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Intraoperative neuromonitoring during brain arteriovenous malformation microsurgeries and postoperative dysfunction

A retrospective follow-up study

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Abstract

To evaluate the effectiveness of intraoperative neuromonitoring (IONM) during arteriovenous malformation (AVM) surgery, we retrospectively analyzed neurologic dysfunction in patients who underwent AVM surgery with (IONM group) and without IONM (non-IONM group). The sensitivity and specificity of short-term neurologic dysfunction were calculated in the IONM group. IONM parameters were obtained in all patients. There was no significant difference in neurologic dysfunction between patients in the IONM and non-IONM groups. The short-term hemiplegia ratio among grade III patients in the IONM group was significantly lower than the non-IONM group. The sensitivity of IONM for predicting short-term neurologic dysfunction in the IONM group was 86.7% with a specificity of 100%. Of the different parameters monitored intraoperatively, the somatosensory-evoked potential (SEP), maximum expiratory pressure (MEP), and brain auditory-evoked potential (BAEP) may be beneficial in grade III and IV patients. The BAEP complemented the SEP and MEP. Electromyography and the visual-evoked potential have promise in preserving cranial nerve and visual function. For grades I and II patients, no SEP monitoring was safe. For grade V patients, further investigation is required to prevent neurologic dysfunction because of highly related risks for disability and postoperative complications. Moreover, a larger sample size is required to demonstrate the usefulness of IONM during awake craniotomies.

Abbreviations: AVM = arteriovenous malformation, BAEP = brain auditory-evoked potential, EEG = electroencephalography, EMG = electromyography, IONM = intraoperative neuromonitoring, MEP = maximum expiratory pressure, SEP = somatosensory-evoked potential, TcMEPs = transcranial electrical motor-evoked potentials, VEP = visual-evoked potential.

Keywords: brain arteriovenous malformations microsurgeries, intraoperative neuromonitoring, postoperative dysfunction

1. Introduction

An intracranial arteriovenous malformation (AVM) is an extremely detrimental clinical condition. Greater than 50% of AVM patients exhibit intracranial hemorrhage and 20% to 25% have focal or generalized lifelong seizures that become more severe with age.[1,2] Although advances in intraoperative neuromonitoring (IONM) techniques, such as somatosensory-evoked potentials (SEPs) and electroencephalography (EEG),[3] have improved treatment for vascular diseases, a comprehensive study is lacking.

With advancements in neuroimaging, microsurgical technology, and IONM, surgical resection of AVMs in eloquent motor areas is considered a safe option for specific cases with simultaneous functional assessments, and is also an option for treating deep AVMs[4]; however, treatment-associated morbidity of high-grade level AVMs is still high, and whether or not application of IONM during AVM surgery can decrease cerebral ischemia and damage to eloquent areas is not clear.

To study related questions and explore the effectiveness of IONM during AVM surgery, we adopted the Spetzler–Martin grading system to accurately estimate the risks involved with microsurgical resection (Table 1).[5–7] Resection against grade I, II, or III AVMs according to the Spetzler–Martin classification scheme was shown to be associated with low treatment-associated morbidity, while the treatment-associated morbidity-to-grade IV and V AVMs ratio was 31.2% and 50%, respectively (Iancu-Gontard et al, 2007; Kim et al, 2012). We further evaluated the effectiveness of IONM among patients with different Spetzler–Martin grades by monitoring neurologic dysfunction. Our study will provide the clinical basis for wider clinical application of IONM.[7,8]

2. Patients and methods

2.1. Patient and AVM characteristics

Microsurgical resections were carried out by 1 neurosurgeon. One group of AVM patients (non-IONM group) was composed of 37 males and 32 females with an average age of 36.8 years (range, 9–74 years). Thirty-four patients in the non-IONM group

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Table 1

Spetzler–Martin grading system.

Graded feature		Points assigned
AVM size, cm		
<3		1
3–6		2
>6		3
Eloquence of adjacent brain		
No		0
Yes	Motor cortex (SEP, MEP) Dominant hemisphere language cortex Visual cortex in occipital cortex (VEP) Cranial nerves (EEG)	1
Venous drainage		
Superficial		0
Deep		1
Grade = size + eloquence + venous drainage		

AVM = arteriovenous malformation, EEG = electroencephalography, MEP = maximum expiratory pressure, SEP = somatosensory-evoked potential, VEP = visual-evoked potential.

