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Aortic arch replacement and elephant trunk procedure: an interdisciplinary approach to surgical reconstruction, perfusion strategies and blood management

Christine McKay[1], Peter Allen[1], Philip M Jones[2], Michael WA Chu[3]

Abstract

Surgical treatment of patients who present with large aneurysms of the ascending aorta, transverse arch and descending aorta, including the thoracic and abdominal aorta typically consists of a two-staged elephant trunk procedure. Typically, these operations are lengthy, requiring long cardiopulmonary bypass times, deep hypothermic circulatory arrest and multiple anastamotic suture lines, which increases the risks for coagulopathic bleeding and the need for massive transfusions. The purpose of this report is to describe our approach, involving advanced surgical techniques and the innovative perfusion considerations as well as modified blood management strategies to minimize perioperative blood loss and the need for transfusions. All of the above will highlight critical cardiac team communications. An ever-evolving case requires forward thinking, revised judgments, open discussion and the continued involvement of all team members. In turn, this ensures evidence-based medical and perfusion practices that lead to achieving a positive peri-operative course, with optimal blood conservation.

Keywords

aortic arch; aorta; aortic aneurysm; elephant trunk procedure; cardiopulmonary bypass circuit modifications; blood management

Background

The elephant trunk procedure was designed to treat complex aneurysms involving extensive segments of the aorta from ascending to descending[1]. This can be accomplished as a single-stage operation through a clamshell incision[2] or as a two-staged approach[1]. A two-staged approach requires the ascending, transverse and proximal descending aorta be reconstructed through a median sternotomy while suspending an elephant trunk graft within the descending aorta. The second part of the two-staged approach uses the suspended elephant trunk graft to secure the remaining thoraco-abdominal aortic repair at a later date, following recovery from the first stage. This may be accomplished in an open repair fashion or with an endovascular stent[3-6]. The two-stage approach reduces cross-clamp and cardiopulmonary bypass time and potentiates safer clamping of the proximal descending aorta[1].

A myriad of perfusion considerations support different surgical approaches, dependent on patient anatomy. These may include deep circulatory hypothermic arrest, with isolated retrograde cerebral, antegrade cerebral, mesenteric and renal perfusion. Many cannulation strategies exist and can be tailored for each individual patient, dependent on aneurysmal anatomy. The elephant trunk procedure may be performed in concomitance with coronary artery bypass, aortic valve repair or replacement, Dor procedure, atrial septal defect repair or a tricuspid ring annuloplasty[7].

Bleeding-related complications and excessive transfusion requirements are common, based on the extensive operation, multiple anastamoses, hypothermia, platelet dysfunction and lengthy cardiopulmonary bypass times. Additional

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complications arising from this procedure include death, stroke, renal failure, pulmonary complications, paraplegia, paraparesis and vocal cord paralysis[1,8]. Stage 1 mortality rates have been reported to be from 6.5% to 12.7%[7,9-11]. Interstage mortality is not insignificant; however, if the patient undergoes a successful stage 2 repair, long-term survival can be excellent[12]. The 5-year survival rate ranges from 69% up to 79%[1,7,10,11,13].

Clinical Summary

We would like to present two different cases, demonstrating the diverse applicability of these techniques across the spectrum of diseases of the aortic arch. Patient 1 is a slight 70-year-old female with hypertension, hyperlipidemia and chronic obstructive pulmonary disease who presented with a large aortic aneurysm involving the ascending, transverse and descending aorta, extending from the aortic annulus down to the level of the abdominal aorta at the superior mesenteric artery take-off (Figure 1). The aneurysm measured 55 mm and 65 mm at the largest diameter in the ascending and descending thoracic aorta, respectively, on computed tomography. She also experienced significant dyspnea from transient left lung collapse secondary to external left mainstem bronchus compression from anterior and posterior aneurismal expansion, confirmed on bronchoscopy. Cardiac catheterization demonstrated significant three vessel coronary artery disease. Following extensive discussion with the patient, she wished to proceed with elective aortic arch replacement and coronary artery bypass. The surgical plan was to replace the ascending, transverse and proximal descending aorta using the elephant trunk technique, with concomitant triple vessel coronary artery bypass. Then, in a second-stage operation, replace the thoracic and abdominal aorta with a specially designed branched endovascular stent graft to repair the distal aortic aneurysm, while maintaining visceral organ perfusion.

Figure 1. Pre-operative computed tomography scan of a complex aneurysm of the ascending, transverse, descending and thoracoabdominal aorta.

The second case was a 53-year-old previously healthy male who presented with acute chest pain and differential blood pressure across his upper limbs. Past medical history was significant only for hypertension. Computed tomography demonstrated an acute type A aortic dissection, limited to the aortic root, ascending aorta and aortic arch. Transesophageal echocardiography confirmed the dissection flap in the ascending aorta, but not yet in the descending aorta; moderate aortic insufficiency with non-coronary cusp prolapse was also identified. The surgical plan was to repair the aortic valve, replace the ascending aorta and aortic arch with head vessel reimplantation, along with a distal elephant trunk because of his generously sized descending aorta.

