# Comparable Cerebral Blood Flow in Both Hemispheres During Regional Cerebral Perfusion in Infant Aortic Arch Surgery

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*Background.* **Cerebral protection during aortic arch repair can be provided by regional cerebral perfusion (RCP) through the innominate artery. This study addresses the question of an adequate bilateral blood flow in both hemispheres during RCP.**

*Methods.* **Fourteen infants (median age 11 days [range, 3 to 108]; median weight, 3.6 kg [range, 2.8 to 6.0 kg]) undergoing RCP (flow rate 54 to 60 mL $\cdot$ $kg^{-1}$ $\cdot$ $min^{-1}$) were prospectively included. Using combined transfontanellar/transtemporal two- and three-dimensional power/color Doppler sonography, cerebral blood flow intensity in the main cerebral vessels was displayed. Mean time average velocities were measured with combined pulse-wave Doppler in the basilar artery, and both sides of the internal carotid, anterior, and medial cerebral arteries. In addition, bifrontal regional cerebral oximetry ($rSO_2$) was assessed. Comparing both hemispheres, measurements were performed at target temperature (28°C) during full-flow total body perfusion (TBP) and RCP.**

*Results.* **A regular circle of Willis with near-symmetric blood flow intensity to both hemispheres was visualized in all infants during both RCP and TBP. In the left internal carotid artery, blood flow direction was mixed (retrograde, n = 5; antegrade, n = 8) during TBP and retrograde during RCP. Comparison between sides showed comparable cerebral time average velocities and $rSO_2$, except for higher time average velocities in the right internal carotid artery (TBP $p = 0.019$, RCP $p = 0.09$). Unilateral comparison between perfusion methods revealed significantly higher $rSO_2$ in the right hemisphere during TBP (82% ± 9%) compared with RCP (74% ± 11%, $p = 0.036$).**

*Conclusions.* **Bilateral assessment of cerebral $rSO_2$ and time average velocity in the main great cerebral vessels suggests that RCP is associated with near-symmetric blood flow intensity to both hemispheres. Further neurodevelopmental studies are necessary to verify RCP for neuroprotection during aortic arch repair.**

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Cerebral protection during infant aortic arch repair is being ensured by either deep hypothermic circulatory arrest or regional cerebral perfusion (RCP) through the innominate artery. Although those distinct cardiopulmonary bypass techniques have evolved to sometimes even "religious" conviction [1], randomized controlled trials were unable to demonstrate a difference between both neuroprotective methods with regard to the incidence of perioperative cerebral injury or neurodevelopmental outcome [2, 3]. Some studies have suggested that a longer duration of deep hypothermic circulatory arrest is associated with neurocognitive impairment [4–6], but despite the missing evidence of a time limit [4, 7], perioperative electrical seizures with impaired motor development [8] and brain damage eminent on magnetic resonance imaging were consistent also with RCP [2, 9, 10]. Nevertheless, reduced postoperative intubation time, better renal function, and age-adequate neurodevelopment have been reported after using RCP [7, 11, 12].

The distribution and intensity of cerebral blood flow during RCP is of main concern, and effective cerebral monitoring could lower this burden [13]. Both regional cerebral oxygen saturation ($rSO_2$) from the frontal cortex [14, 15] and time average velocity (TAV) of blood flow in the medial cerebral artery (MCA) have been interpreted as potential surrogate indicators for cerebral perfusion during infant cardiac surgery [13–20]. Low intraoperative $rSO_2$ levels may impact psychomotoric development [7, 21, 22] and correlate with postoperative cerebral lesions diagnosed by magnetic resonance imaging [7, 9, 10, 14, 22–24]. Measurement of cerebral

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**Abbreviations and Acronyms**

| | |
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| CPB | = cardiopulmonary bypass |
| ICA | = internal carotid artery |
| MCA | = medial cerebral artery |
| RCP | = regional cerebral perfusion |
| $rSO_2$ | = regional cerebral oxygen saturation |
| TAV | = time average velocity |
| TBP | = total body perfusion |
| 3D | = three-dimensional |
| 2D | = two-dimensional |

TAV may protect the patients from the potential danger of excessive cerebral blood flow, resulting in cerebral edema or intracranial hemorrhage, particularly in the context with aortic arch surgery using RCP [13].

In the MCA, TAV is usually displayed continuously by transcranial Doppler sonography from the temporal window. Nowadays transfontanellar sonography has become routine for analysis in pediatric patients whose fontanelles are not closed, and it can be applied as a point-of-care method during cardiac surgery [25]. In this study, for the first time combined transfontanellar/transtemporal two-dimensional (2D) and three-dimensional (3D) sonography were used to display the intensity of vessel perfusion in both hemispheres during RCP. For quantitative analysis, TAV in various cerebral arteries and frontal $rSO_2$ were compared between hemispheres.