(49.3%) exhibited hemorrhage and underwent resections without IONM between July 2007 and July 2009. The other group of AVM patients (IONM group) was composed of 43 males and 30 females with average age of 34.9 years (range, 6–76 years). Forty-one patients in the IONM group (56.2%) exhibited hemorrhage and underwent resections between June 2010 and June 2013 (Table 2). All the patients signed the informed consent including surgery and IONM. This is a cohort study without the approval of ethics committee.

2.2. AVM characteristics

All AVMs were graded based on pre-operative angiograms. The nidus size, venous drainage pattern, eloquence, and Spetzler–Martin grade were assessed by the operating neurosurgeon (Table 2).

Table 2

Patient demographic.

	Group 1	Group 2
Male, n (%)	37	43
Female, n (%)	32	30
Age, y	36.8 (range, 9–74 y)	34.9 (range, 6–76 y)
Rupture	34	41
Spetzler–Martin grade n (%)		
I	12 (17.39%)	15 (20.55%)
II	27 (39.13%)	16 (21.91%)
III	19 (27.54%)	21 (28.77%)
IV	7 (10.14%)	14 (19.18%)
V	4 (5.79%)	7 (9.59%)
AVM size, n (%), cm		
<3	25	26
3–6	33	35
>6	11	12
Venous drainage, n (%)		
Superficial	26	28
Deep	43	45
Eloquence, n (%)		
Yes	21	24
No	48	49

AVM = arteriovenous malformation.

According to Spetzler–Martin grading, there were 12 patients (17.4%) with grade I AVMs, 27 (39.1%) with grade II AVMs, 19 (27.5%) with grade III AVMs, 7 (10.1%) with grade IV AVMs, and 4 (5.8%) with grade V AVMs in the non-IONM group. The mean AVM diameter was 36 mm (range, 20–70 mm). Forty-three patients had deep venous drainage and 21 patients were considered eloquent. In the IONM group, there were 15 patients (20.6%) with grade I AVMs, 16 (21.9%) with grade II AVMs, 21 (28.8%) with grade III AVMs, 14 (19.2%) with grade IV AVMs, and 7 (Table 2) (9.6%) with grade V AVMs.

2.3. Neurophysiologic monitoring during surgery (IOMN)

Intraoperative monitoring followed standard protocols. In general, neurophysiologic monitoring was carried out based on location (with reference to the functional area) and blood supply of the AVM lesions. In the case of the nidus of the AVM located in a functional area, the cortical MEP was directly measured to locate the motor cortex. Surgery was performed in the awake state to avoid damaging the language cortex and flash visual-evoked potential (VEP) and electromyography (EMG) was measured for protecting the visual cortex and cranial nerves (EP Works; Xltek Ltd., Oakville, Ontario, Canada). In addition, somatosensory stimulation-evoked potentials (SEPs) of the median and tibial nerves, as well as transcranial electrical motor-evoked potentials (TcMEPs) were continuously monitored in all cases to monitor neural structures at risk for brain ischemia.[9,10] BAEPs was monitored as a supplement if the nidus was located in posterior fossa or refer to the vertebral and basilar artery's vascular.

Constant voltage stimuli consisting of 3 to 5 rectangular pulses with a 1~5 ms inter-stimulus interval were delivered with a D185 stimulator (Digitimer Ltd., Letchworth Garden City, UK) and evoked potentials were monitored as the MEP.[10] The highest response before surgery was recorded as the baseline value. A decrement >80% in the MEP amplitude or a 50% decrement in the somatosensory-evoked potential (SSEP) or the BAEP wave-V amplitudes (as well as a 10% increment in the peak latency of the SSEPs or BAEP) relative to the baseline value was regarded as warning thresholds. The SEP, MEP, and BAEP were continuously monitored in all patients and any alterations beyond the thresholds were promptly reported to the neurosurgeon. On the basis of these IONM-parameters, the neurosurgeon had the option to protect cerebral function by increasing blood pressure, cooling, inducing burst suppression, working more expeditiously, removing the clip or retractor, and/or restarting the surgical procedure until the parameters recovered (Table 3).

