Brain Arteriovenous Malformations Located in Premotor Cortex: Surgical Outcomes and Risk Factors for Postoperative Neurologic Deficits

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■ OBJECTIVE: **The premotor cortex (PMC) is known to have a dual role in movement and language processing. Nevertheless, surgical outcomes of brain arteriovenous malformations located in PMC (PMC-BAVMs) have not been well defined. The aim of this study was to determine surgical outcomes and risk factors for neurologic deficits (NDs) after surgery in patients with PMC-BAVMs.**

■ METHODS: **We retrospectively reviewed patients with PMC-BAVMs who underwent surgical resection of the nidus. All patients had undergone preoperative functional magnetic resonance imaging, diffusion tensor imaging, magnetic resonance imaging, three-dimensional time-of-flight magnetic resonance angiography, and digital subtraction angiography. Functional and angioarchitectural factors were analyzed with respect to postoperative NDs. Function-related fiber tracts, corticospinal tract, and dominant arcuate fasciculus were tracked. Lesion-to-fiber distance was measured.**

■ RESULTS: **We identified 36 patients with PMC-BAVMs. Radical resection was achieved in all patients. Four patients (11.1%) presented with limb-kinetic apraxia and bradykinesia. Short-term NDs developed in 12 (33.3%) patients, among which 6 developed aphasias and 7 developed muscle weakness. A shorter lesion-to-eloquent fiber distance ($P = 0.012$) and larger nidus size ($P = 0.048$) were significantly associated with short-term NDs. Long-term NDs occurred in 5 patients. Larger nidus size was significantly associated ($P = 0.015$) with long-term NDs.**

■ CONCLUSIONS: **Varying degrees of motor and language deficits can be induced immediately after resection of PMC-BAVMs. Permanent and long-term severe motor or language deficits are rare. Shorter lesion-to-eloquent fiber distance is a risk factor for short-term NDs. Larger nidus size is a risk factor for short-term and long-term NDs.**

INTRODUCTION

Brain arteriovenous malformations (BAVMs) are precarious brain malformations with a significant risk for bleeding, neurologic deficits (NDs), and death.[1] Microsurgical resection is effective in eliminating the cumulative lifetime risk of intracranial hemorrhage.[2] Contrary to resection of brain tumors, in patients with BAVMs, radical resection of the lesion is often necessary for intraoperative hemostasis and reduction of the risk of postoperative rebleeding.[3] Therefore, identifying

Key words
- Diffusion tensor imaging
- Premotor cortex BAVMs
- Risk factor
- Surgical outcome

Abbreviations and Acronyms
3D: Three-dimensional
AF: Arcuate fasciculus
BAVM: Brain arteriovenous malformation
CST: Corticospinal tract
CT: Computed tomography
DSA: Digital subtraction angiography
DTI: Diffusion tensor imaging
LFD: Lesion-to-eloquent fiber distance
M1: Primary motor cortex (area 4)
MRI: Magnetic resonance imaging
MS: Muscle strength
ND: Neurologic deficit
PMC: Premotor cortex
ROI: Region of interest
S-M: Spetzler-Martin
TOF: Time-of-flight

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BAVMs that can be safely resected is of utmost importance. The surgical safety of BAVMs located in the premotor cortex (PMC-BAVMs) is undetermined.

The PMC was delineated by Fulton and is located at the frontal agranular cortex (area 6) rostral to the primary motor cortex (area 4) (M1).[4] As opposed to M1, which directly controls movements, most studies suggest that PMC has strong connections with M1 and the prefrontal cortex and is well placed to influence the generation of movements and select responses based on cues.[4-6] In recent years, some authors advocated the involvement of dominant PMC in language production.[6-8] In addition, PMC-BAVMs may exist beside the eloquent fiber tracts, including the corticospinal tract (CST) and arcuate fasciculus (AF). The resection of PMC-BAVMs might cause fiber injury leading to postoperative language and motor deficits.[9,10] To the best of our knowledge, the postoperative surgical outcomes of PMC-BAVMs have not been reported.

Diffusion tensor imaging (DTI) tractography is an important, noninvasive technique that enables in vivo visualization of the course and characterization of fiber tracts in three-dimensional (3D) images.[11,12] It has been considered an additional reliable tool for preoperative lesion localization and patient-specific trajectory planning.[13-15] With a DTI tractograph, the spatial relationship between passing fiber and arteriovenous malformation nidus can be easily visualized, and the lesion-to-eloquent fiber distance (LFD) can be measured. In this article, we reviewed all the PMC-BAVM cases in our hospital in the past 4 years and attempted to determine the surgical outcomes and identify the risk factors for postoperative NDs in arteriovenous malformations located in this special area. The findings derived from DTI tractography and angioarchitectural factors were analyzed with respect to surgical outcomes in patients with PMC-BAVMs.

MATERIALS AND METHODS

Patients

This study adhered to good clinical practice and ethical principles described in the Declaration of Helsinki and was approved by the Institutional Review Board of Beijing Tiantan Hospital affiliated with Capital Medical University (ky2012-016-02). Written informed consent was obtained from each participant or family members. All patients with PMC-BAVMs were reviewed from our arteriovenous malformation database of a prospective, randomized, controlled clinical trial (ClinicalTrials.gov Identifier: NCT01758211).[16] Only patients who met the following criteria were included in the present study: 1) preoperative magnetic resonance imaging (MRI) revealed that the nidus involved the PMC area (lateral aspect of Brodmann area 6), 2) the nidus did not involve the traditional primary motor cortex and language cortex, and 3) preoperative functional MRI revealed that the nidus did not involve the motor and language activation area. Clinical data were collected from electronic medical records and prospectively collected database by 2 trained neurosurgeons (F.L., Y.J.). Demographic variables, including age and sex, were collected. Angioarchitectural information for each PMC-BAVM, such as nidus size, deep venous drainage, diffuseness, and Spetzler-Martin (S-M) grade, were obtained from preoperative MRI and angiography. Function-related fiber tracts (CST or AF) were also tracked. If the lesion was located in a language-dominant hemisphere, CST and AF were tracked concurrently. If not, only the CST was tracked. Lesion-to-fiber (CST or AF) distance was

Table 1. Characteristics of Patients with Brain Arteriovenous Malformations Located in Premotor Cortex

Variable	Value
Number of patients	36
Age, years, mean ± SD	27.1 ± 11.3
Sex	
Male	20 (55.6%)
Female	16 (44.4%)
Side	
Left	18 (50.0%)
Right	18 (50.0%)
Angioarchitecture	
Size, mm, mean ± SD	43.7 ± 15.6
Hemorrhage*	
Yes	3 (8.3%)
No	33 (91.7%)
DV drainage	
Yes	1 (2.8%)
No	35 (97.2%)
Diffuse nidus	
Yes	10 (27.8%)
No	26 (72.2%)
PA supply	
Yes	11 (30.6%)
No	25 (69.4%)
Initial presentation	
Headache	6 (16.7%)
Hemorrhage	5 (13.9%)
Seizure	23 (63.9%)
Others	2 (5.6%)
S-M score	2.5 ± 0.8
Preoperative NDs	1 (2.8%)
Seizure history	26 (72.2%)
Follow-up, months, mean ± SD (range)	14.7 ± 9.2 (5–33)
Postoperative complications	3 (8.3%)
Short-term NDs, 1 week	12 (33.3%)
Long-term NDs	5 (13.9%)

DV, deep venous; PA, perforating artery; S-M, Spetzler-Martin; ND, neurologic deficit.
*Previous hemorrhage according to preoperative computed tomography or magnetic resonance imaging.