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Retrospective Analysis of Thromboelastography-Directed Transfusion in Isolated CABG: Impact on Blood Product Use, Cost, and Outcomes

Roberta E. Redfern, PhD;* Gabriel Naimy;* Michael Kuehne, PhD, PA-C;† Kevin Fleming, CCP;‡ Nathan Bobulski, CCP;‡ John T. Chen, PhD;§ Michael G. Moront, MD†

**Research Department, ProMedica Toledo Hospital, Toledo, Ohio; †ProMedica Toledo Hospital, Department of Cardiothoracic Surgery, Toledo, Ohio; ‡ProMedica Toledo Hospital, Department of Perfusion Services, Toledo, Ohio; and §Department of Mathematics and Statistics, Bowling Green State University, Bowling Green, Ohio*

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Abstract: Cardiac surgeries account for approximately 20% of blood use in the United States. Allogeneic transfusion has been associated with increased risk of morbidity and mortality, further justifying the need to reduce blood use. This study aimed at determining whether a point-of-care coagulation test, thromboelastography (TEG), impacted blood product administration and outcomes. Patients undergoing isolated coronary artery bypass grafting (CABG) were retrospectively reviewed before the use of TEG (2008–2009) (n = 640) and after implementation (2011–2012) (n = 458). Blood product use was compared between time frames. Logistic regression and generalized linear models were created to estimate the impact on outcomes including the reoperation rate, mortality, and cost. The mean use of each blood product was significantly reduced in the perioperative period. Overall blood product use was decreased by over 40%. Mediastinal re-exploration of bleeding was significantly reduced with TEG (4.8 vs. 1.5%). Six-month mortality was not impacted in this cohort nor was the readmission rate or hospital length of stay. However, blood cost and patient charges were significantly lower after TEG was introduced. The use of TEG to guide the administration of blood products during isolated CABG significantly affected the amounts and types of products given intra- and perioperatively. This resulted in less chest tube drainage, fewer returns to the operating room, and more accurate diagnosis of coagulopathic status. Cost savings to the patient and institution were appreciated as a consequence of these improved clinical outcomes.
Keywords: thromboelastography, blood products administration, coronary artery bypass grafting, mediastinal re-exploration, coagulopathy. *J Extra Corpor Technol. 2020;52:103–11*

Allogeneic blood products are often used in cardiac surgery (1). Specifically, excessive postoperative bleeding is associated with increased risk of transfusion. Transfusion of allogeneic blood products may result in a number of adverse events including transfusion-associated lung injury, transfusion-associated circulatory overload, immunosuppression, or nosocomial infection (2–6). Some studies have suggested that transfusion may also be associated with worse long-term outcomes (7–10). Consequently, strategies to reduce the need for transfusion have been widely investigated. Of particular interest are those that may also impact postoperative bleeding and the need for reoperation following a cardiac procedure.

The use of thromboelastography and rotational thromboelastometry (TEG and ROTEM) viscoelastic coagulation monitoring tests has attracted new interest in the past two decades (11). The kinetics of clot formation is evaluated by these tests, which provides a qualitative measure of

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Address correspondence to: Michael Moront, MD, Cardiothoracic Surgeons for Northwest Ohio, ProMedica Toledo Hospital, 2109 Hughes Drive, #720, Toledo, OH 43606. E-mail: morontmd@icloud.com
Summary Statement: The use of thromboelastography to guide perioperative management after isolated coronary artery bypass grafting reduced transfusion rates as well as return to OR for re-exploration of bleeding.
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hemostatic function. Unlike conventional laboratory tests (i.e., protime [PT]/international normalized ratio [INR] and aPTT) that are plasma based and provide static end points, these tests analyze whole blood and better represent the dynamic coagulation process in vivo. TEG and ROTEM analyses can be performed at the point of care and provide actionable data in a timely manner. The graphic and numeric parameters generated provide global information about the clot formation rate, strength, and dissolution (12). Interpretation of these results allows for a goal-directed use of blood products to target and achieve hemostasis, hence minimizing empirical transfusions (Table 1). A number of studies have suggested that blood product usage has decreased with adoption of ROTEM and TEG (13–15). However, important clinical outcome measures, such as the rate of reoperation, complications of interest, and mortality, have been variable. This variability may be due in part to heterogeneous populations and study design, where prospective trials with strict algorithms and restrictive transfusion protocols have often reported less pronounced improvements (13,16–18).

