How do we manage cardiopulmonary bypass coagulopathy?

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BACKGROUND: Patients who undergo cardiopulmonary bypass (CPB) are at risk for coagulopathy. Suboptimal turnaround time (TAT) of laboratory coagulation testing results in empiric administration of blood products to treat massive bleeding. We describe our initiative in establishing the coagulation-based hemotherapy (CBH) service, a clinical pathology consultation service that uses rapid TAT coagulation testing and provides comprehensive assessment of bleeding in patients undergoing CPB. A transfusion algorithm that treats the underlying cause of coagulopathy was developed.

STUDY DESIGN AND METHODS: The coagulation testing menu includes all aspects of coagulopathy with close proximity of the laboratory to the operating room to allow for rapid test results. The hemotherapy pathologist monitors laboratory results at several stages in surgery and uses a comprehensive algorithm to monitor a patient's hemostasis. The optimal number and type of blood products are selected when the patient is taken off CPB.

RESULTS: The CBH service was consulted for 44 ventricular assist device implants, 30 heart transplants, and 31 other cardiovascular surgeries from May 2012 through November 2013. The TAT for laboratory tests was 15 minutes for complete blood count, antithrombin, and coagulation panel and 30 minutes for VerifyNow and thromboelastography, in comparison to 45 to 60 minutes in normal settings. The transfusion algorithms were used with optimal administration of blood components with preliminary data suggestive of reduced blood product usage and better patient outcomes.

CONCLUSION: We described the successful introduction of a novel pathology consultation service that uses a rapid TAT coagulation testing menu with transfusion algorithms for improved management of CPB patients.

Bleeding is a frequent complication of major cardiac surgery. For example, 81% of patients who underwent left ventricular assist device (LVAD) implantation had postoperative bleeding requiring the use of blood products and 30% required reoperation attributable to bleeding.[1] There are multiple mechanisms by which bleeding can occur during and after cardiac surgery. Cardiopulmonary bypass (CPB) causes a decrease in platelet (PLT) count by approximately 50% and also PLT function impairment.[2-4] Furthermore, CPB causes decreased levels of a number of coagulation factors and von Willebrand factor.[2,4] Fibrinolysis is increased in patients who undergo CPB, possibly due to endothelial activation and the action of tissue plasminogen activator.[5] Large doses of heparin are given during CPB to inhibit clotting of the bypass circuit followed by reversal with protamine after surgical hemostasis; rebound effect of heparin may occur causing postoperative bleeding.[4] Conversely, excessive protamine doses may act as an anticoagulant. Before surgery, patients are frequently on anti-PLT agents such as aspirin or

ABBREVIATIONS: APTT = activated partial thromboplastin time; CBC = complete blood count; CBH = coagulation-based hemotherapy; CPB = cardiopulmonary bypass; LVAD = left ventricular assist device; OR(s) = operating room(s); PT = prothrombin time; TAT = turnaround time; TEG = thromboelastography.

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clopidogrel or taking anticoagulants such as warfarin. Additionally, cardiac surgery patients often have a number of medical comorbidities that contribute to bleeding including end-stage renal disease that can cause uremic PLT dysfunction, liver disease causing deficiency of coagulation factors and PLT sequestration, and malabsorption with associated vitamin K deficiency.[4]

The complications of bleeding during and after cardiac surgery are significant. The increased requirement for blood transfusions places patients at risk for alloimmunization, nosocomial infections, transfusion-related infectious diseases, and other transfusion-associated complications.[6-8] Bleeding patients may require additional surgeries, which occur in as many as 60% of LVAD patients.[9] Blood product usage increases the risk of human leukocyte antigen alloimmunization, making more difficult the process of finding an appropriately matched organ donor and placing patients at risk for future allograft rejection.[7,10] Large volumes of transfused blood products may trigger an inflammatory response that causes respiratory problems, pulmonary hypertension, and the risk of right ventricular failure.[9] Inappropriate management of the bleeding patient can also cause poor outcomes by dilution of coagulation factors. Finally, cardiac surgeries use as much as 25% of the blood products in the United States.[4] Interventions that safely reduce bleeding and the resulting blood product use have the potential to improve patient morbidity with tremendous potential for cost savings.

