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Disclosures

None.

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Radiological Findings, Clinical Course, and Outcome in Asymptomatic Moyamoya Disease: Results of Multicenter Survey in Japan

Satoshi Kuroda, Nobuo Hashimoto, Takashi Yoshimoto, Yoshinobu Iwasaki and for the Research Committee on Moyamoya Disease in Japan

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Radiological Findings, Clinical Course, and Outcome in Asymptomatic Moyamoya Disease

Results of Multicenter Survey in Japan

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Background and Purpose—Although the development of a noninvasive MR examination has increased the opportunity to identify asymptomatic patients with moyamoya disease who have experienced no stroke episodes, their clinical features are still unclear. This was the first multicenter, nation-wide survey focused on asymptomatic moyamoya disease in Japan and was designed to clarify their clinical features.

Methods—A clinical database of asymptomatic patients with moyamoya disease was collected from 12 participating hospitals in Japan between 2003 and 2006. In total, 40 patients were enrolled in this historical prospective cohort study. Of these, 6 underwent surgical revascularization, including superficial temporal artery to middle cerebral artery anastomosis and/or pial synangiosis. Their demographic and radiological findings as well as outcome were evaluated.

Results—On initial evaluation, cerebral infarction and disturbed cerebral hemodynamics were detected in ≈20% and 40% of the involved hemispheres, respectively. Angiographical stage was more advanced in more elderly patients. Of 34 nonsurgically treated patients, 7 experienced transient ischemic attack (n=3), ischemic stroke (n=1), or intracranial bleeding (n=3) during follow-up periods (mean, 43.7 months). The annual risk for any stroke was 3.2%. Disease progression was associated with ischemic events or silent infarction in 4 of 5 patients. No cerebrovascular event occurred in the 6 patients who underwent surgical revascularization.

Conclusions—The findings revealed that asymptomatic moyamoya disease is not a silent disorder and may potentially cause ischemic or hemorrhagic stroke. Asymptomatic patients with moyamoya disease should be carefully followed-up to further clarify their outcome and to establish the management guideline for them. (***Stroke.*** **2007;38:1430-1435.)**

Key Words: cerebral infarction ■ disease progression ■ intracranial bleeding ■ moyamoya disease ■ ■ prognosis

Moyamoya disease is characterized by progressive stenosis of the terminal portion of the bilateral internal carotid arteries and is associated with an abnormal vascular network, called moyamoya vessels.[1] The etiology of the disease is still unknown; however, several epidemiological studies have suggested the involvement of some genetic factors in its pathogenesis. The potential contribution of infections has also been pointed out, although specific pathogens have not been identified.[2]

It is well known that moyamoya disease causes transient ischemic attacks (TIAs), cerebral infarction, or intracranial bleeding in both children and adults. Intracranial bleeding, in particular, often results in a poor outcome.[3,4] Cerebral revascularization surgery is believed to reduce the incidence and improve the long-term prognosis in patients with moyamoya disease.[3,5,6] The recent development of noninvasive diagnostic modalities, including MRI and MRA, has led to the realization that the incidence of asymptomatic moyamoya disease may be higher than previously thought.[7-9] "Asymptomatic" patients with moyamoya disease have previously been defined as those who have experienced neither ischemic nor hemorrhagic episode, although the definition is not determined.[7-9] However, even in Japan, their epidemiology is still obscure, and guidelines for the management of asymptomatic moyamoya disease have not yet been established. Thus, it is essential to elucidate their clinical features and natural course so that guidelines for the management of asymptomatic patients can be established. As a preliminary study, we have previously analyzed the clinical data of 10 asymptomatic patients whose diagnoses were made at Hokkaido University Hospital as moyamoya disease. However, the results were limited in their usefulness because of small patient numbers and short follow-up periods.[8]

Based on these considerations, we conducted the first multicenter, nation-wide survey focused on asymptomatic patients

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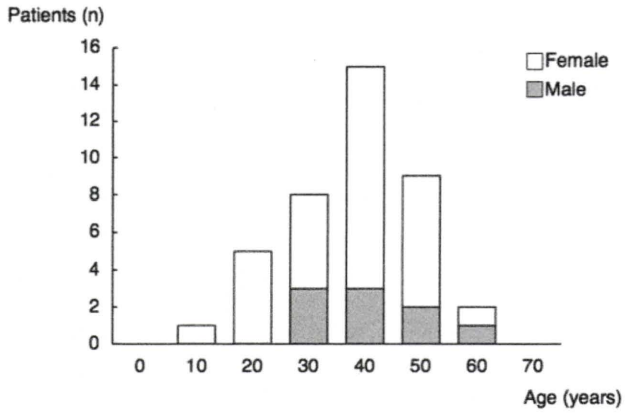

Figure 1. Distribution of age and gender in 40 patients enrolled in this study because of asymptomatic moyamoya disease.

with moyamoya disease to clarify clinical characteristics, radiological findings, and outcome. We believe that the accumulation of this clinical data will be valuable for the establishment of management guidelines for moyamoya disease.[10]

Materials and Methods

Participating Centers and Hospitals

In August 2003, we sent an invitation to participate to the members of the Research Committee on Moyamoya Disease of the Japan of Ministry of Health, Labor and Welfare of Japan, in 16 hospitals. Of these, 12 hospitals accepted our invitation, and a total of 40 asymptomatic patients were enrolled in this historical prospective cohort study (see Appendix). Follow-up data were collected from the 12 participating hospitals in March 2006.

Patients

All patients were Japanese and met the guidelines for the diagnosis of moyamoya disease set by the Research Committee on Moyamoya Disease of the Ministry of Health and Welfare of Japan. All of them previously had no ischemic or hemorrhagic episode and were neurologically free. Patients who experienced any episode suggestive of TIA, cerebral infarction, intracranial bleeding, seizure, or involuntary movement caused by moyamoya disease were excluded. MRI and MRA were performed in all patients, using a 1.5-T whole-body magnetic resonance imager. Cerebral angiography was performed in 37 of 40 patients. Using xenon CT, single photon emission tomography, or PET, cerebral blood flow and cerebrovascular reactivity to acetazolamide were determined in 35 of 40 patients.

In this study, patient demographical data, radiological findings, medical and surgical treatment, and outcome were precisely analyzed.

Statistical Analysis

Continuous variables were expressed as percentage or as mean±SD. Statistical analysis was performed using χ^2 test and Kruskal-Wallis test as appropriate. The statistical level of significance was set at $P<0.05$. Statistical analysis was completed with StatView version 5.0 (SAS Institute, Inc).

Results

Demographic Features

Of 40 asymptomatic patients with moyamoya disease, there were 13 males and 27 females. Thus, the female-to-male ratio was 2.1. Their mean age at diagnosis was 41.4±12.6 years, ranging from 13 to 67 years (Figure 1). Thirty-seven patients had typical "bilateral" moyamoya disease (definite cases) diagnosed, and the remaining 3 had "unilateral" moyamoya disease diagnosed (probable cases). Therefore, the total number of involved hemispheres was 77.

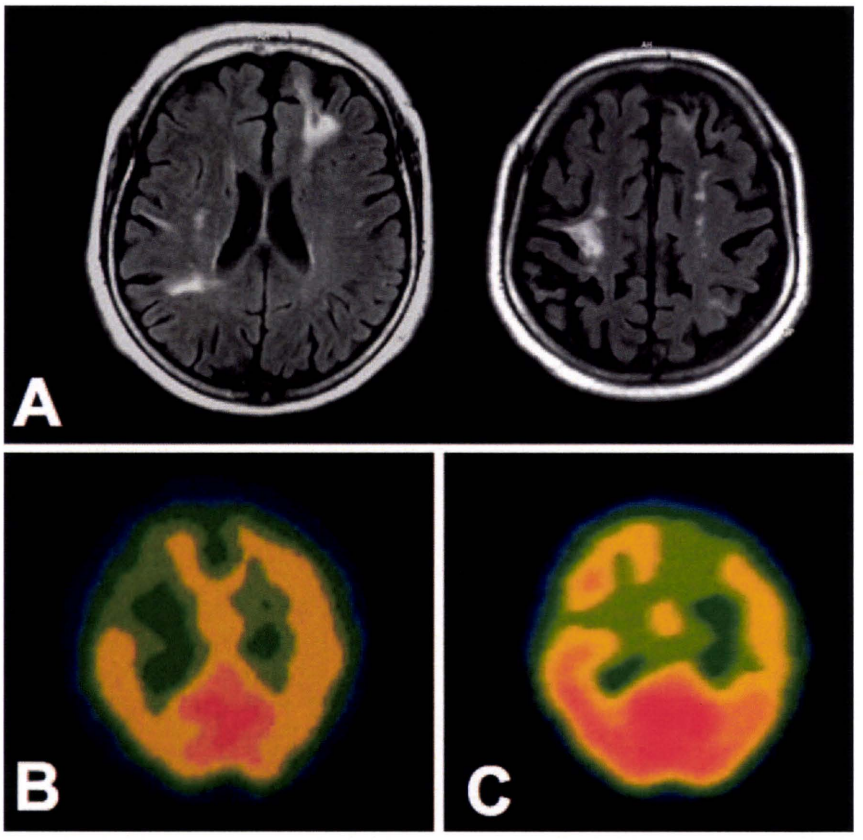

Figure 2. Radiological findings of a 65-year-old woman with asymptomatic moyamoya disease. Note multiple cerebral infarctions in both hemispheres on MRI (A) and reduction of cerebral blood flow and its reactivity to acetazolamide on single photon emission tomography before (B) and after intravenous injection of acetazolamide (C).

