4D Flow MRI assessment of cerebral blood flow after extracranial-intracranial bypass

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Purpose

Extracranial-to-intracranial (EC-IC) bypass surgery is performed to augment or re-establish the blood flow in the patients with restricted flow at the internal carotid artery (ICA). [1,2] Surgically created anastomosis will induce flow disturbances and alter the velocity profiles. However, the vascular hemodynamic environment after EC-IC bypass is not well known. It is difficult to assess the impact of EC-IC bypass surgery on cerebral hemodynamic noninvasively, because each patient has different pathological conditions, the pattern of collateral circulation at Willis circle, the elasticity of vessel wall, and the blood pressure. Time-resolved phase-contrast (4D Flow) MRI can provide information about blood flow volume (BFV) and direction and pressure gradient, which may be related to hemodynamic and vascular pathology. The aim of this study was to assess the BFV and direction and pressure gradient in patients after EC-IC bypass using 4D Flow MRI.

Methods and Materials

We enrolled 19 patients (12 men; mean 66 years) who underwent EC-IC bypass successfully. 10 of the 19 patients with post ligation of ICA received radial artery graft (RAG) bypass surgery, and the remaining 9 patients with internal carotid artery occlusion received superficial temporal artery (STA) bypass. The 4D Flow MRI was performed using a 3.0 T with the following parameters: TR / TE = 8.4 / 5.4ms, FA = 13 degree, VENC = 70 cm/s, voxel size = 0.82 x 0.82 x 1.4mm^3, 15 cardiac phases, and acquisition time = 8 min. The velocity data and pressure gradient map were generated using GTFlow software (GyroTools) (Fig. 1).

Analysis: First, we investigated the BFV and flow direction of M1 related to bypass graft types. The flow direction was classified into anterograde and retrograde direction, compared to the flow direction of the native M1. Second, the pressure gradient at the M1, from the origin of MCA to the bifurcation (M1-M2 segment), was calculated. Third, we calculated the BFV difference as (BFV of contralateral ICA + BFV of basilar artery) – BFV of bypass graft, and the correlation between the BFV difference and pressure gradient at the M1 was evaluated in patients who had no early bifurcation at M1.

Result

EC-IC bypass was patent in all patients (Fig. 2b). Retrograde flow was observed at M1 in 10 of the 19 patients. The retrograde flow at M1 was observed more frequently in the patients with RAG bypass (n = 8 / 10) than in those with STA bypass (n = 2 / 9, $p < 0.05$) (Fig. 2c). The BFV of bypass artery was higher in the patients with RAG bypass in those with STA bypass (3.41 ± 0.95 ml/s vs. 1.90 ± 1.02 ml/s, $p < 0.01$). Pressure gradient at M1 was successfully calculated in 11 of the 19 patients. The 5 patients with anterograde flow of the M1 showed positive pressure gradient at M1 (18.4 ± 14.4Pa), whereas the other 6 patients with retrograde flow of the M1 showed negative pressure gradient at M1 (-38.1 ± 13.8Pa). The pressure gradient at M1 significantly correlated with the BFV difference (Fig. 3; r=0.742, p<0.01).

Conclusion

4D Flow MRI provides information about cerebral hemodynamic in the patients post EC-IC bypass. The 4D Flow MRI visualizes and quantifies the cerebral blood flow volume and pressure gradient after EC-IC bypass. The retrograde flow at M1 is more frequent and the BFV of bypass artery is higher in the patients with RAG bypass. The pressure gradient at M1 correlates with the BFV difference between the contralateral ICA plus BA and EC-IC bypass.

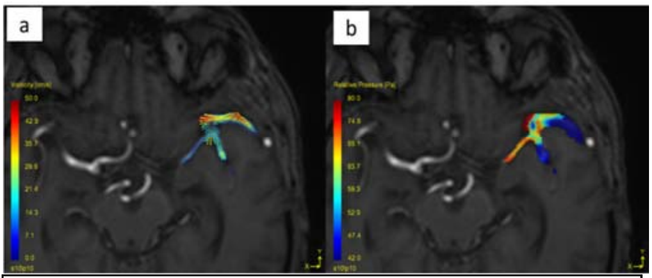

Fig. 1: 4D Flow MRI provides velocity map (left) and relative pressure map near M1-M2 bifurcation (right).