The goal of this study was to retrospectively analyze the effect of TEG without the use of a strict algorithm, in combination with standard laboratory tests and clinical judgment, on blood product administration in patients undergoing isolated coronary artery bypass grafting (CABG). In addition, we aimed at determining whether the reoperation rate was affected as TEG was used in the immediate postoperative period to monitor hemostatic status and heparin rebound and to distinguish mechanical bleeding versus coagulopathy. We hypothesized that other relevant outcome measures including complications, short-term mortality, and cost would be impacted as a result of reduced transfusion and re-exploration.

MATERIALS AND METHODS

This study was approved by the local Institutional Review Board before commencement of data collection. Written informed consent was waived because of the retrospective nature of the study. All baseline patient characteristics, laboratory values, blood product administration, complications, and mortality were obtained by manual review of each patient's electronic medical record. Charlson Comorbidity Index (CCI) score was calculated retrospectively based on documentation of preoperative diagnoses in the admission record and history and physical notes. Perioperative variables that were considered to be of clinical importance including cross-clamp time, total cardiopulmonary bypass (CPB) time, heparin and protamine doses, cell salvage volumes returned (19), and hematocrit (HCT) levels in the operating room (OR) were collected from perfusion records. Postoperative laboratory results reported are the first recorded in the intensive care unit.

Blood product administration was categorized into three separate temporal categories: perioperative (in the OR and first 24 hours postoperatively), postoperatively (>24 hours after operation), and reoperation. Each blood product was considered separately, while cumulative product use for each temporal period represents summation of all units of products given during that clinical time period. The only reoperation of interest was mediastinal re-exploration for bleeding as this procedure typically occurs within the first 24 hours of the initial CABG surgery. Blood products administered in the OR (on return) and in the following 24 hours were counted in the reoperation blood category and not in the perioperative blood administration category. Complications, including coagulopathy, were considered to have occurred if documented in the operative note, progress notes, or on discharge summary and not by specific, predefined laboratory or physiologic measurements.

All consecutive patients who underwent CABG performed by three surgeons who were present in the pre- and post-TEG periods were identified via electronic query of the institutional billing database. Subjects undergoing CABG at our institution between January 1, 2008 and December 31, 2009 (pre-TEG) and between January 1, 2011 and December 31, 2012 (post-TEG) were identified and reviewed for inclusion. The first year in which TEG was implemented and used was excluded to allow for clinician learning curve (calendar year 2010). All point-of-care thromboelastographs were collected using the TEG 5000 Thrombelastograph Hemostasis Analyzer System (Haemonetics, Braintree, MA). Baseline kaolin heparinase TEG, post-protamine kaolin, and post-protamine kaolin

Table 1. Manufacturer's treatment recommendations and TEG test result interpretation.

Hemostasis State	TEG Result	Treatment
Low platelet function	MA 46–54 mm	DDAVP, .3 mcg/kg
Very low platelet function	MA 41–45 mm	Plateletpheresis, 1 unit
Extremely low platelet function	MA ≤ 40 mm	Plateletpheresis, 2 units
Platelet hypercoagulability	MA >73 mm	Antiplatelet therapy
Enzymatic hypercoagulability	R < 4 minutes	Anticoagulant therapy
Low clotting factors	R 11–14 minutes	FFP, 2 units
Very low clotting factors	R > 14 minutes	FFP, 4 units
Low fibrinogen level	Angle < 45°	Cryoprecipitate, .06 units/kg

heparinase thromboelastographies were performed in all patients in the post-TEG period. In patients with abnormal TEG results, or postoperative bleeding, serial analyses in recovery or the Intensive Care Unit were completed to monitor hemostasis and help guide clinician decision with regard to the possible need for additional protamine, blood products, or return to the OR for re-exploration.