2.4. Anesthesia

Patients were induced with propofol (100–150 μg/kg/min) and maintained with propofol (100–150 μg/kg/min) along with remifentanil (0.1–0.3 μg/kg/min). Low-dose halogenated anesthesia was maintained at <0.5 minimal alveolar concentration (MAC). Rocuronium (0.5 mg/kg) was often used to facilitate intubation. A gauze bite block was placed when performing MEP to avoid laceration of the tongue.[9,11]

2.5. Statistical analysis

Statistical analysis was performed with SPSS 13.0 (SPSS, Inc., Chicago, IL). Postoperation dysfunction ratios in each AVMs grade during short-term and long-term follow-up were compared in 2 groups. The aphasia, hemianopia, hemiplegia, and cranial nerve dysfunction ratio were compared in 2 groups to estimate eloquent

Table 3

Monitoring protocol according to Spetzler–Martin grade.

Ischemia monitoring protocol	
All the AVM surgeries	SEP + MEP
When nidus refer to the vertebral and basilar artery's vascular	BAEP
Eloquent monitoring protocol	
Motor cortex	Direct cortical MEP
Language cortex	Wakeup during surgery
Visual cortex	VEP
Cranial nerve	EMG
Alarm criteria	
SEP	50% ↓ amplitude of cortical waveforms or 10% ↑ latency of cortical waveforms
MEP	Complete loss of signal/abrupt significant decrease in amplitude of 80% or more
BAEP	50% ↓ amplitude of wave V or 0.5–1 ms ↑ latency of wave V
VEP	50% ↓ amplitude of waveforms

AVM = arteriovenous malformation, BAEP = brain auditory-evoked potential, EEG = electroencephalography, EMG = electromyography, MEP = maximum expiratory pressure, SEP = somatosensory-evoked potential, VEP = visual-evoked potential.

damage risk. The sensitivity and specificity of IONM in each AVMs grade were also calculated. Significance was accepted if $P < .05$.

3. Results

3.1. Postoperative neurology dysfunction in non-IONM and IONM patients

In the non-IONM group, 20 patients exhibited short-term neurologic dysfunction, and during long-term follow-up, 5 patients had neurologic dysfunction and 3 patients had hemiplegia, of whom 2 had cranial nerve dysfunction, 1 had hemianopia, and 1 had aphasia (Table 4), In the IONM group, 15 patients exhibited short-term neurologic dysfunction, while during long-term follow-up, 4 patients had neurologic dysfunction and 2 patients had aphasia, among whom 1 had hemiplegia, 1 had hemiplegia and cranial nerve dysfunction, and 1 had hemianopia (Table 5).

Although the ratio of short- to long-term neurologic dysfunction in each grade was lower in the IONM group, there was no significant difference ($P > .05$) compared with the non-IONM group (Fig. 1A, B).

The short- and long-term eloquent region damage was lower in the IONM group; there was no significant difference ($P > .05$) compared with the non-IONM group (Fig. 1C, D).

The short-term hemiplegia ratio of grade III patients was significantly higher in the non-IONM group than the IONM group ($P = .039$). The hemianopia, aphasia, and cranial nerve dysfunction ratios during short- and long-term follow-up were not calculated due to the limited number of cases (Fig. 1E).

3.2. Accuracy of IONM in different Spetzler–Marti classification

Short-term neurologic dysfunction was observed in 15 patients in the INOM group, among whom 2 did not exhibit parameter changes during IONM. The sensitivity of SEP, MEP, EMG, and VEP in predicting short-term neurologic dysfunction was 81.8%, 72.7%, 100%, and 100%, respectively. The specificity of SEP, MEP, EMG, and VEP in predicting short-term neurologic dysfunction was 100%, 100%, 80%, and 100% respectively (Table 6).

4. Discussion

4.1. Rapid development in microsurgical skills in AVM requires more precise protocol for monitoring brain function

An accurate IONM strategy for monitoring brain function and preventing mis-targeting during AVM surgery is important for optimizing prognosis.[12–15] We found that IONM is beneficial in preventing neurologic dysfunction during surgery for AVMs. The parameters observed during IONM can predict neurologic dysfunction postoperationally. Thus, our study provides a clinical basis for wider clinical application of IONM.

SEP has been reported to be useful in identifying cerebral ischemia[16] and is monitored during surgery for AVMs, which

Table 4

Postoperative neurology dysfunction in non-IONM patients.

