Supplementary Material

A grading scale based on arcuate fasciculus segmentation to predict postoperative language outcomes of brain arteriovenous malformations

Expanded Methods and Materials

Neuroimaging

A Brain MRI series were obtained for all patients using a 3.0-T MR scanner (SIEMENS Trio). Sagittal T1-weighted anatomical MR images were acquired using a gradient echo sequence, and the parameters were as follows: TR/TE, 2300/2.98 msec; FOV, 256 mm; slice thickness, 1 mm; total number of slices, 176 slices; matrix size, 64 × 64; voxel size, 1 × 1 × 1 mm^3; flip angle, 9°; and bandwidth, 240. The DTI studies were collected using the diffusion-weighted echo-planar imaging technique with the following parameters: TR/TE, 6100/93 msec; FOV, 230 × 230 mm^2; slice thickness, 3 mm; total number of slices, 45 slices; matrix size, 128 × 128; and 30-directional motion-probing gradient. Time-of-flight Magnetic Resonance Angiography (TOF-MRA) was performed using a 3D TOF gradient-echo acquisition sequence: TR/TE, 22/3.86 msec, slice thickness 1 mm, slices 36 × 4, FOV 220 × 220 mm^2, flip angle 120°, matrix 512 ×512 [1].

Neuroimaging data analyses

The AF were visualized by DTI tractography. The acquired image data were analyzed on the iPlan cranial 3.0 workstation (Brainlab). All image sets were automatically registered with each other and fused to the anatomical images by automatic rigid registration. We used the posterior parietal area of the superior longitudinal fasciculus and the posterior temporal lobe as the regions of interest to track the AF [2]. Tractography was performed with fiber propagation and stopped when the fractional anisotropy crossed below a threshold of 0.20. A minimum fiber length of 70 mm was selected. Two neurosurgeons (Y.M.J. and J.W.) blinded to the clinical information of the patients documented the locations of the regions of interest and the tracked fibers with consensus.

Arcuate fasciculus classifications

According to the criteria of the AF segments delimitation, two neurosurgeons (Y.M.J. and J.W.) who tracked the AF performed the delimitation, and discrepancies were resolved by a senior neurosurgeon (Y.C.). In the judgement for nidus involvement with segmentation I, II, III, or IV for all patients, we calculated the inter-observer ratio (kappa) between the two neurosurgeons (Y.M.J. and J.W.). Because certain nidus involved two adjacent AF segments, the involvement with segmentation I, II, III, or IV was assessed respectively. Good reproducibility was found for the identification of AF segmentation involvement (Cohen's κ= 0.937, 0.856, 0.940, and 0.907 for the detection of segmentation I, II, III, and IV involvement, respectively) in all patients.

Surgery

The treatment strategy for bAVMs was selected based on patient condition, perceived surgical risks, and patient requirements. Instead of patients with ruptured bAVMs, those with intractable seizures, severe headache, low Spetzler-Martin grading (S-M grading), or progressive neurological deficits were also considered for surgery [3-5], which was described in our previous work [6]. Four patients received preoperative stereotactic radiosurgery (SRS), and 8 patients received preoperative embolization. Microsurgical resection of bAVMs was performed by an experienced senior physician (Y.C.). A neuronavigation system was used to help preserve white matter tracts. Intraoperative indocyanine fluorescence angiography and ultrasonography were used to discern the feeding arteries and nidus margin of AVMs. We also performed digital subtraction angiography after surgery to validate radical obliteration.

Language function evaluation and follow-up

Language function assessment was conducted by an experienced neurosurgeon (H.L.) who was blinded to the clinical information of the patients at 7 days (short-term outcomes) and at the last follow-up (long-term outcomes) after surgery. The Edinburgh Handedness Inventory was used to determine the language-dominant hemisphere. Left-handed patients were excluded. Language function was evaluated by the Chinese version of Western Aphasia Battery, which was widely used in the diagnosis of aphasia [7-9]. Additionally, the Aphasia Quotient (AQ) was calculated from the result of the test as follows: AQ = (spontaneous speech score + auditory comprehension score/20 + repetition score/10 + naming score/10) × 2. An AQ of 93.8 or higher (maximal AQ = 100) indicates normal language function while less than 93.8 indicates aphasia [10,11]. We also ensured that no patients had any hearing disturbance or motor paresis due to pyramidal tract disturbance, both of which could affect the Western Aphasia Battery results.

