

The Impact of a Blood Conservation Program in Complex Aortic Surgery

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Abstract

Objective: Recent Society of Thoracic Surgeons and Society of Cardiovascular Anesthesiologists (STS/SCA) guidelines highlight the safety of blood conservation strategies in routine cardiac surgery. We evaluated the feasibility and impact of such a program in complex aortic surgery. **Methods:** Between March 2010 and October 2011, 63 consecutive aortic replacement procedures were performed: aortic root ($n = 17$; 27%), ascending aorta ($n = 15$; 23.8%), aortic arch ($n = 19$; 30.2%), descending aorta ($n = 8$; 12.7%), and thoracoabdominal aorta ($n = 4$; 6.3%). Aortic dissections were present in 32 patients. A multidisciplinary approach to blood conservation included minimal perioperative crystalloid, small priming circuits, hemoconcentration, meticulous hemostasis, and tolerance of postoperative anemia (hemoglobin of ≥ 7 mg/dL). **Results:** Operative mortality was 11.1%. Multivariate predictors of mortality were low preoperative hematocrit (HCT, $P = 0.05$) and endocarditis ($P = 0.021$). Seventy-four percent of patients required no intraoperative packed red blood cell (pRBC) transfusion. For nondissection patients, 80.6% required ≤ 1 U of intraoperatively compared to 54.3% in STS benchmark data ($P < 0.0001$). During the hospital stay, 24 patients (39%) received no pRBCs and 34 patients (54%) received ≤ 1 U of pRBCs. Multivariate predictors of pRBC transfusion were low preoperative HCT ($P = 0.04$) and cardiopulmonary bypass time ($P = 0.01$). Discharge hemoglobin/HCT values were 8.7/26.3 compared to preoperative 12.1/35.5 ($p < 0.001$). Complications were absent in 94% (32/34) of patients receiving ≤ 1 U compared to 59% (17/29) in patients who

received ≥ 2 U ($P = 0.001$). **Conclusions:** These findings demonstrate that a perioperative blood conservation management strategy can be extended to complex aortic surgery and is associated with better clinical outcomes.

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Key Words

Aortic surgery · Blood transfusion · Complications

Introduction

One of the recent advances in cardiac surgery has been the recognition that perioperative transfusion of blood and blood products is associated with an increased risk of postoperative morbidity and mortality [1–8]. As a result, many cardiac surgery programs have implemented blood conservation protocols designed to reduce the number of transfusions that patients receive in the perioperative period [9]. Furthermore, the Society of Thoracic Surgeons (STS) and the Society of Cardiovascular Anesthesiologists (SCA) recently published guidelines, which highlighted the rationale and safety of blood conservation strategies in routine cardiac surgery [10]. Despite the growing evidence supporting the benefit of reducing blood transfusions in routine surgical procedures, little data exist regarding the applicability of these principles to more complex cardiac surgical procedures, such as aortic surgery. Recently, a blood conservation program in place



for cardiac patients undergoing revascularization and/or valvular surgery at our institution was extended to include all patients, including those undergoing complex aortic reconstruction. Here we report the usage of blood for a heterogeneous cohort of patients undergoing aortic surgery and its correlation with outcomes in these patients.

Materials and Methods

Information for 63 patients undergoing scheduled and emergent open aortic procedures between March 1, 2010 and October 1, 2011 were collected; these cases were limited to those of a single surgeon (A.D.) at our institution in order to eliminate the potential confounder of multiple operators. This retrospective review included all patients who underwent surgical repair; no patients were excluded from the analysis. As the institution of the blood conservation program occurred simultaneously with the initiation of an aortic practice of the single surgeon at this institution, no comparison was attempted for those patients undergoing surgery prior to the conservation program. The data analyzed included patient demographics and preoperative characteristics, intraoperative data including cardiopulmonary bypass (CPB) information and packed red blood cell (pRBC) usage, and postoperative outcomes including pRBC transfusions, major complications (respiratory failure, reoperation for bleeding, renal failure, sepsis, infection), and death. The focus of this study was in red blood cell usage, so transfusion of platelets, cryoprecipitate, and fresh frozen plasma was not addressed.

