

Rotational Thromboelastometry-Guided versus Conventional Transfusion Strategies in Adult Cardiac Surgery with Cardiopulmonary Bypass: Impact on Blood Product Utilization

Ramadan Ibrahim Mohamed Ibrahim Auf¹, Randa Ibrahim Amin Ibrahim², Yosry M Thakeb³, Rehab M Al-Ashry⁴, Ahmed Hassan Zaid⁵, Eslam Elshafey⁶, Mazin Essam Aly Elsergany⁷

¹Cardiothoracic Surgery Department, Al-Ahrar Teaching Hospital, General Organization for Teaching Hospitals and Institutes (GOTHI), Egypt

²Central Administration of Blood and Cellular Therapy (CABCT), Ministry Of Health, State of Kuwait

³Cardiothoracic Surgery Department, National Heart Institute, General Organization for Teaching Hospitals and Institutes (GOTHI), Egypt

⁴Cardiology Department, Al-Ahrar Teaching Hospital, General Organization for Teaching Hospitals and Institutes (GOTHI), Egypt

⁵Cardiology Department, National Heart Institute, General Organization for Teaching Hospitals and Institutes (GOTHI), Egypt

⁶Clinical Pathology Department, Al-Ahrar Teaching Hospital, General Organization for Teaching Hospitals and Institutes (GOTHI), Egypt

⁷Cardiothoracic Surgery Department, Banha Teaching Hospital, General Organization for Teaching Hospitals and Institutes (GOTHI), Egypt

*Corresponding author: Eslam Elshafey
Email: eslamelshafeyelsaid245@gmail.com

ABSTRACT

Background: Excessive bleeding and coagulopathy after cardiac surgery with cardiopulmonary bypass (CPB) remain major challenges, increasing transfusion requirements and postoperative complications. Conventional laboratory tests may delay diagnosis and targeted treatment, whereas rotational thromboelastometry (ROTEM) provides rapid, point-of-care assessment of hemostatic function to guide targeted correction of coagulation abnormalities.

Aim: To compare efficacy and short-term safety of ROTEM-guided transfusion versus conventional transfusion strategies in patients undergoing elective cardiac surgery with cardiopulmonary bypass.

Methods: This prospective randomized study included 80 adults undergoing elective cardiac surgery under CPB at the National Heart Institute, GOTHI. Patients were assigned to ROTEM-guided or conventional transfusion groups and underwent CABG, valve replacement, or combined procedures. Cardiovascular risk factors, preoperative antithrombotic therapy, 30-day cardiovascular complications, baseline echocardiographic parameters, and post-transfusion blood pressure were assessed.

Results: The ROTEM-guided group received fewer packed red blood cell (median 2 vs. 4; $P = 0.001$), fresh frozen plasma (median 2 vs. 3; $P = 0.001$), and platelet units (median 1 vs. 2; $P = 0.020$), with similar cryoprecipitate use ($P = 0.182$). Twenty-four-hour chest-drain output was also lower (528.8 ± 141.4 vs. 701.9 ± 174.5 mL; $P = 0.001$). No significant differences were observed in re-exploration, ICU or hospital stay, 30-day mortality, MACE, or other cardiovascular complications. Baseline echocardiographic parameters and post-transfusion blood pressures were also comparable.

Conclusion: In adults undergoing elective cardiac surgery with CPB, ROTEM-guided management reduced blood product use and postoperative chest drain output, without significant differences in measured short-term safety outcomes. However, the sample size was insufficient to establish safety equivalence. Post-protamine ROTEM values were obtained before treatment and should not be interpreted as treatment-related improvement.

KEYWORDS: Rotational thromboelastometry, ROTEM, cardiac surgery, cardiopulmonary bypass, transfusion.

How to Cite: Ramadan Ibrahim Mohamed Ibrahim Auf, Randa Ibrahim Amin Ibrahim, Yosry M Thakeb, Rehab M Al-Ashry, Ahmed Hassan Zaid, Eslam Elshafey, Mazin Essam Aly Elsergany, (2024) Rotational Thromboelastometry-Guided versus Conventional Transfusion Strategies in Adult Cardiac Surgery with Cardiopulmonary Bypass: Impact on Blood Product Utilization, Vascular and Endovascular Review, Vol.7, No.2, 554-566

INTRODUCTION

Perioperative bleeding and coagulopathy remain major challenges in adult cardiac surgery requiring cardiopulmonary bypass (CPB). Excessive postoperative bleeding is associated with increased exposure to allogeneic blood products, re-exploration for bleeding, postoperative morbidity, prolonged resource utilization, and higher healthcare costs [1]. The underlying coagulopathy is frequently multifactorial and may result from hemodilution, consumption of coagulation factors, platelet dysfunction, reduced fibrinogen availability, hyperfibrinolysis, residual heparin effect, hypothermia, acidosis, and the effects of protamine administration. Because these abnormalities may coexist and require different therapeutic approaches, timely identification of the predominant hemostatic defect is essential for targeted transfusion management [1,2].

Conventional perioperative assessment of coagulation generally relies on laboratory tests such as prothrombin time, activated partial thromboplastin time, international normalized ratio, platelet count, and plasma fibrinogen concentration. Although these tests remain clinically useful, their turnaround time may delay therapeutic decisions, and they provide only a limited representation of the dynamic process of whole-blood clot formation. Consequently, empiric transfusion based on isolated laboratory abnormalities or clinical bleeding alone may result in unnecessary exposure to blood components. Contemporary cardiac-surgery patient-blood-management guidelines therefore support goal-directed transfusion algorithms incorporating point-of-care viscoelastic testing when perioperative bleeding and coagulopathy are present [3]. Rotational thromboelastometry (ROTEM) provides a rapid, whole-blood assessment of clot initiation, clot propagation, and maximum clot firmness. Its different assays permit evaluation of distinct components of coagulation. EXTEM reflects extrinsically activated clot formation, whereas FIBTEM evaluates the fibrin-based contribution to clot strength and may help identify reduced fibrinogen availability or impaired fibrin polymerization [4]. By linking specific coagulation abnormalities to predefined treatment thresholds, ROTEM-guided algorithms have the potential to facilitate more selective administration of plasma, platelets, and fibrinogen-containing products while avoiding unnecessary transfusion.

Several observational studies and randomized trials have reported reductions in exposure to allogeneic blood products after implementation of ROTEM-guided or other viscoelastic-based transfusion algorithms in cardiac surgery [5,7–13]. Meta-analyses have also suggested reductions in selected transfusion requirements and, in some analyses, re-exploration for bleeding [14–16]. However, the magnitude of benefit has not been consistent across studies or across individual blood components, and evidence for improvement in clinically important outcomes such as mortality, thromboembolic complications, intensive-care-unit stay, and hospital length of stay remains uncertain [14–16]. Differences in surgical populations, transfusion thresholds, background patient-blood-management practices, permitted hemostatic products, and the specific algorithms used to interpret viscoelastic results may partly explain this heterogeneity.

Thus, although viscoelastic-guided transfusion is increasingly incorporated into cardiac-surgical blood-management pathways, uncertainty remains regarding the extent to which a predefined ROTEM-guided strategy can reduce blood-product utilization and postoperative bleeding without adversely affecting short-term clinical outcomes in patients undergoing elective cardiac surgery with CPB.