Patients undergoing minimally invasive CABG, surgery without the use of CPB, or surgery performed by a surgeon who was not present during both time periods were not eligible for inclusion. Patients undergoing any additional procedures including carotid endarterectomy, left atrial appendage resection, or maze procedures were excluded. Patients undergoing CABG with concomitant valve replacement/repair or aorta procedures were not included in this analysis and have been previously described (20).

Anesthesia was administered in accordance with institutional protocols and remained consistent throughout the entire study. The extracorporeal circuit has been previously described and was primed with 800 mL of crystalloid solution (Normosol-R, Hospira Inc., Lake Forrest, IL), 200 mL 25% albumin (AlbuRx 25, CSL Behring LLC, Kankakee, IL), 200 mL 25% mannitol (Hospira Inc.), and 10,000 units of heparin sodium injection (Fresenius Kabi USA, Lake Zurich, IL) (20). Tranexamic acid and/or aminocaproic acid was used in all cases.

The institutional trigger for transfusion of RBCs remained consistent during the study period, defined as a minimum hemoglobin of 7.0 g/dL during CPB and a minimum HCT of 21%. Transfusion was also used in cases where hemoglobin did not fall below 7.0 g/dL if the patient experienced sudden hemorrhage or became hemostatically unstable both intra- and postoperatively. There were no formal institutional changes in transfusion policies between the pre- and post-TEG periods nor any other significant systematic change in surgical practice that would potentially impact the use of blood products or decision to return to the OR during the study period with the exception of implementation of TEG in cardiac cases.

Statistical Analysis

Continuous variables were expressed as mean ± SD and compared with *t* tests for normally distributed variables. Categorical variables were expressed as frequencies and percentages and compared using the chi-squared test. Propensity scores were calculated and used to compare the rate of re-exploration. A logistic regression model adjusting for patient characteristics, postoperative laboratory values, and postoperative coagulopathy was used to determine the impact of TEG on the odds of reoperation and 6-month all-cause mortality. A generalized linear model was used to estimate the impact of TEG on hospital charges. Two-tailed p-value $< .05$ was considered significant. All analyses were performed using statistical software SAS version 9.2 (SAS Institute Inc., Cary, NC) and R version 3.3.2 (The R Foundation for Statistical Computing, Vienna, Austria).

To assess the economic effect of TEG, mean institutional blood acquisition cost was compared assuming the following costs for each product: $224.78 per unit of packed red blood cells (pRBC), $127.54 per unit plasma, $678 per unit cryoprecipitate (units pooled, 130 mL), and $562.27 per unit of platelets. The total cost between each period was calculated and then normalized to the number of patients in the post-TEG period to estimate the overall savings in blood product acquisition costs. Because acquisition costs are only a fraction of the actual cost of blood product administration (21), these costs were not removed from patient charges before comparison. The actual patient charges before insurance adjustment were electronically queried from the billing database for this cohort of patients. To account for cost changes over time, adjustments were applied based on the inflation factor for hospital cost using the consumer price indices from the Federal Reserve Bank and U.S. Department of Labor for inpatient hospital costs (22). Actual patient charges were compared in a linear model including Charlson Comorbidity Index, postoperative length of stay (LOS), and TEG usage.

RESULTS

Isolated CABG was performed in 640 consecutive patients in the pre-TEG period and 458 in the post-TEG period. As shown in Table 2, baseline characteristics between the two patient populations were not different with respect to age, gender, race, body mass index (BMI, kg/m^2), or procedure type (primary/redo and number of vessels). In both time periods, most of the patients were male and the mean age was similar. A significantly greater proportion of patients required urgent or emergent surgical intervention in the post-TEG period compared with pre-TEG (40.8 vs. 30.6%, respectively). Coagulation laboratory values (PT, INR, and partial thromboplastin time [PTT]) differed by period; however, preoperative platelet counts, hemoglobin, and HCT did not vary between cohorts.