We employed similar strategies in both patients. Initially, a meeting between surgery, perfusion, anesthesia and nursing identified the proposed intra-operative reconstruction and perfusion strategies. Blood conservation strategies consisted of pre-operative hemoglobin optimization, acute normovolemic hemodilution with component therapy, and cardiopulmonary bypass circuit minimization. Up to three independent, simultaneous perfusion systems were going to be required in addition to the main pump-head and the usual venting systems: 1) antegrade cerebral perfusion delivered through an axillary cannulation graft at 15°C, 2) continuous antegrade cardioplegia administered through ostial coronary catheters and vein grafts at 4°C and, 3) possibly lower systemic perfusion delivered at 25°C.

The Circuit (Figure 2)

Once the surgical sequence was understood, a modified cardiopulmonary bypass (CPB) circuit was designed. A Jostra HL20 heart-lung machine (Maquet, Rastatt, Germany) was fitted with three standard roller pumps. The first was a 1/2-inch raceway which was to serve as the main arterial pump and as the antegrade cerebral perfusion (ACP) pump-head. The second was a 1/4-inch raceway, which was to serve as the lower systemic perfusion and the third pump was a 1/4-inch raceway, set up to serve as a sucker (maximum flow of 3.0 LPM). The fourth module was a dual-controlled twin pump-head, originally designed for cardioplegia administration. The first roller was used as a 1/4-inch sucker, with a maximum flow of 1.5 LPM and the second roller was used as a 1/4-inch vent line (also maximum flow of 1.5 LPM). The final pump-head position was fitted with the Quest MPS

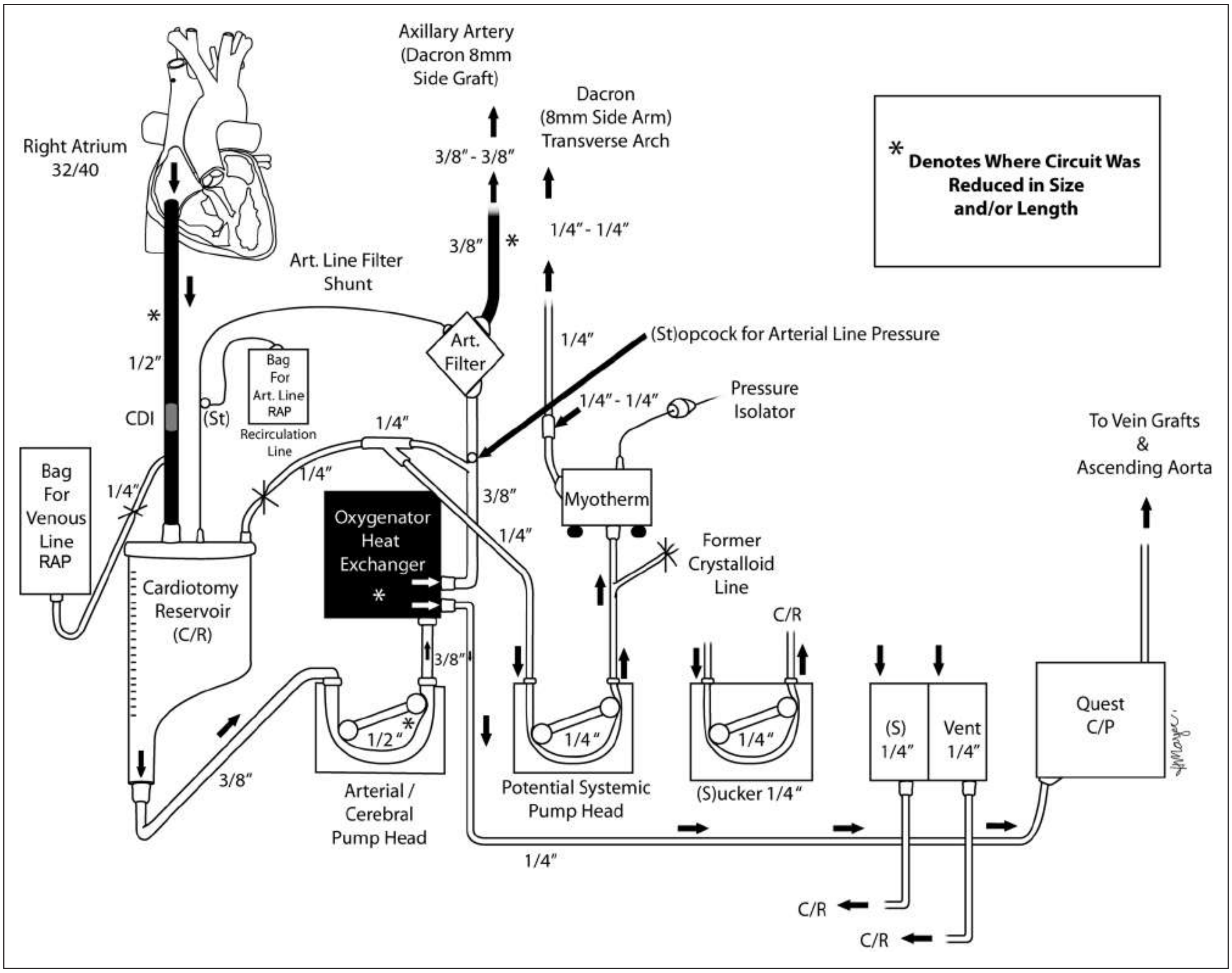

Figure 2. Schematic of CPB Circuit.

