Regional High-Flow Cerebral Perfusion Improves Both Cerebral and Somatic Tissue Oxygenation in Aortic Arch Repair

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Background. Regional cerebral perfusion provides cerebral circulatory support during aortic arch reconstruction. We report the effectiveness of high-flow regional cerebral perfusion (HFRCP) from the right innominate artery to maintain sufficient cerebral and somatic oxygen delivery through collateral vessels.

Methods. Frontal cerebral and thoracolumbar probes to measure somatic regional oxygen saturation (rSO_2) were used to continuously measure oxygenation during cardiopulmonary bypass in 18 patients (weight, 2.1 to 4.3 kg) who underwent arch reconstruction using HFRCP (mean flow, 82; range, 43 to 108 ml/kg/min). Procedures included 9 Norwood procedures, 5 coarctation of aorta/interruption of aorta complex repairs, and 4 aortic arch repairs for a single ventricle. Mean HFRCP duration was 51 ± 17 minutes under moderate hypothermia. Mean radial arterial pressure was kept at less than 50 mm Hg during HFRCP, and chlorpromazine (mean dose, 2.8 mg/kg) was given to all patients before and during HFRCP to increase regional cerebral perfusion flow. Plasma lactate concentration was measured before and after HFRCP.

Results. During HFRCP, mean cerebral rSO_2 was 78.8% ± 9.5%, somatic rSO_2 was 65.4% ± 12.1%, and lactate concentration increased from 3.8 ± 2.2 to 5.5 ± 2.1 mmol/L. There was significant correlation between regional cerebral perfusion flow and somatic rSO_2. Significant inverse correlations were noted between regional cerebral perfusion flow and the increase of lactate concentration and between somatic rSO_2 and the increase of lactate concentration.

Conclusions. High-flow regional cerebral perfusion preserved sufficient cerebral and somatic tissue oxygenation during aortic arch repair. The reduction of vascular resistance of collateral vessels increased both cerebral and somatic blood flow, resulting in improved tissue oxygen delivery.

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I n aortic arch repair, including Norwood stage I palliation, deep hypothermic circulatory arrest (DHCA), which provides surgeons a bloodless and uncluttered operative field, has been used as an adjunctive therapy with cardiopulmonary bypass (CPB). Because of concerns about the effect of DHCA on neurologic complications, alternatives have been sought [1–3]. Regional cerebral perfusion (RCP) has been shown to provide cerebral circulatory support during aortic arch reconstruction. The maintenance of cerebral oxygen saturation during RCP has been demonstrated with near-infrared spectroscopy [2, 4, 5]. In 2001, Pigula and colleagues [5] reported that low-flow RCP (LFRCP) provided somatic circulatory support during neonatal arch surgical procedures and that support of the subdiaphragmatic viscera should improve the ability of neonates to survive the postoperative period [5].

In our institution, high-flow RCP (HFRCP) from the right innominate artery has been induced to maintain sufficient cerebral and somatic oxygen delivery through collateral vessels. We used near-infrared spectroscopy devices to assess changes in oxyhemoglobin saturation in cerebral [2, 4, 5] and somatic [6, 7] regional circulations, before, during, and immediately after aortic arch repair to estimate the effectiveness of HFRCP for cerebral and somatic tissue oxygenation.

Material and Methods

This study received Institutional Review Board approval. Parental consent was obtained for all patients to participate in this study.

Patients and Surgical Technique

The study comprised 18 patients with a mean weight of 3.0 kg (range, 2.1 to 4.3 kg) who underwent arch reconstruction using HFRCP and whose clinical physiologic data were reviewed. Their mean age was 28 days (Table 1). The types of procedures included 9 Norwood stage I palliations, 5 coarctation of aorta/interruption of aorta

Abbreviations and Acronyms

CPB   = cardiopulmonary bypass
DHCA   = deep hypothermic circulatory arrest
HFRCP = high-flow regional cerebral perfusion
LFRCP = low-flow regional cerebral perfusion
RCP   = regional cerebral perfusion
rSo$_2$ = regional oxygen saturation
SD   = standard deviation

complex repair, and 4 aortic arch repairs for a single ventricle (Table 1). Among these 18 patients, 6 (33.3%) needed preoperative mechanical ventilation, and 9 (50%) needed inotropic support because of unstable hemodynamics.

All 18 patients underwent RCP through the right innominate artery. Norwood stage I palliation was performed using techniques previously described [8]. A 3.5-mm polytetrafluoroethylene tube graft was anastomosed to the innominate artery as an arterial catheter. During CPB, the patient was cooled to 25°C. The ascending aorta was transected, and a cardioplegic solution was given.