A significant issue with blood product administration to manage excessive bleeding associated with cardiac surgery is that it is largely empiric secondary to the long turnaround time (TAT) of laboratory assays. The coagulation-based hemotherapy (CBH) service was initiated by our clinical pathology team at the University of Texas at Houston Medical School in collaboration with the Advanced Heart Failure Service at Memorial Hermann Hospital. The CBH service is administered by clinical pathologists and includes preoperative, operative, and postoperative consultations. The CBH pathologist monitors coagulation variables at several stages in the surgery. A comprehensive menu of coagulation testing with real-time results was established to cover all aspects of coagulation, which is used to provide transfusion support recommendations. We describe our initiative in establishing the CBH service that uses a comprehensive and rapid TAT menu of coagulation tests and transfusion management algorithms to prevent and manage bleeding during and after major cardiac surgery.

SCOPE OF THE CBH SERVICE

The CBH service offers intraoperative laboratory and transfusion support for LVAD placement, orthotopic heart transplantation, and total artificial heart or any cardiac surgery with potential high risk for bleeding per assessment by the advanced heart failure team such as patients with multiple valve repairs or emergency surgery while still on clopidogrel. Preoperative assessment of bleeding risk is performed if time permits. Consultation is also available for unexpected acute bleeding during cardiac surgery or in the postoperative period. Additionally, risk assessment and management of coagulopathy associated with cardiac surgery is offered. These consultations are available 24 hours a day, 7 days a week. At our institution, there is one hemotherapy pathologist on service 1 week at a time and 24 hours a day. We write a consultation report for the surgery and progress notes on the patients postoperatively. Usually, we follow the patients until the patient's bleeding is under control or the patient's coagulation status is optimized. Since the surgeons and cardiologists delegate transfusion support of patients to our service, we directly order laboratory tests and transfusions. The hospital's Advanced Heart Failure Clinical Committee has approved this process for all consult cases.

CPT Code 99222 is used for straightforward initial consultations, and 99223 is used for complex cases that require detailed workups and interventions. CPT Code 99223 is also used for initial emergent consultations that include intraoperative care. Follow-up notes use CPT 99231-3 for uncomplicated cases with no or minor bleeding or CPT 99232-3 for complex cases involving more extensive involvement by our service. Since the billing collection is rather low for our service, the salary support for our clinical pathologists, currently in the second year of this service, is supplemented by the hospital to achieve positive outcomes for cardiovascular surgery patients.

ESTABLISHMENT OF REAL-TIME COAGULATION VARIABLES

The coagulation test menu offered by our service includes complete blood count (CBC), prothrombin time (PT), activated partial thromboplastin time (APTT), functional fibrinogen (referred to as fibrinogen), D-dimer, thrombin time, thromboelastography (TEG) with and without heparinase, VerifyNow-P2Y12, and VerifyNow-Aspirin. These tests were selected to cover all aspects of coagulation. The laboratory instruments are located in close vicinity (approx. 70 feet) to the operating rooms (ORs) to allow for rapid delivery of the samples and results. The TAT is additionally enhanced by hand delivering samples from the OR to the STAT laboratory for immediate testing. The laboratory testing is initiated immediately on arrival to the laboratory with ordering by the pathologist occurring simultaneously. Results are used directly from the instrumentation before release into the laboratory information system. Blood products based on these results are immediately selected from a satellite blood bank located inside of the OR STAT laboratory. The STAT laboratory has a

hematology analyzer (Beckman Coulter, Fullerton, CA), a coagulation analyzer (Stago, Parsippany, NJ), an instrument for VerifyNow (Accumetrics, San Diego, CA), and two TEG instruments. The satellite blood bank only dispenses blood products with type and screen and antibody detection performed in the main laboratory. Two laboratory technologists for operating instruments and one blood bank technologist are present. The STAT laboratory and satellite blood bank were created simultaneously with the initiation of the advanced heart failure and hemotherapy services, and are essential components of the service.

