CLINICAL STUDY

A Systematic Approach to Reduce Blood Transfusions in Acute Type A Aortic Dissection Surgery

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Summary

This study aimed to summarize our experience using a systematic approach to reduce blood transfusions in acute type A aortic dissection (ATAAD) surgery.

From August 2016 to June 2020, 326 patients underwent ATAAD surgery in our center employing a systematic approach, which primarily included the following: Liu's aortic root repair technique, Liu's aortic arch inclusion technique with a frozen elephant trunk, moderate-to-mild hypothermia circulatory arrest, and application of centrifugal pump in cardiopulmonary bypass circuit. Patients were divided into two groups based on whether they had blood product transfusion during their hospital stay: transfusion group and transfusion-free group. Preoperative, intraoperative, and postoperative outcomes were compared between the 2 groups.

In the transfusion group, 152 patients were included, and in the transfusion-free group, 174 patients were involved; the transfusion-free rate was 53.37%. Patients in the transfusion group were significantly older than those in the transfusion-free group, and there were more patients with preoperative anemia and malperfusion in the transfusion group. Overall in-hospital mortality was 5.21% (17/326), with 3 mortalities (1.72%) in the transfusion-free group and 14 mortalities (9.21%) in the transfusion group (P = 0.0025). At tested time points, the Hb levels of patients between the 2 groups were similar.

In ATAAD patients, the transfusion group showed significantly older patient age, more incidences of preoperative anemia and malperfusion, and higher in-hospital mortality than the transfusion-free group. Through Liu's systematic approach, ATAAD surgery can be achieved and safely carried out in ATAAD patients without blood product transfusion in selected patients.

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Key words: Surgical treatment, Transfusion-free, Transfusion reduction

Acute type A aortic dissection (ATAAD) is a life-threatening disease that requires prompt surgical intervention. Its surgical mortality and morbidity rates remain high.[1] It is associated with complex aortic reconstruction with multiple anastomosis sites, emergency surgical settings, prolonged cardiopulmonary bypass (CPB) times, hypothermia, and coagulopathy dysfunction.[2] Therefore, even in high-volume centers, ATAAD surgery remains a surgical challenge for cardiac surgeons.

Recently, blood transfusion has been a popular topic in cardiac surgeries. In the United States, approximately 20% of blood transfusions are associated with cardiac surgery.[3,4] On average, 50%-60% of patients undergoing open cardiac surgery receive blood transfusions.[5] Given the side effects and also the increasing shortage of blood supplies, numerous efforts have been made to reduce blood transfusions.[6,7] In some types of cardiac surgeries, "bloodless" cardiac surgeries can be feasible.[8] Nevertheless, in the surgical repair of ATAAD, because of the nature and surgical complexity of the disease, blood transfusion is almost inevitable.[9]

From 2009 to 2016, our center modified several surgical techniques in ATAAD surgeries, which included Liu's aortic arch inclusion technique for aortic arch reconstruction,[10] Liu's aortic root repair technique,[11] and the application of moderate-to-mild hypothermia circulatory arrest.[12] These techniques facilitated the achievement of relatively satisfactory surgical results. In mid-2016, after a series of surgical technique modifications in our center, we started to explore the feasibility of transfusion-free ATAAD surgery.

This study aimed to summarize our experience with a systematic approach to reducing blood transfusion and explore the safety and efficacy of ATAAD surgeries without blood product transfusions.

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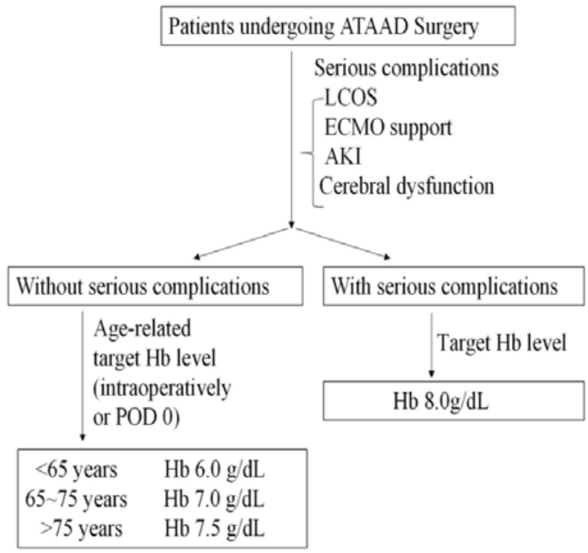

Figure 1. Restrictive transfusion protocol. ATAAD indicates acute type A aortic dissection; LCOS, low cardiac output syndrome; ECMO, extracorporeal membrane oxygenation; AKI, acute kidney injury; and POD, postoperative day.