microplegia delivery system (Quest, Allen, TX). A Jostra HCU30 heater/cooler (Maquet, Rastatt, Germany) was used for the main arterial/antegrade cerebral line and a Medtronic Biomedicus heater/cooler (Medtronic, Minneapolis, MN) was to be used for the lower systemic perfusion of 25 degrees C. Overall, the circuit was optimally reduced by minimizing the length of tubing, utilizing a smaller membrane (Capiox SX15, Terumo, Ann Arbor, MI) and using a Quart arterial line filter (Maquet). The second pump was fitted with 1/4-inch tubing, drawing from the 1/4-inch re-circulation line of the main pump, into a Medtronic MYOtherm® Cardioplegia Delivery System (Medtronic, Minneapolis, MN) on the distal side of the raceway. The crystalloid line of the MYOtherm® was clamped out. The MYOtherm® could be independently cooled by the Biomedicus heater/cooler and had isolated pressure monitoring capabilities. The 3/16-inch table line was replaced by a 3/16 x 1/4-inch connector and a 1/4-inch line to circumnavigate the high line pressures generated by the pre-existing table line.

Cannulation

Arterial cannulation occurred with an 8-mm Dacron side graft anastamosed to the axillary artery, which was connected with a 3/8 x 3/8-inch connector directly to the arterial line. Venous cannulation was performed with a Medtronic DLP 2-stage 40/32Fr cannula inserted into the right atrium. The heart was vented with a Medtronic 20Fr left ventricular vent in the right superior pulmonary vein. In Patient 1, cardioplegia was administered via a Medtronic 14g DLP cannula in the ascending aorta, as well as down the vein grafts to the obtuse marginal(OM)1 and the posterior descending artery (PDA). In Patient 2, cardioplegia was administered directly through 5- and 6-mm coronary ostial catheters (Cal Med, Costa Mesa, CA).

Blood Management

Both patients were at high risk for excessive blood loss and need for massive transfusions, considering the exten-

Table 1. Patient Demographics

	Patient 1	Patient 2
Age	70 years	53 years
Gender	Female	Male
Height	158 cm	173 cm
Weight	55 kg	77 kg
BSA	1.56 m^2	1.92 m^2
Hb prior to CPB	119 g/L	105 g/L

BSA: body surface area, Hb: hemoglobin, CPB: cardiopulmonary bypass.

sive aortic replacement and deep hypothermic arrest. In addition, Patient 1 was female, very small in size and required concomitant coronary artery bypass surgery. Patient 2 also had the added risk factors of an emergent operation and a type A dissection, which are notorious for massive coagulopathy. We are always aggressive in limiting the patient's exposure to allogenic blood products as much as possible. Patient 1 had received preoperative erythropoietin therapy to optimize erythrocyte stores. Based on each patient's demographics (See Table 1), efforts were made to minimize the CPB circuit volume and surface area; retrograde autologous priming (RAP) techniques of the arterial and venous lines and ultrafiltration of the patient were all anticipated maneuvers within the conduct of perfusion. Minimal sponges were to be used and the anesthesiologist was to limit fluid administration. The final aspect of blood management was to attempt acute normovolemic hemodilution (ANH) with combined component therapy.

Peri-operative Course

Prior to the arrival of the patient, team members from surgery, anesthesia, perfusion and nursing gathered to discuss and confirm the course of surgery. The patient underwent single-lumen endotracheal tube intubation and was monitored with a right internal jugular (IJ) catheter, a Swan-Ganz catheter, 5 lead ECG, right radial and left femoral arterial lines, nasopharyngeal and rectal temperature probes and trans-esophageal echocardiogram (TEE). TEE was extremely helpful in Patient 2 in defining the mechanism of aortic insufficiency to guide the surgical repair. Patient demographics are listed in Table 1. In Patient 1, an interesting phenomenon was observed. After anesthetic induction, a noticeable drop in blood pressure occurred. A dose of phenylephrine was administered with an appropriate response noted in an increased blood pressure. However, simultaneously, a dramatic drop in oxygen saturation occurred (98% to 70%). Despite increased ventilation and a FiO_2 of 100%, the patient remained hypoxic. A broncoscope was inserted via the endotracheal tube and the right mainstem bronchus appeared normal. However, the left mainstem bronchus was observed to be intermittently collapsing, coinciding with increased blood pressure. The aortic aneurysm was expanding and creating enough pressure to collapse the bronchus from both an anterior and posterior compression. With selective permissive hypotension, the saturations began to rise back up to normal values. At this point, we decided the only viable option was to proceed with surgery and decompress the aorta anteriorly by resecting the ascending aorta and aortic arch. The posterior compression would have to wait until the second-stage endovascular repair of the descending aorta could be performed. Patient demographics suggested that the patient would receive some form of allogenic blood products. Through team discussion, two units of red blood cells (RBC) were substituted as volume replacement in order to implement ANH. This prevented any further hypoxic episodes during the sequestration of autologous plasma (clotting factors) and platelets. The strategy proved positive. The autologous products were sequestered and the patient's hemoglobin remained unchanged though the process.