PREOPERATIVE EVALUATION

Assessment of bleeding risk is performed preoperatively for patients not emergently going to surgery. Specific risk factors for bleeding associated with cardiac surgery are elicited from the patient including personal or family history of bleeding or history of previous chest surgery, kidney disease, or liver disease. A thorough medication review for anticoagulants or anti-PLT medications with date of last use is conducted, with special attention to those medications listed in Table 1. Baseline laboratory values are obtained including liver function test panel (alanine aminotransferase, aspartate aminotransferase, alkaline phosphatase, bilirubin), blood urea nitrogen, creatinine, CBC, PT, APTT, and fibrinogen. Abnormal results on the preoperative coagulation evaluation are further investigated by the pathologist by performing additional tests such as PT and APTT mixing study, thrombin time, anti-Xa assay, specific factor assays and inhibitors, lupus anticoagulant, or PLT aggregation studies, and so forth, as clinically indicated. All results are interpreted by the hemotherapy pathologist and communicated with the heart failure team. A blood type and screen is also ordered and availability of appropriate blood components is ensured. Many cardiac surgery patients have prior transfusion histories and it is essential to obtain full details on red blood cell (RBC) antibodies, Rh status for women of child-bearing age, cross-match compatibility, or other special component needs. Our blood bank typically cross-matches 10 units of cross-match RBCs and prepares 10 units of fresh frozen plasma (FFP) and 6 apheresis PLT units. In the case of patients with clinically significant antibodies against RBC antigens, 20 units of antigen-negative RBCs are cross-matched. Institutional blood bank protocols and discussions with the clinicians are used when it is not possible to acquire sufficient antigen-negative units; this decision is highly patient and situation specific.

INTRAOPERATIVE MANAGEMENT

CPB uses an extracorporeal circuit to provide oxygenation to tissues while allowing surgery to be conducted in a bloodless, motionless field.[19] Venous cannulation with

TABLE 1. Medications requiring special attention before major cardiac surgery[11,12]

Medication	Mechanism of action	Time to discontinue before surgery	Type of support
Abciximab (ReoPro)	GPIIb-IIIa inhibition	5-7 days*	PLTs during or after surgery
Argatroban	Direct thrombin inhibitor	4 hr before surgery	Reversal mechanism not fully established, dialysis, FVIIa‡[13]
Apixaban (Eliquis)	Direct FXa inhibitor	CrCl > 50 mL/min: 3 days CrCl 30-50 mL/min: 4 days	Reversal mechanism not fully established, aPCC 20-25 U/kg‡[14]
Aspirin	Inhibitor of cyclooxygenase	None†	PLTs during or after surgery
Bivalirudin (Angiomax)	Direct thrombin inhibitor	2 hr	Dialysis, FFP, cryoprecipitate, FVIIa, aPCC 20-25 U/kg‡[15]
Clopidogrel (Plavix)	Inhibition of ADP-P2Y12	5 days	PLTs during or after surgery
Dabigatran (Pradaxa)	Direct thrombin inhibitor	CrCl > 50 mL/min: 3 days CrCl 30-50 mL/min: 4-5 days	Reversal mechanism not fully established, dialysis, FVIIa, aPCC 20-25 U/kg‡[16]
Eptifibatide (Integrilin)	Inhibition of GPIIb-IIIa	3-6 hr	PLTs during or after surgery
Fondaparinux (Arixtra)	Indirect FXa inhibition	2-4 days for patients with normal renal function	Reversal mechanism not fully established, consider FVIIa,‡ aPCC 20-25 U/kg‡[17]
LMWH	Indirect FXa inhibition	24 hr	Protamine (1 mg/mg LMWH)
Prasugrel (Effient)	Inhibition of ADP-P2Y12	7 days	PLTs during or after surgery
Rivaroxaban (Xarelto)	Direct FXa inhibition	CrCl > 30 mL/min: 3 days CrCl 15-29.9 mL/min: 4 days	Reversal mechanism not fully established, aPCC 20-25 U/kg‡[18]
Ticagrelor (Brilinta)	Inhibition of ADP-P2Y12	5 days	PLTs during or after surgery
Unfractionated heparin	FXa and thrombin inhibition	4-6 hr	Protamine (1 mg/100 units heparin)
Warfarin	Vitamin K antagonist	4-7 days	Vitamin K 1-10 mg (oral 24 hr or more before surgery; IV 6-24 hr; FFP, less than 6 hr) Four-factor PCCs for patients who cannot tolerate volume loading