Perioperative factors of interest were also compared; the first HCT collected in the OR, the lowest HCT while on CPB, and the volume of cell salvage returned (mL) were similar between cohorts in the pre- and post-TEG periods (Table 3). However, total CPB time and cross-clamp time were significantly lower in the post-TEG cohort ($p < .0001$, both). The first laboratory values collected postoperatively also varied by group; hemoglobin and HCT values were higher in the post-TEG period, and coagulation tests showed lower overall time to clot formation. Postoperative platelet counts were significantly lower in those patients included in the post-TEG group than those in the pre-TEG group. Importantly, the cumulative volume of chest tube drainage in

Table 2. Baseline patient characteristics.

	Pre-TEG (Mean ± SD)	Post- TEG (Mean ± SD)	*p*-Value
Age (years)	65.0 ± 10.6	65.5 ± 10.9	.44
BMI	30.9 ± 7.6	30.8 ± 13.5	.86
BSA	2.05 ± .26	2.00 ± .25	.003
Charlson Comorbidity Index	4.43 ± 1.97	4.39 ± 2.04	.73
Preoperative laboratory tests			
Hgb (g/dL)	13.3 ± 1.8	13.4 ± 2.2	.33
Hematocrit (%)	38.9 ± 5.0	39.2 ± 5.3	.40
Platelet count ($\times 10^9$/L)	223.1 ± 62.7	216.2 ± 76.8	.11
Protime (sec)	12.3 ± 1.7	11.9 ± 1.8	<.001
Protime INR	1.09 ± .14	1.05 ± .15	<.001
Coagulation PTT (sec)	36.7 ± 17.6	33.9 ± 15.7	.009
	n (%)	n (%)	*p*-Value
Gender (male)	458 (71.1)	325 (71.7)	.87
Race			
African American	35 (5.5)	25 (5.5)	.36
Caucasian	572 (89.4)	413 (90.4)	
Hispanic/Latino	26 (4.1)	10 (2.2)	
Middle Eastern	5 (.8)	4 (.9)	
Asian	1 (.2)	2 (.4)	
Unknown/missing	1 (.2)	4 (.9)	
Preoperative medication			
Antiplatelet	386 (61.2)	276 (60.5)	.68
Anticoagulant	48 (7.6)	30 (6.6)	.59
Procedure type			
Elective	444 (69.4)	271 (59.2)	<.001
Urgent/emergent	196 (30.6)	187 (40.8)	
Procedure			
Primary	617 (96.4)	449 (98.0)	.14
Redo	23 (3.6)	9 (2.0)	
Number of vessels			
One	13 (2.0)	4 (.9)	.28
Two	142 (22.2)	108 (23.6)	
Three	276 (43.1)	198 (43.2)	
Four	183 (28.6)	118 (25.8)	
Five	25 (3.9)	28 (6.1)	
Six	1 (.2)	1 (.2)	
Seven	0 (0)	1 (.2)	

the first 12 hours after surgery was significantly reduced in the post-TEG cohort (501.8 vs. 627.8 mL, $p < .0001$).

Mean cumulative blood product usage in the perioperative period was significantly decreased after TEG was implemented (3.07 vs. 1.67 units, $p < .0001$), whereas product use in the postoperative period was similar (Table 4, all $p > .05$). The mean number of units of blood administered during a reoperation for bleeding was also

Table 3. Perioperative clinical factors.

	Pre-TEG	Post-TEG	*p*-Value
Cell salvage volume (mL)	696.0 ± 289.9	705.8 ± 246.0	.55
First HCT in OR (%)	34.9 ± 6.2	35.0 ± 5.1	.83
Lowest HCT on pump (%)	23.5 ± 3.6	23.3 ± 3.7	.28
Total time on pump (mins)	69.96 ± 18.8	62.27 ± 19.0	<.0001
Total cross-clamp time (mins)	57.8 ± 29.6	51.4 ± 16.5	<.0001
Total heparin dose (units)	35,369.84 ± 9,499.6	39,193.83 ± 11,568.25	<.0001
Total protamine dose (mg)	319.2 ± 65.2	376.1 ± 83.4	<.0001
Chest tube drainage in the first 12 hours (mL)	627.8 ± 341.6	501.8 ± 278.9	<.0001
Postoperative laboratory tests			
Hgb (g/dL)	10.1 ± 1.4	10.4 ± 1.5	.03
Hematocrit (%)	28.8 ± 4.1	29.5 ± 4.7	.01
Platelet count (×109/L)	151.2 ± 44.7	140.9 ± 42.5	.0001
Protime (sec)	15.5 ± 2.1	15.0 ± 6.7	.15
Protime INR	1.36 ± .18	1.30 ± .16	<.0001
Coagulation PTT (sec)	33.5 ± 10.7	30.6 ± 5.2	.009

Table 4. Mean blood product use and exposure to blood products as a function clinical period of hospital stay (before TEG, n = 640; after TEG, n = 458).

