost of unused blood representing the processing, crossmatching, and storage expenses for the 1,335 units that were prepared but not transfused amounted to 600,750 THB.

To further understand the factors associated with blood utilization, a multivariable Firth's penalized logistic regression was conducted (**Table 6**). The analysis revealed that lower baseline hemoglobin was a strong independent predictor of transfusion requirement (aOR 0.44; 95% CI 0.37–0.53, $p < 0.001$). Furthermore, emergency surgeries (aOR 2.74; 95% CI 1.53–5.05, $p < 0.001$) and procedure complexity significantly increased the odds of transfusion. Compared to endovascular procedures, simple open surgeries (aOR 26.1; 95% CI 7.09–147, $p < 0.001$) and complex open surgeries (aOR 143; 95% CI 33.0–1,358, $p < 0.001$) were associated with exceptionally higher transfusion requirements. Baseline comorbidities were not found to be independent predictors after adjusting for these primary factors.

Table 6 Multivariate logistic regression analysis for blood transfusion requirement

Discussion

Despite the complexity and typically high blood utilization associated with aortic surgeries, this study revealed a transfusion rate of only 46.93% and a C/T ratio of 2.13, indicating over-ordering. Previous studies have reported a wide range of C/T ratios, from 3.75 and 4.00 to as high as 9.00.[7, 13, 14, 15] These discrepancies may result from differences in surgical types, study population sizes, procedure urgency, geographic location, and surgical techniques.

Open aortic surgeries generally demonstrated appropriate blood preparation, with the exception of total arch replacement, which showed a higher C/T ratio (2.85). This reflects the complexity and extensive nature of the procedure, which carries a higher risk of significant blood loss and thus requires more extensive preparation. In contrast, endovascular procedures such as TEVAR and EVAR exhibited inappropriate blood use, with C/T ratios of 3.43 and

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2.28, respectively—though these values represent improvements compared to earlier reports, which noted ratios of 4.5 and 3.0.[1]

Emergency surgeries demonstrated appropriate overall blood utilization; however, the urgency of these procedures often necessitates rapid decision-making, which can result in over-preparation. This underscores the need for adequate but targeted blood preparation in emergency settings. The study supports the use of point-of-care testing and blood conservation strategies to optimize resource utilization.

The significant heterogeneity in blood utilization across different aortic procedures is primarily driven by procedural complexity. As demonstrated in our stratified analysis (Table 5), complex open surgeries, particularly CPB and DHCA, inherently carry a higher risk of systemic inflammatory response, coagulopathy, and extensive surgical trauma. This justifies the appropriately higher blood preparation observed in this group. Conversely, the minimally invasive nature of endovascular procedures results in predictably lower blood loss. The consistent over-preparation of PRC in these elective endovascular cases strongly supports transitioning from a routine crossmatching protocol to a more efficient type-and-screen strategy.

In 2018, a standardized blood preparation protocol was introduced, recommending the crossmatching of 2 units of PRC for routine EVAR and TEVAR. Despite this, the current study found that an average of 4 units continues to be prepared, resulting in consistent over-crossmatching. A previous study reported a C/T ratio as high as 11.1, reflecting significant over-preparation. In that context, only 6% of patients required transfusion, with an average intraoperative blood loss of just 200 mL—highlighting the inefficiency of current practices. The infrequency of transfusions during EVAR procedures suggests that a type-and-screen protocol may be more appropriate for routine cases. This approach would help conserve crossmatched blood for true emergencies, thereby improving overall resource management.[16, 20]

However, applying a universal type-and-screen strategy to all endovascular procedures is an overgeneralization. To ensure patient safety, this restrictive blood ordering approach must be strictly limited to uncomplicated, elective cases. Standard routine crossmatching should remain mandatory for patients meeting specific high-risk exclusion criteria. These include clinical urgency (e.g., ruptured or highly symptomatic aneurysms) and severe preoperative anemia (e.g., baseline hemoglobin < 10 g/dL). Furthermore, cases with anticipated technical complexity—such as severe iliofemoral tortuosity or calcification

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predicting difficult vascular access, redo-aortic procedures, or procedures requiring planned open surgical conduits—carry a higher risk of unexpected intraoperative bleeding and still necessitate fully crossmatched blood.