Our multidisciplinary approach to blood conservation included pre-, intra-, and postoperative optimization. Preoperative management included avoidance of medications (e.g., Clopidogrel, low-molecular-weight heparin) known to alter the bleeding profile of patients, as well as (when possible) optimization of the red cell mass with iron, folate, and, when indicated and possible, recombinant erythropoietin. Data relating to red cell mass optimization were not collected. Intraoperatively, we relied on meticulous operative hemostasis, intraoperative hemoconcentration, and tolerance of perioperative anemia (hemoglobin (Hg) \geq 7 mg/dL). An antifibrinolytic (Amicar; Xanodyne Pharmaceuticals, Newport, KY, USA) was used in each case. Perfusion techniques of retrograde autologous priming and small priming volumes were incorporated. All cases utilized cell saver technology. Additionally, recognizing that a significant portion of aortic procedures require some degree of hypothermia with or without circulatory arrest, we chose to remain on bypass until normothermia (venous blood temperature $>$ 37°C) was achieved. Patients underwent various arterial and venous cannulation approaches, depending on the planned procedure and aortic anatomy/pathology, and hypothermic circulatory arrest was used when deemed appropriate. In the postoperative period we continued with min-

Table 1. Patient Demographics and Characteristics: All Aortic Aneurysms and Dissections ($N = 63$)

	Mean (SD)	Range
Age (years)	57.5 (\pm 14.7)	24-86
	<i>n</i>	%
Female	23	36.5
PVD	42	66.7
Urgent	32	50.8
Emergency	17	27.0
Reoperation	12	19.0
COPD	9	14.3
Renal failure/dialysis	7	11.1
CVD	7	11.1
Active endocarditis	5	7.9
MI	4	6.3
Diabetes	4	6.3
Unstable/Shock	2	3.2
Hepatic failure	1	1.6
Extensive calcified aorta	1	1.6

PVD, peripheral vascular disease; COPD, chronic obstructive pulmonary disease; CVD, cardiovascular disease; MI, myocardial infarction.

imizing crystalloid usage. Blood product usage, including platelet transfusions, was based on objective evidence of the physiological need for transfusion rather than relying on automatic triggers or empirical or prophylactic tactics, but we would transfuse pRBCs for Hg $<$ 7 mg/dL. Point-of care testing to quantify coagulation profiles was not performed. Reflexive transfusion of platelets for low platelet counts in patients who were not bleeding was avoided. Patients undergoing endovascular surgery for aortic disease were not included in this analysis. The protocol differed from previous practices in a variety of ways, but the most significant differences were tolerance of anemia, attempting to achieve normothermia, and minimizing crystalloid usage. Statistical analyses were performed with SPSS v19.0 software (SPSS Inc, Chicago, IL, USA). Values are expressed as mean \pm standard deviation and percentages.

This retrospective study was approved by the New York University School of Medicine Institutional Review Board with a specific waiver of individual patient consent. Institutional Review Board exemption for deidentified patient outcome data analysis was obtained and the requirement for written informed consent was waived.

Results

Patient demographics and characteristics are outlined in [Table 1](#). Of the 63 patients, 31 patients were operated on for isolated aortic aneurysms which involved the aortic root ($n = 7$), and ascending ($n = 13$), arch ($n = 6$), descending ($n = 3$), and thoracoabdomi-

