The Application of Regional Cerebral Oxygenation Monitoring in the Prediction of Cerebral Hypoperfusion During Carotid Endarterectomy

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Background: The aim of this study was to assess the diagnostic ability of near-infrared spectroscopy-monitored regional cerebral oxygen saturation (rSO_2) to detect cerebral hypoperfusion during internal carotid artery (ICA) clamping compared with motor and somatosensory evoked potential (EP) monitoring.

Methods: This prospective study recruited consecutive patients undergoing carotid endarterectomy under general anesthesia. Significant EP changes (defined as $>50\%$ decrease in ipsilateral somatosensory EP amplitude or disappearance of contralateral motor EP on >2 consecutive stimulations) during ICA clamping were considered a warning sign for cerebral hypoperfusion. If significant EP changes occurred, the amplitude of the EPs and simultaneous rSO_2 values were recorded before therapeutic intervention. The relationship between reductions in rSO_2 and EP amplitudes was analyzed using Spearman rank-correlation analysis. Receiver operating characteristic curve analysis was used to calculate the optimal cutoff value for the relative reduction in rSO_2. False-positive rates were evaluated according to immediate postoperative motor outcomes.

Results: A total of 203 patients were included for analysis, of whom 23 developed significant EP changes during ICA clamping. There was a positive relationship between decreases in EP amplitude and rSO_2 ($R^2=0.15$, $P=0.02$). A rSO_2 reduction $\geq 16\%$ from baseline had the optimal diagnostic performance for the detection of cerebral hypoperfusion (area under the receiver operating characteristic curve = 0.82; 95% confidence interval: 0.76-0.87). The false-positive rate was 8.9%.

Conclusions: Decreases in rSO_2 correlated with decreases in EP amplitude during ICA clamping. A relative reduction in rSO_2 $\geq 16\%$ could serve as a warning for clamping-associated cerebral hypoperfusion. The 8.9% false-positive rate is a potential clinical limitation of the use of rSO_2 to predict postoperative neurological deficits.

Key Words: carotid endarterectomy, regional cerebral oxygen saturation, somatosensory evoked potential, motor evoked potential, evoked potential, near-infrared spectroscopy

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Carotid endarterectomy (CEA) is the surgical treatment for patients with high-grade carotid artery stenosis and is associated with a perioperative stroke risk of 2.3% to 7.4%.[1,2] It is important to monitor for intraoperative cerebral hypoperfusion in an attempt to reduce poor outcomes.

Many methods are available to monitor the adequacy of cerebral perfusion during CEA. Somatosensory evoked potential (SSEP) and motor evoked potential (MEP) have been found to be valuable in identifying critical cerebral hypoperfusion, and could serve as effective intraoperative neuromonitors to predict the need for a shunt.[3,4] The main disadvantage of evoked potential (EP) monitoring is the requirement for trained monitoring personnel. An additional disadvantage with MEP monitoring is the need to avoid muscle relaxants. Regional cerebral oxygen saturation (rSO_2) monitoring with near-infrared spectroscopy has been used to provide a noninvasive, real-time assessment of cerebral oxygenation and perfusion during CEA, particularly during internal carotid artery (ICA) clamping, when it has been used to predict cerebral ischemic injury.[5] However, there is no consensus on the cutoff value of rSO_2 to define the risk for cerebral hypoperfusion.[6] Moreover, rSO_2 cutoff values reported in previous studies have been compared with electroencephalograph, transcranial Doppler, and single SSEP or MEP, but not with multiple EP monitoring.

The aim of the current study was to assess the diagnostic ability of rSO_2 to detect cerebral hypoperfusion compared with multimodal EP monitoring during ICA cross-clamping. The cutoff value of rSO_2 to predict cerebral hypoperfusion was calculated, and the number of false positives was analyzed to determine its potential use and limitations in clinical practice.