The present prospective randomized study therefore compared a predefined ROTEM-guided transfusion strategy with a conventional laboratory-guided transfusion strategy in adults undergoing elective CABG, valve surgery, or combined procedures with CPB. The primary objective was to compare perioperative utilization of packed red blood cells, fresh frozen plasma, platelets, and cryoprecipitate. Secondary objectives included assessment of postoperative chest-drain output, re-exploration for bleeding, intensive-care-unit and hospital length of stay, 30-day mortality, and exploratory cardiovascular outcomes.

We hypothesized that a ROTEM-guided transfusion strategy would reduce allogeneic blood-product utilization and postoperative bleeding compared with conventional transfusion management, without an increase in measured postoperative complications.

METHODS

This prospective, randomized study was conducted at the Department of Cardiothoracic Surgery, National Heart Institute, GOTH. Recruitment was conducted from February 2023 to August 2023. The study enrolled 80 adults undergoing elective cardiac surgery with cardiopulmonary bypass (CPB). Before enrollment, all patients provided written informed consent. Eighty adult patients between 40 and 77 years of age who were scheduled for elective cardiac surgery, including valve replacement, coronary artery bypass grafting (CABG), or combined procedures under cardiopulmonary bypass (CPB), were included. Eligible patients had no clinically significant baseline coagulopathy; PT and aPTT were within institutional preoperative acceptance ranges, INR was <1.5 on the day of surgery, and preoperative hemoglobin was ≥ 8 g/dL. Patients were excluded if they were undergoing emergency cardiac surgery, had preexisting coagulopathies or platelet disorders, were receiving chronic anticoagulation that could not be safely interrupted, had a history of liver or renal failure, or refused participation.

An independent investigator generated the allocation sequence using computer-generated random numbers with a 1:1 allocation ratio. Sequentially numbered, opaque, sealed envelopes were prepared by a researcher not involved in recruitment. Envelopes were opened after induction of anesthesia. All randomized patients were analyzed according to the intention-to-treat principle:

- **Group A (Conventional transfusion group):** Transfusion decisions were guided by standard laboratory tests (PT, aPTT, INR, platelet count, fibrinogen levels) and clinical judgment (e.g., ongoing bleeding, hemodynamic instability).
- **Group B (ROTEM-guided transfusion group):** Transfusion decisions were based on the predefined ROTEM-guided algorithm described below, using EXTEM and FIBTEM parameters together with the common PRBC hemoglobin trigger.

Preoperative Medication Management

Preoperative antiplatelet and anticoagulant therapies were managed according to standard institutional protocols. Aspirin was continued until the day of surgery. P2Y₁₂ inhibitors (clopidogrel, ticagrelor, or prasugrel) were routinely discontinued at least 5 days before surgery for clopidogrel and prasugrel and 3 days for ticagrelor. Patients requiring uninterrupted dual antiplatelet therapy or chronic anticoagulation that could not be safely interrupted were excluded from the study. For valve patients receiving oral anticoagulants, warfarin was interrupted and bridged when clinically indicated to achieve an INR <1.5 on the day of surgery; direct oral anticoagulants (DOACs) were withheld preoperatively according to institutional protocol.

Anesthesia and Surgical Technique

All patients received standard general anesthesia, induced with fentanyl and maintained with volatile anesthetics and opioid supplementation as required. Cardiopulmonary bypass was established using standard techniques, including systemic heparinization (300–400 IU/kg) to achieve activated clotting time (ACT) $\geq$ 480 seconds, and were maintained at normothermia or mild to moderate hypothermia (30–34°C) as per surgical protocol. Cold blood cardioplegia was used to protect the heart.

Conventional Transfusion Strategy (Group A)

In this group, transfusion decisions were based on:

- Hemoglobin <8 g/dL → PRBC transfusion,
- Platelet count <100 × 10⁹/L with bleeding → Platelet transfusion,
- INR >1.5 or aPTT >50 s with bleeding → fresh frozen plasma,
- Fibrinogen <150 mg/dL with bleeding → cryoprecipitate.

Clinical judgment, including ongoing bleeding and hemodynamic instability, was incorporated when appropriate.

ROTEM Assays and Interpretation (Group B)

ROTEM analysis was performed using a ROTEM delta analyzer (Pentapharm GmbH, Munich, Germany). ROTEM samples were collected at baseline after induction and before heparin administration, immediately after separation from CPB and protamine reversal, and postoperatively in the ICU if bleeding persisted. In the ROTEM-guided group, transfusion decisions followed a predefined institutional algorithm:

- **PRBC transfusion:** Because ROTEM does not assess hemoglobin or hematocrit, the PRBC transfusion trigger was identical to the conventional group, based on a hemoglobin level <8 g/dL or clinical judgment (e.g., active bleeding with hemodynamic instability).
- **Platelet transfusion:** Indicated in the presence of bleeding and a low EXTEM MCF (<40 mm) with a preserved FIBTEM MCF (>10 mm), indicating platelet-driven clot weakness.
- **FFP transfusion:** Indicated for prolonged EXTEM CT (>80 s) despite adequate heparin reversal.
- **Fibrinogen replacement:** Indicated for low FIBTEM MCF (<10 mm). Cryoprecipitate was the standard first-line agent used for this indication; however, fibrinogen concentrate was also permitted as an alternative if cryoprecipitate was unavailable or contraindicated.

ROTEM testing was performed in both groups immediately after protamine administration and before administration of protocol-directed hemostatic treatment. In the conventional group, ROTEM results were concealed from the treating team and were not used to guide transfusion decisions. In the ROTEM-guided group, the results were immediately available and were used according to the predefined transfusion algorithm. Postoperative hemoglobin was measured on ICU admission after completion of intraoperative transfusion.

Data Collection

Data included: demographics and preoperative parameters, including EuroSCORE II; preoperative cardiovascular characteristics (LVEF category, NYHA functional class, previous myocardial infarction, prior PCI/stent, previous cardiac surgery, history of heart failure, atrial fibrillation, pulmonary hypertension, coronary anatomy in CABG/combined cases, and valve pathology in valve/combined cases); preoperative transthoracic echocardiographic measurements (LVEF, LVEDD, LVESD, and PASP); preoperative antiplatelet and anticoagulant therapy and timing of P2Y₁₂ inhibitor discontinuation; intraoperative data (type of surgery, CPB time, aortic cross-clamp time, cell-salvage use, and intraoperative fluid balance); transfusion data (intraoperative and first 24 hours); post-transfusion hemodynamic measurements (SBP, DBP, and MAP); and postoperative outcomes, including chest tube drainage during the first 24 hours, re-exploration, ICU stay, hospital stay, 30-day cardiovascular complications, and MACE.

Transthoracic echocardiography was performed preoperatively in all patients as part of baseline cardiac assessment. The echocardiographic evaluation included left ventricular ejection fraction (LVEF), left ventricular end-diastolic diameter (LVEDD), left ventricular end-systolic diameter (LVESD), and estimated pulmonary artery systolic pressure (PASP), where applicable. Arterial blood pressure was monitored throughout the perioperative period and reassessed after blood-product transfusion; systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) were recorded to characterize post-transfusion hemodynamic status.

Thirty-day follow-up was completed for all randomized participants through scheduled outpatient clinic visits or structured telephone interviews conducted by a research coordinator who was not involved in treatment allocation.