When patients were classified by surgical urgency, emergency procedures demonstrated appropriate overall blood utilization, with a C/T ratio of 1.76, %T of 84.15%, and Ti of 3.63—except in cases involving TAR and TEVAR. Emergency aortic surgeries typically involve patients in critical condition and are associated with a higher risk of significant blood loss. This study found that patients undergoing emergency procedures had lower baseline hematocrit levels and prolonged coagulation times compared to those undergoing elective surgeries, underscoring the need for adequate blood preparation in high-risk situations. However, even in emergency cases, the transfusion rate remained lower than the volume of blood prepared, indicating a tendency to overestimate transfusion requirements. The implementation of point-of-care coagulation testing may support real-time, individualized decision-making and reduce unnecessary blood preparation.[16] Additionally, blood conservation techniques—such as intraoperative cell salvage and the use of tranexamic acid—have shown effectiveness in reducing reliance on allogeneic transfusions, particularly in emergency surgical settings.[14]

Aortic surgeries are major, high-risk procedures that carry a significantly greater likelihood of requiring blood transfusions compared to other types of surgery.[2] Consequently, blood preparation for these procedures often exceeds actual transfusion needs. To address this issue, specific blood preparation guidelines have been developed for various surgical procedures. At Srinagarind Hospital and the QSHC, the Aortic Surgery Unit has established non-emergency blood preparation protocols based on the MSBOS values derived from this study. These are detailed in Appendix A, which also includes blood preparation guidelines from various international institutions.[18, 19] A comparative analysis of this study's findings reveals both differences and similarities in blood preparation practices across surgical types. However, the appropriateness of blood preparation varies between institutions and countries, influenced by multiple factors. These include the surgeon's experience, anticipated blood loss specific to the procedure, surgical technique, the severity and nature of the pathology, the use of cell salvage and point-of-care coagulation testing, and the anesthesiologist's clinical judgment and decision-making.

A key consideration in optimizing blood bank resources is ensuring that more restrictive ordering policies do not compromise patient safety. Although this study did not

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directly measure clinical outcomes such as mortality or length of stay, the shift from Type and Crossmatch(T&C) to Type and Screen(T&S) for procedures with low transfusion probability (such as elective EVAR/TEVAR) is supported by established safety protocols.

In the event of unexpected massive hemorrhage in T&S patients, institutional safety is maintained through the immediate availability of emergency uncrossmatched O-negative (or group-specific) blood, followed by abbreviated crossmatched blood, which can typically be provided within 10–15 minutes. Furthermore, reducing unnecessary crossmatching may indirectly improve patient outcomes by promoting stricter adherence to transfusion triggers. This approach potentially minimizes the risks associated with unnecessary blood product exposure, such as transfusion-associated circulatory overload (TACO) or transfusion-related acute lung injury (TRALI).

Furthermore, it is important to contextualize the definition of "inappropriate" blood preparation. Standard blood utilization thresholds (e.g., C/T ratio < 2.0, %T > 30%, Ti > 0.5) were originally derived from general surgical populations and may not fully capture the clinical realities of high-risk cardiovascular procedures. Given the inherent risk of sudden, catastrophic hemorrhage in complex open aortic surgeries, a slightly higher C/T ratio (2.0–2.5) is clinically justifiable to ensure immediate patient safety. While these traditional metrics effectively highlighted the gross over-preparation in our endovascular cohort, future institutional guidelines must interpret these indices cautiously and consider establishing specialty-specific thresholds tailored to the unique bleeding risks of aortic surgery.

This study reveals a significant misalignment between preoperative blood preparation and actual utilization in aortic surgery. Multivariable analysis identified procedural complexity, surgical urgency, and baseline hemoglobin as the primary independent predictors of transfusion. Although the near-certainty of transfusion in complex open procedures (aOR 143) necessitates intensive preparation, the high C/T ratios in EVAR and TEVAR suggest that current ordering practices for these minimally invasive procedures are often unnecessarily defensive. Adopting the T&S protocol for low-risk cases could significantly streamline blood bank operations.

Furthermore, baseline hemoglobin was identified as the key modifiable factor (aOR 0.44), with each 1 g/dL increase associated with a 56% reduction in the transfusion odds. These results establish a preliminary basis for a tailored MSBOS that accounts for procedure-specific risks. Such a data-driven approach facilitates a balance between patient safety and

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resource conservation, effectively reducing unnecessary crossmatching and institutional expenditure.