METHODS

This single-center, prospective, observational study was carried out at Beijing Tiantan Hospital, Capital Medical University, China. The study was approved by the Ethics Committee of Beijing Tiantan Hospital, Capital Medical University (KY2014-043) and registered in the Chinese Clinical Trial Registration database (www.chictr.org.cn, ChiCTR-DDD-16010088). All patients provided written informed consent.

Patients

Patients with carotid stenosis of 70% or greater scheduled for elective CEA at Beijing Tiantan Hospital between January 2017 and March 2018 were evaluated for eligibility, and recruited consecutively if they fulfilled the following inclusion criteria: age between 18 and 80 years, and American Society of Anesthesiologists physical status II-III. Exclusion criteria included preoperative coagulation abnormalities (activated partial thromboplastin time >1.5 times normal), body mass index $>30\,kg/m^2$, hemoglobin concentration $<10\,g/dL$, serum creatinine $>177\,\mu mol/L$, alanine aminotransferase $>80\,U/L$, aspartate aminotransferase $>80\,U/L$, or refusal of consent.

Anesthesia

All patients underwent CEA with general anesthesia. Anesthesia was induced with etomidate 0.2 to 0.3 mg/kg, sufentanil 0.3 μg/kg, and rocuronium 0.8 mg/kg, and maintained with remifentanil 0.1 to 0.2 μg/kg/min and propofol target-controlled infusion (Marsh pharmacokinetics model for propofol) with a plasma concentration of 2 to 4 μg/mL adjusted to maintain the bispectral index between 40 and 60. No rocuronium was administered after the induction dose. Routine monitoring included electrocardiogram, oxygen saturation, arterial blood pressure (via a radial artery catheter), end-tidal carbon dioxide partial pressure, axillary temperature, and bispectral index. During surgery, end-tidal carbon dioxide partial pressure was adjusted through ventilation to maintain partial pressure of carbon dioxide ($PaCO_2$) between 35 and 40 mm Hg, heart rate was maintained between 50 and 90 beats/min, and axillary temperature was maintained between 36° and 37°C. The mean arterial pressure (MAP) was maintained within 80% to 120% of the preoperative baseline values; MAP was increased by 10% to 20% of baseline during ICA clamping to maintain cerebral perfusion, and decreased by 10% to 20% after unclamping to prevent cerebral hyperperfusion.

Monitoring

rSO_2 was monitored continuously using an INVOS cerebral oximeter (INVOS 5100C; Somanetics Corp., Troy, MI). The rSO_2 sensor was placed on the ipsilateral forehead, about 1 to 2 cm above the eyebrow, according to the manufacturer's instructions.

EPs were monitored by 2 trained electrophysiologists using a Cadwell Cascade neurophysiologic monitoring system (Cascade; Cadwell Laboratories Inc., Kennewick, WA). Surface-stimulating electrodes for SSEP monitoring were placed over each ulnar nerve at the wrists and over each posterior tibial nerve at the ankles. Needle electrodes were placed over the somatosensory cortex at scalp sites C3′-Fz, C4′-Fz, Cz′-Fz, and C3′-C4′ (International 10-20 System) to record the primary cortical responses to stimulation. Ulnar nerves were stimulated at 15 to 25 mA and posterior tibial nerves at 35 to 40 mA. Stimulation frequency was set at 4.71 Hz with a duration of 0.2 ms, 30 to 500 Hz band-pass, and 0.2 ms of interstimulus interval. MEPs were recorded from paired needle electrodes placed bilaterally in the abductor pollicis brevis of the upper limb. Electrical current was delivered to corkscrew electrodes inserted at the C1 and C2 sites (International 10-20 System) with a train of 5 to 8 pulses, at 500 Hz, 100 to 400 V, 100 to 1500 Hz band-pass, 0.5 ms duration, and 2 ms of interstimulus interval.[7]

Significant EP changes, a warning sign for critical cerebral hypoperfusion, were defined as a $>50\%$ decrease in ipsilateral SSEP amplitude or contralateral MEP amplitude disappearance on >2 consecutive stimulations.[3,4,8] When significant EP changes occurred, MAP was increased by 20% to 30% above baseline to maintain perfusion. If the EP changes did not recover immediately after MAP elevation, shunt insertion was suggested. In the current study, the amplitude of EPs and rSO_2 value were recorded simultaneously before the above therapeutic measures were taken to improve perfusion.