No.	Grade	EMG	SEP	MEP	BAEP	VEP	Short-term outcome	Long-term outcome (1 y)
1	I	/	/	/	/	/	Hemiplegia	Excellent
2	I	/	/	/	/	/	Hemiplegia	Excellent
3	II	/	/	/	/	/	Hemiplegia	Excellent
4	II	/	/	/	/	/	Hemiplegia	Excellent
5	II	/	/	/	/	/	Aphasia	Excellent
6	II	/	/	/	/	/	Hemiplegia	Excellent
7	II	/	/	/	/	/	Hemiplegia	Hemiplegia
8	II	/	/	/	/	/	Hemiplegia, Cranial nerve dysfunction	Excellent
9	III	/	/	/	/	/	Hemiplegia, aphasia	Excellent
10	III	/	/	/	/	/	Hemiplegia	Excellent
11	III	/	/	/	/	/	Hemiplegia, Hemianopia	Excellent
12	III	/	/	/	/	/	Hemiplegia	Hemianopia
13	III	/	/	/	/	/	Hemiplegia, Hemianopia	Excellent
14	III	/	/	/	/	/	Hemiplegia,	Excellent
15	III	/	/	/	/	/	Hemiplegia, Hemianopia	Excellent
16	IV	/	/	/	/	/	Hemiplegia, Cranial nerve dysfunction	Excellent
17	IV	/	/	/	/	/	Hemiplegia, Cranial nerve dysfunction	Left hemiplegia and cranial nerve dysfunction
18	IV	/	/	/	/	/	Hemiplegia, aphasia	Aphasia
19	V	/	/	/	/	/	Hemiplegia, cranial nerve dysfunction	Left hemiplegia and cranial nerve dysfunction
20	V	/	/	/	/	/	Hemiplegia, aphasia	Excellent

AVM = arteriovenous malformation, BAEP = brain auditory-evoked potential, EEG = electroencephalography, EMG = electromyography, MEP = maximum expiratory pressure, SEP = somatosensory-evoked potential, VEP = visual-evoked potential.

Table 5

Postoperative neurology dysfunction in IONM patients.

No.	Grade	EMG	SEP	MEP	BAEP	VEP	Short-term outcome	Long-term outcome (1 y)
1	I	/	+	–	/	/	Paresis	Excellent
2	I	/	/	–	/	/	Aphasia	Excellent
3	II	/	+	–	/	/	Paresis	Excellent
4	II	/	–	+	/	/	Paresis	Excellent
5	III	/	+	+	/	/	Hemiplegia	Excellent
6	III	+	+	–	+	/	Hemiplegia	Excellent
7	III	/	–	–	–	/	Aphasia	Aphasia
8	IV	/	+	+	–	/	Hemiplegia	Excellent
9	IV	–	+	+	–	/	Hemiplegia	Excellent
10	IV	–	–	–	–	+	Hemianopia	Left hemianopia
11	IV	–	–	–	–	+	Hemianopia	Excellent
12	IV	+	–	+	+	/	Hemiplegia	Excellent
13	V	+	+	+	+	/	Hemiplegia and cranial nerve dysfunction	Left hemiplegia and cranial nerve dysfunction
14	V	–	+	+	–	/	Aphasia and Hemiplegia	Aphasia and cranial nerve dysfunction
15	V	+	+	–	+	–	Hemiplegia and cranial nerve dysfunction	Excellent

BAEP = brain auditory-evoked potential, EEG = electroencephalography, EMG = electromyography, MEP = maximum expiratory pressure, SEP = somatosensory-evoked potential, VEP = visual-evoked potential.