	Perioperative			Postoperative			Reoperative		
Blood Product Component	Before TEG (Mean ± SD)	After TEG (Mean ± SD)	*p*-Value	Before TEG (Mean ± SD)	After TEG (Mean ± SD)	*p*-Value	Before TEG (Mean ± SD)	After TEG (Mean ± SD)	*p*-Value
Packed red blood cells (units)	1.33 ± 1.73	.97 ± 1.71	<.001	.50 ± 1.03	.44 ± 1.11	.39	.10 ± .65	.03 ± .37	.03
Fresh frozen plasma (units)	.87 ± 1.30	.14 ± .57	<.001	.02 ± .20	.01 ± .15	.40	.05 ± .33	0 ± 0	<.001
Cryoprecipitate (units)	.15 ± .53	.01 ± .16	<.001	0 ± 0	0 ± 0	NA	.02 ± .21	0 ± 0	.008
Platelet (units)	.73 ± .93	.55 ± .87	.001	.01 ± .20	.01 ± .15	.90	.03 ± .19	.01 ± 0.7	.17
Total units	3.07 ± 3.61	1.67 ± 2.66	<.001	.53 ± 1.14	.47 ± 1.21	.36	.20 ± 1.13	.05 ± .49	.002
Exposure	Before TEG Cases (%)	After TEG Cases (%)	*p*-Value	Before TEG Cases (%)	After TEG Cases (%)	*p*-Value	Before TEG Cases (%)	After TEG Cases (%)	*p*-Value
Packed red blood cells	315 (49.2)	156 (34.1)	<.001	154 (24.1)	94 (20.5)	.17	21 (3.3)	5 (1.1)	.02
Fresh frozen plasma	228 (35.6)	30 (6.6)	<.001	8 (1.2)	4 (.9)	.55	13 (2.0)	0 (0)	.001
Cryoprecipitate	50 (7.8)	3 (.7)	<.001	0 (0)	0 (0)	NA	7 (1.1)	0 (0)	.05
Platelet	309 (48.3)	158 (34.5)	<.001	7 (1.1)	6 (1.3)	.74	15 (2.3)	3 (.7)	.03
Total exposure	411 (64.3)	230 (50.0)	<.001	157 (24.5)	96 (20.8)	.17	26 (4.1)	6 (1.3)	.007

lower in the post-TEG period (.20 vs. .05, $p = .002$). These reductions translated into a greater than 40% reduction in overall mean units of blood products given in a period over the entire hospital stay (3.80 vs. 2.18, $p < .0001$). As shown in Table 4, each of the blood products of interest were impacted during the perioperative period (all, $p \leq .001$) and during the total stay (all, $p < .001$). Furthermore, fewer total patients were exposed to any allogeneic blood product during their hospital stay; whereas only 30.8% of patients avoided transfusion in the pre-TEG period, 43.9% did not receive blood products in the post-TEG period ($p < .0001$). Exposure to transfusion was compared in each of the predefined hospital admission time frames as a function of TEG usage. Only the perioperative and reoperative periods were associated with proportional changes in blood product use; however, total exposure to transfusion during the hospital admission was also reduced: 69.5% of patients received some blood product pre-TEG vs. 56.1% post-TEG ($p < .001$).

The rate of return to the OR was also investigated, as postoperative TEG analyses are used to guide the cardiothoracic team in differentiating bleeding due to

Table 5. Generalized linear model effect of TEG on reoperation for exploration of mediastinal bleeding and 6-month mortality (all cause).

