EC-IC Bypass Function in Moyamoya Disease and Non-Moyamoya Ischemic Stroke Evaluated by Intraoperative Indocyanine Green Fluorescence Angiography

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Abstract Indocyanine green (ICG) emits near-infrared fluorescence when it is excited by near-infrared light. The near infrared fluorescence of ICG was applied to the imaging of cerebral vessels during neurosurgical operations such as clipping of aneurysms. In this study, ICG angiography was applied to extracranial-intracranial (EC-IC) bypass surgery to evaluate the hemodynamic changes induced by bypass in moyamoya disease (MD) and non-moyamoya ischemic diseases (non-MD). These patients underwent superficial temporal artery-middle cerebral artery (STA-MCA) anastomosis. We compared the cortical areas where the bypass supplied blood flow between MD and non-MD. ICG angiography clearly demonstrated the bypass blood flow from the anastomosed STA to the cortical vessels including arteries, capillaries, and veins in both MD and non-MD. Interestingly, the anastomosed STA supplied blood flow to a larger cortical area in MD than non-MD. The bypass supplied greater extent of blood flow to the ischemic brain in MD than in non-MD. This difference might be caused by the fact that the perfusion pressure was lower in MD than in non-MD.

1 Introduction

Moyamoya disease is a rare occlusive cerebrovascular disease characterized by progressive stenosis of bilateral terminal portions of the internal carotid arteries (ICAs) [1]. EC-IC (extracranial-intracranial) bypass, such as superficial temporal artery-middle cerebral artery (STA-MCA) anastomosis, has become a standard surgical therapeutic option in moyamoya disease (MD) to prevent recurrent ischemic events [2, 3]. In addition, EC-IC bypass surgery has been performed to prevent stroke in patients with transient ischemic attack (TIA)

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caused by hemodynamic compromise [4, 5]. Indeed, neuroradiological studies have demonstrated beneficial effects of bypass surgery on cerebral hemodynamic status in both MD [3, 4] and non-MD ischemic diseases [4]. However, little is yet known regarding the difference in bypass function between patients with these conditions.

Indocyanine green (ICG) fluorescence angiography has been used as a technique for assessment of vascular flow. ICG emits near-infrared fluorescence when it is excited with near-infrared light [6]. Thus, ICG fluorescence is highly transmittable through biological tissue compared with visible light fluorescence. ICG fluorescence was first applied to retinal angiography [7]. In the field of neurosurgery, ICG fluorescence angiography has been used to confirm successful aneurysm clipping during surgery [7]. In addition, ICG angiography has been used for intraoperative assessment of bypass patency in EC-IC bypass surgery [10]. In the present study, employing ICG angiography, we evaluated not only patency of the bypass graft, but also blood supply via the bypass to the cortex during STA-MCA anastomosis in MD and non-MD. We compared changes in cortical perfusion by bypass blood flow between these patients.

2 Methods

We investigated 13 patients undergoing craniotomy for STA-MCA anastomosis. The subjects included 5 patients with moyamoya disease (mean age [mean ± SD], 21.8 ± 8.6 years) and 8 with non-moyamoya ischemic disease (58.1 ± 11.7 years), including 4 patients with occlusion of the ICA and 4 patients with occlusion of the MCA. In the moyamoya disease patients, cerebral angiography revealed stage 3 in 2 patients, stage 4 in 2 patients and stage 5 in 1 patient, according to the angiographical staging of moyamoya disease [1]; the principal routes of collateral circulation were mainly moyamoya vessels in these patients. In contrast, in the non-moyamoya patients, leptomeningeal anastomosis supported the collateral circulation. All moyamoya disease patients had suffered multiple episodes of TIA, while MRI did not demonstrate cerebral infarction in these patients. The present study was approved by the Committee for Clinical Trials and Research on Humans. The ethical committee of our university hospital approved the protocol of the study.

In all patients, we employed SPECT (PRISM 2000XP, Shimadzu Co., Japan) to measure the regional cerebral blood flow (rCBF) at rest and at 10 min after intravenous injection of acetazolamide (1.0 g). To evaluate the regional hemodynamics, regions of interest were designated in the cortical territory of the MCA. SPECT demonstrated a reduced rCBF at rest (< 30 ml/100 g/min) and reactivity to acetazolamide (%CVR < 10%) before surgery in all of the moyamoya disease and non-moyamoya ischemic disease patients.

