Evaluation of the Patency of an Extracranial-Intracranial Bypass Using Magnetic Resonance Angiography with Selective Presaturation of Bypass Vessels

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Abstract

Three-dimensional time-of-flight magnetic resonance (MR) angiography using radiofrequency presaturation pulses was used to evaluate the patency of extracranial-intracranial (EC/IC) bypass in 11 patients. Presaturation causes signal loss in the vascular territory supplied by the presaturated EC/IC bypass graft. In all patients with a patent EC/IC bypass graft confirmed on conventional angiography, disappearance of the signal of the middle cerebral artery receiving blood flow from the bypass graft was clearly observed on MR angiograms with presaturation, indicating patency of the EC/IC bypass graft. MR angiography with presaturation pulses is a noninvasive and repeatable method for evaluation of the function of an EC/IC bypass graft.

Key words: extracranial-intracranial bypass, magnetic resonance angiography, selective presaturation

Introduction

Magnetic resonance (MR) angiography is a noninvasive, easily repeated method for screening for cerebrovascular disease since it allows clear visualization of the large vessels in the vicinity of the circle of Willis and the M₁ and M₂ segments of the middle cerebral artery (MCA), can locate stenoses and aneurysms in extra- or intracranial vessels,^{1-4,9-12,14)} and determine whether a bypass graft is patent.^{5-8,13)}

MR angiography demonstrates patency of an extracranial-intracranial (EC/IC) bypass graft by a clear connection of vascular signals between the bypass graft and the MCA. An EC/IC bypass is also considered patent if the signal intensity of the MCA is increased after an EC/IC bypass procedure. However, because MR angiography provides static images, the direction of flow and whether the blood within a bypass graft really flows into the MCA are difficult to detect.

Saturation is a technique used in MR imaging which applies stronger or more frequent radiofre-

quency pulses to a tissue by increasing the flip angle or decreasing the repetition time, respectively, reducing the magnetization of the tissue on the z-axis. The result is a lower signal intensity which causes the tissue to appear dark.¹³⁾ Presaturation is a related technique used in MR angiography by the multi-slice method. A slice containing a blood vessel can be saturated, resulting in the blood flow downstream appearing as a weakened or absent signal in another slice.⁵⁻⁸⁾

MR angiography using presaturation of individual vessels can determine the origin of the vascular supply,⁷⁾ the presence or absence of collateral blood flow, and the direction of blood flow.⁶⁾ If the saturation slice contains an EC/IC bypass graft, the blood flow from the bypass graft entering the vascular territory of the MCA will reduce the signal intensity of the MCA flow, differentiating the blood flow of the EC/IC bypass from the intracranial blood flow, thus demonstrating the distribution of the blood flow from the EC/IC bypass into the MCA territory.

This study evaluated the use of three-dimensional time-of-flight (3D-TOF) MR angiography with a presaturation pulse sequence for investigating the

patency of an EC/IC bypass graft.

Clinical Materials and Methods

This study included 11 patients, nine males and two females, aged between 45 and 72 years (mean 59 yrs) with focal neurological deficits of varying duration. Nine patients had received a superficial temporal artery (STA)-MCA anastomosis and two patients an external carotid artery-radial artery graft (ECA-RA)-MCA anastomosis. All patients underwent brain MR imaging, 3D-TOF MR angiography, and conventional angiography. The time interval between MR and conventional angiography varied from 1 to 6 days (mean 3.5 days) in patients with an STA-MCA anastomosis and from 5 days to 23 months in patients with an ECA-RA-MCA anastomosis.

MR examinations used a 1.5-T system (Magnetom SP; Siemens, Munich, Germany). 3D-TOF MR angiography used a gradient-echo pulse sequence and fast imaging with steady-precession technique, with a repetition time of 40 msec and echo time of 7.0 msec. A 256×256 matrix was used. Sixty-four partitions were acquired within a section thickness of

50 mm in an imaging time of 7 minutes and 50 seconds. The images were collected by a single addition. Flow presaturation was used to eliminate the vascular signal within the EC/IC bypass graft with a presaturation slab 10–20 mm thick which was applied to the STA or the RA used as an EC/IC bypass graft. After 3D construction by maximum-intensity projection, the images before presaturation were compared with those after presaturation to evaluate the function of the EC/IC bypass. The images were also compared with the conventional cerebral angiograms.