Reoperation	Pre-TEG, n (%)	Post-TEG, n (%)
Yes	31 (4.8)	7 (1.5)
No	609 (95.2)	451 (98.5)
Effect	Odds Ratio Estimate	95% Confidence Limits
BMI	1.01	.96–1.07
Charlson Comorbidity Index	1.09	.90–1.32
Postoperative HGB (g/dL)	.84	.50–1.40
Postoperative HCT (%)	1.15	.97–1.37
TEG	2.98	1.21–7.35
6-Month Mortality*	Pre-TEG, n (%)	Post-TEG, n (%)
Yes	13 (2.0)	7 (1.5)
No	619 (98.0)	431 (98.5)
Effect	Odds Ratio Estimate	95% Confidence Limits
BMI	1.00	.95–1.05
Charlson Comorbidity Index	.70	.57–.86
Chest tube drainage	1.00	1.00–1.00
Postoperative HCT (%)	.79	.63–.98
Postoperative HGB (g/dL)	2.37	1.29–4.36
Postoperative platelet count (×109/L)	1.00	.99–1.01
Coagulopathy	.42	.13–1.35
TEG (0 vs. 1)	1.15	.41–3.17

*Alive status was unknown and removed from analysis in 6 cases pre-TEG and 21 cases post-TEG.

coagulopathy vs. surgical bleeding. In the pre-TEG period, 31 (4.9%) patients were taken back to the OR for re-exploration of mediastinal bleeding. The rate of reoperation after TEG was implemented was reduced by more than three times, wherein only seven (1.5%, $p = .03$) patients returned to the OR. A model adjusting for confounding factors was created to determine whether this impact was associated with TEG use (Table 5). After adjusting for BMI, postoperative laboratory values, and CCI, TEG reduced the odds of reoperation by approximately 3-fold (OR 2.98, 95% CI 1.21–7.35). This reduction in the rate of re-exploration remained significant on propensity score–matched analysis ($p = .04$).

Complications of interest were abstracted from discharge summaries and hospital progress notes as shown in Table 6. The incidence of most complications did not vary by period. Coagulopathy (noted in either the OR or any time postoperatively) was much less frequent in the post-TEG period (15.5 vs. 3.3%). In addition, the prevalence of cumulative pulmonary complications was lower with TEG use (15.2 vs. 7.2%), as were neurological complications (5.9 vs. 2.4%) and dysrhythmias including ventricular tachycardia/ventricular fibrillation (1.3 vs. 0%). Other rhythm disorders, arrhythmia, and atrial fibrillation were not impacted with TEG nor was renal failure or the rate of actual surgical bleeding postoperatively. Furthermore, the total LOS (8.43 vs. 8.37 days, $p = .86$) was not impacted by the reduction in the rate of reoperation or complications. Finally, 30-day readmission rates were compared between pre-TEG and post-TEG periods and were similar (9.3 vs. 11.4%, respectively $p = .25$). All-cause mortality within 6 months was also similar on univariate analysis (2.1 vs. 1.6%, $p = .6$). A generalized linear model (Table 5) adjusting for relevant variables confirmed that TEG did not impact 6-month all-cause mortality rates (OR 1.15, 95% CI .41–3.17).

Economic analyses of the results suggest considerable savings. The total acquisition cost of blood products for the entire hospital stay compared by pre- and post-TEG cohort indicates approximately $425 savings per patient; adjusted to the number of patients in both groups, this represents nearly $200,000 in blood acquisition savings during a 2-year period. Moreover, by comparison, actual hospital charges to the patient, after adjustment for inflation, were also substantially affected with use of TEG. In a generalized linear model, postoperative LOS was found to be associated with patient charges. The mean charges after TEG was implemented decreased significantly; after adjusting for CCI and postoperative LOS (Table 7), the reduction in charges was approximately $5,700 per patient and was strongly associated with the use of TEG.

Table 6. Incidence of postoperative complications before and after the implementation of TEG.

