J Extra Corpor Technol. 2017;49:283–290
The Journal of ExtraCorporeal Technology

TEG-Directed Transfusion in Complex Cardiac Surgery: Impact on Blood Product Usage

Kevin Fleming, CCP;* Roberta E. Redfern, PhD;† Rebekah L. March, MPH;‡
Nathan Bobulski, CCP;* Michael Kuehne, PhD, PA-C;§ John T. Chen, PhD;¶ Michael Moront, MD§

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

Abstract: Complex cardiac procedures often require blood transfusion because of surgical bleeding or coagulopathy. Thrombelastography (TEG) was introduced in our institution to direct transfusion management in cardiothoracic surgery. The goal of this study was to quantify the effect of TEG on transfusion rates peri- and postoperatively. All patients who underwent complex cardiac surgery, defined as open multiple valve repair/replacement, coronary artery bypass grafting with open valve repair/replacement, or aortic root/arch repair before and after implementation of TEG were identified and retrospectively analyzed. Minimally invasive cases were excluded. Patient characteristics and blood use were compared with *t* test and chi-square test. A generalized linear model including patient characteristics, preoperative and postoperative lab values, and autotransfusion volume was used to determine the impact of TEG on perioperative, postoperative, and total blood use. In total, 681 patients were identified, 370 in the pre-TEG period and 311 patients post-TEG. Patient demographics were not significantly different between periods. Mean units of red blood cells, plasma, and cryoprecipitate were significantly reduced after TEG was implemented (all, $p < .0001$); use of platelets was reduced but did not reach significance. Mean units of all blood products in the perioperative period and over the entire stay were reduced by approximately 40% (both, $p < .0001$). Total proportion of patients exposed to transfusion was significantly lower after introduction of TEG ($p < .01$). Controlling for related factors on multivariate analysis, such as preoperative laboratory values and autotransfusion volume, use of TEG was associated with significant reduction in perioperative and overall blood product transfusion. TEG-directed management of blood product administration during complex cardiac surgeries significantly reduced the units of blood products received perioperatively but not blood usage more than 24 hours after surgery. Overall, fewer patients were exposed to allogenic blood. The use of TEG to guide blood product administration significantly impacted transfusion therapy and associated costs. **Keywords:** cardiopulmonary bypass, blood conservation, point-of-care testing, thrombelastography. *J Extra Corpor Technol. 2017;49:283–290*

Cardiac procedures, particularly those which require the use of cardiopulmonary bypass (CPB), often result in perioperative bleeding requiring the use of blood product transfusion. In spite of advances in hemostatic management of these patients, it is estimated that 10–15% of the nation's blood supply is used in patients undergoing cardiac procedures (1). The Society of Thoracic Surgeons estimates from their database that approximately 50% of all cardiac surgeries require transfusions, with an even greater proportion of complex cases requiring blood product transfusion (2). CPB is accomplished by altering hemostasis; hypothermia has deleterious effects on platelet function and coagulation is compromised by fluid replacement and hemodilution, such that CPB is commonly associated with excessive blood loss and coagulopathy, even in patients without any preexisting hemostatic abnormalities (3–6). It is known that some patients are at higher risk of requiring blood transfusion before surgery: those of advanced age, decreased blood cell volume or small body size, those who suffer from anemia before or during the procedure, patients treated with anticoagulants, and those who are being treated for emergent or complex procedures are more likely to require blood products (2,4). Although clinicians are able to identify high-risk patients, it is not possible to predict the effects of surgery on each patient's hemostatic abilities, and use of blood products are associated with worse short- and long-term outcomes (2,7).

Received for publication May 2, 2017; accepted August 12, 2017.
Address correspondence to: Michael Moront, MD, Cardiothoracic Surgeons for Northwest Ohio, 2109 Hughes Drive, #720, Toledo, OH 43606. E-mail: morontmd@icloud.com
This research was presented orally at the AmSECT 55th International Conference, Boston, MA, April 29 to May 2, 2017.
The senior author has stated that the authors have reported no material, financial, or other relationship with any healthcare-related business or other entity whose products or services are discussed in this paper.

Furthermore, conservation of blood product use is expected to come at a significant cost savings; one study cited a $5,000 per patient savings in abdominal surgeries (8).

As our society continues to age, more patients undergoing surgery will begin to be included in subgroups of those who are likely to lose more blood perioperatively because of advanced age, anticoagulant use, or chronic renal failure. Many new pharmacologic agents are being used to control the use of blood products, alongside old technologies such as thromboelastography (TEG) and rotational thromboelastograms (ROTEM) which have evolved significantly and are now being applied to better predict specific blood product usage in individual patients. TEG is a point-of-care test that may be used alone or in combination with conventional coagulation analyses to guide clinicians' efforts in treating various coagulopathies. These tests have the advantage of giving immediate results, but are also beneficial because the viscoelastic analysis of clot formation provides global information on the dynamics of clot development, stabilization, and dissolution.