This study has several limitations. Its retrospective design may have led to incomplete data collection and a relatively small sample size, potentially affecting the accuracy and generalizability of the findings. Additionally, our study focused primarily on blood utilization indices (e.g., C/T ratio, %T) and did not correlate these practices with clinical outcomes, such as postoperative complications, mortality, or long-term survival. While this limits our ability to directly observe the impact of transfusion practices on patient recovery, our findings provide a necessary baseline for improving blood bank efficiency in aortic surgery. Furthermore, our proposed MSBOS serves as a conceptual model based on retrospective data. We acknowledge that before this schedule can be routinely implemented, a prospective 'pilot' phase—where the impact on clinical outcomes, emergency blood availability, and cost-savings are closely monitored—would be beneficial. Such future research will be essential to validate whether this data-driven approach truly reduces resource waste without compromising the immediate availability of blood products for high-risk patients. Future research should aim to develop and validate predictive models for blood utilization that incorporate patient-specific variables, such as age, comorbidities, and baseline coagulation profiles. Prospective studies comparing outcomes before and after the implementation of MSBOS could provide stronger evidence for its clinical effectiveness and utility.

Conclusion

Overall, preoperative PRC preparation for aortic surgery demonstrated a trend toward over-ordering, primarily driven by elective cases and specific procedures, such as EVAR, TEVAR, and TAR. In contrast, blood preparation for emergency aortic surgeries remained appropriate. Multivariable analysis identified baseline hemoglobin, surgical urgency, and procedural complexity as the primary independent predictors of transfusion requirements. Notably, lower baseline hemoglobin was the key modifiable factor, while complex open surgeries were associated with an exceptionally high likelihood of transfusion. These findings provide a preliminary basis for developing MSBOS tailored to aortic procedures. Implementing such a schedule has the potential to streamline blood bank efficiency and reduce unnecessary crossmatching workloads. However, further prospective studies and institutional validation are warranted to confirm the safety and effectiveness of these recommendations before they are widely adopted in clinical practice.

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Conflict of interest

There are no conflicts of interest to declare.

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Table 1 Demographic and baseline characteristics of the patients who underwent aortic surgery (n= 504)

Variables	Total (n = 504)	Elective (n = 321)	Emergency (n = 183)	p-value
Age (years); median (IQR)	69 (60, 75)	69 (61, 75)	69 (59, 77)	0.681
Male gender	374 (74.21)	249 (77.57)	125 (68.31)	0.022
Weight (kg); median (IQR)	60 (52,70)	60 (52,70)	60 (52,69)	0.775
ASA physical status				<0.001
II	33 (6.55)	33 (10.28)	0 (0.00)	
III	341 (67.66)	255 (79.44)	86 (46.99)	
IV	120 (23.81)	32 (9.97)	88 (48.09)	
V	10 (1.98)	1 (0.31)	9 (4.92)	
Preoperative laboratory; median (IQR)				
Hematocrit (%)	33.85 (29.50, 38.50)	34.80 (30.50, 39.50)	32.70 (27.30, 37.10)	<0.001
Prothrombin Time (sec)	12.20 (11.40, 13.30)	12.10 (11.35, 13.00)	12.50 (11.60, 13.70)	0.008
INR	1.05 (0.98, 1.14)	1.04 (0.97, 1.12)	1.07 (1.00, 1.21)	0.002
Partial Thromboplastin Time (sec)	28.2 (25.2, 31.7)	28.40 (25.25, 31.80)	27.75 (25.20, 31.00)	0.621
Operation time (min); median (IQR)	290 (195, 450)	285 (200, 445)	300 (182, 464)	0.829
Cardiopulmonary bypass used	97 (19.25)	46 (14.33)	51 (27.87)	<0.001
Cardiopulmonary bypass time (min); mean ± SD	211.32±64.79	200.48±69.18	221.10±59.54	0.118
Lowest body temperature (°C); median (IQR)	34.80 (33.60, 35.50)	34.80 (34.00, 35.50)	34.80 (31.20, 35.70)	0.698

