Thromboelastography-Guided Transfusion Algorithm Reduces Transfusions in Complex Cardiac Surgery

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Transfusion therapy after cardiac surgery is empirically guided, partly due to a lack of specific point-of-care hemostasis monitors. In a randomized, blinded, prospective trial, we studied cardiac surgical patients at moderate to high risk of transfusion. Patients were randomly assigned to either a thromboelastography (TEG)-guided transfusion algorithm ($n = 53$) or routine transfusion therapy ($n = 52$) for intervention after cardiopulmonary bypass. Coagulation tests, TEG variables, mediastinal tube drainage, and transfusions were compared at multiple time points. There were no demographic or hemostatic test result differences between groups, and all patients were given prophylactic antifibrinolytic therapy. Intraoperative transfusion rates did not differ, but there were significantly fewer postoperative and total transfusions in the TEG group. The proportion of patients receiving fresh-frozen plasma (FFP) was 4 of 53 in the TEG group compared with 16 of 52 in the control group ($P < 0.002$). Patients receiving platelets were 7 of 53 in the TEG group compared with 15 of 52 in the control group ($P < 0.05$). Patients in the TEG group also received less volume of FFP (36 ± 142 vs 217 ± 463 mL; $P < 0.04$). Mediastinal tube drainage was not statistically different 6, 12, or 24 h postoperatively. Point-of-care coagulation monitoring using TEG resulted in fewer transfusions in the postoperative period. We conclude that the reduction in transfusions may have been due to improved hemostasis in these patients who had earlier and specific identification of the hemostasis abnormality and thus received more appropriate intraoperative transfusion therapy. These data support the use of TEG in an algorithm to guide transfusion therapy in complex cardiac surgery. **Implications:** Transfusion of allogeneic blood products is common during complex cardiac surgical procedures. In a prospective, randomized trial, we compared a transfusion algorithm using point-of-care coagulation testing with routine laboratory testing, and found the algorithm to be effective in reducing transfusion requirements.

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Despite numerous advances in technologic and pharmacologic therapy to improve hemostasis, cardiac surgical procedures still consume 10%–20% of the nation's supply of allogeneic blood products (1). Partly responsible for this large consumption is the perceived absence of an accurate, affordable, and well accepted array of bedside tests of the hemostatic system that are able to specifically detect those physiologic derangements contributing to a coagulopathy. The institution of extracorporeal circulation has well documented effects on the hemostatic and fibrinolytic systems and results in platelet dysfunction, coagulation factor activation and depletion, and fibrinolysis (2). Strategies to reduce bleeding, such as the collection and reinfusion of autologous blood products (3), alterations in heparin and protamine dosing (4), and the prophylactic use of antifibrinolytic therapy (5), have allowed reductions in mediastinal tube drainage (MTD) and transfusion requirements; however, microvascular bleeding and transfusions still occur (6). The ability to further reduce empiric transfusions in a high-risk population that is already prophylactically treated with some of the aforementioned strategies will be dependent on point-of-care tests that measure the integrity of the hemostatic system. The resulting rapid reporting of test results that interrogate the platelets, coagulation cascade, and the fibrinolytic system would lead to more appropriate and discriminating transfusion practices in cardiac surgery.

A transfusion algorithm that measures platelet number and the coagulation system has been proposed by Despotis et al. (7), and results in reduced transfusion requirements compared with standard transfusion practices. However, this algorithm does not use a test of platelet function, a frequently cited cause of postcardiopulmonary bypass (CPB) coagulopathy. Thromboelastography (TEG) is a point-of-care viscoelastic measure of

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clot formation and clot dissolution that measures coagulation, platelet function (8), platelet-fibrinogen interactions, and fibrinolysis. Prior studies have retrospectively documented reduced bleeding and reoperation rates using TEG monitoring (9). Our hypothesis was that using TEG as a point-of-care test of the hemostatic system would result in prompt identification of hemostasis disorders and a reduction in transfusion requirements compared with laboratory-based testing. This would help to reduce the costs and risks associated with allogeneic transfusions. In a prospective, randomized trial, we compared bleeding and transfusion requirements in cardiac surgical patients at moderate to high risk of microvascular bleeding using a TEG-guided algorithm or standard laboratory coagulation testing.