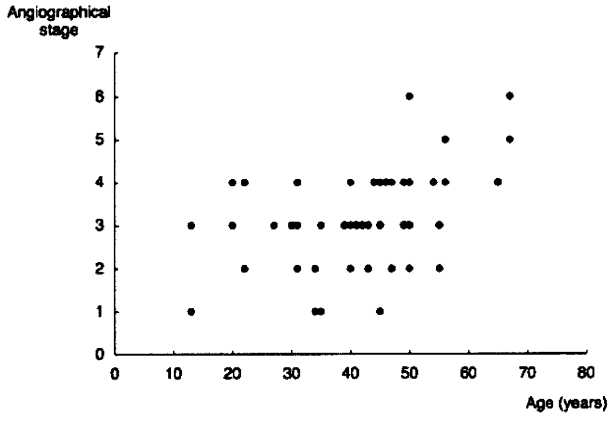

Figure 3. Relationship between age and angiographical stage in asymptomatic moyamoya disease.

Clues to the diagnosis were tension-type headache in 14 patients, dizziness in 5, and head trauma in 4. Five patients were incidentally diagnosed on MRI and MRA performed for a brain health check-up. Five diagnoses were made on MRI and MRA performed for screening, because a member of their family had moyamoya disease diagnosed. They were siblings in 2 and offspring in 3. The remaining 7 cases were diagnosed on MRI and MRA performed because of an unrelated disease in other organs.

Radiological Findings

MRI detected cerebral infarction in 16 (20.8%) of 77 involved hemispheres, or in 12 (30%) of 40 patients (Figure 2). However, there was no cerebral infarction in the uninvolved hemispheres or in the vertebrobasilar territories. No intracranial bleeding was noted. Disease stage, as determined by cerebral angiography, varied widely. Of 72 examined hemispheres, four (5.6%) were graded as stage 1, 10 (13.9%) as stage 2, 33 (45.8%) as stage 3, 21 (29.2%) as stage 4, 2 (2.8%) as stage 5, and 2 (2.8%) as stage 6. Thus ≈75% of the hemispheres were graded as stage 3 or stage 4. Correlation analysis revealed that older patients had significantly more advanced disease stage (P=0.0134; Figure 3).

Cerebral blood flow studies showed that 39 (55.7%) of 70 examined hemispheres had normal cerebral blood flow and cerebrovascular reactivity to acetazolamide. However, 24 hemispheres (34.3%) had moderate impairment of cerebral hemodynamics, ie, normal cerebral blood flow but reduced cerebrovascular reactivity to acetazolamide. Seven (10%) had reduced cerebral blood flow and cerebrovascular reactivity, suggesting a marked reduction of cerebral perfusion pressure (Figure 2).[11]

Treatments and Outcome

Of 40 subjects, 6 underwent bypass surgery, including superficial temporal artery to middle cerebral artery anastomosis, on one or both hemispheres. Eleven patients were medically treated with anticonvulsants, antiplatelet agent, or other pharmacological agents. The remaining 24 patients were conservatively followed-up as outpatients. All patients were followed-up for a mean period of 43.7 months, with a range of 1 to 150 months.

Of 6 patients who underwent bypass surgery, none experienced any ischemic or hemorrhagic episodes during follow-up periods.

TABLE 1. Summary of Clinical Data in 10 Asymptomatic Patients Who Developed Cerebrovascular Events or Showed Silent Radiological Changes During Follow-Up Periods

Case	Age	Gender	Cerebral Infarction	Angiographical Stage		CBF Study	Bypass Surgery	Cerebrovascular Event	Radiological Change	Follow-Up Period (months)
				Rt	Lt					
Symptomatic Transition										
1	22	F	None	4	2	CBF/CVR decrease (Rt)	None	TIA (Rt)	Cerebral infarction (Rt), disease progression (both)	36
2	49	M	None	3	3	CVR decrease (both)	None	TIA (Lt)	None	93
3	33	F	None	4	3	Normal	None	TIA (Lt)	Disease progression (Lt)	17
4	62	M	None	2	3	CVR decrease (Rt)	None	Ischemic stroke (Lt)	Cerebral infarction (Lt), disease progression (both)	45
5	31	M	None	4	4	Not done	None	Hemorrhagic stroke (Lt)	ICH (Lt)	1
6	51	F	None	4	4	Normal	None	Hemorrhagic stroke (Lt)	ICH (Lt)	54
7	33	F	Lt (+)	3	3	CVR decrease (both)	None	Hemorrhagic stroke (Rt)	ICH (Rt)	42
Silent Radiological Changes										
8	47	M	None	4	2	CVR decrease (Rt)	None	None	Cerebral infarction (Lt), disease progression (both)	14
9	56	F	None	3	2	Normal	None	None	Disease progression (Lt)	60
10	51	F	Rt (+)	4	3	CVR decrease (Rt)	None	None	Microbleeds (Rt)	8

CBF, cerebral blood flow; CVR, cerebrovascular reactivity; ICH, intracerebral hemorrhage.

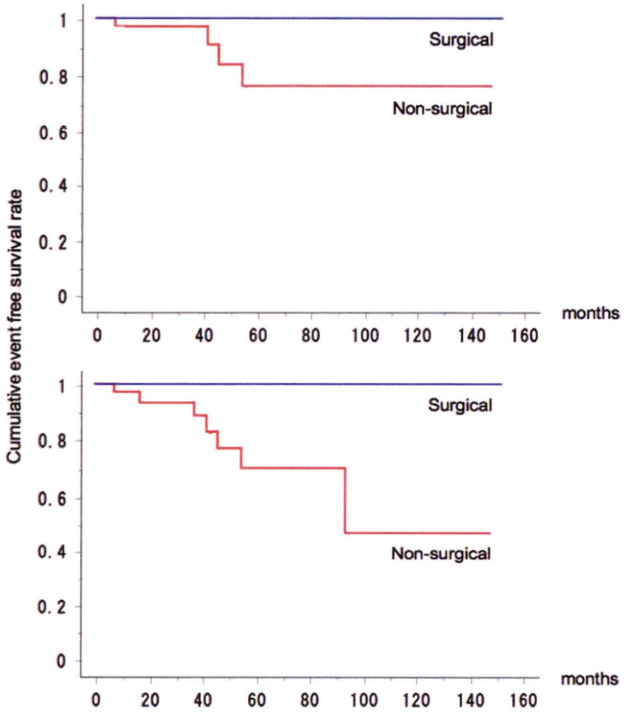

Figure 4. Kaplan–Meier cumulative event-free survival rate curves for stroke (top) and for all cerebrovascular event including TIA and stroke (bottom). Data for nonsurgically treated patients are shown in red; data for surgically treated patients are shown in blue.

Of other 34 nonsurgically treated patients, 7 experienced cerebrovascular events. Of these, 3 patients had TIA, 1 had ischemic stroke, and 3 had intracranial bleeding. Thus, 4 patients had ischemic or hemorrhagic stroke during follow-up periods (Table 1). The annual risk for any stroke was 3.2%. Figure 4 shows a Kaplan-Meier curve to demonstrate the time to cerebrovascular event.

Table 2 shows the relationship between cerebral hemodynamics at initial diagnosis and cerebrovascular events in nonsurgically treated patients. Disturbed hemodynamics was significantly linked to ischemic episodes ($P<0.05$). Disease progression caused TIA and ischemic stroke in both patients who showed normal hemodynamics on initial evaluation.

No death was observed during the patient follow-up periods. The outcome in March 2006 was categorized based on a modified Rankin scale score of 0 (n=38), 1 (n=1, ischemic stroke) and 4 (n=1, intracranial bleeding). Thus, favorable outcome (defined as modified Rankin scale ≤2) was observed in 39 (97.5%) of the 40 patients.

TABLE 2. Relationship Between Cerebral Hemodynamics at Initial Diagnosis and Cerebrovascular Events During Follow-Up Periods in Patients Who Were Medically Treated

	Cerebrovascular Event		
	None	TIA/Infarct	Bleeding
Normal	36	2*	1
Moderate ischemia	15	1	1
Severe ischemia	5	1	0
Not examined	6	0	1

*Cerebrovascular events were closely related to disease progression during follow-up periods.

Follow-Up MRI and MRA

None of 6 surgically treated patients had any new cerebral infarction and intracranial bleeding on follow-up MRI.

Of other 34 nonsurgically treated patients, 7 had new lesions on follow-up MRI (Table 1). Of these, 3 had new cerebral infarction, asymptomatic in 1 patient and asymptomatic in 2. Other 4 patients had new intracerebral hemorrhage, asymptomatic in 1 patient and symptomatic in 3. Of 34 nonsurgically treated patients, 5 showed progression of disease stage on follow-up MRA or cerebral angiography (Figure 5). Disease progression was asymptomatic in 1 patient, but caused silent cerebral infarction in 1, TIA in 2, and ischemic stroke in another (Table 1).

Discussion

This study is the first multicenter, nation-wide survey focused on asymptomatic patients with moyamoya disease and has important implications for defining its clinical features, radiological findings, and prognosis. Our findings are summarized as follows. Cerebral infarction and disturbed cerebral hemodynamics were detected in ≈20% and 40% of the involved hemispheres, respectively. Angiographical stage was more advanced in more elderly patients. Of 34 nonsurgically treated patients, 7 experienced TIA, ischemic stroke or intracranial bleeding during a mean follow-up period of 43.7 months. Cerebral infarction or intracerebral hemorrhage did not occur in 6 patients who underwent surgical revascularization.

