

Angiographic Neovascularization after Bypass Surgery in Moyamoya Disease: Our Experience at Hiroshima University Hospital

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ABSTRACT

In this study, we investigated the effect of different bypass procedures on postoperative neovascularization in patients with moyamoya disease at Hiroshima University Hospital. Fourteen cerebral hemispheres of seven patients with moyamoya disease were investigated. Five of the 14 hemispheres underwent direct bypass surgery and the remaining 9 underwent indirect bypass. The neovascularization after bypass surgery was evaluated by cerebral angiography. The extent of angiographic neovascularization after direct or indirect bypass surgery was graded as good, fair or poor. Postoperative neovascularization status (good, fair or poor) was compared with the bypass procedure (direct and indirect bypass). Good neovascularization was observed in 8 hemispheres and the remaining 6 had poor neovascularization. Direct bypass surgery was significantly more effective for angiographic neovascularization than the indirect procedure in moyamoya patients (χ^2 -test, $p < 0.05$). Therefore, we concluded that the direct bypass procedure is a better choice for moyamoya disease as evidenced by angiographic neovascularization.

Key words: *Bypass surgery, Moyamoya disease, Neovascularization*

Moyamoya disease is characterized by the angiographic findings of arterial stenosis and occlusion of the circle of Willis¹⁴. Ischemic attacks may occur following reduced cerebral perfusion due to arterial stenosis and occlusion. Bypass surgeries are performed to enhance the development of natural collaterals and to prevent the progression of the disease^{4,7,15}. The surgical bypass procedure for moyamoya disease is classified into direct and indirect bypass. The direct bypass procedure is a bypass by direct anastomosis between two arteries such as superficial temporal artery (STA) – middle cerebral artery (MCA) anastomosis⁶. The indirect bypass procedure is a bypass by non-anastomotic surgery such as encephaloduro-arterio-synangiosis (EDAS), encephalo-myosynangiosis (EMS), encephalo-galeo-synangiosis (EGS) and encephalo-duro-arterio-myosynangiosis (EDAMS)^{2,8,9,16}. After bypass surgery, it has been found that neovascularization develops on follow-up cerebral angiography and the ischemic attacks diminish significantly¹⁰. In this study,

we investigated the effect of different bypass procedures on angiographic neovascularization in patients with moyamoya disease at Hiroshima University Hospital.

MATERIALS AND METHODS

The clinical characteristics of the patients and their post-operative neovascularization status are summarized in Table 1. Between April 2002 and December 2006, 12 patients with moyamoya disease were treated surgically at Hiroshima University Hospital. From these, 7 patients with moyamoya disease who underwent follow-up digital subtraction angiography (DSA) were included in this study. The patients consisted of 5 females and 2 males ranging in age from 6 to 36 years (mean age, 18.0 years). Four were pediatric patients and three were adults. All patients were diagnosed as having moyamoya disease on the basis of DSA findings. The cerebral angiograms of these moyamoya patients were classified

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Table 1. Summary of 7 patients with Moyamoya disease

Patient No.	Age / Sex	Disease	Symptom	Angiographic			Neovascularization in MCA territory	Follow-up Period (month)
				Side	Stage	Operation		
1	15 / F	Moyamoya	Infarction	Rt	2	STA-MCA-EMS	Good	39
				Lt	2	EDAS	Poor	39
2	24 / F	Moyamoya	TIA	Rt	3	EDAS	Good	31
				Lt	3	EDAS	Good	31
3	13 / F	Moyamoya	TIA	Rt	3	EDAS	Poor	9
				Lt	3	EDAS	Poor	9
4	36 / M	Moyamoya	TIA	Rt	3	STA-MCA-EMS	Good	7
				Lt	3	STA-MCA-EMS	Good	7
5	22 / F	Moyamoya	TIA	Rt	3	STA-MCA-EMS	Good	23
				Lt	3	STA-MCA-EMS	Good	23
6	10 / M	Moyamoya	TIA	Rt	2	EDAS	Poor	16
				Lt	2	EDAS	Poor	16
7	6 / F	Moyamoya	TIA	Rt	3	EDAS	Poor	14
				Lt	3	EDAS	Poor	14

No.= number; F= female; M= male; TIA= transient ischemic attack; Rt=right; Lt= left; EDAS=encephalo-duro-arterio-synangiosis ; STA-MCA-EMS=encephalo-myo-synangiosis procedure in combination with superficial temporal artery-middle cerebral artery anastomosis

according to the angiographic staging system proposed by Suzuki et al¹⁴. Out of 14 hemispheres of 7 patients, 5 were classified as stage 2 and 9 were classified as stage 3 moyamoya. The clinical symptom was cerebral ischemia in all patients, with one patient having cerebral infarction and 6 patients having transient ischemic attacks (TIAs), such as transient hemiparesis and sensory disturbance, several times a month.