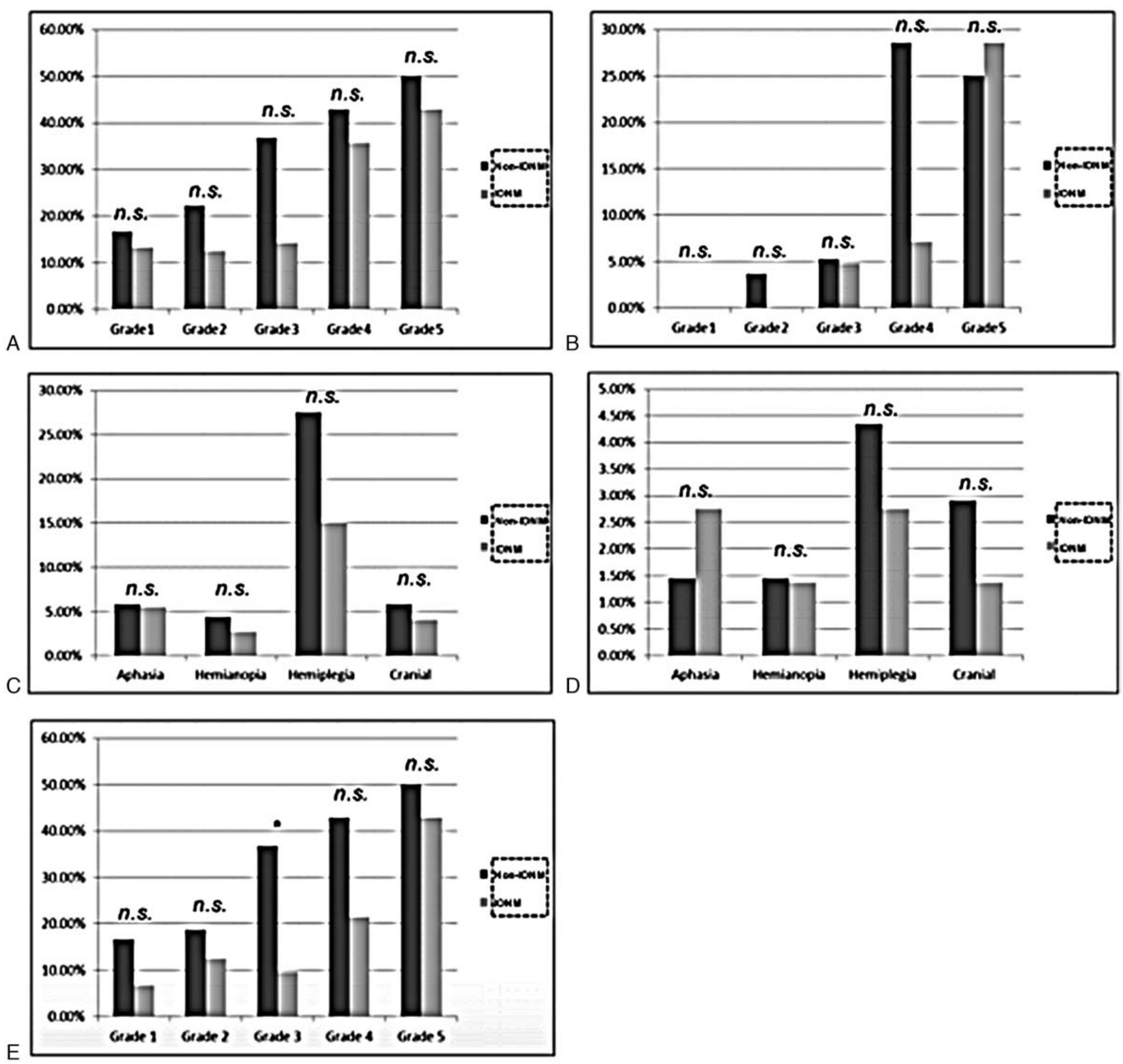

Figure 1. Postoperative neurology dysfunction in AVMs-patients at different Martin grades A, ratio of short-term neurology dysfunction B, ratio of long-term neurology dysfunction C, ratio of short-term eloquent region damage D, ratio of long-term eloquent region damage E, ratio of short-term hemiplegia.

Table 6

The accuracy of IONM to in different IONM methods.

Grade	A	B	C	D	Sensitivity	Specificity
SEP	9	0	2	62	81.82%	100%
MEP	8	0	3	64	72.72%	100%
EMG	3	1	0	4	100%	80%
VEP	2	0	0	1	100%	100%

A, B, C, and D are the number of observed patients in each cell. A are the true positives; B are the false positives; C are the false negatives; D are the true negatives. Sensitivity = true positive rate = A / (A + C). Specificity = true negative rate = D / (B+D).

