Noninvasive Evaluation of Collateral Blood Flow through Circle of Willis in Cervical Carotid Stenosis Using Selective Magnetic Resonance Angiography

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Background: Preoperative assessment of intracranial collateral circulation is helpful in predicting cerebral ischemia during surgical procedures for cervical internal carotid artery (ICA) stenosis. However, magnetic resonance angiography (MRA) and other less-invasive techniques cannot evaluate collateral blood flow because these techniques are nonselective. Hence, by using a newly developed selective MRA technique, we attempted to visualize collaterals via the circle of Willis in patients with ICA stenosis. *Methods:* Twelve patients who underwent carotid endarterectomy were prospectively examined with a 1.5-T MR scanner. Both selective and nonselective MRA were obtained using a 3-dimensional time-of-flight technique, with or without a cylindrical saturation pulse that suppresses the flow signal from the region of the target ICA. Maximum intensity projection MRA images were generated and compared with digital subtraction angiography (DSA) images. *Results:* In all patients, the distal flow signal of the ipsilateral ICA was completely suppressed on selective MRA compared with nonselective MRA. In addition, collateral blood flow through the anterior and posterior communicating arteries was visualized in 5 and 2 patients, respectively. These findings corresponded well with the DSA imaging. *Conclusions:* Selective MRA techniques can readily suppress signals from the distal blood flow of the target artery and visualize the presence of collateral flows through the circle of Willis in patients with cervical ICA stenosis. **Key Words:** Magnetic resonance angiography—cervical carotid stenosis—circle of Willis—collateral blood flow—carotid endarterectomy.

Introduction

Atherosclerotic stenosis of the cervical internal carotid artery (ICA) is a risk factor for a stroke event, and selected patients may be candidates for carotid endarterectomy or carotid artery stenting.[1] For determining therapeutic strategies and predicting complications of surgical procedures, several imaging modalities including ultrasound, computed tomography, and magnetic resonance imaging

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(MRI) are widely used to evaluate degree of stenosis and intraplaque characteristics.[1] In addition, preoperative assessment of intracranial collateral circulation is considered to be helpful in predicting cerebral ischemia during and after surgical procedures.[2] However, less-invasive techniques such as magnetic resonance angiography (MRA) cannot evaluate intracranial collateral circulation because these methods nonselectively visualize intracranial arteries. Hence, we attempted to suppress the flow signal from the target arterial region using a selective MRA technique with a newly developed cylindrical saturation pulse and evaluated whether collateral flows via the circle of Willis exist in patients with severe cervical ICA stenosis.

Materials and Methods

From March 2010 to May 2012, we prospectively enrolled 12 patients (11 men and 1 woman; age range, 58-78 years; mean age, 69.0 years) with symptomatic cervical carotid stenosis of more than 70% who underwent carotid endarterectomy. The study was carried out after obtaining approval from our institutional review board and written, informed consent from the subjects.

MRI examinations were performed using a 1.5-T scanner (Echelon Vega; Hitachi Medical Corporation, Tokyo, Japan) and an 8-channel head coil. Axial 3-dimensional time-of-flight (TOF) MRA was obtained with the following parameters: repetition time, 46 ms; echo time, 6.9 ms; flip angle, 20°; field of view, 24 × 17 cm^2; matrix size, 512 × 160; slice interval, .6 mm (after zero-fill interpolation); number of slices, 128; number of excitations, 1; and acquisition time, 5 minutes and 32 seconds. For selective suppression of blood flow signal in the unilateral ICA territory, a double-oblique cylindrical saturation pulse with a 30-mm diameter was applied to a location in which only the petrous portion of the target ICA was included (Fig 1). Selective MRA with the saturation pulse on the affected ICA and nonselective MRA without the pulse were obtained in an uninterrupted manner. Multidirectional target maximum intensity projection images were generated from the data sets using console software. Axial T1-weighted, T2-weighted, T2*-weighted, fluid-attenuated inversion recovery, and diffusion-weighted images were also obtained to evaluate ischemic or hemorrhagic changes in the brain parenchyma. Intra-arterial digital subtraction angiography (DSA) was performed within 1 week before or after the MRI scans using a flat-panel detector angiography system (AREX-VC; Toshiba Medical Corporation, Tokyo, Japan). Anteroposterior and lateral views of bilateral internal carotid angiography and vertebral angiography were obtained.

Two neuroradiologists (M.S. and K.K.) blinded to the patients' clinical information and visually assessed whether collateral blood flows in the circle of Willis were present on the MRA and DSA images. They also evaluated whether blood flow signal was suppressed in the target arterial regions and other regions on the selective MRA images, compared with nonselective images.

Results

Selective and nonselective MRA images with adequate quality were successfully obtained from all the patients and were eligible for visual interpretation. DSA images could not be obtained from 2 patients because of a history of adverse effects from iodine contrast agents and marked arterial tortuosity that resulted in an incomplete procedure. The images were evaluated in the remaining 10 patients. No patients needed shunt procedures during the cross-clamping of the ICA, showed substantial findings on intraoperative monitors such as electroencephalogram, transcranial Doppler ultrasound, and transcranial cerebral oxygen saturation, or had adverse events during or after surgery.

Compared with corresponding nonselective MRA images, selective MRA images with the saturation pulse on the petrous portion of the affected ICA showed dramatically suppressed flow signals from the distal portions of the affected ICA, whereas those from other arteries were maintained in all patients (Fig 2). In 3 patients, flow signals from the distal arteries (the ipsilateral middle cerebral artery [MCA] and anterior cerebral artery [ACA] in 2 cases and the ipsilateral MCA in 1 case) were also suppressed, suggesting no collateral circulation through the anterior communicating artery (ACoA) or posterior communicating artery (PCoA). In 3 patients, the ipsilateral MCA and ACA remained visible, suggesting the existence of collateral flow through the ACoA. In 2 patients, flow signals from ipsilateral ACA were suppressed at the proximal part (A1) but remained visible at distal parts (A2–A3), suggesting the existence of collateral flow to ACA through the ACoA. In another 2 patients, the flow signals of the ipsilateral MCA and PCoA were evident, whereas that of the ipsilateral proximal ACA was attenuated or absent, suggesting collateral flow through the PCoA. These findings corresponded well with those obtained on DSA in all patients (Fig 2). There were no cases in which the results of visual assessment were different between the readers.

Discussion

3-dimensional TOF MRA is widely used as a noninvasive technique to evaluate steno-occlusive lesions in the intracranial cerebral arteries.[3] Sometimes, this technique is also used to assess intracranial hemodynamics. Several studies showed that signal attenuation of the distal cerebral arteries on MRA can roughly reflect ischemic penumbra in acute stroke patients and hemodynamic ischemia in patients with ICA stenosis or occlusion[4,5] and that the configuration of the circle of Willis including the presence of the ACoA and PCoA may predict potential collaterals during intraoperative carotid clamping.[6,7]