Epidemiology of Asymptomatic Moyamoya Disease

Previously, asymptomatic cases of moyamoya disease have only been sporadically reported.[7,9] Screening of family members with moyamoya disease has also identified small numbers of asymptomatic patients.[12,13] Therefore, the incidence of asymptomatic moyamoya disease had been considered to be very low. However, Yamada et al[14] reported the results of a nation-wide questionnaire conducted in 1994 and identified 33 asymptomatic patients (1.5%) out of a total of 2193 patients. Recently, Nanba et al[8] (2003) reviewed their single-center experiences and precisely reported the clinical features of 10 asymptomatic patients with moyamoya disease. Therefore, although an accurate prevalence of asymptomatic moyamoya disease is still unknown, it may be much higher than considered before. The female-to-male ratio and mean age of the patients in these studies were similar to those of moyamoya disease as a whole.[15]

Of the 40 patients, 23 had moyamoya disease diagnosed when they visited hospitals for treatment of complaints unrelated to moyamoya disease. Although it is known that moyamoya disease is sometimes associated with migraine,[16] the headaches of these patients were considered to be tension-type. The remaining 17 patients had no symptoms and had moyamoya disease diagnosed incidentally during screening examinations using MRI and MRA. Thus, noninvasive MR examination would increase the opportunity to detect asymptomatic moyamoya disease in future.[17]

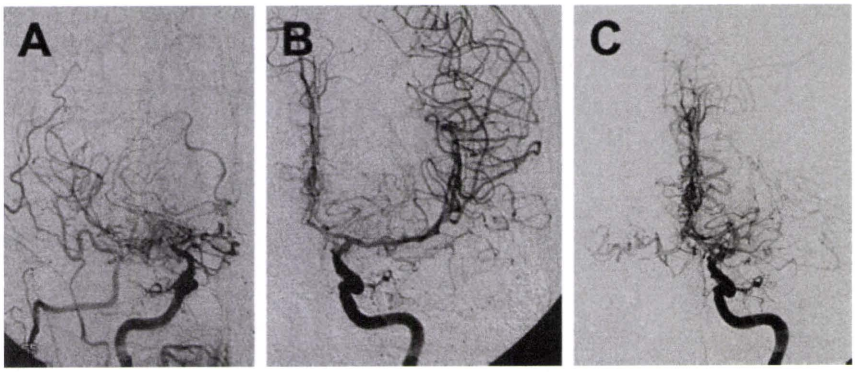

Figure 5. Internal carotid angiograms of a 51-year-old man who experienced ischemic stroke 4 years after initial diagnosis. Right (A) and left (B) internal carotid angiograms on initial diagnosis, and left internal carotid angiogram (C) 4 years later.

Silent Radiological Findings

Silent cerebral infarction was noted in ≈20% of the involved hemispheres but was not detected in other territories. The incidence was almost same as that of silent cerebral infarction (21%) in 1015 elderly patients aged 60 to 90 years (mean, 72 years).[18] According to a population-based consecutive autopsy study in Japan, the incidence of silent cerebral infarction was 4.4% in 40- to 59-year-old population.[19] Therefore, moyamoya disease may be related to the development of silent cerebral infarction even in asymptomatic patients. Although adults with moyamoya disease have also been known to have intracranial bleeding, no intracranial bleeding was observed in this study. However, very recent studies have shown that T2*-weighted MRI can detect microbleeds in a certain subgroup of patients with moyamoya disease.[20,21] With this technique, however, further study would be necessary to predict their risk for intracranial bleeding by assessing for the presence of microbleeds.

In this study, cerebral blood flow measurements demonstrated that ≈40% of the involved hemispheres had a moderate or severe reduction of cerebral perfusion reserve, despite the fact that patients remained asymptomatic. Recent studies have proven that both increased oxygen extraction fraction and impaired reactivity to acetazolamide can be independent predictors for subsequent ischemic stroke in patients with occlusive carotid artery diseases.[11,22–24] Therefore, critical follow-up would be essential for patients found to have increased oxygen extraction fraction or impaired cerebrovascular reactivity.

Clinical and Radiological Course

This study clearly demonstrates that disease stage is more advanced in older patients. Although disease progression in adult moyamoya disease was believed to be very rare before, a recent study has shown that disease progression occurs in ≈20% of patients during a mean follow-up period of 6 years.[25] Occlusive arterial lesions progress in both anterior and posterior circulation, in both bilateral and unilateral types, and in both symptomatic and asymptomatic patients. Multivariate analysis has revealed that female gender is an independent risk factor for disease progression.[25] Therefore, it should be emphasized that disease progression may occur silently and cause ischemic or hemorrhagic stroke even in asymptomatic patients. Aging-related atherosclerosis may also be involved in disease progression in elderly patients. Indeed, this study demonstrates that disease progression occurred in 5 asymptomatic patients, caused TIA or ischemic stroke in 3 patients, and resulted in silent cerebral infarction in one. The findings strongly suggest that it is quite important to repeat MRI and MRA at regular intervals when asymptomatic patients are conservatively followed-up to detect disease progression before ischemic stroke occurs.

There is no guideline to direct how asymptomatic patients with moyamoya disease should be managed.[8] In this study, of the 34 nonsurgically treated patients, 7 patients experienced cerebrovascular episodes, including TIA. The annual risk for ischemic or hemorrhagic stroke was 3.2%. Disease progression was closely related to the onset of ischemic episodes. Nanba et al[8] reported that 1 of 10 asymptomatic patients experienced ischemic stroke during follow-up periods. Yamada et al[14] also evaluated the natural course of 33 asymptomatic patients with moyamoya disease; they reported that 2 patients died from intracranial bleeding, and 4 patients experienced TIA during a mean follow-up period of 44 months.

Of note, there is a peculiarity common to the present study and the report by Yamada et al.[14] None of patients who underwent surgical revascularization had any cerebrovascular event during follow-up periods, except for surgical morbidity.[14] These findings may suggest that asymptomatic moyamoya disease is not a silent disorder and readily progresses to cause ischemic or hemorrhagic stroke. Surgical revascularization may be indicated, at least, in patients who have disturbed cerebral hemodynamics if surgical morbidity is low enough, because the procedure is considered effective for improving cerebral blood flow and metabolism and preventing ischemic stroke.[26,27] It is still unclear whether surgical revascularization could reduce the incidence of intracranial bleeding caused by moyamoya disease, although a randomized clinical trial in Japan is ongoing.[28] Even if patients are conservatively followed-up, precise and regular MRI/MRA examinations could be essential for improving long-term outcome by predicting subsequent ischemic and hemorrhagic stroke, because repeated MRI/MRA have the ability to detect disease progression and silent microbleeds before the onset of ischemic or hemorrhagic stroke.[20,21,25]

Limitation of This Study

There are certain limitations to this study that should be noted. This study is a historical prospective cohort study and not a prospective cohort study. The subjects included in this study were collected from 12 hospitals. These hospitals are considered representative of the major institutions in Japan responsible for the management of moyamoya disease. Ide-

ally, however, a prospective cohort or randomized study should be performed on the basis of a larger population of asymptomatic patients to build the accurate evidence on the clinical features and outcome of this disease.

Conclusions

This multicenter, nation-wide survey reveals that the prevalence of asymptomatic patients with moyamoya disease may be higher than previously thought. Although these patients are still "asymptomatic," their radiological findings are not always normal. A certain subgroup has silent cerebral infarction, advanced arterial lesions, and impaired cerebral hemodynamics. Of 34 nonsurgically treated patients, 7 transitioned to become "symptomatic" patients during follow-up periods. Silent radiological findings were added in 3 other patients. None of patients who underwent surgical revascularization experienced any cerebrovascular event during follow-up periods. Careful and long-term neurological and radiological follow-up would be essential to improve the outcome of these patients by preventing ischemic and hemorrhagic stroke. Further prospective studies may be necessary to finalize the management guideline for asymptomatic patients with moyamoya disease.

Appendix

All of clinical data in this study were collected from Department of Neurosurgery, Iwate Medical University; Department of Neurology, Keio University; Department of Neurosurgery, Chugoku Rosai Hospital; Department of Neurosurgery, Nara Medical University; Department of Neurosurgery, Nagasaki University; Departments of Neurology and Neurosurgery, Kyushu Medical Center; Department of Neurosurgery, Nagaoka Central Hospitals; Department of Neurosurgery, Nagoya City University; Departments of Neurology and Neurosurgery, Kitasato University; Department of Neurosurgery, Gifu University; Department of Neurosurgery, Sapporo Medical University; and Department of Neurosurgery, Hokkaido University.

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Disclosures

None.

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Peri-Operative Complications in Adult Moyamoya Disease

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Summary

The incidence and causes of peri-operative haemodynamic complications in adult Moyamoya disease were examined by reviewing 55 surgically treated adult patients. Ninety-nine craniotomies were performed in these patients, and eight peri-operative complications (four infarctions, two haemorrhagic infarctions and two reversible ischaemic neurological deficits without a new lesion) were seen. All of the eight haemodynamic complications arose in the initially affected hemispheres regardless of the side of operation. Some non-surgical haemodynamic risk factors, i.e., hypercapnia, hypocapnia and hypotension/hypovolaemia, were noted in all of the eight cases, although the statistical analysis could not clarify the relevance of such factors to peri-operative complications. Surgical factors which might be responsible for the complications were noted in three cases.

Sparing vital collateral vessels and minimum brain retraction as well as avoidance of non-surgical haemodynamic risk factors are considered to be essential to prevent peri-operative haemodynamic brain damage in adult Moyamoya disease.

Keywords: Moyamoya disease; adult; peri-operative haemodynamic complications; surgical factors; non-surgical factors.

Introduction

Moyamoya disease can be divided into two clinical entities, namely juvenile and adult types[7, 12, 14]. Although these two types show similar angiographic findings, it is not clear whether adult cases are only the extension or the continuity of juvenile cases or not. The juvenile type of Moyamoya disease is found after cerebral ischaemic attacks in almost all the cases during childhood. In contrast, the adult type often manifests intracranial bleeding and less frequent cerebral ischaemic attacks.

For Moyamoya disease associated with cerebral ischaemia, extracranial/intracranial (EC/IC) bypass has been done in the hope of preventing further ischaemic insults[1–4, 14]. Because of the disturbance of autoregulation under hypoperfusion states[8, 13], special care is necessary to prevent hypotension and hypocapnia during the peri-operative periods[5, 6, 9, 10]. In addition, we have also noted the potential hazard of peri-operative hypercapnia worsening the ischaemic conditions in juvenile cases (manuscript submitted).

