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Technique Articles

A Safe and Flexible Cardiopulmonary Bypass Technique for Complex Aortic Surgery without the Requirement for Deep Hypothermic Circulatory Arrest

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Abstract: This article describes an adaptable technique of full-body perfusion during complex aortic surgery, which was performed on six consecutive patients, at a nasopharyngeal temperature of 28–34°C for a mean duration of 5 hours. A modified perfusion system was used to provide upper and lower body perfusion through axillary and femoral artery cannulation. The option of selective antegrade cerebral perfusion was also available if required. A simple custom-made circuit and application of additional monitoring such as cerebral oximetry makes this technique a safe and flexible method of providing continuous whole-body perfusion at moderate hypothermia and above. We found that these patients all had no major coagulopathies after the procedure and demonstrated no observable neurological, renal, or gastrointestinal dysfunction on recovery. **Keywords:** axillary and femoral artery cannulation, aortic surgery, selective antegrade cerebral perfusion. *JECT. 2013;45:254–258*

OVERVIEW

Complex aortic surgery is capable of presenting several challenges to the cardiac team including the requirement of unique surgical and perfusion techniques for a particular case. Even if there is sufficient time for the team to develop a plan of action, often once the procedure has begun, a new strategy needs to be quickly decided on. A change in strategy once cardiopulmonary bypass (CPB) has been initiated may require cutting into the circuit, causing a delay to the surgeon and an added risk of desterilizing the circuit and introducing air emboli. It is well documented that air emboli greatly increase the risk of patient morbidity and mortality, in particular neurological dysfunction (1,2). We describe a few simple modifications to our standard extracorporeal perfusion circuit to provide continuous whole-body perfusion without risk or delay during ascending and aortic arch surgery.

DESCRIPTION

Six patients presented for complex aortic surgery for replacement of the ascending aorta and/or aortic arch (Table 1). For each of these patients, the described simple and adaptable CPB technique was used.

Patient 1 was a 26-year-old man presenting with a dissected aorta from the left subclavian artery and along 7–8 cm of the descending aorta after a road traffic accident. He sustained a splenic rupture, fractured hip, and paraplegia caused by ischemia during the incident.

Patient 2, a 41-year-old man with Marfan's, demonstrated an aortic dissection from the aortic root to the bifurcation of the innominate artery with aortic valve insufficiency.

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Table 1. Demographics of the six patients presented for complex aortic surgery.

Patient No.	Gender	Age (years)	Weight (kg)	Preoperative Hemoglobin (g/dL)	Postoperative Hemoglobin (g/dL)	Preoperative Platelet Count ($\times 10^9$/L)	Postoperative Platelet Count ($\times 10^9$/L)	Cardiopulmonary Bypass Time (minutes)	X-clamp Time (minutes)	Minimum Temperature (°C)
1	Male	26	100.0	14.0	8.4	239	117	177	87	32
2	Male	41	93.0	12.7	5.5	194	82	333	253	28
3	Female	65	70.0	11.3	9.7	188	170	147	86	34
4	Female	47	68.8	13.9	7.9	328	110	434	240	28
5	Male	40	108.5	13.4	8.9	300	256	347	301	32
6	Female	79	70.9	13.9	7.8	224	81	422	282	28

Patient 3 was a 65-year-old woman with a 5.5 cm ascending aortic aneurysm to the origin of the innominate artery.

Patient 4 was a 47-year-old woman presenting with a 7 cm aortic root aneurysm and a 5 cm descending thoracic aneurysm.

Patient 5, a 40-year-old man, was diagnosed with a chronic type A aortic dissection to the origin of the innominate artery.

Patient 6 was a 79-year-old woman who presented with a grossly dilated aortic root of 8.5 cm extending along the aortic arch.

EXTRACORPOREAL CIRCUIT DESIGN

The extracorporeal circuit consisted of our standard CPB tubing pack (Maquet Cardiopulmonary AG, Rastatt, Germany), Affinity arterial filter (Medtronic, Minneapolis, MN), Sorin CS14 cardioplegia set (Sorin Group, Milano, Italy), and Quadrox adult oxygenator (Maquet Cardiopulmonary AG) mounted on a Sorin SIII four roller pump base incorporating a Sorin 3T heater cooler unit (Sorin Group). The circuit was modified by connection of a custom-made CPB circuit table pack in the postarterial filter line (Figure 1). This consisted of a 3/8-inch Y connector attached to two lengths of 3/8-inch polyvinyl chloride (PVC) tubing for connection to the femoral artery and axillary artery, respectively, with one piece of tubing incorporating a red strip for easy identification. The scrub nurse was then able to clamp and divide the modified table pack (Figure 1) and discard the 3/8-inch Y connection along with the prebypass filter. Thus, two arterial lines were made available for connection to the axillary and femoral artery cannulation sites. An ultrasonic flow probe, using the Sorin SCP Console (Sorin Group), was attached to the axillary arterial tubing to enable differential blood flow to be determined. The circuit also included our custom-made Selective Antegrade Cerebral Perfusion Circuit (SACPC) connected to the oxygenator recirculation line (Figure 2). The SACPC consisted of 1/4-inch PVC tubing (Chalice Medical, Worksop, UK) and a pediatric arterial filter (Terumo, Elkton, MD) with flow rate controlled by a separate roller pump (Sorin Group), which was pressure-regulated and connected to the arterial roller pump. Circuit prime consisted of 1500 mL of Hartmann's, 500 mL of Voluven, 30 mmol of sodium bicarbonate, 12 mmol of magnesium, and 5000 IU of porcine heparin sodium.