TEG allows for the evaluation of individual components of the hemostatic system independently as well as the interaction between platelets and the plasma coagulation system, platelet function, platelet–fibrinogen interactions, and fibrinolysis (9). There are four main measures provided after activation of the blood sample with kaolin (with or without heparinase, as appropriate) which indicate the time required for start of clot formation (R), the time from the start of clot formation until maximum firmness is reached (angle), the maximum clot firmness (MA), and the maximum fibrinolysis (LY30), reported as a percentage of MA (10). Overall, TEG gives a view of the entire process of coagulation from the activation of platelets and formation of fibrin through development of the entire clot and its eventual breakdown. Moreover, a qualitative, rather than purely quantitative measure of platelets as obtained from standard laboratory tests, can be obtained allowing for accurate identification of hemostasis aberrancies (11). In combination with a hemostatic algorithm, these tests provide rational guidance for the types and amounts of products that may be needed.

Several studies have investigated the efficacy of TEG in comparison with standard laboratory testing with clinical judgment in the reduction of blood product usage, morbidity, and mortality. Although many studies did report a decrease in the use of platelets, red blood cell (RBC), or fresh frozen plasma (FFP) units, an increase in the use of fibrinogen was often observed (1,7,9,12–15). However, many of these reports failed to find significant differences in the cumulative number of allogenic units used or in the postoperative outcomes of interest (rate of re-exploration surgery and blood loss), leaving the role of TEG in cardiac surgery controversial (9,16–19). Few studies have reported their cost savings after implementation of this type of point-of-care testing; however, initial results are promising (15,20).

Several studies suggest that TEG may benefit patients and hospitals by providing guidance in the usage of blood products, improving outcomes, and decreasing costs. Prospective studies show significant decreases in transfusion rates, whereas many retrospective studies provide varying results, perhaps because of clinicians not adhering perfectly to TEG guidance. We hypothesized that in our institution with real world use, in which surgeons use both TEG results and their own clinical experience to guide their blood product usage, TEG would have a significant impact on blood product usage in terms of cumulative (mean) units transfused as well as the proportion of patients exposed to allogenic transfusion.

MATERIALS AND METHODS

Institutional Review Board approval was obtained before commencement; informed consent was waived because of the retrospective nature of this cohort study. All patients who underwent complex cardiac surgery, defined as open multiple valve repair/replacement, coronary artery bypass grafting (CABG) with open valve repair/replacement, or aortic root/arch repair with CPB before (January 1, 2008 to December 31, 2009) and after implementation of TEG (January 1, 2011 to December 31, 2012) were retrospectively identified using the institutional billing database and reviewed via the electronic medical record. The 2010 calendar year was excluded to account for clinical learning curve. Minimally invasive cases were excluded; only patients treated by three surgeons present during both time periods were eligible for inclusion. Patient characteristics including gender, age, race, body mass index (BMI), body surface area (BSA), and preoperative medications were abstracted from the medical record. Comorbid conditions included in the calculation of Charlson comorbidity index (CCI) were recorded and CCI determined for each patient (21). Preoperative diagnosis, procedure completed, and urgency of procedure (elective, urgent, or emergent) were collected. Preoperative laboratory values including platelet count, hemoglobin, hematocrit (HCT), and standard coagulation values (partial thromboplastin time, protime, and protime international normalized ratio) were also collected.

Perioperative variables including cross clamp time, circulatory arrest time, total time on pump, first HCT in operating room (OR), lowest HCT in OR, preoperative activated clotting time (ACT), preoperative TEG kaolin heparinase (where applicable), operating time (start of operation to close), and cell saver volume returned were recorded. Perioperative blood product transfusion, including platelets (apheresis), RBCs, cryoprecipitate, and

FFP were defined as units transfused in the OR and within the first 24 hours postoperatively. Perioperative complications, particularly coagulopathy in OR, were documented. Postprotamine TEG results completed in the OR were also recorded; TEG 5000 Thromboelastograph Hemostasis Analyzer System (Haemonetics, Braintree, MA) was used in all 311 patients in the post-TEG period. Generally, the TEG results were used to guide transfusions as described in Table 1; however, this algorithm was not followed strictly and surgeon's judgment was also used to direct therapy.

Postoperative laboratory values collected during the first lab draw in the intensive care unit were recorded for comparison, as was chest tube drainage during the first 12 hours following surgery. Units of blood product transfused in the postoperative period were separated as those given within 24–48 hours after surgery and products transfused more than 48 hours after surgery. Complications during the stay, as well as hematological and coagulation laboratory tests before discharge were documented.