In adult cases of Moyamoya disease, not only the EC/IC bypass but also evacuation of haematoma, clipping of associated aneurysms and other surgical procedures may become necessary. These operations should be done when there is cerebral hypoperfusion, narrowing of the major arteries or abnormal dilatation of the perforating vessels.

Table 1. *Clinical Profile of 55 Patients with Adult Moyamoya Disease*

Age at onset (yrs)	
Mean	37.3
Range	16–62
Male : Female	20 : 35
Manifestation	
Infarction	14
TIA	6
Haemorrhage	33
Incidental	2
Surgical procedure	
Direct bypass surgery	85
Indirect bypass surgery	1
Direct bypass surgery with another procedure	4[a]
Evacuation of haematoma	7
Resection of peripheral aneurysm	2

[a]Including clipping of the neck and coating of an aneurysm, a proximal clipping for distal aneurysm and a removal of meningioma.

In the present study, we have analysed 55 cases of surgically treated adult Moyamoya disease to clarify contributory factors of peri-operative complications.

Clinical Materials and Methods

We have performed 99 craniotomies on 55 adults (16 years old or more at onset) with Moyamoya disease in the past 15 years. Table 1 summarizes the clinical findings in these 55 patients.

Eight peri-operative haemodynamic complications (four infarctions, two haemorrhagic infarctions, and two reversible ischaemic neurological deficits (RIND) without a new lesion on neuro-imaging studies) were seen in eight patients. Postoperative transient ischaemic attacks (TIA) were excluded from this analysis.

Clinical records of these eight patients were analysed in detail with special reference to surgical procedures and peri-operative haemodynamic conditions, such as mean arterial blood pressure (MAP), blood gas data, as well as neurological signs and neuroradiological findings. Non-surgical haemodynamic factors were defined in the present study as hypercapnia ($PaCO_2 > 45$ torr), hypocapnia ($PaCO_2 < 35$ torr) and hypotension/hypovolaemia (MAP < 85% of the pre-operative MAP).

The data of these eight patients were compared with those of the 47 adult patients without such a complication.

Statistical analysis was performed using the Chi-square test.

Results

Features of the Patients with a Peri-Operative Complication

Table 2 summarizes the clinical data of the eight patients with a peri-operative haemodynamic complication. Diagnosis of Moyamoya disease was made after intracranial bleeding in four cases (two with thalamic and two with intraventricular haemorrhage) and after cerebral ischaemia in three cases (two infarctions and

Table 2. *Clinical Profile of Eight Patients with Peri-Operative Complications*

Case no.	Age (yrs/ sex)	Manifestation		Peri-operative complication			Probable cause of complication	
		Type	Affected hemisphere	Mode of operation	Type	Location of LDA/HDA	Non-surgical factor[a]	Surgical factor
1	23/F	infarction	right	lt. STA-MCA	infarction	rt. frontal	hypocapnia	none
2	29/M	incidental (head trauma)	none	rt. STA-MCA	infarction	lt. temporo-parietal	hypercapnia	none
3	38/M	thalamic haemorrhage	left	lt. STA-MCA, "neck" clipping of lt. P1–P2 aneurysm via subtemporal approach	infarction	lt. frontal	hypocapnia, hypercapnia, hypotension/ hypovolaemia	narrowing of the posterior communicating artery by the clip
4	41/F	intra-ventricular haemorrhage	left	resection of lt. distal aneurysm via transcortical approach	infarction	lt. parieto-occipital	hypotension/ hypovolaemia	retraction of the brain
5	18/M	infarction	right	rt. STA-MCA	haemorrhagic infarction	rt. parieto-occipital	hypercapnia	none
6	29/F	thalamic haemorrhage	left	lt. STA-MCA	haemorrhagic infarction	lt. fronto-parietal	hypercapnia	none
7	17/M	transient ischaemic attack	right	rt.STA-MCA	RIND corresponding to the operated hemisphere	none	hypercapnia, hypotension/ hypovolaemia	none
8	49/F	intra-ventricular haemorrhage	left	lt. STA-MCA, feeder clipping of lt. distal aneurysm via interhemispheric transcallosal approach	RIND corresponding to the operated hemisphere	none	hypocapnia	retraction of the brain

LDA low density area; *HDA* high density area; *F* female; *M* male; *STA-MCA* superficial temporal artery to middle cerebral artery anastomosis; *RIND* reversible ischaemic neurological deficit.

[a]See text for the definitions of hypercapnia, hypocapnia and hypotension/hypovolaemia.

one TIA); the remaining one case (Case 2) was diagnosed incidentally after head trauma.

EC/IC bypass surgery was done in five patients. In the other two patients, bypass surgery was done at the same time with aneurysmal clipping (neck clipping of a P_1–P_2 aneurysm and feeder clipping of a distal aneurysm). In the other patient, resection of a distal aneurysm of the lateral posterior choroidal artery was done.

In all of eight patients, haemodynamic complications arose in the initially affected hemispheres regardless of the side of operation. In Cases 1 and 2, a postoperative infarction arose in the contralateral hemispheres to the bypass surgery at the second operation. The first bypass surgery had been already done in these hemispheres, because cerebral blood flow (CBF) was predominantly reduced in these hemispheres before the first operation. In the remaining six patients, peri-operative haemodynamic complications occurred in the operated hemisphere, although no lesions were newly seen on the postoperative computerized tomography (CT) scans in the two cases of RIND (Cases 7 and 8).

Probable Causes of Peri-Operative Complications

The involvement of surgical factors in the complications was suspected in the three patients who underwent additional surgical procedures besides bypass surgery (Table 2). Narrowing of a vital collateral vessel was noted postoperatively in Case 3 and retraction of the brain was suggested to be one of the probable causes of the postoperative deterioration in Cases 4 and 8. Postoperative angiography confirmed the patency of EC/IC bypasses in all the patients, and surgical factors to which the complications might be attributable were not associated with these bypass surgeries.

In all of the eight patients, some non-surgical haemodynamic risk factors were seen with various combinations during the peri-operative periods. Hypercapnia, hypotension/hypovolaemia and hypocapnia were

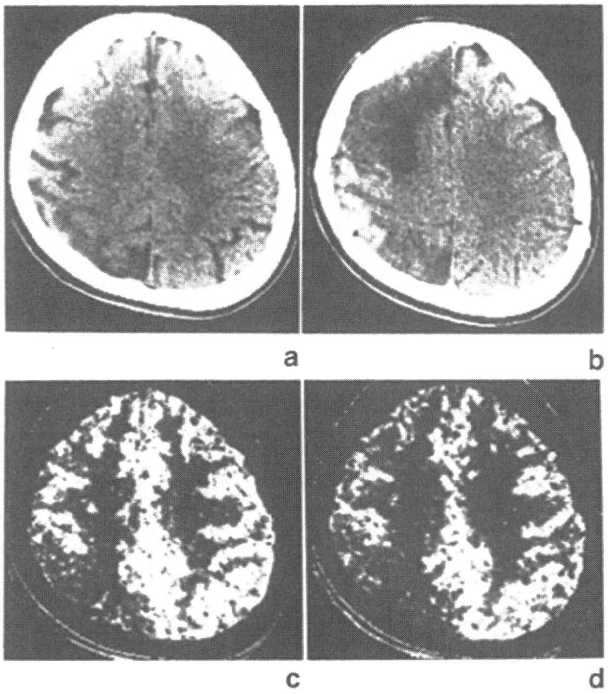


Fig. 1. Case 1. Pre-operative CT (a) demonstrating atrophy following infarction at the right parieto-occipital region. CT (b) obtained after the second operation (left STA-MCA anastomosis) revealed an infarction in the right fronto-parietal region. Cortical hyperdensity is seen in the right parietal region. Pre-operative Xe-CT images at rest (c) and after acetazolamide (Diamox) challenge (d). Cerebral blood flow (CBF) is shown to be decreased at rest in the right hemisphere, especially in the right perieto-occipital region corresponding to the infarction shown in pre-operative CT. CBF is further decreased after Diamox challenge in the fronto-parietal regions bilaterally but predominantly on the right

Table 3. *Peri-Operative Non-Surgical Haemodynamic Factors in Eight Adult Patients with Peri-operative Complications*

Peri-operative complications	Hypercapnia	Hypocapnia	Hypotension/ Hypovolaemia
Yes (n = 8)	5 (62.5%)	3 (37.5%)	3 (37.5%)
Infarction (n = 4)	2	2	2
Haemorrhagic infarction (n = 2)	2	0	0
RIND without LDA (n = 2)	1	1	1
No (n = 47)	22 (46.8%)	22 (46.8%)	16 (34.0%)
Total (n = 55)	27 (49.1%)	25 (45.5%)	19 (34.5%)

RIND reversible ischaemic neurological deficit; *LDA* low density area. See text for definitions of hypercapnia, hypocapnia and hypotension/hypovolaemia.

noted in five, three and three patients, respectively. Table 3 shows the relationship between the type of complication and these factors. There was no difference in the incidence of every factor between the patients with and without a complication, although both of the two patients with a haemorrhagic infarction had evidence of hypercapnia without any other factors.