Results

Table 1 shows the patient clinical conditions, bypass procedure, and conventional and MR angiography findings. Conventional cerebral angiography demonstrated the patency of the EC/IC bypass in nine patients. The connection of the EC/IC bypass grafts with the MCAs were not always visible on MR angiograms. When presaturation pulses were applied to the bypass graft in these patients, the signal of both the bypass graft and the MCAs was absent

Table 1 Patient profiles and angiographical evaluation of bypass patency

Case No.	Age/ Sex	Symptoms	Vascular lesions	Surgery	Patency by conventional angiography	Patency by MR angiography with presaturation
1	62/M	rt hemiparesis	lt ICA occlusion lt A ₂ -A ₃ occlusion	lt STA-MCA anastomosis A ₃ -A ₃ anastomosis	good	+
2	65/M	lt hemiparesis vertigo, ataxia	rt M ₁ occlusion rt ICA occlusion bil VA occlusion	rt STA-MCA anastomosis	good	+
3	63/M	lt hemiparesis rt hemiparesis TIA	rt ICA stenosis lt ICA occlusion	rt STA-MCA anastomosis lt PAA-MCA anastomosis	good poor	+
4	66/F	rt oculomotor nerve paresis	rt ICA giant aneurysm	trapping rt ECA-RA-MCA anastomosis	good	+
5	60/M	rt hemiparesis TIA	lt ICA occlusion	lt STA-MCA anastomosis	good	+
6	58/M	aphasia rt hemiparesis	lt M ₁ occlusion lt M ₁ reopen	lt STA-MCA anastomosis	poor	-
7	51/M	rt hemiparesis RIND	lt ICA occlusion	lt STA-MCA anastomosis	good	+
8	72/F	aphasia rt hemiparesis	lt ICA occlusion	lt STA-MCA anastomosis	poor	-
9	55/M	aphasia rt hemiparesis	lt ICA stenosis lt M ₁ occlusion	lt STA-MCA anastomosis	good	+
10	53/M	lt hemiparesis	rt A ₁ occlusion rt ICA occlusion	rt STA-MCA anastomosis	good	+
11	45/M	lt hemiparesis RIND	rt ICA stenosis	rt ICA ligation rt ECA-RA-MCA anastomosis	good	+

A₁, A₂, A₃: A₁, A₂, A₃ segments of the anterior cerebral artery, A₃-A₃: A₃-A₃ side-to-side, ICA: internal carotid artery, M₁: M₁ segment of the MCA, PAA: posterior auricular artery, RIND: reversible ischemic neurological deficit, TIA: transient ischemic attack, VA: vertebral artery.

(presaturation effect). This demonstrated blood flow through the graft into the MCA. Conventional cerebral angiography showed no patency of the STA-MCA anastomosis in Cases 6 and 8, due to reopening of the occluded vessels or a technical problem. MR angiography revealed no signal in the bypass graft although the signal intensity of MCAs varied. When a presaturation band was applied to the bypass graft in these patients, there was no change in the signal intensity of the MCAs. Therefore, there was no blood supply from the graft to the MCA in these patients.

Representative Cases

Case 4: A 66-year-old female visited our clinic with right oculomotor nerve paresis. Conventional angiography detected a giant aneurysm ($30 \times 30 \times 19$ mm) arising at the cavernous portion of the right internal carotid artery (Fig. 1 *left*). The aneurysm was eliminated from the internal carotid artery circulation by trapping after vascular reconstruction using an ECA-RA-MCA anastomosis. Conventional cerebral angiography confirmed disappearance of the aneurysm and satisfactory revascularization 4 weeks after surgery (Fig. 1 *right*). She returned home without oculomotor nerve paresis. MR angiography demonstrated patency of the anastomosis using the presaturation method at the outpatient department

Fig. 1 Case 4. *left*: Preoperative right carotid angiogram, anteroposterior view, demonstrating a giant aneurysm ($30 \times 30 \times 19$ mm) arising at the cavernous portion of the internal carotid artery. *right*: Right carotid angiogram, anteroposterior view, 4 weeks after surgery, showing elimination of the aneurysm from the carotid circulation and establishment of a vascular reconstruction using an ECA-RA-MCA anastomosis.

Fig. 2 Case 4, 10 months after surgery. *left*: MR angiogram, axial view, demonstrating the RA graft (arrow) and the connected MCA. *right*: MR angiogram with presaturation, axial view, disclosing signal loss in the territory of the MCA supplied by the bypass graft.

Fig. 3 Case 6, 3 weeks after surgery. *left*: MR angiogram, axial view, demonstrating the signal of the MCA with no signal of the STA. *right*: MR angiogram with presaturation to the bypass graft (arrow), axial view, showing persistence of the signal of the MCA, suggesting poor function of the anastomosis and reopening of the occluded vessels.

10 and 24 months after surgery (Fig. 2).

