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Case Reports

Simultaneous Individually Controlled Upper and Lower Body Perfusion for Valve-Sparing Root and Total Aortic Arch Replacement: A Case Study

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Abstract: Optimal perfusion strategies for extensive aortic resection in patients with mega-aortic syndromes include: tailored myocardial preservation, antegrade cerebral perfusion, controlled hypothermia and selective organ perfusion. Typically, the aortic arch resection and elephant trunk procedure are performed under hypothermic circulatory arrest with myocardial and cerebral protection. However, mesenteric and systemic ischemia occur during circulatory arrest and commonly rely upon deep hypothermia alone for metabolic protection. We hypothesized that simultaneously controlled mesenteric and systemic perfusion can attenuate some of the metabolic debt accrued during circulatory arrest, which may help improve perioperative outcomes. The perfusion strategy consisted of delivering a 1 to 3 liter per minute flow at 25°C to the head/upper body via right axillary graft and simultaneous perfusion to the lower body/mesenteric organs of 1 to 3 liters per minute at 30°C via a right femoral arterial graft. We describe our technique of simultaneous mesenteric, systemic, cerebral and myocardial perfusion, and protection utilized for a young male patient with Marfan's syndrome, while undergoing a valve sparing root replacement, total arch replacement and elephant trunk reconstruction. This perfusion technique allowed us to deliver differential flow rates and temperatures to the upper and lower body (cold head/warm lower body perfusion) to minimize ischemic debt and quickly reverse metabolic derangements. **Keywords:** aortic arch, aorta, aortic aneurysm, Marfan's syndrome, elephant trunk, cardiopulmonary bypass, modified extracorporeal circuit, cerebral perfusion, lower body perfusion. *JECT. 2011;43:245–251*

INTRODUCTION

Complex aortic arch reconstruction often exposes patients to periods of prolonged ischemia, which may result in significant end organ dysfunction. Deep hypothermic circulatory arrest (DHCA) remains a common method of organ protection during repair of these complex transverse arch operations (1). Selective cold antegrade cerebral perfusion (ACP), through axillary artery cannulation, has emerged as a strategy for optimal cerebral protection and has been shown to decrease neurological complications and improve recovery times (2). Similarly, myocardial preservation is used to protect the heart from ischemic complications. Despite these well-accepted principles of selective organ perfusion, perioperative end organ dysfunction remains a significant cause of patient morbidity and mortality after radical reconstruction of the aortic arch. Complications of mesenteric and renal ischemia are particularly concerning because of the poor associated prognosis. Visceral, renal, and lower limb ischemia are often exacerbated during periods of DHCA, in which tissue preservation consists primarily of systemic hypothermia alone. We hypothesize that maintaining cerebral and myocardial protection alone is not sufficient and consideration must also be given to the spine, viscera, and lower body to decrease perioperative morbidity and mortality. Simultaneous mesenteric and lower body perfusion in addition to myocardial and cerebral

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Figure 1. Preoperative computed tomography scan.

perfusion may be especially beneficial in complex aortic reconstruction surgery.

We describe our perfusion technique of using selective cold antegrade cerebral and warm systemic perfusion during a complex aortic arch reconstruction in a 22-year-old man with recently diagnosed Marfan's syndrome. He presented with new-onset back pain, an expanding aortic arch aneurysm, and a Type B aortic dissection. Computed tomography (CT) demonstrated an ascending aorta diameter of 6.0 cm, aortic arch of 6.5 cm, and a dissected descending thoracic aorta of 6.4 cm extending distally to the left common iliac artery (Figure 1). A two-stage procedure was proposed to achieve complete aortic resection with the least perioperative risk. We first addressed the aortic root, ascending aorta, and aortic arch through a sternotomy. This was followed 2 months later by a thoracoabdominal aortic resection after the patient had recovered adequately from the first stage. During the first surgical repair, we used a technique that allowed separate upper and lower body perfusion at different temperatures, which allowed earlier lower body rewarming while still optimizing cold cerebral protection. We believe this technique also provides important mesenteric and lower limb perfusion during long periods of circulatory arrest and may avoid severe perioperative metabolic derangements and ischemic complications.

