

## Technique Articles

# Technical Description of the Use of Selective Perfusion Techniques During the Norwood Procedure for Hypoplastic Left Heart Syndrome

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**Abstract:** Since the introduction of the Norwood procedure for surgical palliation of hypoplastic left heart syndrome in 1983, refinements have been made to the original procedure to improve patient outcomes while still accomplishing the original goals of the procedure. One of these refinements has been the introduction of regional selective perfusion to limit the duration of

circulatory arrest times and optimize the regional flow distribution. In this paper we describe our technique for performing selective cerebral and lower body perfusion during the Norwood procedure. **Keywords:** Norwood procedure, selective perfusion, hypoplastic left heart syndrome, deep hypothermic circulatory arrest, regional oxygen saturation. *JECT. 2011;43:261–263*

Surgical palliation for hypoplastic left heart syndrome (HLHS) was first described by Norwood et al. in 1983 (1). The original surgical procedure consisted of reconstruction of the aortic arch and ascending aorta utilizing circulatory arrest, atrial septostomy, and modified Blalock Taussig shunt for pulmonary blood flow (Norwood Procedure) (1). Today while the goals of the procedure are the same, improvements in surgical techniques, including improved myocardial preservation strategies, use of right ventricular to pulmonary artery conduits for pulmonary blood flow, and reduction of total circulatory arrest time through the use of selective perfusion strategies, have led to significant improvement in outcomes for patients undergoing the Norwood procedure (2,3). We describe our technique of using selective cerebral and distal perfusion with continuous cold-blood cardioplegia during neo aortic reconstruction with reference to early outcomes.

## METHODS AND DESCRIPTION OF STRATEGY

This study was approved by the institutional review board. Because of the retrospective nature of the data review, need for parental consent was waived.

Patients undergoing the Norwood procedure are prepared in the standard fashion for open heart surgery including induction of endotracheal anesthesia, placement of radial and femoral arterial lines, central venous access, placement of cerebral and somatic regional oxygenation saturation sensors over the forehead and flank, and sterile preparation and draping of the patient. A median sternotomy is performed. Following systemic heparinization, cannulation for cardiopulmonary bypass (CPB) is accomplished with an appropriately sized arterial cannula (DLP, Medtronic, Minneapolis, MN) in the pulmonary artery, and a single venous cannula (DLP, Medtronic, Minneapolis, MN) placed through the right atrial appendage. Our neonatal cardiopulmonary bypass circuit consists of a 3/16" × 1/4" arterial venous loop (Sorin USA, Arvada, CO), neonatal oxygenator (D100, Sorin USA, Arvada, CO or FX-05; Terumo, Ann Arbor, MI), arterial filter if D100 oxygenator used (D130, Sorin USA, Arvada, CO), pediatric cardioplegia set (pediatric BCD Vanguard, Sorin USA, Arvada, CO), and hemoconcentrator (HPH 400, Minntech, Minneapolis, MN). An in line blood gas monitor (CDI 500, Terumo,

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Ann Arbor, MI) is also used for continuous blood gas monitoring. Near infrared spectroscopy monitoring of the cerebral and somatic regions is also used for measurement of regional oxygen saturation (rSO<sub>2</sub>) (INVOS, Somanetics, Troy, MI).

Our prime consists of initially priming and debubbling the circuit with 500 mL Plasma-Lyte A (Baxter, Deerfield, IL) buffered with 10 meq sodium bicarbonate per liter. The circuit was then drained of excess prime, and 2000 units heparin, 50 mL 25% albumin, 100 mL fresh frozen plasma, 1 g/kg 20% mannitol, and a calculated amount of packed red blood cells to achieve an on bypass hematocrit between 25–30% was added. The prime was then concentrated through a hemoconcentrator and buffered to physiologically normal pH using additional sodium bicarbonate if necessary. A blood gas of the prime was obtained prior to initiation of CPB.

