Control of Cardiopulmonary Bypass Flow Rate Using Transfontanellar Ultrasonography and Cerebral Oximetry During Selective Antegrade Cerebral Perfusion

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NEONATAL AORTIC ARCH reconstruction has been performed under deep hypothermic circulatory arrest (DHCA) because this affords a bloodless surgical field and a long cardiac arrest time by reducing brain metabolism and oxygen demand.[1] Despite these advantages, regional cerebral perfusion (RCP), including selective antegrade cerebral perfusion (SACP), is performed more widely than DHCA because this protects the brain from hypoxic ischemic injury by maintaining blood flow to the brain, avoids the complications of DHCA, and minimizes the risk of neurologic injury.[2,3] The bypass flow rate during SACP varies among institutions, which ranged from 20 to 108 mL/kg/min.[4–7] However, there is no established optimal SACP flow rate yet for neonates and infants. Pediatric patients with congenital heart diseases have impaired cerebral autoregulation and are prone to widespread neurologic injury.[8,9] Therefore, delicate adjustment of the bypass flow rate is required during SACP via neurologic monitoring.

The authors report a case of bypass flow rate adjustment based on cerebral blood flow velocity (CBFV) as measured by transfontanellar ultrasonography (TFU) and regional cerebral oxygen saturation (rSO_2) monitored using near-infrared spectroscopy (NIRS) during SACP for neonatal aortic arch reconstruction. After commencement of SACP with bypass flow rate of 50 mL/kg/min, NIRS values significantly increased, and CBFV, at anterior cerebral arteries, were also 3-fold higher than baseline values. Because of concern about cerebral hyperperfusion, the authors adjusted the bypass flow rate to 27 mL/kg/min to restore the baseline values of rSO_2 and CBFV. As in this case, multimodal neurologic monitoring may be useful during congenital heart surgery to prevent potential neurologic complications.

CASE PRESENTATION

A 1-month-old premature female infant (47 cm, 3.0 kg) was admitted for repair of coarctation of the aorta. Her gestational age was 35 weeks and the birth weight 1.6 kg. At admission, there was a difference in blood pressure between the upper and lower extremities (102/45 and 60/35 mmHg, respectively).

Preoperative cardiac CT revealed a hypoplastic aortic arch with severe narrowing of the proximal descending thoracic aorta, but the brain sonographic findings were normal.

Before induction of anesthesia, a pediatric SomaSensor™ probe of INVOS® (Somanetics Corporation, Troy, MI) was attached to each side of the forehead to begin monitoring of bilateral regional cerebral oxygen saturation (rSO_2). The baseline left and right rSO_2 was 67% and 72%, respectively.

After induction of anesthesia, arterial blood pressure monitoring was commenced at the right radial and dorsalis pedis arteries, and central venous catheterization was performed. There was significantly different systolic blood pressure between the radial and dorsalis pedis arteries, which was 92 and 44 mmHg, respectively. A 3- to 8-MHz omniplane transesophageal echocardiography probe was inserted (S8-3t, Philips iE33 system; Philips Healthcare, Andover, MA).

TFU was performed using a sector probe (S12-3, Philips iE33 system; Philips Healthcare), which is used for transthoracic echocardiography via the anterior fontanel. Before surgery was commenced, baseline bilateral CBFVs at the anterior cerebral artery (ACA) were measured (Fig 1; Video clip 1). Systolic and diastolic CBFV was 58 cm/s and 8 cm/s, respectively, in both ACAs.

After aortic and venous cannulae were inserted without any problems, CPB was commenced. At the time of initiating CPB, nasopharyngeal and rectal temperatures were 34.1ºC and 34.6ºC, respectively. The bypass flow rate was maintained at 120 to 170 mL/kg/min. The rSO_2 was maintained at 57% to 70% in the left frontal area and 62% to 75% in the right frontal area. Systolic CBFVs at the bilateral ACA were maintained at about 20 cm/s (Fig 2).

Nasopharyngeal and rectal temperatures were lowered gradually to 23.5ºC and 25.0ºC. After cross-clamping of the aorta, the aortic cannula was advanced further into the right innominate artery, and SACP was commenced at a bypass flow rate of 50 mL/kg/min. The mean blood pressure measured at the right radial artery was 28 mmHg after commencement of SACP. About 15 minutes later, the authors noticed that the right rSO_2 was greater than 93%, whereas the left rSO_2 was maintained at about 70%. At that time, TFU revealed a CBFV of 60 cm/s at the proximal part of both ACAs (Video clip 2), and the mean blood pressure had decreased to 12 mmHg. Suspecting that the tip of the aortic cannula might have moved toward the right common carotid artery (CCA), the authors performed a transesophageal echocardiographic examination; however, the flow distributions at the right CCA and subclavian artery were not seen clearly. After notification of possible cannula advancement into the right CCA, the surgeon tried to adjust the cannula position. However, he said that repositioning of the cannula was difficult because the length of the innominate artery was only about 5 mm. Based on the patient's history of preterm birth and because of the authors' concern about cerebral hyperperfusion, it was decided to adjust the bypass flow rate to restore the baseline values of rSO_2 and