MARFAN'S SYNDROME

Patients who require extensive aortic resection often have pan-aortic disease as a result of connective tissue disorders. Marfan's syndrome, the most common inherited connective tissue disorder, is an autosomal-dominant condition with multisystem manifestations involving skeletal, cardiovascular, and ocular abnormalities (3). It is usually associated with fibrillin-1 gene mutations, an extracellular matrix protein, and its diagnosis requires the presence of several clinical criteria, according to Ghent (3). It affects one in 10,000 individuals of all races and ethnic backgrounds (4). The most common cause of mortality is aortic root rupture or aortic dissection.

PERFUSION CONSIDERATIONS

Theory of Independent Control of Upper and Lower Body

Deep hypothermic circulatory arrest without perfusion to the mesenteric organs and lower body contributes significantly to perioperative morbidity and mortality (5). Prolonged periods of hypothermia can result in pulmonary, renal, and hematological organ dysfunction (1,5). Even short interruptions to lower body perfusion can result in significant metabolic debt. Separate lower body perfusion and temperature regulation may attenuate mesenteric metabolic derangements and allow more effective lower body rewarming while maintaining important cerebral hypothermia. Therefore, lower body perfusion where temperature and perfusion can be independently controlled may potentially diminish metabolic debt. Visceral perfusion at a higher temperature (tepid or normothermic) has been reported to reduce postoperative bleeding and inflammatory reactions compared with moderate and deep hypothermic cardiopulmonary bypass (CPB) (6–8). An additional advantage of independent control of the upper and lower body flow includes the ability to change strategy based on unique surgical and patient needs (7). If the repair is more complex than anticipated, one option may be to keep the upper and lower body at 25°C or lower if required. This perfusion strategy also offers the ability to rewarm the lower body while still maintaining cold cerebral blood flow.

Modified Circuit

A Jostra HL20 heart lung (H/L) machine (Maquet, Rastatt, Germany) was fitted with two standard roller pumps and two dual-controlled twin pumps for the suckers and vents (Figure 2). The first pump (P1) consisted of the standard half-inch raceway tubing to serve as the main arterial pump head as well as for ACP. The second pump (P2) consisted of a 3/8-inch tubing raceway to serve as the pump for lower body perfusion. The last pump on the five base H/L machine is the Quest MPS microplegia delivery system (Quest, Allen, TX). We used a Capiox SX 25 membrane oxygenator (Terumo, Ann Arbor, MI) and Quart arterial filter (Maquet, Rastatt, Germany). We used an HCU30 heater/cooler (Maquet) for the main arterial/cerebral circuit. A 3/8-inch Y was inserted into the main circuit of the arterial pump just before the transducer. A 3/8-inch tubing segment was connected to the second pump and downsized by a 3/8 × ¼-inch connector to a Cardiotherm cardioplegia (Medtronic, Minneapolis, MN) device. This device was used off-label to simply regulate the temperature of the perfusate and provide a port to transduce pressure. The Cardiotherm was connected to a