Aortic arch reconstruction was performed using the same techniques in both patients, where the innominate and carotid bypass grafts were constructed first in order to minimize cerebral ischemia, followed by the elephant trunk reconstruction. Figure 3 depicts a 12-mm Dacron graft with an 8-mm side arm, intended for the innominate

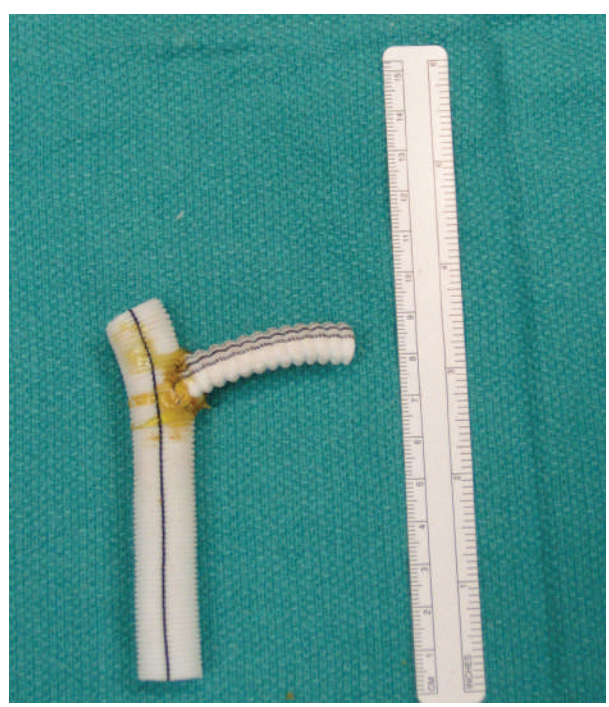

Figure 3. Intra-operative photograph of innominate artery (12-mm Dacron graft) and left carotid artery (8-mm Dacron graft) reconstructive grafts.

and left carotid arteries. The subclavian artery was going to be reconstructed with its normal anatomic orientation to facilitate the endovascular second stage of the operation. The proximal end of the 12-mm graft would be anastamosed to the ascending aortic graft. Figure 4 demonstrates a 28-mm Dacron graft, invaginated, with sutures placed to retrieve the 'telescoped' proximal end of the graft and a radiopaque band sewn to the distal end of the "elephant trunk" for land marking in stage 2 of the elephant trunk procedure.

Surgical preparation began with a small right infraclavicular incision to expose the axillary artery for anastamosis with an 8-mm end-to-side graft for arterial cannulation and antegrade cerebral perfusion. Following median sternotomy, the ascending aorta, proximal aortic arch, innominate and carotid arteries were dissected out and exposed. In Patient 1, left internal thoracic artery and endoscopic saphenous vein harvesting was performed. Following systemic heparinization, venous and cardioplegia cannulation followed. The left ventricular vent was placed via the right superior pulmonary vein. CPB was initiated with a flow of 2.5 L/m/m^2 associated with arterial line pressures of 120-160mmHg.

During cooling, the ascending aorta was cross-clamped in both cases and cold crystalloid cardioplegia was administered in an antegrade fashion to achieve diastolic arrest. Cold blood microplegia was delivered antegradely for the remainder of the operation. The patients were cooled to 25°C and, in Patient 1, the distal anastamoses of the coronary arteries were sewn. The cardioplegia delivery was switched to the vein grafts. In Patient 2, the aortic valve was repaired by reconstruction of the non-coronary sinus and commissural resuspension. Saline testing demonstrated a competent aortic valve with good cuspal coaptation. At this point, the anesthesiologist packed the patient's head in ice. Once the patient's systemic temperature reached 25°C, pump flows were reduced to 10-15ml/kg for ACP, the temperature of the perfusate was decreased further to 15°C and the innominate and left carotid arteries were clamped. ACP at 15°C and cardioplegia at 4°C were commenced (Figure 5).

The origins of the head vessels were resected since they were severely atherosclerotic in Patient 1 and partially dissected in Patient 2. The preformed 12-mm graft was anastamosed to the innominate artery and the 8-mm graft was anastamosed to the left carotid artery. The graft was de-aired and the innominate cross-clamp was moved proximally so that antegrade cerebral perfusion could be administered simultaneously via the right and left carotid arteries (Figure 6). The 28-mm Dacron elephant trunk graft was then telescoped down into the descending aorta and anastamosed just distal to the left subclavian. The arch graft was then retrieved via distal retraction sutures back into the mediastinum. (Figure 7)

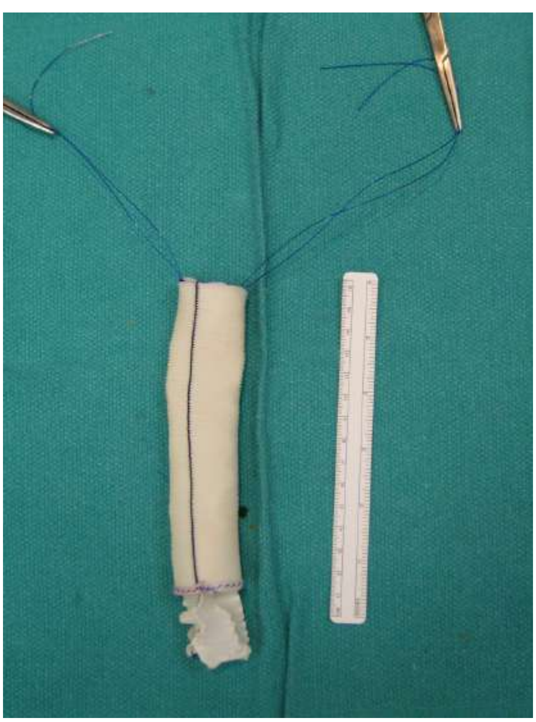

Figure 4. Intra-operative photograph of elephant trunk and transverse aortic arch (26 or 28-mm Dacron graft) reconstructive graft.

