Magnetic Resonance Angiography of Cerebral Arteries After Neonatal Venoarterial and Venovenous Extracorporeal Membrane Oxygenation

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Background and Purpose—In newborns with severe respiratory failure, extracorporeal membrane oxygenation (ECMO) has been proven to improve survival. With venoarterial ECMO, the right common carotid artery is ligated, whereas with venovenous ECMO, this carotid artery remains intact. The authors present the magnetic resonance angiography (MRA) evaluation of cerebral hemodynamics in a case of venoarterial and a case of venovenous ECMO.

Methods—With 2D phase-contrast MRA flow volume (mL/min), measurements are obtained of the brain feeding arteries and draining veins. Time-of-flight and flow-directional MRA are used to demonstrate the anatomy and flow patterns at the level of the circle of Willis.

Results—A total volume flow of 63 mL/min at the skull base and collateral flow via the anterior circle of Willis were measured in the infant after venoarterial ECMO, and a total volume flow of 86 mL/min and a fetal type configuration of the circle of Willis were observed in the infant after venovenous ECMO.

Conclusion—MRA is a useful technique to quantify cerebral blood flow in neonates after venoarterial or venovenous ECMO and could be used to select neonates with insufficient collateral compensation after venoarterial ECMO, requiring revascularization surgery. (Stroke. 2006;37:000-000.)

Key Words: carotid arteries ■ extracorporeal membrane oxygenation ■ magnetic resonance angiography ■ occlusion

In newborns with severe respiratory failure, extracorporeal membrane oxygenation (ECMO) has been proven to improve survival.1 The combination of the pre-existent severe hypoxia and the ECMO procedure itself with ligation of the right common carotid artery may result in brain lesions in 20% to 50% of the neonates.1 To prevent ischemic complications, revascularization surgery has been performed after venoarterial ECMO.2 Alternatively, ligation of the common carotid artery can be prevented by venovenous ECMO, with a purely venous access in the circulation. A flow velocity comparison with ultrasound between vеноarterial and venovenous ECMO demonstrated decreased intracranial flow velocities during vеноarterial and preserved flow velocities during venovenous ECMO.3

In our institution, a routine MRI examination is performed after an ECMO procedure to evaluate the presence of ischemic brain damage. Advantages of MRI examination after an ECMO procedure are the potential of a combined evaluation brain anatomy and the cerebral hemodynamics with magnetic resonance angiography (MRA) techniques. We report the results of MRA measurements of flow volume (mL/min) collateral flow and vascular anatomy in 2 full-term neonates, 1 after vеноarterial ECMO and 1 after venovenous ECMO.

Patient A
In patient A (birth weight 3460 g), vеноarterial ECMO with occlusion of the right common carotid artery and right jugular vein was performed because of persistent pulmonary hypertension of the neonate. Anatomical MRI performed at 3 weeks and 4 days postnatal age demonstrated no hemorrhagic or ischemic lesions. A fast phase-contrast (PC) sagittal survey was obtained to plan the 2D PC MRA scans for volume flow measurements (Figure 1A). Two-dimensional PC MRA scan time was 40 s, with a velocity sensitivity of 30 cm/s.4 Quantitative flow values were calculated in each vessel separately by integrating over manually drawn regions of interest that enclosed the vessel lumen of the arteries and veins of interest (Figure 1B and 1C).

The interobserver variation (J.H., F.G.) of volume flow measurements was 2.1 mL/min corresponding to 5.5%. At the skull base, a total arterial flow was measured of 63 mL/min, with a volume flow of 44 mL/min for the left internal carotid artery (ICA) and 19 mL/min for the left internal carotid artery (ICA) and 19 mL/min for the left internal carotid artery (ICA). Below the carotid bifurcation, a total
arterial flow was measured of 95 mL/min, with a volume flow of 61 mL/min for the left common carotid artery, 24 mL/min for the right vertebral artery, and 10 mL/min for the right vertebral artery. The total venous volume flow draining via the left jugular vein below the level of the carotid bifurcation was 97 mL/min. The time-of-flight MRA, planned parallel to the circle of Willis, demonstrated occlusion of the right ICA (Figure 2A). Flow-directional–sensitive MRA images demonstrated collateral filling of the right middle cerebral artery via the anterior part of the circle of Willis, with reversed flow in the precommunicating segment (A1) of the right anterior cerebral artery (Figure 2B and 2C). No collateral flow was detected via the right posterior communicating artery.