Table 2. RBC Utilization: All Aortic Aneurysms and Dissections ($N = 63$)

pRBCs	Intraoperative	Postoperative	Total perioperative
0 U	44 (74%)	34 (54%)	24 (39%)
1 U	8 (13%)	10 (16%)	10 (16%)
2 U	2 (3%)	9 (14%)	11 (17%)
3 U	4 (6%)	4 (6%)	7 (11%)
4+ U	5 (4%)	6 (10%)	11 (17%)

nal aorta ($n = 2$). Thirty-two patients had aortic dissections including 15 acute and 17 chronic dissections. The acute dissections were primarily Type A dissections ($n = 14$), whereas the chronic dissections were more evenly divided between Type A ($n = 7$) and Type B ($n = 8$). The one acute Type B dissection had radiographic evidence of a contained posterior leak (confirmed at operation), prompting emergency surgical intervention. Mean CPB time was 161 ± 75 min and mean aortic cross-clamp time was 97 ± 60 min. Thirty-one patients underwent a period of full circulatory arrest with a mean time of 25 ± 20 min and a mean core temperature of $16.0 \pm 2.8^\circ\text{C}$. Of the 31 patients who required a period of hypothermic circulatory arrest, 18 underwent selective antegrade cerebral perfusion for a mean time of 18.0 ± 13.2 min; in the remaining 13 patients cerebral protection was afforded by hypothermia alone, with a mean cerebral ischemic time of 23.1 ± 9 min. Of the 63 patients, only 1 patient (undergoing emergency repair of a ruptured thoracoabdominal aortic aneurysm) received recombinant activated Factor VII (rFVIIa; NovoSeven, Novo-Nordisk, Copenhagen, Denmark).

The in-hospital mortality rate was 11.1% (7 patients) and the respiratory failure rate was 11.1% (7 patients). There were six (9.5%) reoperations for bleeding within the first 36 hours, and four patients (6.3%) developed renal failure requiring dialysis. Additional complications included gastrointestinal bleeding in two patients (3.2%), cerebrovascular accidents in two patients (3.2%), and sepsis in one patient (1.6%). The mean postoperative length of stay was 11.6 days (range 1-52 days). There were no sternal wound infections or myocardial infarctions.

Table 2 outlines the utilization of pRBCs and separates the transfusions by timing, i.e., either intraoperatively or postoperatively. The majority of patients in the intraoperative period did not require

Table 3. Comparison of Preoperative and Postoperative Hemoglobin/Hematocrit Levels: All Aortic Aneurysms and Dissections

	Preoperative	Postoperative	Discharge
Hemoglobin (mean \pm SD)	12.1 ± 2.4	10.5 ± 1.7	$8.7 \pm 1.4^*$
Hematocrit (mean \pm SD)	35.5 ± 6.8	30.3 ± 6.3	$26.3 \pm 4.4^*$

* $P < 0.0001$ compared to preoperative, paired t test.

a pRBC transfusion, using our criteria. Although not included in the statistical analysis, the average platelet, fresh frozen plasma (FFP), and cryoprecipitate transfusion was (mean [range]) 1.03 U [0-10], 1.37 U [0-20], and 0.13 U [0-2], respectively. In addition, more than one third did not require pRBC transfusion in either the intraoperative or postoperative period. For those patients who were transfused, most required only 1 or 2 U. With this conservative approach, there was a noticeable decrease in mean hemoglobin and hematocrit levels with time; these data are presented in Table 3. A paired t test comparison of preoperative and discharge mean hemoglobin (12.1 versus 8.7, $P < 0.001$) and hematocrit (35.5 versus 26.3, $P < 0.001$) demonstrated a statistically significant decrease.

Patients were subsequently divided into two groups based on their transfusion requirement (Table 4). Thirty-four (54%) patients required 0 or 1 U of pRBCs during their hospitalization, while 29 (46%) patients required two or more units of pRBC. Patients requiring 0-1 U of pRBCs were more likely to have suffered no complication (94.1% versus 59%, $p < 0.001$), and were less likely to have suffered a major complication [see Appendix A for

Table 4. Relationship between Postoperative Complications and RBC Utilization: All Aortic Aneurysms and Dissections

	0-1 U of pRBCs ($n = 34$)	2 or more units of pRBCs ($n = 29$)	p -value
No complications	32 (94%)	17 (59%)	0.001
Major complications (respiratory/renal failure, sepsis, mortality)	0 (0%)	11 (38%)	<0.001