Case 6: A 58-year-old male complained of sudden onset of motor aphasia and weakness of his right extremities, and was admitted to our department. Conventional angiography showed occlusion of the M_1 segment of the left MCA. A STA-MCA anastomosis was performed 24 days after onset of his symptoms. MR angiography with presaturation of the bypass graft showed no disappearance of the MCA signals 1 and 3 weeks, and 4 and 9 months after the bypass procedure (Fig. 3), suggesting poor function of the bypass. Conventional angiography confirmed poor patency of the EC/IC bypass and reopening of the occluded vessels 3 weeks after surgery. The weakness

Fig. 4 Case 7, 12 months after surgery. *left*: MR angiogram, axial view, demonstrating connection of the signal between the STA (arrow) and the MCA. *right*: MR angiogram with presaturation to the bypass graft, axial view, showing disappearance of the signal of the MCA, suggesting patency of the anastomosis.

of his right extremities improved gradually and he could walk with a stick.

Case 7: A 51-year-old male was admitted to our hospital because of right hemiparesis. Conventional angiography detected occlusion of the left internal carotid artery. The findings of single photon emission computed tomography (SPECT) before and after administration of acetazolamide indicated a STA-MCA anastomosis which was performed 6 months after onset of his symptoms. Postoperative conventional angiography confirmed the patency of the EC/IC bypass. MR angiography with presaturation also demonstrated the patency of the bypass 12 and 24 months after surgery (Fig. 4).

Case 9: A 55-year-old male complained of sudden onset of motor aphasia and weakness of his right extremities, and was admitted to our department. Conventional angiography showed occlusion of the M₁

segment of the left MCA and stenosis of the left internal carotid artery. A STA-MCA anastomosis was performed 64 days after onset of his symptoms, based on the findings of SPECT. He could hold a brief conversation postoperatively. The weakness on his right extremities was also improved and he could walk without any support. MR angiography with presaturation to the bypass graft showed disappearance of the signal of the MCAs 2 weeks, and 4 and 16 months after the bypass procedure (Fig. 5 *left, center*). Conventional angiography confirmed patency of the EC/IC bypass 2 weeks after surgery (Fig. 5 *right*).

Case 10: A 53-year-old male developed left hemiparesis 2 weeks prior to admission to our clinic for surgical treatment. Conventional angiography revealed occlusion of the right internal carotid artery and the A₁ segment of the right anterior cerebral artery, and filling in the right MCA territory from the posterior communicating artery. A STA-MCA anastomosis was performed based on the findings of SPECT 6 weeks after admission. MR angiography with presaturation to the bypass graft demonstrated signal loss of the posterior trunk of the M₂ segment of the MCA and no change in the signal of the other MCA branches 2 weeks after surgery (Fig. 6). These findings suggested that the posterior trunk of the M₂ segment of the MCA received blood from the bypass graft and the other MCA branches were supplied by the posterior communicating artery. Postoperative conventional angiography confirmed the patency of the anastomosis between the STA and the posterior trunk of the M₂ segment of the MCA 2 weeks after surgery.

Fig. 5 Case 9, 2 weeks after surgery. *left*: MR angiogram, axial view, demonstrating the signal of the MCA with no signal of the STA. *center*: MR angiogram with presaturation to the left temporal area, axial view, showing loss of the signal of the MCA, suggesting patency of the anastomosis. *right*: Conventional angiogram 2 weeks after surgery, lateral view, showing patency of the STA-MCA anastomosis.

Fig. 6 Case 10, 2 weeks after surgery. *left*: MR angiogram, axial view, demonstrating the anterior (arrow) and posterior trunk (arrowhead) of the M₂ segment of the MCA. *right*: MR angiogram with presaturation to the bypass graft, axial view, demonstrating signal loss of the posterior trunk of the M₂ segment of the MCA and no change in the signal of the anterior trunk (arrow) of the M₂ segment, suggesting that the posterior trunk is supplied by the STA and the anterior trunk by the M₁ segment of the MCA.

Discussion

Our study showed that presaturation applied to an EC/IC bypass graft causes the presaturated flow within the graft to manifest as a signal loss in the vascular territory receiving blood from the bypass graft. Signal loss in the territory of the MCA after presaturation can confirm the patency of an EC/IC bypass graft. The findings of MR angiography with presaturation agreed with those of conventional angiography in all our patients with EC/IC bypasses. In particular, MR angiography with presaturation of Case 10 showed that the posterior trunk of the M₂ segment of the MCA received blood from the bypass graft, while the anterior trunk of the M₂ segment of the MCA was supplied from the M₁ segment of the MCA, fully confirmed by conventional angiograms.

MR angiography with a presaturation method is a useful modality for evaluating the function of an EC/IC bypass. Elimination of the signal of the MCAs after presaturation is clear evidence of the patency of a bypass using MR angiography. MR angiography allows evaluation of the patency of a bypass in the outpatient department, and can be repeated as often as necessary.

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