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Long-term Outcomes of Combined Revascularization Surgery for Moyamoya Disease in the Elderly: A Single Institute Experience

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Abstract

The opportunity to treat older patients with Moyamoya disease (MMD) is increasing. However, the surgical outcomes after combined direct and indirect revascularization for elderly patients with MMD are not fully understood, especially for those ≥60 years old. This retrospective study examined 232 consecutive hemispheres of 165 adults with MMD who underwent combined revascularization. Clinical features and surgical outcomes were compared between the elderly (≥60 years) and nonelderly group (<60 years). Thirteen (5.6%, 64.4 ± 4.0 years old) and 219 hemispheres (94.4%, 40.2 ± 10.8 years old) were included in the elderly and nonelderly group, respectively. The proportion of clinical presentations before surgery did not differ. However, the prevalence of hypertension and hyperlipidemia was significantly higher in the elderly group than in the nonelderly group. Meanwhile, hyperthyroidism was observed only in the nonelderly group. No significant intergroup differences were observed in the incidence of perioperative complications occurring within four weeks postsurgery. Notably, the elderly group was more prone to develop perioperative intracerebral hemorrhage (odds ratio (OR) 3.14, 95% confidence interval (CI) 0.45-13.5) than the nonelderly group. During a median follow-up period of 7.8 years, the incidence of stroke recurrence occurring later than four weeks postsurgery was not significantly different between the groups (hazard ratio, 1.19; 95% CI 0.133-10.6). The prevalence of independent outcomes (76.9% vs. 90.4%, P = 0.14) and mortality (7.7% vs. 1.4%, P = 0.21) did not differ significantly between the elderly and nonelderly groups, respectively. Perioperative intracerebral hemorrhage may be common in the elderly and should be considered to achieve a favorable surgical outcome.

Keywords: elderly, Moyamoya disease, revascularization, surgical outcome

Introduction

Moyamoya disease (MMD) is a cerebrovascular disorder of unknown etiology characterized by progressive stenoocclusive changes at the terminal segment of the internal carotid arteries (ICA) and abnormal vascular network formation at the base of the brain.[1,2] The age distribution is one of the unique clinical features of MMD, characterized by two peaks of age distribution at 5 years and about 40 years.[3] Although surgical revascularization is recommended as a reasonable treatment of choice for MMD of all ages presenting with cerebral ischemic or hemorrhagic symptoms,[4] "age" has been reported as a significant factor influencing the incidence of perioperative complication, including focal cerebral hyperperfusion and perioperative stroke.[5-8] In addition, age-dependent clinical response to direct versus indirect revascularization procedures has been suggested since the indirect procedure alone is insufficient and a direct or combined procedure is necessary for adult patients.[2,4,9] Recent Japanese-nationwide, prospective registry revealed increasing number of patients in older population presented for MMD diagnosis and treatment probably due to the aging population and decreasing number of birth rate in Japan.[10] However, limited number of studies have demonstrated short- and long-term outcomes after surgical revascularization in elderly patients

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with MMD, especially in ≥60 years old.[11-13)]

Therefore, this study retrospectively investigated short-(perioperative) and long-term outcomes after combined direct and indirect revascularization for MMD in the elderly population (≥60 years old) performed at our hospital. For an excellent understanding of the surgical outcome of MMD in the elderly, we compared the clinical features and short-/long-term surgical outcomes between the "elderly" and "nonelderly" groups as defined below. The results of this study provide valuable information and potentially guide the establishment of future therapeutic strategies for MMD in the elderly population.

Methods

Ethical approval

This study was approved by the Institutional Review Board of our hospital (approval number: 015-0086). Because this retrospective observational study has a very low risk for the study participants, this study adopts an opt-out arrangement by providing the necessary information to make an informed decision and include safeguards to protect privacy.

