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Hybrid Operating Room for the Treatment of Spetzler-Martin Grade III–V Brain Arteriovenous Malformation: An Institutional Experience

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ABSTRACT

AIM: To report our institutional experience of the one-stop treatment of Spetzler–Martin grade (SMG) III–V brain arteriovenous malformations (BAVMs) in a hybrid operating room.

MATERIAL and METHODS: Clinical data obtained from all the patients with SMG III–V BAVMs who underwent one-stop treatment in a hybrid operating room were analyzed. The measures included imaging characteristics, intraoperative blood loss, postoperative complications, residual lesions, and the presence of postoperative recurrence. Outcomes were assessed using the Glasgow outcome scale (GOS) score at six months post-surgery.

RESULTS: A total of 16 patients were included in this study, 7 of whom underwent endovascular embolization followed by microsurgical resection and 9 underwent intraoperative cerebral angiography-assisted microsurgery. The average intraoperative blood loss was 473.3 mL. A remnant of BAVMs was found on the intraoperative cerebral angiography of one patient. Two patients underwent decompressive craniectomy due to postoperative cerebral swelling, including one patient with occipital lobe cerebral infarction and aphasia. No mortality was recorded. At the six-month postoperative follow-up visit, the GOS scores were 3 (n=4, 25.0%), 4 (n=4, 25.0%), and 5 (n=8, 50.0%). No recurrence was noted on brain digital subtraction angiography (DSA) in any of the postoperative reexaminations.

CONCLUSION: A hybrid operating room can fully combine the advantages of microsurgery and endovascular interventions, allowing for a high resection rate in the surgical treatment of SMG III–V BAVMs and a low rate of postoperative complications.

KEYWORDS: Brain arteriovenous malformation, Hybrid operating room, Interventional embolization

ABBREVIATIONS: SMG: Spetzler–Martin grade, **BAVMs:** Brain arteriovenous malformations, **GOS:** Glasgow outcome scale, **DSA:** Digital subtraction angiography, **SRS:** Stereotactic radiosurgery, **CT:** Computed tomography, **CTA:** Computed tomography angiography, **fMRI:** Functional magnetic resonance imaging, **LED:** Lesion-to-eloquence distance.

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INTRODUCTION

Spontaneous brain hemorrhage in young individuals caused by brain arteriovenous malformations (BAVMs) is a prevalent cerebrovascular disease (10). The Spetzler–Martin grade (SMG) is a commonly used grading system for evaluating BAVMs. It is used to assess the severity of malformation by evaluating the characteristics of arterial blood supply, venous drainage, and their relationship to brain functional areas. Grade III–V BAVMs typically exhibit significantly intricate characteristics in terms of location, vascular structure, and hemodynamics. Thus, it is difficult to achieve complete resection of the lesion using conventional microsurgery, and this technique may also cause inevitable damage to neurological function (14). In contrast, endovascular interventional embolization demonstrates high safety and occlusion rates for small BAVMs. However, for larger BAVMs, the occlusion rate is low, and incomplete occlusion of the lesion can cause hemodynamic changes, thereby increasing the risk of rupture (6). In addition, stereotactic radiosurgery (SRS) is known to be associated with risk of hemorrhage during the latency period (7). In recent years, the use of hybrid operating rooms in neurosurgery has resulted in successful one-stop treatment of BAVMs, gradually becoming the primary treatment option. However, the efficacy of this approach for high-grade BAVMs has been poorly investigated (1,17,21). In the present study, the clinical data of 16 patients with SMG III–V BAVMs who underwent treatment in the hybrid operating room of our hospital were retrospectively analyzed. In this study we aimed to report our institutional experience of the one-stop treatment of SMG III–V BAVMs in a hybrid operating room and provide a reference for clinical treatment.

MATERIAL and METHODS

The local Institutional Review Board approved the present study protocol given the retrospective nature of the study (the Ethlics Committee of Northern Jiangsu People's Hospital Date: 2021/05/06). We obtained written informed consent from all patients in this study.

Patient Selection

We conducted a retrospective analysis of patients with SMG III–V BAVMs who were treated in the hybrid operating room from March 2016 to June 2022. The inclusion criteria were: (i) confirmation of SMG III–V BAVMs by digital subtraction angiography (DSA) and (ii) patients who received surgical treatment in the hybrid operating room. The exclusion criteria were: (i) presence of other causes of cerebral hemorrhage, (ii) severe organ dysfunction, and (iii) patients who received treatment in a fractionated manner. Clinical and angiographic data of the patients who were included in the final analysis were evaluated. The clinical information included imaging characteristics, intraoperative blood loss, operative time, postoperative complications, residual lesions, and postoperative recurrence. Study outcomes were assessed using the Glasgow outcome scale (GOS) score at six months post-surgery. All patients were treated by senior neurosurgeons and interventional radiologists.