Methods

This research protocol was approved by our Institutional Review Board, and all patients gave written, informed consent to participate. Adult patients were recruited if they were undergoing a cardiac surgical procedure that had a moderate to high risk for requiring a transfusion. These criteria were determined according to the classification of Hardy et al. (10), in which coronary artery bypass grafting patients had the least transfusions, followed by valvular procedures, which had intermediate blood usage, and combined procedures, which had the highest utilization. Thus, the current study included patients undergoing single valve replacement, multiple valve replacement, combined coronary artery bypass plus valvular procedure, cardiac reoperation, or thoracic aortic replacement. Patients were excluded from enrollment if they had significant preexisting hepatic disease (transaminase levels >2 times control) or renal disease requiring dialysis, or if they required preoperative inotropic support. Patients receiving preoperative heparin infusion and those who had taken aspirin within the past 7 days were included.

In a prospective fashion, using a table of random numbers, patients were randomly assigned to receive either algorithm-based transfusion therapy (TEG) or standard laboratory-based transfusion therapy (control). At the onset of surgery, the patient received prophylactic antifibrinolytic therapy (ε-aminocaproic acid [EACA] 150 mg/kg IV bolus followed by an infusion of 15 $mg \cdot kg^{-1} \cdot h^{-1}$) at the discretion of the attending anesthesiologist. CPB was conducted in the standard fashion using moderate hypothermia, membrane oxygenator, arterial line filtration, and nonheparin-coated circuits. Anticoagulation for CPB was accomplished with bovine lung heparin (Fujisawa USA Inc., Deerfield, IL) 300 U/kg administered into the right atrium by the surgeon. Celite activator was used to measure the activated clotting time (ACT); Hemochron; International Technidyne Corp., Edison, NJ). ACT >400 s was accepted as adequate anticoagulation for CPB. Additional heparin in 5000-U increments was administered to maintain the ACT at least 400 s. Protamine (Elkins Sinn Inc., Cherry Hill, NJ) was given in a ratio of 1 mg/100 U of the total heparin dose and was administered over a 20-min period.

Baseline coagulation testing in all patients included a platelet count, prothrombin time (PT), activated partial thromboplastin time (aPTT), fibrinogen level, and a celite and tissue factor (TF)-activated TEG. During rewarming on CPB, a platelet count and a celite and TF-activated TEG with heparinase modification were measured. After protamine administration, PT, aPTT, fibrinogen level, and celite and TF-activated TEG were measured. Additional testing at this time included a heparinase-modified celite-activated TEG to rule out residual heparinization. The specific TEG variables that were measured included reaction time (R time; 2 mm = 1 min), α angle, maximal amplitude (MA), and lysis index at 30 min (LY30; percent reduction of MA at 30 min).

The TEG analyzer was turned on and allowed to warm to 37°C. Celite-activated TEG was performed on whole blood added to a 1-mL volume bullet containing celite activator. The total sample volume for TEG analysis was 360 μL. TF-activated TEG was performed using 10 μL of TF (ORTHO RecombiPlasTin® Hemoliance; Ortho Diagnostic Systems Inc., Raritan, NJ) placed in the cuvette to which 350 μL of whole blood was added to yield a total sample volume of 360 μL.

The anesthesiologist and surgeon caring for the patient were blinded to the patient's group assignment. All intraoperative results of the TEG and laboratory coagulation tests were interpreted by an anesthesiologist investigator not directly involved with the patient's care. The recommended therapy according to the patient's group assignment was communicated to the anesthesiologist and surgeon by this investigator, as appropriate. The platelet count and TEG (TEG group only) measured during CPB were used to determine the blood products that would be ordered from the blood bank. The coagulation test results obtained after protamine administration were used to direct actual transfusion therapy according to the group assignment. Transfusions were administered only in the event of significant clinical bleeding in conjunction with an abnormal test result. If clinical bleeding was not diagnosed, no transfusions were administered. Significant bleeding was defined objectively as >100 mL in a 3-min period or subjectively as the absence of visible clots in the surgical field. Packed red blood cells (PRBCs) were transfused when the hematocrit (Hct) was <25%. During CPB, a Hct of 21% was accepted. Transfusion of non-red blood cell (RBC) component therapy was performed according to the following protocol.