After cardiac arrest, the ascending aorta was incised vertically down to the sinus level and anastomosed to the main pulmonary artery in a side-to-side fashion to maintain sufficient coronary blood flow. Under RCP, the descending aorta was clamped, and the main pulmonary artery was anastomosed directly to the aortic arch. The right ventricular pulmonary artery conduit was contracted through the right side of the neoaorta using a 5-mm expanded polytetrafluoroethylene graft. For aortic arch repair, under RCP, the descending aorta was directly anastomosed to the ascending aorta or the aortic arch after complete resection of ductal tissue. For patients with a coarctation of aorta/interruption of aorta complex, the ventricular septal defect was closed under cardiac arrest after completion of the aortic arch repair.

Table 1. Patient Demographic Data

Variable	Mean ± SD or No. (%)
Age, d	28 ± 47
Weight, kg	3.0 ± 0.6
Type of procedure	
Norwood	9
CoA/IAA complex	5
Arch repair for SV	4
Pre-op mechanical ventilation	6/18 (33.3)
Pre-op inotropic support	9/18 (50.0)
CPB time, min	171 ± 51
RCP time, min	51 ± 17
RCP flow, mL/min/kg	82 ± 20
RAP during RCP, mmHg	40 ± 10

CoA = coarctation of aorta;   CPB = cardiopulmonary bypass;   IAA = interruption of aorta;   RAP = radial arterial pressure;   RCP = regional cerebral perfusion;   SD = standard deviation;   SV = single ventricle.

CPB Systems and Techniques

Our miniaturized CPB system was reported previously [9, 10]. To achieve a CPB system with a low priming volume, a low prime oxygenator and reservoir with a priming volume of 40 mL (Baby RX, Terumo Inc, Tokyo, Japan), 15-mL arterial filters (Filtia, JMS Inc, Hiroshima, Japan), and a smaller and shortened extracorporeal circuit was needed. To shorten the circuit, the CPB roller pump was placed close enough to the operative field to minimize the tubing length. Our CPB system consisted of a distant roller-pump head, a remote-controlled unit, and a sterilized sheet. The distant roller-pump and remote-controlled unit (Tonokura Compo III, Tonokura Medical Inc, Tokyo, Japan) allows maximal proximity to the operative field. The sterilized sheet (50 × 100 mm, Steri-Sheet, Tonokura Medical Inc, Tokyo, Japan), made of polyvinyl chloride, acts as a protective barrier between the first assistant and the CPB unit [9]. The minimum priming volume of this system is currently 140 mL, with 15 mL in the reservoir level. The biocompatible surface coating can reduce the inflammatory response and improve the outcome of the operation [9]. Poly-2-methoxyethyl acrylate is one of the potential coating materials, and poly-2-methoxyethyl acrylate-coated circuits have already been reported to suppress the inflammatory response in clinical settings [11].

High-flow (200 mL/kg/min) moderate hypothermic (25°C) CPB was used. Blood-gas management was performed using the pH-stat strategy. The arterial oxygen pressure was kept at more than 300 mm Hg with oxygen saturation of 100% in all patients. Before HFRCP, mannitol (5 mg/kg) was given to all patients as deoxygenation to prevent the brain injury due to hyperoxygenation. The hematocrit level was kept at more than 25% during CPB using transfusion of red blood cells. DHCA was not used. Crystalloid cardioplegic solution (10 mL/kg) was given every 20 minutes.

After termination of CPB, modified ultrafiltration was performed with a polymethylmethacrylate hemofilter for all patients. Modified ultrafiltration was started with an ultrafiltration rate of 20 mL/kg/min for 10 minutes. Heparinization was neutralized by protamine sulfate until the activated coagulation time had normalized. Solu-Medrol (30 mg/kg; Pfizer, New York, NY) was routinely given to all the patients before CPB. Aprotinin was not used in this study.

Monitoring and Data Acquisition

Blood pressure was invasively monitored at the right radial artery and the femoral artery. The central venous pressure was monitored with an inferior venous catheter from the right femoral vein. Arterial oxygen saturation was monitored continuously in the upper and lower extremities (Nellcor N200; Pleasanton, CA). Systemic venous oxygenation was monitored continuously during CPB from the venous drainage (Terumo CDI-500; Tokyo, Japan).

Near-infrared spectroscopy probes were placed on the patient's midline forehead (cerebral) and midline back