Study participants

Consecutive 232 hemispheres from 165 adult patients aged ≥16 years who underwent surgical revascularization at our hospital between February 1983 and March 2023 were included. The diagnosis was made based on the diagnostic criteria established by the Research Committee on Moyamoya Disease (Spontaneous Occlusion of the Circle of Willis) in 1978 and its revised versions in 1987, 1995, 2009, 2015, and 2021.[2,14)] To describe the clinical features of MMD in the elderly, we reviewed all clinical records, including demographics, age at surgery, clinical presentation, angiographical disease stages, and comorbidities (i.e., hypertension, hyperlipidemia, diabetes mellitus, and hyperthyroidism) in a hemisphere-based manner, treating each hemisphere as an independent entity. Thus, the 232 hemispheres included in this study were divided into two groups (elderly and nonelderly) based on the age at which each hemisphere underwent surgical revascularization. The "elderly" group underwent surgical revascularization at the age of ≥60 years, whereas the "nonelderly" group underwent revascularization at the age of <60 years.

Surgical procedure and management protocol

All patients underwent precise neuro-radiological examinations, including magnetic resonance (MR) imaging/angiography, computed tomography (CT), cerebral angiography, and N-isopropyl-p-[^{123}I] iodoamphetamine single-photon emission computed tomography (^{123}I-IMP-SPECT) before surgery. Surgical revascularization was predominantly indicated for symptomatic hemispheres following the concurrent management guidelines recommended in Japan.[2,4)] The surgical procedure of combined revascularization was standardized as previously described.[5,15,16)] Briefly, single or double-barrel (exceptionally triple-barrel) direct superficial temporal artery (STA) to middle cerebral artery (MCA, M4) anastomosis combined with indirect pial synangiosis using the dura mater, temporal muscle, and pericranium was the principal procedure in our department. Sufficient hydration, prompt blood pressure control, and hemoglobin concentration maintenance were performed, and single antiplatelet, anti-inflammatory agents, such as minocycline,[17)] and antiepileptics were administered perioperatively as described elsewhere.[5,15)]

Short-term surgical outcome (perioperative complication)

In this study, transient and permanent perioperative neurological deterioration and wound complication, including wound infection or necrosis requiring re-admission or surgical intervention, within four weeks postsurgery were regarded as perioperative complications. As described elsewhere, the underlying pathology of perioperative neurological deterioration was evaluated based on the radiological examinations, including CT imaging obtained at postoperative days (POD) 0, 1, 7, and 14 (For intracerebral hemorrhage; ICH, and temporal muscle swelling),[18,19)] MR imaging and angiography obtained at POD 2 (For cerebral infarct or other parenchymal pathology, including cortical vasogenic edema and the patency of direct bypass),[5,15)] and ^{123}I-IMP-SPECT obtained at POD 0-2 and 7 (For radiological focal HYPER- or HYPO-perfusion determined by qualitative evaluation based on the previously reported criteria).[20,21)] The incidence of perioperative cerebral infarct, ICH, and wound troubles were used to assess the short-term surgical outcome.

Long-term surgical outcome

We further studied the incidence of stroke recurrence occurring later than four weeks postsurgery and the modified Rankin Scale (mRS) at the latest visit as a performance status measure to evaluate long-term outcomes. Suppose long-term in-person visits were not feasible, we conducted a phone survey to gather information about long-term outcomes.

Statistics

All data were analyzed using standard descriptive statistics. Continuous variables are expressed as mean ± standard deviation (SD) or median and interquartile range (IQR). For categorical variables, the number of participants and percentages were calculated. The categorical variables were compared using Fisher's exact test or the chi-squared test, whereas the continuous variables were compared using the Mann-Whitney U test (for non-normally distributed data) or unpaired Student's t-test (for normally distributed data). The OR and the corresponding 95% CI for the ob-