PERFUSION TECHNIQUE

Cannulation of the axillary and femoral artery was achieved using an 8-mm Gelweave graft (Vascutek Ltd., Scotland, UK) anastomozed to the vessel using the side graft technique (3). CPB was established through two 24-Fr Andocor arterial cannulae (Chalice Medical, Worksop, UK) inserted into the Gelweave grafts and a two-stage 34/46-Fr venous cannula (Medtronic Inc, Minneapolis, MN) inserted through the right atrium (Figure 3). Total flow rate was calculated at a reference of 2.4 L/m^2/min, which was increased to maintain oxygen delivery above 272 mL/m^2/min if the hemoglobin concentration was within our protocol of at least 6 g/dL (4). Myocardial protection was achieved with an antegrade induction dose of 1000 mL 4:1 high-strength Harefield formulation cold blood cardioplegia (Terumo BCT, Larne, UK) with 500-mL maintenance doses every 20 minutes through the aortic root and/or coronary ostia. Patients were cooled to a nasopharyngeal temperature in the range of 34–28°C (Table 1).

During periods of the operation that required complete isolation of the cerebral circulation from the remaining systemic circulation, cross-clamps were placed across the origin of the innominate artery and the descending aorta. Continuous total-body perfusion was achieved through the femoral and axillary arterial line of the CPB circuit. Cerebral blood flow was maintained at 10–15 mL/kg to achieve a right and left radial pressure of 50–70 mmHg by using a tubing gate clamp on the axillary arterial line (5). Distal aortic blood flow (displayed flow rate – axillary arterial line flow rate) was provided by the femoral arterial line to maintain femoral artery pressure between 50 and 70 mmHg (6). Monitoring of the left radial pressure and application of the INVOS 5100C Non-invasive Bi-lateral Cerebral Oximeter (Covidien, Dublin, Ireland) enabled anomalies of the circle of Willis (C of W) to be detected. Large anatomic variations in the C of W have been described; thus, the left

