JECT. 2004;36:324–328
The Journal of The American Society of Extra-Corporeal Technology

Original Articles

A Technique for Performing Antegrade Selective Cerebral Perfusion Without Interruption of Forward Flow or Cannula Relocation for Pediatric Aortic Arch Reconstruction

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Presented at the American Society of Extra-Corporeal Technology, 11th Annual Symposium on New Advances in Blood Management, September 25–27, 2003

Abstract: New technology and advances in extracorporeal bypass circuitry and surgical techniques have drastically improved outcomes in infants with congenital heart defects. Hypothermia with circulatory arrest has fallen out of favor in many institutions over the last decade in part from data implicating even short circulatory arrest times to long-term neurologic sequelae. Implementing continuous cerebral perfusion techniques for aortic arch reconstruction is desirable in ameliorating neurologic complications because long-term survival of complex defects can be more routinely achieved. Many centers have implemented alternative means of alleviating cerebral ischemic periods by incorporating selective antegrade or retrograde cerebral perfusion techniques. The incidence of post-operative neurologic events is low when alternative cerebral perfusion techniques are used. Many techniques used to perform continuous cerebral perfusion involve brief periods of circulatory arrest, usually for perfusion cannula repositioning. Herein we describe a technique for performing continuous antegrade cerebral perfusion without a need to interrupt forward flow. **Keywords:** cerebral perfusion, circulatory arrest, neurologic outcomes. *JECT. 2004;36:324–328*

Hypothermia is routinely used during cardiopulmonary bypass (CPB) to decrease organ metabolic activity in an effort to prolong cardiac ischemic time, increase the level of safety during emergent situations, and to allow for reduced blood flow when surgical field visualization becomes impaired. Deep hypothermic circulatory arrest (DHCA) historically has been used in patients where aortic cannulation techniques are compromised by the pathology of the defect or by the repair itself. The "safe" duration of DHCA is unknown. Experimental animal evidence indicates that at 90 minutes of DHCA at 18°C, there is a high incidence of irreversible neurologic injury with prolonged abnormalities of cerebral blood flow and oxygen metabolism (1). Even at time periods just above 30 minutes, there is evidence of brain injury (2). Neurologic injuries and abnormalities of cerebral metabolism occur during deep hypothermia, even if blood flow is not interrupted (3). In 1993, Newburger et al. reported that low flow hypothermic CPB resulted in less neurologic injury when compared to DHCA (4).

In an effort to reduce the amount of time patients require DHCA, many institutions are implementing techniques of selective cerebral perfusion (SCP), where the brain receives very little ischemic time, for operations involving the transverse aortic arch (5–9). This technique can involve head perfusion with distal aortic perfusion or head perfusion alone, use of multiple cannulae, and perfuse one or all head vessels. SCP was first reported in 1981 by Soma et al., wherein they performed selective cerebral perfusion using four separate circuits to perfuse all four head vessels at one time (10). Not until the late 1980s and early 1990s did this technique begin to gain favor as a safe alternative to DHCA.

One of the major issues concerning implementation of

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SCP was in determining the safe pressure and flow adequate to maintain cerebral tissue perfusion. In 1989, Matsuda et al. described optimal perfusion criteria for SCP to be a bilateral superficial temporal artery pressure of 50 mmHg and venous oxygen saturation of the superior vena caval line or internal jugular vein of 90% (11). In 1990, Matsuwaka et al. described the optimum criteria for SCP to be much the same as Matsuda had depicted except with pressures of only 40 mmHg being necessary for adequate cerebral protection (12). In 1995, Schwartz et al. reported that, because of noncerebral collateral blood flow, flow to the brain was determined by pressure alone (13). In 1999, Watanabe et al. reported that pressures under 20 mmHg and over 40 mmHg can cause cerebral ischemia and that optimal SCP pressures should fall within this range (14).

Other issues concerning the implementation of SCP were in the cannula selection and bypass circuitry necessary to perform the technique safely. Many reports advocate cannulating more than one head vessel while utilizing one or two separate CPB circuits. However, in 1994, Aoyagi et al. reported that a single cannula in the innominate artery gave satisfactory cerebral protection as long as the patency of the Circle of Willis was confirmed (15). In 1999, Imoto et al. reported the ability to perform the Norwood Stage I procedure without the need for DHCA by cannulating the Right Modified Blalock–Taussig Shunt (RMBTS) for SCP during the aortic arch reconstruction (16).

Limiting the amount of DHCA time necessary for patients undergoing aortic arch reconstruction is essential in reducing the amount of neurologic dysfunction potentially associated with this procedure. Many techniques have been described depicting ways in which SCP can be implemented in an effort to reduce DHCA time. Most of those techniques require some brief periods of DHCA for cannula removal and placement into the head vessels. Herein we describe a simple and safe technique for implementing SCP without the need for DHCA.