## Material and Methods

### *Study Design*

The local Ethics Committee was notified, and the Institutional Review Board gave its approval. Patient recruitment was done prospectively. Inclusion criteria were aortic arch repair in infants with open fontanelle, and availability of the entire scientific team composed of a surgeon, ultrasonography specialist, documental assistant, and perfusionist.

The study included intraoperative combined transfontanellar/transtemporal 2D and 3D ultrasonographic imaging of both blood flow intensity in both hemispheres and assessment of mean TAV displayed in basilar artery, bilateral internal carotid artery (ICA), bilateral anterior cerebral artery, and bilateral MCA. In addition, bilateral cerebral frontal $rSO_2$ was measured. Data were collected after reaching target temperature (28°C) at two given timepoints: (1) during "full flow" total body perfusion (TBP) as a control group; and (2) during RCP.

### *Surgery*

After initiation of anesthesia with midazolam (0.1 to 0.2 mg/kg) and fentanyl (3 μg/kg), arterial blood pressure monitoring lines were placed in the right radial artery and in one femoral artery. Measurement of $rSO_2$ (%) was performed by continuous plotting of the somatic reflectance oximetry in both frontal hemispheres (INVOS; Somanetics, Troy, MI). After midline sternotomy and heparin administration (400 IE/kg), a 3.5-mm polytetrafluoroethylene tube (Gore-Tex; W.L. Gore & Assoc, Flagstaff, AZ) was anastomosed to the innominate artery and cannulated with a 10F arterial cannula (Maquet, Hirrlingen, Germany). Cardiopulmonary bypass (CPB) with an estimated flow of 3.0 L/$m^2$ body surface area (175 to 200 mL/kg) was started after bicaval cannulation, 12F to 16F [Medtronic, Minneapolis, MN), and the patient was cooled to 28°C rectal temperature. In case of ductal-dependent descending aortic circulation, both pulmonary arteries were snared, and an 8F arterial cannula was introduced into the proximal patent ducus arteriosus and connected to a second arterial line with a selective roller pump. Continuous anesthesia on CPB was provided by propofol 1% (6 mg $\cdot$ $kg^{-1}$ $\cdot$ $h^{-1}$) and remifentanyl (0.5 μg $\cdot$ $kg^{-1}$ $\cdot$ $min^{-1}$). Mean radial and femoral arterial pressure was balanced between 35 mm Hg and 50 mm Hg. Our actual CPB setting does not allow additional administration of $CO_2$ for an effective pH-stat blood gas management. Therefore, to induce cerebral vasodilation for homogenous cerebral tissue cooling, the alpha-stat strategy with elevated $pCO_2$ (target approximately 50 mm Hg) was used, and nitroglycerin (1 to 2 μg $\cdot$ $kg^{-1}$ $\cdot$ $min^{-1}$) was infused during cooling. A 4F cannula (Medtronic) was inserted into the aortic root. After reaching target temperature, distal aortic perfusion was finished. Arch vessels and the descending aorta were clamped.

Cerebral protection through RCP was begun with 30% estimated flow (52 to 60 mL/kg). Myocardial protection was ensured by either continuous myocardial perfusion with 10% estimated flow after connecting the second arterial line to the aortic root cannula, or by cardioplegic arrest using a single shot (40 mL/kg) of Bretschneider's solution (Custodiol; Dr F. Köhler Chemie, Bensheim, Germany), which was injected into the aortic root at a rate of 40 to 50 mL/min with a temperature of 4°C. Arch repair included coarctation-resection and augmentation of the aortic concavity with a patch of bovine pericardium. Patients undergoing the Norwood procedure additionally underwent atrial septectomy, division of the main pulmonary artery, and Damus-Kaye-Stansel anastomosis; pulmonary perfusion was ensured by either right ventricle to pulmonary artery conduit in hypoplastic left heart syndrome or by modified Blalock-Taussig shunt in patients with systemic left ventricle. After the aortic and supraaortic cross clamps were removed, reperfusion was started until the patients were warmed to 36°C. Weaning from CPB was supported with low-dose adrenalin (0.1 μg $\cdot$ $kg^{-1}$ $\cdot$ $min^{-1}$) and milrinon (1 μg $\cdot$ $kg^{-1}$ $\cdot$ $min^{-1}$).

### *Ultrasonography Imaging*

All ultrasonographic examinations were performed by a single pediatrician especially qualified in ultrasonography diagnostics using a high-end ultrasonography system, Logiq E9 (GE Healthcare, Milwaukee, WI); for transfontanellar ultrasonography a multifrequent sector probe S4-10 (7 MHz) and 3D/4D curved array probe RNA 5-9-D (8 MHz) were used, and for transtemporal Doppler sonography, a sector probe M5S (3 MHz) was used. For