EMG = electromyography, MEP = maximum expiratory pressure, SEP = somatosensory-evoked potential, VEP = visual-evoked potential.

provides complementary information regarding cortical and subcortical structures, thus we did not include an electroencephalogram (EEG), which can be affected by anesthetic agents and other confounding variables. To address false-negative results during SEP monitoring,[17–19] we combined the BAEP and the SSEP. The BAEP is a complementary evaluation reflecting brainstem status. A sudden loss of wave V in the BAEP is most likely due to ischemia, indicating interrupted blood supply to the vestibulocochlear nerve. Simultaneous monitoring of the SEP and BAEP can decrease the false-positive and false-negative rates.[20] Such a notion is in agreement with our observations that the SEP was stable during surgery in patient 12, who had an AVM located in the posterior circulation and had postoperative hemiplegia based on a change in the BAEP, and patient 6, who had hemiplegia and exhibited a BAEP change, but not a MEP change. Thus, although there was considerable sensitivity (81.8%) and specificity (100%) for evaluating short-term hemiplegia, the incidence of false-negative SEP results can be further decreased when combined with the BAEP, thus indicating that the BAEP results decrease false-negative SEP results and preserve brainstem function.

We implemented both TcMEP and DcMEP for detecting impending lesion in motor cortex or its efferent pathways and identifying passing arteries that support corticospinal tract when following feeding arteries to periphery. Several studies have suggested that MEP is a most reliable technique for detecting blood flow disturbances in internal carotid artery and MCA regions.[21] Thus, MEP monitoring is useful for preventing intraoperative injury of corticospinal tract and identifying exact feeding arteries from passing arteries. In our study, the sensitivity and specificity of MEP for predicting a new motor paresis were 72.7% and 100%, respectively, suggesting that MEP is another good complementation to SEP. Our observations that MEP-changes appeared in patients 4, 12 without SEP-change and appeared earlier than SEP-change in surgery support such notion. The sensitivity and specificity of SEP+MEP+BAEP to evaluate hemiplegia were both 100% in Grade III, IV, V patients. Thus, combinational application of MEP and SEP can serve to monitor motor and sensory function effectively during surgery.

Although it is difficult to obtain stable VEP in real time during IONM for anesthesia-induced interruption and insufficient and unstable stimuli delivery, VEP was still included to monitor the function of visual pathways, especially for a high risk of optic apparatus damage. Permanent VEP loss points to postoperative severe visual dysfunction, while transient VEP changes do not.[22] In our study, stable VEP was acquired in all 3 patients with AVMs located in occipital lobe among whom 2 exhibited VEP changes during surgery, 1 exhibited hemianopia during short-term follow-up, while 1 exhibited hemianopia during long-term follow-up. This result indicated that VEP may serve to evaluate visual function on line and is promising in predicting visual impairment, while its effectiveness to preserve visual function still needs more cases to be explored.

As for protecting cranial nerve, EMG was monitored in 8 patients during surgery. Previous studies have proved that EMG can be prevent cranial nerve injury during identifying and localizing cranial nerves.[23,24] In our study, the sensitivity and specificity of EMG to evaluate cranial nerve dysfunction were 100% and 80%, respectively, indicating the promise in optimizing neurologic outcomes.

We performed awake craniotomies to identify and locate the language cortex in 3 patients, but did not observe any IONM parameter changes during surgery. All 3 patients exhibited aphasia after surgery, and 2 of the patients developed aphasia during long-term follow-up. Thus, further studies are required to verify the usefulness of awake craniotomies in resecting AVMs located in brain regions related to language function.

In summary, we observed a trend toward better postoperative neurologic function in patients undergoing IONM surgery, indicating that IONM is beneficial, especially for patients with grade III AVMs. During surgery, the SEP, MEP, and BAEP results, and the combined SEP, MEP, and BAEP results can predict hemiplegia in patients with grade III and IV AVMs. Furthermore, the EMG and VEP findings have good potential in preventing cranial nerve and visual dysfunction. For awake craniotomies, more studies are needed to demonstrate clinical usefulness in preventing neurologic dysfunction.

References

[1] Peschillo S, Caporlingua A, Caporlingua F, et al. Historical landmarks in the management of aneurysms and arteriovenous malformations of the central nervous system. World Neurosurg 2016;88:661–71.

[2] Ogilvy CS, Stieg PE, Awad I, et al. Special Writing Group of the Stroke Council, American Stroke AssociationRecommendations for the management of intracranial arteriovenous malformations: a statement for healthcare professionals from a Special Writing Group of the Stroke Council, American Stroke Association. Stroke 2001;32:1458–71.