Intraoperative Management

Anesthesia was conducted in accordance with institutional protocols; anesthesiologists and anesthetic techniques remained consistent throughout the entire study. The extracorporeal circuit consisted of a membrane oxygenator (Sorin PrimO2X; Sorin Group USA, Arvada, CO), a roller pump system (Stockert S5; Sorin Group Deutschland GMBH, Munchen Germany), and a Quest MPS for cardioplegia (Quest MPS; Quest Medical Inc., Allen, TX). The circuit was primed with 800 mL of crystalloid solution (Normosol-R; Hospira Inc, Lake Forest, 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).

A desired ACT value of 480 seconds, determined with Hemochron Signature Elite (Accriva Diagnostics, San Diego, CA), for initiation of CPB was achieved by administration of 300 U/kg bolus dose of unfractionated heparin. Additional heparin (5,000–10,000 units) was provided intraoperatively, when needed, to maintain ACT >480 seconds. Tranexamic acid was routinely used in both study arms according to standard clinical protocol. Protamine was administered after termination of CPB at a 1:1 ratio (1 mg protamine : 100 units heparin) with regard to bolus heparin dose; postprotamine samples were collected 10 minutes after protamine dosing. In the pre-TEG period, ACT was completed, and additional protamine was given in this sample if postoperative ACT was considered clinically significantly higher than baseline preoperative levels. In the period after TEG, ACT was performed as well as kaolin and kaolin heparinase sample analysis. 50 mg additional protamine was delivered if the r-K was .5 minutes greater than r-KH, 100 mg additional protamine was administered if the difference between these measures was greater than one minute. A cell salvage device with reinfusion of shed mediastinal blood was used routinely during both study periods.

The trigger for transfusion of RBCs was the same during the entire 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 became hemostatically unstable or experienced sudden hemorrhage.

Statistical Analysis

Patient characteristics are presented with descriptive statistics and compared using student *t* test for continuous variables and chi-square test for categorical variables. Mean blood product usage was compared between time periods using student *t* test; proportion of patients exposed to allogenic transfusion as a function of operative period were compared using chi-square test. A generalized linear model including patient characteristics, preoperative and postoperative lab values, and autotransfusion volume was used to determine the impact of TEG on perioperative, postoperative, and total blood use. SAS version 9.2 (SAS Institute Inc., Cary, NC) was used for statistical analysis; two-tailed p-value $< .05$ was considered statistically significant.

Table 1. TEG result interpretation and treatment decision guidance.

TEG Result	Hemostasis State	Common Treatment
R value (minutes)		
<4	Enzymatic hypercoagulability	Anticoagulant of choice
11–14	Low clotting factors	2 units FFP
>14	Very low clotting factors	4 units FFP
MA value (mm)		
46–54	Low platelet function	.3 mcg/kg DDAVP
41–45	Very low platelet function	1 unit platelet pheresis
≤40	Extremely low platelet function	2 units platelet pheresis
>73	Platelet hypercoagulability	Antiplatelet therapy
Angle (degrees)		
<45	Low fibrinogen level	.06 units/kg cryoprecipitate

RESULTS

Six hundred eighty one patients who underwent complex cardiac surgery were identified during the entire study period. Overall, 370 underwent surgery in the years before TEG was implemented in our institution and 311 were treated after TEG was included as standard of care. Baseline patient demographics including age, gender, race, BMI, BSA, CCI, and preoperative lab values did not vary significantly between study groups (Table 2). The urgency of procedure (elective vs. emergent/urgent) and the incidence of a redo operation were also similar between pre- and post-TEG cohorts.

Perioperative characteristics were compared between study periods, as shown in Table 2. Initial laboratory values including first HCT in the OR and ACT were similar, as were circulatory arrest time and autotransfusion volume documented during surgery. The procedures performed could not be compared as they were variable combinations of those presented in Table 3. Surgeries before TEG's implementation proved to be significantly, though not clinically, longer than in the post-TEG timeframe. In addition, pre-TEG time on pump and cross clamp time was significantly longer than post-TEG. In the first 12 hours after surgery, patients treated before TEG had more drainage documented by nursing staff from chest tubes (Table 3, p = .03).

The mean units of blood products, including RBCs, FFP, cryoprecipitate, and platelets, were compared between cohorts, as shown in Table 4. The post-TEG period demonstrated significantly lower blood product use in the perioperative period (in the OR and the first 24 hours postoperatively) with regard to RBC, FFP, and cryoprecipitate. The use of platelets was reduced by 5% but did not reach statistical significance. Blood product administration in the postoperative period defined as 24–48 hours after surgery did not demonstrate significant reductions (Table 4). However, those patients treated in the post-TEG period required less blood at >48 hours after surgery than those treated before its implementation. In addition, the need for blood products during a reoperation (limited to mediastinal re-exploration for possible bleeding) was reduced in the post-TEG period, where mean units of RBCs and FFP were significantly reduced. Moreover, the overall mean blood product administration use echoes these results, the total units of all products were reduced; RBCs, FFP, and cryoprecipitate significantly so. The total number of units administered during admission per patient was reduced by approximately 40% ($p < .001$).