Complication, n (%)	Pre-TEG	Post-TEG	*p*-Value
Atrial fibrillation	85 (13.3)	76 (16.6)	.12
Arrhythmia/rhythm dysfunction	44 (6.9)	40 (8.7)	.25
Bleeding at site	14 (2.2)	4 (.9)	.09
Coagulopathy	99 (15.5)	15 (3.3)	<.0001
Pulmonary complication	97 (15.2)	33 (7.2)	<.0001
Prolonged ventilation	44 (6.9)	20 (4.4)	.08
Neurological complication	38 (5.9)	11 (2.4)	.005
Renal failure	63 (9.8)	40 (8.7)	.54
Vtach/Vfib	8 (1.3)	0 (0)	.016

DISCUSSION

The results of this study demonstrate that the use of TEG alongside standard laboratory tests to guide blood product administration can substantially reduce the amount of products given to patients undergoing isolated CABG and prevent exposure of a portion of patients to allogeneic transfusion compared with empirical transfusion practices. However, the purpose of TEG-directed transfusion is not only to minimize unnecessary transfusions but also to ensure appropriate products are used to prevent and treat coagulopathy. Importantly, TEG use in the immediate postoperative period reduced the rate of reoperation considerably, guiding clinicians' decisions as to whether bleeding required re-exploration.

Previous studies have described similar results with regard to blood product use and the impact of TEG on transfusion practice. In most retrospective and prospective reports, evidence indicates significant reductions in the use of platelets (14,18,23,24). Our results are similar to those reported by Ak et al. (13); however, in that study, patients undergoing re-sternotomy or urgent/emergent cases were not included. Although some studies have reported non-significant reductions in the mean number of units of platelets used with TEG guidance, those who have investigated the proportion of patients receiving platelets in addition to the number of units used have observed improvements in patient exposure to platelets (16). Interestingly, Spiess et al. (25) investigated subgroups of their study populations and found that although the complex cases did not demonstrate an important difference in platelet use, the rate of use was significantly reduced in the isolated CABG patients. Overall, it appears that the TEG's

Table 7. Charges as a function of TEG use.

Variable	Degrees of Freedom	*F*-Value	*p*-Value
CCI	1	3.60	.0582
Postoperative LOS	1	970.34	<.0001
TEG	1	5.27	.0219
Charges	Mean		*p*-Value
Pre-TEG	$167,423.15		.02
Post-TEG	$161,684.70		

ability to measure platelet function and clot strength can be advantageous versus using absolute platelet count and clinical judgment to achieve goal-directed platelet therapy.

Packed red blood cell transfusions decreased by 27.1% perioperatively ($p < .0001$) after TEG was implemented, despite the fact that this product's use is not directly guided by the assay. It is possible that RBC transfusions were less often necessary as a result of more effective hemostasis and less overall hemodilution because use of non-blood products such as fresh frozen plasma (FFP) decreased (15). Reduction in RBC transfusion was not the result of a change in clinical practice over the study time frame, except introduction of TEG, as the institutional transfusion trigger remained constant at Hgb $\leq$ 7 g/dL. Previously published studies have varied in findings regarding RBC transfusion; however, a meta-analysis of TEG and ROTEM suggested that RBC transfusion was reduced in both randomized controlled trials and observational studies (15). Substantial impacts in the use of FFP and cryoprecipitate were also observed in the TEG-directed group, similar to the current literature (17,26), in which the effect of TEG on the use of these products was more dramatic than that on RBCs or platelets. In this cohort, the use of FFP during the primary surgery and during re-exploration surgery was reduced by nearly 84% and administration of cryoprecipitate was reduced by over 93%.

Reoperation secondary to postoperative bleeding is an essential outcome measure in cardiac surgery. In this study, we found a clinically and statistically significant change in the rate of return to the OR after the introduction of TEG, which has been noted in previous reports in cardiac surgery (24,25,27–29). In our institution, TEG assays are completed postoperatively after the administration of protamine to ensure complete heparin reversal before exiting the OR. Heparin rebound, which can occur up to 2 hours following surgery, is common in these patients and can be identified with the assay (30). In the post-TEG cohort, 76 (16.5%) patients received additional protamine based on TEG results. TEG is performed again alongside standard laboratory tests shortly after arrival to the recovery area, where an abnormal TEG spurs serial testing to determine whether products are needed or coagulopathy exists. In the context of excessive bleeding, TEG is performed such that abnormal chest tube drainage accompanied by normal TEG prompts re-exploration for surgical cause of bleeding. In this group of patients, chest tube drainage was significantly lower in the post-TEG group likely because of a better ability to achieve hemostasis postoperatively. In those studies that report no reduction in the rate of re-exploration, there has been more appropriate re-exploration for bleeding (17,31). In many studies where the reduction did not meet significance, TEG allowed for more appropriate intervention where re-exploration resulted more often in findings of surgical bleeding than coagulopathy (13,16–18).