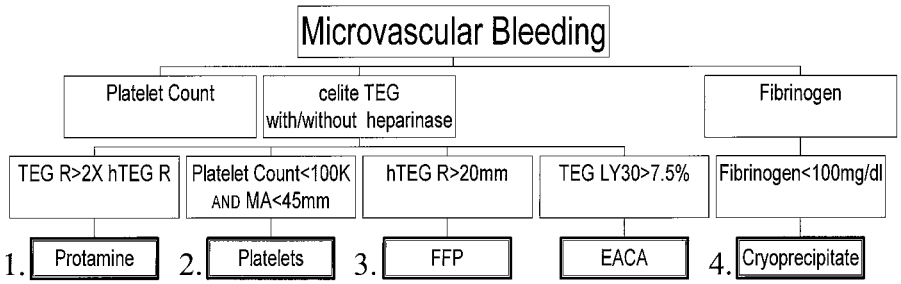

Figure 1. Algorithm for transfusion requirements in the thromboelastography (TEG) group. Once bleeding was diagnosed, patients received blood transfusions based on the results of the tests in the algorithm. Based on the assumption that bleeding is often platelet-related and on the fact that the platelet count and TEG results return promptly, therapy was given in the numbered order of priority. hTEG = heparinase-activated TEG, R = reaction time, MA = maximum amplitude, FFP = fresh-frozen plasma, LY30 = lysis index at 30 min, EACA = ϵ-aminocaproic acid.

In the patients randomized to the TEG group, data from the celite-activated TEG was used to guide transfusion therapy 10 min after protamine completion (Figure 1). Transfusion therapy was prescribed in the presence of bleeding:

1. Additional protamine (50 mg) was given if the heparinase modified TEG R time was less than one half of the non-heparinase R time.
2. If bleeding persisted, 6 U of platelets was transfused if platelet count <100,000/μL AND TEG MA <45 mm.
3. If bleeding persisted, 2 U of fresh-frozen plasma (FFP) was given if R time was >20 mm.
4. If bleeding persisted, 10 U of cryoprecipitate was transfused if fibrinogen level <100 mg/dL.
5. If bleeding persisted and if the TEG showed evidence of fibrinolysis (LY30 > 7.5%), additional antifibrinolytic therapy (EACA 10 g) was given at the discretion of the physicians caring for the patient. In both groups, if a patient received a transfusion, the abnormal tests were repeated and treated in accordance with the algorithm as long as the patient was still in the operating room.

In the patients randomized to the control group, data from laboratory-based tests were used to guide transfusion therapy 10 min after protamine completion (Figure 2).

1. Additional protamine (50 mg) was given if ACT exceeded baseline by 15%.
2. If bleeding persisted, 6 U of platelets was transfused if platelet count <100,000/μL.
3. If bleeding persisted, 2 U of FFP was given if PT >150% of control.
4. If bleeding persisted, 10 U of cryoprecipitate was transfused if fibrinogen level <100 mg/dL.
5. If bleeding persisted and if above therapy failed to reduce bleeding, an additional bolus of antifibrinolytic therapy (EACA 10 g) was given at the discretion of the physicians caring for the patient.

Postoperative blood loss into mediastinal drainage tubes was measured at 6-h intervals, and transfusion requirements were recorded for 2 days postoperatively. If, at any time, life-threatening hemorrhage was diagnosed by the anesthesiologist and/or surgeon, transfusion therapy was permitted empirically before obtaining the appropriate laboratory results. Transfusions in the intensive care unit (ICU) after the first postoperative hour were performed at the discretion of the ICU physician, who was blinded to the patient's group assignment.

The data were analyzed for differences between the TEG and the control groups with regard to transfusions and postoperative bleeding. The MA values of TF-activated samples were compared with those of celite-activated samples to establish that MA is unaffected by the type of activator used. The R time value was compared between TF- and celite-activated samples to document the acceleration of fibrin formation and the earlier appearance of MA when using TF. Normally distributed continuous data were analyzed using Student's *t*-test or two-way analysis of variance. Nonparametric data were analyzed using the Mann-Whitney *U*-test. Categorical data, such as transfusion incidence, were subject to χ^2 analysis. Repeated-measures analysis of variance was used to analyze coagulation test results throughout the perioperative period, with $P < 0.05$ considered statistically significant. All analyses were two-tailed.

Using preliminary data on the incidence of transfusions in complex cardiac operations, a power analysis was conducted to determine the number of patients needed to determine with 90% power and $\alpha = 0.05$ that our intervention would significantly reduce transfusions in this patient population. If the algorithm allowed a reduction in such transfusions from 85% to 50% of high-risk patients, 200 patients would need to be studied. We designed the study to examine the data after 100 patients were enrolled, using an extension based on conditional power (11). If, after 100 patients were studied, the incidence of transfusion using the TEG-based algorithm was significantly lower than that using standard laboratory tests (with $\alpha = 0.02$), the study would be halted and the algorithm would be recommended for all comparable cardiac procedures (11). If significance was not found, 100 additional patients would be enrolled, and the subsequent significance level would be set at $\alpha = 0.03$ to ensure an overall significance level $P < 0.05$.