Outcomes

- **Primary Transfusion Outcomes:** The primary transfusion outcomes were the numbers of packed red blood cell, fresh frozen plasma, platelet, and cryoprecipitate units transfused intraoperatively and during the first 24 postoperative hours.
- **Secondary Outcomes:** Postoperative bleeding, re-exploration for bleeding, ICU stay, total hospital stay, 30-day mortality, an exploratory post-transfusion hemodynamic assessment (SBP, DBP, and MAP), and an exploratory 30-day cardiovascular safety analysis including MACE and individual cardiovascular complications.

Outcome Definitions and Ascertainment

New-onset atrial fibrillation was defined as an episode of atrial fibrillation lasting at least 30 seconds, detected by continuous telemetry in the ICU or on a 12-lead ECG, and requiring clinical management with rate-control or rhythm-control therapy, including pharmacological or electrical cardioversion when indicated.

Perioperative myocardial infarction was adjudicated according to the Fourth Universal Definition of Myocardial Infarction [6]. For CABG-related myocardial infarction (type 5), a postoperative cardiac troponin elevation >10 times the 99th-percentile upper reference limit within 48 hours was required together with new pathological Q waves, angiographic evidence of new graft or native coronary artery occlusion, or imaging evidence of new loss of viable myocardium or a new regional wall-motion abnormality. For valve-only procedures, myocardial infarction was adjudicated according to the applicable non-CABG criteria in the same consensus definition.

Stroke was defined as a new acute focal neurological deficit confirmed by neurological assessment and corroborated by brain computed tomography or magnetic resonance imaging. Transient ischemic attack was defined as a transient focal neurological deficit resolving within 24 hours without evidence of acute infarction on brain imaging.

Postoperative Cardiovascular Complications and MACE:

To comprehensively assess safety beyond standard outcomes, an exploratory analysis of major postoperative cardiovascular complications was conducted within the first 30 postoperative days. An exploratory composite endpoint of Major Adverse Cardiovascular Events (MACE) was defined as cardiovascular death, perioperative myocardial infarction (PMI), stroke/transient ischemic attack (TIA), or a clinically significant thromboembolic event. PMI was defined according to the Fourth Universal Definition of Myocardial Infarction [6]. Additional cardiac outcomes reported were new-onset atrial fibrillation (AF), ventricular arrhythmias requiring intervention, low cardiac output syndrome (LCOS), prolonged inotrope/vasopressor requirement (>24 hours), need for intra-aortic balloon pump (IABP) or other mechanical circulatory support (MCS), cardiac arrest, and valve thrombosis when applicable.

Sample Size and Power Considerations

The study enrolled 80 patients (40 per group).. The trial was not powered to establish equivalence or non-inferiority for uncommon postoperative or cardiovascular safety events.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics version 27.0. Categorical data were presented as frequencies and percentages and compared using the Pearson Chi-square test, with Fisher's exact test for sparse 2×2 tables and continuity correction where appropriate. Quantitative data were expressed as mean ± SD for normally distributed variables and median (IQR) or range for non-normally distributed variables. The independent-samples t-test or Mann-Whitney U test was used as appropriate. All tests were two-sided, with $P < 0.05$ considered statistically significant.

RESULTS

Participant Flow

Of 115 patients assessed for eligibility, 35 were excluded: 20 did not meet the inclusion criteria, 10 were receiving anticoagulation that could not be safely interrupted, and 5 declined participation. The remaining 80 patients were randomized in a 1:1 ratio to the conventional transfusion strategy (n=40) or the ROTEM-guided strategy (n=40). All 80 randomized participants received the allocated intervention, were included in the final intention-to-treat analysis, and completed 30-day follow-up; no patients were lost to follow-up.

Baseline and Perioperative Characteristics

Table 1: Comparison of baseline data between the studied groups.

		Conventional (n=40)	ROTEM (n=40)	P-value
Age	Mean $\pm$ SD	58.3 $\pm$ 7.4	58.1 $\pm$ 6.6	0.888
	Range	40 – 77	43 – 72	
Gender	Male	29 (72.5%)	31 (77.5%)	0.796
	Female	11 (27.5%)	9 (22.5%)	
BMI (kg/m²)	Mean $\pm$ SD	28.3 $\pm$ 4.4	27.4 $\pm$ 4.5	0.387
	Range	21.8 – 37.6	18.3 – 39.3	
HTN	N (%)	16 (40.0%)	22 (55.0%)	0.263
DM	N (%)	15 (37.5%)	17 (42.5%)	0.64
EuroSCORE II (%)	Median (IQR)	2.1 (1.2 - 3.5)	1.9 (1.1 - 3.8)	0.752

BMI: Body Mass Index; HTN: Hypertension; DM: Diabetes Mellitus; EuroSCORE II: European System for Cardiac Operative Risk Evaluation II; IQR: Interquartile Range; SD: Standard Deviation.

Age, gender, BMI, hypertension, and diabetes mellitus did not differ statistically significantly between the studied groups ($P > 0.05$). Preoperative surgical risk was also comparable: the median EuroSCORE II was 2.1% (IQR: 1.2–3.5) in the conventional group and 1.9% (IQR: 1.1–3.8) in the ROTEM-guided group ($P = 0.752$), indicating a similar estimated operative mortality risk (Table 1).

Table 2: Comparison of surgical procedures between the studied groups.

		Conventional (n=40)	ROTEM (n=40)	P-value
Surgery Type	CABG	19 (47.5%)	25 (62.5%)	0.266
	Valve	18 (45.0%)	11 (27.5%)	
	Combined CABG and valve surgery	3 (7.5%)	4 (10.0%)	

CABG: Coronary artery bypass grafting.

There was no statistically significant difference in the distribution of surgery type (CABG, valve surgery, or combined procedures) between the two groups ($P > 0.05$) (Table 2).

Table 3: Comparison of preoperative laboratory data between the studied groups.

		Conventional (n=40)	ROTEM (n=40)	P-value
Preoperative Hb (g/dL)	Mean $\pm$ SD	12.5 $\pm$ 1.9	12.1 $\pm$ 1.6	0.31
Platelets (x10³/μL)	Mean $\pm$ SD	216.9 $\pm$ 55.9	210.6 $\pm$ 56.3	0.618
INR	Mean $\pm$ SD	1.1 $\pm$ 0.2	1.1 $\pm$ 0.1	0.820

Hb: Hemoglobin; INR: International Normalized Ratio; SD: Standard Deviation.

There was no statistically significant difference between the two groups regarding preoperative hemoglobin level, platelet count, or INR ($P > 0.05$) (Table 3).

Table 4: Comparison of preoperative cardiovascular characteristics between the studied groups.