Endovascular Intervention

Interventional embolization supplies consisted of several microcatheters, including Marathon (Medtronic, Minneapolis, MN, USA), Echelon10 (Medtronic), and Apollo (Medtronic). The liquid embolic agent used was Onyx (Medtronic). Removable coils were utilized for the embolization of flow-related intracranial aneurysms. If all the feeding arteries were in superficial locations in the brain, embolization was not performed. Targeted interventional embolization was performed for BAVMs with deep-feeding arteries and flow-related aneurysms. For high-flow BAVMs, embolization through the main feeding arteries was achieved. Complete embolization of the malformed vascular mass was unnecessary, but the artery providing the blood supply close to the malformed mass was embolized. It was crucial to ensure that the main venous drainage was not affected during embolization. HyperForm balloons (Medtronic) were also deployed to control the flow in the main feeding artery if the BAVMs were diffuse or if some deep feeding arteries could not be selected for embolization. During the procedure, the patients' blood pressures and heart rates were strictly monitored. After embolization, brain DSA was repeated to assess the rate of embolization and changes in the configuration of the malformed mass.

Microneurosurgical Treatment

All patients were provided with preoperative venous access, and blood retrieval devices were prepared for autologous blood transfusion. The appropriate surgical approach was determined based on the location of the vascular malformation. Care was taken to avoid damage to the superficial venous drainage during dura mater opening, and the superficial blood supplying arteries were blocked during the operation. Intraoperatively, if it was unclear whether a vessel was an artery or a vein, clamping the vessel with a temporary blocking clip was attempted. Deep dissection was performed along the glial proliferation zone around the vascular malformation and the deep arterial blood supply was blocked. During surgery, other blood vessels and brain tissue involving functional areas were protected. Finally, the venous drainage was blocked, and resection of the vascular malformation was completed.

Postoperative Treatment and Follow-up

After surgery, the patients' blood pressures were managed in the intensive care unit, with the mean arterial pressure controlled between 60 and 70 mmHg. Head computed tomography (CT) scans were reviewed at the following intervals: one day, three days, and one week post-surgery; and at discharge. A one-month postoperative follow-up evaluation was conducted either through an outpatient visit or a telephone call. After six months, the patients underwent DSA or computed tomography angiography (CTA) for review. Patient prognosis at six months postoperatively was assessed based on GOS score.

RESULTS

A total of 16 patients were included in the final analysis, including 12 men and four women who ranged in age from 20 to 62 years (mean age, 40.4 years). All patients presented