Methods

Patients and study design: Between August 2016 and June 2020, 326 consecutive patients with ATAAD underwent surgical treatment in our center. All patients were diagnosed with ATAAD using computed tomography angiography. ATAAD was defined as aortic dissection presenting within 14 days from symptom onset.

The ethics board of the Second Hospital of Jilin University, China, approved this retrospective single-center observational study (NO: 2021-212). In this study, the requirement for informed consent was waived. All data were obtained from patient records and were reviewed retrospectively. Follow-up assessments were conducted during outpatient clinic visits or via telephone interviews; the latest follow-up was in March 2022.

Systematic approach: To reduce blood transfusions in ATAAD surgeries, a systematic approach (called Liu's procedure in short) was implemented, which mainly included the following: Liu's aortic root repair technique, Liu's aortic arch inclusion technique with a frozen elephant trunk, moderate-to-mild hypothermia circulatory arrest, and application of centrifugal pump in CPB circuit.

Restrictive blood transfusion strategy: To reduce blood transfusions, a restrictive blood transfusion protocol was implemented both intraoperatively and postoperatively. For patients without serious complications, including low cardiac output syndrome (LCOS), acute kidney injury (AKI), cerebral dysfunction, or requirement for extracorporeal membrane oxygenation (ECMO) support, the target hemoglobin (Hb) level was related to age. For patients < 65 years old, a Hb level of approximately 6 g/dL intraoperatively or on the day of the operation was accepted. The target Hb level was 7 g/dL for patients between 65 and 75 years old and > 7.5 g/dL for patients > 75 years old. For those with LCOS, AKI, cerebral dysfunction, or ECMO support requirement, the Hb level should be > 8 g/dL. Figure 1 presents the flow chart of our restrictive protocol.

The Hb levels of all patients were measured in the central laboratory. Hb levels at different time points, that is, preoperative, on the day of operation (POD 0), postoperative days (POD) 1-7, and on the day before discharge, were identified and recorded.

Operation: Following the induction of general anesthesia, a thermostatic cooling blanket was applied to the back of the patient. Two atrial pressure lines (one radial artery and one pedal artery) and a transesophageal echocardiogram monitoring probe were established. The right axillary and femoral arteries were prepared for CPB cannulation. After carrying out a median sternotomy, CPB was established through cannulas in the right axillary artery, femoral arteries, and the superior and inferior vena cava. A centrifugal pump (Sorin, Mirandola, Italy) was utilized in the CPB circuit. To initiate core cooling, the left side of the heart was vented through the right superior pulmonary vein. Using antegrade or retrograde cold blood cardioplegia infusion or HTK solution, myocardial protection was achieved. Rectal temperature probes were placed for temperature monitoring. The target rectal temperature at circulatory arrest was 28-34.5°C.

For brain protection, we utilized antegrade selective cerebral perfusion via right axillary artery and left common carotid artery cannulations at a flow rate of 650-1000 mL/minute. Near-infrared spectroscopy was employed for cerebral monitoring before September 2019. Saturation of superior and inferior vena cava blood was used to monitor cerebral oxygen saturation after cerebral-body separate perfusion was utilized from October 2019 to June 2020 in this study.

In our previous reports, the aortic arch repair and aortic root reinforcement technique were described in detail.[10,11]

Statistical analysis: Categorical data were presented as frequencies and proportions, and continuous data were presented as mean ± standard deviation. Univariate analyses were performed using *t* test or the Mann-Whitney *U* test for continuous variables and chi-square or the Fisher exact test for categorical variables. Using the Kaplan-Meier method, survival was estimated. Pearson correlation analysis was performed to show the relationship between certain variables, with in-hospital mortality and postoperative morbidity. Multivariate logistic regression analysis including covariates that were significantly different between the two groups was conducted for risk factor identifications. All statistical analyses were performed using SPSS (SPSS Inc, Chicago, IL). A P value of < 0.05 was considered statistically significant.