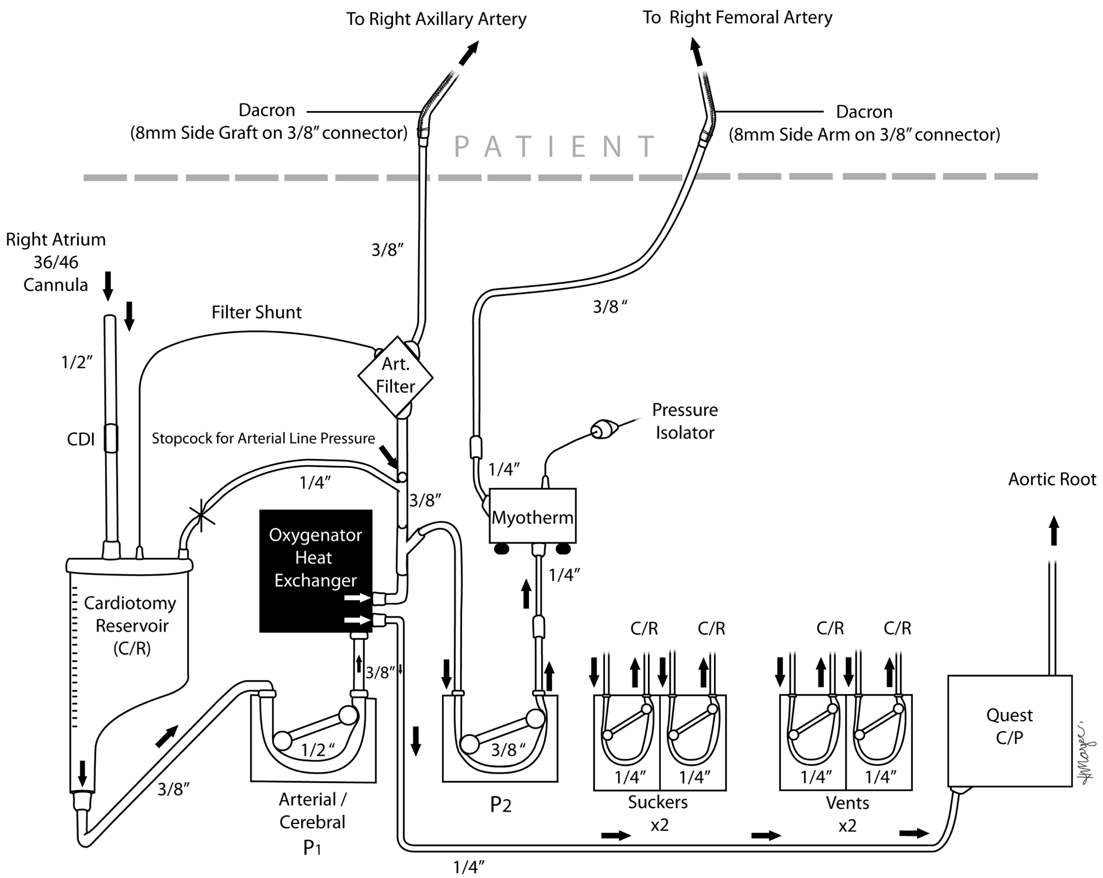

Figure 2. Diagram of the circuit for cool head, warm body perfusion.

Biomedicus Bio-Cal 370 (Medtronic) heater/cooler for independent control of temperature.

Cannulation Techniques

Our patient was 191 cm tall and weighed 82 kg with a body surface area of 2.08 m^2 and calculated blood flow of 5.0 lpm. The main pump circuit blood was delivered through a 3/8-inch connector directly into an 8-mm Dacron side graft sewn end-to-side to the right axillary artery (Figure 3). Central venous drainage was achieved using a half-inch venous line connected to a Medtronic DLP 2-stage 36/46 Fr cannula in the right atrium. The 3/8-inch lower body arterial circuit was connected to another 8-mm Dacron side graft sewn end-to-side to the right common femoral artery (see Figure 4). Cardioplegia was administered through a 14-g DLP cannula in the ascending aorta as well as direct coronary ostial catheters. Initial antegrade cardioplegia was delivered into the aortic root using 1 L of cold crystalloid cardioplegia (20 mEq/L KCl) followed by intermittent cold blood microplegia (1–24 mEq/L KCl) through the coronary ostia. A total of 32,054 mL of cardioplegia was delivered throughout the case, of which only 1071 mL was crystalloid.

Physiologic Monitoring

Mean arterial pressures from the right radial arterial line determined appropriate antegrade cerebral flow rate and the left femoral arterial line monitored adequacy of lower body flow. Core temperature was monitored through rectal and nasopharyngeal probes in addition to venous inlet, arterial outlet, and at the Cardiotherm/myotherm. We used pH stat blood gas management for the cooling phase to a rectal temperature of 25°C and alpha stat for the rest of the case. Ice bags were applied to the head to optimize cerebral cooling. Cerebral saturations were monitored with the INVOS® (Somanetics, Boulder, CO) to determine the adequacy of cerebral perfusion and give us an indication of technical problems or physiological change (9,10) (see Figure 4).