As a bypass procedure, direct bypass (STA- MCA anastomosis) was selected for the adults, and indirect bypass (EDAS) was chosen for the pediatric patients, because indirect bypass has been found to enhance the formation of sufficient collaterals in pediatric patients with moyamoya disease^{8,11}. Regarding surgical bypass procedure for the MCA territory, 5 of 14 hemispheres underwent EMS in combination with STA- MCA anastomosis (STA-MCA-EMS) and 9 of 14 hemispheres underwent EDAS. Similarly, all patients underwent EGS as a surgical bypass procedure for the anterior cerebral artery (ACA) territory. After surgical bypass, all the patients were found to be symptom-free till the last follow-up.

For follow-up angiographic evaluation, selective DSA of the external carotid artery was performed after the surgical bypass for all patients. The range of follow-up period was 7 to 39 months, the mean being 19.8 months. The extent of angiographic neovascularization after STA-MCA-EMS or EDAS procedure was graded as good, fair or poor as described by Matsushima et al⁹. Good signified that the neovascularization area was more than two-thirds of the MCA distribution,

fair that the neovascularization area was between one-third and two-thirds of the MCA distribution, while poor signified that the neovascularization area was less than one-third of the MCA distribution (Fig. 1 and 2). Two of the authors (S.S. and M.S.) evaluated the extent of postoperative angiographic neovascularization in MCA territory, and their results corresponded.

Statistical analysis was performed using the software package of StatView, version 5.0. Postoperative neovascularization status (good, fair and poor) was compared with the bypass procedure (STA-MCA-EMS and EDAS) by using χ^2 -test to check the effect and role of each type of bypass procedure on neovascularization. The values of $p < 0.05$ were regarded as statistically significant. An analysis to see the relation between postoperative neovascularization status and follow up period was not performed.

RESULTS

The result of angiographic evaluation for neovascularization status of the 14 hemispheres is summarized in Table 1. Out of 14, good neovascularization was observed in 8 hemispheres and the remaining 6 had poor neovascularization. There was a statistically significant difference between STA-MCA-EMS and EDAS ($p=0.017$) in terms of postoperative neovascularization status. Our study showed that the STA-MCA-EMS resulted in significantly better neovascularization than EDAS did.

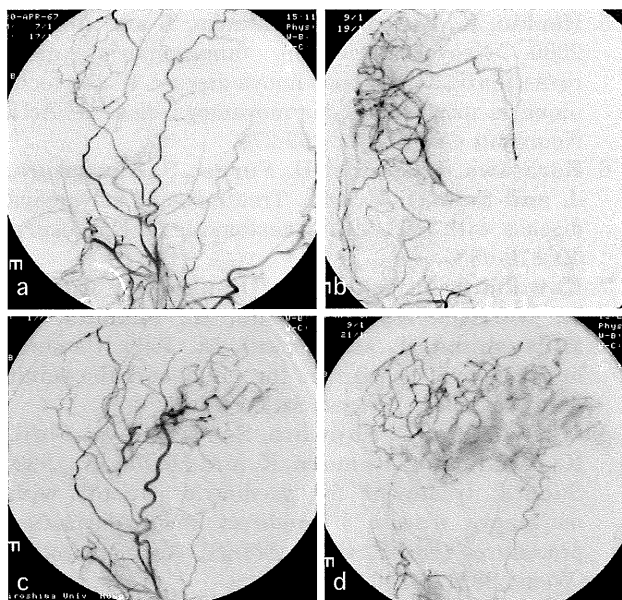


Fig. 1. Patient No. 4: A 36-year-old male with moyamoya disease

- Preoperative right external carotid angiogram, lateral view, revealed no collateral blood flow to the MCA territory.
- Early phase of the right external carotid angiogram, anteroposterior view, obtained 7 months after operation, showed rich blood supply to the MCA territory through combined STA-MCA anastomosis and EMS.
- Early phase of the right external carotid angiogram, lateral view, obtained 7 months after operation, showed rich blood supply to the MCA territory through combined STA-MCA anastomosis and EMS.
- Late phase of the right external carotid angiogram, lateral view, obtained 7 months after operation, showed a neovascularization area of more than two-thirds of the MCA territory through combined STA-MCA anastomosis and EMS. Postoperative neovascularization status was graded as good.