Results

The patients were divided into 2 groups based on whether they received blood transfusions during their hospital stay: transfusion group (n = 152) and transfusion-free group (n = 174). Perioperative information and survival during follow-up were compared between the 2 groups.

Preoperative background: Table I outlines the preopera-

Table I. Preoperative Patient Characteristics

Characteristics	Transfusion-free (n = 174)	Transfusion (n = 152)	P-value
Age (years)	51.8 ± 0.83	55.9 ± 0.87	0.006*
Male	35 (68.6%)	16 (47.1%)	0.07
BSA (m^2)	1.86 ± 0.01	1.78 ± 0.01	0.002*
Marfan syndrome	4 (2.29%)	5 (3.2%)	0.74
Previous cardiac surgery	2 (1.15%)	2 (2.63%)	> 0.99
Hypertension	154 (82.1%)	130 (85.5%)	0.50
Chronic obstructive pulmonary disease	17 (9.80%)	12 (7.89%)	0.69
Coronary artery disease	27 (15.5%)	32 (21.05%)	0.19
Mean ejection fraction (%)	63.2 ± 0.53	62.2 ± 0.43	0.16
Diabetes mellitus	13 (7.5%)	15 (9.8%)	0.55
Chronic renal disease	20 (11.5%)	13 (8.5%)	0.46
Preoperative anemia	34 (19.54%)	54 (35.52%)	0.0017*
Malperfusion			
Cerebral malperfusion	0 (0%)	4 (2.63%)	0.04*
Coronary malperfusion	6 (3.45%)	8 (5.26%)	0.58
Extremity malperfusion	3 (1.96%)	16 (10.5%)	0.0007*
Visceral malperfusion	0 (0%)	4 (2.63%)	0.04*
Kidney malperfusion	4 (2.29%)	9 (5.92%)	0.15
Multiple malperfusion	0 (0%)	6 (3.95%)	0.009*

*$P < 0.05$. BSA indicates body surface area.

Table II. Operative Data

	Transfusion-free (n = 174)	Transfusion (n = 152)	P-value
Procedures			
Ascending aorta replacement + aortic arch inclusion technique + frozen elephant trunk	174 (100%)	152 (100%)	
Aortic valve replacement	7 (4.02%)	8 (5.26%)	0.60
Bentall procedure	18 (10.34%)	10 (6.57%)	0.52
Coronary artery bypass graft	5 (2.87%)	6 (3.95%)	0.76
Femoral-femoral artery bypass graft	0	11 (7.23%)	0.0002*
Ascending aorta-left subclavian artery bypass graft	8 (4.60%)	7 (4.60%)	> 0.999
Intraoperative data			
Circulatory arrest time (minutes)[#]	40.96 ± 7.35	40.31 ± 10.32	0.50
Aortic cross-clamp time (minutes)	108.6 ± 18.99	106.1 ± 22.88	0.32
CPB time (minutes)	148.8 ± 23.59	162.7 ± 51.56	0.0026*
Intraoperative ECMO	0 (0%)	4 (2.63%)	0.04*
Intraoperative cell salvage (mL)	341 ± 162	538 ± 358	< 0.001
Intraoperative blood transfusions	0	98 (64.5%)	
RBC transfusion (U)	0	6.07 ± 3.67	< 0.0001*
Serum transfusion (mL)	0	590 ± 408.8	< 0.0001*
PLT transfusion (U)	0	1.324 ± 2.198	
Cryoprecipitation (U)	0	4.53 ± 9.54	

ECMO indicates extracorporeal membrane oxygenation; CPB, cardiopulmonary bypass; RBC, red blood cell; and PLT, platelet.
[#]Include circulatory arrest time and aortic balloon occlusion perfusion time. *$P < 0.05$.

tive data. The patients in the transfusion group are significantly older than those in the transfusion-free group (P = 0.006). The body surface area was significantly larger in the transfusion-free group (P = 0.002). Hypertension was noted in 85.5% (130/152) and 82.1% (154/174) of the patients in the transfusion and transfusion-free groups, respectively. Thirty-four patients in the transfusion-free group and 54 in the transfusion group had preoperative anemia (P = 0.0017), which was defined as a preoperative Hb level of < 12 g/dL in males and < 11 g/dL in females.