Table 1 Baseline demographic and clinical characteristics

	Total	Elderly (≥60)	Nonelderly (<60)	P-value
Hemispheres, n	232	13	219	
Age at surgery, years, SD	42 ± 12	64 ± 4.0	40 ± 11	*<0.0001*
Female, n (%)	177 (76.3)	10 (76.9)	167 (76.3)	0.96
Comorbidities, n (%)				
Hypertension, n (%)	96 (41)	10 (77)	86 (39)	*0.015*
Diabetes mellitus, n (%)	23 (9.9)	2 (15)	21 (9.6)	0.50
Hyperlipidemia, n (%)	36 (16)	5 (39)	31 (14)	*0.027*
Hyperthyroidism, n (%)	10 (4.3)	0 (0)	10 (4.6)	N/A
Clinical presentation				
Cerebral infarct, n (%)	52 (22)	4 (31)	48 (22)	0.46
TIA, n (%)	94 (41)	3 (23)	91 (42)	0.20
ICH, n (%)	38 (16)	4 (31)	34 (16)	0.16
Asymptomatic, n (%)	16 (6.9)	2 (15)	14 (6.4)	0.23
Suzuki's Angiographical stage, mean [IQR]	3 [3-4]	4 [3-4]	3 [3-4]	0.12
Bilateral disease, %	209 (90)	11 (85)	198 (90)	0.50
Surgery				
Combined bypass, n (%)	228 (98)	13 (100)	215 (98)	N/A
Direct bypass, n (%)	4 (1.7)	0 (0.0)	4 (1.8)	N/A

SD, standard deviation; TIA, transient ischemic attack; ICH, intracranial hemorrhage; IQR, interquartile range; N/A, not applicable

served events of interest were obtained using the univariate logistic regression analysis. Kaplan-Meier analysis was performed to describe the probability of stroke recurrence as a long-term outcome measure. A survival curve comparison between the groups was conducted using the log-rank test. The level of statistical significance was set at $P < 0.05$. Statistical analyses were performed using the GraphPad Prism software (version 10.0.2; San Diego, CA, USA).

Results

Clinical characteristics of MMD in the elderly

Out of the consecutive 232 adult hemispheres treated with combined revascularization, except for four hemispheres treated with direct revascularization in our hospital between 1983 and 2023, 13 hemispheres (5.6%) were included in the "elderly" group (≥60 years old) and 219 hemispheres (94.4%) in the "nonelderly" group (<60 years old). Demographic and baseline characteristics are summarized in Table 1. Notably, the mean age was 64.4±4.0 (range: 60-71) and 40.2±10.8 (range: 16-59) years old in the elderly and nonelderly group at surgery, respectively. The prevalence of comorbidities, such as hypertension (76.9% vs. 39.3%) and hyperlipidemia (38.5% vs. 14.2%), were significantly high in the elderly group, whereas hyperthyroidism was observed only in the nonelderly group (0% vs. 4.6%). No significant differences were observed in clinical presentation, angiographical disease stage, or bilateral/unilateral disease between the two groups.

Short-term surgical outcome

The incidences of perioperative complications occurring within four weeks postsurgery are summarized in Table 2. The incidence of cerebral infarct was 7.7% (one hemisphere) and 5.5% (12 hemispheres) in the elderly and nonelderly group, respectively (OR, 1.44; 95% CI, 0.08-8.29), and that of ICH was 15.4% (two hemisphere) and 5.5% (12 hemispheres) in the elderly and nonelderly groups, respectively (OR, 3.14; 95% CI, 0.45-13.5). No wound troubles were observed in the elderly group (0%), in contrast to the nonelderly group (5.5%, 12 hemispheres). Overall, the incidence of perioperative surgical complications was 23.1% (three hemispheres) and 16.4% (36 hemispheres) in the elderly and nonelderly groups, respectively (OR, 1.53; 95% CI, 0.33-5.28). Notably, the elderly group showed a trend toward a higher incidence of perioperative ICH than cerebral infarction, as shown in Fig. 1A, depicting each OR and 95% CI of the observed perioperative complications as a short-term surgical outcome measure. The mRS deterioration was absent in the elderly group during discharge, while 1.4% of patients (3 hemispheres) in the nonelderly group showed mRS deterioration (Table 2).