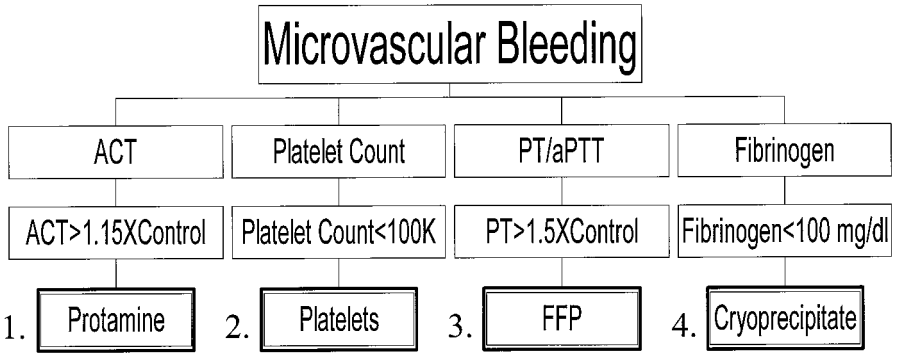

Figure 2. Algorithm for transfusion requirements in the control group. Once bleeding was diagnosed, patients received blood transfusions based on the results of the tests in the algorithm. Based on the assumption that bleeding is often platelet-related and on the fact that the platelet count results return promptly, therapy was given in the numbered order of priority. ACT = activated clotting time, PT = prothrombin time, aPTT = activated thromboplastin time, FFP = fresh-frozen plasma.

Results

One hundred seven patients were enrolled in the protocol, and 105 patients fully completed the protocol. One patient enrolled but not studied was undergoing cardiac reoperation and was placed emergently on CPB because of massive hemorrhage during sternotomy. The patient was excluded from the study at this time. The other patient who did not complete the protocol was excluded due to a severe protamine reaction that required immediate reinstitution of CPB. Both of these patients were in the TEG group.

Two patients (both in the control group) died from hemodynamic causes in the postoperative period, and two patients (both in the control group) were reexplored for postoperative bleeding. In one patient, a specific surgical source of bleeding was discovered. This patient's bleeding and transfusion data were excluded from analysis, because he received multiple blood products as a result of surgical bleeding. One patient (in the TEG group) suffered a postoperative cerebrovascular ischemic event.

The demographic characteristics of each group are listed in Table 1. There were no statistical differences in demographic variables between the two groups. All patients were administered EACA therapy at the dose described in Methods. Laboratory tests of coagulation and TEG variables differed significantly with time but were not different between the TEG and control groups. Tables 2 and 3 provide a comparison of coagulation tests and TEG variables between the two groups. Data in Table 3 demonstrate the significantly shortened R time value using TF activation compared with celite activation. Initial fibrin formation occurred in approximately 3 min using TF activation.

In the postprotamine interval, five patients in the TEG group had evidence of residual circulating heparin, and all were given additional protamine. Three patients in the control group had ACT >15% above baseline and were given additional protamine. Five patients in the TEG group and two patients in the control group had evidence of fibrinolysis indicated by the LY30 >7.5%. No patients in either group had life-threatening hemorrhage that necessitated the transfusion of allogeneic blood products before obtaining hemostatic test results.

Table 1. Demographic Variables

	TEG	Control
Age (yr)	64.5 ± 15	67.1 ± 14.5
Gender (male/female)	27/25	33/19
Weight (kg)	70 ± 25	74 ± 18
Procedure type by transfusion risk[a]		
Moderate[b]	16 (31)	17 (33)
High[c]	35 (69)	34 (67)
Preoperative hematocrit (%)	36.7 ± 7.1	36.7 ± 5.0
CPB time (min)	163 ± 60	167 ± 71
Cross-clamp time (min)	101 ± 47	122 ± 57
Minimal temperature (°C)	19.2 ± 5.0	19.9 ± 5.7
Total heparin dose (kU)	23.4 ± 11.8	24.4 ± 11.3
Total protamine dose (mg)	281 ± 109	286 ± 119

Values are mean ± SEM or *n* (%).
TEG = thromboelastography, CABG = coronary artery bypass grafting, CPB = cardiopulmonary bypass.
[a] Hardy et al. (9).
[b] Single valve, repeat CABG.
[c] Combined procedures, repeat valve.