The incidences of cerebral malperfusion, extremity malperfusion, visceral malperfusion, and multiple malperfusion were significantly higher in the transfusion group than in the transfusion-free group. Table I lists the details of preoperative data.

Operative data: Table II shows the operative data. In this study, all patients had Liu's aortic root repair, ascending aorta replacement, and Liu's aortic arch inclusion technique with FET. The concomitant procedures were similar between the 2 groups, except that those in the transfusion group had significantly more femoral-femoral artery bypass grafts (P = 0.0002). ECMO was conducted on 4 patients in the transfusion group. Those in the transfusion group had significantly longer CPB time (P = 0.0026),

Table III. Postoperative Mortality and Morbidity

	Transfusion-free (n = 174)	Transfusion (n = 152)	P-value
Hospital mortality	3 (1.72%)	14 (9.21%)	0.0025*
MODS	2 (1.15%)	8 (5.26%)	0.049*
Paraplegia	0	1 (0.66%)	0.46
Stroke			
Permanent	4 (2.30%)	8 (5.26%)	0.23
Temporary	7 (4.02%)	5 (3.29%)	0.78
Low cardiac output syndrome	1 (0.57%)	5 (3.29%)	0.10
Postoperative ECMO	0	6 (3.95%)	0.02*
Mechanical ventilation time (hours)	39.29 ± 27.9	71.33 ± 44.78	0.0006*
Tracheotomy due to respiratory failure	0	6 (3.95%)	0.02*
Renal failure requiring dialysis	16 (9.20%)	19 (12.5%)	0.37
Sepsis	1 (0.57%)	8 (5.26%)	0.014*
Deep/sternal wound infection	0	3 (1.97%)	0.10
Reoperation for bleeding	4 (2.30%)	6 (3.95%)	0.523
Chest tube drainage during the first 24 hours (mL)	264.9 ± 182.3	371.6 ± 213.5	0.09
Hospital length of stay (days)	18.27 ± 7.11	19.52 ± 14.8	0.865
ICU stay (days)	4.7 ± 3.7	12.1 ± 10.94	0.0002*
Postoperative transfusions	0		
RBC transfusion (U)	0	6.18 ± 7.26	
Serum transfusion (mL)	0	737.6 ± 990.3	
PLT transfusion (U)	0	0.97 ± 2.05	
Cryoprecipitation (U)	0	3.662 ± 9.31	

MODS indicates multiple organ dysfunction syndrome; ECMO, extracorporeal membrane oxygenation; ICU, intensive care unit; RBC, red blood cell; and PLT, platelet. *$P < 0.05$.

whereas no significant difference in circulatory arrest time and aortic cross-clamp time was found between the 2 groups. Intraoperative blood loss was recorded by intraoperative cell salvage. The amount of intraoperative blood cell salvage was 341 ± 162 mL in the transfusion-free group and 538 ± 358 mL in the transfusion group ($P < 0.001$).

Ninety-eight patients had an intraoperative blood transfusion, thereby leading to an intraoperative transfusion-free rate of 69.93% (228/326), and the mean transfusion amounts of red blood cells (RBCs), serum, cryoprecipitate, and platelet were 6.07 ± 3.67 U, 590 ± 408.8 mL, 4.53 ± 9.54 U, and 1.324 ± 2.198 U, respectively. The patients with Liu's procedure alone and with Liu's procedure with concomitant procedures were compared in terms of transfusion rate; 44.7% (110/246) patients with Liu's procedure alone and 52.5% (42/80) patients with Liu's procedure with concomitant procedures received blood product transfusion. No significant difference in transfusion rate between patients with or without concomitant procedures was found ($P = 0.24$).