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Variables	Total (n = 504)	Elective (n = 321)	Emergency (n = 183)	p-value
Intraoperative blood loss (ml); median (IQR)	300 (120, 900)	300 (100, 700)	500 (150, 1170)	0.002
Cell savage used (ml); median (IQR)	439.50 (300, 600)	448 (343, 590)	431 (300, 641)	0.910
Type of operation				
Open aortic surgery	116 (23.02)	53 (16.51)	63 (34.43)	<0.001
TAR with FET	33 (6.55)	18 (5.61)	15 (8.2)	
Open aneurysmorhaphy	21 (4.17)	8 (2.49)	13 (7.1)	
TAR	19 (3.77)	7 (2.18)	12 (6.56)	
Partial arch replacement	19 (3.77)	6 (1.87)	13 (7.1)	
Thoracoabdominal aortic replacement	11 (2.18)	8 (2.49)	3 (1.64)	
Aortic arch replacement	5 (0.99)	5 (1.56)	0 (0)	
Hemi-arch replacement	5 (0.99)	1 (0.31)	4 (2.19)	
Ascending aortic replacement	3 (0.6)	0 (0)	3 (1.64)	
Endovascular surgery	388 (76.98)	268 (83.49)	120 (65.57)	<0.001
EVAR	215 (42.66)	148 (46.11)	67 (36.61)	
TEVAR	173 (34.33)	120 (37.38)	53 (28.96)	

Data are presented as a number (%) unless indicated otherwise.

Abbreviation: TAR, total arch replacement; TAR with FET, total arch replacement with frozen elephant trunk; EVAR, Endovascular Aortic Aneurysm Repair; TEVAR, Thoracic Endovascular Aortic Aneurysm Repair.

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Table 2 Blood component utilization indices in patients undergoing aortic surgery (n = 504)

Blood component	Crossmatch		Transfusion		C/T ratio	%T	Ti
	Case (n)	Unit	Case (n)	Unit			
Packed Red Cell	504	2515	334	1180	2.13	66.27	2.34
Fresh Frozen Plasma	455	2343	117	694	3.38	25.71	1.53
Platelet Concentrate	329	3030	146	1992.8	1.52	44.37	6.06
Cryoprecipitate	94	917	92	1312	0.70	97.87	13.96

Abbreviations: C/T ratio, Crossmatch to Transfusion ratio; %T, transfusion probability; Ti, Transfusion index. Appropriate blood usage was defined as C/T ratio < 2.0, %T > 30%, and Ti > 0.5.

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Table 3 PRC utilization indices in adult aortic surgery categorized by type of operation

Type of operation	no. of case	Crossmatch PRC		Transfusion PRC		C/T ratio	%T	Ti	MSBOS
		Case (n)	Unit	Case (n)	Unit				
Open aortic surgery	**116**	**116**	**988**	**116**	**611**	**1.62**	**97.41**	**5.27**	**7.91**
TAR with FET	33	33	294	33	168	1.75	100.00	5.09	7.64
Open aneurysmorhaphy	21	21	158	21	136	1.16	90.48	6.48	9.71
TAR	19	19	185	19	65	2.85	100.00	3.42	5.13
Partial arch replacement	19	19	154	19	90	1.71	94.74	4.74	7.11
Thoracoabdominal aortic replacement	11	11	94	11	90	1.04	100.00	8.18	12.27
Aortic arch replacement	5	5	39	5	23	1.70	100.00	4.60	6.90
Hemiarch arch replacement	5	5	34	5	23	1.48	100.00	4.60	6.90
Ascending arch replacement	3	3	30	3	16	1.88	100.00	5.33	8.00
Endovascular surgery	**388**	**388**	**1527**	**388**	**569**	**2.68**	**56.96**	**1.47**	**2.21**
EVAR	215	215	842	215	369	2.28	59.07	1.72	2.57
TEVAR	173	173	685	173	200	3.43	54.34	1.16	1.73

Abbreviations: TAR, total arch replacement; TAR with FET, total arch replacement with frozen elephant trunk; EVAR, Endovascular Aortic Aneurysm Repair; TEVAR, Thoracic Endovascular Aortic Aneurysm Repair; C/T ratio, Crossmatch to Transfusion ratio; %T,

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transfusion probability; Ti, Transfusion index; MSBOS, Maximum Surgical Blood Ordering Schedule. Appropriate blood usage was defined as C/T ratio < 2.0, %T > 30%, and Ti > 0.5.

