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# Intraoperative neurophysiological monitoring during the surgery of spinal arteriovenous malformation: sensitivity, specificity, and warning criteria

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ABSTRACT

*Objective:* The incidence of spinal arteriovenous malformation (SAVM) is low, but its treatment is challenging. Intraoperative neurophysiological monitoring (IONM) for intramedullary tumors has been a benchmark in neurosurgery. This study aimed to determine the sensitivity, specificity, and warning criteria of IONM for SAVM surgeries.

*Materials and Methods:* From November 2012 to January 2016, 55 patients underwent SAVM surgery with IONM at the Neurosurgery Department of Xuanwu Hospital of Capital Medical University, China. Modified McCormick grading scale was used to evaluate patients' function 3 days before and immediately, 1 week, 3 months, and 6 months after surgery. IONM was performed including somatosensory evoked potential (SEP), trans-cranial motor-evoked potential (tcMEP), and electromyography (EMG). All patients were followed up every 3 or 6 months.

*Results:* The SAVM locations were cervical spine in 15 (27.3%) patients, thoracic in 24 (43.6%), thoracolumbar in 12 (21.8%), and lumbar in 4 (7.3%). TcMEP and SEP were could be monitored in 53 (96.4%) and 33 (60.0%) patients, respectively. Using > 80% irreversible amplitude reduction of the tcMEP as threshold, the sensitivity, specificity, and positive and negative predictive values were 77.3%, 87.1%, 81.0%, and 84.4%, respectively; using > 50% irreversible amplitude reduction of the tcMEP as the warning criterion, these values were 81.8% 74.2%, 69.2%, and 85.2%, respectively.

*Conclusion:* In practical applications of tcMEP for SAVM surgeries, the 50% irreversible amplitude reduction of the tcMEP criterion can be used to warn the surgeon, while the > 80% criterion can be used to stop the operation in order to avoid neurological impairments.

## 1. Introduction

Spinal vascular lesions account for about 5%–9% of all vascular malformations of the central nervous system [1], or 3%–4% of all intradural spinal lesions [2]. Merland and his team classified spinal vascular lesions into four primary kinds: dural arteriovenous fistula (AVF), perimedullary AVF, intramedullary spinal arteriovenous malformation (SAVM), and metameric AVM [3]. Patients are likely to be diagnosed with a spinal cord syndrome when having motor and/or sensory defect, bladder, and bowel discomfort, as well as physical ailments. Following the initial onset of symptoms, most of the cases recover, at least partially. Nevertheless, SAVM patients tend to experience recurrent events with increased probability of sequelae [4]. In half of the cases, the clinical events are caused by hemorrhage, which is detected quite easily using magnetic resonance imaging (MRI) or computed tomography. For the remaining cases, the symptoms develop due to venous hypertension, steal, or mass influence [5].

Treatment of SAVM is challenging and the intramedullary AVM is the most challenging lesion among the SAVMs. For avoiding the risk of neurological deficits, intraoperative neurophysiological monitoring (IONM) has been put to use for identifying the impending iatrogenic neurologic injury [6]. In 1972, Nash used the somatosensory evoked potentials (SEP) for evaluating the function of the spinal cord during surgery [7]. Nonetheless, a large number of studies reported instances of iatrogenic postoperative para- or tetra-paresis/plegia despite SEP monitoring [8,9]. In the 1990s, the adoption of motor-evoked potentials (MEP) evoked by transcranial electrical stimulation (TES) for inspecting corticospinal motor function has considerably enhanced the IONM utility and dependability during spinal surgery. Single-method IONM techniques have been shown to be insufficient when it comes to carrying out the evaluations of both the ascending and descending pathways [10]. The combination of tcMEP and SEP is likely to bring forth an improved performance with respect to spinal neurosurgery [11]. Nevertheless, the criteria of tcMEP for iatrogenic injury during spinal

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surgery is controversial, and most studies of MEP monitoring during surgery used amplitude reduction, usually 50% or 80% of baseline amplitude, as the primary warning criteria [12–16]. Therefore, our study used these two criteria for the analysis.

The present study aimed to assess the values of SEP and tcMEP in monitoring the spinal surgery of 55 patients with SAVM. The sensitivity and specificity of combined SEP and tcMEP in iatrogenic injury were evaluated. Furthermore, the criteria of tcMEP for this surgery were also explored.

## 2. Materials and methods

### *2.1. Patients*

This study included 55 consecutive patients (34 males and 21 females; average age 32.6 years, range 7–68 years) who underwent SAVM surgery at the Department of Neurosurgery in Xuanwu Hospital of Capital Medical University, China, from November 2012 to January 2016. All through the study, the patients underwent IONM comprising SEP, tcMEP, and EMG during the entire surgical process. The data for demographic attributes, SAVM location (level of the spine) on MRI investigations, spinal DSA to delineate the angio-architecture of the SAVM, and surgical plane were also documented. The findings of preoperative and postoperative neurological tests were also studied retrospectively in connection with IONM information.