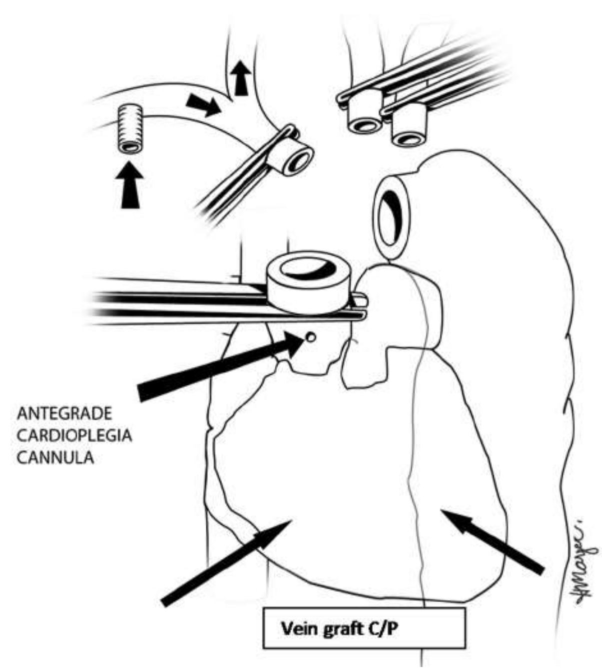

Figure 5. Schematic drawing of antegrade cerebral perfusion via 8-mm Dacron side graft anastamosed to axillary artery. The antegrade cardioplegia delivery is marked with the upper arrow. The remaining arrows indicate the saphenous vein graft cardioplegia perfusion in Patient 1 (vein grafts not drawn).

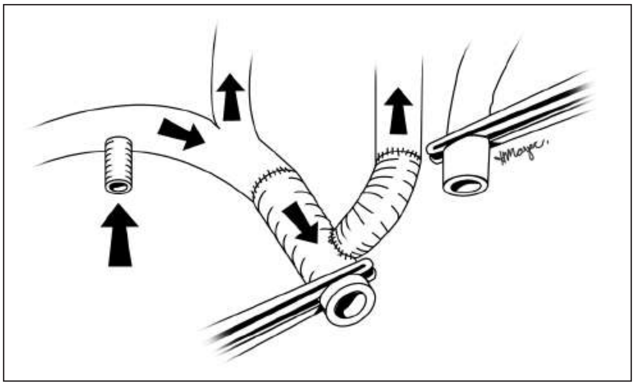

Figure 6. Schematic drawing of simultaneous bilateral antegrade cerebral perfusion.

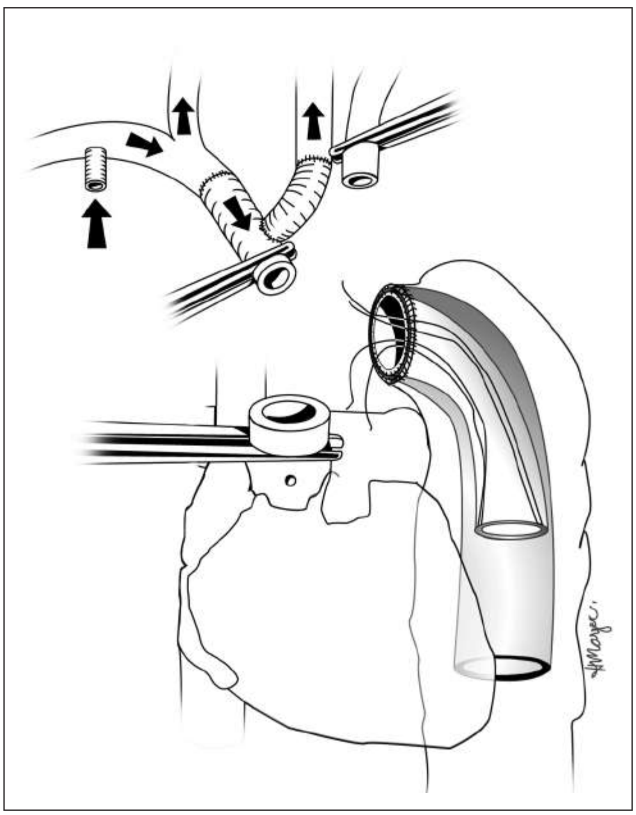

Figure 7. Schematic drawing of elephant trunk graft in situ.

The left subclavian artery was then anastamosed directly to the distal portion of the arch graft in Patient 1. In Patient 2, the elephant trunk was tailored as to anastamose at the base of the subclavian without obstructing distal flow to the subclavian. Approximately 15 minutes was required to sew the proximal end of the innominate/carotid graft to the ascending aortic graft. ACP was intermittently interrupted, with the total cerebral anoxic time of 15 and 9 minutes in Patients 1 and 2, respectively. The graft was de-aired upon completion of this anastamosis.

The cross-clamp was moved proximally; a return to full CPB, reperfusion and rewarming occurred. The proximal end of the ascending aortic tube graft was then anastamosed to the sinotubular junction (Figure 8a, 8b). The cross-clamp was removed and, in Patient 1, a side-biting clamp was placed on the ascending aorta and the proximal vein grafts were anastamosed. The heart was de-aired via the left ventricular and aortic root vents.