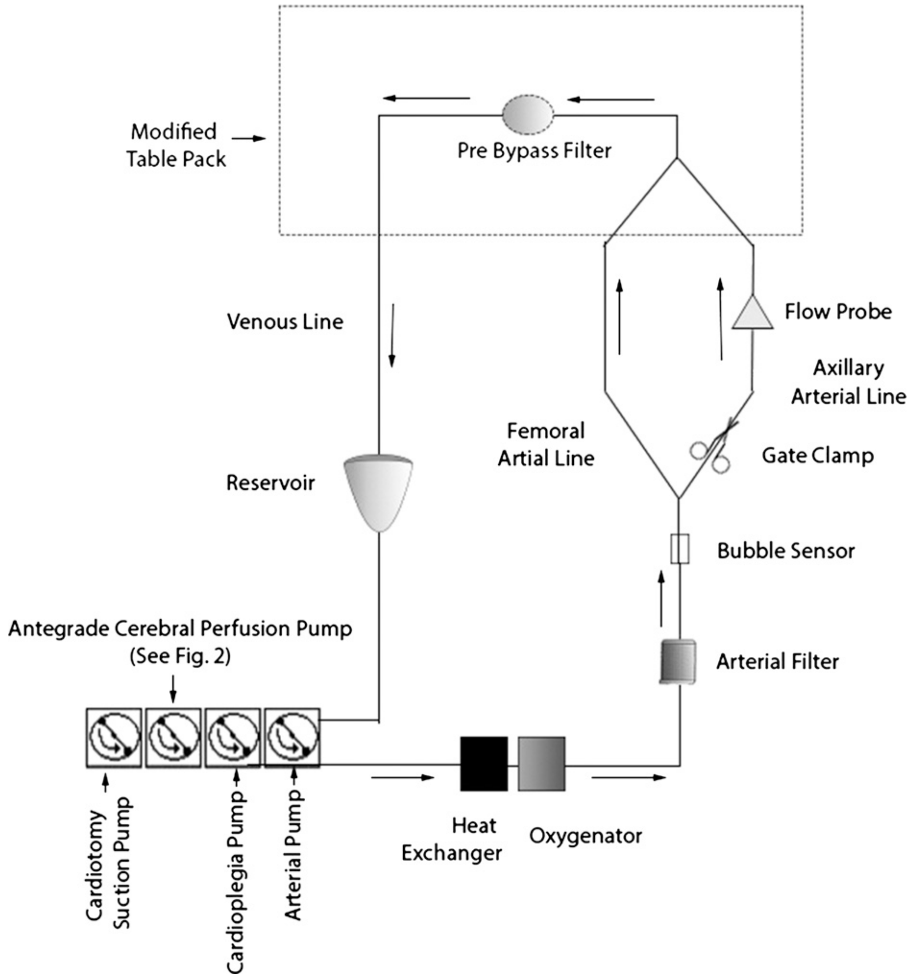

Figure 1. Modified cardiopulmonary bypass circuit design for complex aortic.

cerebral hemisphere would not be sufficiently perfused by right axillary perfusion alone in this particular group of patients (7). If the adequacy of left cerebral perfusion was questionable, that is, a mismatch greater than 20 mmHg between the left and right radial pressure or a regional oxygen saturation value difference greater than 10% between the left and right displayed on the INVOS monitor, direct cannulation of the left carotid artery was performed. This was necessary in three of our six reported cases using either a 15-Fr retrograde self-inflating cardioplegia cannula (Edwards Lifesciences, Unterschleissheim, Germany) or a 12-Fr pediatric aortic cannula (Maquet Cardiopulmonary AG). Perfusion was provided through the SACPC to provide a total cerebral blood flow (right axillary blood flow + SACPC blood flow) of 10–15 mL/kg (5).

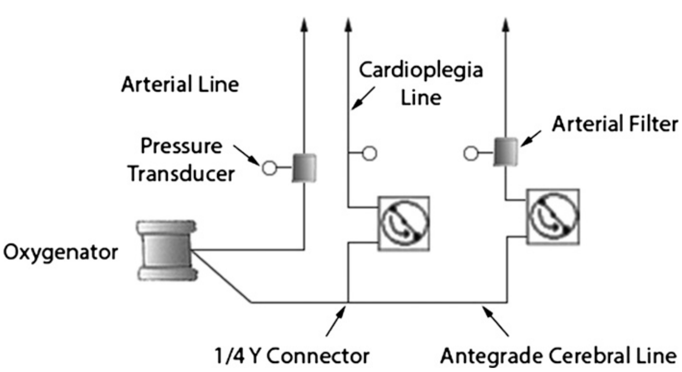

Figure 2. Selective antegrade cerebral perfusion circuit design.

After completion of the surgical procedure, the patients were rewarmed to a nasopharyngeal temperature of 36.5°C and terminated from CPB uneventfully after an average CPB time of 5 hours. After protamine administration, the axillary and femoral artery Dacron grafts were cut and over sewn with 5-0 polypropylene suture.

No perfusion-related technical problems occurred during these cases and all patients experienced no permanent renal, gastrointestinal, or neurological dysfunction. Patients were extubated between 9 hours and 6 days and on average discharged on Day 8. Furthermore, five patients had normal postoperative thromboelastograph results. All patients received blood products at some stage during their postoperative period. However, from our past experience using

Figure 3. Side graft cannulation technique of the axillary and femoral artery for complex aortic surgery.

deep heart circulatory arrest (DHCA), we feel blood product use would have been greater.

DISCUSSION

DHCA has historically been the mainstay for complex aortic surgery involving the aortic arch to protect vital organs for a limited period (8). Although the majority of patients will withstand 30 minutes of total-body DHCA without developing significant neurological complications, it is known to increase coagulopathic hemorrhage, metabolic acidosis, and hyperglycemia with mortality at 8–15% (8,9). Supplementary retrograde or antegrade cerebral perfusion during DHCA offers cerebral protection during extended periods with a majority of benefits demonstrated during the antegrade approach (10). Furthermore, some spinal cord circulation is provided by cerebral perfusion to the anterior spinal artery through the vertebral arteries (11). However, hypothermic studies have demonstrated inadequate oxygen delivery to the brain as a result of the high affinity of hemoglobin for oxygen. Therefore, it is important to deliver a high PO_2 and adequate blood flow rate to fully saturate plasma, that is, a mixed venous saturation above 95% (12). Over the past decade, many studies have discussed the advantage of a more physiological approach using antegrade cerebral perfusion at moderate hypothermia (6). Our perfusion technique follows this understanding and provides further adaptability by the option of total-body perfusion alongside cerebral perfusion at mild to moderate hyperthermia, thereby protecting vital organs from permanent ischemic injury.