Data Collection and Outcomes

The baseline values for EPs and rSO_2 were determined one minute before ICA clamping. If significant EP changes (either MEP or SSEP) occurred during clamping, the amplitude of the EPs and the rSO_2 value were recorded simultaneously before measures were taken to improve perfusion as noted above. Otherwise, the minimum amplitude of EPs and the rSO_2 value during clamping were recorded at the same time point. Changes in EPs and rSO_2 and during ICA clamping were compared with preclamp baselines, calculated as ΔEP and ΔrSO_2, respectively. Arterial blood gas analysis was carried out 1 minute before ICA clamping, 10 minutes postclamping, and immediately after the clamp was removed.

Motor function was assessed by the same researcher on the day before surgery and immediately after the patient fully awakened from anesthesia. Postoperative motor deficit was defined as new-onset motor deficit or decreased motor function immediately after recovery from anesthesia. The false-positive rate of rSO_2 monitoring was calculated according to the postoperative motor deficit. In the case of a new motor deficit, the patient was evaluated every day until recovery of the deficit or discharge from hospital.

Sample Size Estimation and Statistical Analysis

On the basis of our results (area under the curve [AUC], 0.82; number of significant EP cases, 23), the test level α was set as 0.05 and the β value was calculated to be 0.05, and the post hoc analysis for the power of the test was 95%. All participants were divided into 2 groups on the basis of whether significant EP changes did or did not occur during ICA clamping. Continuous variables with a normal distribution are presented as mean and SD, and compared using Student *t* test. Non-normally distributed continuous variables are presented as median and interquartile range, and compared using the Mann-Whitney *U* or the Friedman test. Categorical variables are presented as numbers with percentages, and compared using the Pearson χ^2 or Fisher exact tests. The relationship between monitoring parameters was analyzed using the Spearman rank-correlation test. Receiver operating characteristic (ROC) curve analysis was used to assess the ability of rSO_2 to predict cerebral hypoperfusion during ICA clamping, and optimal cutoff values were identified by the maximum sum of sensitivity and specificity.[9] The corresponding sensitivity, specificity, positive predictive value, and negative predictive value were calculated on the basis of the optimal cutoff value. *P*-value <0.05 was considered to indicate statistical significance. Statistical analyses were carried out using IBM's Statistical Package for the Social Sciences (SPSS), version 21.0 (Chicago, IL), and MedCalc, version 8.1.1.0 (Mariakerke, Belgium) software.

RESULTS

A total of 268 patients were assessed for eligibility; 65 patients were excluded, leaving 203 for inclusion in the final analysis (Fig. 1). Twenty-three patients developed significant EP changes during ICA clamping and received therapeutic intervention by elevation of MAP to 20% to 30% above baseline. There were no significant differences in baseline demographics, operation laterality, comorbidities, degree of carotid stenosis, or ICA cross-clamping time between the patients with (n = 23) and without (n = 180) significant EP changes (Table 1). In addition, MAP, heart rate, $PaCO_2$, and hemoglobin concentration during the peri-ICA clamping