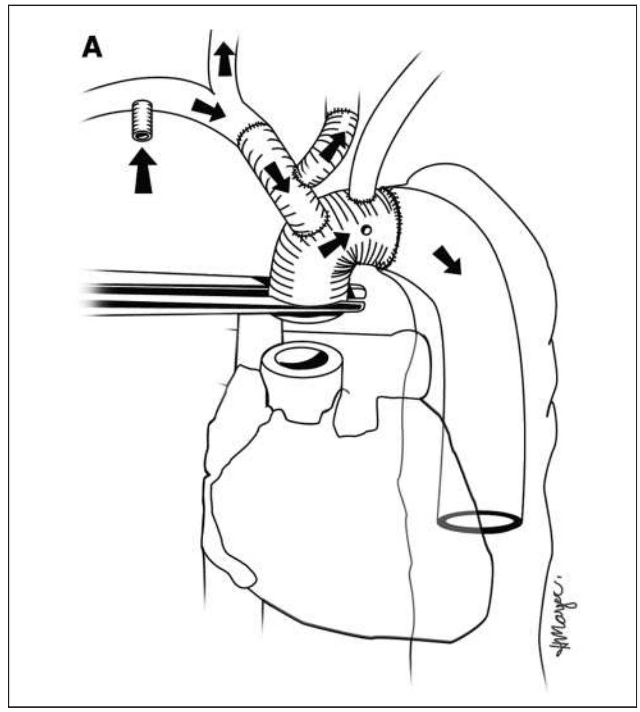

Figure 8a. Schematic drawing of anastamosis of ascending arch tube graft to the sinotubular junction.

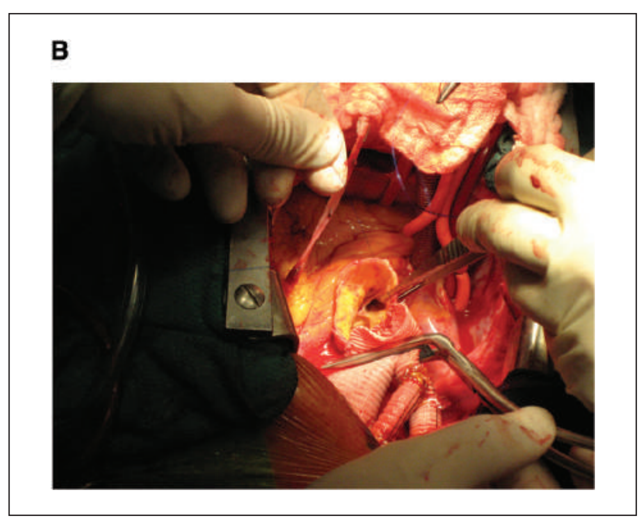

Figure 8b. Intra-operative photograph demonstrating the anastamosis of the ascending tube graft to the sinotubular junction.

Following complete rewarming, CPB was discontinued, with low dose epinephrine, excellent hemodynamic stability and no bleeding in either patient. Table 2 demonstrates the cardiopulmonary, cross-clamp, antegrade cerebral perfusion and total cerebral anoxic times.

Blood Products. (See Table 3 for blood products administered and the rationale during the peri-operative course.)

Using our restrictive blood management strategy, Patient 1 required 3 units packed RBC while on pump, but no further RBC transfusions during the hospitalization. Patient 2 did not require any packed RBC transfusions during the intra-operative or total hospital course. All of the autologous products were given back at the appropriate times.

Table 2. Cardiopulmonary Bypass Details

	Patient 1	Patient 2
Total CPB time (min)	236	187
Cross-clamp time (min)	136	120
Antegrade cerebral perfusion and systemic arrest time (min)	74	44
Cerebral anoxic time (min)	15	9

CPB: cardiopulmonary bypass.

Table 3. Total Blood Products Administered

Products Administered	Patient 1	Rational for Administration	Patient 2	Rational for Administration
RAP/Ultrafiltration Volumes	500/3000 ml		700/2500 ml	
RBC	2units ANH 3units CPB	Support ANH Hb 58, 65, 78 g/L	0	Hb 88, 78, 82 g/L
ANH	400ml autologous RBC 450 ml autologous Plasma 100 ml autologous Platelets	Patient's own product	None	
FFP	2units (569 ml) Post autologous products	INR 1.8, PTT 26 Prophylactic administration	4units (1213 ml) Post protamine	Prophylactic administration
Platelets 1 adult unit: (5 donor exposures)	1 Adult unit (348 ml) Post autologous products		1 Adult unit (342 ml) Post protamine	
Autologous RBC (Cell Saver)	600 ml Post protamine	Patient's own product	320 ml Post protamine	Patient's own product
Total Units (Donor) Exposure		8 (12)		5 (9)

RAP: retrograde autologous priming; RBC: red blood cells; ANH: acute normovolemic hemodilution; FFP: fresh frozen plasma; CPB: cardiopulmonary bypass; Hb: hemoglobin; INR: international normalization ratio; TTP: thrombotic thrombocytopenic purpura.