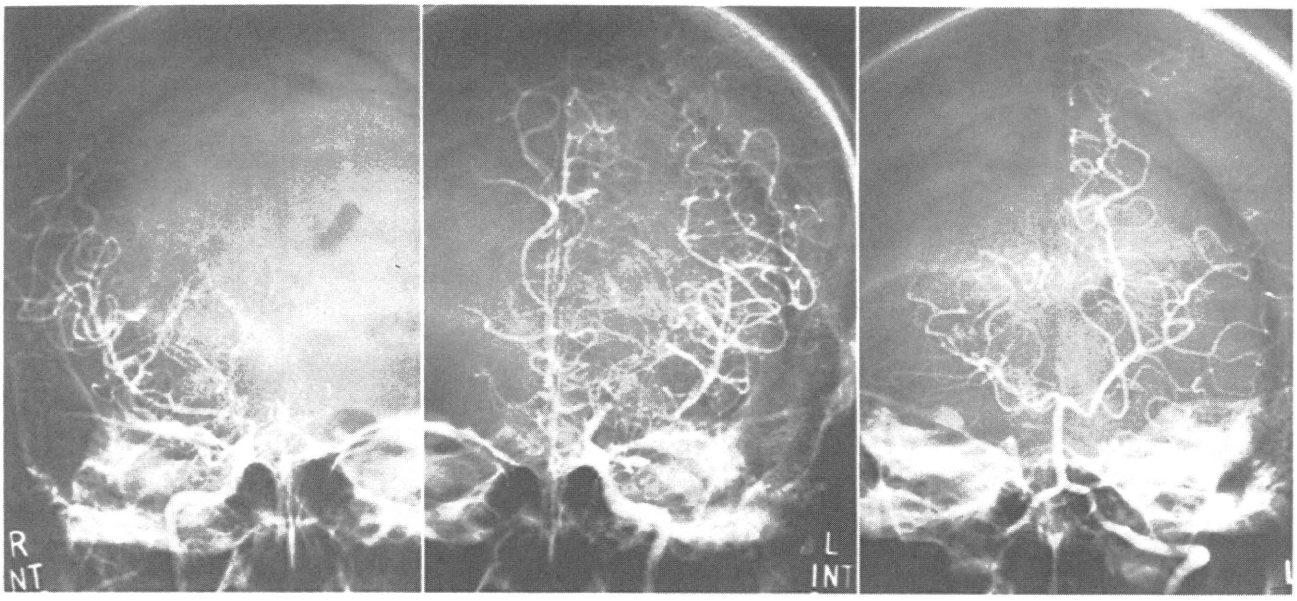
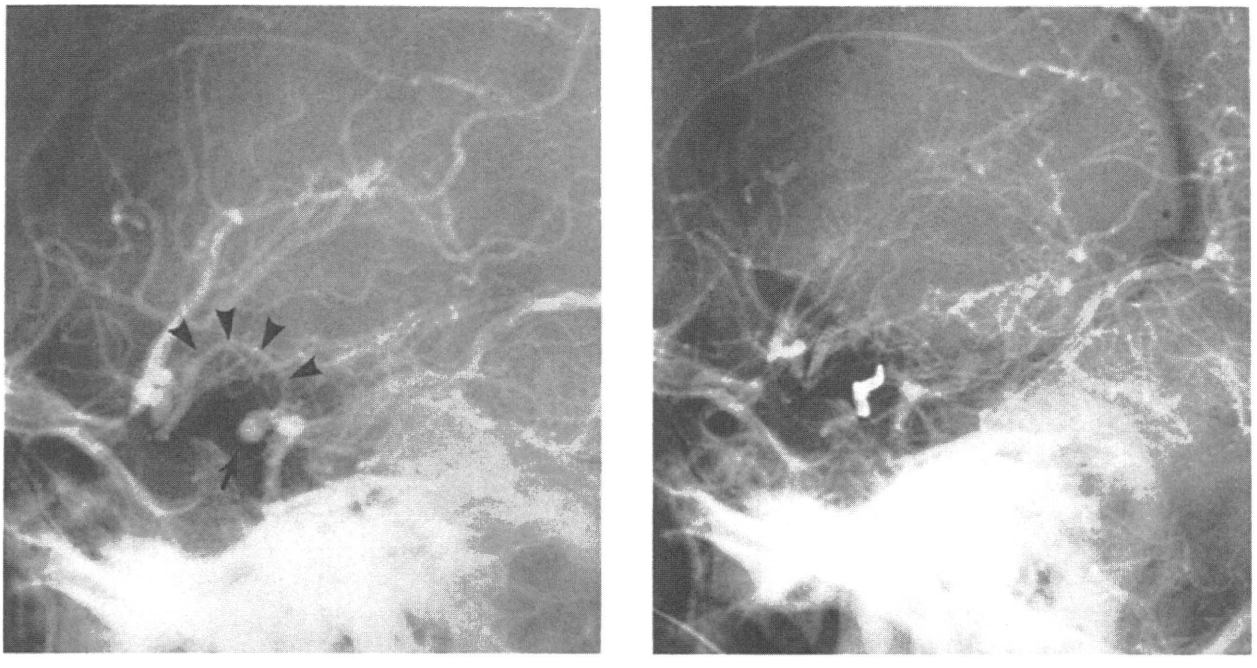


Fig. 2. Case 1. Antero-posterior views of right (left) and left (middle) CAG demonstrating bilateral stenoses of the internal carotid artery at its terminal portion and the origins of middle and anterior cerebral arteries. Left VAG (right) showing occlusion of the right posterior cerebral artery



a b

Fig. 3. Case 3. Lateral views of pre-operative (a) and postoperative (b) right VAG. A saccular aneurysm located at the left P 1–P 2 portion is seen (arrow). The left anterior and middle cerebral arteries are filled through the enlarged left posterior communicating artery (PCoA; arrowheads). Postoperatively, the aneurysm is not shown, but the left PCoA is remarkably stenotic; collateral flow to the anterior and middle cerebral arteries through the PCoA becomes poor

Illustrative Cases

Case 1

This 23-year-old woman developed a left hemiparesis with left homonymous hemianopsia. Her left hemispheres improved to nearly normal within four weeks. A CT scan (Fig. 1 a) demonstrated atrophy following infarction in the right occipital lobe. Cerebral angiography (Fig. 2) revealed bilateral narrowing of the internal carotid artery (ICA) at its terminal portion and the right posterior cerebral artery, indicating Moyamoya disease. A Xenon-CT scan (Xe-CT; Fig. 1 c) showed the hypoperfusion in the right hemisphere, especially in the occipital lobe corresponding to the infarction. The Xe-CT with acetazolamide (Diamox) challenge (Fig. 1 d) revealed the reduction of haemodynamic reserve in the fronto-parietal region bilaterally but predominantly on the right side.

She underwent right superficial temporal artery-middle cerebral artery (STA-MCA) anastomosis. One month after the first bypass surgery, left STA-MCA anastomosis was done.

Postoperatively, she exhibited left hemiparesis. A CT (Fig. 1 b) demonstrated a new low density area (LDA) in the right fronto-parietal region in which reduction of haemodynamic reserve was indicated by the pre-operative Xe-CT study. She was discharged with mild weakness in her right fingers two months after the second operation. Postoperative angiography confirmed the bypasses to be patent. Hypocapnia (minimum $PaCO_2$ = 25.4 torr) was seen during her intra- and postoperative periods. No other risk factors were noted in her peri-operative clinical course.

Case 3

This 38-year-old man suddenly developed speech difficulty and right hemiparesis. A CT scan showed a haematoma in the left thalamus penetrating into the lateral ventricle. Cerebral angiography revealed narrowing of the right ICA at its terminal portion, occlusion of the left ICA at just distal to the origin of the ophthalmic artery and so-called "moyamoya vessels". A saccular aneurysm was also demonstrated at the left P_1–P_2 portion (Fig. 3 a).

Four months after the ictus, his hemiparesis recovered markedly and he underwent clipping of the neck of the aneurysm via the subtemporal approach. Left STA-MCA anastomosis was done at the same time.

Postoperatively, his hemiparesis deteriorated and a CT showed a large LDA in the left frontal lobe. Postoperative angiography (Fig. 3 b) revealed marked narrowing of the left posterior communicating artery (PCoA) and poor filling of the anterior circulation through the PCoA.

The infarction was considered to be caused by reduction of the blood flow through the PCoA, being a vital collateral to the infarcted area. In this case, intra-operative hypercapnia and hypotension/hypovolaemia were noted and hypocapnia was seen postoperatively. His hemiparesis did not improve in the follow-up period.

Discussion

Moyamoya disease is a clinical entity characterized by bilateral spontaneous occlusion of the ICA at its terminal portion[7, 11]. The age distribution at onset shows two peaks in the first and fourth decades[12, 14]. It is not clear whether these two types have the same pathogenesis and pathophysiology. It is also not clear whether decreased haemodynamic reserve or autoregulation affects the operative results in adult cases as in juvenile cases.

In contrast to juvenile cases, the majority of adult cases are associated with intracranial bleeding[7, 12, 14]. Cerebral ischaemic attacks are seen less frequently in adult cases than juvenile cases, even when they are presented by cerebral ischaemia. Therefore, the haemodynamic conditions in adult cases are considered to be more stable than those in juvenile patients. However, the incidence of peri-operative haemodynamic complications was 14.5% (8/55) in adult patients of our series, similar to that in juvenile patients (16.9%, 21/124) (manuscript submitted). Moreover, there was no difference in the incidence of such a complication between the haemorrhagic type and the ischaemic type.

There are two major points concerning the cause of peri-operative haemodynamic complications in adult Moyamoya disease. The first is the involvement of non-surgical haemodynamic factors[5, 8–10, 13]. In our series, although the statistical analysis could not clarify the relevance of such factors to haemodynamic complications, some risk factors were noted in all of the eight patients with a peri-operative complication. This indicates that these haemodynamic risk factors promote cerebral hypoperfusion in adult patients as well as in juvenile patients. Even if patients had no history of cerebral ischaemic attacks, their haemodynamic reserve is often reduced, as assessed by CBF studies. Moreover, a CBF study with Diamox challenge is useful for evaluating the risk of peri-operative complications (manuscript submitted). Therefore, an adequate CBF study should be done to the extent possible in all the patients with Moyamoya disease, although it may be difficult in the patients requiring urgent surgery for intracranial bleeding. Peri-operative management under normocapnia and normotension would be better to prevent peri-operative complications even in adult cases[10].