A generalized linear model was created to investigate factors associated with blood product use during the perioperative period and over the entire admission (Table 5). BSA, autotransfusion volume, lowest HCT while on pump,

Table 2. Baseline patient characteristics—demographic information on admission. Laboratory values represent those collected at advanced preadmissions testing for elective cases and most recent preoperative lab values for those patients undergoing emergent or urgent surgery, where available.

	Before TEG (n = 370)	After TEG (n = 311)	p-Value
Age (yr)	69.9 ± 11.3	68.9 ± 11.1	.25
BMI (kg/m^2)	31.03 ± 6.2	29.95 ± 6.2	.37
BSA (m^2)	1.99 ± .26	1.97 ± .25	.13
CCI (points)	4.99 ± 2.03	5.45 ± 2.09	.44
Preoperative Labs			
HGB (g/dL)	13.0 ± 2.14	12.8 ± 1.86	.35
HCT (%)	37.9 ± 5.72	37.8 ± 5.43	.84
Platelet count ($\times 10^9$/L)	211.7 ± 70.3	204.3 ± 64.2	.16
Protime (seconds)	14.2 ± 5.4	14.4 ± 12.1	.79
Protime INR	1.22 ± .42	1.18 ± .38	.16
Coagulation PTT (second)	35.6 ± 15.6	34.6 ± 15.4	.44
Gender			
Male	219 (59.2)	189 (60.8)	.67
Female	151 (40.8)	122 (39.2)	
Race			
African American N (%)	12 (3.3)	13 (4.2)	.71
Caucasian N (%)	326 (88.1)	279 (89.7)	
Hispanic/Latino N (%)	7 (1.9)	6 (1.9)	
Middle Eastern N (%)	4 (1.0)	2 (.6)	
Other N (%)	4 (1.0)	1 (.3)	
Unknown/Missing N (%)	17 (4.6)	10 (3.2)	
Procedure type			
Elective N (%)	330 (89.2)	262 (84.2)	.35
Urgent/Emergent N (%)	37 (10.0)	37 (11.9)	
Procedure			
Primary N (%)	301 (81.4)	261 (83.9)	.38
Redo N (%)	69 (18.6)	50 (16.1)	

CCI, Charlson Comorbidity Index; HCT, hematocrit; HGB, hemoglobin; INR, International Normalized Ratio.

Table 3. Perioperative characteristics.

	Before TEG	After TEG	*p*-Value
Surgical time (hours)	4.75 ± 1.13	4.34 ± .97	<.001
Preop ACT (second)	149.3 ± 20.2	148.4 ± 16.0	.49
First HCT in OR (%)	33.5 ± 4.48	33.4 ± 4.92	.77
Cross clamp time (minutes)	118.3 ± 36.5	104.9 ± 30.2	<.001
Time on pump (minutes)	154.1 ± 44.5	139.1 ± 37.4	.004
Circulatory arrest time (minutes)*	18.5 ± 7.2	17.8 ± 12.1	.96
Cell saver volume (mL)	1,002.8 ± 402.0	952.4 ± 417.9	.12
Chest tube drainage (mL)	763.7 ± 430.4	684.3 ± 507.0	.03
Procedure(s)			
Aortic arch replacement/repair N (%)	62 (16.8)	64 (20.6)	NA
Aortic root replacement/repair N (%)	46 (12.4)	34 (10.9)	
Mitral valve replacement/repair N (%)	235 (63.5)	193 (62.1)	
Aortic valve replacement/repair N (%)	214 (57.8)	185 (59.5)	
Tricuspid valve replacement/repair N (%)	75 (20.3)	83 (26.7)	
CABG	279 (75.4)	209 (67.2)	

*Mean given represents only those cases where circulatory arrest was used; proportion between two periods was similar (10.3% vs. 10.9%).

preoperative platelet count, 12-hour chest tube drainage, postoperative HCT, and platelet count were among factors that were strongly associated with both perioperative blood product use and total units of blood product administered. TEG was among the factors very strongly associated with the administration of blood products ($p < .001$, Table 5).