Blood Conservation Strategy

As a result of the complexity of this case, the anticipated length of CPB, moderate hypothermia, and potential for high risk bleeding, we used a comprehensive blood management strategy (11). We performed acute normovolemic hemodilution (ANH) by removing 2 whole blood units from the patient. We separated the blood

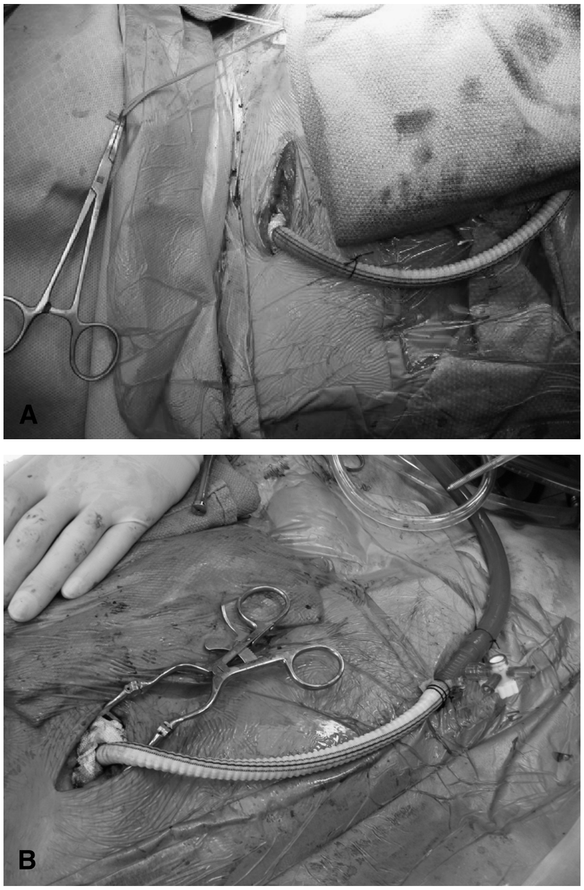

Figure 3. Intraoperative photographs demonstrating axillary (A) and femoral (B) cannulation with 8-mm Dacron side grafts.

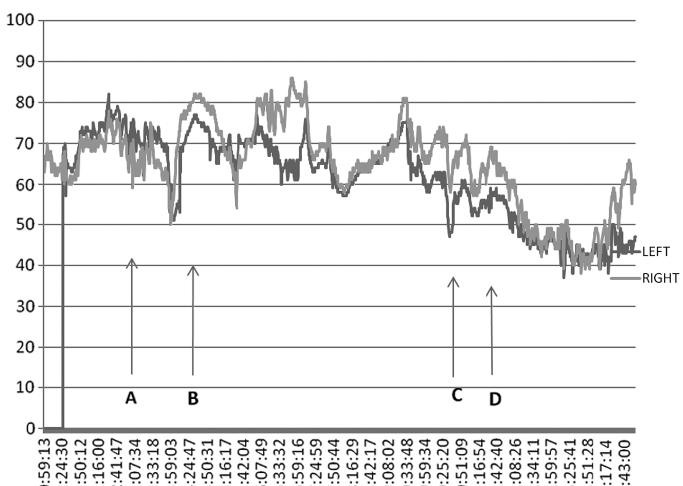

Figure 4. Near-infrared spectroscopy study. (A) On cardiopulmonary bypass (CPB). (B) Circulatory arrest time. (C) Crossclamp off reperfusion time. (D) Off CPB.

components into 460 mL of autologous red blood cells, 400 mL of autologous plasma, and 100 mL of platelet-rich plasma. The patient tolerated ANH well and had an initial preoperative hemoglobin of 13.6 g/dL. Retrograde autologous priming was used to decrease hemodilution effects. A cell saver and ultrafiltration were also used. The ANH blood components were returned to the patient before coming off CPB as a result of the 8-hour expiration of the blood products. A total of 800 mL of colloid solution was added to the pump throughout the case. After the 407 minutes of CPB, the patient required 4 units of packed red blood cells, 8 units of fresh-frozen plasma, one pack of irradiated platelets, and 4.8 mg of recombinant factor VIIa. A total of 1354 mL of washed red blood cells was returned to the patient.