* Abciximab may persist longer.
† Aspirin is not discontinued before cardiac surgery at our institution because our group considers the protective benefit to outweigh the bleeding risk in cardiac surgery patients.
‡ Use of PCC and rFVIIa is off label.
aPCC = activated prothrombin complex concentrate; CrCl = creatinine clearance; LMWH = low-molecular-weight heparin.

TABLE 2. Laboratory tests ordered for each phase of surgery

Test	Induction of anesthesia (baseline)	Just before off-pump	After heparin reversal	As needed for excessive bleeding
TEG			†	X
Heparinase-TEG		X		
CBC	X	X	X	X
Coagulation panel*	X	X	X	X
Antithrombin	X			
VFN-aspirin*‡	X			
VFN-P2Y12*‡	X			

* Coagulation panel includes PT, APTT, fibrinogen, thrombin time, and D-dimer.
† Optional.
‡ Performed if a pharmacologically induced PLT dysfunction is suspected or medication history is not known at the time of surgery.
VFN-aspirin = VerifyNow-aspirin; VFN-P2Y12 = VerifyNow-P2Y12.

tubing removes blood from the lungs and heart to a reservoir where it is oxygenated and returned to the cannulated arterial vasculature by a pump. Patients are anticoagulated with heparin just before initiation of CPB to prevent clot formation in the circuit. Once the surgery has been completed, patients are rewarmed and circulating blood is hemoconcentrated. Finally, CPB circuit is discontinued and heparin is reversed with protamine.[19]

The CBH pathologist remains in the vicinity of the OR and monitors the patient at several stages of the surgery (Table 2). The first set of laboratory tests is collected after induction of anesthesia as the baseline and includes CBC; PT; APTT; fibrinogen; thrombin time; D-dimer; antithrombin activity; VerifyNow-Aspirin if the patient has a history of aspirin use; and VerifyNow-P2Y12 if the patient is on clopidogrel, prasugrel, or ticagrelor. The baseline laboratory collection may be omitted for stable patients with very recent preoperative labs. Blood products are not usually necessary while the patient is on CPB because the patient needs to be hypocoagulable during this part of the surgery. Only RBCs are needed to keep the hemoglobin (Hb) in the range of 8 to 10 g/dL during CPB.

The second set of tests is collected at the rewarming and after hemoconcentration phase of surgery, just before discontinuation of CPB. Patients frequently develop microvascular bleeding after CPB secondary to a variety of coagulation abnormalities.[4] The set of laboratory variables collected at this stage of surgery is the most critical because they allow the hemotherapy pathologist to identify the underlying cause of bleeding if it occurs, that is, bleeding secondary to coagulopathy and not due to surgical bleeding. These results are used to determine the underlying cause of coagulopathy if present and are used to determine the blood component types and number of units to transfuse to the patient after CPB discontinuation and heparin neutralization.

