Original Article doi: 10.2176/jns-nmc.2024-0090

Neurol Med Chir (Tokyo) 65, 167-176, 2025 Online February 10, 2025

Severity of Clinical Symptoms of Supplementary Motor Area Syndrome Correlates with the Extent of Tumor Resection in the Brain

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Abstract

A unified view on recovery from supplementary motor area syndrome after glioma resection is lacking. This study retrospectively examined the relationship between motor function, higher brain function, the ability to perform activities of daily living, and social reintegration and the extent of tumor resection in patients who underwent resection of tumors near the supplementary motor area. We assigned 24 consecutive patients into 3 groups according to the depth of tumor resection: resection involving (A) only the supplementary motor area (5 patients); (B) the supplementary motor area and cingulate gyrus (11 patients); and (C) the supplementary motor area, cingulate gyrus, and corpus callosum (8 patients). Motor paralysis, language function, and the ability to perform activities of daily living were evaluated perioperatively and 2 months postoperatively, whereas successful social reintegration was examined retrospectively. In group C, 62% of patients developed severe paralysis after surgery, with slow recovery and delayed ambulation ($p = 0.0869$). Patients with tumors in the left hemisphere, specifically those extending to the cingulate gyrus and corpus callosum, showed decreased scores for postoperative word recall; however, recovery was observed after 2 months. The Functional Instrumental Measure score, which indicates the activity of daily living ability, showed the largest difference preoperatively and postoperatively in group C. The World Health Organization tumor grade ($p = 0.0445$) and extent of tumor resection ($p = 0.0011$) were inversely correlated with social reintegration 6 months postoperatively. Overall, the findings suggest that early social reintegration is influenced by the World Health Organization tumor grade (2021 World Health Organization classification) and the extent of tumor resection.

Keywords: glioma resection, supplementary motor area, corpus callosum, cingulate gyrus, activities of daily living

Introduction

The supplementary motor area (SMA) is located on the medial aspect of the frontal lobe, anterior to the inferior primary motor area, and is the medial portion of Brodmann's area 6[1,2] (Fig. 1-1). SMA syndrome refers to the dysfunction that occurs following tumor resection near the SMA. Clinical symptoms of SMA syndrome include severe contralateral hemiplegia, mutism and akinesia, delayed motor onset, and impaired motor programming. Recovery from SMA syndrome is relatively quick.[3-5] However, some patients experience prolonged impairment of fine motor skills,[6] and a unified view on the timing of recovery is lacking. In glioma surgery, it is essential to achieve maximum possible resection and functional preservation.[7,8]

Rehabilitation of patients with gliomas should address functional recovery, symptom management, quality of life, social factors, and environmental factors.[9] To promote early social reintegration of patients with gliomas, the mid- to long-term functional prognosis should be predicted