Table 2 Short- and Long-term outcome of revascularization surgery for adults with moyamoya disease

Variables	Total	Elderly (≥60)	Nonelderly (<60)	Odds ratio (95% CI)	P-value
Hemispheres, n	232	13	219		
Short-term surgical outcomes					
Perioperative Complication, n (%)	39 (17)	3 (23.1)	36 (16)	1.53 (0.33-5.3)	0.54
Infarct, n (%)	13 (5.6)	1 (7.7)	12 (5.5)	1.44 (0.08-8.3)	0.74
Hemorrhage, n (%)	14 (6.0)	2 (15.4)	12 (5.5)	3.14 (0.45-14)	0.17
Wound trouble, n (%)	12 (5.2)	0 (0.0)	12 (5.5)	N/A	
mRS deterioration after peri-operative complication, n (%)	3 (1.3)	0 (0.0)	3 (1.4)	N/A	
Long-term clinical outcomes					
Follow-up years, mean (range)	7.8 (0-39)	6.9 (1.4-14)	7.8 (0-39)	N/A	0.48
Latest mRS, median (range)	0 (0-6)	0 (0-6)	0 (0-6)	N/A	0.31
mRS 0-2, n (%)	208 (90)	10 (77)	198 (90)	N/A	0.14
mRS 6, n (%)	4 (1.7)	1 (7.7)	3 (1.4)	N/A	0.21
Stroke recurrence, n (%)	16 (6.9)	1 (7.7)	15 (6.8)	N/A	0.92

mRS; modified Rankin Scale, CI; confidence interval, N/A, not applicable

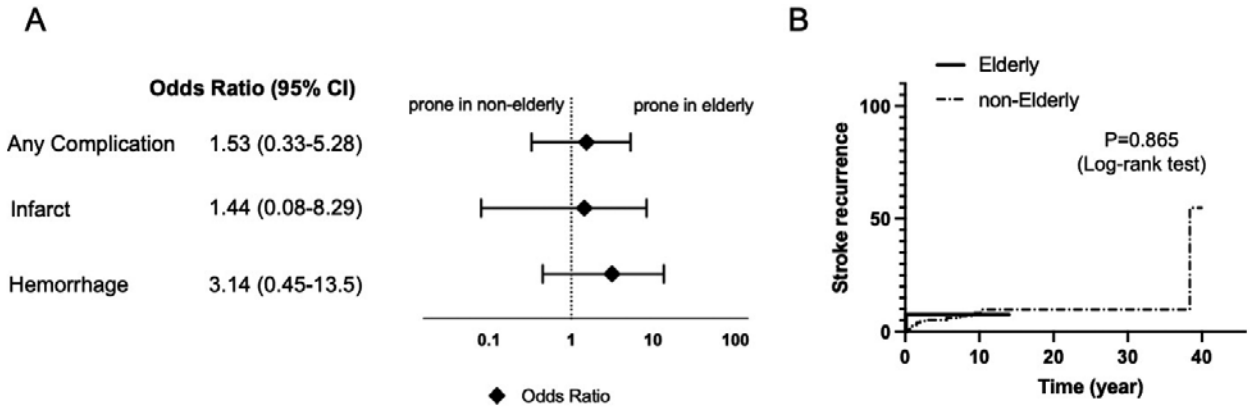

Fig. 1 Univariate logistic regression analysis of the incidence of perioperative complications (A), and survival curves for the stroke recurrence after revascularization surgery (B) between elderly and nonelderly patients with Moyamoya disease.

Long-term surgical outcome

The incidence of stroke recurrence occurred later than four weeks postsurgery and the modified Rankin Scale (mRS) at the latest visit are summarized in Table 2. Kaplan-Meier analysis of stroke recurrence probability (Fig. 1B) revealed 10-year stroke-free survival rates of 84.6% and 92.5% in elderly and nonelderly groups, respectively. Survival curve comparisons revealed no significant differences between the two groups (hazard ratio (HR) in the elderly to the nonelderly group, 1.19; 95% CI 0.133-10.6, P = 0.865; Fig. 1B). During a median (IQR) follow-up period in 6.9 (1.4-13.8) years, 76.9% (10 out of 13 hemispheres) of the elderly group showed a favorable outcome (mRS scores 0-2). Whereas, during a median (IQR) follow-up period in 7.8 (0.0-39.4) years, 90.4% (198 out of 219 hemispheres) of the nonelderly group showed a favorable outcome (mRS scores 0-2). The mortality (mRS6) during the long-term follow-up period between the two groups (7.7% vs. 1.4% in the elderly vs. nonelderly groups, P = 0.21) did not significantly differ. The underlying condition of these mRS6 outcomes was ICH in all four hemispheres.