Postoperative data: Fifty-four patients did not receive intraoperative blood products but had postoperative blood transfusions. Therefore, 152 patients were included in the transfusion group. Table III lists the postoperative mortality and morbidity. Overall in-hospital mortality was 5.21% (17/326), with 3 mortalities (1.72%) in the transfusion-free group and 14 mortalities (9.21%) in the transfusion group ($P = 0.0025$). The 3 mortalities in the transfusion-free group included 2 deaths due to multiple organ dysfunction syndrome (MODS) and one death due to LCOS. The 14 mortalities in the transfusion group included 8 deaths due to MODS, one death due to paraplegia, and 5 deaths due to LCOS. MODS incidence was significantly higher in the transfusion group than in the transfusion-free group. Furthermore, paraplegia occurred in one patient (0.66%) in the transfusion group; the patient had a sudden cardiac arrest during cerebral spinal fluid drainage. Permanent stroke was noted in 5.26% (8/152) and 2.30% (4/174) of the patients in the transfusion and transfusion-free groups, respectively ($P = 0.23$). Temporary stroke incidence was similar between the 2 groups. Postoperative ECMO was performed in 6 patients in the transfusion group, whereas no patient in the transfusion-free group received ECMO support ($P = 0.02$).

Mechanical ventilation time was significantly longer in the transfusion group than in the transfusion-free group (71.33 ± 44.78 hours versus 39.29 ± 27.9 hours; $P = 0.0006$). Six patients (3.95%) in the transfusion group had tracheotomy due to respiratory failure; no patient in the transfusion-free group had tracheotomy ($P = 0.02$). Renal failure requiring dialysis was observed in 9.20% of the patients (16/174) in the transfusion-free group and 12.5% of the patients (19/152) in the transfusion group ($P = 0.37$).

The average amounts of postoperative RBCs, serum, platelet, and cryoprecipitate transfusion were 6.18 ± 7.26 U, 737.6 ± 990.3 mL, 0.97 ± 2.05 U, and 3.62 ± 9.31 U, respectively. In this study, a total of 152 patients received blood transfusion during their hospital stay; thus, the transfusion-free rate of the 326 patients was 53.37% (51/85).

Pearson correlation analysis shows that 9 variables were significantly correlated with in-hospital mortality ($P < 0.05$) (ranking from strong to low), including extremity malperfusion (0.972), kidney malperfusion (0.774), multi-

Table IV. Change in Hb Level

	Transfusion-free (n = 174)	Transfusion (n = 152)	P-value
Preoperative	12.9 ± 1.85	12.4 ± 1.83	0.028*
POD 0	9.28 ± 1.97	9.25 ± 1.90	0.89
POD 1	9.19 ± 1.47	9.24 ± 2.14	0.86
POD 3	8.44 ± 2.18	8.89 ± 2.53	0.19
POD 5	9.02 ± 2.11	8.64 ± 2.40	0.25
POD 7	9.07 ± 2.22	8.67 ± 2.93	0.28
Before discharge	9.22 ± 1.95	9.18 ± 2.5	0.89

POD indicates postoperative day. *P < 0.05.

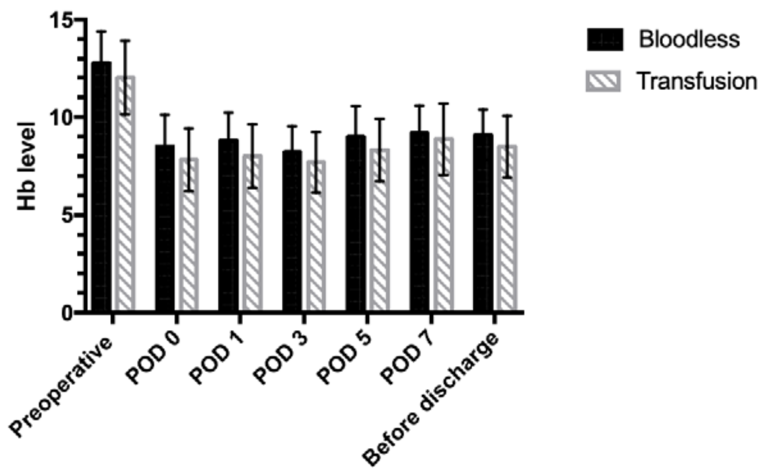

Figure 2. Change in Hb level. POD, postoperative day.