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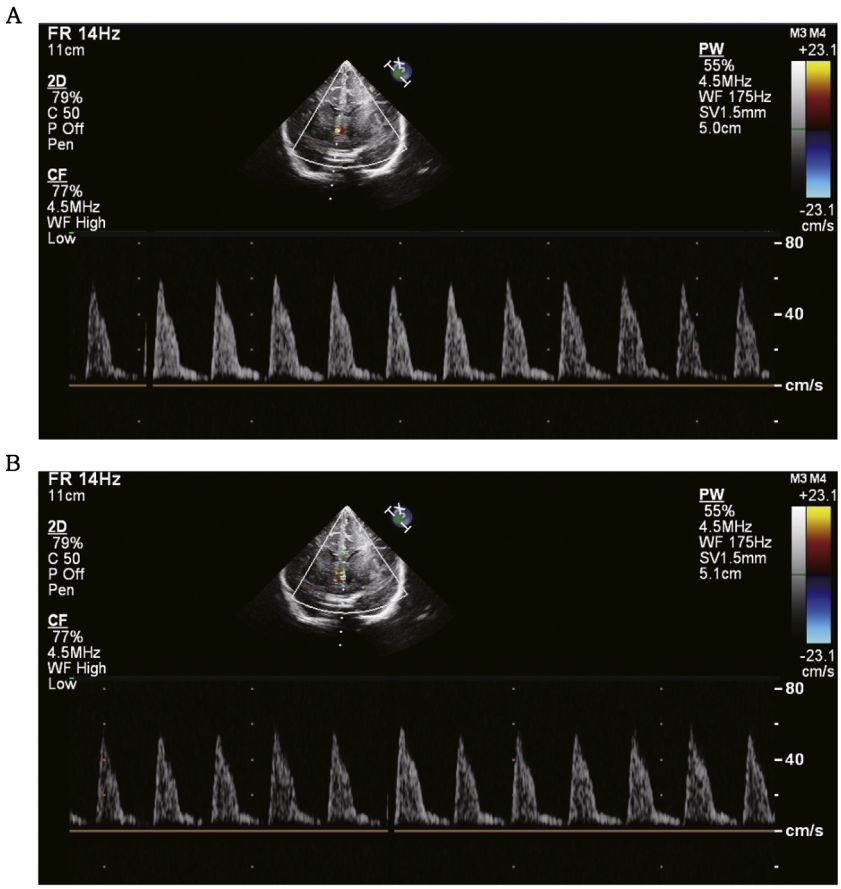

Fig 1. Cerebral blood flow velocity (CBFV) at the left (A) and right (B) anterior cerebral arteries (ACA). Baseline CBFV was determined via pulsed-wave Doppler using a transthoracic echocardiographic sector probe, before cardiopulmonary bypass. The peak CBFV at the left and right ACA were similar (about 55-60 cm/s).

CBFV. After careful monitoring of the rSO_2 and CBFV, the bypass flow rate decreased to 27 mL/kg/min. As a result, the CBFV at the right ACA decreased to the baseline level of 20 cm/s. The rSO_2 became 61 and 78% on the left and right sides, respectively, and did not change significantly during the remaining SACP time (Fig 3; Table 1).

pH-stat management was used during CPB, including the period of SACP, and $PaCO_2$ was maintained at 50 to 60 mmHg. The total SACP time was 42 minutes. After extended end-to-end coarctoplasty, the patient was weaned successfully from CPB with some inotropic support.

Ten days after surgery, brain ultrasonography showed normal findings. The patient was discharged on postoperative day 12 without any complications.

DISCUSSION

The incidence of neurologic complications after congenital heart surgery in children is reported to be up to 25%.[10] The causes of neurologic complications are multifactorial. For example, patients with chromosomal abnormalities, such as deletion of chromosome 22, are at higher risk of central nervous system abnormalities with coarctation of the aorta.[11] Moreover, cerebral autoregulation has been suggested not to be developed fully in neonates[12] and cerebral dysgenesis is not rare in neonates with congenital heart disease.[13] The management techniques used for such patients, such as arterial blood gas management, the rate or extent of cooling and warming and control of the bypass flow rate during CPB, may affect their neurologic outcomes.[14,15]

Neonatal complex heart surgery, including aortic arch reconstruction, traditionally has been performed under DHCA. However, concerns about neurologic morbidity and mortality[16–19] have predisposed some clinicians to the use of RCP, which allows for perfusion of the brain and potential minimization of the deleterious effects of DHCA.

Monitoring of rSO_2 using NIRS technology has become routine during CPB, and its usefulness has been investigated for patients undergoing congenital heart surgery under DHCA and RCP. Kurth et al[20] analyzed the rSO_2 values and neurologic outcomes of 26 infants and children who had undergone congenital heart surgery with CPB and DHCA. The authors found that 3 patients with low rSO_2 index suffered postoperative neurologic complications. Pigula et al[21] found that the NIRS values in pediatric patients under DHCA were significantly lower than those under SACP, concluding that RCP with continuous monitoring of rSO_2 could reduce the brain ischemic time. Additionally, the authors controlled