Surgical outcome after combined revascularization for MMD in patients over 60 years old

To further clarify the surgical outcomes after STA-MCA anastomosis combined with indirect revascularization for MMD in the elderly, especially in patients above 60 years, the short- and long-term surgical outcomes in the 13 hemispheres of the elderly group are intricately summarized in Table 3. Notably, two patients in the elderly group had perioperative ICH, which developed on postoperative days 0 and 2, respectively. One of these two patients, a 68-year-old man with symptomatic MMD (Suzuki's angiographical stage 4, Table 3, case number 1) underwent STA-

Table 3 Summary of clinical features and surgical outcomes of moyamoya disease in the elderly group

Case No.	Age	Sex	Side	Clinical presentation	Stage	Comorbidities	Perioperative complication					Long-term outcome		
							All stroke	Infarct	ICH	Wound trouble	mRS change	Follow-up duration (year)	Stroke recurrence	Latest mRS
1	68	M	R	Infarct	4	HT	yes	no	yes	no	2→2	10.0	no	2
2	69	F	L	Infarct	5	none	yes	yes	no	no	5→5	2.6	no	5
3	63	F	L	TIA	3	HT, HL	no	no	no	no	0→0	13.8	no	0
4	71	F	L	TIA	4	none	no	no	no	no	0→0	2.9	no	0
5	62	F	R	ICH	4	HL	no	no	no	no	0→0	2.7	no	0
6	69	M	R	Infarct	6	HT, DM, HL	no	no	no	no	0→0	2.5	no	0
7	61	F	R	Asymptomatic	3	HT, DM, HL	no	no	no	no	0→0	11.6	no	0
8	67	M	R	Infarct	4	HT, DM, HL	no	no	no	no	0→0	10.6	no	0
9	60	F	R	Asymptomatic	4	HT	no	no	no	no	2→2	9.8	no	1
10	62	F	L	ICH	3	none	no	no	no	no	4→4	9.4	no	3
11	65	F	L	ICH	3	HT	no	no	no	no	1→1	8.2	yes	6
12	60	F	R	ICH	3	HT	yes	no	yes	no	0→0	4.3	no	0
13	60	F	L	TIA	4	HT	no	no	no	no	0→0	1.4	no	0

M; male, F; female, R; right, L; left, TIA; transient ischemic attack, ICH; intracerebral hemorrhage, Stage; Suzuki's angiographical stage, HT; hypertension, HL; hyperlipidemia, DM; diabetes mellitus, mRS change; modified Rankin Scale change by perioperative complication

MCA single barrel anastomosis combined with encephaloduro-myo-arterio-pericranio-synangiosis (EDMAPS) for the right hemisphere with cerebral infarct. On postoperative day 0, he developed dysarthria and ataxia with subarachnoid hemorrhage in the right sylvian and basal cistern and thin subdural hematoma at the site of STA-MCA anastomosis. No cerebral hyperperfusion was noted (SPECT data unavailable). He was observed conservatively and discharged without mRS deterioration (Fig. 2A). The other patient, a 60-year-old woman with past right temporal lobe hemorrhage (Table 3, case number 12) underwent STA-MCA double barrel anastomosis and EDMAPS on the right hemisphere. On postoperative day 2, she developed severe left hemiparesis with intracerebral hematoma at the site of STA-MCA anastomosis. Diffusion weighted image showed no evidence of cerebral infarct, and IMP-SPECT showed hypoperfusion on the same day, suggesting local vasogenic edema without cerebral hyperperfusion.[22] She was conservatively treated and recovered by rehabilitation (Fig. 2B). In addition, one patient (Table 3, case number 11) in the elderly group who initially developed posterior hemorrhage in the left periventricular region developed rebleeding in the left cerebral hemisphere.[23] Thus, after five weeks of STA-MCA double barrel anastomosis and EDMAPS for the left Suzuki's angiographical stage 3 hemisphere without perioperative complication, she developed lethal ipsilateral intracerebral hemorrhage including the left periventricular region at home (imaging data unavailable). She was conservatively treated in a rural hospital and died after 8 years of hospitalization.