The third set of laboratory tests is collected after the patient is off CPB, 10 minutes after heparin reversal with protamine, and before blood products are administered. Transfusion after heparin reversal is based on the laboratory results obtained before discontinuation of CPB, with adjustment based on the postprotamine results when they become available. Selection of blood components is based on a predefined transfusion algorithm (Table 3).

The CBH pathologists at our institution, which consist of hematopathologists and transfusion medicine physicians, developed the transfusion algorithms by reviewing the literature for algorithms used during cardiac pulmonary bypass surgery and hence the algorithms are based on standard transfusion practice.[21,22] The group prepared a comprehensive hemotherapy guide, which includes all the algorithms, and the current version of this guide can be reviewed on our Web site http://hemepathreview.com (go to Item 14 and then go to Guide for Hemotherapy). Criteria for transfusion are listed in the references section of this guide. Furthermore, the group periodically reviews the algorithms and they are continuously revised based on experience learned on CBH service. The guide is also annually reviewed and approved by the hospital's Advanced Heart Failure Clinical Committee. Relevant criteria on medications are reviewed with input from clinical pharmacists assigned to advanced heart failure service.

The hemotherapy pathologist remains near the OR for the duration of the surgery to select appropriate laboratory tests to order. The laboratory results are reviewed as they become available, and appropriate blood components are selected. The pathologist works with the anesthesiologist to ensure that the right blood product and number of units are administered to the patient to treat coagulopathy while avoiding inappropriate use of products.

Consultations are occasionally requested when the patient is already in the OR with bleeding, usually in the context of emergency surgery. When this occurs, the clinical information is obtained from the surgical team, including the number and type of blood components already transfused. A new baseline set of coagulation tests is ordered. The hemotherapy pathologist interprets the results and manages the coagulopathy using the available data and the transfusion algorithm (Table 3).

TABLE 3. Details of transfusion algorithm

Coagulation issue	Laboratory abnormality and action
Use more protamine to neutralize excess heparin	If APTT > 45 and TT > 25 give protamine 50 mg/70 kg
Quantitative or qualitative PLT defect	If (50K < PLTs < 100K) → 2 single-donor apheresis units (PLTs ↑60)
	If (PLTs < 50K) → three single-donor apheresis units (PLTs ↑90)
	or
	If (35 < MA < 45) and (EPL < 15) and (LY30 < 8) → 2 single-donor apheresis units (PLTs ↑60)
	If (MA < 35) and (EPL < 15) and (LY30 < 8) → 3 single-donor apheresis units (PLTs ↑90)
	or
	If (130 PRU < VFN-P < 210 PRU) → 2 single-donor apheresis units (PLTs ↑60)
	If (VFN-P < 130 PRU) → 3 single-donor apheresis units (PLTs ↑90)
	or
	If (350 < VFN-A < 550) → 2 single-donor apheresis units (PLTs ↑60)
	If (VFN-A < 350) → 3 single-donor apheresis units (PLTs ↑90)[20]
Clotting factor deficiency	If (10 < hTEG-R < 15) → 2 units of FFP (clotting factors ↑10%)
	If (15 < hTEG-R < 20) → 4 units of FFP (clotting factors ↑20%)
	If (20 < hTEG-R) → 6 units of FFP (clotting factors ↑30%)
	If (20 < PT < 25) or (45 < APTT < 50) → 2 units of FFP
	If (25 < PT) or (50 < APTT) → 4 units of FFP
Mild fibrinogen deficiency	If (150 < fibrinogen < 200) or (20 < Alpha < 45 with normal MA) → 2 units of FFPs
Marked fibrinogen deficiency or uremic PLT dysfunction	Fibrinogen < 150 or
	Chronic renal failure and bleeding with normal coagulation results → 10 units of cryoprecipitate
Primary fibrinolysis	If (EPL > 15% or Ly30 > 8%) and (MA < 50 or CI < 1.0) → tranexamic acid, INJ, 1000 mg/10 mL over 10 min
	or
	If (fibrinogen < 150) and (D-dimer > 10) → tranexamic acid, INJ, 1000 mg/10 mL
Mild antithrombin deficiency	Antithrombin 35%-50% → 2 units of FFP before heparin administration
Severe antithrombin deficiency	Antithrombin < 35% → ATIII concentrate
	Dose (IU) = (desired level – baseline level) × weight (kg)/1.4 before heparin administration
Anemia	Hb < 10 g/dL → give RBCs to keep Hb at least 10 g/dL
Bleeding not responding to treatment	(EPL < 15% or Ly30 < 8%) and (MA < 70 or CI < 3.0) consider rFVIIa (15 μg/kg)