Table V. Transfusion in Patients with ECMO

	Patients with ECMO (n = 10)	Patients without ECMO (n = 142)	P-value
RBC	18 ± 13.84	7.82 ± 5.85	0.005*
Serum	2893 ± 1084	762.2 ± 814	< 0.0001*
PLT	2.43 ± 2.44	2.26 ± 2.88	0.8875
Cryo	11.43 ± 10.69	7.35 ± 16.55	0.542

ECMO indicates extracorporeal membrane oxygenation. *P < 0.05.

ple malperfusion (0.613), coronary malperfusion (0.611), visceral malperfusion (0.461), intraoperative ECMO implantation (0.461), cerebral malperfusion (0.339), preoperative anemia (0.398), and CPB time (0.122).

Pearson correlation analysis between variables with postoperative morbidity was also conducted. Nine variables were recognized to be correlated with postoperative morbidity (P < 0.05) (ranking from strong to low), including extremity malperfusion (0.919), kidney malperfusion (0.732), coronary malperfusion (0.576), intraoperative ECMO implantation (0.461), multiple malperfusion (0.436), visceral malperfusion (0.436), preoperative anemia (0.420), cerebral malperfusion (0.320), and CPB time (0.180).

At multivariate analysis, body surface area, extremity malperfusion, kidney malperfusion, multiple malperfusion, and intraoperative ECMO implantation were identified as independent risk factors for in-hospital mortality.

HB level change: Table IV and Figure 2 show the data on the Hb level and the change trend. At the test time points, no difference in Hb level was found between the 2 groups.

Blood product usage and ECMO: In our study, the relationship between blood product usage and ECMO implantation was also investigated. Four patients had intraoperative ECMO, and 6 had postoperative ECMO. Patients with ECMO support had significantly greater RBC (18 ± 13.84 U versus 7.82 ± 5.85 U; P < 0.005) and serum (2.893 ± 1.084 mL versus 762.2 ± 814 mL; P < 0.0001) transfusion volumes when compared with those without ECMO support. Between the two groups, the amount of platelet and cryoprecipitates were similar (Table V).

Follow-up: A total of 309 patients were discharged from the hospital (transfusion-free group, n = 171; transfusion group, n = 138), with a follow-up rate of 70.55% (218/309) (transfusion-free group, 70.2% [120/171]; transfusion

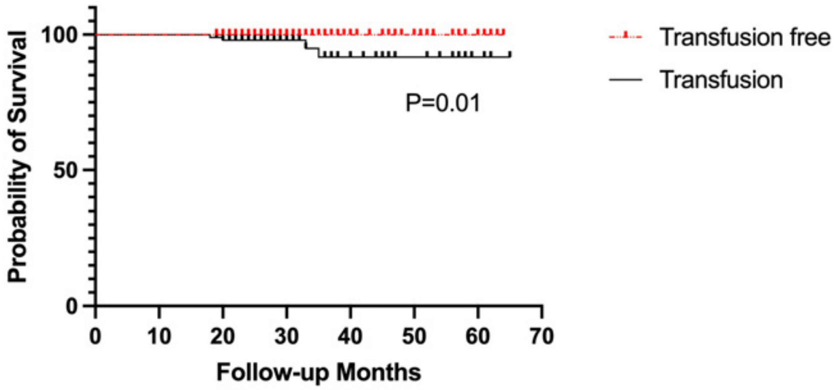

Figure 3. Survival curve line of follow-up patients.

group, 71.02% [98/138]). In the transfusion-free group, the mean follow-up time was 30.33 ± 14.97 months, and in the transfusion group, it was 36.4 ± 14.10 months. During the follow-up, 4 patients in the transfusion group died of non-aortic causes, and no deaths occurred in the transfusion-free group. The survival rate of the patients (Figure 3) who were successfully followed up was 98.16% (214/218) (transfusion-free group, 100% [120/120]; transfusion group, 95.91% [94/98], $P = 0.01$).