The other point is the influence of operative procedures. In our series, surgical factors that might be involved in the peri-operative complications were not seen with bypass surgeries. Sparing of vital collateral vessels is essential to prevent peri-operative ischaemic brain damage and to provide a better outcome. Minimum brain retraction is also important. In our two cases (Cases 4 and 8), a self-retaining retraction system was used and the retraction force was considered to be usual or relatively low in a retrospective review of the operation video. However, an infarction arose in the retracted area in Case 4 and postoperative neurological

deterioration continued for a month in Case 8. Brain tissue in Moyamoya disease would be in a hypoperfusion state and vulnerable to retraction or compression. In addition, when craniotomies are required for intracranial bleeding, revascularizations should be simultaneously done to improve such a hypoperfusion state.

In Moyamoya disease, in contrast with revascularizations for atherosclerotic occlusive cerebrovascular disease, EC/IC bypass operations could not achieve rapid improvement of the cerebral circulation. It takes several months to improve cerebral circulation after bypass surgery. Therefore, we should bear in mind that haemodynamic complications may arise within the area in which haemodynamic reserve was initially decreased, even where revascularization has been done.

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Comparison of 3.0- and 1.5-T Three-dimensional Time-of-Flight MR Angiography in Moyamoya Disease: Preliminary Experience[1]

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Purpose: To prospectively compare 3.0- and 1.5-T three-dimensional (3D) time-of-flight (TOF) magnetic resonance (MR) angiography in patients with moyamoya disease, with special emphasis on the visualization of abnormal netlike vessels (moyamoya vessels).

Materials and Methods: Study protocols were approved by the local ethics committee; written informed consent was obtained from all patients. The study included 24 consecutive patients with moyamoya disease (four male and 20 female patients). Patients ranged in age from 17 to 66 years (mean age, 41 years). Moyamoya disease had been diagnosed in all patients before they were entered into the study. All patients underwent 3D TOF MR angiography at both 3.0 and 1.5 T; imaging examinations were performed within 14 days of each other. Maximum intensity projections (MIPs) obtained with MR angiography performed at both 3.0 and 1.5 T were evaluated by two neuroradiologists; the visualization of moyamoya vessels was graded according to a 4-point scale. For both 3.0- and 1.5-T imaging, the number of high-signal-intensity areas and the summation of cross-sectional areas of high signal intensity on source images obtained at the same level of MR angiography were compared quantitatively by using the Wilcoxon matched-pair signed-rank test.

Results: Moyamoya vessels were better visualized on MIPs obtained with 3.0-T imaging than on MIPs obtained with 1.5-T imaging ($P < .001$). At the identical level of the source image, 3.0-T imaging depicted more high-signal-intensity areas than did 1.5-T imaging. Wider cross-sectional areas of moyamoya vessels were visualized with 3.0-T imaging than with 1.5-T imaging ($P < .001$).

Conclusion: Moyamoya vessels are better depicted with MR angiography at 3.0 T than at 1.5 T.

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Moyamoya disease is a rare cerebrovascular occlusive disease of unknown origin and is characterized by stenosis or occlusion of both internal carotid arteries (ICAs) at the supraclinoid portion (1,2). Although this disease occurs predominantly in Asian populations, particularly in Japan, it has also been reported in other countries (3–5). The major symptoms of moyamoya disease are related to age, with transient ischemic attack often seen in pediatric patients and intracranial hemorrhage often seen in adults.

The principal angiographic feature of moyamoya disease is bilateral stenosis or occlusion of the supraclinoid portions of the ICAs, potentially extending to the proximal portions of the anterior cerebral arteries and middle cerebral arteries (MCAs), with the presence of abnormal netlike vessels (moyamoya vessels) in the basal areas (1). Leptomeningeal collateral vessels from the posterior cerebral arteries or transdural collateral vessels from the external carotid arteries may also be present (1).

With the development of magnetic resonance (MR) imaging techniques, the diagnosis of moyamoya disease with MR imaging and MR angiography has become possible (6). When ICA occlusion and moyamoya vessels are demonstrated at MR angiography, conventional angiography is unnecessary, particularly in pediatric patients (6). Interpretation of high-quality images is crucial when diagnosing moyamoya disease with MR imaging without conventional angiography. Precise evaluation of abnormal vascular networks in the basal ganglia, in addition to vascular occlusion, is essential for securing a definitive diagnosis of moyamoya disease (6–8).

MR imaging techniques with 3.0-T imaging have gradually become prevalent. Imaging at 3.0 T provides a better signal-to-noise ratio, which increases approximately linearly with constant magnetic induction field from 1.5- to 3.0-T imaging (9,10). The T1 relaxation time increases at higher magnetic field strengths, and this produces improved vessel-tissue contrast at 3.0-T imaging (11–13). A better signal-to-noise ratio and increased T1 relaxation time at 3.0-T imaging contribute to the improved quality of MR angiography. Furthermore, Willinek et al (14) demonstrated that, in the diagnosis of cerebrovascular occlusive disease, high-spatial-resolution three-dimensional (3D) time-of-flight (TOF) MR angiography at 3.0 T is superior to that at 1.5 T. To our knowledge, however, no reports have focused on the comparison of 3.0- and 1.5-T MR angiography in patients with moyamoya disease.

Thus, the purpose of our study was to prospectively compare 3.0- and 1.5-T 3D TOF MR angiography in patients with moyamoya disease, with special emphasis on the visualization of moyamoya vessels.

Scores in the Depiction of Moyamoya Vessels

Patient No.	1.5-T Field Strength	3.0-T Field Strength
1	2	3
2	2	3
3	1	2
4	2	3
5	2	2
6	2	2
7	3	3
8	1	2
9	2	3
10	2	2
11	3	3
12	3	3
13	2	3
14	2	3
15	2	3
16	1	3
17	2	3
18	2	3
19	2	3
20	1	3
21	1	3
22	2	3
23	3	3
24	1	3

Note.—Scores used in the depiction of moyamoya vessels are as follows: 3 = excellent (vessel segments were clearly and continuously visualized, and vessel-tissue contrast is high), 2 = visible (vessel segments are visualized and adequate for a confident diagnosis, but vessel-tissue contrast is not particularly high), 1 = scarcely visible (vessel segments were visualized but inadequate for diagnosis), and 0 = not visible.

Materials and Methods

Study Design and Patients

A prospective study was performed with 24 consecutive patients with moyamoya disease (four male and 20 female patients) between December 2003 and September 2004. Moyamoya disease had been diagnosed in all patients with conventional angiography before they were entered into our study (6). The mean patient age was 41 years (age range, 17–66 years). Patients were initially suspected of having moyamoya disease due to transient ischemic attack or cerebral infarction (n = 14), intracranial hemorrhage (n = 9), or incidental findings at MR imaging after a traffic accident (n = 1). Of the 24 patients, seven (29%) had not undergone any surgical synangiosis procedure. Seventeen of the 24 patients (71%) had undergone creation of a superficial temporal artery (STA)–MCA anastomosis combined with encephalomyosynangiosis (n = 15) or encephaloduroarteriosynangiosis (n = 2). All patients had undergone regular follow-up. In these 17 patients, the mean postoperative duration at the time of our study was 89 months (range, 7–288 months).

Study protocols were approved by the local ethics committee, and all pa-

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Abbreviations:
ICA = internal cerebral artery
MCA = middle cerebral artery
MIP = maximum intensity projection
STA = superficial temporal artery
3D = three dimensional
TOF = time of flight

Author contributions:
Guarantors of integrity of entire study, all authors; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; literature research, Y.M., K.K., M.K., A.Y., K.N., T.H., H.F.; clinical studies, Y.F., K.K., T.O., K.N., T.H., H.F.; statistical analysis, Y.F., Y.M., M.K., A.Y., K.N., N.H., H.F., K.T.; and manuscript editing, Y.F., Y.M., T.O., N.H., H.F., K.T.

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tients provided written informed consent before entering the study. When the patient was a minor, additional written informed consent was also obtained from the parent.

MR Imaging

Our study was performed with 3.0-T (Magnetom Trio; Siemens, Erlangen, Germany) and 1.5-T (Magnetom Symphony; Siemens) MR units. Circular polarized head coil arrays were used for both MR units. The following parameters were used for 3.0-T MR angiography: 22.0/3.7 (repetition time msec/echo time msec), 20° flip angle, 0.8-mm-thick sections, 200 × 200-mm field of view with a 512 × 208 matrix, effective voxel size of 0.39 × 0.96 × 0.8 mm, and acquisition time of 5 minutes 51 seconds. The following parameters were used for 1.5-T MR angiography: 35/7, 0.8-mm-thick sections, 20° flip angle, 200 × 200-mm field of view with a 512 × 208 matrix, effective voxel size of 0.39 × 0.96 × 0.8 mm, and acquisition time of 6 minutes 21 seconds. The repetition time and echo time could not be matched because of the limitations of specific absorption rate with the 3.0-T MR system.

Image Analysis

Transverse and lateral maximum intensity projections (MIPs) obtained with 3.0- and 1.5-T MR angiography were independently assessed by two neuroradiologists (Y.F. and Y.M., with 8 and 19 years of experience, respectively). Lateral MIPs were reconstructed with data from the ipsilateral hemisphere. To evaluate the visibility of moyamoya vessels under identical circumstances, we evaluated only transverse and bilateral MIP images instead of reviewing all the angles of MIP images. The visibility of moyamoya vessels was assessed and scored as follows: 3, excellent (vessel segments were clearly and continuously visualized, and vessel-tissue contrast appears to be high); 2, visible (vessel segments are visualized and adequate for a confident diagnosis, but vessel-tissue contrast does not appear to be particularly high); 1, scarcely visible (vessel segments were visualized but inadequate for diagnosis); and 0, not visible. Readers were blinded to field strength; discrepancies between the two readers were resolved by consensus. A consensus reading was required in one patient for 3.0-T images (4.2%) and in three patients for 1.5-T images (12.5%).