Aortic Reconstruction

A standard midline sternotomy was used with right axillary artery cannulation through an 8-mm Dacron side graft. Simultaneously, a small 4-cm right femoral cutdown was performed where another 8-mm Dacron graft was attached in an end-to-side fashion to the common femoral artery. The CPB circuit had two arterial lines and axillary and femoral sites were connected individually to the 8-mm Dacron grafts. A customized trifurcated aortic arch bypass graft was created by sewing two 8-mm grafts to a 12-mm graft end-to-side for the innominate artery, carotid artery, and subclavian artery, respectively (see Figure 5). The aortic arch measured a maximum of 65 mm in diameter with the ascending aorta estimated to be 40 mm in diameter. We elected to resect the aortic root and ascending aorta as well because of the high risk for aortic catastrophe in patients with Marfan's syndrome. CPB and systemic cooling was initiated through the axillary artery.

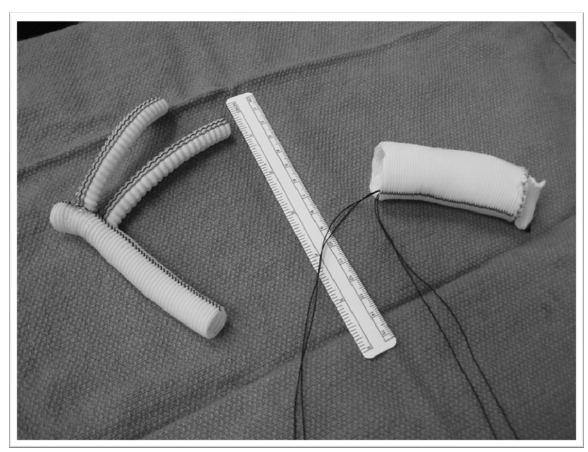

Figure 5. Intraoperative photograph of homemade grafts for trifurcated head vessel reconstruction with innominate, carotid and subclavian artery branches (left). On the right, the "elephant trunk" and transverse arch graft is seen.

During cooling, we crossclamped the ascending aorta and began resecting proximal into the aortic root. Myocardial preservation was achieved through direct coronary ostial catheters. The aortic valve was tricuspid in nature. A valve-sparing root replacement using a reimplantation technique was used to preserve the native aortic valve. The sinuses of the native aortic root were excised and the commissures resuspended within a 30-mm Dacron graft that was necked down to a proximal diameter of 25 mm. The valve was sewn into the neoaortic root using two suture layers (see Figure 6). At 25°C, circulatory arrest with continuous antegrade cerebral perfusion approximately 1–2 L per minute was initiated (10–15 mL/kg). Antegrade cerebral flow was accomplished through the right axillary artery graft. The customized aortic arch graft was then anastomosed separately to the innominate, left carotid, and left subclavian arteries. Also, while performing the head vessel bypasses, we initiated low-flow systemic and mesenteric perfusion through the femoral artery occurred at a rate of 1–3 L per minute with a temperature of 25°C. Excess blood return through the descending thoracic aorta was recovered by a sump vent.

The proximal descending thoracic aorta was then dissected out and a 26-mm Dacron elephant trunk graft was placed down the descending thoracic aorta. The aortic dissection flap was reapproximated to exclude the false lumen. The elephant trunk was retelescoped back into the mediastinum and subsequently the head vessels were attached to the aortic arch graft. The aortic crossclamp was then reapplied and full systemic and cerebral rewarming was initiated through the right axillary graft. We initially started to rewarm the lower body at a faster rate than the head as a result of the independent temperature and flow control. Next the left coronary button was reattached followed by completion of the aortic root graft onto the aortic arch graft and reattachment of the right coronary button (see Figure 7). The patient was easily weaned from

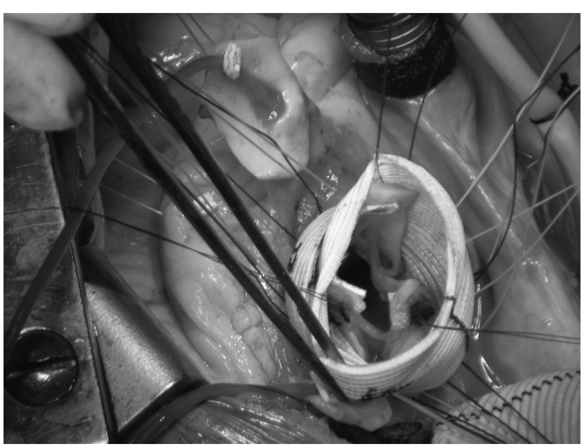

Figure 6. Intraoperative photograph demonstrating the valve sparing aortic root replacement.