All patients underwent neurological assessment before surgery, 3 h postoperatively, at discharge, and at the 3- to 6-month. The clinical data was developed in accordance with the changed version of the modified McCormick grading scale.[17] The clinical situation was studied by a researcher unaware of the IONM findings (Yu, JX, PhD, resident).

### *2.2. Transcranial motor-evoked potential (tcMEP)*

For each process, tcMEP findings were recorded to scrutinize corticospinal tract integrity using paired subdermal needle electrodes placed in the bilateral thenar muscles for upper extremity and in the anterior tibialis or abductor hallucis brevis muscles for the lower extremity. Regarding the cervical lesions, more segmental tcMEP findings were documented from the bilateral deltoid, biceps, and triceps muscles for representing segment-level performance sporadically. For lumbar lesions, more tcMEP results were documented from the bilateral quadriceps and tibialis anterior muscles. Motor evoked potentials were elicited by transcranial electrical motor cortex imitation. The stimulating sites were C1 and C2 [International 10/20 electroencephalogram (EEG) electrode system] [18]. Corkscrew electrodes posed to be the most appropriate for fixation to the head, and impulses of 300-μs duration and intensities between 150 and 400 V were used. A continued reduction of at least 50% of the amplitude of any tcMEP was used as a warning standard. A continued amplitude of tcMEP reduction of more than 80% was termed critical, and surgery was temporarily suspended.

### *2.3. Somatosensory evoked potentials (SEP)*

SEP were performed through stimulation of the median nerve (intensity, 10–20 mA) at the wrist and the posterior tibial nerve (strength, 20–40 mA) at the ankle (duration, 0.3 ms; repetition speed, 4.7 Hz). The recordings were used with the corkscrew electrodes placed at Cz/Fz (legs) and C3/C4/Fz (arms) in accordance with the International 10/20 EEG electrode system. The warning criteria were set for SEP as a 50% reduction in amplitude or a 10% growth in latency.

### *2.4. Electromyography (EMG)*

The free-running EMG was recorded in cervical and lumbar regions with the same channels, suggesting the segmental and root recordings similar to those already obtained in tcMEP.

### *2.5. Anesthesia*

Induction was performed with 1–2 mg/kg midazolam, 0.15 mg/kg etomidate, 0.3 μg/kg sufentanil, 0.6 mg/kg rocuronium bromide, or 0.15 mg/kg atracurium. Moreover, following induction and intubation, general anesthesia continued to make use of 0.2–0.4 μg/ (kg min) remifentanil and 4–6 mg/(kg h) propofol. No muscle relaxant or inhalational agent was used throughout the surgical procedure.

### *2.6. Criteria for IONM correlations*

True positive: Patients came from surgery displaying an observable new neurological deficits that was favorably associated with related IONM results.

True negative: Patients came from surgery showing no neurological deficits together with no changes on IONM results.

False negative: Patients came from surgery exhibiting clinically observable neurological deficits yet with no indications of neurological deficits on the associated IONM findings.

False positive: Patients came from surgery showing no changes in neurological function intact, albeit permanent abolishment in IONM findings.

In our studies, a decrease of one or more than one grade in the McCormick grading scale immediately after surgery, compared with the preoperative score, was defined as a postoperative neurological deficit. Although temporary changes of evoked potentials were not termed as forecasting the indicators for neurologic deficits, those events were studied and contrasted with the clinical performance result.

### *2.7. Statistical analysis*

Continuous data were tested with the Kolmogorov-Smirnov test to determine if their distribution was normal. Normally distributed continuous variables were presented as mean ± standard deviation. Non-normally distributed continuous data were presented as median. The patient data were studied for association among SEP and tcMEP monitorability and postoperative results, taking into consideration age, sex, and spinal cord level. The chi-square test (significance, $P < .05$) was used for assessing the null hypothesis, suggesting no association between categorical variables and the monitoring result. If the sample size was no larger than 5, the Fischer's exact test was used. The sensitivity, specificity, and predictive values were calculated. All analyses were performed using SPSS 16.0 (IBM, Armonk, NY, USA). Two-sided P-values < .05 were considered statistically significant.

## 3. Results

### *3.1. SAVM location and monitorability*

Table 1 presents the characteristics of the patients. The SAVM was located in the cervical spine in 15 (27.3%), thoracic spine in 24 (43.6%), thoracolumbar spine in 12 (21.8%), and lumbar spine in 4 (7.3%). The SAVM location was determined with the help of MRI. TcMEP was measurable in 53 (96.4%) patients, while SEP existed in only 33 (60.0%). The two patients in whom tcMEP was not measurable experienced sizable preoperative performance impairment, one having changed McCormick grade of 5 and the other having that of 4 as opposed to a mean McCormick grade of 1.8 ± 0.9 in the measurable tcMEP group. The mean score for preoperative McCormick grades with respect to SEP-measurable and non-measurable patients were 1.6 ± 0.9 and 2.4 ± 1.2, respectively.