Received April 16, 2024; Accepted November 28, 2024

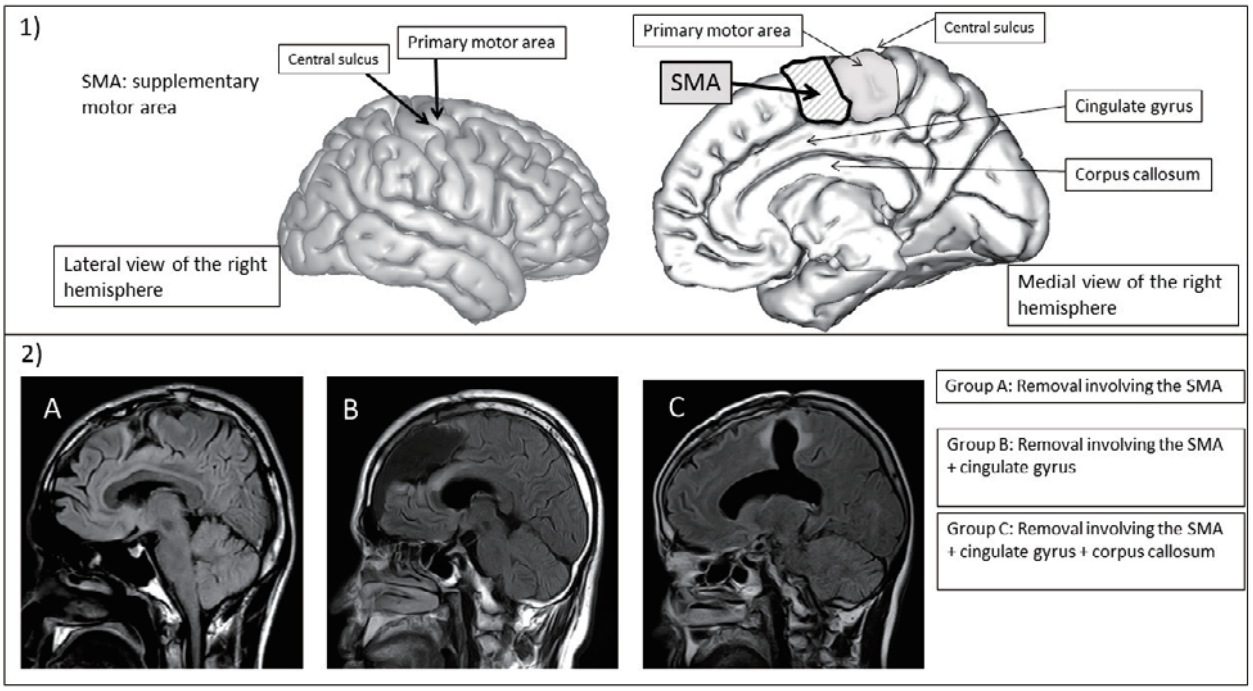

Fig. 1 Anatomical location of the SMA and classification of the extent of tumor resection based on postoperative MRI.
1) Anatomical location of the SMA.
2) Classification of the extent (depth) of tumor resection based on postoperative MRI.
A: Resection involving the SMA.
B: Resection involving the SMA and cingulate gyrus.
C: Resection involving the SMA, cingulate gyrus, and corpus callosum.
MRI: magnetic resonance imaging; SMA; supplementary motor area

based on motor and higher brain function assessments as well as early adjustment to the environment.[10] However, there is no consensus on the ability to predict the development of SMA syndrome or the recovery process. Therefore, this study retrospectively examined the clinical outcomes (motor function, higher brain function, ability to perform activities of daily living [ADLs], and early social reintegration) of patients after glioma craniotomy near the SMA according to the extent of tumor resection and predicted factors associated with early social reintegration.

Materials and Methods

Patient selection and preoperative evaluation

This study was conducted in accordance with the principles of the Declaration of Helsinki and the Ethical Guidelines for Medical and Health Research Involving Human Subjects (Provisional Translation as of March 2015) and was approved by the Ethics Committee of Tokyo Women's Medical University (number 3540-R6). Written informed consent was obtained from all participants. We retrospectively analyzed the data of 24 consecutive patients with gliomas located near the SMA who underwent resection at the Department of Neurosurgery, Tokyo Women's Medical University Hospital, between January 2017 and May 2023. Preoperative diagnosis was made using magnetic resonance imaging (MRI) with T1- and T2-weighted images (WIs), fluid-attenuated inversion recovery images, and T1 WIs with gadolinium-based contrast agent. These magnetic resonance (MR) images helped identify the preoperative tumor location and determine the extent of tumor resection.

At our hospital, we typically remove tumors during awake surgery to assess intraoperative motor and language function. Although awake surgery is recommended for the supplementary motor cortex, the final decision is made by a team of neurosurgeons, considering the patient's personality and overall condition.

Evaluation of preoperative function

Voluntary evaluation of the upper and lower extremities

Voluntary evaluation of the upper and lower limbs was conducted using the Brunnstrom recovery stage (BRS). Thus, it was possible to evaluate the unique motor pattern of the recovery process.[11]

Higher brain function assessment

The Mini Mental State Examination-Japanese (MMSE-J) and Frontal Assessment Battery (FAB) scores were used to assess higher brain function. The presence of mutism,

word fluency, word recall (a task based on generating as many words as possible starting with a specific Japanese letter within 60 sec), and object naming (a task based on naming 10 objects) were assessed to determine language symptoms.

Assessment of ADL skills

The Functional Instrumental Measure (FIM) is the most reliable and valid tool for functional assessment.[12-15] The specific evaluation items consisted of 18 motor and cognitive items, each of which was rated on a 7-point scale (1 = full assistance, 7 = independence) and included cognitive items such as communication and social cognition.

Surgery

All 24 patients underwent intraoperative MRI (AIRIS II; Hitachi Medical Corporation, Tokyo, Japan) after craniotomy using a neuronavigational system (Brain Lab) to optimize lesion resection. Nerve monitoring and awake craniotomy were performed to preserve neurological function during the perioperative period. The 2021 World Health Organization (WHO) classification of tumors[16] was used for grading excised tumors.

Based on MR images obtained 3 months postoperatively, neurosurgeons classified the extent of tumor resection into 3 groups: resection involving (A) only the SMA; (B) the SMA and cingulate gyrus; and (C) the SMA, cingulate gyrus, and corpus callosum (Fig. 1-2). Additionally, for patients with tumor resection involving the cingulate gyrus and corpus callosum (group C), a neurosurgeon different from the one who performed the procedure measured the distance from the central sulcus to the posterior margin of the resection cavity on the MR images obtained 3 months postoperatively.

Evaluation of postoperative function

Voluntary evaluation of the upper and lower limbs

Changes in the BRS of the upper and lower limbs were compared based on the extent of tumor resection on the day after surgery and once every week thereafter for up to 2 months. We also compared the recovery processes between the left and right hemispheres.