[3] Florence G, Guerit JM, Gueguen B. Electroencephalography (EEG) and somatosensory evoked potentials (SEP) to prevent cerebral ischaemia in the operating room. Neurophysiol Clin 2004;34:17–32.

[4] Potts MB, Young WL, Lawton MT. UCSF Brain AVM Study ProjectDeep arteriovenous malformations in the basal ganglia, thalamus, and insula: microsurgical management, techniques, and results. Neurosurgery 2013;73:417–29.

[5] Spetzler RF, Martin NA. A proposed grading system for arteriovenous malformations. J Neurosurg 1986;65:476–83.

[6] Hamilton MG, Spetzler RF. The prospective application of a grading system for arteriovenous malformations. Neurosurgery 1994;34:2–7.

[7] Iancu-Gontard D, Weill A, Guilbert F, et al. Inter- and intraobserver variability in the assessment of brain arteriovenous malformation angioarchitecture and endovascular treatment results. AJNR Am J Neuroradiol 2007;28:524–7.

[8] Kim H, Pourmohamad T, Westbroek EM, et al. Evaluating performance of the spetzler-martin supplemented model in selecting patients with brain arteriovenous malformation for surgery. Stroke 2012;43: 2497–9.

[9] Aatif M, Husain MD. A Practical Approach to Neurophysiologic Intraoperative Monitoring. Demos Medical Publishing, Newyork:2008.
[10] Gloria MG, Marc RN, Jaime RL. Intraoperative Neurophysiologic Monitoring. Cambridge University Press, Cambridge:2010.
[11] Saleh O, Baluch A, Kaye AJ, et al. Arteriovenous malformation, complications, and perioperative anesthetic management. Middle East J Anesthesiol 2008;19:737–56.
[12] Spetzler RF, Hargraves RW, McCormick PW, et al. Relationship of perfusion pressure and size to risk of hemorrhage from arteriovenous malfor-mations. J Neurosurg 1992;76:918–23.
[13] Kombos T, Pietilä T, Kern BC, et al. Demonstration of cerebral plasticity by intra-operative neurophysiological monitoring: report of an uncommon case. Acta Neurochir (Wien) 1999;141:885–9.
[14] Wischnewski M, Schutter DJ. Efficacy and time course of paired associative stimulation in cortical plasticity: implications for neuropsychiatry. Clin Neurophysiol 2016;127:732–9.
[15] Wunderlich G, Knorr U, Herzog H, et al. Precentral glioma lesion determines the displacement of cortical hand representation. Neurosurgery 1998;42:18–27.
[16] Buchthal A, Belopavlovic M. Somatosensory evoked potentials in cerebral aneurysm surgery. Eur J Anaesthesiol 1992;9:493–7.
[17] Emerson RG, Turner CA. Monitoring during supratentorial surgery. J Clin Neurophysiol 1993;10:404–11.
[18] Friedman WA, Chadwick GM, Verhoeven FJ, et al. Monitoring of somatosensory evoked potentials during surgery for middle cerebral artery aneurysms. Neurosurgery 1991;29:83–8.
[19] Momma F, Wang AD, Symon L. Effects of temporary arterial occlusion on somatosensory evoked responses in aneurysm surgery. Surg Neurol 1987;27:343–52.
[20] Chang SD, Lopez JR, Steinber GK. The usefulness of electrophysiological monitoring during resection of central nervous system vascular malformations. J Stroke Cerebrovasc Dis 1999;8:412–22.
[21] Sasaki T, Kodama N, Matsumoto M, et al. Blood flow disturbance in perforating arteries attributable to aneurysm surgery. J Neurosurg 2007;107:60–7.
[22] Kodama K, Goto T, Sato A, et al. Standard and limitation of intraoperative monitoring of the visual evoked potential. Acta Neurochir 2010;152:643–8.
[23] Minahan RE, Mandir AS. Neurophysiologic intraoperative monitoring of trigeminal and facial nerves. J Clin Neurophysiol 2011;28:551–65.
[24] Singh R, Husain AM. Neurophysiologic intraoperative monitoring of the glossopharyngeal and vagus nerves. J Clin Neurophysiol 2011;28:582–6.