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 inspiratory 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 inspiratory pressure, SEP = somatosensory-evoked potential, TcMEPs = transthoracic electrical motor-evoked potentials, VEP = visual-evoked potential.

Keywords: brain arteriovenous malformations microsurgeries, intraoperative monitoring, 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-type-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]
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            | 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.

Table 2
Patient demographic.

|                   | Group 1 | Group 2 |
|-------------------|---------|---------|
| Male, n (%)       | 37      | 43      |
| Female, n (%)     | 32      | 30      |
| Age, y (range)    | 36.8 (9–74 y) | 34.9 (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 (9.39%)  |
| AVM size, cm, n (%) |         |          |
| <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 (9.6%) with grade V AVMs.

2.3. Neurophysiologic monitoring during surgery (IONM)

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; Xtek Ltd., Oakville, Ontario, Canada). In addition, somatosensory stimulation-evoked potentials (SEP) 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 (SEP) 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
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).

Table 3

| Monitoring protocol according to Spetzler–Martin grade. |
|----------------------------------------------------------|
| Ischemia monitoring protocol: All the AVM surgeries. |
| When nidus refer to the vertebrobasilar artery's vascular |
| eloquent monitoring protocol: Motor cortex. |
| 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.

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–Martin classification

Short-term neurologic dysfunction was observed in 15 patients in the non-IONM 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).

Table 4

| Postoperative neurology dysfunction in non-IONM patients. |
|----------------------------------------------------------|
| No. | Grade | EMG | SEP | MEP | BAEP | VEP | Short-term outcome |
|-----|-------|-----|-----|-----|------|-----|-------------------|
| 1   | I     |     |     |     |      |     | Hemiplegia        |
| 2   | I     |     |     |     |      |     | Hemiplegia        |
| 3   | I     |     |     |     |      |     | Hemiplegia        |
| 4   | I     |     |     |     |      |     | Aphasia           |
| 5   | II    |     |     |     |      |     | Hemiplegia        |
| 6   | II    |     |     |     |      |     | Hemiplegia        |
| 7   | II    |     |     |     |      |     | Hemiplegia        |
| 8   | II    |     |     |     |      |     | Hemiplegia, Cranial nerve dysfunction |
| 9   | II    |     |     |     |      |     | Hemiplegia, aphasia |
| 10  | II    |     |     |     |      |     | Hemiplegia, Hemianopia |
| 11  | II    |     |     |     |      |     | Hemiplegia, Hemianopia |
| 12  | II    |     |     |     |      |     | Hemiplegia, Hemianopia |
| 13  | II    |     |     |     |      |     | Hemiplegia, Hemianopia |
| 14  | II    |     |     |     |      |     | Hemiplegia, Hemianopia |
| 15  | II    |     |     |     |      |     | Hemiplegia, Hemianopia |
| 16  | IV    |     |     |     |      |     | Hemiplegia, Cranial nerve dysfunction |
| 17  | IV    |     |     |     |      |     | Hemiplegia, Cranial nerve dysfunction |
| 18  | IV    |     |     |     |      |     | Hemiplegia, aphasia |
| 19  | V     |     |     |     |      |     | Hemiplegia, Cranial nerve dysfunction |
| 20  | V     |     |     |     |      |     | Hemiplegia, aphasia |

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

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 postoperatively. 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 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   | I     | /   | +   | –   | /    | /   | 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        | Excellent              |
| 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.
blood suggested that MEP is a most reliable technique for detecting following feeding arteries to periphery. Several studies have identifying passing arteries that support corticospinal tract when impending lesion in motor cortex or its efferent pathways and function.

Results decrease false-negative SEP results and preserve brainstem when combined with the BAEP, thus indicating that the BAEP incidence of false-negative SEP results can be further decreased by the SEP. The BAEP is a complementary evaluation re

vestibulocochlear nerve. Simultaneous monitoring of the SEP and brainstem status. A sudden loss of wave V in the BAEP is most severe visual dysfunction, while transient VEP changes do not.

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 prevent cranial nerve injury during identifying and localizing cranial nerves. 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.

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