The parietal branch of the STA was anastomosed end-to-side to the M4 portion of the MCA. In moyamoya disease patients, encephalo-myo-synangiosis

was performed after the STA-MCA anastomosis. The physiological parameters during surgery were within the normal ranges in all patients; there were no significant differences in physiological parameters between the moyamoya disease and non-moyamoya disease groups.

Employing indocyanine green (ICG) angiography, we evaluated the hemodynamic changes in the patients during STA-MCA anastomosis. The ICG angiography system (Photodynamic Eye, C9830, Hamamatsu Photonics) consists of a light source (780 nm) and a CCD camera with optical filter (840 nm). The CCD camera is mounted on a three-legged stool, which is fitted with sterilized plastic covers. The distance between the CCD camera lens and operative field was 10 cm.

In order to image ICG fluorescence, ICG solution was injected into a branch vessel of the STA after the STA-MCA anastomosis. We analyzed the time course of ICG fluorescence intensity at ROI on the cortex. In addition, in order to analyze the ICG perfusion area quantitatively, we calculated the perfusion space when ICG fluorescence intensity reached the maximum level.

3 Results

Figure 1a shows an example of ICG fluorescence angiography after injection of ICG. We could obtain real time images of the bypass flow from the graft to the cortical vessels, and could confirm patency of the bypass graft in all cases. ICG fluorescence intensity rapidly increased to the maximum level and returned to

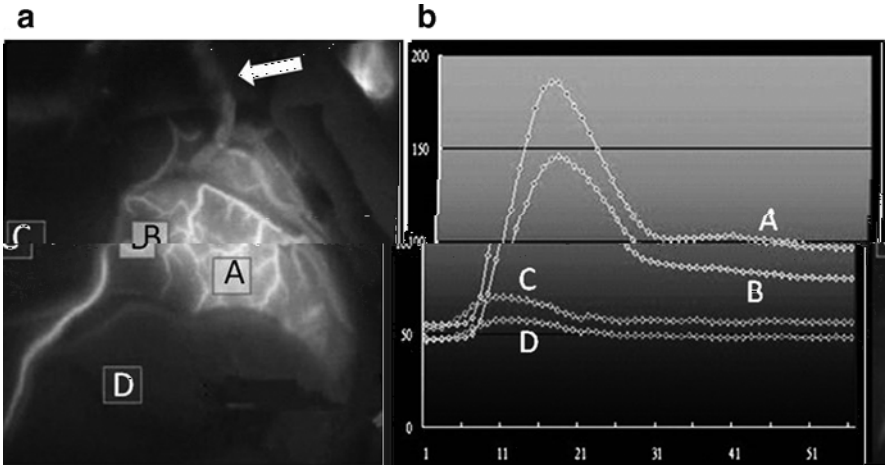

Fig. 1 Intraoperative ICG angiography during STA-MCA anastomosis. *Right*: A picture of ICG angiography at about 15 s after injection of ICG into the STA. *Left*: Time courses of ICG intensity curve. *Red* and *blue lines* correspond to *red ROI* and *blue ROI* in the *right figure*, respectively

the control level when the ROI was set at the perfusion area of ICG (Fig. 1b). In contrast, when the ROI was set outside the perfusion area, no remarkable increase of ICG fluorescence intensity was observed. Figure 2 compares the ICG perfusion areas in MD and non-MD. The STA supplied blood to a larger cortical area in MD (20.7 ± 6.6 cm^2) than non-MD (6.7 ± 4.5 cm^2, $p < 0.05$).

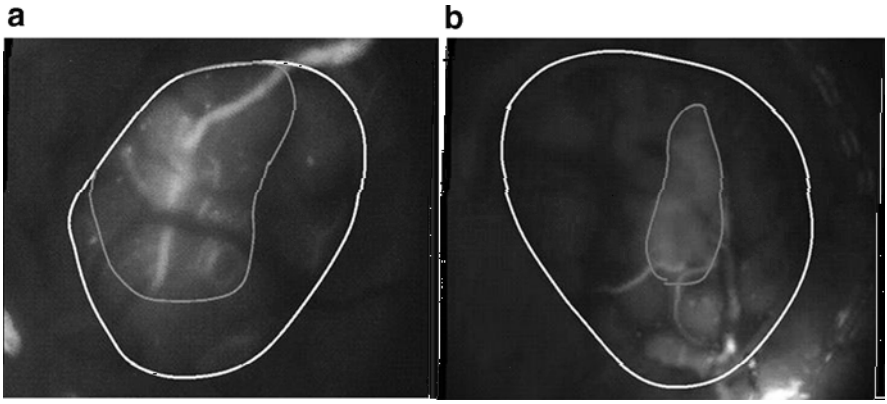

Fig. 2 Examples of cortical areas where anastomosed STA supplied blood flow between MD and non-MD. ICG angiography demonstrated that the STA supplied blood to larger cortical areas in MD (*left*) than those in non-MD (*right*)