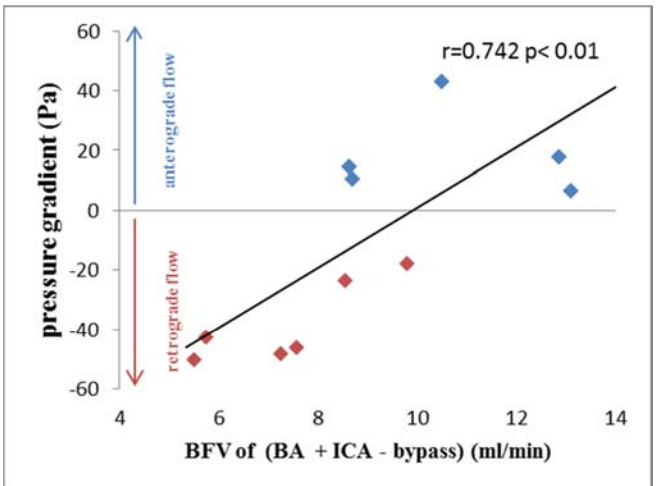

Fig. 3: The pressure gradient at M1 significantly correlates with the subtraction of bypass-BFV from the sum-BFV of contralateral ICA and BA.

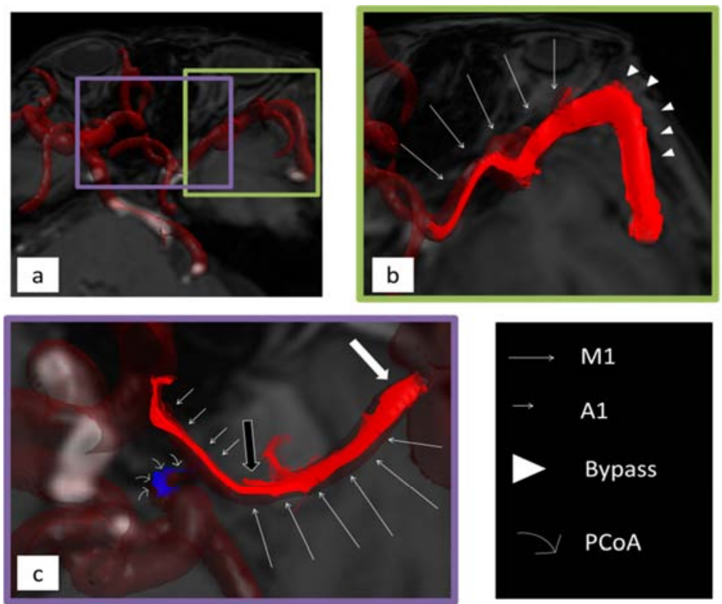

Fig. 2: 72-years-old woman with the left ICA aneurysm post ligation of the ICA and RAG bypass. (a): Volume rendering of the cerebral arteries. (b): Enlarged view of green line square. The patent EC-IC bypass (arrowheads). The bloodstream from the bypass subsequently flows into the M1 as retrograde flow (long arrows). (c): Enlarged view of purple line square. The M1 of MCA has retrograde flow (long arrows), and the A1 of ACA subsequently maintains inherent anterograde flow (short arrows). The PCoA shows retrograde flow (curved arrows). We calculate pressure gradient from the origin of M1 (black solid arrow) to the bifurcation of M1-M2 (white solid arrow).

Reference

1. Schmiedek P, Piepgras A, Leinsinger G, et al. Improvement of cerebrovascular reserve capacity by EC-IC arterial bypass surgery in patients with ICA occlusion and hemodynamic cerebral ischemia. J Neurosurg 1994;81:236-244.
2. Murai Y, Mizunari T, Umeoka K, et al. Radial artery grafts for symptomatic cavernous carotid aneurysms in elderly patients. Neurol India 2011;59:537-541.