Six-hour MTD (including the volume reinfused) was 362 ± 274 mL in the TEG group compared with 469 ± 637 mL in the control group, ($P = 0.63$). Twenty-four–hour MTD was 702 ± 500 mL in the TEG group compared with 901 ± 847 mL in the control group ($P = 0.27$). The overall incidence of transfusion was 22 of 53 (41.5%) in the TEG group compared with 34 of 52 (65.4%) in the control group ($P = 0.01$). The overall incidence of non-RBC transfusion was 7 of 53 (13%) in the TEG group and 17 of 52 (33%) in the control group ($P < 0.02$). Table 4 displays the differences in transfusion volumes and transfusion incidence in the intraoperative and postoperative periods, as well as the total transfusion requirements in each group.

Discussion

In our population of moderate to high-risk cardiac surgical patients, using TEG-guided hemostasis monitoring resulted in a reduction in transfusion volume

Table 2. Coagulation Data

	Baseline		Warming on CPB		Postprotamine		ICU	
	TEG	Control	TEG	Control	TEG	Control	TEG	Control
ACT (s) (90–120 s)	165 ± 34	170 ± 49	—	—	158 ± 93	149 ± 20*	—	—
Platelets (×1000/μL) (120–500 ×1000/μL)	203 ± 66	200 ± 78	92 ± 79†	96 ± 79†	NA	NA	111 ± 48†	120 ± 48†
PT (s) (12–14 s)	13.0 ± 1.1	12.9 ± 1.3	—	—	18.1 ± 2.3*	21.3 ± 26†	16.1 ± 1.7	15.7 ± 1.6
aPTT (s) (25–34 s)	31.6 ± 6.9	34.1 ± 13.1	—	—	52.2 ± 48.0†	43.0 ± 14	35.9 ± 6.1	36.8 ± 10.2
Fibrinogen (mg/dL) (150–500 mg/dL)	409 ± 82	416 ± 118	—	—	239 ± 86†	246 ± 86†	259 ± 95†	263 ± 118†

Normal range is in parentheses.
CPB = cardiopulmonary bypass, ICU = intensive care unit, ACT = activated clotting time, PT = prothrombin time, aPTT = activated partial thromboplastin time, TEG = thromboelastography.
* $P < 0.05$ versus baseline.
† $P < 0.01$ versus baseline.

Table 3. Thromboelastography Data

	Baseline		Warming on CPB		Postprotamine	
	TEG	Control	TEG	Control	TEG	Control
R celite (mm) (7–14 mm)	15.1 ± 6.4	14.2 ± 5.9	10.5 ± 5.2	9.9 ± 3.9	15.4 ± 7.3	15.6 ± 7.1
R celite + heparinase (mm)	NM	NM	NM	NM	13.8 ± 9.5	14.6 ± 7.9
α celite (°) (61–73°)	63 ± 10	67 ± 8	62 ± 10	64 ± 11	55 ± 18*	53 ± 20*
MA celite (mm) (56–65 mm)	66 ± 6	69 ± 7	55 ± 11*	56 ± 9*	57 ± 7*	58 ± 9*
R tissue factor (mm)†	6.4 ± 9.8	4.7 ± 6.0	8.3 ± 7.6	6.1 ± 5.8	6.7 ± 3.9	5.2 ± 2.9
α tissue factor (°)	64 ± 14	68 ± 11	56 ± 16*	61 ± 15*	54 ± 20*	54 ± 24*
MA tissue factor (mm)	64 ± 11	66 ± 8	54 ± 9*	56 ± 11*	58 ± 8*	60 ± 10*

Normal range is in parentheses.
All cardiopulmonary bypass samples were obtained after heparinase modification.
ICU = intensive care unit, TEG = thromboelastography, R = reaction time, MA = maximal amplitude, NM = not measured.
* $P < 0.01$ versus baseline.
† $P < 0.0001$ celite versus tissue factor.

Table 4. Bleeding and Transfusion Requirements

	Intraoperative			Postoperative			Total		
	TEG	Control	*P*	TEG	Control	*P*	TEG	Control	*P*
Packed red blood cells (mL)	267 ± 423	346 ± 449	0.4	103 ± 252	177 ± 318	0.27	354 ± 487	475 ± 593	0.12
Fresh-frozen plasma (mL)	22 ± 101	113 ± 407	0.4	33 ± 169	146 ± 378	0.13	36 ± 142	217 ± 463	<0.04
Platelet concentrates (mL)	22 ± 75	41 ± 122	0.6	11 ± 46	42 ± 107	0.3	34 ± 94	83 ± 160	0.16
Autologous reinfusion volume (mL)	—	—		128 ± 145	141 ± 290	0.19	—	—	
6-h MTD + reinfusion volume (mL)	—	—		362 ± 274	469 ± 637	0.63	—	—	
24-h MTD + reinfusion volume (mL)	—	—		702 ± 500	901 ± 847	0.27	—	—	
Packed red blood cells	17/53	23/52	0.2	10/53	16/52	0.16	22/53	31/52	0.06
Fresh-frozen plasma	3/53	8/52	0.1	2/53	11/52	<0.007	4/53	16/52	0.002
Platelet concentrates	5/53	8/52	0.4	3/53	9/52	0.06	7/53	15/52	<0.05