Time to ambulatory independence

Time to ambulatory independence was compared based on the extent of tumor resection. Ambulatory independence was defined as the ability to walk without the need for medical assistance or supervision, including putting on and taking off a brace or cane.

Higher brain function and language symptoms

Higher brain function was assessed using the MMSE-J and FAB scores, word fluency, and object naming tasks at 1 week and 2 months postoperatively and compared based on the extent of tumor resection.

Changes in ADLs

Changes in ADLs were assessed preoperatively and at 1 week and 2 months postoperatively using the FIM. Comparisons were made based on the extent of tumor resection between the left and right hemispheres. The groups were analyzed to compare the following clinical factors: age (divided into two groups: ≥40 years and <40 years), sex, newly diagnosed or recurrent cases, tumor resection under awake or general anesthesia, tumor location (left or right), tumor grade (2021 WHO classification), and extent of tumor resection.

Social reintegration

Patients were interviewed by their outpatient attending physicians approximately 6 months postoperatively, with "return to society" defined as return to preoperative life. Patients were classified into 2 groups: the reintegration group comprising those who had returned to their preoperative lifestyle and the no-reintegration group comprising those who had not returned to their preoperative lifestyle. The following clinical factors were compared between groups: age (divided into 2 groups: ≥40 years and <40 years), sex, newly diagnosed or recurrent cases, tumor resection under awake status or general anesthesia, tumor location (left or right), tumor grade (2021 WHO classification), and extent of tumor resection (involving the SMA, cingulate gyrus, and corpus callosum).

Statistical analysis

The Mann-Whitney U test was used to analyze the time to ambulation and MMSE-J, FAB, and FIM scores. Fisher's exact test was used to analyze age, sex, newly diagnosed or recurrent cases, tumor resection while awake or under general anesthesia, tumor location, and WHO tumor grade. Both tests were performed using JMP Pro ver. 17 software (SAS Institute, Cary, NC, USA), with $p < 0.05$ considered statistically significant.

Results

Summary of clinical data

The patient characteristics are summarized in Table 1. Groups A, B, and C comprised 5, 11, and 8 patients, respectively. In group A, the condition was newly diagnosed in all patients. In group B, the condition was newly diagnosed in 9 cases and recurrent in 2 cases. In group C, the condition was newly diagnosed in 6 cases and recurrent in 2 cases. In group A, the tumors involved the left and right hemispheres in 3 and 2 cases, respectively; in group B, the tumors involved the left and right hemispheres in 9 and 2 cases, respectively; and in group C, the tumors involved the left and right hemispheres in 5 and 3 cases, respectively. Based on the tumor grade, group A comprised 1, 3, and 1 cases of grade 2, 3, and 4 tumors; group B comprised 5, 5, and 1 cases of grade 2, 3, and 4 tumors; and

Table 1 Clinical characteristics and outcome of groups A–C (n=24)

	Group A: (n=5) Tumor resection involving the SMA	Group B: (n=11) Tumor resection involving the SMA and cingulate gyrus	Group C: (n=8) Tumor resection involving the SMA, cingulate gyrus, and corpus callosum
Median age (min–max)	38 (29–49)	39 (25–44)	44.5 (31–62)
Sex			
Male	3	8	4
Female	2	3	4
Hand dominancy			
Rt	5	10	8
Lt	0	1	0
Diagnosis			
Newly diagnosed	5	9	6
Recurrence	0	2	2
Location			
Rt	2	2	3
Lt	3	9	5
Tumor removal while			
Awake	2	10	4
Under general anesthesia	3	1	4
Tumor grade (WHO2021)			
Grade 1	0	0	1
Grade 2	1	5	2
Grade 3	3	5	3
Grade 4	1	1	2
Outcome (return to work)			
Possible	3	11	2
Failed	2	0	6

SMA, supplementary motor area; Rt, right; Lt, left; WHO, World Health Organization

group C comprised one, 2, 3, and 2 cases of grade 1, 2, 3, and 4 tumors, respectively.

Awake and general (under anesthesia) surgeries were performed on 16 and 8 patients, respectively. Surgical resection was deemed feasible with resection of >90%, and no intraoperative motor-evoked potential reduction or loss was observed.

The extent of tumor resection and changes in the upper and lower limb motor functions

Of the 24 cases, 13 (54.2%) developed severe paralysis (BRS ≤ III) immediately after surgery.