Our results are similar to others' with regard to postoperative mortality. The all-cause 6-month mortality rate was slightly lower in the post-TEG group, but this did not reach significance and could not be attributed to the assay on multivariate analysis. Whereas Weber et al. (18) noted improved 6-month mortality in patients undergoing complex cardiac surgery most studies describe no improvement with TEG-directed management. It is important to note the heterogeneity of mortality reporting as authors often provide in-hospital, 30-day mortality, or 6-month mortality estimates (13,16,28,29). Other short-term outcomes of interest were not associated with TEG in this analysis, including 30-day readmission and overall hospital LOS, also consistent with previous research (13,14,16,18,32).

The reductions in blood product use and reoperations are associated with lower costs; considering blood product acquisition costs, we estimate nearly $200,000 in savings to the hospital in the 2-year study period evaluated here. Over the 8 years since we adopted TEG, we extrapolate this amount to represent at least $700,000 in avoided blood product usage in isolated CABG cases alone. Furthermore, 15 reoperations were avoided, representing nearly $270,000 in prevented charges. We estimate nearly $1.65 million savings in avoided blood products and reoperations over the 8 years of TEG use. The cost of performing the test does not negatively impact cost to patients, as we have shown a significant reduction in total patient charges by study period, with over $5,700 savings in charges per patient.

There are many possible limitations of the current study. First, there may be limited generalizability to other facilities as this study was conducted within a single center. Because of the study design, these results do not represent a direct comparison of TEG with standard laboratory test results; rather, TEG was added to the armamentarium used to guide clinical decision-making. In addition, patients included were treated by three different surgeons and the TEG was completed and interpreted by eight perfusionists. This could introduce variability in clinical practice for which we cannot account as there was no strict transfusion protocol in place; ultimately, standard laboratory and TEG results were used to guide treatment; however, clinical situations may override test results based on surgeon choice. Cases included were not matched between study periods, for example, the number of vessels bypassed or proportion of emergent cases versus elective cases varied by study period. In addition, there were some differences noted in cross-clamp and total CPB times, which could affect results including those regarding postoperative coagulation status. Because of the retrospective nature of the study, cause-and-effect relationships cannot be determined and only associations can be inferred. Changes in clinical practice as well as the awareness of the goal to reduce transfusions and blood product use may have impacted the results over time, and it is not possible to determine how

well these clinicians adhered to institutional transfusion guidelines pre- or post-TEG. We expect that the clinical team's awareness of the need to reduce blood product did have an impact on actual practice, as this predicated the implementation of TEG for transfusion guidance. Moreover, previous research has shown that the implementation of an algorithm with point-of-care hemostatic testing can reduce transfusion, where clinician adherence was not documented, such that the culture of having an algorithm in and of itself may impact transfusion practices (33). As in any retrospective study, the quality and availability of documentation could have impacted results as well. We have continued to monitor blood product use to the present day after implementing TEG and have observed continued significant decreases in transfusion rates, which may be because of improved compliance with TEG results as well as continued institutional and cultural changes surrounding transfusion (Supplementary Table 1).

CONCLUSION

In conclusion, this retrospective observational cohort study demonstrated that the use of TEG to guide transfusion therapy practices significantly reduced the use of blood products in isolated CABG procedures. Reduction of transfusion rates of FFP and cryoprecipitate use was most marked; however, transfusion of platelets and red blood cells also decreased after TEG was implemented. Importantly, fewer patients were exposed to transfusion overall, and the use of TEG to guide decisions regarding reoperation in the context of excessive postoperative bleeding significantly reduced the rate of re-exploration. TEG provides accurate, real-time results to guide clinical decisions regarding appropriate blood transfusion and bleeding management in cardiac surgery.

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