Following arterial and venous cannula placement, and confirmation of adequate anti-coagulation (activated clotting time > 480 seconds) CPB was initiated at a calculated cardiac index of 2.5 L/min/m<sup>2</sup> and the patient was cooled to a rectal temperature of 25°C. During the cooling segment of the surgery, pH-stat blood gas management was used. PaO<sub>2</sub> was maintained above 400 mmHg. Following mobilization of the aorta and snaring of the head vessels, preparation was made for circulatory arrest and selective perfusion. A loading dose of 50 µg/kg over 15 minutes of milrinone was given through the CPB circuit prior to circulatory arrest to promote even cooling of the body. Prior to hypothermic circulatory arrest blood gas management was switched to alpha-stat strategy. This strategy was then used for the remainder of the procedure. Once the patient had been cooled to 25 degrees, antegrade cold blood cardioplegia was started and given continuously through the periods of circulatory arrest and selective perfusion through a 20 gauge angiocath catheter. Cardioplegia was initially delivered at a 4:1 blood to crystalloid ratio with a temperature < 4°C at approximately 30–40 mL/min flow to achieve line pressures between 150–170 mmHg. In the absence of electrical activity of the heart, the blood to crystalloid ratio was reduced to 16:1. If electrical activity resumed, the volume of crystalloid delivered would have been increased. CPB was then discontinued and the arterial cannula removed. A brief period of circulatory arrest was used for the initial period of the neo aortic reconstruction. Once ready for selective perfusion two 6 french, manual inflating, retrograde cardioplegia cannulas (DLP, Medtronic, Minneapolis, MN) were used to cannulate the innominate artery and the descending thoracic aorta. Following placement and deairing, the selective perfusion cannulas were connected to the arterial line of the CPB circuit via 8 inch segments of 1/8" tubing with male to male luer connections, attached to a single high flow stopcock coming off the arterial cannula. The arterial cannula was clamped distal to the luer

lock containing the high flow stopcock and the segments of 1/8" tubing. Flow was slowly started through both selective perfusion cannulas targeting a flow of 50 mL/kg/min and adjusted to achieve rSO<sub>2</sub> values within ± 10% of baseline (measured at anesthesia induction) with mean upper and lower body arterial pressures 35–40 mmHg and 30–35 mmHg, respectively. As flow was increased, there was a steady increase in both cerebral and somatic rSO<sub>2</sub> readings. Line pressure in the arterial line of the CPB circuit was kept below 300 mmHg. Following completion of the neo aortic reconstruction, cardioplegia and selective perfusion was stopped. The selective perfusion catheters were removed, and the aortic cannula was replaced. The aortic cannula was then placed in the newly constructed neo aorta. CPB was then slowly recommenced until a calculated cardiac indexed flow of a 2.5 L/min/m<sup>2</sup> was achieved and the patient was then rearmed to rectal temperature of 36.5°C. A short period of low flow "sucker bypass" was used during the atrial septectomy. During rewarming a conduit for pulmonary blood flow was constructed using either a modified Blalock Taussig Shunt or a right ventricular to pulmonary artery conduit. A right ventricular to pulmonary conduit was selected in patients who had ascending aortic diameter equal to or less than .6 mm/kg. Prior to separation from CPB, .5 g/kg of 20% mannitol and 25 µg/kg of milrinone were loaded through the CPB circuit. Blood gas and electrolytes were normalized, and prior to separation from CPB the patient was transfused with packed red blood cells to achieve a hematocrit of at least 36%. The patient was then weaned from CPB following systemic rewarming, titration of inotropic support, and ventilation with 100% oxygen and inhaled nitric oxide.

## RESULTS

Between July 2008 and January 2011, 13 patients underwent the Norwood procedure for hypoplastic left heart syndrome. Intraoperative rSO<sub>2</sub> information was available for nine of these patients. Of note, four patients in our series underwent a hybrid palliation involving patent ductus arteriosus stenting, bilateral pulmonary artery banding, and balloon atrial septostomy prior to surgical Norwood palliation. Of the nine patients in our series, seven underwent Norwood palliation with right ventricular to pulmonary artery conduit, one patient underwent Norwood palliation with a modified Blalock Taussig shunt, and one patient underwent comprehensive ascending aorta/aortic arch augmentation with bi-directional Glenn procedure following a hybrid type palliative procedure in the neonatal period. Demographic information is listed in Table 1.