A particle-counting method was used for source images from MR angiography. With use of ImageJ software, a

Figure 1

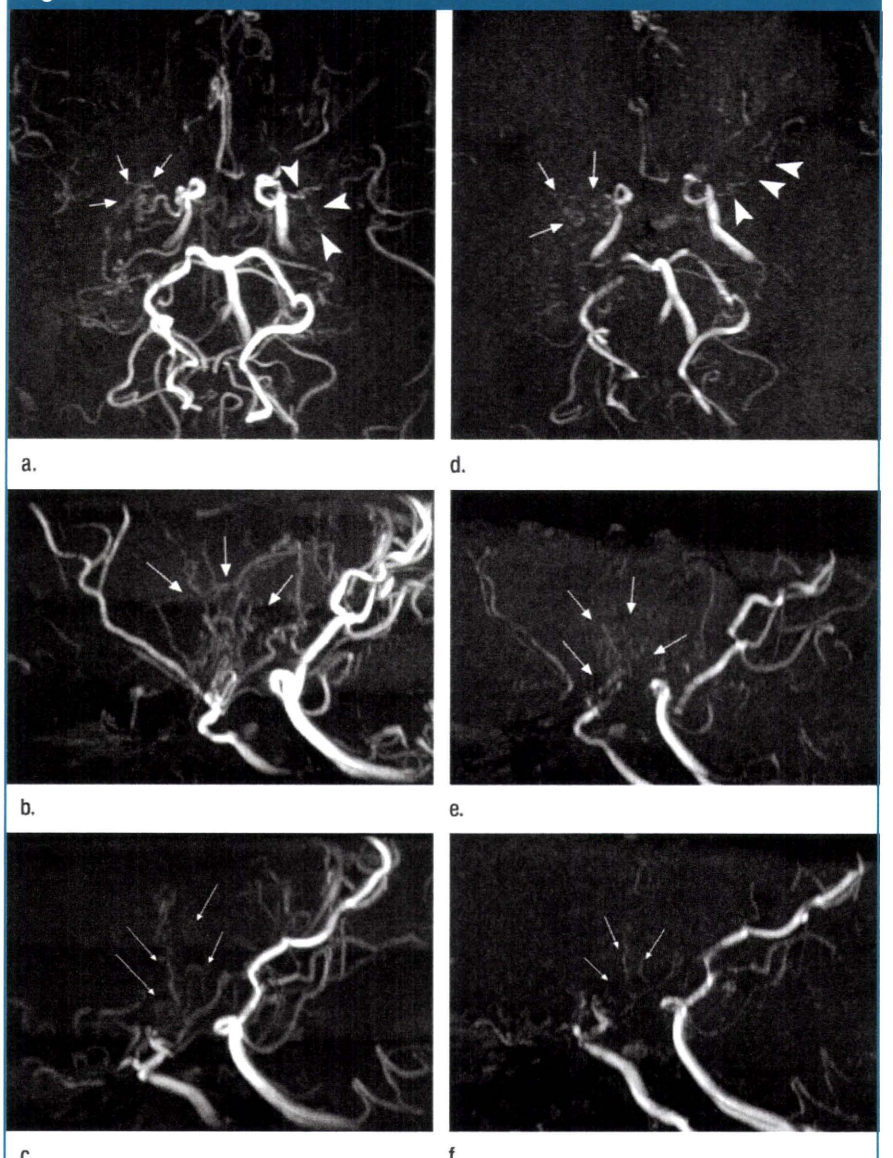

Figure 1: MIPs from 3D TOF MR angiography in a 58-year-old woman show moyamoya vessels (arrows) from ICAs. **(a)** Transverse MIP, **(b)** lateral MIP of the right side, and **(c)** lateral MIP of the left side from 3.0-T MR angiography (22.0/3.7). **(d)** Transverse MIP, **(e)** lateral MIP of the right side, and **(f)** lateral MIP of the left side from 1.5-T MR angiography (35/7). Transverse MIPs reveal more moyamoya vessels on the right side from the right ICA than on the left side. Moyamoya vessels from the right ICA are more clearly seen with 3.0-T imaging than with 1.5-T imaging. On the left side, 1.5-T MR angiography shows slight and discontinuous moyamoya vessels (arrowheads in **d**), whereas 3.0-T MR angiography shows fine moyamoya vessels (arrowheads in **a**) continuously and more clearly. MIPs from 3.0-T imaging were scored as 3 (excellent) and those from 1.5-T imaging were scored as 2 (visible).

Java-based image analysis program developed at the U.S. National Institutes of Health (*http://rsb.info.nih.gov/ij/index.html*), high signal intensity in the basal ganglia of the anterior circulation, which correspond to moyamoya vessels (1), were manually selected and semiautomatically counted by one neuroradiologist (Y.F.). Image selection from 3.0- and 1.5-T MR angiographic data obtained in the same patient was performed simultaneously, as identical section levels can be selected; this enabled comparison of images obtained at 3.0 and 1.5 T. Image selection procedures were performed with two personal computers by using ExaVision Lite software (Ziosoft, Tokyo, Japan). Regions of interest were carefully selected in bilateral basal ganglia without including any cisternal structures because major branches of anterior cerebral arteries and MCAs are located in the interhemispheric fissure and sylvian fissure, respectively. We determined the threshold for the source images with MR angiography to make the brightest part of brain parenchyma just black out to minimize the variances of the thresholds and obtained the binary data from MR angiography. The number of high signal intensities and the summation of cross-sectional areas of high signal intensity, which correspond to the cross-sectional area of moyamoya vessels, were obtained for 3.0- and 1.5-T imaging.

Statistical Analysis

For statistical evaluation, scores for MIPs obtained with MR angiography, the number of high-signal-intensity areas, and the summation of cross-sectional areas of high signal intensity were compared by using the Wilcoxon matched-pair signed-rank test with software (JMP 5.0; SAS Institute, Cary, NC). This was done because the Shapiro-Wilk test was performed for normality and the null hypothesis rejected. A P value of less than .05 was considered to indicate a statistically significant difference.

Figure 2

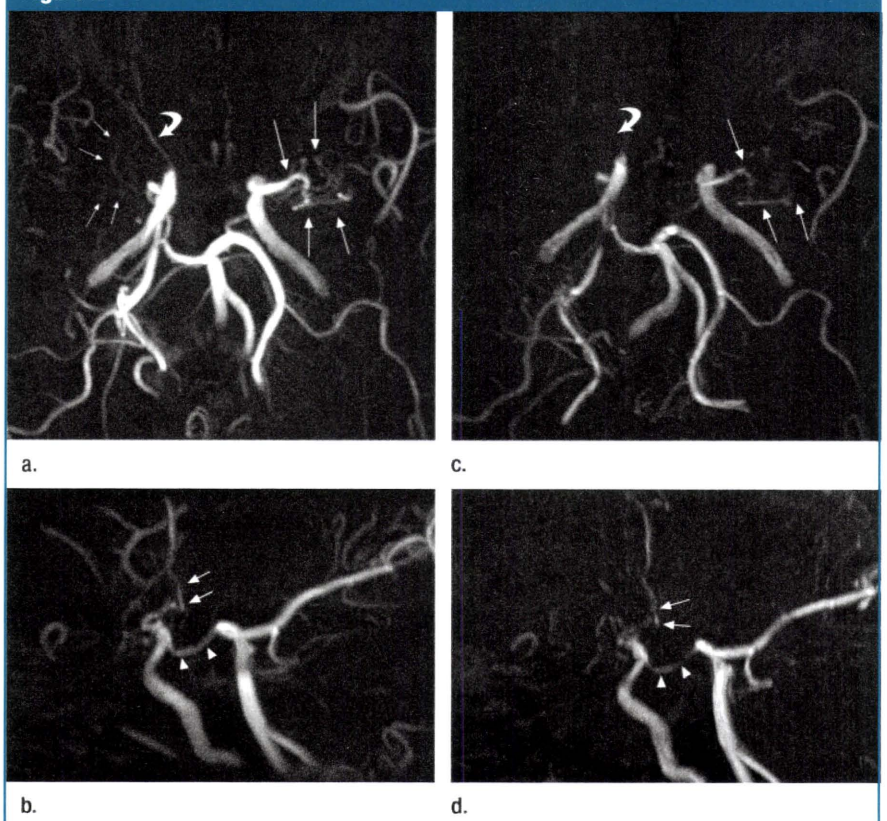

Figure 2: MIPs from 3D TOF MR angiography in a 49-year-old man. **(a)** Transverse MIP and **(b)** lateral MIP of the left side from MR angiography (22.0/3.7). **(c)** Transverse MIP and **(d)** lateral MIP of the left side from 1.5-T MR angiography (35/7). Images obtained at 3.0 T reveal prominent moyamoya vessels on the left side (long straight arrows in **a**, arrows in **b**) and scarce moyamoya vessels on the right side (short straight arrows in **a**). Images obtained at 1.5 T show moyamoya vessels on the left side (straight arrows in **c**, arrows in **d**) but no apparent moyamoya vessels on the right side. Note that the posterior communicating artery (arrowheads in **b** and **d**) and right ophthalmic artery (curved arrow in **a** and **c**) are visualized more clearly at 3.0 T than at 1.5 T. MIPs from 3.0-T imaging were scored as 3 (excellent), whereas images obtained at 1.5 T were scored as 2 (visible).

Results

MIPs were obtained with 3D TOF MR angiography in the 24 patients (Table) (Figs 1, 2). MIPs from 3.0-T MR angiography depicted moyamoya vessels more clearly than did those from 1.5-T MR angiography ($P < .001$).

The number of high-signal-intensity areas in anterior circulations (anterior cerebral artery and MCA territories) on source images obtained at both 3.0 and 1.5 T showed that the number of high-signal-intensity areas at 3.0-T imaging was greater than that at 1.5-T imaging ($P < .001$) (Figs 3, 4). Cross-sectional areas of high-signal-intensity were larger at 3.0-T imaging than at 1.5-T imaging ($P < .001$) (Fig 5).