Discussion

In the present study, we demonstrated the clinical characteristics, incidence of perioperative complications, and long-term clinical outcomes of elderly patients with MMD, especially those aged ≥60 years. The clinical presentation of MMD was similar in the elderly and nonelderly groups. In the elderly group, comorbidities, such as hypertension (76.9%) and hyperlipidemia (38.5%), were frequently observed, while hyperthyroidism was not. Although statistically not significant, the incidence of perioperative ICH was high in the elderly group (OR, 3.14; 95% CI, 0.45-13.5). The 10-year stroke-free survival rate, as a long-term surgical outcome measure, was also comparable between the elderly and nonelderly groups (84.6% and 92.5%). Thus, the HR for the stroke recurrence occurring later than four weeks postsurgery was not significantly higher in the elderly group compared to the nonelderly group (1.19, 95% CI 0.133-10.6). In addition, during a median follow-up period of 7.8 years, the favorable long-term functional outcome (mRS0-2, 76.9% vs. 90.4%) and mortality rates (mRS6, 7.7% vs. 1.4%) did not significantly differ between the two groups, respectively. Our observations revealed that the surgical outcomes following combined direct/indirect revascularization for adult MMD were comparable in the elderly population, suggesting that combined direct/indirect revascularization can be safely applied even in the

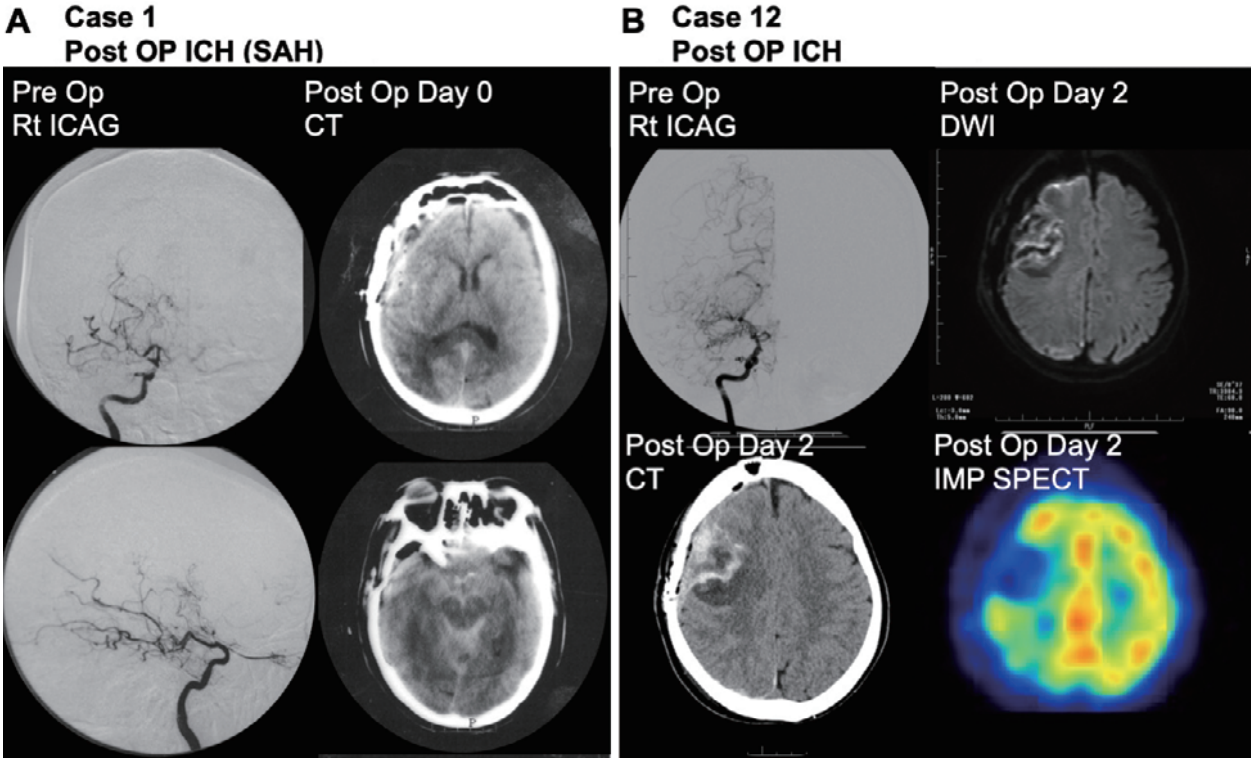

Fig. 2 Pre and postoperative imaging of elderly patients with Moyamoya disease (MMD) who developed perioperative hemorrhagic complications. (A) Case 1, 68-year-old man with MMD with right parietal lobe infarct. Pre-operative cerebral angiograms showing occlusion at the terminal portion of the right internal carotid artery with minimization of basal moyamoya and increase of ethmoid moyamoya vessels (Suzuki's angiographical stage 4). Postoperative head CT scan depicted subarachnoid hemorrhage in the right sylvian and basal cistern and thin subdural hematoma at the site of anastomosis. (B) Case 12, 60-year-old woman with MMD with right temporal lobe old hemorrhage. Cerebral angiogram showing severe stenosis at the terminal portion of the right internal carotid artery with marked development of basal moyamoya vessels (Suzuki's angiographical stage 3). Postoperative head CT scan depicted intracerebral hematoma in the right frontal lobe where superficial temporal artery - middle cerebral artery anastomosis was performed. Diffusion weighted image showed no acute cerebral infarct around the hematoma. Also, ^{123}I-IMP SPECT depicted hypoperfusion at the site of hematoma.