Finally, the proportion of patients exposed to allogenic blood transfusion was compared between periods using chi-square test (Table 6). Fewer patients received blood products of any type in the perioperative period (88.1 vs. 82.0%, $p = .02$), while those receiving blood 24–48 hours after surgery was not significantly different. The proportion of patients not receiving blood also increased in the post-TEG cohort when considering the >48 hours after surgery timeframe (65.4% vs. 75.9%, $p = .003$). Furthermore, fewer patients were exposed to blood products during a mediastinal re-exploration in the post-TEG period (3.2% vs. 7.6%).

Table 4. Blood product usage.

	Before TEG ($n = 370$)	After TEG ($n = 311$)	*p*-Value
	Mean ± SEM	Mean ± SEM	
Perioperative			
RBC	2.99 ± .14	2.38 ± .13	.002
FFP	2.15 ± .09	.70 ± .07	<.001
Cryo	.91 ± .07	.17 ± .03	<.001
Platelets	1.28 ± .05	1.26 ± .08	.83
>24 and <48 hours			
RBC	.43 ± .04	.34 ± .04	.13
FFP	.008 ± .006	.04 ± .02	.17
Cryo	0 ± 0	0 ± 0	N/A
Platelets	.02 ± .008	.02 ± .008	.99
>48 hours			
RBC	1.11 ± .17	.60 ± .11	.01
FFP	.22 ± .06	.03 ± .01	.006
Cryo	.02 ± .01	.01 ± .007	.55
Platelets	.11 ± .04	.07 ± .02	.40
Reoperative			
RBC	.25 ± .06	.10 ± .04	.04
FFP	.07 ± .02	.009 ± .007	.007
Cryo	.05 ± .02	.02 ± .01	.25
Platelets	.04 ± .01	.04 ± .01	.70
Total RBC	4.78 ± .26	3.41 ± .20	<.001
Total FFP	2.45 ± .12	.80 ± .08	<.001
Total cryoprecipitate	.98 ± .07	.20 ± .03	<.001
Total platelets	1.45 ± .07	1.38 ± .09	.53
Total units periop	7.33 ± .28	4.44 ± .24	<.001
Total units 24–48 hours	.46 ± .04	.39 ± .06	.37
Total units >48 hours	1.46 ± .23	.73 ± .13	.005
Total units reop	.41 ± .10	.17 ± .06	.03
Total units over stay	9.66 ± .44	5.79 ± .34	<.001

Table 5. Multivariate analysis of factors associated with blood product administration during the perioperative period (in OR and first 24 hours) and over the entire length of stay.

Intercept	DF	Mean Square	*F* Value	Pr > *F*
Perioperative units blood products				
BSA	1	166.73	15.1	.0001
CCI	1	25.68	2.32	.13
First HCT in OR	1	32.98	2.98	.08
Cell save volume (mL)	1	1,151.30	104.02	<.0001
Lowest HCT on pump	1	495.29	44.75	<.0001
Preop HGB	1	53.95	4.87	.03
Preop platelet count	1	173.56	15.68	<.0001
Medications: Anticoagulant	1	.058	.01	.94
Medications: Antiplatelet	1	2.778	.25	.62
12-hour chest tube drainage	1	1,804.73	163.05	<.0001
Postop HGB	1	9.52	.86	.35
Postop HCT	1	387.51	35.01	<.0001
Postop platelet count	1	108.32	9.79	.002
Complication: Coagulopathy	1	14.16	1.28	.26
TEG	1	920.98	83.21	<.0001
Total units blood products				
BSA (m^2)	1	240.48	8.42	.004
CCI	1	172.73	6.05	.01
First HCT in OR	1	30.78	1.08	.30
Cell save volume (mL)	1	1,752.19	61.38	<.0001
Lowest HCT on pump	1	656.79	23.01	<.0001
Preop HGB	1	91.81	3.22	.07
Preop platelet count	1	438.36	15.36	.0001
Medications: Anticoagulant	1	3.93	.14	.71
Medications: Antiplatelet	1	4.38	.15	.70
12 hour chest tube drainage	1	3,023.89	105.93	<.0001
Postop HGB	1	4.70	.16	.69
Postop HCT	1	405.90	14.22	.0002
Postop platelet count	1	585.65	20.52	<.0001
Complication: Coagulopathy	1	61.10	2.14	.14
TEG	1	1,644.14	57.60	<.0001

DF, degrees of freedom.