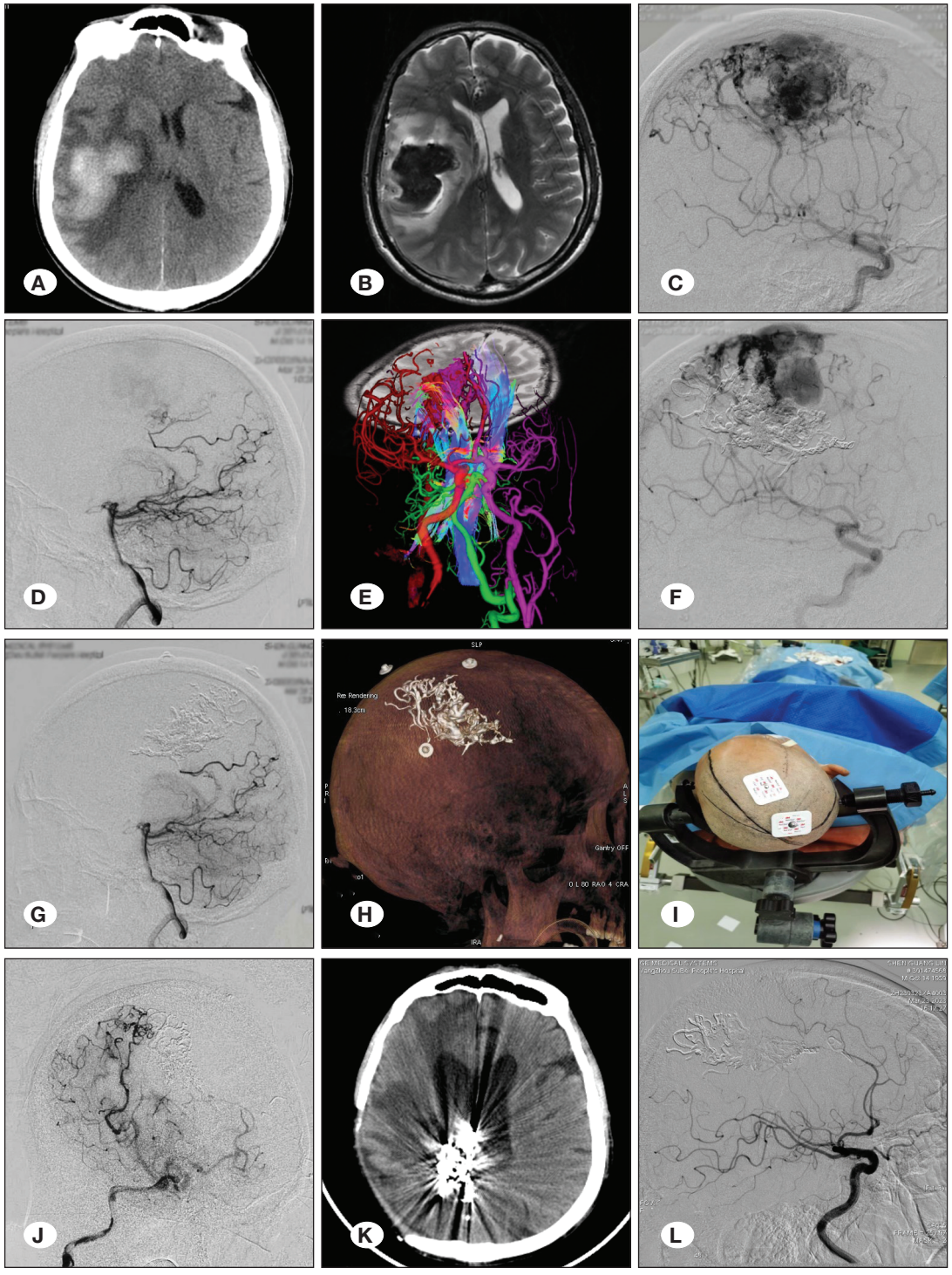

Figure 1: A 60-year-old male patient was diagnosed with grade V arteriovenous malformation (AVM) in the right frontoparietal region. Preoperative imaging (CT and magnetic resonance imaging [MRI]) shows a right frontotemporal hematoma **(A, B)**. Further imaging using digital subtraction angiography (DSA) shows the presence of a right frontoparietal AVM, with feeders originating from the right anterior and middle cerebral arteries as well as the right posterior cerebral artery **(C, D)**. Preoperative localization and determination of the relationship between the vascular mass and the surrounding functional areas were achieved using 3D angiographic imaging and fusion images obtained from functional MRI **(E)**. The main feeders of the malformed vascular mass were successfully embolized using endovascular techniques **(F, G)**. Before surgical resection, the deformed vascular mass was accurately localized to determine the appropriate surgical approach **(H, I)**. Intraoperative DSA showing complete nidus resection **(J)**. CT examination was performed three months after hematoma evacuation and lesion resection **(K)**, and follow-up DSA conducted three years post-surgery showed no recurrence **(L)**.

with cerebral hemorrhage as their initial diagnosis. Symptoms included headache (n=2), a combination of hemiplegia and headache (n=7), light coma (n=2), seizure (n=2), aphasia (n=1), hemianopia (n=1), and a combination of hemiplegia and aphasia (n=1). The diameter of the vascular malformations in the 16 patients ranged from 2 to 8 cm (mean diameter, 4.5 cm). Seven malformations were located in the temporal lobe, four in the frontoparietal lobe, two in the frontal lobe, two in the occipital lobe, and one in the parietal lobe. Additionally, two patients had flow-related intracranial aneurysms. According to the SMG classification, 10 (62.5%) cases were grade III, four (25.0%) were grade IV, and two (12.5%) were grade V.

Various treatment modalities were implemented. Seven patients underwent a combination of endovascular embolization and microsurgical resection, whereas nine patients underwent intraoperative cerebral DSA-assisted microsurgical resection. Complete resection of lesions was achieved in all patients. The average intraoperative blood loss was 473.3 mL. In one patient, residual lesions were observed on intraoperative cerebral angiography and subsequently resected. In the remaining patients, intraoperative cerebral angiography showed complete resection or occlusion of the malformed vascular mass. In two patients with flow-related intracranial aneurysms, the aneurysms were clamped intraoperatively. Six patients underwent intraoperative decompressive craniectomy. In addition, two patients underwent decompressive craniectomy for postoperative brain swelling, with one patient experiencing occipital cerebral infarction and aphasia, whereas the other had no complications. No mortality was recorded. At the six-month postoperative follow-up assessment, two patients experienced delayed seizure, whereas the remaining patients showed improvement or exhibited no deterioration in their neurological function compared to the pre-discharge period. The patients' GOS scores were 3 (n=4; 25.0%), 4 (n=4; 25.0%), and 5 (n=8; 50.0%). No recurrences were observed on repeat cerebral angiography (Table I).