Figure 7. Intraoperative photograph demonstrating the aortic arch reconstruction.

cardiopulmonary bypass and transesophageal echocardiography demonstrated an excellent repair with no aortic insufficiency and a 6-mm height of leaflet coaptation. The total operative time was 14 hours 30 minutes with a total pump and crossclamp time of 407 and 322 minutes, respectively. There were no periods of cerebral ischemia and total cerebral perfusion time was 224 minutes with flows of 1–3 lpm. The lowest cerebral saturation during the entire CPB time period was 53%. Separate lower body perfusion was 207 minutes with flows varying from 1 lpm to 3 lpm. Intraoperative biochemical assessment showed a peak lactate of 12.6 mmol/L and lowest bicarbonate level was 19.1. However, an arterial blood gas before separation from CPB demonstrated that the metabolic debt was quickly reversing with a lactate of 5.4 mmol/L, bicarbonate of 29.2, and base excess of 4.2. Reperfusion time after crossclamp removal was 69 minutes. Rewarming continued to the cerebral/upper body for 83 minutes before the crossclamp removal. The lower body temperature remained tepid from 25–28°C in the early part of the case and was rewarmed earlier than the cerebral flow to speed total body rewarming (5° gradient). Post-CPB, the patient came off the pump with a hemoglobin of 9.5 g/dL and on minimal inotropic support.

Postoperative Course

The patient's immediate postoperative hemodynamics were favorable. He remained on minimal inotropic support with epinephrine at 1 μg/min and nitroglycerine at 20 μg/min for approximately 6 hours. Chest tube losses were a total of 250 mL over 12 hours. He was ventilated for 14 hours and extubated the morning of Postoperative Day (POD) 1. Postoperative convalescence revealed no evidence of temporal neurological dysfunction. On POD 3, the patient was transferred to the surgical floor and made an uneventful convalescence. He was discharged home on POD 10. Postoperative CT demonstrated an intact aortic

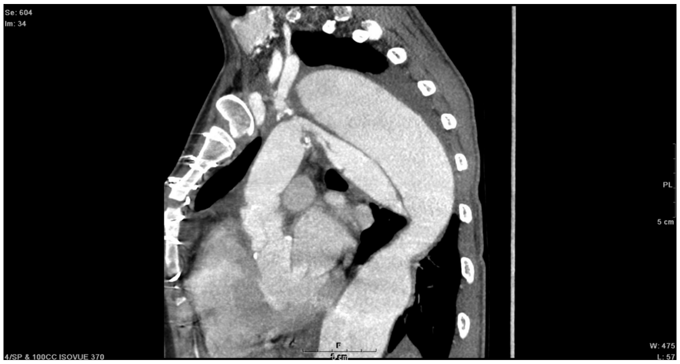

Figure 8. Postoperative computed tomography scan demonstrating intact aortic root, ascending aorta, aortic arch with head vessel, and elephant trunk reconstruction.

arch repair with the elephant trunk sitting deep within the true lumen of the descending aorta (Figure 8).

DISCUSSION

This case report describes our myocardial, cerebral, and visceral perfusion strategy during complex aortic valve and arch reconstruction for a young patient with Marfan's syndrome. We demonstrated that this complex perfusion technique enabled extensive aortic reconstruction while providing optimal mesenteric and systemic protection in addition to cerebral and myocardial protection. Our technique is similar to cool head–warm body (CHWB) perfusion first described by Matsuwaka et al. from Japan in 1998. They demonstrated simultaneous hypothermic cerebral perfusion and tepid/normothermic visceral perfusion can be a useful adjunct during aortic surgery, providing improved overall recovery (12). Takano et al. retrospectively analyzed the safety and usefulness of the CHWB perfusion in their series of 59 patients in 1999. They separated the groups into deep hypothermia (nasopharyngeal temperature of 20°C), moderate hypothermia (nasopharyngeal temperature of 28°C), and the CHWB (nasopharyngeal temperature of 25°C and bladder temperature of 32°C). They concluded that CHWB perfusion in aortic surgery is a safe and useful technique in shortening the operation time and reducing blood loss (6). However, this group suggests that further study is required before objective conclusions can be made about the clinical usefulness of this strategy.