References

1. Lin F, Zhao B, Wu J, et al. Risk factors for worsened muscle strength after the surgical treatment of arteriovenous malformations of the eloquent motor area. *Journal of neurosurgery* 2016;125(2):289-98. doi: 10.3171/2015.6.JNS15969 [published Online First: 2015/12/05]
2. Catani M, Jones DK, ffytche DH. Perisylvian language networks of the human brain. *Annals of neurology* 2005;57(1):8-16. doi: 10.1002/ana.20319 [published Online First: 2004/12/15]

3. Spetzler RF, Ponce FA. A 3-tier classification of cerebral arteriovenous malformations. Clinical article. *Journal of neurosurgery* 2011;114(3):842-9. doi: 10.3171/2010.8.JNS10663 [published Online First: 2010/10/12]
4. Derdeyn CP, Zipfel GJ, Albuquerque FC, et al. Management of Brain Arteriovenous Malformations: A Scientific Statement for Healthcare Professionals From the American Heart Association/American Stroke Association. *Stroke* 2017;48(8):e200-e24. doi: 10.1161/STR.0000000000000134 [published Online First: 2017/06/24]
5. Spetzler RF, Martin NA. A proposed grading system for arteriovenous malformations. 1986. *Journal of neurosurgery* 2008;108(1):186-93. doi: 10.3171/JNS/2008/108/01/0186 [published Online First: 2008/01/05]
6. Jiao Y, Lin F, Wu J, et al. A supplementary grading scale combining lesion-to-eloquence distance for predicting surgical outcomes of patients with brain arteriovenous malformations. *Journal of neurosurgery* 2018;128(2):530-40. doi: 10.3171/2016.10.JNS161415 [published Online First: 2017/04/01]
7. Chen WL, Ye Q, Zhang SC, et al. Aphasia rehabilitation based on mirror neuron theory: a randomized-block-design study of neuropsychology and functional magnetic resonance imaging. *Neural regeneration research* 2019;14(6):1004-12. doi: 10.4103/1673-5374.250580 [published Online First: 2019/02/15]
8. Wang S, Wang CX, Zhang N, et al. The Association Between Post-stroke Depression, Aphasia, and Physical Independence in Stroke Patients at 3-Month Follow-Up. *Front Psychiatry* 2018;9:374. doi: 10.3389/fpsyt.2018.00374 [published Online First: 2018/09/05]
9. Liu L, Luo XG, Dy CL, et al. Characteristics of language impairment in Parkinson's disease and its influencing factors. *Translational neurodegeneration* 2015;4(1):2. doi: 10.1186/2047-9158-4-2 [published Online First: 2015/02/17]
10. Thomson AM, Taylor R, Whittle IR. Assessment of communication impairment and the effects of resective surgery in solitary, right-sided supratentorial intracranial tumours: a prospective study. *British journal of neurosurgery* 1998;12(5):423-9. doi: 10.1080/02688699844628 [published Online First: 1999/03/10]
11. Li J, Du D, Gao W, et al. The regional neuronal activity in left posterior middle temporal gyrus is correlated with the severity of chronic aphasia. *Neuropsychiatric disease and treatment* 2017;13:1937-45. doi: 10.2147/NDT.S140091 [published Online First: 2017/08/10]

Supplementary Tables

Supplementary Table 1 Difference in baseline characteristics between patients with and without postoperative LD.