Values are mean ± SD or proportion of patients transfused.
Nonparametric statistics performed for all data not conforming to normal distribution.
TEG = thromboelastography, MTD = chest tube drainage.

and a reduced number of patients receiving a transfusion. All patients in this study received prophylactic antifibrinolytic therapy, which could have made it more difficult to elicit differences in transfusion therapy—a finding that has been suggested by Horrow et al. (12). Furthermore, because the reductions in transfusions in the TEG group were primarily a result of postoperative transfusion rates, when the algorithm was no longer enforced, the lower transfusion rate must have been the result of perceived better hemostasis by the ICU staff. Potential reasons for this include less early postoperative chest tube drainage (not statistically significant), normal hemostasis test results, fewer blood products available at the bedside (previously ordered from the blood bank), or a combination of these factors.

The lack of a statistical difference in hemostasis variables measured on arrival in the ICU further supports that the two groups were hemostatically similar, despite the subsequent disparities in transfusions administered in the ICU. Additionally, the ICU physicians may have transfused more FFP in the control group because of a perception of inadequate hemostasis and in response to the intraoperatively measured PT, before the postoperative PT results were available. One patient in the control group who received numerous transfusions of PRBC and non-PRBC components was excluded from analysis because a surgical source of bleeding was present on reexploration. Had this patient's data been included, the difference in transfusions between the two groups would have been even greater, merely strengthening our results.

The exact mechanism of this reduction in transfusions is not evident from the current data; however, TEG has a number of advantages compared with routine hemostasis monitors. One advantage of TEG is that results can be readily obtained during CPB, and early identification of hemostasis abnormalities can result in prompt and appropriate treatment. TEG results were generally available in 10–15 min. Laboratory PT and aPTT are only measured after protamine administration and require 45–60 min for results. The presence of normal TEG test results during CPB would have forestalled the ordering of allogeneic blood products during the surgical procedure, thus making these products less available to practitioners postoperatively. During the time that it takes to order and receive products postoperatively (30–60 min), many patients improve without any specific therapy and will not be transfused. A second advantage of TEG in the current study is that information relating to platelet function (MA) was available in 10–15 min, whereas information regarding platelet count was available in 20–30 min and was only quantitative in nature. Thus, TEG provided a more timely and qualitative measure of platelets. Using TF to activate the TEG accelerated the production of the MA even further (6–8 min) without altering the results.

Analysis of the data revealed that the two groups were similar in their demographic comparisons and in their measured hemostasis variables intraoperatively. Transfusion requirements did not differ intraoperatively, despite use of the transfusion algorithm. However, using the transfusion algorithm reduced postoperative and, thus, total transfusion of non-RBC component therapy. There was a statistically significantly lower volume of FFP transfused, and a reduced incidence of transfusion of FFP and platelet concentrates in the study group.

Although extensively studied, bleeding after CPB remains an elusive problem. Microvascular coagulopathy occurs after cardiac surgery because the integrity of the inflammatory, coagulation, and fibrinolytic cascades becomes disrupted when blood comes into contact with the extracorporeal circuit. This results in contact activation, platelet activation, leukocyte activation, TF expression, and, ultimately, stimulation of complement and inflammation. Technologic and pharmacologic interventions aimed at reducing the transfusion needs of cardiac surgical patients have met with variable success (13–15). Prophylactic use of synthetic antifibrinolytic drugs has been shown to reduce bleeding, but transfusion requirements are more difficult to affect because transfusion threshold values vary so widely (12). However, the widespread use of the serine protease inhibitor aprotinin has been associated with reductions in both bleeding and transfusion requirements, and it is associated with a "dry" surgical field (16,17). This subjective assessment of microvascular bleeding as the stimulus to transfuse is common practice and is often the reason that transfusion practices vary and are linked to inappropriate or empiric therapy (1). Thus, rapid and accurate diagnosis of hemostasis abnormalities after CPB is critical to appropriate treatment. Conversely, rapid and accurate diagnosis of normal hemostasis in a patient who is bleeding postoperatively is also important for the prompt initiation of surgical reexploration.