Alpha = TEG alpha in degrees; APTT = activated partial thromboplastin time in seconds; ARU = aspirin reaction units; CI = TEG coagulation index; EPL = thromboelastography estimated percent lysis in percent; fibrinogen units in mg/dL; hTEG = thromboelastography with heparinase; LY30 = thromboelastography percent clot lysis at 30 minutes in percent; MA = thromboelastography maximum amplitude in mm; PLT = PLTs in k/cmm; PRU = P2Y12 reaction units; PT = prothrombin time in seconds; TEG-R = thromboelastography reaction time in min; TT = thrombin time in seconds; VFN-aspirin = VerifyNow-aspirin; VFN-P2Y12 = VerifyNow-P2Y12.

POSTOPERATIVE MANAGEMENT

All patients with intraoperative hemotherapy consults are followed after surgery for at least 24 hours. The highest risk for acute postoperative bleeding typically occurs within 4 to 6 hours after surgery. Patients' laboratory variables are followed closely during this critical period with CBC, PT, APTT, and chest tube output. Patients with high risk of bleeding after cardiac surgery include those with long CPB time (more than 3 hr) due to complicated surgery, prior history of chest operation, liver disease, renal disease, obesity-associated heparin rebound, residual effect of anticoagulant and anti-PLT medications, and large-volume transfusion during surgery causing right ventricular failure.[4]

Excessive bleeding is defined as sustained chest tube output of 150 to 200 mL/hour or more than 2 L in 24 hours.[23] Acute postoperative bleeding is managed by ordering baseline laboratory tests consisting of CBC, PT, APTT, fibrinogen, thrombin time, and TEG if recent values are not available. In general, transfusion is started to replace blood loss; for every 1000 mL of chest tube output, 2 units of RBCs, 1 unit of FFP, and 1 apheresis unit of PLTs are administered with simultaneous replacement of the patient's calcium. Correction of the specific cause of coagulopathy is made when laboratory results become available according to the guidelines in Table 3. The same STAT laboratory used in the OR is located in the vicinity of where patients are located postoperatively such that results quickly become available. If the chest-tube output is more than 800 to 1000 mL/hr and is not alleviated by transfusion, a low dose (15-30 μg/kg) recombinant factor (rF)VIIa is considered, which is an off-label use. Chest tube output of less than 150 mL/hr is the targeted level for acute bleeding. Once bleeding has improved, no further interventions are usually needed. Another set of

coagulation variables is ordered in 2 hours to monitor for development of additional coagulopathy.

Effective management of blood components during and immediately after surgery often prevents development of significant coagulopathy and bleeding. For patients without acute bleeding in the postoperative period, the standard thresholds for transfusion are used. The goal Hb is at least 8 g/dL, goal fibrinogen between 100 and 150 mg/dL, and a PLT count of at least $50 \times 10^9/\mu L$.