Variables	Short-term LD			Long-term LD		
	No (n =73)	Yes (n =62)	P value	No (n =121)	Yes (n =14)	P value
Age (mean ± SD, years)	27.0±12.5	29.6±11.9	0.220‡	27.3±11.4	35.4±16.9	0.113‡
Male, no. (%)	51 (69.9)	39 (62.9)	0.393§	79 (65.3)	11 (78.6)	0.385§
LD history, no. (%)	5 (6.8)	14 (22.6)	0.009§¶	11 (9.1)	8 (57.1)	<0.001§¶
Size (mean ± SD, mm)	33.0±12.7	39.3±15.6	0.011‡¶	35.8±14.0	36.8±17.7	0.802‡
Hemorrhage, no. (%)	38 (52.1)	31 (50.0)	0.812§	57 (47.1)	12 (85.7)	0.006§¶
Deep perforating arteries feeding, no. (%) *						
AChA feeding	2 (2.7)	9 (14.5)	0.013§¶	6 (5.0)	5 (35.7)	0.002§¶
PChA feeding	2 (2.7)	5 (8.1)	0.247§	7 (5.8)	0 (0.0)	1.000§
LLSA feeding	9 (12.3)	8 (12.9)	0.920§	12 (9.9)	5 (35.7)	0.017§¶
DV drainage, no. (%)	5 (6.8)	7 (11.3)	0.366§	10 (8.3)	2 (14.3)	0.360§
Diffuse nidus, no. (%)	10 (13.7)	18 (29.0)	0.029§¶	24 (19.8)	4 (28.6)	0.488§
S-M grading (mean ± SD)	2.5±0.7	2.6±0.8	0.455‡	2.5±0.7	2.6±1.1	0.667‡
AF segments involvement, no. (%) †						
I	33 (45.2)	18 (29.0)	0.053§	46 (38.0)	5 (35.7)	0.866§
II	5 (6.8)	14 (22.6)	0.009§¶	12 (9.9)	7 (50.0)	0.001§¶
III	28 (38.4)	33 (53.2)	0.084§	56 (46.3)	5 (35.7)	0.452§
IV	16 (21.9)	9 (14.5)	0.270§	21 (17.4)	4 (28.6)	0.292§

Abbreviations: AChA= anterior choroidal artery; AF= arcuate fasciculus; DV= deep venous; LD= language deficits; LLSA= lateral lenticulostriate artery; PChA= posterior choroidal artery; S-M = Spetzler-Martin. *BAVMs supplied by more than one deep perforating arteries were counted repeatedly; †BAVMs involving more than one AF segments were counted repeatedly; ‡t-test; §Chi-square test; ¶P Value< 0.05.

Supplementary Table 2 Comparison of surgical outcomes of patients with type IV AF-bAVMs.

Variables	Subtypes of segment IV		P value
	IVa (n =8)	IVb (n =17)	
Short-term LD, no. (%)	7 (87.5)	2 (11.8)	0.001*†
Long-term LD, no. (%)	3 (37.5)	1 (5.9)	0.081*
Complications, no. (%)	2 (25.0)	5 (29.4)	1.000*

Abbreviations: AF-bAVMs= brain arteriovenous malformations (bAVMs) involving arcuate fasciculus; LD= language deficits; * Chi-square test; †P value< 0.05.

Supplementary Table 3 Difference in postoperative LD between patients with and without language eloquence involvement.

Language eloquence	Short-term LD			Long-term LD		
	No (n =73)	Yes (n =62)	P value	No (n =121)	Yes (n=14)	P value
Broca’ area, no. (%)			0.226 *			0.685 *
Yes	22 (62.9)	13 (37.1)		32 (91.4)	3 (8.6)	
No	51 (51.0)	49 (49.0)		89 (89.0)	11 (11.0)	
Wernicke’s area, no. (%)			0.696 *			0.596 *
Yes	19 (51.4)	18 (48.6)		34 (91.9)	3 (8.1)	
No	54 (55.1)	44 (44.9)		87 (88.8)	11 (11.2)	

Abbreviations: LD= language deficits. *Chi-square test.