Abnormal TEG values (18) and the TEG MA (19) have been shown to be more sensitive and specific predictors of abnormal bleeding after CPB than routine coagulation tests or other on-site monitors. This supports the belief that platelet dysfunction is a major contributor to post-CPB bleeding. Ideally, a goal-directed algorithm for transfusion therapy after CPB should measure platelet function in addition to platelet number and coagulation. Despotis et al. (7) reported using an algorithm that stratifies patients into treatment groups by platelet count, yet does not use a specific test of platelet function. Until recently, specific point-of-care tests of platelet function other than TEG were not available. Although TEG as a technology has been in existence since 1947, its use at the point of care

has only recently been promoted because of its disposable components and coagulation activators that speed the reporting of test results. The intricacies of platelet physiology make bedside platelet function testing extremely complex. However, novel platelet function monitors have recently been introduced into the marketplace and may also be of value for use in transfusion algorithms post-CPB (19).

In the current study, we sought to test a transfusion algorithm that would be available for use at the point of care and that would measure those aspects of the hemostatic system that are most frequently perturbed by CPB: platelet function, coagulation factor activity, residual heparinization, and fibrinolysis. The TEG measures the physical properties of fibrin formation, platelet-fibrin interactions, and fibrinolysis by using a single test (20). TEG can be used at the point of care and can be modified as follows. Heparinase modification allows for measurement during the CPB interval so that early information regarding hemostasis can be obtained and judicious ordering of allogeneic blood products can proceed (21). The TF modification, relative to celite activation, hastens the time to fibrin formation (R time value) and provides for early identification of a low MA value that would be a marker for platelet dysfunction (22). This could be extremely useful in patients with documented coagulation factor dysfunction in whom the R time value would be prohibitively long, and in whom the MA would be uninterpretable. The celite TEG allows for diagnosis of coagulation factor dysfunction (R time value prolongation). Comparison of the celite TEG R time value with and without heparinase modification yields information about residual heparin activity and the need for additional protamine therapy.

A transfusion algorithm that is predicated on the intraoperative PT for the transfusion of FFP should be carefully reevaluated. Consideration should be given to redefining the normal PT (23) after CPB because PT is so often increased at this time in the absence of pathologic bleeding (24). Consider the current study, in which PT was increased intraoperatively in both groups, yet the R time value was increased in neither group. Because laboratory abnormalities were only treated in conjunction with clinical bleeding according to the protocol, this resulted in no intraoperative differences in FFP transfusion between groups. Had rigid transfusion criteria not been enforced in the control group, indiscriminate FFP administration may have taken place, and differences in intraoperative FFP transfusion might have been statistically significant. Furthermore, the return of the increased PT values to <1.5 times control values in both groups at ICU admission supports the contention that many post-CPB hemostasis abnormalities improve with time.

We designed this study to evaluate use of a transfusion algorithm that could be applied during CPB in patients at moderate to high risk of transfusion. In a population with a high prevalence of transfusions, a significant reduction in transfusion is more likely to be detected, if such a difference exists. Because of ethical concerns regarding withholding an intervention that may minimize transfusions, study extension based on conditional power was planned after the study of 100 patients. Because a significant reduction in transfusions resulted from the intervention ($\alpha < 0.02$), the study was terminated, and the algorithm is now used for all high-risk patients.

As a point-of-care test, TEG potentially allows for earlier diagnosis of hemostasis abnormalities and specific identification of the type of disturbance(s) present during cardiac surgical procedures. The use of activators shortens the time for reporting of results so that allogeneic blood products can be promptly and rationally transfused. Using a TEG-guided transfusion algorithm, we were able to demonstrate a lower incidence of and a reduced volume of allogeneic blood products transfused in a population of patients at risk of transfusion-related complications.