elderly population aged ≥60 years.

To the best of our knowledge, a limited number of reports[11-13] demonstrated the safety and efficacy of cerebral revascularization surgery in elderly patients with MMD. Previously, Williamson et al.[12] reported favorable clinical outcomes of revascularization surgery (including both direct and indirect bypasses) in 33 patients with MMD aged >50 years (mean age 59.0 ± 7.6 years) during surgery. They showed that perioperative complications occurred in six of these 33 cases (18%): two cases of hemorrhage, two cases of cerebral infarction, and two minor complications. Moreover, favorable long-term clinical outcomes were observed in surgically treated elderly patients with MMD. Similarly, Ge P et al.[11] reported favorable clinical outcomes in elderly patients with MMD treated with revascularization surgery, with a predominance of direct bypass procedures (70 out of 87 procedures). This study's authors reviewed the clinical data of 74 patients surgically treated for MMD at age ≥50 (mean age 54.0 ± 3.7 years), and they reported that perioperative infarct or hemorrhage rate was 6.9%, lower than that seen in our series. This report's[11] authors concluded that revascularization surgery can be safely performed, improving the hemodynamic insufficiency in elderly patients. In addition, Gupta et al.[13] reported a small case series of eight elderly patients with MMD aged >60 years during treatment. Among them, indirect bypass surgery was performed in four out of eight patients. In this series, two of the six patients exhibited perioperative functional worsening, whereas one of the two patients who did not undergo revascularization surgery suffered from ICH. Following Gupta et al.'s observations, the authors[13] concluded that revascularization surgery in elderly patients with MMD might offer potential benefits by stabilizing progressive symptoms. Compared to the aforementioned reports,[11-13] our study focused on even older populations of MMD patients, specifically those aged >60 years (mean age 64.4 ± 4.0 years). Furthermore, to the best of our knowledge, the present study is the first to shed light on the differences in clinical course and postoperative long-term outcomes between elderly and younger adult patients with