In group A, severe paralysis (BRS II or less) was not observed in any case; moderate (BRS IV) paralysis was observed in only one case, and slight (BRS V) paralysis was observed in one case, which improved after 2 weeks and completely recovered after approximately 1 month. In group B, 4 (36.4%) patients had severe paralysis (BRS I-II) in the upper limbs immediately after surgery, 5 (45.5%) patients had moderate paralysis (BRS III-IV) that improved rapidly approximately 2 weeks after surgery, and all patients showed full recovery after 6 weeks. In group B, 4 patients (36%) had severe upper and lower extremity paralysis, 5 (46%) had moderate paralysis, and 2 (18%) had mild paralysis, but recovered rapidly within one to 3 weeks after surgery. In group C, 5 (62%) patients had severe paralysis (BRS I-II) in the upper limbs, with improvement observed after 2-3 weeks; however, the improvement was slower than that in groups A and B. After 2 months, one patient each remained with moderate and mild paralysis (Fig. 2-1). Regardless of the extent of tumor resection, voluntary improvement in finger functions preceded the recovery of the

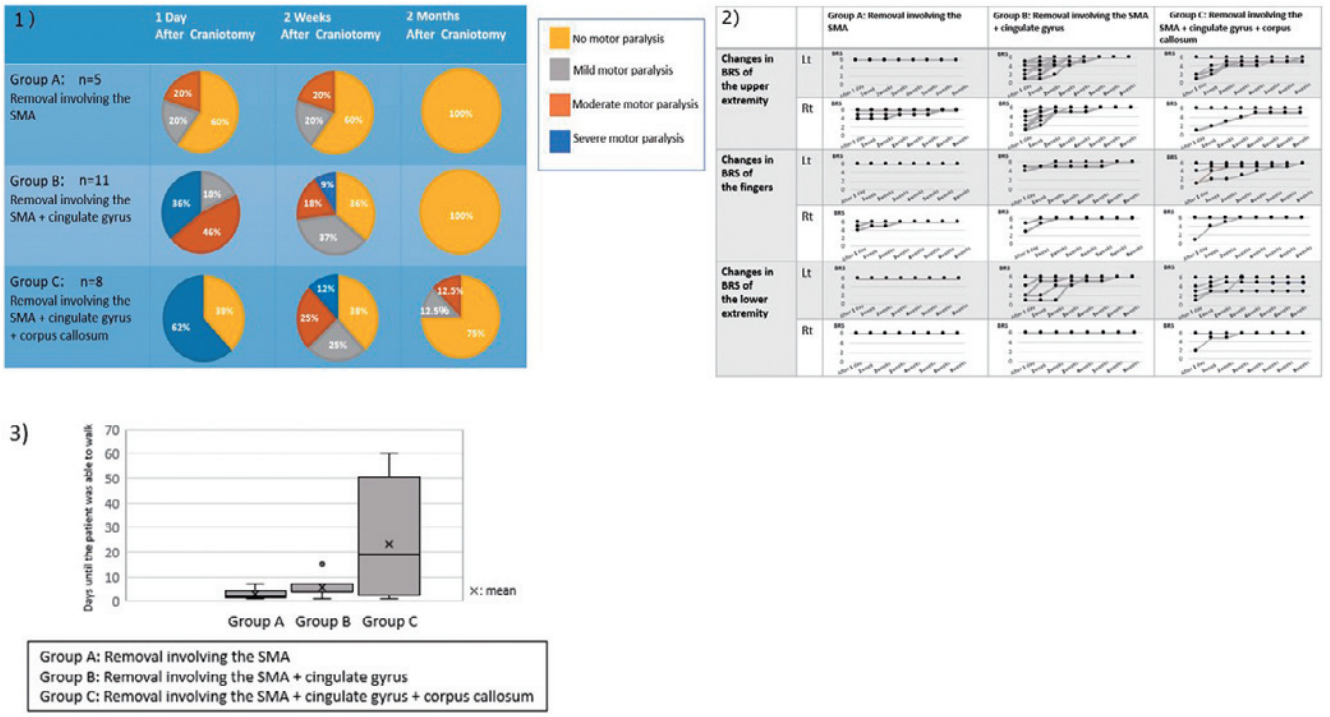

Fig. 2 Incidence and course of SMA syndrome according to the extent of tumor resection.
1) Percentage of severity of SMA syndrome on the day after tumor resection and 2 weeks and 2 months postoperatively.
2) The extent (depth) of tumor resection and recovery of motor paralysis in the upper extremities, fingers, and lower extremities according to the BRS.
3) The extent of brain tumor resection and the number of days to ambulation.
Group A: tumor resection involving the SMA.
Group B: tumor resection involving the SMA and cingulate gyrus.
Group C: tumor resection involving the SMA, cingulate gyrus, and corpus callosum.
BRS: Brunnstrom recovery stage; SMA; supplementary motor area

entire upper extremity; however, improvement in finger functions was observed approximately 1 week postoperatively in most cases. Even in group C, which showed slow improvement, the speed of functional recovery in the fingers was rapid, with all but 2 cases reaching BRS ≥5 after 3 weeks. No significant difference was noted in the progress between the left and right hemispheres, and the timing of improvement was similar (Fig. 2-2).