Discussion

Our results demonstrate that moyamoya vessels are better depicted with MIPs from 3.0-T MR angiography than with those from 1.5-T MR angiography. More moyamoya vessels (in both number and cross-sectional area) were detected at 3.0-T imaging than at 1.5-T imaging. The particle-counting method with use of ImageJ software has been applied to cell counting in biologic studies (15,16). In our study, we used this method in the postprocessing of MR angiographic data to assess moyamoya vessels. This method may be useful for objective and longitudinal evaluations

Figure 3

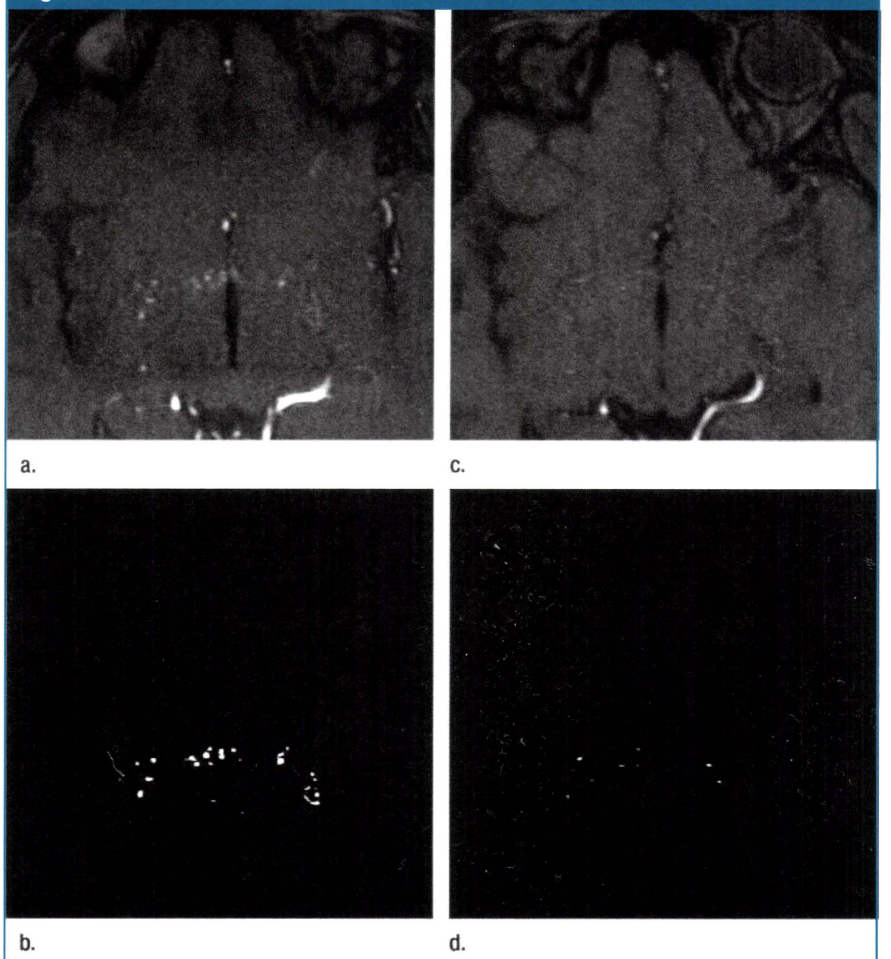

Figure 3: Images obtained in a 58-year-old woman. Source images from MR angiography obtained at the same level at **(a)** 3.0 T (22.0/3.7) and **(c)** 1.5 T (35/7). More high-signal-intensity areas in both basal ganglia were seen at 3.0-T imaging than at 1.5-T imaging. The area of anterior circulation was selected and changed into binary data. The number of high-signal-intensity areas was calculated semiautomatically, and the total number of cross-sectional areas of high signal intensity was calculated by using software. **(b)** Binary data image obtained at 3.0 T shows more high-signal-intensity areas than **(d)** data from the source image obtained at 1.5 T.

Figure 4

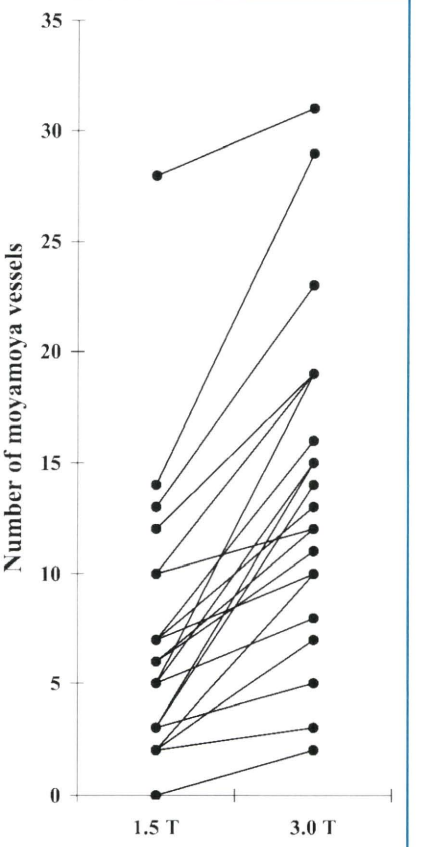

Figure 4: Graph shows the number of moyamoya vessels visualized at 3.0- and 1.5-T imaging. The moyamoya vessels were counted semiautomatically on MR angiography source images obtained at the same levels. More high-signal-intensity areas were seen at 3.0 T than at 1.5 T.

because the number and cross-sectional area of moyamoya vessels are provided.

Moyamoya disease is a rare cerebrovascular disease. In adult patients, intracerebral hemorrhage is one of the most common complications at disease onset (17–20). For patients with moyamoya disease and hemorrhage, repeat bleeding is the most crucial event that affects quality of life (21,22). The mechanisms of repeat bleeding supposedly involve rupture of moyamoya vessels. Moyamoya vessels have a tendency to contract; when that happens, the remaining moyamoya vessels receive more pressure, which leads to vessel rupture (18). Thus, observation of the appearance of moyamoya vessels at periodic follow-up MR angiography is clinically important (23,24). The results of our study demonstrate that more information about moyamoya vessels can be obtained with 3.0-T MR angiography than with 1.5-T MR angiography. This enables more precise evaluation of moyamoya vessels with regard to factors such as stenosis, dilatation, and increases or decreases in number. Our study was a preliminary study that targeted moyamoya disease. To our knowledge, this is the first study in which the visibility of moyamoya vessels has been described at both 3.0- and 1.5-T MR angiography.

One limitation of our study is that most of our patients (71%) had undergone surgical treatment. After bypass surgery (creation of STA-MCA anastomosis, encephalomyosynangiosis, and encephaloduroarteriosynangiosis), collateral arteries develop from the external cerebral artery and the amount of moyamoya vessels decreases in about 50% of patients (8). In our study, only seven patients had not undergone surgery; thus, a more precise interpretation of our results would be to say that

Figure 5

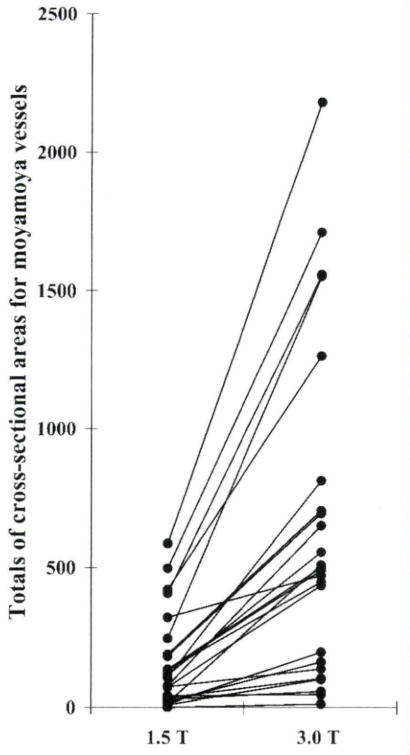

Figure 5: Graph shows the cross-sectional area of moyamoya vessels. The total cross-sectional areas for moyamoya vessels at the same level of MR angiography source images were calculated semiautomatically and compared between 3.0- and 1.5-T MR systems. Larger cross-sectional areas were visualized with 3.0-T imaging than with 1.5-T imaging. The total cross-sectional area is given as pixels.

our study demonstrated the advantages of 3.0-T imaging over 1.5-T imaging for follow-up evaluation. Although 3.0-T imaging may indeed prove advantageous in the diagnosis of moyamoya disease, larger numbers of preoperative patients should be studied in the future. In preoperative treatment planning, conventional angiography would be required because it can provide more detailed information about moyamoya vessels and other major vessels than does 3.0-T MR angiography; thus, comparative studies between 3.0-T MR angiography and conventional angiography may be needed in the future. We did not evaluate stenosis or dilatation of ICAs, anterior cerebral arteries, and MCAs because most patients had undergone conventional angiography several years before the MR examinations, which made it difficult for us to verify the findings with use of a reference standard. This is another limitation. In our study, visualization of STA-MCA bypass was not evaluated because aliasing artifacts affected STA-MCA bypass in some patients, STA-MCA bypass sites were not included in the fields of view in all patients, and most patients had undergone postoperative angiography several years before the MR examinations. Further studies may be needed to evaluate the findings of MR angiography in cases of STA-MCA bypass. Although the readers were blinded to the field strength of MR angiographic images, there were some differences in image quality of moyamoya vessels between 3.0- and 1.5-T images. It is possible that the readers were influenced by these differences.

In conclusion, moyamoya vessels are better depicted at 3.0-T 3D TOF MR angiography than at 1.5-T 3D TOF MR angiography. Radiologists must be aware of the differences, especially when patients undergo follow-up MR angiography with both 3.0- and 1.5-T MR systems.

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