We chose a moderate hypothermia (25°C rectal temperature) strategy for initial cooling of the entire body through the axillary route. This route is proven to be fast, simple, and convenient with less cannula clutter in the operative field (13). Continuous ACP was maintained throughout the period of CPB at a temperature of 25°C. Flows varied between 1 and 3 lpm depending on whether flow was directed to the axillary artery and continued bihemispherically through the left common carotid artery at first and later the anastomosed graft using a mean perfusion pressure of 50–70 mmHg as a guide (2,14). A mild hypothermia (28–32°C) strategy avoids the effects of deep hypothermia and may help to decrease transfusion volume and reduce duration of intubation and intensive care unit stay (7,8). Others suggest that safety margins may be jeopardized with the mild hypothermia approach and a moderate hypothermia strategy may be better (7,8,15). The optimal perfusion temperature and ACP flow rates have not yet been clearly defined in the literature (13,15). The lower body perfusion was maintained at a temperature of 25°C. When lower body flow was established consistently, we were able to quickly correct the acidosis and decrease lactates from a peak level of 12.6–5.4 mmol/L before the termination of CPB. Also, as the acidosis was being corrected, we were able to rewarm the lower body to 30°C rectal 79 minutes before the upper body was rewarmed.

The limitations of this perfusion protection strategy include the complexity of circuit design. It required two perfusionists approximately 2 hours to develop and build a circuit to provide as many safety measures, monitors, temperature probes, and pressure transducers as possible. Therefore, this type of perfusion circuit would be difficult to prepare in an emergent situation; however, because we have overcome the learning curve, we are now able to set up this circuit with much less time. With two pumps to perfuse the upper and lower body independently, the need to confirm flows and pressures safely was important. The disadvantages of using lower body retrograde flow include the risk of atheroembolism. However, if differential lower body flow is lower than upper body antegrade flow, then the embolic risk is minimal. In addition, retrograde embolization is unlikely because total arch replacement often requires isolation of the descending aorta from the head vessels during reconstruction. Teamwork was extremely important to the success of this case. It was facilitated by communication with the cardiac surgeon, the anesthesiologist, and the perfusion team regarding flows, pressure monitoring, and surgical sequence (11).

Another advantage of this perfusion strategy includes the continued protection offered especially during long procedures. The surgical option to reconstruct the aortic valve required the operative times to be longer and the repair was much more demanding than a simple replacement. The benefits of this technique for a 22 year old outweigh the risks of longer perioperative times. The advantages of aortic valve preservation include lower risk of infective endocarditis plus avoidance of typical prosthetic valve complications such as thrombotic and hemorrhagic complications in mechanical prosthesis and structural valve deterioration in bioprosthetic valves (16). However, a negative feature of the aortic valve-sparing operation is it is technically more demanding, requiring surgical expertise and optimal patient selection (16). The mid- to long-term clinical outcomes of this operation have been very favorable, especially in patients with Marfan's syndrome as reported by Forteza and David (17,18). This perfusion strategy may provide better organ preservation when patients undergo extensive aortic reconstructions.

CONCLUSION

Independent control of upper body and lower body perfusion for complex aortic arch surgery may offer significant benefits, including optimal brain protection, mesenteric and lower body protection, earlier rewarming, and faster metabolic correction compared with DHCA alone. This approach proved to be beneficial in this case as we undertook a very complex and lengthy aortic reconstruction. The perfusion strategy enabled simultaneous cerebral, myocardial, and visceral organ protection against prolonged ischemia and we demonstrated favorable biochemical and clinical outcomes. Further investigation is warranted.

Addendum

Approximately 11 weeks later, the patient underwent the second stage of the operation. He had an open repair of the thoracoabdominal aortic aneurysm. The patient required 171 minutes of left heart bypass with flows varying from 1.5 to 3.1 lpm with selective mesenteric perfusion. The patient was extubated on POD 2 and was alert and interactive, moving all limbs. He was discharged home after an uneventful in-hospital course. At 6 months follow-up, he is doing well and has returned to his regular activities.

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