DECISION SUPPORT MODULE

We have developed and utilized a decision support module in our CBH consultation service.[24] The core of our module is a spreadsheet template (Microsoft Excel, Microsoft Corp., Redmond, WA) used to gather and compute data on CPB patients intraoperatively. The decision support module is embedded into the Excel file where the user enters laboratory results and through our 45 embedded algorithms, recommendations for transfusion products will be displayed in the Excel file. This module has greatly increased the productivity and efficiency of our service by decreasing the time it takes to come to a transfusion recommendation, double-checking recommendations, and being an excellent tool for teaching.

OUTCOMES

The CBH service began May 2012. As of November 2013, intraoperative consultations on 44 LVAD patients, 30 orthotopic heart transplants, and five total artificial hearts have been performed. Additionally, intraoperative consultations for 31 other cases included aortocoronary bypass and valve replacements for patients with a high risk of bleeding. The transfusion algorithm rules were used and optimal transfusion was coordinated with the anesthesia and surgery attending physicians on all cases.

An essential component in the success of this service was the establishment of almost real-time coagulation variables. TAT for laboratory tests for the CBH service ranged from 16 ± 10.3 minutes for a CBC, 20 ± 9.5 minutes for a coagulation panel (includes PT, APTT, fibrinogen, thrombin time, D-dimer), and 27.8 ± 9.9 minutes for VerifyNow tests. TEG TAT is on average 63.7 ± 19.1 minutes; however, essential components are available off the instrument after achieving MA at around 30 minutes. This is in contrast to average TATs for STAT results of 45 minutes to 60 minutes in typical settings. The ability to obtain laboratory results in a close-to-real-time manner allows the CBH pathologist to preempt the exact cause of coagulopathy as it occurs.

The CBH pathologist interprets the coagulation results and recommends transfusion based on predefined transfusion algorithms. Preliminary data from the first 17 patients who underwent LVAD implantation and had a CBH consult show that markedly fewer blood products were administered.[25] On average, these LVAD patients had 5.9 ± 4.5 RBC units, 5.3 ± 3.3 FFP units, 2.3 ± 1.6 PLT doses, and 0.2 ± 0.4 cryoprecipitate doses intraoperatively and less than two total blood products within the postoperative 48-hour period (0.8 ± 1.8 RBC units, 0.2 ± 0.93 FFP units, 0.6 ± 1.9 PLT doses, and 0.1 ± 0.2 cryoprecipitate doses). The cumulative transfusion rate of patients undergoing this CBH protocol was 15.4 units, much lower than the previously published transfusion rate of 74 total units for LVAD implantation.[26] Additionally, the rate of emergency reoperation in our cohort of LVAD patients is only 8.3% compared to a national rate of 23%.[27,28]

EDUCATION AND TRAINING

The principles of coagulation test selection, interpretation, blood product selection, communication with clinical colleagues, and the ability to be part of a health care team are all important skills to learn. Thus, residents are included as part of the CBH service. Our pathology residents have obtained a valuable training experience with this unique coagulation and transfusion service. The CBH rotation is integrated into clinical pathology rotations and also offered as a full-month elective. Residents are included in all aspects of the service. Residents are specifically expected to learn how to order and interpret coagulation tests to learn how to investigate hemostatic disorders. The trainees are expected to acquire expertise in clotting factors and inhibitors and their relationship to blood product use. Preoperative assessment of bleeding and management of bleeding during the intraoperative and postoperative period are parts of the curriculum.

Finally, residents learn the importance of communication with the medical and surgical services and being a member of the health care team. The teaching program relies heavily on direct patient and medical staff interaction via daily patient rounds and clinical consultation for all matters related to transfusion support of the complex heart failure patients in our tertiary care center, a 1000-bed hospital. Coordination and close communication with cardiologists, surgeons, anesthesia physicians, and clinical pharmacists is an essential part of this consultation. The trainees are given graduated responsibility in consultations to provide timely laboratory tests and transfusion. The trainees also take calls with pathology faculty to manage patients during off-hours.