Table 5. Comparative Analysis of NYU Aortic Aneurysm Procedures and STS Data

	NYU March 2010–Oct 2011		STS 2010	
	<i>n</i>	%	<i>n</i>	%
Thoracic Aneurysm Procedures (Open)	31		16,893	
Aneurysms				
Ascending	20	64.5	11,662	69.0
Arch	6	19.4	3343	19.8
Descending	3	9.7	1205	7.1
TAAA	2	6.5	683	4.0
Demographics				
Mean age	58		61	
≥65 yr old	12	38.7		44.9
Gender				
Female	16	51.6		33.2
Operative Data				
Cross-clamp time (min)	102.1		120	
Perfusion time (min)	160.5		168.6	
Intraoperative Blood Product Used				
0 U	25	80.6		47
1 U	0	0.0		7.3
2 U	2	6.5		12.7
3 U	3	9.7		6.7
4+ Units	1	3.2		26.3
χ^2 with 1 degree of freedom	232.0112			
<i>p</i> -value	<0.0001			
Postoperative Blood Product Used				
0 U	21	67.7		49.0
1 U	3	9.7		10.5
2 U	4	12.9		13.8
3 U	2	6.5		6.5
4+ U	1	3.2		20.4
Outcomes: Aortic Aneurysms				
Postoperative length of stay (mean)	11.2		10.1	
Complications				
Respiratory failure	3	9.7		30.8
Reoperation	2	6.5		14.6
Renal failure	1	3.2		9.4
Stroke	1	3.2		5.5
Sternal wound infection	0	0.0		0.3
Mortality	3	9.7		8.7

definitions of complications], including respiratory failure, renal failure, sepsis, and mortality (0% versus 38%, $P < 0.001$). Further analysis for the patients receiving transfusions demonstrated that major complications were only found with transfusion of >2 U of pRBCs. Backward stepwise logistic regression analysis was performed to define predictive variables for blood transfusion requirements. The two significant variables were prolonged CPB time ($P = 0.015$) and low preoperative hematocrit ($P =$

0.042). Multivariate predictors of mortality included endocarditis ($P = 0.021$) and low preoperative hematocrit ($P = 0.05$).

Table 5 outlines a comparison between our aortic aneurysm procedures during the study period ($n = 31$) and available data from the STS database for 2010. In our cohort, 80.6% of patients required ≤ 1 intraoperative unit of PRBCs compared to 54.3% in STS benchmark data, which was statistically significant ($P < 0.0001$).

Discussion

It has been appreciated that cardiac surgery is associated with significant usage of blood and blood products, comparable to that used in orthopedics and trauma surgery on a per patient basis. Recent evidence and consensus statements have advocated for a shift in the paradigm regarding transfusion practices in cardiac surgery, but there remains wide variability in such practice, even when comparisons are controlled and matched. For “routine” cases where bleeding (and, therefore, need for transfusion) would not be anticipated, reflexive practices may be engrained into clinical practice, such as transfusing to a hemoglobin of > 0 mg/dL or administering the traditional “round” of products (e.g., FFP, cryoprecipitate, platelets) for the postoperative patient who appears coagulopathic.

For procedures that have been characterized as more likely to result in bleeding, including complex aortic procedures, blood conservation practices have been questioned, despite growing evidence that transfusion and/or the need for transfusion is associated with worse outcomes. Cambria et al. [11] demonstrated that for repair of thoracoabdominal aortic aneurysms, pRBC transfusion requirement was one of two independent correlates of mortality (odds-ratio 1.4, $P = 0.005$). It is difficult to assess how much blood and blood products are given to any patient since studies often refer to intraoperative transfusion or postoperative chest tube output without a unifying benchmark. In a similar but smaller study, Rahe-Meyer et al. [12] found that with a thromboelastogram (TEG)-directed transfusion protocol, blood product utilization in the first 24 hours postoperatively decreased from 16.4 to 2.5 U; two thirds of the protocol patients did not require any product in the first postoperative day. The authors attributed this to TEG-directed intraoperative administration of fibrinogen concentrate.