Variable	Conventional (n=40)	ROTEM (n=40)	P-value
LVEF category			0.842
Preserved ($\geq 50\%$)	28 (70.0%)	27 (67.5%)	
Mildly reduced (41–49%)	8 (20.0%)	10 (25.0%)	
Reduced ($\leq 40\%$)	4 (10.0%)	3 (7.5%)	
NYHA functional class			0.654
I–II	22 (55.0%)	24 (60.0%)	
III–IV	18 (45.0%)	16 (40.0%)	
Previous MI	15 (37.5%)	14 (35.0%)	0.815
Previous PCI/Stent	10 (25.0%)	8 (20.0%)	0.587
Previous CABG / Cardiac Surgery	2 (5.0%)	1 (2.5%)	1.000
History of Heart Failure	12 (30.0%)	10 (25.0%)	0.617

Variable	Conventional (n=40)	ROTEM (n=40)	P-value
Presence of Atrial Fibrillation	5 (12.5%)	4 (10.0%)	1.000
Pulmonary Hypertension	6 (15.0%)	5 (12.5%)	0.744
Coronary Anatomy (for CABG/Combined)*			0.952
Left-main disease	7 (31.8%)	9 (31.0%)	
Multivessel disease	15 (68.2%)	20 (69.0%)	
Valve Pathology (for Valve/Combined)**			0.923
Aortic Valve Disease	10 (47.6%)	8 (53.3%)	
Mitral Valve Disease	9 (42.9%)	6 (40.0%)	
Double Valve Disease	2 (9.5%)	1 (6.7%)	
Primary Valve Dysfunction			0.466
Stenosis	11 (52.4%)	9 (60.0%)	
Regurgitation	8 (38.1%)	6 (40.0%)	
Mixed	2 (9.5%)	0 (0.0%)	

Data are presented as n (%). *For coronary anatomy, percentages use the applicable subgroup denominators of 22 Conventional and 29 ROTEM patients undergoing CABG or combined procedures. **For valve pathology and primary valve dysfunction, percentages use the applicable subgroup denominators of 21 Conventional and 15 ROTEM patients undergoing valve or combined procedures. LVEF: Left Ventricular Ejection Fraction; NYHA: New York Heart Association; MI: Myocardial Infarction; PCI: Percutaneous Coronary Intervention; CABG: Coronary Artery Bypass Grafting.

NYHA classes I–II and III–IV were combined to ensure adequate cell sizes for statistical testing.

No statistically significant baseline differences were detected in the measured cardiovascular characteristics (Table 4). LVEF category and NYHA functional class distributions were similar, as were previous myocardial infarction, prior PCI, previous cardiac surgery, heart failure history, preoperative atrial fibrillation, and pulmonary hypertension. Among CABG/combined patients, the proportions with left-main and multivessel disease were similar using the applicable subgroup denominators. Among valve/combined patients, the distributions of valve pathology and primary valve dysfunction were also similar. These comparisons describe measured baseline characteristics but do not establish formal equivalence between groups.

Baseline echocardiographic assessment

Table 5: Comparison of baseline echocardiographic assessment between the studied groups.

Echocardiographic parameter	Measure	Conventional (n=40)	ROTEM (n=40)	P-value
LVEF (%)	Mean ± SD	58.4 ± 6.7	57.9 ± 6.4	0.734
LVEDD (mm)	Mean ± SD	50.2 ± 5.6	49.7 ± 5.3	0.683
LVESD (mm)	Mean ± SD	33.1 ± 4.8	32.7 ± 4.6	0.705
PASP (mmHg)	Mean ± SD	31.8 ± 6.9	32.5 ± 7.2	0.659

LVEF: Left Ventricular Ejection Fraction; LVEDD: Left Ventricular End-Diastolic Diameter; LVESD: Left Ventricular End-Systolic Diameter; PASP: Pulmonary Artery Systolic Pressure; SD: Standard Deviation.

No statistically significant between-group differences were detected in baseline LVEF, LVEDD, LVESD, or PASP (all $P > 0.05$) (Table 5).

Table 6: Comparison of preoperative antiplatelet and anticoagulant therapy between the studied groups.

Variable	Conventional (n=40)	ROTEM (n=40)	P-value
Aspirin	32 (80.0%)	34 (85.0%)	0.572
P2Y12 Inhibitor (any)	10 (25.0%)	8 (20.0%)	0.587
- Clopidogrel	7 (17.5%)	5 (12.5%)	0.755
- Ticagrelor	2 (5.0%)	3 (7.5%)	1.000
- Prasugrel	1 (2.5%)	0 (0.0%)	1.000
Dual Antiplatelet Therapy (DAPT)	8 (20.0%)	6 (15.0%)	0.557
Oral Anticoagulants	6 (15.0%)	5 (12.5%)	0.744
- Warfarin	4 (10.0%)	3 (7.5%)	1.000

Variable	Conventional (n=40)	ROTEM (n=40)	P-value
- DOACs	2 (5.0%)	2 (5.0%)	1.000
Timing of P2Y12 Discontinuation (days)			0.815
Median (IQR)	5.0 (5.0 - 5.0)	5.0 (5.0 - 6.0)	

Data are presented as n (%) or median (IQR). P-values were calculated using the Chi-square test, Fisher's exact test, or Mann-Whitney U test, as appropriate. DAPT: Dual Antiplatelet Therapy; DOACs: Direct Oral Anticoagulants; IQR: Interquartile Range.

Preoperative medication exposure was compared because of its potential effect on perioperative bleeding (Table 6). No statistically significant differences were detected in aspirin, P2Y12 inhibitor, DAPT, or oral anticoagulant exposure. The median timing of P2Y12 inhibitor discontinuation was 5.0 days in both groups and did not differ significantly ($P = 0.815$).

Table 7: Comparison of operative variables between the studied groups.

		Conventional (n=40)	ROTEM (n=40)	P-value
CPB duration (min)	Mean $\pm$ SD	110.5 $\pm$ 29.8	112.0 $\pm$ 30.7	0.825
	Range	40.0 – 153.0	50.0 – 205.0	
Aortic cross-clamp time (min)	Mean $\pm$ SD	70.5 $\pm$ 22.0	76.0 $\pm$ 21.7	0.26
	Range	26.0 – 114.0	30.0 – 130.0	
Cell saver used	N (%)	17 (42.5%)	23 (57.5%)	0.264
Total intraoperative fluid balance (mL)	Mean $\pm$ SD	+2550 $\pm$ 450	+2380 $\pm$ 410	0.083

CPB: Cardiopulmonary Bypass; SD: Standard Deviation; mL: milliliters.

No statistically significant between-group differences were detected in CPB duration, aortic cross-clamp time, or cell-salvage use (Table 7). Total intraoperative fluid balance also did not differ significantly between the conventional and ROTEM-guided groups (+2550 $\pm$ 450 mL vs. +2380 $\pm$ 410 mL, respectively; $P = 0.083$).

Blood Product Utilization

Table 8: Comparison of blood product utilization between the studied groups.

		Conventional (n=40)	ROTEM (n=40)	P-value
Packed red blood cell units	Median	4	2	0.001
	Range	2.0 – 7.0	1.0 – 4.0	
FFP units	Median	3	2	0.001
	Range	1.0 – 6.0	1.0 – 3.0	
Platelet units	Median	2	1	0.020
	Range	0.0 – 2.0	0.0 – 2.0	
Cryoprecipitate units	Median	1	1	0.182
	Range	0.0 – 3.0	0.0 – 2.0	

FFP: Fresh frozen plasma.

The ROTEM-guided group showed lower median utilization of packed red blood cells, fresh frozen plasma, and platelets compared with the conventional group. Median cryoprecipitate requirements were similar between groups. Overall, ROTEM guidance was associated with reduced blood product utilization, particularly for packed red blood cells and fresh frozen plasma (Table 8).

Postoperative Bleeding

Table 9: Comparison of chest-drain output between the studied groups.