Mean intraoperative rSO<sub>2</sub> values are represented in Table 2. Individual values were obtained at 10-minute intervals from each patient during the procedure. Mean

**Table 1.** Description of patient demographical information and intraoperative variables.

Variable	n = 9
Age (days)	46.8 ± 62.9
Weight (kg)	3.9 ± .8
CPB time (mins)	197.6 ± 61.8
Circulatory arrest (mins)	20.8 ± 10.5
Selective perfusion (mins)	45.5 ± 12.5

Values are listed as statistical mean.

**Table 2.** Mean intraoperative regional oxygen saturation percentages.

	Cerebral rSO <sub>2</sub> (%)	Somatic rSO <sub>2</sub> (%)
Baseline	48 ± 11.3	49.6 ± 12.7
CPB (prior to circulatory arrest)	62.7 ± 16.4	68.6 ± 12.5
Circulatory arrest	27.7 ± 10.7	37.7 ± 13.9
Selective perfusion	49.5 ± 19.9	65.2 ± 18.7
Resumption CPB	57.6 ± 15.1	67.3 ± 15.2

**Table 3.** Comparison and univariate analysis of regional oxygen saturation between circulatory arrest and selective perfusion periods.

	Circulatory Arrest	Selective Perfusion	p Value
Cerebral rSO <sub>2</sub> (%)	27.7	49.5	<.001
Somatic rSO <sub>2</sub> (%)	37.7	65.2	<.001

Significance:  $p < .05$ .

values were calculated during the listed segments of the procedure. Mean rSO<sub>2</sub> values between periods of circulatory arrest and selective perfusion were compared with a statistically significant difference ( $p < .05$ ) (Table 3).

## DISCUSSION

The use of selective perfusion techniques during aortic arch reconstruction in the neonatal population has been previously described in the literature (3,4). The advantage of this technique is that it allows for continuous blood flow to the brain as well as the distal organs, while providing the surgeon a clear surgical field to complete the reconstruction of the aortic arch while avoiding a prolonged period of deep hypothermic circulatory arrest, and the potentially negative neurological and renal complications. Because of our limited periods of circulatory arrest, employing moderate hypothermia of 25–28°C would be sufficient for cerebral protection. Our technique of using two separate selective perfusion cannulas allowed us to easily establish selective perfusion using the existing luer lock connection

in our arterial cannulas without the need to cut additional components into the CPB circuit.

The use of near infrared spectroscopy monitoring has demonstrated to be helpful during the period of selective perfusion and has been previously described in the literature (5). During circulatory arrest, there is a noticeable drop in both cerebral and somatic rSO<sub>2</sub> values from baseline. Once selective perfusion was initiated there was a steady rise in those values. We use these rSO<sub>2</sub> values in combination with proximal and distal perfusion pressure, as well as by measuring pressure within the arterial line of the CPB circuit to determine appropriate flow during selective perfusion. Achieving rSO<sub>2</sub> within ± 10% of baseline with mean upper and lower body arterial pressure 35–40 mmHg and 30–35 mmHg, respectively, represent our target values.

Our technique of using continuous cold blood cardioplegia is performed to potentially protect the myocardium from coronary hypoperfusion and ischemia. This may be beneficial to higher risk patients undergoing Norwood palliation and includes patients with mitral stenosis-aortic atresia subtype HLHS and critically small ascending aorta diameter (<2 mm) (6).

Utilizing selective perfusion techniques during the Norwood procedure can be accomplished in a technically simple manner. Our technique demonstrated a reproducible, safe, and effective strategy to potentially protect patients for the deleterious neurodevelopmental effects of prolonged deep hypothermic circulatory arrest during the critical state of surgical neo aortic reconstruction. Smaller ascending aorta and certain HLHS anatomical subtypes (such as mitral stenosis/aortic atresia) and especially patients with sinusoids might carry survival disadvantage after the Norwood procedure (6).

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