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Table 4 PRC utilization indices in adult aortic surgery categorized by elective and emergency procedures

Type of operation	no. of case	Crossmatch PRC		Transfusion PRC		C/T ratio	%T	Ti	MSBOS
		Unit	Case (n)	Unit	Case (n)				
Elective case	**321**	**1345**	**321**	**515**	**180**	**2.61**	**56.07**	**1.60**	**2.41**
Open aortic surgery									
TAR with FET	18	158	18	76	18	2.08	100.00	4.22	6.33
Thoracoabdominal aortic replacement	8	72	8	52	8	1.38	100.00	6.50	9.75
Open aneurysmorhaphy	8	58	8	39	7	1.49	87.50	4.88	7.31
TAR	7	67	7	26	7	2.58	100.00	3.71	5.57
Partial arch replacement	6	44	6	28	6	1.57	100.00	4.67	7.00
Aortic arch replacement	5	39	5	23	5	1.70	100.00	4.60	6.90
Hemiarch arch replacement	1	10	1	4	1	2.50	100.00	4.00	6.00
Endovascular surgery									
EVAR	148	497	148	170	74	2.92	50.00	1.15	1.72
TEVAR	120	400	120	97	54	4.12	45.00	0.81	1.21

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Type of operation	no. of case	Crossmatch PRC		Transfusion PRC		C/T ratio	%T	Ti	MSBOS
		Unit	Case (n)	Unit	Case (n)				
Emergency case	**183**	**1170**	**183**	**665**	**154**	**1.76**	**84.15**	**3.63**	**5.45**
Open aortic surgery									
TAR with FET	15	136	15	92	15	1.48	100.00	6.13	9.20
Open aneurysmorrhaphy	13	100	13	97	12	1.03	92.31	7.46	11.19
Partial arch replacement	13	110	13	62	12	1.77	92.31	4.77	7.15
TAR	12	118	12	39	12	3.03	100.00	3.25	4.88
Hemiarch arch replacement	4	24	4	19	4	1.26	100.00	4.75	7.13
Ascending arch replacement	3	30	3	16	3	1.88	100.00	5.33	8.00
Thoracoabdominal aortic replacement	3	22	3	38	3	0.58	100.00	12.67	19.00
Endovascular surgery									
EVAR	67	345	67	199	53	1.73	79.10	2.97	4.46
TEVAR	53	285	53	103	40	2.77	75.47	1.94	2.92

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Table 5 Stratified analysis of blood utilization by procedural complexity and urgency status

Complexity Factor	Subgroup	n (%)	Mean ± SD (units)	Median (IQR)	C/T Ratio	%T	P-value
Surgical Approach	Endovascular (EVAR/TEVAR)	388 (77.0%)	3.94 ± 2.17	4.0 (2.0 - 4.0)	2.68	56.96	<0.001*
	Open Aortic Surgery	116 (23.0%)	8.52 ± 2.25	10.0 (6.0 - 10.0)	1.62	97.41	
Complexity (CPB)	With CPB/DHCA	97 (19.2%)	8.70 ± 2.21	10.0 (6.0 - 10.0)	1.80	98.97	<0.001*
	Without CPB	407 (80.8%)	4.11 ± 2.30	4.0 (2.0 - 4.0)	2.35	58.48	
Urgency Status	Elective	321 (63.7%)	4.19 ± 2.55	4.0 (2.0 - 6.0)	2.61	56.07	<0.001*
	Emergency/Rupture	183 (36.3%)	6.39 ± 2.99	6.0 (4.0 - 10.0)	1.76	84.15	

*Significant at $p < 0.05$ using Mann-Whitney U test. CPB: Cardiopulmonary Bypass; DHCA: Deep Hypothermic Circulatory Arrest; C/T Ratio: Crossmatch-to-Transfusion Ratio.

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Table 6 Multivariate logistic regression analysis for blood transfusion requirement

Predictors	Adjusted OR	95% CI	p-value
Age (years)	1.01	0.99 – 1.03	0.38
Gender			
Male	Reference	—	—
Female	0.80	0.43 – 1.49	0.48
Urgency status			
Elective	Reference	—	—
Emergency	2.74	1.53 – 5.05	<0.001
Procedure complexity			
Endovascular	Reference	—	—
Simple Open	26.1	7.09 – 147	<0.001
Complex Open	143	33.0 – 1,358	<0.001
Baseline comorbidities			
Chronic kidney disease	1.17	0.52 – 2.70	0.70
Coronary artery disease	0.55	0.10 – 2.89	0.48
Diabetes mellitus	0.78	0.35 – 1.74	0.54
Hypertension	1.37	0.78 – 2.40	0.27
Baseline hemoglobin (g/dL)	0.44	0.37 – 0.53	<0.001