DESCRIPTION OF SCP FOR HLHS

Once the patient has been intubated, and venous access has been accomplished, a right radial or axillary arterial line is placed for monitoring of cerebral perfusion pressures during SCP. The patient is then positioned and prepped in normal fashion for median sternotomy. Once the chest and pericardial sac have been opened, all vessels are exposed, and the proximal end of an appropriate sized RMBTS is placed on the innominate artery. After hemostasis is achieved on the proximal end of the RMBTS, the patient is fully heparinized with 300 IU/kg of heparin in preparation for CPB. Once the post-heparinization activated clotting time (ACT) reaches three times baseline level, the patient is considered to be adequately anticoagulated to commence CPB. ACTs are maintained above 400 seconds for the duration of the bypass. An 8 or 10 Fr BioMedicus (Medtronic Corp, Minneapolis, MN) arterial cannula is placed in the patent ductus arteriosus (PDA), and a 16 or 18 Fr right angled Polystan (Jostra Corp, Hirrlingen, Germany) venous cannula is placed in the right atrium. The arterial and venous lines of the CPB circuit are then connected to the cannulae.

Once the activated clotting time has been verified, CPB is commenced, and the right and left pulmonary arteries are snared (Figure 1). The patient is then cooled to a bladder temperature of 20°C. While cooling, the head vessels are dissected and encircled with snares, the PDA is snared at its insertion onto the pulmonary artery (PA), the main pulmonary artery (MPA) is removed from the left and right pulmonary arteries, and a patch is placed on the PAs where the MPA inserted. Once the patient has reached a core temperature of 20°C, the RMBTS is flushed, and a Bard Ureteral Catheter Adapter (Covington, GA) is inserted into the distal end of the shunt and secured with a 1.0 Silk tie (Figure 2). A cardioplegia "Y" is then placed onto the Bard catheter, and the cardioplegia line and aortic root vent are appropriately placed onto the "Y." The shunt, "Y," and cardioplegia infusion line are then de-aired through the aortic root vent, which is set to gravity drainage (Figure 3). The distal innominate artery is then clamped distal to the insertion of the RMBTS using small vascular clamps. The aortic arch is then clamped proximal to the left common carotid artery, and 40 mL/kg of 4:1 blood cardioplegia is delivered at 10 cc/kg/min through the RMBTS and retrograde down the ascending aorta at 6°C (Figures 4 and 5). The patient remains on full CPB through the aortic cannula in the PDA during this time. Once cardioplegia has been given, the cardioplegia "Y" is clamped, the crystalloid line of the

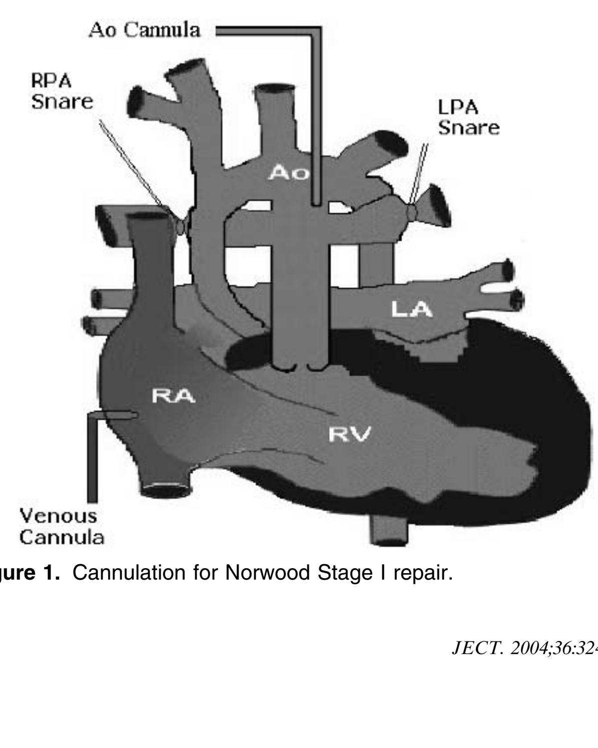

Figure 1. Cannulation for Norwood Stage I repair.

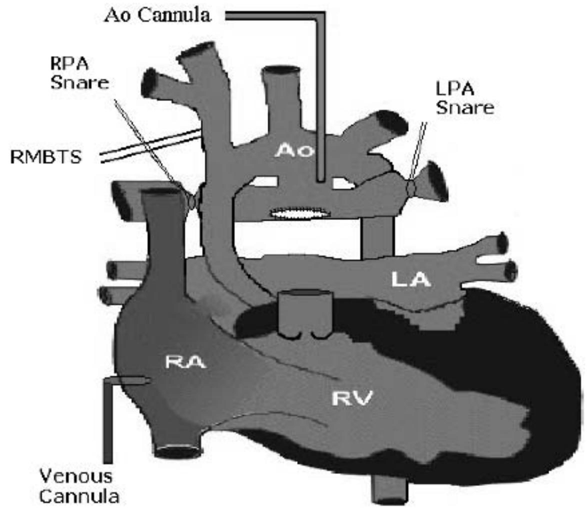

Figure 2. RMBTS location after MPA removal for Norwood Stage I.