In this study, we sought to determine the usage of blood for a heterogeneous cohort of patients undergoing aortic surgery. Our results are consistent with other reports of decreased postoperative morbidity associated with fewer pRBC transfusions. In this study, 94.1% of patients who required 0 or 1 U of pRBCs suffered no perioperative complications. While this retrospective study may not prove causation, it certainly highlights the relationship between transfusions and complications in this group of patients. As cardiac

surgeons and the physicians and nurses who care for these patients perioperatively gain experience with blood product conservation in routine cases, we believe that these practices can be safely extended to more complicated cardiac surgeries, including complex aortic reconstruction. Presumably, the benefits afforded to patients who undergo “routine” cardiac surgery without transfusion would be extended to this patient group as well. As such, we would suggest that the type of procedure performed may not be an appropriate part of a transfusion algorithm. Likewise, the empiric use of blood-product derivatives as prophylaxis may not be necessary. Goksedef et al. [14] described their experience with complex aortic surgery, propensity matching patients treated with and without rFVIIa for those patients found to be coagulopathic following aortic surgery. In their study, there was a significant decrease in bleeding requiring exploration and need for blood transfusion in patients who received rFVIIa given for refractory bleeding. This reduction translated to a decrease from 9 ± 4 to 7 ± 2 U of pRBCs. In our current study, we had one patient with refractory bleeding.

In addition, the current study demonstrates that the application of the principles of a blood conservation program to patients undergoing complex procedures will decrease the number of transfusions these patients receive. In this challenging group of patients, only 10 patients (16%) required >2 U of pRBCs in the postoperative period. While intraoperative measures to conserve blood will reduce the need for postoperative transfusions, it is likely that the tolerance of perioperative anemia was the most significant factor, as evidenced by the fact that the mean discharge hemoglobin was 8.7 mg/dL. This change in practice requires a collaborative effort among all members of the surgical and intensive care unit team. In a different environment, without open communication between the surgeons, intensivists, nurses, and other team members, many of these patients likely would have received a transfusion prior to discharge.

As is inherent in most retrospective observational analyses, the current study is not without limitations. Perhaps most important is the difficulty in determining exactly why any given patient was transfused. Despite the implementation of the aforementioned blood conservation guidelines, invariably some patients will receive transfusions who may not have needed them. Likewise, some patients who were oth-

erwise stable may not have been transfused despite a perioperative hemoglobin value that was below the standard threshold. With retrospective assessment of the available data, it is difficult to control for all of the variables that impact a clinical decision.

Perhaps the major lesson from reviewing data such as these is to remind ourselves of the potential harm of giving a transfusion to a patient both during and after cardiac surgery. In addition, we would caution that the indiscriminate transfusion of patients after complex aortic procedures may not be beneficial. Follow-up of this group of patients over the coming years will allow us to further evaluate the effect of perioperative transfusions on their long-term outcome.

Conclusion

Recent STS/SCA guidelines highlight the advantages of implementing a blood conservation program for routine cardiac surgery cases. This study shows that a previously implemented blood conservation program for routine cardiac surgery can be safely extended to complex aortic procedures. The implementation of such a program can decrease the number of transfusions in this patient population and is associated with improved outcomes in these complicated patients.

Appendix A: Definitions of Complications

Stroke

Permanent new focal neurological deficit occurring more than 24 hours postoperatively.

Bleeding Requiring Reoperation

Unplanned reoperation to control bleeding or to evacuate large hematomas in the thorax or pericardium.

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Deep Sternal Wound Infection

Drainage of purulent material from the sternotomy or thoracotomy wound. This event was only reported when associated with instability of the sternum. A sternal wound infection was reported as a postprocedural event even if it did not become apparent until after the patient was discharged from the hospital.