DISCUSSION

Our results demonstrated the use of TEG intra- and postoperatively enabled identification of the appropriate allogeneic blood products to achieve hemostasis in complex cardiac surgeries, which reduced the overall number of units used and decreased patient exposure. Empirical transfusion practices, guided by standard laboratory tests and clinical judgment as in the pre-TEG group, often results in overtreatment of blood products. The TEG analysis differs from and complements standard tests (e.g., prothrombin time [PT], activated partial thromboplastin time (aPTT), and platelet count) by measuring the dynamic functions involved in clot formation and breakdown. The TEG's ability to examine specific aspects of coagulation allows us to pinpoint any existing blood component deficiencies that may cause bleeding. These results enabled identification of the appropriate blood product (platelets, FFP, and cryoprecipitate) to be administered to avoid coagulopathy in our complex cardiac patients. Furthermore, this study shows that the use of TEG to guide transfusion therapy was successful in decreasing unnecessary transfusions regarding RBCs, FFP, and cryoprecipitate thus reducing transfusion exposure and individualizing patient blood management.

Table 6. Allogenic blood product exposure.

Blood Received, *n* (%)	Before TEG N (%)	After TEG	*p*-Value
Perioperative			
Yes	326 (88.1)	255 (82.0)	.02
No	44 (11.9)	56 (18.0)	
24–48 hours			
Yes	102 (27.6)	69 (22.2)	.11
No	268 (72.4)	242 (77.8)	
>48 hours			
Yes	128 (34.6)	75 (24.1)	.003
No	242 (65.4)	236 (75.9)	
Reoperative period			
Yes	26 (7.6)	10 (3.2)	.03
No	344 (92.4)	301 (96.8)	

Treatment of coagulopathy in complex cardiac surgeries can be an elusive problem. Despite multimodal blood conservation interventions and pharmacological strategies used to minimize the need for blood components in cardiac surgery, transfusion of blood products during complex cardiac surgery procedures is often necessary. Compared with those undergoing simple cardiac procedures, particularly isolated CABG, this complex surgical patient population is typically older, sicker, and more prone to hemostatic disorders. The fact that the administration of platelets was not significantly reduced in this cohort could be due to the nature of complex surgeries and the specific impact on platelet function and number. Previous studies of CABG only populations have reported a significant decrease in the use of platelet transfusion with thrombelastography (9). Conversely, a retrospective study of mixed cardiac cases suggested an increase in platelet use in the context of reduced overall blood product usage with the implementation of ROTEM, whereas nonsignificant reductions in platelet use have also been reported in aorta-only cases (12,22). There is a predictable increase in platelet dysfunction during complex cases because of longer pump times and mechanical damage resulting in thrombocytopenia, which contribute to increased blood loss and derangements of hemostasis (11,23). It is known that prolonged CPB impacts the functionality of platelets because of activation and loss of certain receptors, exposure to heparin, hemodilution, and direct contact with the artificial surfaces of the CPB circuit; in this study, there was not a clinically significant difference in the CPB times in the two study periods (24,25). The lack of significant platelet transfusion reduction in the post-TEG group in this study indirectly supports the need for empirical platelet transfusions during high risk complex cardiac surgeries. It is important to reiterate that the purpose of TEG-directed transfusion is not only to minimize unnecessary transfusions, but to make them meaningful to prevent coagulopathy.

Coagulation factors and fibrinogen have been shown to be less affected by the extracorporeal circuit and increased pump times in comparison to platelet function, which might explain the reduced need for FFP and cryoprecipitate compared with platelets in complex surgeries with extended pump times. In this analysis, substantial reductions in the use of FFP (67.5%) and cryoprecipitate (81.3%) were observed perioperatively in the TEG-directed group compared with the pre-TEG group. These results echo the reports of previous studies which have reported more dramatic impact on FFP and cryoprecipitate usage with TEG (26,27). Importantly, the current report is a real-world view of how TEG in combination with other tests and clinical judgment impacted product use, as opposed to a randomized clinical trial with strict algorithm adherence.

Allogeneic RBC transfusions in the post-TEG group were also significantly reduced in this cohort with mean units transfused reduced by 20.5% peri-operatively ($p < .0001$). Although not directly related to TEG parameter guidance, there may be a relationship between maintaining the patients' initial red cell mass with reduced hemodilution with non-red cell blood products such as FFP. Both of our study groups had similar transfusion triggers (Hgb $\leq$ 7 g/dL), although it is not possible to rule out variations in these transfusion practices among the operating surgeons. However, starting HCT and BSA, both key factors related to RBC transfusion due to anemia and small patient body size (circulating blood volume) were not different between the groups. These data are comparable to previous reports which have observed lower RBC transfusion rates in cardiac patients with TEG guidance. A meta-analysis of TEG and ROTEM studies found that odds of RBC transfusion was approximately .62 over all studies; importantly, this was similar (.54) when considering only randomized controlled trials, suggesting the test performs similarly in real-world situations (28).

In the pre-TEG group, conventional/empirical protocols with clinical judgment were used to treat bleeding. Although necessary to avoid patient hemorrhage, the conventional approach often leads to blindly transfusing the patients with blood products to treat critical coagulopathy. Conventional lab tests such as PT and aPTT are often not used in these intraoperative situations because of lengthy turn-around time which have been reported to range from 29 to 235 minutes (28,29).