DISCUSSION

BAVM treatment is aimed at complete occlusion or resection of the vascular malformation to eliminate the risk of bleeding (16). Previous studies revealed that BAVMs classified as SMG I–II were effectively treated with brain microsurgical resection, endovascular intervention, or SRS (2,4,11). Conservative treatment is preferred for asymptomatic patients with a higher BAVM grade, whereas aggressive treatment is necessary for patients with a history of epilepsy or BAVM rupture (12). However, a single treatment method is not effective for BAVMs classified as SMG III–V. Therefore, most patients with SMG III–V BAVMs require comprehensive treatment, which may include a combination of endovascular embolization and microsurgical resection, SRS and delayed microsurgical resection, or endovascular embolization and SRS. However, the last two methods have a prolonged procedure time and are not suitable for BAVM rupture and hemorrhage because they may pose a risk of bleeding from the malformed vascular mass. In recent years, one-stop treatment of complex cerebral BAVMs has become possible with the use of hybrid operating rooms in neurosurgery. This involves microsurgical resection assisted by endovascular intervention, such as DSA, balloon temporary blocking techniques, and embolization.

In this study, the treatment plan was designed based on the patient's pre- or intraoperative imaging results. Of the 16 patients, seven had BAVMs with deep feeding arteries and underwent embolization before microsurgical resection. The advantages of intraoperative embolization are as follows (9,18): 1) controlling the deep and main feeding arteries of the lesion can reduce the risks posed by and difficulty of microsurgery, minimizing intraoperative bleeding, and shortening the operation time; 2) the coil and liquid embolic agent used in embolization can serve as a marker during microsurgery; and 3) reducing the volume of the malformed vascular mass ensures a sufficiently safe distance between the lesion and the brain's functional area, minimizing nerve function damage during microsurgical resection. The incidence of intervention-related complications in hybrid procedures is low. In one study the authors reported that the complication rate of interventional surgery for BAVMs was 24.1%, and the incidence of bleeding-related complications was 9.7% (20). Song et al. adopted a combination of embolization and resection in 18 patients, of whom two developed intervention-related complications (15). Grüter et al. treated 18 patients with a combination of embolization and resection, and the rate of intervention-related complication was 5.6% (5). In the present study there were no intervention-related complications among the seven treated patients. This could be attributed to our method of intraoperative embolization that targeted the major feeding artery rather than the entire lesion, resulting in a low incidence of embolism-related complications.

Intraoperative real-time DSA and an image fusion technique can be used to effectively treat BAVMs. Postoperative hemorrhage in patients with BAVMs is associated with incomplete occlusion of the malformed vascular mass and residual lesions (22). Therefore, complete resection is crucial for such patients. Intraoperative cerebral angiography can be employed to detect residual vascular components. Immediate intraoperative cerebral angiography after surgical resection of BAVMs revealed that the proportion of residual lesions was 8.9%–18.1% (3,19). Other studies have shown that the postoperative re-bleeding rate was 7.9% in patients who underwent surgery in a hybrid operating room and that the re-bleeding rate was 14.2% in patients without hybrid surgery (13,18). In our study, patient 7 was treated with intraoperative cerebral angiography, and a residual lesion was observed on intraoperative DSA examination after resection of the malformed vascular mass. An aneurysm clip-positioning marker was placed in the operative field to assist in locating the residual lesion and reentering the operative area for resection. No patient had re-bleeding during the follow-up period. Preoperative functional magnetic resonance imaging (fMRI) is particularly important in the treatment of BAVMs as it can assist neurosurgeons in identifying the exact location of a BAVM and in determining its relationship to the crucial functional regions of the brain. This information is critically important for surgical planning and the determination of treatment strategies. Jiao et al. proposed the use of fMRI to visualize functional areas and conducting tracts, and

Table I: Clinical Characteristics of 16 Patients with Brain Arteriovenous Malformation