DISCUSSION

Moyamoya disease is a rare cerebral arterial angiopathy characterized by chronically progressive stenosis and occlusion of the supraclinoid portion of the internal carotid artery and the proximal portions of the ACA and MCA, accompanied by development of abnormal net-like vessels comprising dilated perforating arteries, the so-called moyamoya vessels¹⁴). There is a tendency toward a higher incidence of the disease among Japanese and Asian populations, though its exact etiology is unknown. Pediatric patients have a higher occurrence rate of cerebral ischemia resulting in transient ischemic events or strokes and intellectual deterioration, whereas adult patients are more prone to hemorrhage and aneurysm development³). Treatment by surgical bypass has been the usual trend to encourage the development of

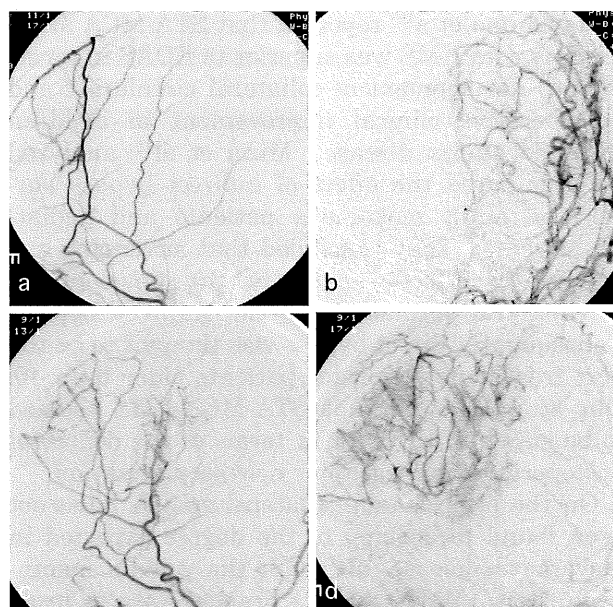


Fig. 2. Patient No. 3: A 13-year-old female with moyamoya disease

- Preoperative left external carotid angiogram, lateral view, revealed early filling of the ACA territory through the MMA branch, but no collateral blood flow to the MCA territory.
- Early phase of the left external carotid angiogram, anteroposterior view, obtained 9 months after operation, showed neovascularization to the MCA territory through EDAS.
- Early phase of the left external carotid angiogram, lateral view, obtained 9 months after operation, showed neovascularization to the MCA territory through EDAS.
- Late phase of the left external carotid angiogram, lateral view, obtained 7 months after operation, showed a neovascularization area of less than one-third of the MCA territory through EDAS. Postoperative neovascularization status was graded as poor.

natural collaterals which may alter the course of progressive hemodynamic stress^{4,7,12,15}).

The surgical bypass procedure for moyamoya disease is classified into direct and indirect bypass. The direct bypass technique is direct anastomotic bypass surgery such as STA-MCA anastomosis⁶). The indirect bypass technique is non-anastomotic bypass surgery such as EDAS, EMS, EGS and EDAMS^{2,8,9,16}). An alternative technique is a combination of the direct and indirect bypass procedures such as STA-MCA-EMS⁹), which is routinely performed in our hospital. Houkin et al⁵) analyzed the effect of direct and indirect bypass on moyamoya disease. They showed that for pediatric cases, indirect bypass using temporal muscle (the deep temporal artery) and dura mater (the middle meningeal artery) induced good neovascularization. They also suggested that the direct bypass was a useful technique for adult moyamoya disease. In addition,

Matsushima et al⁹⁾ reported that STA-MCA anastomosis with EMS was superior to EDAS in terms of both development of collateral circulation and postoperative clinical improvement in children with moyamoya disease. Mizoi et al¹¹⁾ analyzed and compared the effect of indirect bypass surgery on adult moyamoya patients and pediatric patients. They concluded that advancing age apparently affects adversely the development of collateral formation by the indirect bypass. Consequently, direct bypass was thought to be the best treatment option for patients older than 40. Our study showed that STA-MCA-EMS seemed to be superior to EDAS in terms of the degree of postoperative angiographic neovascularization.

On the other hand, collateral vessels have not been found to develop to the degree expected in moyamoya disease, although the middle meningeal artery (MMA) and its branches are in proximity to the ischemic cortex¹⁾. The dura mater of patients with moyamoya disease may act as a natural anatomical barrier between the internal carotid artery territory and the external carotid circulation, thus explaining the relative lack of natural collateral circulation between the MMA circulation and the ischemic brain in this disease^{1,13)}.

In our study, although clinical symptoms improved after any bypass surgery, STA-MCA-EMS was significantly effective as compared to EDAS in terms of the angiographic neovascularization. Therefore, STA-MCA-EMS might be more effective than EDAS in angiographic neovascularization.

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