At our institution, the TEG is operated by perfusionists in the immediate vicinity of the cardiac ORs, providing true-point-of-care information. The addition of TEG technology to our practice arms the surgeon with novel, timely knowledge regarding the patient's hemostatic requirements during the critical moments of cardiac surgery. Using preoperative standard laboratory tests and clinical diagnosis in addition to TEG assessments provides a complete hemostasis picture. Interpretations regarding coagulation imbalances were more accurate using information including TEG-directed values with standard test results, as information of both platelet quantity and quality was available. In the postoperative setting, the surgeon had more accurate knowledge on whether post-operative bleeding was surgical (requiring operative repair) or related to impaired clotting which could be remedied with additional blood components. Because heparin rebound can be misdiagnosed as a surgical bleed resulting in unnecessary mediastinal re-exploration, incomplete heparin reversal and heparin rebound can be eliminated as a cause for bleeding first with the use of the K and KH assay (30). Any remaining circulating heparin is answered with the administration of additional protamine. A bleeding patient with a "normal" TEG would suggest the need for re-exploration. In this way, TEG is able to help reduce the use of blood products postoperatively and impact the use of blood products during reoperations.

There are several known limitations of the current study. First, this study was conducted within a single center, which may limit generalizability to other facilities. The study was retrospective in nature, such that it was neither possible to assign interventions to the patients nor to blind any of the study staff to the interventions received. Because of the study design, the results and management directed by TEG cannot be directly compared with the results and management directed by standard laboratory tests; the period after implementation of TEG represents a combination of the results of standard tests, TEG, and clinical judgment. Furthermore, three separate surgeons were included in the study, and the TEG was completed and interpreted by eight different perfusionists over the study period; there was no analysis to determine whether there were practice differences between any of the staff involved, and because no strict transfusion protocol was followed, this could introduce variability for which we cannot account. It is possible that in the post-TEG period, clinicians were aware of initiatives to reduce blood product use, which could introduce bias. In addition, the complex cases that were included were not matched between study periods nor tightly controlled, for example, the proportion of emergent cases vs. elective cases. Moreover, because aorta procedures were included alongside multivalve and CABG/valve cases, the impact of TEG and relative reductions observed may not be representative of every case type included. Finally, all transfusions were included, regardless of the cause. As such, differences in those >48 hours in particular, may be due to other complications occurring after cardiac surgery, but not necessarily related. For example, two patients received massive blood transfusions for gastrointestinal bleeding and are represented in the >48-hour transfusion category. Similarly, practice differences and adherence to transfusions triggers by attending and consulting

physicians more than 48 hours after surgery may not have been consistent, limiting comparability.

CONCLUSION

In conclusion, this observational cohort study demonstrated that the use of thrombelastography to guide transfusion therapy practices significantly reduced the use of blood products in complex cardiac cases which are often prone to bleeding and require transfusion perioperatively. The changes observed were most drastic with regards to FFP and cryoprecipitate; however, the use of packed RBCs was also significantly lower with TEG-directed transfusion. Overall, the success of TEG requires physician support, as well as skilled operation and interpretation. This will provide accurate, reliable results that can be used real time to make allogenic transfusion decisions, which are often left to clinical judgment and experience alone.