Extent of tumor resection and time to ambulation

Five of the 8 patients with severe paralysis in group C experienced slow functional recovery. Only 3 of these 5 patients were able to achieve walking independence within 2 months, whereas the other 2 achieved modified independence. The median time(range) to ambulation was 2 (1-7), 4 (1-15), and 19 (1-60) days in groups A, B, and C, respectively. Although no significant difference was observed in the extent of tumor resection or the number of days to ambulation, 2 cases in group C showed independence with cane walking. Time to ambulation was greater in group C than in the other groups (p = 0.0869) (Fig. 2-3).

Extent of tumor resection, changes in higher brain function, and language symptoms

The MMSE-J score showed a slight decrease from a preoperative median score of 30 to 28 postoperatively in group A; however, the decrease was minor, and the score increased to a median score of 30 after 2 months. The trend was similar in group B, with a preoperative median score of 29 decreasing to 28 postoperatively and increasing to 30 2 months later. In group C, the preoperative and postoperative median scores were 29 and 26, respectively, with a cutoff of less than 30 after 2 months; however, the score increased to 30 after 2 months. No significant differences were observed between groups A, B, and C preoperatively, postoperatively, or 2 months later (preoperatively, group A vs. group B: p = 0.207, group B vs. group C: p = 0.229, group A vs. group C: p = 0.280; postoperatively, group A vs. group B: p = 0.207, group B vs. group C: p = 0.229, group A vs. group C: p = 0.280; 2 months later, group A vs. group B: p = 1.000, group B vs. group C: p = 1.000, group A vs. group C: p = 0.649).

The FAB score showed a mild postoperative decrease in all the groups with median preoperative, postoperative,

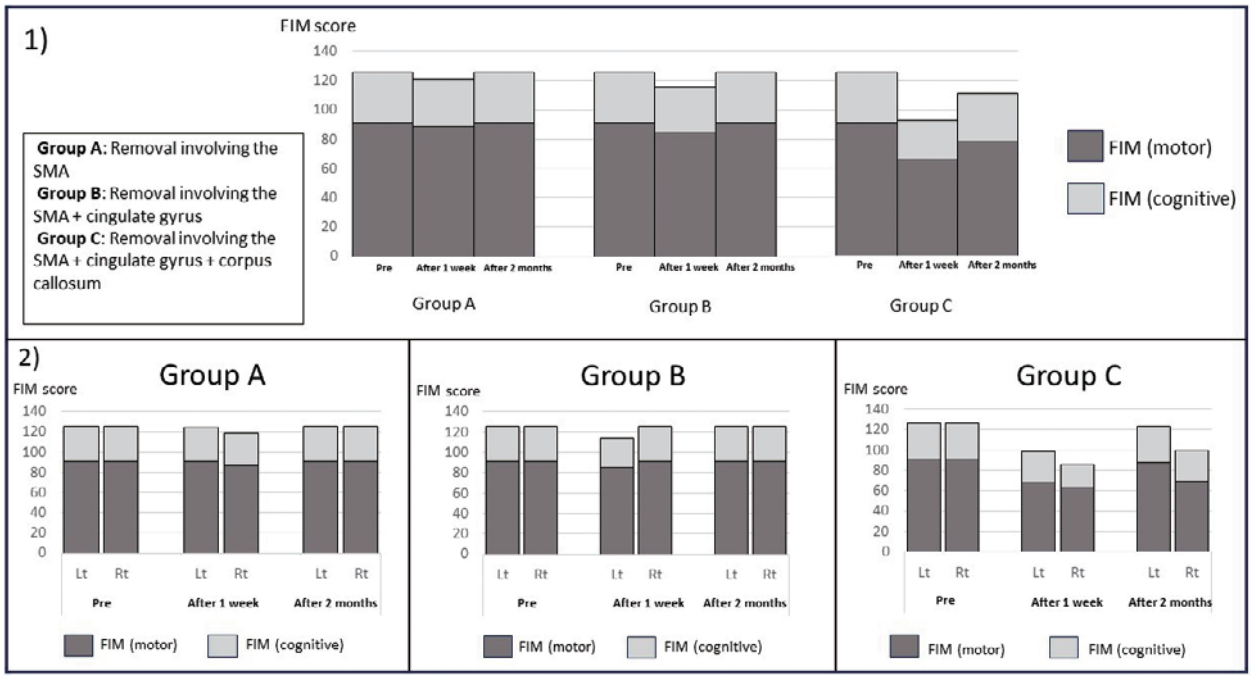

Fig. 3 Changes in FIM scores before, after, and 2 months following surgery.
1) Comparison of average FIM scores by the extent (depth) of tumor resection.
Group A: tumor resection involving the SMA.
Group B: tumor resection involving the SMA and cingulate gyrus.
Group C: tumor resection involving the SMA, cingulate gyrus, and corpus callosum.
FIM (Motor); FIM motor score (13-91)
FIM (Cognitive); FIM cognitive score (5-35)
2) Comparison of average FIM scores between the left and right hemispheres.
Group A: Comparison of average FIM scores between the left and right hemispheres in group A.
Group B: Comparison of average FIM scores between the left and right hemispheres in group B.
Group C: Comparison of average FIM scores between the left and right hemispheres in group C.
FIM: Functional Instrumental Measure; SMA; supplementary motor area