		Conventional (n=40)	ROTEM (n=40)	P-value
Drain 0–12h (mL)	Mean $\pm$ SD	403.8 $\pm$ 144.5	286.4 $\pm$ 102.3	0.001
	Range	107.0 – 675.0	90.0 – 472.0	
Drain 12–24h (mL)	Mean $\pm$ SD	298.1 $\pm$ 110.9	242.4 $\pm$ 98.5	0.020
	Range	60.0 – 570.0	54.0 – 469.0	
Total drain (mL)	Mean $\pm$ SD	701.9 $\pm$ 174.5	528.8 $\pm$ 141.4	0.001
	Range	284.0 – 1115.0	255.0 – 783.0	

SD: Standard deviation; mL: milliliters.

The ROTEM-guided group had significantly lower chest drain output during both postoperative intervals and in total. Re-exploration for bleeding was numerically less frequent in the ROTEM group, but the difference was not statistically significant (Table 9).

Postoperative Clinical Outcomes

Table 10: Comparison of postoperative outcomes between the studied groups.

		Conventional (n=40)	ROTEM (n=40)	P-value
ICU-admission Hb after intraoperative transfusion (g/dL)	Mean $\pm$ SD	12.9 $\pm$ 2.2	11.7 $\pm$ 2.1	0.013
	Range	8.3 – 17.9	8.1 – 16.5	
ICU stay (days)	Median	3	3	0.115
	Range	1.0 – 5.3	1.0 – 5.9	
Hospital stay (days)	Median	8	8	0.952
	Range	3.7 – 12.5	3.3 – 15.7	
Re-exploration for bleeding	N (%)	6 (15.0%)	2 (5.0%)	0.264
30-day mortality	N (%)	1 (2.5%)	1 (2.5%)	1.000

SD: Standard deviation; Hb: Hemoglobin; ICU: Intensive care unit.

The ROTEM-guided group had a significantly lower ICU-admission hemoglobin concentration after completion of intraoperative transfusion than the conventional group ($P = 0.013$). The median ICU stay was 3 days in both groups, and the median hospital stay was 8 days in both groups, with no statistically significant differences in either outcome. Re-exploration for bleeding occurred in 5.0% versus 15.0% of patients, but this difference was not statistically significant. All-cause 30-day mortality was 2.5% in each group. These findings should not be interpreted as proof of equivalent postoperative safety because of the small sample and low event counts (Table 10).

Post-transfusion Hemodynamic Stability

Table 11: Comparison of post-transfusion blood pressure between the studied groups.

Blood pressure parameter	Measure	Conventional (n=40)	ROTEM (n=40)	P-value
SBP (mmHg)	Mean $\pm$ SD	118.6 $\pm$ 12.4	116.9 $\pm$ 11.8	0.532
DBP (mmHg)	Mean $\pm$ SD	69.8 $\pm$ 8.1	68.7 $\pm$ 7.6	0.532
MAP (mmHg)	Mean $\pm$ SD	86.1 $\pm$ 8.7	84.8 $\pm$ 8.2	0.494

SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; MAP: Mean Arterial Pressure; SD: Standard Deviation.

Post-transfusion systolic blood pressure, diastolic blood pressure, and mean arterial pressure showed no statistically significant between-group differences (all $P > 0.05$) (Table 11). These findings provide a descriptive assessment of measured post-transfusion blood pressure and should not be interpreted as proof of hemodynamic equivalence.

Exploratory 30-Day Cardiovascular Outcomes

Table 12: Comparison of 30-day postoperative cardiovascular complications between the studied groups.

Variable	Conventional (n=40)	ROTEM (n=40)	P-value
MACE (Composite)	4 (10.0%)	3 (7.5%)	1.000
- Cardiovascular death	0 (0.0%)	0 (0.0%)	—
- Perioperative MI	2 (5.0%)	1 (2.5%)	1.000
- Stroke / TIA	1 (2.5%)	1 (2.5%)	1.000
- Thromboembolic event	1 (2.5%)	1 (2.5%)	1.000
Other Cardiac Complications			
New-onset Atrial Fibrillation	9/35 (25.7%)	8/36 (22.2%)	0.730
Ventricular Arrhythmia	2 (5.0%)	1 (2.5%)	1.000
Low Cardiac Output Syndrome (LCOS)	3 (7.5%)	2 (5.0%)	1.000
Prolonged Inotrope/Vasopressor use (>24h)	6 (15.0%)	5 (12.5%)	0.745
IABP / Mechanical Support	1 (2.5%)	1 (2.5%)	1.000
Cardiac Arrest	1 (2.5%)	0 (0.0%)	1.000

Variable	Conventional (n=40)	ROTEM (n=40)	P-value
Valve Thrombosis (valve/combined subgroup)	0/21 (0.0%)	0/15 (0.0%)	—

Data are presented as n (%) unless an at-risk denominator is shown. P-values were calculated using Pearson's chi-square test or Fisher's exact test, as appropriate. New-onset AF excludes patients with preoperative AF (at-risk denominators: Conventional n=35; ROTEM n=36). Valve thrombosis is reported for valve/combined patients only (Conventional n=21; ROTEM n=15). No P-value was calculated when both groups had zero events. MACE: Major Adverse Cardiovascular Events; MI: Myocardial Infarction; TIA: Transient Ischemic Attack; LCOS: Low Cardiac Output Syndrome; IABP: Intra-aortic Balloon Pump.

Because the study was not powered for cardiovascular events, an exploratory analysis of 30-day postoperative cardiovascular complications was performed (Table 12). There was no statistically significant difference in the composite MACE endpoint between the conventional and ROTEM-guided groups (10.0% vs. 7.5%, respectively; $P = 1.000$). Rates of perioperative myocardial infarction, stroke/TIA, and thromboembolic events were low, with no statistically significant between-group differences. Among patients without preoperative AF, new-onset AF occurred in 9/35 (25.7%) conventional-group patients and 8/36 (22.2%) ROTEM-group patients ($P = 0.730$). Low cardiac output syndrome occurred in 7.5% versus 5.0% ($P = 1.000$), and prolonged inotrope/vasopressor use occurred in 15.0% versus 12.5% ($P = 0.745$). No valve thrombosis was observed in the applicable valve/combined subgroups (0/21 vs. 0/15); because both groups had zero events, no comparative P-value was calculated. These findings remain exploratory and should not be interpreted as evidence of cardiovascular safety equivalence. While 30-day all-cause mortality was 2.5% (one patient in each group, as reported in Table 10), both deaths were classified as non-cardiovascular. Consequently, cardiovascular mortality was 0% in both groups (Table 12).

Pre-treatment ROTEM Parameters

Table 13: Comparison of pre-treatment ROTEM parameters immediately after protamine administration between the studied groups.