The custom-made CPB circuit table pack consisting of a split arterial line for axillary and femoral artery perfusion reduced set-up time and dependability of the scrub team for assembly. Furthermore, the ability to control blood flow independently through the femoral and axillary arterial line, through a tubing gate clamp, and flow probe using a single arterial roller pump reduced circuit complexity. Many safety features were also incorporated into the SACPC such as pressure regulation and arterial pump control to prevent oxygenator negative pressure air embolism transmission.

Our arterial cannulation approach using the side graft technique was more time-consuming than direct vessel cannulation. However, it was advantageous in patients with small vessels to provide optimal bidirectional blood flow across the cannulated vessel. Our two-site arterial cannulation enabled distribution of the total blood flow. Moreover, it minimized bleeding and avoided compromised pump flow rate through small vessels associated with axillary cannulation alone. In addition to axillary cannulation providing antegrade cerebral perfusion, it may diminish gross cerebral emboli and retrograde aortic dissection associated with femoral cannulation by competing with retrograde femoral perfusion in the ascending aorta (13).

The introduction of cerebral monitoring provided reassurance of adequate cerebral perfusion. Furthermore, it enabled optimization of cerebral perfusion parameters and identified situations where direct antegrade cerebral perfusion of the left carotid was necessary.

This perfusion technique incorporates a preassembled arterial perfusion circuit that is safe and adaptable with the flexibility to provide separate selective antegrade perfusion circuitry. It eliminates the need to perform DHCA for complex aortic surgery in a limited time period. However, appropriate training and good communication among the surgeon, anesthetist, scrub nurse, and perfusionist is paramount toward a successful outcome. Other adjunct techniques such as autologous priming and platelet sequestration and zero-balanced ultrafiltration may easily be integrated into this perfusion technique (14,15).

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REFERENCES

1. Lynch JE, Riley JB. Microemboli detection on extracorporeal bypass circuits. Perfusion. 2008;23:23–32.

2. Maas C, Boogaart A, Eilander S, et al. Intermitttent antegrade/selective cerebral perfusion during circulatory arrest for repair of the aortic arch. Perfusion. 1997;12:127–32.
3. Di Eusanio M, Schepens MAAM, Morshuis WJ, et al. Brain protection using antegrade selective cerebral perfusion: A multicenter study. Ann Thorac Surg. 2003;76:1181–9.
4. Ranucci M, Romitti F, Isgro G, et al. Oxygen delivery during cardiopulmonary bypass and acute renal failure after coronary operations. Ann Thorac Surg. 2005;80:2213–20.
5. Colangelo N, Benussi S, Piazza G, Alfieri O. A simplified technique for antegrade selective cerebral perfusion. Perfusion. 2002;17:187–9.
6. Charumathi D, Vaijanath P, Sekhar L, et al. Aortic arch replacement with moderate hypothermia and a modified 3-pump circuit. Perfusion. 2011;26:141–4.
7. Merkkola P, Tulla H, Ronkainen A, et al. Incomplete circle of Willis and right axillary artery perfusion. Ann Thorac Surg. 2006;82:74–9.
8. Fitzgerald D, Resley J, Speor A, Munoz R, Hill A. Antegrade cerebral perfusion with hypothermic circulatory arrest: A case report. Perfusion. 2003;18:303–6.
9. Conolly S, Arrowsmith JE, Klein AA. Deep hypothermic circulatory arrest. Continuing Education in Anaesthesia, Critical Care & Pain. 2010;10:138–42.
10. Kazui T, Yamashita K, Washiyama N, et al. Usefulness of antegrade selective cerebral perfusion during aortic arch operations. Ann Thorac Surg. 2002;74:1806–9.
11. Dommisse GF. The blood supply of the spinal cord. J Bone Joint Surg Br. 1974;56:225–35.
12. Dexter F, Kern FH, Hindman BJ, Greeley WJ. The brain uses mostly dissolved oxygen during profoundly hypothermic cardiopulmonary bypass. Ann Thorac Surg. 1997;63:1725–9.
13. Ogino H, Sasaki H, Minatoya K, et al. Evolving arch surgery using integrated antegrade selective cerebral perfusion: Impact of axillary artery perfusion. J Thorac Cardiovasc Surg. 2008;136:641–9.
14. Murphy GJ, Reeves BC, Rogers CA, Rizvi SIA, Culliford L, Angelini GD. Increased mortality, postoperative morbidity, and cost after red blood cell transfusion in patients having cardiac surgery. Circulation. 2007;116:2544–52.
15. Zhu X, Ji B, Wang G, et al. The effects of zero-balance ultrafiltration on postoperative recovery after cardiopulmonary bypass: A meta-analysis of randomized controlled trials. Perfusion. 2012;27:386–92.