Sepsis

Temperature $>101^{\circ}\text{F}$ (38.5°C) and increased white blood cell (WBC) and positive blood culture or Temperature $<98.6^{\circ}\text{F}$ (37°C) and decreased WBC and positive blood culture.

Endocarditis

Two or more positive blood cultures without another obvious source, demonstrated valvular vegetation, or acute valvular dysfunction caused by infection.

Renal Failure Requiring Dialysis

The need for temporary or permanent renal dialysis of any type.

Gastrointestinal Bleeding

Any postoperative episode of vomiting blood, gross blood in the stool, perforation or necrosis of the stomach or intestine.

Respiratory Failure

Pulmonary insufficiency requiring intubation and ventilation for a period of 72 hours or more, at any time during the postoperative stay. For patients who were placed on and taken off ventilation several times, if the total of these episodes was 72 hours or more, then pulmonary insufficiency was assigned.

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EDITOR'S QUESTIONS

1. Does any surgeon feel he does not practice “meticulous operative hemostasis”?

Yes, but belief and practice may diverge. These cases by and large are performed by the cardiothoracic surgery residents, but the attending does not generally leave the room until complete closure. This was an important part (perhaps unwritten) in the blood conservation approach. Soft tissue and/or needle hole bleeding was treated actively rather than, for example, attributing to “coagulopathy” and relying on coagulation factors and blood transfusion to handle the bleeding.

2. Do you feel that the hemostatic benefits of staying on CPB to warm a bit more (to 37°C) outweigh the detriment of further prolongation of CPB time?

Yes. Aggressive warming to a core temperature of 37°C did not appear to add much more to the CPB time. Of note, core temperature was determined by the venous blood temperature. Depending on the type of procedure, there can be a substantial cooling between the time of disconnecting from CPB and closure (for example, with a thoracoabdominal aortic aneurysm), so having that additional buffer can be critical.

3. You indicate that you minimize crystalloid usage post-op. What do you use? Do you stay unusually “dry”?

Unless contraindicated, either pressors, inotropes, or a combination of both is used in the post-op period in response to hypotension, instead of fluid boluses.

We determine fluid requirements based on intraoperative fluid and baseline needs.

4. How did you pick the <7 mg/dL transfusion criterion?

7 mg/dL is based on transfusion recommendations of the STS/SCA.

5. Do you feel that you could have avoided the relatively high reoperation rate (9.5%) by routine administration of platelets or plasma (especially in the DHCA group)?

No. The patients requiring reoperation all had surgical bleeding (despite my earlier comments on meticulous surgery) which generally does not respond to platelet or plasma transfusion. DHCA is not a risk factor for bleeding despite the reputation it has achieved, with the caveat that DHCA probably matters when you don't rewarm completely. More recent work (including work by Gerald Levy) would suggest that the coagulopathy seen postoperatively reflects fibrinolysis, and that cryoprecipitate would be more helpful.

6. Avoiding intraoperative pRBC transfusion seems to be a goal in your series. What was gained by delaying transfusion to the postoperative period?

The goal in our series was to lower overall transfusion rates. We accepted lower hematocrits leaving the operating room, recognizing that some patients would require transfusion, some patients would have a natural increase in hematocrit as they diuresed, but all patients would have an easier time coming off the ventilator.

7. Do you think the transfusions “caused” the complications in the high-transfusion group; or

did the complications and transfusions simply reflect sicker patients?

This question has been explored clinically, and when patients are matched, we have seen higher complications in patients who are transfused. This was one of the reasons for this study. There is great heterogeneity in transfusion rates in this country (and within centers), and surgeons may suffer from a

"Lake Wobegon Effect," i.e., every surgeon's patients are sicker than everyone else's.

8. How should we change our practice based on this report?

I believe that this study should not be an end-all or indictment of current practices, but simply illustrates that with a motivated multidisciplinary team, blood conservation can be successfully employed.