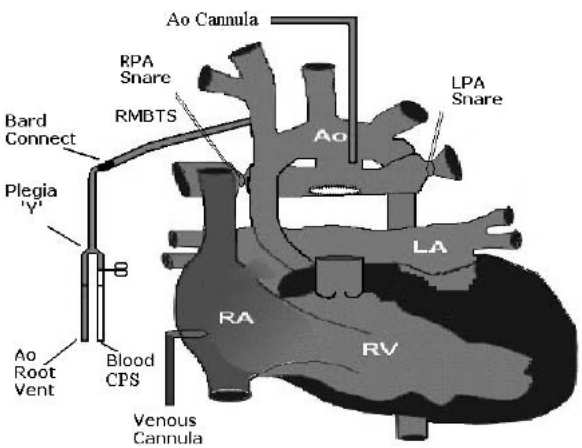

Figure 3. RMBTS cannulation and de-airing.

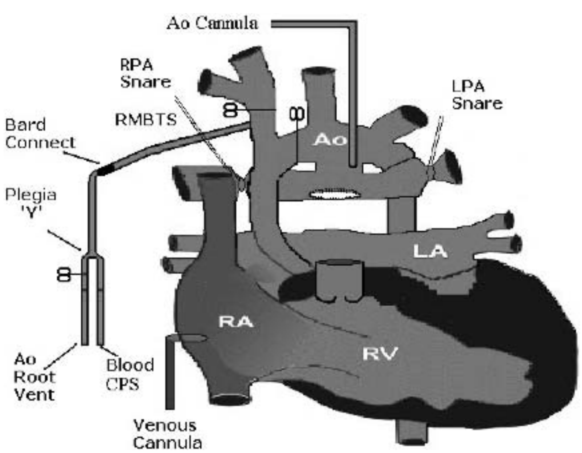

Figure 4. Cardioplegia delivery through RMBTS.

Figure 5. Cardioplegia delivery and clamp locations with RMBTS cannulation.

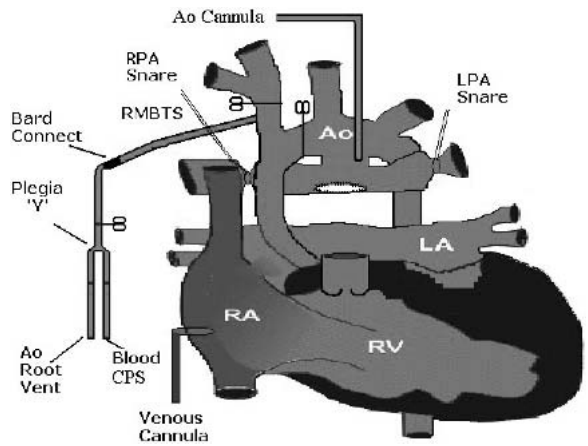

Figure 6. Flushing of circuit in preparation for SCP.

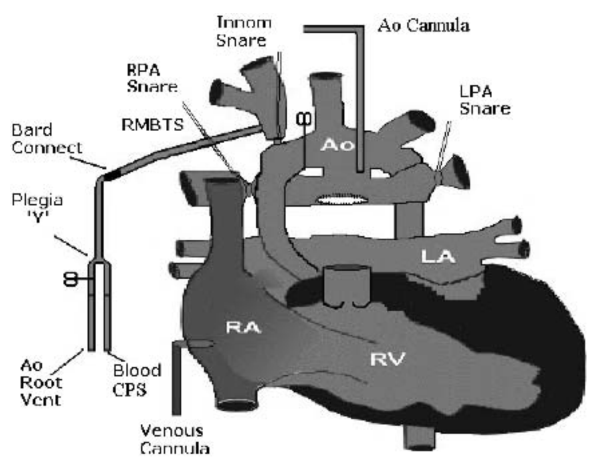

Figure 7. Initiation of SCP with forward perfusion through PDA.

blood cardioplegia boot tubing is removed from the pump, and the cardioplegia system is flushed through the aortic root vent and warmed to a temperature of 18°C (Figure 6). The clamp on innominate artery is then removed, the head vessels are snared, and selective cerebral perfusion (SCP) is started at 25 cc/kg/min at 18°C. Flow is slowly increased until a right radial or axillary artery pressure of 35 mmHg is achieved (Figure 7). Once SCP has been successfully initiated, the arterial flow through the PDA is slowly stopped, and the cannula is removed (Figure 8). The ve-