Discussion

Blood transfusion has been a subject of interest in cardiac surgery considering that RBC transfusions increase the risk of transfusion-related acute lung injury, hemolytic transfusion reactions, transfusion-associated infections, and short- and long-term mortalities.[13] Despite the efforts to implement evidence-based protocols to standardize and decrease blood use in cardiac surgery, data from the Society of Thoracic Surgeons reveal that cardiac surgery accounts for a significant proportion of blood product use.[14]

Owing to the frangibility of aortic tissue, ATAAD surgery is a complex procedure, which makes blood transfusion almost inevitable. There are currently no reports on the safety and feasibility of transfusion-free ATAAD surgery, except case reports of Jehovah's Witnesses.[15-17] Blood transfusion reduction in ATAAD surgery is still a significant challenge for aortic surgeons.

Is blood transfusion always necessary in ATAAD surgery? What is the obstacle to the achievement of transfusion-free ATAAD surgery? With these questions, we started to explore the feasibility of transfusion-free ATAAD surgery since August 2016 after a series of surgical technique modifications[10,11] and the application of mild-to-moderate hypothermia circulatory arrest[12] in ATAAD surgery in our center. From August 2016 to June 2020, there were 326 patients with ATAAD who underwent surgery in our center. Through the implementation of our systematic approach and the restrictive transfusion protocol, we achieved transfusion-free surgery in 174 of 326 patients with ATAAD. Of the 152 patients who received blood transfusions, 98 received intraoperative blood transfusions, and 54 had postoperative blood transfusions. Thus, in our study, the intraoperative transfusion-free rate was 69.93% (228/326), and the overall in-hospital transfusion-free rate was 53.37% (174/326).

Several factors contributed to our results. Reducing intraoperative bleeding is the most challenging in achieving transfusion-free ATAAD surgeries. Ascending aorta replacement with hemiarch replacement and ascending aorta replacement with total arch replacement under deep hypothermia circulatory arrest (DHCA) are the currently most widely utilized methods for ATAAD. For ascending aorta replacement with hemiarch replacement, the tissue of patients with ATAAD is extremely fragile, which adds to the risk of bleeding from anastomosis sites of aortic arch and aortic root. Additionally, DHCA would lead to coagulation system dysfunction, thereby increasing the risk of intraoperative bleeding. For TAR, a more extensive disassociation and resection of the entire aortic arch are mandatory. Anastomosis of the brachiocephalic vessels has 3 anastomosis sites, and the distal arch anastomosis is deep, which makes the control of potential bleeding difficult.[18] Under such conditions, catastrophic intraoperative bleeding may take place. Some patients even die of severe bleeding in the operating room.[19] Therefore, achieving transfusion-free ATAAD surgery with total arch replacement is extremely challenging.

In our center, we adopted Liu's aortic arch inclusion technique; we repaired the aortic arch from inside the aortic arch. Therefore, resection or disassociation of the aortic arch was not required. Furthermore, the replacement of the 3 brachiocephalic vessels was not needed, thereby reducing the number of anastomosis sites and avoiding potential graft-related complications. Additionally, our technique reinforced the proximal aortic arch anastomosis site with internal and external vascular strips. Distal aortic arch anastomosis site was also avoided in this technique. Thus, bleeding from aortic arch anastomosis sites was completely avoided.[10] Besides the aortic arch technique, we employed Liu's aortic root repair technique, which has 2 main advantages. First, we repaired the dissected aortic root with double vascular prosthetic rings that were placed inside and outside the aortic root. Second, the false lumen was divided by 3 to 5 vertical mattress sutures, which quickly promoted false lumen thrombosis.[11] Liu's aortic arch and aortic root repair techniques would significantly reduce intraoperative bleeding, leaving no surgical bleeding from anastomosis sites. This was a significant contribution to transfusion-free aortic surgery.

The achievement of transfusion-free ATAAD surgery, especially intraoperative bleeding reduction from anastomosis sites, could be strongly guaranteed by the combination of the 2 aforementioned surgical techniques. In our study, chest tube drainage during the first 24 hours was 264.9 ± 182.3 mL in the transfusion-free group and 371.6 ± 213.5 mL in the transfusion group. Hence, secure intraoperative bleeding control and meticulous surgical techniques are crucial for ATAAD surgery.