References

1. Stover EP, Siegel LC, Parks R, et al. Variability in transfusion practice for coronary artery bypass surgery persists despite national consensus guidelines: a 24-institution study. Institutions of the Multicenter Study of Perioperative Ischemia Research Group. Anesthesiology 1998;88:327–33.
2. Bick RL. Hemostatic defects associated with cardiac surgery, prosthetic devices, and other extracorporeal circuits. Semin Thromb Hemost 1985;11:249–80.
3. Lavee J, Martinowitz U, Mohr R, et al. The effect of transfusion of fresh whole blood versus platelet concentrates after cardiac operations: a scanning electron microscope study of platelet aggregation on extracellular matrix. J Thorac Cardiovasc Surg 1989;97:204–12.
4. Jobes DR, Aitken GL, Shaffer GW. Increased accuracy and precision of heparin and protamine dosing reduces blood loss and transfusion in patients undergoing primary cardiac operations. J Thorac Cardiovasc Surg 1995;110:36–45.
5. Horrow JC, Hlavacek J, Strong MD, et al. Prophylactic tranexamic acid decreases bleeding after cardiac operations. J Thorac Cardiovasc Surg 1990;99:70–4.
6. Kytola L, Nuutinen L, Myllyla G. Transfusion policies in coronary artery bypass: a nationwide survey in Finland. Acta Anaesthesiol Scand 1998;42:178–83.
7. Despotis GJ, Santoro SA, Spitznagel E, et al. Prospective evaluation and clinical utility of on-site monitoring of coagulation in patients undergoing cardiac operation. J Thorac Cardiovasc Surg 1994;107:271–9.
8. Khurana S, Mattson JC, Westley S, et al. Monitoring platelet glycoprotein IIb/IIIa-fibrin interaction with tissue factor-activated thromboelastography. J Lab Clin Med 1997;130:401–11.
9. Spiess BD, Gillies BSA, Chandler WL, Verrier E. Changes in transfusion therapy and reexploration rate after institution of a blood management program in cardiac surgical patients. J Cardiothorac Vasc Anesth 1995;9:168–73.
10. Hardy JF, Perrault J, Tremblay N, et al. The stratification of cardiac surgical procedures according to use of blood products: a retrospective analysis of 1480 cases. Can J Anaesth 1991;38:511–7.

11. Proschan MA, Munsberger SA. Designed extension of studies based on conditional power. Biometrics 1995;51:1315–24.
12. Horrow JC, Van Riper DF, Strong MD, et al. The dose-response relationship of tranexamic acid. Anesthesiology 1995;82:383–92.
13. Birdi I, Izzat MB, Bryan AJ, Angelini GD. Normothermic techniques during open heart operations. Ann Thorac Surg 1996;61: 1573–80.
14. Davies GG, Wells DG, Mabee TM, et al. Platelet-leukocyte plasmapheresis attenuates the deleterious effects of cardiopulmonary bypass. Ann Thorac Surg 1992;53:274–7.
15. Ovrum E, Holen EA, Tangen G, et al. Completely heparinized cardiopulmonary bypass and reduced systemic heparin: clinical and hemostatic effects. Ann Thorac Surg 1995;60:365–71.
16. Lass M, Welz A, Kocks M, et al. Aprotinin in elective primary bypass surgery: graft patency and clinical efficacy. Eur J Cardiothorac Surg 1995;9:206–10.
17. Levy JH, Pifarre R, Schaff HV, et al. A multicenter, double blind, placebo-controlled trial of aprotinin for reducing blood loss and the requirement for donor blood transfusion in patients undergoing coronary artery bypass grafting. Circulation 1995;92: 2236–44.
18. Tuman KJ, Spiess BD, McCarthy RJ, Ivankovich AD. Comparison of viscoelastic measures of coagulation after cardiopulmonary bypass. Anesth Analg 1989;69:69–75.
19. Ereth MH, Nuttall GA, Klindworth JT, et al. Does the platelet-activated clotting test (HemoSTATUS) predict blood loss and platelet dysfunction associated with cardiopulmonary bypass? Anesth Analg 1997;85:259–64.
20. Okude M, Yamanaka A, Akihama S. The effects of pH on the generation of turbidity and elasticity associated with fibrinogen-fibrin conversion by thrombin are remarkably influenced by sialic acid in fibrinogen. Biol Pharmacol Bull 1995;18:203–7.
21. Tuman KJ, McCarthy RJ, Djuric M, et al. Evaluation of coagulation during cardiopulmonary bypass with a heparinase-modified thromboelastographic assay. J Cardiothorac Vasc Anesth 1994;2:144–9.
22. Mongan PD, Hosking MP. The role of desmopressin acetate in patients undergoing coronary artery bypass surgery. Anesthesiology 1992;77:38–46.
23. Nuttall GA, Oliver WC, Beynen FM, et al. Determination of normal versus abnormal partial thromboplastin time and prothrombin time after cardiopulmonary bypass. J Cardiothorac Vasc Anesth 1995;9:353–4.
24. Nuttall GA, Oliver WC, Ereth MH, Santrach PJ. Coagulation tests predict bleeding after cardiopulmonary bypass. J Cardiothorac Vasc Anesth 1997;11:815–23.