and 2-month scores of 17.5, 16.5, and 18 in group A; 18, 14, and 16 in group B; and 18, 17, and 18 in group C, respectively. No significant differences were noted between the groups preoperatively, postoperatively, and 2 months postoperatively (preoperatively, group A vs. group B: p = 0.419, group B vs. group C: p = 0.164, group A vs. group C: p = 1.000; postoperatively, group A vs. group B: p = 0.156, group B vs. group C: p = 0.636, group A vs. group C: p = 0.805; 2 months later, group A vs. group B: p = 0.358, group B vs. group C: p = 0.160, group A vs. group C: p = 1.000).

Regarding language symptoms, 15 patients had mutism, aphasia, and dysarthria in the left hemisphere. The preoperative average word recall scores for left hemisphere cases were 14, 12.8, and 7.8 in groups A, B, and C, respectively. The postoperative average word recall scores were 9, 5.3, and 7.8 in groups A, B, and C, respectively. After 2 months, the average word recall scores were 13, 10.2, and 9.3 in groups A, B, and C, respectively. Preoperatively, object naming scores for left hemisphere cases were not reduced in any case, with scores of 10, 9.2, and 8.6 in groups A, B, and C, respectively. Postoperatively, these scores remained stable in all cases after 2 months. The mutism resolved after 2 months.

The extent of tumor resection and change in ADLs

The preoperative decline in ADLs was not observed in any of the groups, with a median FIM score of 126 and a mean FIM score of 125.7 (motor, 91; cognitive, 34.7). One week postoperatively, the mean FIM scores were 126 (motor, 91; cognitive, 35), 114.8 (motor, 84.75; cognitive, 30.08), and 92.9 (motor, 65.8, cognitive, 27.1) in groups A, B, and C, respectively. Two months postoperatively, the mean FIM scores were 126 (motor, 91; cognitive, 35), 125.6 (motor, 91; cognitive, 34.6), and 111.3 (motor, 78.5; cognitive, 32.8) in groups A, B, and C, respectively (Fig. 3-1). Although some patients in groups B and C showed significant postoperative decline in the FIM score, each group showed improvement after approximately 2 months. Of the 8 patients in group C, 3 did not achieve ADL independence after 2 months. No significant differences were observed in the extent of tumor resection (p = 0.2333). Similarly, no signifi-

Table 2 Relationship between each clinical factor and early social reintegration (n=24, Fisher's exact test)

Factor	Return to work		Total	p-value
	Possible	Failed		
Age: <40 years	7 (70%)	3 (30%)	10	1.0000
≥40 years	9 (64.3%)	5 (35.7%)	14	
Sex: Male	10 (66.7%)	5 (33.3%)	15	1.0000
Female	6 (66.7%)	3 (33.3%)	9	
Diagnosis: Newly diagnosed	14 (70%)	6 (30%)	20	0.5784
Recurrence	2 (50%)	2 (50%)	4	
Location: Lt	12 (75%)	4 (25%)	16	0.3625
Rt	4 (50%)	4 (50%)	8	
Tumor removal while: Awake	12 (75%)	4 (25%)	16	0.3625
Under general anesthesia	4 (50%)	4 (50%)	8	
Tumor grade (WHO 2021): Grade 1	0 (0%)	1 (100%)	1	0.0445#
Grade 2	7 (87.5%)	1 (12.5%)	8	
Grade 3	8 (72.7%)	3 (27.3%)	11	
Grade 4	1 (25%)	3 (75%)	4	
Extent of tumor removal:				
Tumor resection involving the SMA (group A)	3 (60%)	2 (40%)	5	0.0011#
Tumor resection involving the SMA and cingulate gyrus (group B)	11 (100%)	0 (0%)	11	
Tumor resection involving the SMA, cingulate gyrus, and corpus callosum (Group C)	2 (25%)	6 (75%)	8	

p-values < 0.05 were considered statistically significant.
SMA, supplementary motor area; Rt, right; Lt, left; WHO, World Health Organization