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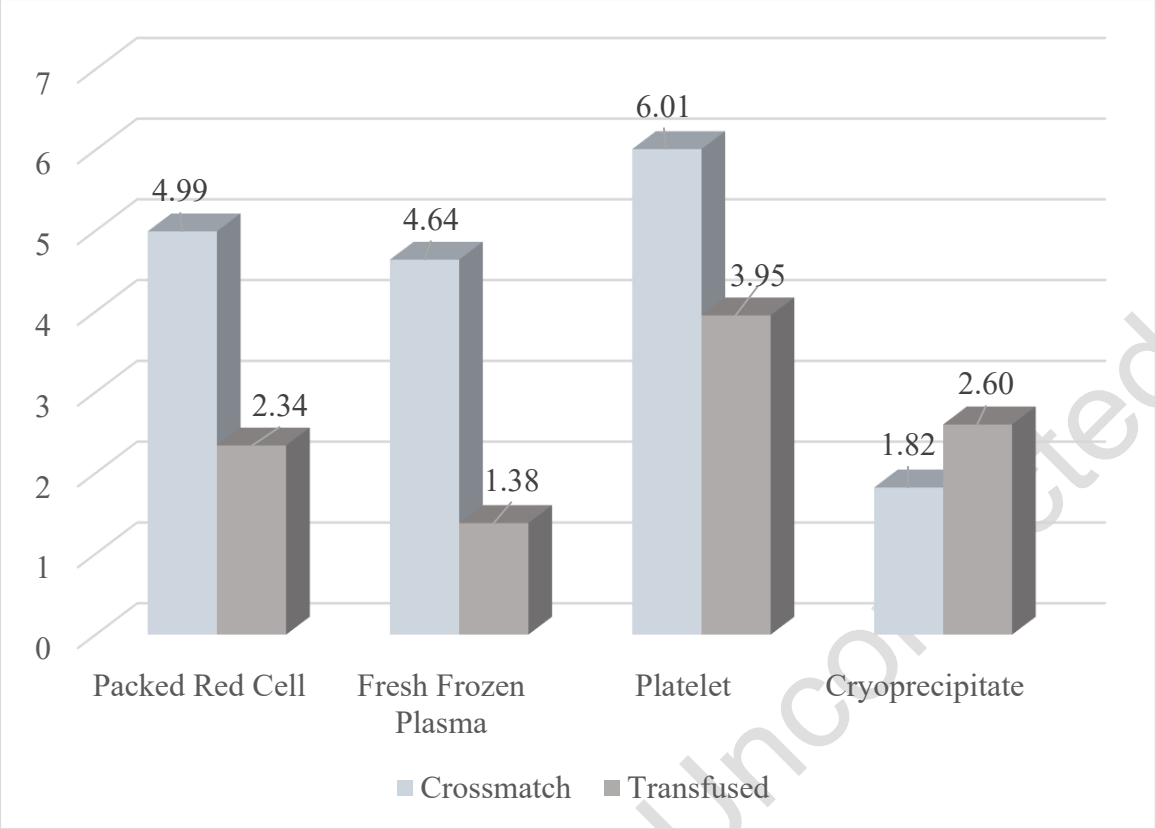


Figure 1 Average number of blood and blood components crossmatched and transfused (units per case)

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Appendix A Maximum blood order schedule in aortic surgery

Type of operation	Recommended maximum number of units		
	Proposed for SNH and QSHC	**UKM**	**JHK**
Open aortic surgery			
Aortic arch replacement	7	4	4
Ascending aortic replacement	8	4	4
Hemiarch replacement	6	4	4
Open aneurysmorrhaphy	8	6	N/A
Partial arch replacement	7	4	4
Thoracoabdominal aortic replacement	10	N/A	12
Total arch replacement	6	N/A	N/A
Total arch replacement with frozen elephant trunk	7	N/A	N/A
Endovascular surgery			
EVAR	2	6	2
TEVAR	2	N/A	2

Abbreviation: EVAR, Endovascular Aortic Aneurysm Repair; TEVAR, Thoracic Endovascular Aortic Aneurysm Repair; UKM, University Kebangsaan Malaysia Medical Centre; JHK, Johns Hopkins Hospital; N/A, not available.

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