DISCUSSION

We describe the successful implementation of a novel CBH service that uses comprehensive and rapid TAT coagulation testing variables in combination with a

transfusion algorithm to optimize management of patients with a high risk of bleeding and subsequent morbidity and mortality. Our data show a rapid TAT for all tests ordered, resulting in essentially real-time availability of coagulation results allowing the pathologist to treat the underlying cause of bleeding. The intraoperative testing protocol allows the hemotherapy pathologist to anticipate bleeding and the underlying cause. Our data also show a decrease in blood product use and reoperation for LVAD patients who are at an especially high risk for blood product need;[26,27] however, these data are not available for the same cardiac surgeons and cardiologists in the absence of a hemotherapy pathologist.

The CBH service provides an example of the important role that the pathologist can serve as clinical consultant. Clinical pathologists, especially those trained in transfusion medicine, have extensive knowledge of coagulation testing and interpretation, hemostasis, and the selection of blood products.[29] Clinical pathologists have long been involved in consultations involving interpretation of coagulation tests and clinical issues related to alloantibodies and transfusion reaction evaluations. Nevertheless, there is potential for clinical pathologists to further expand their role to direct management of coagulopathy in acute bleeding situations. The complexity of coagulation testing, the shortage of specialists in this field, and the high costs of blood transfusion with associated complications all indicate that there is a knowledge gap that can be fulfilled by coagulation and transfusion medicine physicians. Managing patients directly in an effective manner can lead to optimal outcome for patients. The positive clinical outcomes include reduction in complication rates, blood utilization, and shortened hospital stays, all elements of critical importance in the new health care environment. Other reports in the literature highlight improved outcomes and cost savings by pathology consultation. For example, pathology consultation for coagulation factor replacement for hemophilia patients in a tertiary center resulted in appropriate therapy and significant financial savings.[30] Blood bank monitoring of blood components and intervention when suboptimal transfusion practice was identified resulted in improved survival and decreased transfusion need in the postoperative period of massively transfused patients.[31] Tormey and Smith[29] review potential models by which clinical pathologists can integrate consultation on coagulation into daily practice.

Clinical pathology consultation services such as CBH increase the visibility of laboratory medicine practitioners in addition to providing better patient care and effective health care resource utilization.[29,32] Indeed, the American Society for Clinical Pathology has stated that pathology and laboratory medicine must play an increased part of patient care to be important players in the future health care environment.[33] The CBH pathologist participating in patient rounds and writing consultation and progress notes educates clinicians about appropriate test ordering and interpretation and transfusion practices. Such interactions increase the availability of clinical pathologists and increases the impact they can have on patient care.[29] Of note, the role of the CBH service is considered critical by the advanced heart failure clinicians at our institution.

Finally, pathology consultation services can produce revenue for the laboratory.[34] Laboratory medicine consultation services that can demonstrate improved outcomes and more effective utilization of health care resources can add quantifiable value to the services provided by the laboratory. Health care costs in the United States continue to increase and occupy a significant percentage of the gross domestic product. However, such increased use of resources has not yielded value in terms of improving patient outcomes. There is now an increasing emphasis on paying for outcomes or performance, as opposed to fee for service.[35] Interaction of laboratory staff with medical and surgical teams can both lead to improved utilization of limited resources and improved patient outcomes.[36]

In summary, we have successfully introduced a novel pathology consultation service that provides laboratory and transfusion support to patients with a high risk of bleeding and associated morbidity. There is a demand for such services, and clinical pathologists with their knowledge of coagulation testing, interpretation, and optimal transfusion practices can help fill this need.[29] However, limitations of such services include the large amount of time required of attending pathologists who are also expected to cover other pathology services. Not all clinical pathology faculties initially had the required experience and knowledge for the service. Nonetheless, this initiative by the CBH pathologists integrates several aspects of clinical pathology with the skills of cardiac surgeons and cardiologists to achieve better care for patients and optimal use of blood products.

CONFLICT OF INTEREST

The authors have disclosed no conflicts of interest.

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