		Conventional (n=40)	ROTEM-guided (n=40)	P-value
EXTEM CT (sec)	Mean $\pm$ SD	70.9 $\pm$ 14.5	63.0 $\pm$ 14.3	0.017
	Range	37.0 – 107.0	35.0 – 99.0	
EXTEM CFT (sec)	Mean $\pm$ SD	107.7 $\pm$ 34.6	93.5 $\pm$ 28.4	0.050
	Range	40.0 – 178.0	35.0 – 163.0	
EXTEM MCF (mm)	Mean $\pm$ SD	58.5 $\pm$ 8.4	60.7 $\pm$ 6.9	0.221
	Range	35.0 – 76.0	46.0 – 77.0	
FIBTEM MCF (mm)	Mean $\pm$ SD	9.7 $\pm$ 3.5	11.9 $\pm$ 3.3	0.005
	Range	4.0 – 16.0	5.0 – 19.0	

SD: Standard deviation; CT: Clotting time; CFT: Clot formation time; MCF: Maximum clot firmness; EXTEM: Extrinsic thromboelastometry; FIBTEM: Fibrin-based clot firmness.

The post-protamine ROTEM samples summarized in Table 13 were obtained before protocol-directed hemostatic treatment. At this pre-treatment time point, the ROTEM-guided group had a shorter EXTEM clotting time (CT) than the conventional group ($P = 0.017$) and a higher FIBTEM maximum clot firmness (MCF) ($P = 0.005$). EXTEM CFT was numerically shorter but did not meet the prespecified significance criterion of $P < 0.05$ ($P = 0.050$), and EXTEM MCF did not differ significantly ($P = 0.221$). Because these measurements preceded hemostatic treatment, the between-group differences cannot be attributed to the ROTEM-guided intervention and should be considered a post-CPB pre-treatment imbalance when interpreting subsequent transfusion and bleeding outcomes.

DISCUSSION

Principal findings

In this randomized study of adults undergoing elective cardiac surgery with CPB, a ROTEM-guided transfusion strategy was associated with lower use of red blood cells, fresh frozen plasma, and platelets, together with lower postoperative chest-drain output, compared with a conventional laboratory-guided strategy. Cryoprecipitate use was similar, and no statistically significant differences were detected in re-exploration, ICU or hospital length of stay, all-cause 30-day mortality, or the exploratory cardiovascular outcomes. These findings are directionally consistent with a blood-conservation effect of viscoelastic-guided management, but the significant post-protamine ROTEM differences that were already present before protocol-directed hemostatic treatment limit causal attribution and are central to interpretation of the study.

Transfusion requirements and comparison with prior studies

The reduction in allogeneic blood-product exposure is broadly consistent with prior cardiac-surgical experience. Görlinger et al. reported that implementation of a point-of-care coagulation algorithm in cardiovascular surgery was associated with

lower exposure to allogeneic transfusion and fewer unplanned re-explorations [5]. In the prospective HEROES-CS cohort, Kuiper et al. found lower blood loss and absolute reductions in red-cell and plasma transfusion after implementation of a ROTEM-guided algorithm, whereas the reduction in platelet transfusion was smaller and not statistically significant [7]. Similarly, Fassl et al. observed lower use of red cells, plasma, and overall allogeneic products in complex proximal aortic surgery managed with thromboelastometry [8], and Karrar et al. reported substantial reductions in red cells, platelets, and plasma after implementation of a protocolized ROTEM strategy in proximal aortic surgery with deep hypothermic circulatory arrest [9]. Additional cardiac-surgery evidence supports this direction. Herruzo et al. evaluated 1,772 consecutive cardiac-surgery and heart-transplant patients across conventional testing, ROTEM, and ROTEM plus VerifyNow pathways and observed progressively lower red-cell transfusion with the point-of-care strategies, although the historical-control design limits causal inference [11]. In a prospective randomized trial of 100 coagulopathic cardiac-surgery patients, Weber et al. found that thromboelastometry and whole-blood impedance aggregometry-guided therapy reduced packed red-cell exposure and several secondary transfusion and resource outcomes compared with conventional testing [12]. Karkouti et al. subsequently reported in a 12-hospital stepped-wedge cluster randomized trial that an integrated point-of-care hemostatic algorithm reduced red-cell and platelet transfusions and major bleeding after cardiac surgery [13]. The magnitude and product-specific pattern of effect, however, has not been uniform across studies. St-Onge et al. found fewer erythrocyte and plasma units after ROTEM implementation in proximal aortic surgery, but the reduction in the proportion of patients receiving erythrocytes did not remain statistically significant in all propensity-matched analyses [10]. The present finding of lower platelet use therefore differs from the HEROES-CS experience, in which platelet exposure changed little [7]. Evidence syntheses likewise suggest that the clearest signal is reduced transfusion exposure rather than improvement in hard clinical outcomes. Deppe et al., in a meta-analysis of 17 randomized and observational studies including 8,332 cardiac-surgery patients, found lower allogeneic blood-product exposure and fewer re-explorations for bleeding, without clear reductions in in-hospital mortality or ICU/hospital length of stay [14]. Serraino and Murphy analyzed 15 randomized trials involving 8,737 participants and found lower frequencies of red-cell and platelet transfusion, but no significant reduction in mortality, reoperation for bleeding, stroke, ventilation time, or hospital length of stay; they also judged the certainty of evidence to be low or very low for the assessed outcomes [15]. In contrast, Lodewyckx et al., in a systematic review and meta-analysis of 11 trials including 8,294 patients, did not find a significant reduction in the proportion of patients receiving any blood product or in all-cause mortality, although modest reductions in exposure to specific blood components were observed [16]. Such heterogeneity is clinically plausible because transfusion algorithms differ in their thresholds, permitted factor concentrates, platelet-function assessment, background antifibrinolytic practice, and adherence, while study populations range from routine elective CABG or valve surgery to complex aortic procedures. These differences argue against treating ROTEM as a single uniform intervention; the clinical effect depends on the algorithm in which the test is embedded.

Cryoprecipitate use was not significantly different between groups. This does not necessarily indicate absence of a fibrinogen-directed effect. ROTEM-guided pathways can redistribute hemostatic therapy rather than uniformly reduce every product; for example, Karrar et al. reported reduced allogeneic transfusion together with greater use of fibrinogen and prothrombin-complex concentrates [9]. Because fibrinogen-concentrate administration was not separately quantified in the present study, the net effect on fibrinogen replacement cannot be fully determined.

Postoperative bleeding and clinically important outcomes

The lower chest-drain output observed with ROTEM guidance is concordant with several cardiac-surgical reports but should be interpreted separately from re-exploration. Fassl et al. described lower allogeneic exposure in aortic surgery managed with thromboelastometry [8], whereas Karrar et al. reported a marked reduction in surgical re-exploration among elective proximal aortic cases after protocol implementation [9]. By contrast, Kuiper et al. found reduced blood loss without a statistically significant change in rethoracotomy [7]. The present study similarly showed less drainage but no statistically significant reduction in re-exploration. This divergence is not unexpected: chest-drain volume is a continuous and relatively frequent endpoint, whereas re-exploration is uncommon, influenced by surgical as well as coagulopathic bleeding, and requires substantially larger samples to demonstrate moderate treatment effects. Historical cardiac-surgical series also show that re-exploration is multifactorial and is associated with procedural complexity and prolonged CPB [17-19].

ICU and hospital length of stay were similar between groups. This differs from the HEROES-CS cohort, in which implementation of ROTEM guidance was accompanied by a shorter hospital stay [7]. Differences in case mix, local discharge pathways, baseline length of stay, and the limited size of the present study may explain why a transfusion and bleeding signal did not translate into a detectable length-of-stay effect. The absence of such a difference should therefore not be interpreted as evidence that the strategies are clinically equivalent.