MMD. Moreover, nearly all the patients in our series underwent combined revascularization procedures, including direct and indirect bypass surgeries. Consistent with the aforementioned previous reports,[11,12] we found beneficial effects of direct and indirect revascularization surgery for MMD in the elderly. Moreover, the incidence of perioperative complications, likelihood of long-term stroke recurrence, and functional outcomes between elderly and younger adult patients with MMD did not significantly differ. Therefore, the present study pioneers the demonstration of the effectiveness and safety of this surgical procedure, combined bypass surgery, within this specific population. These findings prove that favorable outcomes can be expected in elderly patients with MMD, similar to those observed in younger adult patients.

Interestingly, although the difference was not statistically significant, we found a high incidence of perioperative hemorrhagic complications in elderly patients with MMD. This finding might be explained by the high prevalence of comorbidities in elderly patients with MMD, a possible potential risk factor for perioperative cerebral hyperperfusion.[7,24] Perioperative cerebral hyperperfusion is a characteristic perioperative complication following MMD revascularization surgery,[5,7] which has been reported to cause hemorrhagic complications.[8,25] An immediate increase in cerebral blood flow induced by revascularization surgery leads to a drastic increase in the internal pressure of the cerebral arteries known to be fragile in patients with MMD. Disrupting these fragile vessels is an important mechanism underlying perioperative hemorrhagic complications. Since aging and high blood pressure are important factors that may increase the incidence of perioperative hyperperfusion and aggravate its severity,[7,26] the high prevalence of comorbidities in the elderly population may play a significant role in the trend toward a high hemorrhagic complication incidence. In addition, the high prevalence of other comorbidities, such as hyperlipidemia and diabetes mellitus, considered risk factors of atherosclerosis, may also play a role in exacerbating the fragility of cerebral arteries in elderly patients with MMD. When treating elderly patients with MMD in clinical practice, careful perioperative management and monitoring are crucial to prevent these devastating perioperative complications and attain favorable clinical outcomes.

The major limitations of this study are its retrospective nature, variable baseline characteristics, and small sample size. Further studies must validate these findings. Currently, the Multicenter survey of Moyamoya Disease Over the age of SixTy (MODEST) trial, a nationwide prospective cohort study of elderly patients with MMD, is ongoing, and the results are highly anticipated (unique identifier: UMIN 000044293). Another major limitation of this study was the lacking perioperative hyperperfusion data. Since this retrospective cohort study included several patients who underwent surgery in a relatively early period (1980s to the early 1990s), for whom cerebral blood flow data were unavailable, a comprehensive investigation of the data was impossible. This significant factor must be addressed in future studies. Despite these limitations, we believe compiling these data and conducting clinical studies are essential for establishing treatment guidelines for patients with this uncommon disease.

Conclusion

The clinical outcomes following combined revascularization surgery in elderly patients with MMD are comparable to those in the nonelderly population regarding perioperative complications and long-term clinical outcomes. Our findings suggest that the elderly population is prone to perioperative hemorrhagic complications and particular attention is encouraged to achieve favorable outcomes when treating elderly patients with MMD.

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Abbreviations

CI, confidence interval; CT, computed tomography; EDMAPS, encephalo-duro-myo-arterio-pericranio-synangiosis; HR, hazard ratio; ICA, internal carotid artery; ICH, Intracerebral hemorrhage; ^{123}I-IMP-SPECT, N-isopropyl-p-[^{123}I] iodoamphetamine SPECT; IQR, interquartile range; MCA, middle cerebral artery; MMD, Moyamoya disease; MR, magnetic resonance; mRS, modified Rankin Scale; OR, odds ratio; SD, standard deviation; SPECT, single-photon emission computed tomography; STA, superficial temporal artery; TIA, transient ischemic attack.

Conflicts of Interest Disclosure

All authors who are members of the Japan Neurosurgical Society (JNS) have registered self-reported COI disclosure statement forms on the website for JNS members.

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