cant differences were noted in the preoperative, postoperative, and 2-month FIM scores between the left and right hemisphere cases (p = 0.5178, p = 0.9779, and p = 0.4621, respectively) (Fig. 3-2). Comparing the difference in postoperative decline in FIM scores, the average FIM scores were 4.8, 10.3, and 34.2 in groups A, B, and C, respectively. The postoperative FIM score was significantly lower in group C than in the other groups (p = 0.0539). In contrast, no significant difference was found in the FIM scores between the left and right hemispheres (p = 0.9336). The differences between the 2-month and preoperative FIM scores were 0, 0.5, and 14.7 in groups A, B, and C, respectively (p = 0.3555). In group C, patients with severe postoperative motor paralysis and impaired ADLs had an average distance of 38.0 (25.1-60.4) mm from the central sulcus to the extraction site. For patients with persistent motor paralysis and ADL disability after 2 months, the average distance was 32.7 (23.5-42.0) mm. In contrast, patients without postoperative motor paralysis or ADL impairment had a mean distance of 50.3 (38.7- 64.5) mm.

Relationship between clinical factors and early social reintegration

Six months postoperatively, 16 patients were in the reintegration group and 8 were in the no-reintegration group. No significant differences were noted in age, sex, newly diagnosed or recurrent cases, tumor resection while awake or under general anesthesia, and tumor location; however, significant differences were found in the WHO tumor grade and extent of tumor resection (p = 0.0445 and p = 0.0011, respectively).

Regarding the WHO tumor grade, 1 patient with a grade 1 tumor did not show return to society, while 7 (87.5%) of the 8 patients with grade 2 tumors and 8 (72.7%) of the 11 patients with grade 3 tumors showed return to society within 6 months after surgery, compared with only one (25%) of the 4 patients with grade 4 tumors who showed return to society.

Regarding the extent of tumor resection, 3 (60%) of the 5 patients in group A and all 11 patients (100%) in group B showed return to society within 6 months after surgery, whereas only 2 (25%) of the 8 patients in group C showed return to their preoperative lifestyle 6 months after surgery (Table 2).

Discussion

In this study, we characterized the clinical manifesta-

tions of SMA syndrome after tumor resection near the SMA according to the extent of tumor resection and identified clinical factors associated with social reintegration. The appearance of long-term motor paralysis and involvement of the cingulate gyrus in language symptoms after tumor resection involving the corpus callosum has been reported.[17,18] In our study, the clinical manifestations of SMA syndrome were severe motor paralysis and slow recovery based on the extent of tumor resection, especially when the corpus callosum was removed. Moreover, achieving independent walking and ADL independence required a long rehabilitation. The extent of tumor resection and tumor grade may be involved in social reintegration following SMA syndrome.

The extent of tumor resection and changes in upper and lower limb motor function

The severity and duration of SMA syndrome were more closely related to the extent of tumor resection rather than to the volume of tumor removed.[18] Indeed, cortical resection close to the premotor cortex is associated with a pronounced SMA syndrome.[17] In our study, based on the extent of tumor resection, motor function recovery was more likely to occur in patients with severe motor paralysis who underwent resection involving the cingulate gyrus and corpus callosum; however, the recovery process was prolonged.

Regarding recovery of voluntary movements in the SMA, patients recover completely within 3 months, and once mobility is initiated, recovery is rapid.[18] However, while one study showed that recovery begins a few days after surgery and is almost complete after approximately 1 month,[19] another study indicated that recovery begins 1 week after surgery and is almost complete after 6 months,[4] suggesting some variations in the recovery process across studies.

In our study, the appearance of motor paralysis and the recovery process were correlated with the extent of tumor resection. In group A, no cases of severe paralysis were observed, and moderate-to-slight motor paralysis (BRS ≥IV) improved over time. In group C, more than half of the patients experienced severe postoperative motor paralysis, and improvement was observed approximately 2 weeks after surgery in some patients. Characteristically, recovery of finger functions was observed in many patients before recovery of upper extremity function (proximal part). Taken together, these findings indicate that full recovery may be achieved approximately 1 month after resection involving only the SMA. Therefore, a rehabilitation program should be established, considering that patients whose cingulate gyrus and corpus callosum were removed may require more time for improvement and that some patients may still have difficulties in fine motor skills and experience discomfort. The recovery process from cerebrovascular disorders is characterized by recovery from the central side, which is quantified using the BRS; however, the recovery process from SMA syndrome often occurs from the peripheral side and does not align with the typical recovery pattern. Thus, active movement of the fingers can facilitate movement in the shoulders, elbows, and other parts of the body.

The extent of tumor resection and time to ambulation

The time to ambulation was longer when the SMA and corpus callosum were removed than when only the SMA or cingulate gyrus was removed. The SMA is involved not only in motor paralysis but also in motor initiation, postural coordination, and coordination.[20] The balance response and timing of movement initiation are important factors in the ability to walk, and maintaining stable mobility is essential for social integration. The SMA is believed to have fibers extending to the contralateral motor area,[21] which may also influence postural coordination. Long-term improvements can be expected owing to the presence of ipsilateral fibers. A rehabilitative approach that incorporates recovery responses and balanced function is considered effective.