Postoperative hemoglobin and transfusion exposure

ICU-admission hemoglobin after intraoperative transfusion was lower in the ROTEM-guided group. In the context of fewer red-cell units, this finding is compatible with a more restrictive exposure to transfusion, but the study was not designed to identify an optimal postoperative hemoglobin target. Observational cardiac-surgery data have associated even limited perioperative red-cell exposure with worse long-term outcomes [20], providing a rationale for avoiding unnecessary transfusion; however, such associations are susceptible to confounding by illness severity and do not establish that lower

hemoglobin concentrations are intrinsically safer. In patients with coronary disease or ventricular dysfunction, the clinical objective remains to minimize avoidable transfusion while preserving adequate oxygen delivery. The present short-term findings therefore support cautious blood conservation rather than a specific transfusion threshold.

Interpretation of the ROTEM findings

Viscoelastic testing offers a conceptually different assessment from conventional plasma-based coagulation tests by characterizing clot initiation, propagation, and firmness in whole blood; FIBTEM additionally provides information on the fibrin contribution to clot strength [1,4]. This can support targeted treatment when a conventional abnormality does not correspond to a clinically relevant deficit in clot formation. Soh et al. showed that abnormal ROTEM thresholds after heparin reversal in off-pump CABG were independently associated with greater perioperative bleeding and transfusion requirement [21], supporting the clinical relevance of post-procedural viscoelastic abnormalities.

In the present study, however, the post-protamine ROTEM measurements summarized in Table 13 were obtained before protocol-directed hemostatic treatment, and EXTEM clotting time and FIBTEM maximum clot firmness already favored the ROTEM group at that time point. These differences cannot represent a treatment effect. Rather, they may indicate a more favorable post-CPB coagulation profile in the ROTEM arm that independently reduced subsequent treatment requirements. The randomized design reduces systematic baseline confounding, but chance imbalances remain possible in a study of this size. Accordingly, the observed reductions in transfusion and drainage should be interpreted as associations with the assigned strategy rather than as effects explained solely by ROTEM-guided treatment.

Exploratory cardiovascular safety

No statistically significant differences were detected in the exploratory 30-day MACE composite or in individual cardiovascular complications. Post-transfusion SBP, DBP, and MAP also showed no statistically significant between-group differences, providing a limited descriptive assessment of immediate hemodynamic status after transfusion. These findings are clinically reassuring but not definitive because event counts were low and the trial was not powered for safety equivalence or non-inferiority. Prior observational studies provide similarly cautious signals: Görlinger et al. reported fewer thrombotic or thromboembolic events after implementation of a point-of-care coagulation algorithm, without a mortality difference [5], while Fassl et al. found no association between thromboelastometry guidance and increased adverse events [8]. Kuiper et al. likewise did not demonstrate changes in mortality or rethoracotomy despite reductions in transfusion exposure [7]. Taken together, these studies support continued evaluation of clinical safety but do not establish that viscoelastic-guided algorithms improve cardiovascular outcomes.

Strengths and limitations

The study has several strengths. It used randomized allocation with concealed assignment, included a clinically representative mixture of CABG, valve, and combined procedures, characterized preoperative cardiovascular risk and antithrombotic exposure, included quantitative baseline echocardiographic assessment and post-transfusion blood-pressure measurements, and evaluated transfusion, bleeding, and short-term clinical outcomes within the same cohort. ROTEM was measured in both groups after protamine, with results concealed from the conventional-treatment team, allowing the pre-treatment coagulation profiles of the randomized groups to be compared directly.

Several limitations are important. This was a single-center study with 80 participants, limiting precision for infrequent outcomes such as re-exploration, mortality, and cardiovascular events. The original protocol-derived assumptions underlying the a priori sample-size determination were unavailable for the present report. Treating clinicians could not be blinded to the transfusion strategy. The inclusion of different cardiac operations increases clinical generalizability but also introduces heterogeneity in bleeding risk. The post-protamine pre-treatment imbalance in EXTEM CT and FIBTEM MCF may have contributed to subsequent differences in transfusion and bleeding. No patient-level adjusted sensitivity analysis was available to account simultaneously for procedure type, baseline hemoglobin, cell-salvage use, CPB duration, and the post-CPB coagulation profile. Although the ROTEM algorithm allowed fibrinogen concentrate for FIBTEM MCF <10 mm, its administration was not systematically quantified in the database; therefore, the specific impact of fibrinogen concentrate versus cryoprecipitate cannot be determined. Post-transfusion blood pressure was assessed using SBP, DBP, and MAP only and does not constitute a comprehensive hemodynamic assessment incorporating serial perfusion or cardiac-output measurements. Protocol-adherence data were not formally reported, long-term outcomes and cost-effectiveness were not assessed, and the cardiovascular analysis was exploratory and should be regarded as hypothesis-generating.

Clinical implications and future research

The findings are consistent with a potential role for viscoelastic testing as one component of a structured patient-blood-management pathway rather than as an isolated replacement for clinical assessment or conventional laboratory testing. The most defensible clinical implication is that a rapid, algorithm-based assessment of clot formation may reduce unnecessary exposure to selected allogeneic products while maintaining short-term outcomes within the limits of the available sample. The results do not establish a mortality benefit, cardiovascular safety equivalence, or superiority of any specific transfusion threshold.

Future multicenter studies should use prespecified, standardized ROTEM treatment thresholds, harmonized definitions of transfusion and bleeding outcomes, and adequate power for clinically important events. Stratification or covariate adjustment for procedure type, baseline hemoglobin, cell-salvage use, CPB duration, and post-CPB coagulation profile would help distinguish the effect of the management strategy from perioperative risk. Studies should also quantify factor-concentrate exposure, including fibrinogen concentrate, evaluate protocol adherence, incorporate longer cardiovascular follow-up, and examine cost-effectiveness. Within these constraints, the present findings add randomized evidence that ROTEM-guided management may reduce blood-product utilization and postoperative bleeding in elective cardiac surgery,

CONCLUSION

In adults undergoing elective cardiac surgery with CPB, assignment to a ROTEM-guided transfusion strategy was associated with lower use of RBCs, FFP, and platelets and with lower postoperative chest-drain output than conventional laboratory-guided management. No statistically significant differences were detected in re-exploration, length of stay, 30-day mortality, or exploratory cardiovascular outcomes, but the study was not powered to establish safety equivalence. Because post-protamine ROTEM values differed between groups before hemostatic treatment, the magnitude of the observed transfusion and bleeding differences cannot be attributed solely to ROTEM guidance. Larger multicenter trials using standardized algorithms and clinically powered endpoints are warranted.

Funding: This research received no external funding.

Conflict of Interest: The authors declare no conflicts of interest.