4 Discussion

The present study demonstrated that the STA supplied blood to a larger cortical area in MD than non-MD. This finding is consistent with our previous study, which employed visual light spectroscopy to evaluate the effects of STA blood flow on the cerebral blood oxygenation (CBO) in the MCA territory during surgery in MD and non-MD [11]. We found that the STA blood flow increased the concentration of oxyhemoglobin in cortical vessels and oxygen saturation in the cortex, indicating that the bypass supplied blood flow to the ischemic brain; CBO changes were observed more frequently in MD than in non-MD. These observations suggest that the anastomosed STA supplied more blood to the ischemic brain in MD than non-MD, although the recipient artery of MD tends to be smaller and more fragile than that of non-MD. It should be noted, however, that several studies have reported the occurrence of hyperperfusion syndrome in patients with MD following STA-MCA anastomosis [11]; [13]; hyperperfusion syndrome tends to occur after carotid endarterectomy [14]or high flow bypass [15], rather than low flow bypass such as STA-MCA anastomosis.

The details of the physiological mechanisms underlying the differences in cortical perfusion induced by bypass blood flow between MD and non-MD

remain unclear; however, perfusion pressure may play a role in the STA blood supply to the ischemic brain. Our previous study using visual light spectroscopy revealed lower oxygen saturation in the cortex before anastomosis in MD than that in non-MD, suggesting that the perfusion pressure in MD was less than that in non-MD. In addition, our study on postoperative bypass function demonstrated that the bypass functioned better in cases with a lower rCBF before surgery [16]. Further studies are needed to clarify the physiological mechanism that underlies the difference in bypass blood supply between MD and non-MD.

5 Conclusion

The bypass begins to supply blood to a greater extent in MD than in non-MD, possibly because the perfusion pressure is lower in MD than in non-MD. The intraoperative ICG angiography system is considered useful for evaluating bypass function and facilitates safe and accurate bypass surgery

References

1. Suzuki J (1986) Moyamoya disease. Springer Berlin Heidelberg, New York.
2. Khan N, Schuknecht B, Boltshauser E et al. (2003) Moyamoya disease and Moyamoya syndrome: experience in Europe; choice of revascularisation procedures. Acta Neurochir (Wien) 145:1061–1071.
3. Saito N, Nakagawara J, Nakamura H, et al. (2004) Assessment of cerebral hemodynamics in childhood moyamoya disease using a quantitative and a semiquantitative IMP-SPECT study. Ann Nucl Med 18:323–331.
4. Anderson DE, McLane MP, Reichman OH et al. (1992) Improved cerebral blood flow and CO_2 reactivity after microvascular anastomosis in patients at high risk for recurrent stroke. Neurosurgery 31:26–33.
5. Ueno M, Nishizawa S, Toyoda H et al. (2001) Assessment of cerebral hemodynamics before and after revascularization in patients with occlusive cerebral revascularization by means of quantitative IMP-SPECT with double-injection protocol. Ann Nucl Med mepe95.5-234..3(.7(Mdocy2(gn)-262.52t)0(en34..3(.7as34..3(.7rel)-2d)-502(17105.9(blood)-307(flow)]TJ

12. Furuya K, Kawahara N, Morita A et al. (2004) Focal hyperperfusion after superficial temporal artery-middle cerebral artery anastomosis in a patient with moyamoya disease: case report. J Neurosurg 100:128–132.
13. Ogasawara K, Komoribayashi N, Kobayashi M et al. (2005) Neural damage caused by cerebral hyperperfusion after arterial bypass surgery in a patient with moyamoya disease: case report. Neurosurgery 56:E1380.
14. Piepgras DG, Morgan MK, Sundt TM et al. (1988) Intracerebral hemorrhage after carotid endarterectomy. J Neurosurg 68:532–536.
15. Stiver SI, Ogilvy CS (2002) Acute hyperperfusion syndrome complicating EC-IC bypass. J Neurol Neurosurg Psychiatry 73:88–89
16. Murata Y, Katayama Y, Sakatani K et al. (2003) Evaluation of extracranial- intracranial arterial bypass function by using near-infrared spectroscopy. J Neurosurg 99:304–310.