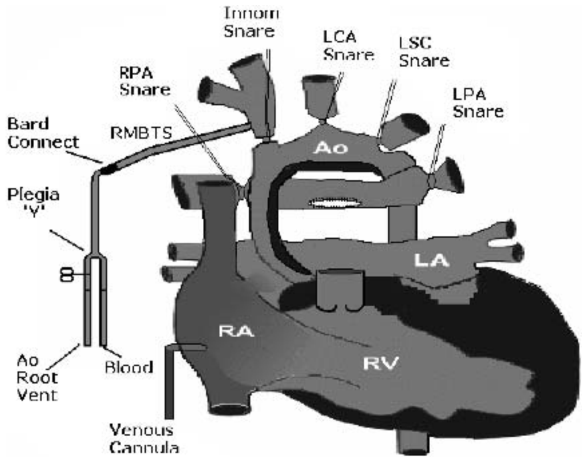

Figure 8. SCP with aortic cannula removed.

nous cannula remains in place open to capture blood flow returning to the right atrium from the superior vena cava. Because gas exchange and blood flow to the cardioplegia system are dependent upon flow through the main arterial pump, it is necessary to circulate through the recirculation lines on the CPB circuit during SCP.

While on SCP, the ascending aorta and aortic arch are reconstructed. A small vascular clamp is placed on the descending aorta, distal to the patch site, to keep collateral blood flow from SCP out of the surgical field. Once the aorta has been reconstructed, the neo-aorta is de-aired with saline, and aortic purse strings are placed in the ascending aorta. The arterial cannula is then placed in the ascending aorta, and flow at a cardiac index of 1.0 is instituted. SCP continues, and the head vessel snares remain in place while the neo-aorta and aortic arch are thoroughly de-aired. Once the neo-aorta has been successfully de-aired, and the suture lines are checked, the head vessel snares are removed, and SCP is stopped. Cardiac index is now increased to full flow, and the patient is slowly rewarmed. The distal end of the RMBTS is placed on the right pulmonary artery during the warming period. Once the patient is fully warmed, and hemodynamics are satisfactory with the shunt open, the patient is weaned from CPB.

DISCUSSION

One advantage of this technique is the ability to maintain continuous cerebral perfusion to the patient safely and easily without the need for cannula removal and relocation or the use of cumbersome ancillary bypass equipment or circuits. This technique also alleviates the need for direct ascending aortic cannulation for cardioplegia delivery, especially in the very small ascending aorta typically found in HLHS. SCP through the RMBTS allows one to de-air the neo-aorta thoroughly with forward flow through the aortic cannula while still perfusing the head without the need to feel rushed to place the patient on CPB because of brain ischemic time. Having a positive pressure in the head vessels while removing the snares is also advantageous in that any air trapped in the ostia of the head vessels will be pushed downstream to the descending aorta rather than up to the brain.

One disadvantage of this technique is the need to run two pumps simultaneously. Should the primary pump stop for any reason, and the SCP pump continue to run, there is a possibility of creating a negative pressure within the circuit that would pull air across the membrane oxygenator. As a means to overcome this potential problem, the SCP pump can be slaved to the primary pump to stop both in the event that the primary pump is arrested for any reason. This will shut down both pumps and alleviate the possibility of creating a negative pressure state in the CPB circuit.

We have also encountered two patients with aberrant right subclavian arteries off the transverse arch where we were unable to measure cerebral pressure adequately in the right radial or axillary artery. In those cases, we chose to proceed with our SCP protocol and maintain 30 mL/kg/min blood flow while closely monitoring SCP line pressure.

There are a few safety concerns to be aware of when performing SCP in this manner. Ensuring the cardioplegia system is warmed from 6°C to 18°C before starting SCP is imperative. Failure to do so may result in excessive brain cooling and choreoathetosis. Any kinking of the RMBTS during the procedure will result in over pressurizing the SCP circuit. It is, therefore, imperative to have positive pressure pump shut-off safety devices in place and on during this technique, for both the primary perfusion circuit as well as the SCP circuit. Finally, as discussed earlier, there is a need to recirculate through the main perfusion circuit during the procedure through recirculation lines. When reinstituting primary CPB through the neo-aorta, these shunts must be closed to commence forward flow through the arterial cannula in the neo-aorta. Failure to do so can cause retrograde flow of air down the aortic cannula.

CONCLUSION

Eliminating the need for DHCA is key to reducing neurologic injury associated with aortic arch reconstruction. Performing SCP through the RMBTS using a blood cardioplegia system is a safe alternative to DHCA during this repair. This technique allows for continuous, uninterrupted flow to the brain during the entire procedure.

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