Patient Outcome

Both patients had done well, with good reconstructive results (Figure 9a, 9b), hemodynamic stability and no bleeding. Patient 1 was extubated on post-op day (POD) 1, with good renal function, no further blood products and no neurological deficit. Unfortunately, on POD 5, the patient developed spontaneous thrombotic thrombocytopenic purpura (TTP) with associated renal failure. Renal ultrasound and computed tomography revealed widely patent renal arteries and veins, but absent cortical blood flow. The etiology of this sudden decline with TTP was unknown. Nephrology and hematology were consulted, but, despite best management, she succumbed on POD 5. Post mortem analysis confirmed TTP and demonstrated patent arch reconstruction without any signs of proximal thrombus. Patient 2 recovered well, with hemodynamic stability, and without any significant bleeding. He was neurologically intact and extubated on the first post-operative day. He continued to recover without complication, allowing for his discharge home on the fifth post-operative day. His follow-up computed tomography scan demonstrates the aortic arch reconstruction with elephant trunk (Figure 10).

Discussion

The Peri-Operative Blood Conservation Program (PBCP) committee and cardiac team at our institution have developed an aggressive blood management strategy for cardiac patients at high risk for bleeding. During the course of these complex operations, this new strategy implemented by our PBCP was successfully employed with excellent results. The ANH technique involves sequestering

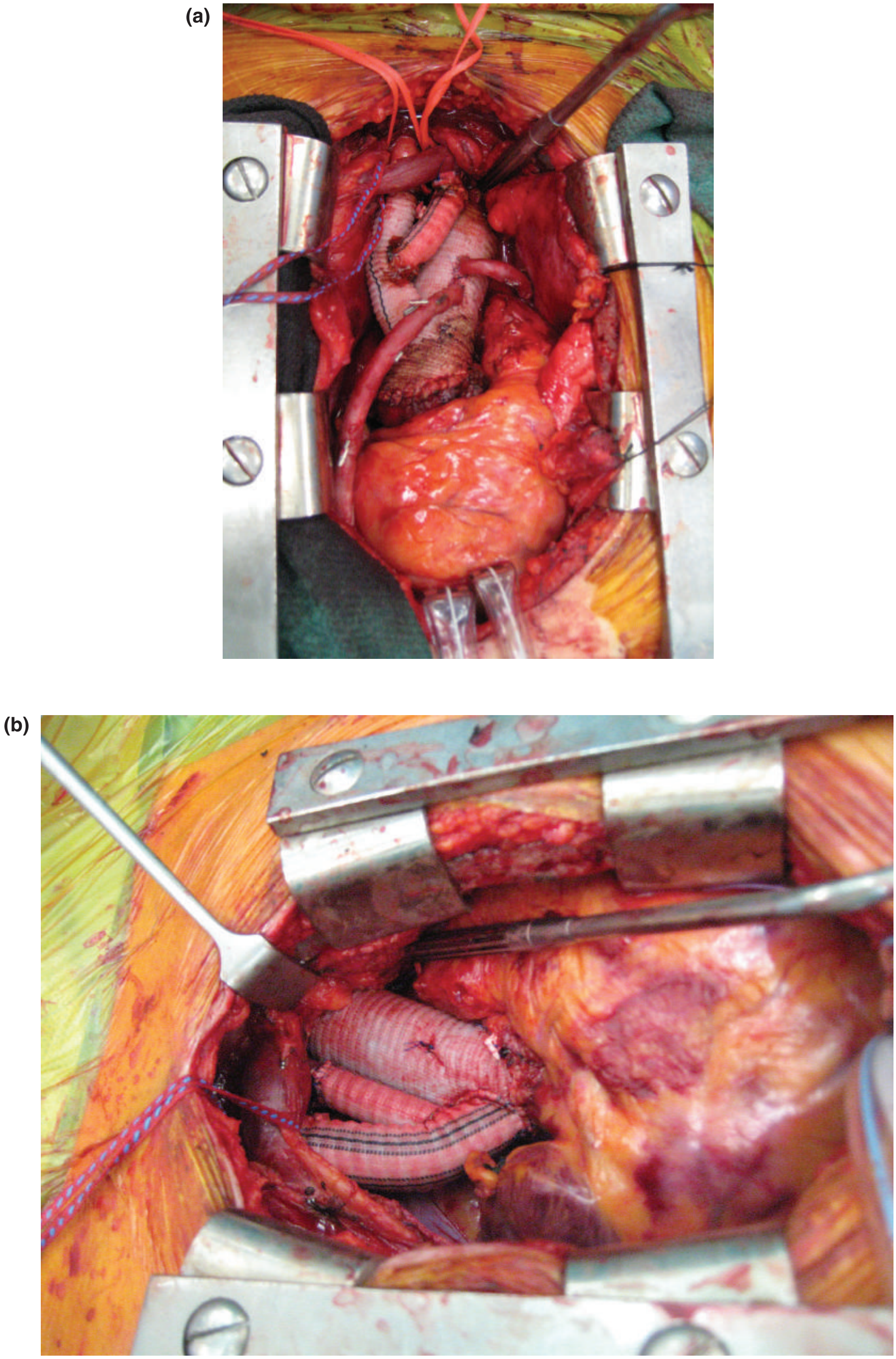

Figure 9. Intra-operative photograph demonstrating the final operative reconstruction in Patient 1 (9a) and Patient 2 (9b).