**Patient B**

In patient B (birth weight 3500 g), venovenous ECMO without ligation of the right common carotid artery was performed because of meconium aspiration syndrome. Anatomical MRI performed at 3 weeks and 3 days postnatal age demonstrated a small subcortical parietaooccipital ischemic lesion on the right side. Using 2D PC MRA, the total arterial volume flow measured at the skull base was 86 mL/min, with a 33 mL/min contribution of the right ICA, 37 of the left ICA, and 16 mL/min of the basilar artery. Below the carotid bifurcation a total arterial volume flow was measured of 115 mL/min, with a 28 mL/min contribution of the right jugular vein and 93 mL/min contribution of the left jugular vein. The time-of-flight MRA demonstrated a fetal type circle of Willis, with filling of the right anterior, middle, and posterior cerebral artery from the right ICA, with a hypoplastic precommunicating segment (P1) of the right posterior cerebral artery (Figure 3A). Flow-directional–sensitive MRA images demonstrate anterior to posterior flow via the right posterior communicating artery in accordance with the dominant feeding of the right posterior cerebral artery from the right ICA (Figure 3B and 3C).

**Discussion**

In the current study, 2D PC MRA was used for volume flow (mL/min) measurements in the brain feeding arteries. With 2D PC MRA, the blood flow velocity–induced changes in magnetic resonance (MR) signal (phase shift) are exploited to measure cerebral blood volume quantitatively. As demonstrated, MRA volume flow measurements can be added to existing MR protocols, with an additional scan time of ≈40 s for combined volume flow measurements of the ICAs and basilar artery. Alternatively, arterial volume flow measurements in the extracranial arteries in preterm and term neonates can be performed with color duplex sonography. When MRI is routinely performed for detailed anatomical evaluation in the follow-up of an ECMO procedure, adding the described MRA scans provides quantitative information of flow through arteries and veins (Figure 1) and detailed information of the intracranial vasculature. The mean total volume flow of 95 mL/min for neonate A and 115 mL/min for

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**Figure 1.** Planning (A) 2D PC MRA volume flow measurement at the skull base (B) and below the carotid bifurcation (C). 1 represents left ICA; 2, basilar artery; 3, sinus ethmoidales inferior; 4, left common carotid artery; 5, vertebral arteries; 6, left jugular vein.

**Figure 2.** Patient A, Venoarterial ECMO. The time of flight MRA scan (A) demonstrates an occluded right carotid artery and 2D PC MRA scans (B and C) demonstrate collateral flow via the anterior circle of Willis toward the right middle cerebral artery with retrograde flow in the right A1 segment of the anterior cerebral artery (arrowheads).
neonate B with both neonates of 45 weeks postmenstrual age are in accordance with previous ultrasound measurements in preterm and term neonates, with a measured volume flow of 85 mL/min at 42 weeks postmenstrual age and an observed flow increase in these ultrasound studies of 6 mL/min per week increase in postmenstrual age.5 Most likely, physiological variation in volume flow, as has been observed in previous ultrasound studies, may explain the difference in flow between the 2 neonates of similar age in the present study.5,6 The degree of respiratory failure severity, positioning in the dedicated neonate head coil, and MRI acquisition protocol were similar for both neonates.

A previous study demonstrated the use of time-of-flight MRA for anatomical evaluation of the circle of Willis after ECMO.7 In addition to flow quantification, we combined anatomical MRA images with flow-directional–sensitive MRA at the level of the circle of Willis. With anatomical and functional information, we demonstrate collateral flow from the contralateral ICA via the anterior communicating artery and flow direction in a fetal variant type circle of Willis. Visualization of the intracranial vasculature is important because 50% of the neonates has a variant type of the circle of Willis.8 Potentially, neonates with a variant type circle of Willis, such as a missing or hypoplastic precommunicating segment (A1) of the anterior cerebral artery or a fetal type feeding of the posterior cerebral artery, will be more vulnerable for ischemia after venoarterial ECMO with less collateral capacity.

In the present study a velocity encoding of 30 cm/s was used to benefit from the full dynamic range of the 2D PC MRA for volume flow measurements with relatively low flow velocities. The pixel size of the 2D PC MRA scans of 1 mm was small compared with the mean vessel size of 3.4±1.0 mm (mean±SD) to avoid potential underestimation of flow measurements. Previously, validation studies have demonstrated the quantitative accuracy of 2D PC MRA for volume flow measurements in the brain feeding arteries,4,9 and comparisons have been made between MR PC flow quantification and ultrasound flow measurements.10

In conclusion, intracranial and extracranial volume flow measurements are reported in 2 neonates after an ECMO procedure. Collateral flow via the anterior circle of Willis is demonstrated in patient A after venoarterial ECMO, and a fetal configuration of the circle of Willis is demonstrated in patient B with a venovenous ECMO. MRA may be used in future studies to select neonates with insufficient collateral compensation after venoarterial ECMO requiring revascularization surgery.

References
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