Furthermore, temperature management during ATAAD surgery is crucial in achieving satisfactory results. DHCA is the most often utilized technique in ATAAD surgery, which significantly affects coagulation functions. Dysfunction in the coagulation system results in bleeding, which could inevitably increase the risk of blood transfusions.[20,21] Recently, antegrade cerebral perfusion in combination with moderate systemic hypothermia has been reported in ATAAD surgery, and several groups have proven its effectiveness and safety.[12,22,23] In our center, we have been adopting moderate hypothermia circulatory arrest with antegrade selective cerebral perfusion for brain protection since June 2013. In our study, we compared the outcomes of patients with ATAAD surgery using DHCA with those using moderate hypothermia circulatory arrest. We proved that with sufficient cerebral perfusion, moderate hypothermia circulatory arrest could significantly optimize brain and lung functions when compared with DHCA, although no significant difference in abdominal organ function protection was noted. The application of the cerebral-body separate perfusion technique since October 2019 would also reduce the side effects of DHCA on coagulation function. Moreover, compared with DHCA, mild-to-moderate hypothermia circulatory arrest could protect coagulation system function and reduce surgical field errhysis.[12] Thus, temperature management, which could result in coagulation function protection and reduction in surgical field errhysis, is another important factor that contributes to transfusion-free ATAAD surgery.

Another factor that contributes to transfusion-free ATAAD surgery is the application of a centrifugal pump in the CPB circuit. Centrifugal pumps have shown advantages in reducing hemolysis and proinflammatory cytokine release.[24-26] ATAAD surgery is associated with CPB time, which increases the risk of blood cell damage with the traditional roller pump. In our center, centrifugal pumps in the CPB circuit were utilized in all patients with ATAAD. This strategy also helped us achieve transfusion-free ATAAD surgery.

To achieve ATAAD surgery without blood product transfusion, our team, including surgeons, anesthesiologists, perfusionists, and ICU doctors, developed a restrictive blood transfusion protocol. We stratified the patients without serious complications by age. For patients aged < 65 years old, the Hb level can be 6 g/dL. For patients between 65 and 75 years old, we increased the Hb transfusion threshold to 7 g/L considering the organ function degeneration with increasing age. For patients aged > 75 years old, the Hb transfusion threshold was 7.5 g/dL. For patients with serious complications (LCOS, AKI, cerebral dysfunction, and ECMO support requirement), the transfusion threshold was increased to 8 g/L.

Habitual transfusion is another factor that leads to surgical transfusion. Not all personnel in the surgical team have full knowledge of transfusion-free surgery.[27-30] Therefore, to prevent habitual transfusion, the whole surgical team, including surgeons, anesthesiologists, perfusionists, and ICU doctors, should share the same knowledge on transfusion protocol and strengthen the awareness of transfusion-free surgery.

To the best of our knowledge, this study is the first to specifically focus on blood transfusion in ATAAD surgery. Our study showed that transfusion-free ATAAD surgery can be performed safely in patients with ATAAD with the implementation of the systematic approach and the restrictive blood transfusion protocol.

Limitations: The limitations of this investigation primarily include the nonrandomized study design, small sample sizes, and heterogeneous patient population.

Conclusions

In ATAAD patients, the transfusion group exhibited significantly older patient age, more incidences of preoperative anemia and malperfusion, and higher in-hospital mortality than the transfusion-free group. Using Liu's systematic approach, ATAAD surgery can be achieved and safely applied in ATAAD patients without blood product transfusion in selected patients.

Disclosure

Conflicts of interest: All the authors have no conflicts of interest to declare.

Author contribution: C.Z. and K.L. designed the work. M.H., Y.Z., Y.W., and H.P. made acquisition, analysis, or interpretation of data. T.W., Z.Z., and D.L. made substantial contributions to the conception of the work. All the authors drafted the work and revised it critically for important intellectual content. All the authors provided final approval of the version to be published.

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