The extent of tumor resection, changes in higher brain function, and language symptoms

In this study, language symptoms in patients in whom the left hemisphere was involved were more prominent for word fluency than for object naming. Decreased spontaneity and spontaneous speech, which are hallmarks of SMA syndrome, may also be affected by decreased word fluency. This is consistent with the findings of a previous report showing the involvement of the cingulate gyrus in word fluency.[17] Given that patients with transient aphasia have a high possibility of recovery[22] and that improvement was expected after 2 months even in cases where the cingulate gyrus and corpus callosum were removed in our study, efforts should be made to promote activity and increase speech and language variation from an early stage.

The extent of tumor resection and change in ADLs

Reports on ADL ability and social reintegration in patients who underwent tumor resection involving the SMA are lacking. In terms of the extent of tumor resection, patients with removal up to the corpus callosum showed a decline in ADLs; however, most patients showed improvement 2 months after rehabilitation. The postoperative decline in the FIM score may be related to the extent of tumor resection, and the improvement after 2 months suggests the importance of early postoperative active rehabilitation intervention and environmental adjustments by multiple professionals. Postoperatively, resection involving the cingulate gyrus and corpus callosum resulted in decreased word recall scores, whereas resection involving the corpus callosum resulted in a decreased ability to walk. We examined the correlation between the left and right

hemispheres and the extent of tumor resection and found no significant differences in ADL ability between the left and right hemispheres during any period. When analyzing the FIM scores for the left and right hemispheres, we observed that motor scores had a greater influence than cognitive scores.

Relationship between clinical factors and early social reintegration

In our study, the 2021 WHO-defined tumor grade and extent of tumor resection were associated with social reintegration. One patient with a grade 1 tumor, which was resected along with the corpus callosum, had difficulty in returning to society early due to prolonged postoperative rehabilitation. A high proportion of patients with grade 2 tumors (87.5%) showed a return to preoperative life shortly after the procedure, followed by 72.7% of patients with grade 3 tumors compared with only 4 patients (25%) with grade 4 tumors who achieved a return to preoperative life. Typically, standard treatment plans are based on pathology results, with patients with grade 4 glioblastoma, in particular, requiring multidisciplinary treatment after surgery, as resectability can significantly impact survival.[23] The introduction and continuation of treatment may influence reintegration. The results demonstrated an inverse correlation between the WHO tumor grade and social reintegration.

Patients in group B achieved 100% social reintegration within 6 months, whereas only 25% of patients in group C showed social reintegration, possibly due to post-resection motor dysfunction and prolonged decline in ADL capacity. Meanwhile, among the 2 patients in group A who failed to show return to society within 6 months, one with a WHO grade 4 tumor had to stop working, and the other who worked in the transport sector required more time to return to society. Resection of the corpus callosum prolonged the duration of SMA syndrome, thus significantly delaying ambulation and necessitating long-term rehabilitation.

Postoperative SMA syndrome has been reported to be associated with resection of the cingulate gyrus and deep white matter, rather than with tumor size,[18,24] and may involve intraoperative frontal aslant tract damage.[25-27] In our study, the incidence of SMA syndrome resulting in severe motor paralysis was 54.2% in 13 of 24 patients and was characterized by severe symptoms and delayed recovery due to the removal of the corpus callosum. Therefore, following preoperative functional assessment, active rehabilitation should be provided in the early postoperative period to improve motor and higher brain functions, ADL capacity, and early return to society.

Limitations

This study has some limitations. First, the number of cases was small. Additionally, we were unable to examine the role of the frontal aslant tract, which refers to the white matter fibers observed on MRI. More detailed data can be obtained by adding imaging analysis of postoperative white matter fibers.

Conclusions

This study showed that the extent of tumor resection was associated with the development of SMA syndrome and the time to ambulation. We observed a trend toward decreased ADL capacity postoperatively, especially in cases wherein the corpus callosum was removed. The WHO tumor grade and extent of tumor resection may affect the return to society approximately 6 months after craniotomy. To facilitate postoperative rehabilitation, it is important to actively share information regarding the extent of tumor resection and tumor grade among multiple specialists, including doctors, nurses, and rehabilitation staff.

This study indicates that the addition of information on the extent of tumor resection and tumor grade may help predict early functional prognosis, suggesting that a seamless rehabilitation program should be established to facilitate early ADL independence and social reintegration.

Acknowledgments

This work was supported in part by a Japan Society for the Promotion of Science KAKENHI Grant-in-Aid for Scientific Research (B) (grant number JP22H03443).

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author, M.T., upon reasonable request.

Disclaimer

Takakazu Kawamata and Yoshihiro Muragaki are the Editorial Board members of the Journal. They were not involved in the peer-review or decision-making process for this paper.

Conflicts of Interest Disclosure

All authors have no conflict of interest.

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