REFERENCES

1. Bolliger D, Tanaka KA. Point-of-care coagulation testing in cardiac surgery. *Semin Thromb Hemost.* 2017;43(4):386-396. doi:10.1055/s-0037-1599153.
2. Shore-Lesserson L, Baker RA, Ferraris VA, Greilich PE, Fitzgerald D, Roman P, Hammon JW. The Society of Thoracic Surgeons, The Society of Cardiovascular Anesthesiologists, and The American Society of ExtraCorporeal Technology: Clinical Practice Guidelines-Anticoagulation During Cardiopulmonary Bypass. *Ann Thorac Surg.* 2018;105(2):650-662. doi:10.1016/j.athoracsur.2017.09.061.
3. Tibi P, McClure RS, Huang J, Baker RA, Fitzgerald D, Mazer CD, Stone M, Chu D, Stammers AH, Dickinson T, Shore-Lesserson L. STS/SCA/AmSECT/SABM Update to the Clinical Practice Guidelines on Patient Blood Management. *Ann Thorac Surg.* 2021;112(3):981-1004. doi:10.1016/j.athoracsur.2021.03.033.
4. Gronchi F, Perret A, Ferrari E, Marcucci CM, Flèche J, Crosset M, Schoettker P, Marcucci C. Validation of rotational thromboelastometry during cardiopulmonary bypass: a prospective, observational in-vivo study. *Eur J Anaesthesiol.* 2014;31(2):68-75. doi:10.1097/EJA.0b013e328363171a.
5. Görlinger K, Dirkmann D, Hanke AA, Kamler M, Kottenberg E, Thielmann M, Jakob H, Peters J. First-line therapy with coagulation factor concentrates combined with point-of-care coagulation testing is associated with decreased allogeneic blood transfusion in cardiovascular surgery: a retrospective, single-center cohort study. *Anesthesiology.* 2011;115(6):1179-1191. doi:10.1097/ALN.0b013e31823497dd.
6. Thygesen K, Alpert JS, Jaffe AS, Chaitman BR, Bax JJ, Morrow DA, White HD; ESC Scientific Document Group. Fourth universal definition of myocardial infarction (2018). *Eur Heart J.* 2019;40(3):237-269. doi:10.1093/eurheartj/ehy462.
7. Kuiper GJ, van Egmond LT, Henskens YM, Roekaerts PM, Maessen JG, ten Cate H, Buhre WF, Lancé MD. Shifts of transfusion demand in cardiac surgery after implementation of rotational thromboelastometry-guided transfusion protocols: analysis of the HEROES-CS observational, prospective open cohort database. *J Cardiothorac Vasc Anesth.* 2019;33(2):307-317. doi:10.1053/j.jvca.2018.08.203.
8. Fassl J, Matt P, Eckstein F, Filipovic M, Gregor M, Zenklusen U, Seeberger MD, Bolliger D. Transfusion of allogeneic blood products in proximal aortic surgery with hypothermic circulatory arrest: effect of thromboelastometry-guided transfusion management. *J Cardiothorac Vasc Anesth.* 2013;27(6):1181-1188. doi:10.1053/j.jvca.2013.02.009.
9. Karrar S, Reniers T, Filius A, Bunge JJH, Bekkers JA, Hoeks SE, ter Horst M. Rotational thromboelastometry-guided transfusion protocol to reduce allogeneic blood transfusion in proximal aortic surgery with deep hypothermic circulatory arrest. *J Cardiothorac Vasc Anesth.* 2022;36(4):1029-1039. doi:10.1053/j.jvca.2021.08.020.
10. St-Onge S, Lemoine É, Bouhout I, Rochon A, El-Hamamsy I, Lamarche Y, Demers P. Evaluation of the real-world impact of rotational thromboelastometry-guided transfusion protocol in patients undergoing proximal aortic surgery. *J Thorac Cardiovasc Surg.* 2019;157(3):1045-1054.e4. doi:10.1016/j.jtcvs.2018.07.043.
11. Herruzo A, Hinojosa R, Adsuar A, Noval JA, Smani T, Ordoñez A. Clinical impact of rotational thromboelastometry in cardiac surgery. *Transfus Clin Biol.* 2021;28(3):276-282. doi:10.1016/j.tracbi.2021.03.003.
12. Weber CF, Görlinger K, Meininger D, Herrmann E, Bingold T, Moritz A, Cohn LH, Zacharowski K. Point-of-care testing: a prospective, randomized clinical trial of efficacy in coagulopathic cardiac surgery patients. *Anesthesiology.* 2012;117(3):531-547. doi:10.1097/ALN.0b013e318264c644.

13. Karkouti K, Callum J, Wijeyesundera DN, Rao V, Crowther M, Grocott HP, Pinto R, Scales DC. Point-of-Care Hemostatic Testing in Cardiac Surgery: A Stepped-Wedge Clustered Randomized Controlled Trial. *Circulation*. 2016;134(16):1152-1162. doi:10.1161/CIRCULATIONAHA.116.023956.
14. Deppe AC, Weber C, Zimmermann J, Kuhn EW, Slottosch I, Liakopoulos OJ, Choi YH, Wahlers T. Point-of-care thromboelastography/thromboelastometry-based coagulation management in cardiac surgery: a meta-analysis of 8332 patients. *J Surg Res*. 2016;203(2):424-433. doi:10.1016/j.jss.2016.03.008.
15. Serraino GF, Murphy GJ. Routine use of viscoelastic blood tests for diagnosis and treatment of coagulopathic bleeding in cardiac surgery: updated systematic review and meta-analysis. *Br J Anaesth*. 2017;118(6):823-833. doi:10.1093/bja/aex100.
16. Lodewyckx C, Heinrichs J, Grocott HP, Karkouti K, Romund G, Arora RC, Tangri N, Rabbani R, Abou-Setta A, Zarychanski R. Point-of-care viscoelastic hemostatic testing in cardiac surgery patients: a systematic review and meta-analysis. *Can J Anaesth*. 2018;65(12):1333-1347. doi:10.1007/s12630-018-1217-9.
17. Van Osch D, Dieleman JM, Nathoe HM, Boasson MP, Kluin J, Bunge JJ, Nierich AP, Rosseel PM, van der Maaten JM, Hofland J, Diephuis JC. Intraoperative high-dose dexamethasone in cardiac surgery and the risk of rethoracotomy. *Ann Thorac Surg*. 2015;100(6):2237-2242. doi:10.1016/j.athoracsur.2015.06.025.
18. Dacey LJ, Munoz JJ, Baribeau YR, Johnson ER, Lahey SJ, Leavitt BJ, Quinn RD, Nugent WC, Birkmeyer JD, O'Connor GT; Northern New England Cardiovascular Disease Study Group. Reexploration for hemorrhage following coronary artery bypass grafting: incidence and risk factors. *Arch Surg*. 1998;133(4):442-447. doi:10.1001/archsurg.133.4.442.
19. Hall TS, Sines JC, Spotnitz AJ. Hemorrhage-related reexploration following open heart surgery: the impact of preoperative and postoperative coagulation testing. *Cardiovasc Surg*. 2002;10(2):146-153. doi:10.1016/S0967-2109(01)00129-6.
20. Surgenor SD, Kramer RS, Olmstead EM, Ross CS, Sellke FW, Likosky DS, Marrin CA, Helm Jr RE, Leavitt BJ, Morton JR, Charlesworth DC. The association of perioperative red blood cell transfusions and decreased long-term survival after cardiac surgery. *Anesth Analg*. 2009;108(6):1741-1746. doi:10.1213/ANE.0b013e3181a2a696.
21. Soh S, Kwak YL, Song JW, Yoo KJ, Kim HJ, Shim JK. Rotational thromboelastometry predicts increased bleeding after off-pump coronary artery bypass surgery. *Ann Thorac Surg*. 2017;104(4):1318-1324. doi:10.1016/j.athoracsur.2017.02.046.