Figure 10. Post-operative computed tomography scan of final aortic arch reconstruction of patient 2.

approximately 1L of the patient's whole blood into citrated transfer packs, while their volume is being replenished with either a crystalloid or colloid solution. The theoretical implication is that the patient will bleed less RBC, platelets and plasma to the cardiotomy suckers and/or, in the case of cardiac surgery, the blood components will have no exposure to the heart-lung machine[14, 15]. The patient's whole blood is then separated into RBC, platelet rich plasma and platelet poor plasma (clotting factors). The advantage of this method is the patient's RBC may be transfused back at any time (before a second whole blood withdrawal, during CPB, prior to, or post heparin reversal). The platelets and clotting factors can then be preserved from the trauma of CPB, the loss to an outside sucker or cell saver and may be transfused back to the patient only after heparin reversal.

In Patient 1, the technique was modified slightly to avoid any further hypoxic episodes. Rather than potentiating further hypoxia as a result of an induced anemia, the patient's hemoglobin level was maintained by infusing RBC as a volume substitute for the whole blood withdrawal. This modification secured our ability to sequester the patient's own platelets and clotting factors and further preserve them for subsequent transfusion.

We had first trialed ANH with component therapy in 2008[16]. Five patients undergoing complex cardiac procedures (2 Bentalls, 2 redo coronary artery bypass grafts and 1 repair of the ascending aorta plus aortic valve replacement) saw transfusion rates decreased by 60%. The mean transfusion rate was 1.8+/-2units. Three of the five patients received no allogenic blood products. Prior to this implementation, the expected transfusion rate was nearly 100% for these types of procedures. While it is clearly understood that these are only preliminary findings, our cardiac team recognized that this was a potential area of study to be investigated. Another important finding from this trial was that analysis of the blood components confirmed contents, counts and viability of the platelets and clotting factors that were sequestered. Minimizing donor exposure is a well-accepted practice, due to the potential adverse effects of allogenic transfusions[17-19]. Limited transfusions were seen in Patient 1 and Patient 2. Patient 1 was an older female, with a significantly smaller body surface area (BSA), a slightly higher hemoglobin, longer CPB time and required a concomitant CABG x 3. Patient 2 was a younger male, larger BSA and an adequate blood cell mass to sustain him through the procedure. Patient 2 was at a disadvantage in that the urgency of his condition (type A dissection) did not allow for the safe administration of ANH component therapy. Of note, Patient 2 was exposed to slightly more allogenic products and donors post protamine, despite his larger size.

A point of interest worth discussing further is the potential flow-limiting CPB circuit modifications. The Medtronic MYOtherm® Cardioplegia Delivery System is unable to deliver up to 3 LPM at 25 degrees C. The standard delivery table line of the MYOtherm® has a 3/16-inch diameter. Line pressures of 330mmHg are generated at 1.2 LPM (using water at room temperature). These pressures can be circumvented by substituting the existing 3/16-line with a 1/4 x 3/16-connector and a 1/4-inch diameter table delivery line. This modification reduced the line pressure to 130mmHg at flows of 3.0 LPM. In the event that systemic perfusion at 25°C had been necessary, the patient's perfusion requirements would have been satisfied. No cannula was to be utilized; a 1/4 x 1/4-inch connector via a side graft would have been attached to the transverse arch tube graft. A small hole, noted in Figure 8, located in the vicinity of the left subclavian artery anastamosis, marks the potential location of a side graft that would have been attached for the use of lower systemic perfusion. A cross-clamp would have been placed proximal to the cannulation site.

Further review of the circuit promoted copious amounts of thought-provoking discussion within our own perfusion department. While it was unanimous that this circuit design was optimal for this surgeon under these circumstances (i.e. no femoral artery access), there was discussion as to the safety and ease of having to draw a greater volume from the main arterial pump-head than was being generated. A simple, simultaneous upramping of flows on both pump-heads should manage the maneuver. Caution is paramount so that the increases in systemic flow are not at a higher rate than the arterial pump-head, so as not to draw air across the membrane. A slave alarm could be set up with this Jostra heart-lung machine to stop the systemic pump if for whatever reason the arterial pump-head was shut down. This would not, however, protect against air entrainment if a malaligned simultaneous increase or decrease occurred. Careful communication between the surgeon and perfusionist would be mandatory. It is noted that this is only one method of circuitry to achieve perfusion for this complex aortic surgery. Any circuit design should consider simplicity, safety, patient anatomy and surgical preferences.

Ongoing communication and an ability to voice concerns during continuously dynamic complex operations proves invaluable to successful peri-operative results. Issues such as a newly discovered collapsing left mainstem bronchus in Patient 1 may have cancelled the surgery altogether. Open discussions about whether or not to stent the bronchus and whether to proceed with the ANH and component therapy techniques promoted best practices for the patient. Within the existing literature, there appear to be as many variations of the elephant trunk procedure as there are surgical preferences, as well as patient presentations.

Conclusions

Well thought, effective strategies and cohesive teamwork are critical to achieving excellent peri-operative outcomes with minimal blood transfusions. Identifying perfusion needs via surgical requests in advance enabled appropriate equipment choices to provide the most efficient and effective methods for ease and surgical speed. Surgical precision in combination with a variety of blood management strategies, such as ANH component therapy, RAP, ultrafiltration and team communication proved to notably limit the patients' exposure to allogenic blood products. It also ensured minimal blood loss and a successful peri-operative reconstruction of an ascending, transverse and proximal descending aorta.

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