Case	Sex	Age (years)	Presenting symptom	BAVM location	BAVM diameter (cm)	SMG	Preoperative GOS score	Treatment modality	Residue detected by intraoperative cerebral angiography	Blood loss (mL)	Recurrence post-surgery	Perioperative Complications	GOS score at six months follow-up
1	M	20	ICH, aphasia, dyskinesia	L-FP	5.0	S2E1V1	3	DSA + balloon-assisted OP	No	600	No	No	3
2	M	28	ICH, visual field deficit	R-O	7.0	V	4	Embo + balloon-assisted OP	No	700	No	No	5
3	M	21	ICH, light coma	R-FP	8.0	S3E1V0	3	Embo + OP	No	800	No	No	3
4	F	44	ICH, headache, dyskinesia	R-F	4.0	S2E1V0	4	DSA + OP	No	300	No	No	4
5	M	26	ICH, headache, dyskinesia	R-T	4.0	S2E1V0	4	DSA + OP	No	500	No	No	4
6	M	35	ICH, headache, dyskinesia	L-T	2.0	S1E1V1	4	DSA + OP	No	600	No	Aphasia, cerebral infarction	4
7	M	55	ICH, headache, dyskinesia	R-T	4.0	S2E1V1	3	Embo + OP	Yes	500	No	No	3
8	M	60	ICH, headache, dyskinesia	R-FP	8.0	V	3	Embo + OP	No	500	No	No	3
9	F	27	ICH, headache	R-P	3.0	S2E1V0	5	DSA + OP	No	300	No	No	5
10	F	59	ICH, aphasia	L-T	4.6	S2E0V1	4	Embo + OP	No	400	No	No	5
11	F	44	ICH, light coma	R-T	2.0	S1E1V1	3	DSA+ OP	No	500	No	No	5
12	M	33	ICH, headache, dyskinesia	R-O	4.0	S2E1V0	4	DSA + OP	No	600	No	No	5
13	M	54	ICH, seizure	L-T	4.0	S2E1V0	5	Embo + OP	No	400	No	No	5
14	M	42	ICH, headache, dyskinesia	R-T	5.2	S2E0V1	4	DSA + OP	No	400	No	No	4
15	M	62	ICH, headache	R-F	4.0	S2E1V1	5	DSA + OP	No	200	No	No	5
16	M	37	ICH, seizure	R-FP	3.8	S2E1V0	5	Embo + OP	No	400	No	No	5

M: *Male,* ***F:*** *Female,* ***L,*** *Left,* ***R,*** *Right,* ***F:*** *Frontal lobe,* ***T:*** *Temporal lobe,* ***P:*** *Parietal lobe,* ***O:*** *Occipital lobe,* ***SMG:*** *Spetzler–Martin grade,* ***DSA:*** *Digital subtraction angiography,* ***Embo:*** *Embolization,* ***Op:*** *Operation,* ***ICH:*** *Intracranial hematoma.*

measured the distance (lesion-to-eloquence distance [LED]) between the malformed vascular cluster and aforementioned structures as a preoperative indicator for predicting the occurrence of postoperative functional deficits (8). They suggested that when the LED was less than 4.95 mm, the incidence of functional deficits significantly increased post-surgery. Therefore, in this study, we used fMRIs for patients who were able to cooperate with the examination before surgery and fused it with 3D-reconstructed DSA to elucidate the distance between the malformed vascular mass and functional brain area. Thus, the patients in our study all experienced either a reduction in neurologic deficits post-surgery or were no worse than before surgery.

Limitations

This study represents a retrospective analysis of a case series conducted at a single center. It is noteworthy that this analysis lacked a control group for comparison with the treatment strategy under investigation. In addition, the sample size was relatively small, and infratentorial BAVMs were not included. Further accumulation of cases is necessary to validate the relevant conclusions drawn from this study.

CONCLUSION

The results of this study indicated that a hybrid operating room can fully combine the advantages of microsurgery and endovascular interventions, allowing for a high resection rate in the surgical treatment of complex BAVMs and a low rate of postoperative complications. In addition, we recommend routine preoperative fMRI examination when possible, which will enhance protection of brain function.

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The study was approved by the Institutional Review Board of Northern Jiangsu People's Hospital, and all patients or relatives signed the informed consent for treatment. We would like to acknowledge the hard and dedicated work by all the staff that implemented the intervention and evaluation components of the study.

Declarations

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Availability of data and materials: The datasets generated and/or analyzed during the current study are available from the corresponding author by reasonable request.

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AUTHORSHIP CONTRIBUTION

Study conception and design: JC, BS, YZ
Data collection: LH, KY
Analysis and interpretation of results: LS, KH
Draft manuscript preparation: JC
Critical revision of the article: BS, YZ
Other (study supervision, fundings, materials, etc...): KY, LS
All authors (JC, BS, LH, KY, LS, KH, YZ) reviewed the results and approved the final version of the manuscript.

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