REFERENCES

1. Westbrook AJ, Olsen J, Bailey M, et al. Protocol based on thromboelastograph (TEG) out-performs physician preference using laboratory coagulation tests to guide blood replacement during and after cardiac surgery: A pilot study. Heart Lung Circ. 2009;18:277–88.
2. Ferraris VA, Brown JR, Despotis GJ, et al. 2011 update to the Society of Thoracic Surgeons and the Society of Cardiovascular Anesthesiologists blood conservation clinical practice guidelines. Ann Thorac Surg. 2011;91:944–82.
3. Mahdy AM, Webster NR. Perioperative systemic haemostatic agents. Br J Anaesth. 2004;93:842–58.
4. Hartmann M, Sucker C, Boehm O, et al. Effects of cardiac surgery on hemostasis. Transfus Med Rev. 2006;20:230–41.
5. Levy JH, Sniecinski RM. Prohemostatic treatment in cardiac surgery. Semin Thromb Hemost. 2012;38:237–43.
6. Lee GC, Kicza AM, Liu KY, et al. Does rotational thromboelastometry (ROTEM) improve prediction of bleeding after cardiac surgery? Anesth Analg. 2012;115:499–506.
7. Weber CF, Gorlinger K, Meininger D, et al. Point-of-care testing: A prospective, randomized clinical trial of efficacy in coagulopathic cardiac surgery patients. Anesthesiology. 2012;117:531–47.
8. Jensen LS, Grunnet N, Hanberg-Sorensen F, et al. Cost-effectiveness of blood transfusion and white cell reduction in elective colorectal surgery. Transfusion. 1995;35:719–22.
9. Ak K, Isbir CS, Tetik S, et al. Thromboelastography-based transfusion algorithm reduces blood product use after elective CABG: A prospective randomized study. J Card Surg. 2009;24:404–10.
10. Anderson L, Quasim I, Soutar R, et al. An audit of red cell and blood product use after the institution of thromboelastometry in a cardiac intensive care unit. Transfus Med. 2006;16:31–9.
11. Aoki K, Sugimoto A, Nagasawa A, et al. Optimization of thromboelastography-guided platelet transfusion in cardiovascular surgery. Gen Thorac Cardiovasc Surg. 2012;60:411–6.
12. Girdauskas E, Kempfert J, Kuntze T, et al. Thromboelastometrically guided transfusion protocol during aortic surgery with circulatory arrest: A prospective, randomized trial. J Thorac Cardiovasc Surg. 2010;140:1117–24 e2.
13. Johansson PI, Solbeck S, Genet G, et al. Coagulopathy and hemostatic monitoring in cardiac surgery: An update. Scand Cardiovasc J. 2012; 46:194–202.
14. Rafiq S, Johansson PI, Ostrowski SR, et al. Hypercoagulability in patients undergoing coronary artery bypass grafting: Prevalence, patient characteristics and postoperative outcome. Eur J Cardiothorac Surg. 2012;41:550–5.
15. Spalding GJ, Hartrumpf M, Sierig T, et al. Bedside thrombelastography. Cost reduction in cardiac surgery. Anaesthesist. 2007;56: 765–71.
16. Cui Y, Hei F, Long C, et al. Perioperative monitoring of thromboelastograph on blood protection and recovery for severely cyanotic patients undergoing complex cardiac surgery. Artif Organs. 2010;34: 955–60.
17. Hvas AM, Boas TW, Jensen M, et al. Change in hemostatic intervention after implementation of thromboelastometry. J Cardiothorac Vasc Anesth. 2012;26:227–31.
18. Wikkelsoe AJ, Afshari A, Wetterslev J, et al. Monitoring patients at risk of massive transfusion with thrombelastography or thromboelastometry: A systematic review. Acta Anaesthesiol Scand. 2011;55: 1174–89.
19. Zisman E, Eden A, Shenderey A, et al. The effect of acute autologous blood transfusion on coagulation dysfunction after cardiopulmonary bypass. Eur J Anaesthesiol. 2009;26:868–73.
20. Christensen MC, Krapf S, Kempel A, et al. Costs of excessive postoperative hemorrhage in cardiac surgery. J Thorac Cardiovasc Surg. 2009;138:687–93.
21. Charlson ME, Pompei P, Ales KL, et al. A new method of classifying prognostic comorbidity in longitudinal studies: Development and validation. J Chronic Dis. 1987;40:373–83.
22. Gorlinger K, Dirkmann D, Hanke AA, et al. 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;115:1179–91.
23. Aldea GS, Soltow LO, Chandler WL, et al. Limitation of thrombin generation, platelet activation, and inflammation by elimination of cardiotomy suction in patients undergoing coronary artery bypass grafting treated with heparin-bonded circuits. J Thorac Cardiovasc Surg. 2002;123:742–55.
24. Besser MW, Klein AA. The coagulopathy of cardiopulmonary bypass. Crit Rev Clin Lab Sci. 2010;47:197–212.
25. Paparella D, Brister SJ, Buchanan MR. Coagulation disorders of cardiopulmonary bypass: A review. Intensive Care Med. 2004;30: 1873–81.
26. Shore-Lesserson L, Manspeizer HE, DePerio M, et al. Thromboelastography-guided transfusion algorithm reduces transfusions in complex cardiac surgery. Anesth Analg. 1999;88:312–9.
27. Royston D, von Kier S. Reduced haemostatic factor transfusion using heparinase-modified thrombelastography during cardiopulmonary bypass. Br J Anaesth. 2001;86:575–8.
28. Bolliger D, Tanaka KA. Roles of thrombelastography and thromboelastometry for patient blood management in cardiac surgery. Transfus Med Rev. 2013;27:213–20.
29. Gorlinger K, Shore-Lesserson L, Dirkmann D, et al. Management of hemorrhage in cardiothoracic surgery. J Cardiothorac Vasc Anesth. 2013;27(Suppl):S20–34.
30. Galeone A, Rotunno C, Guida P, et al. Monitoring incomplete heparin reversal and heparin rebound after cardiac surgery. J Cardiothorac Vasc Anesth. 2013;27:853–8.