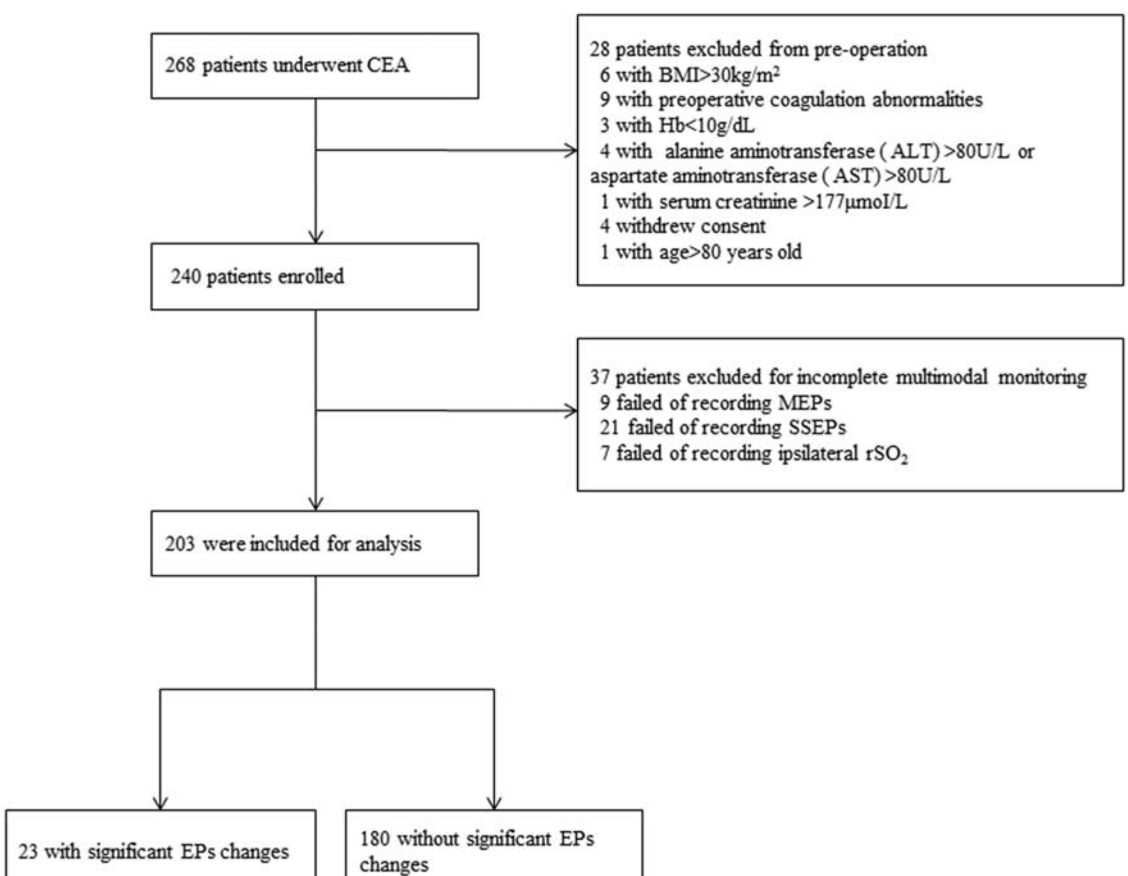

FIGURE 1. Patient recruitment flowchart. BMI indicates body mass index; CEA, carotid endarterectomy; EP, evoked potential; Hb, hemoglobin; MEP, motor evoked potential; rSO_2, regional cerebral oxygen saturation; SSEP, somatosensory evoked potential.

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TABLE 1. Demographics and Baseline Characteristics

Variables	All Patients (N = 203)	Significant EPs Changes (N = 23)	No Significant EPs Changes (N = 180)	P
	Median (IQR)/n (%)			
Age (y)	62 (61-64)	65 (59-68)	62 (58-67)	0.97
BMI (kg/m^2)	25 (24-25)	25 (23-27)	24 (23-26)	0.96
Male sex	170 (84)	16 (70)	154 (86)	0.06
CEA left site	107 (53)	16 (70)	91 (53)	0.07
Hypertension	149 (73)	20 (87)	129 (72)	0.09
Diabetes mellitus	79 (39)	9 (39)	70 (39)	0.58
Coronary artery disease	32 (16)	7 (30)	25 (14)	0.06
Hyperlipidemia	175 (86)	21 (91)	154 (86)	0.35
Smoke history	142 (70)	14 (61)	128 (71)	0.34
Symptomatic indication	189 (93)	23 (100)	166 (89)	0.38
Degree of ipsilateral stenosis				0.46
50%-69%	5 (2)	1 (4)	4 (2)	
70%-99%	198 (98)	22 (96)	176 (98)	
Degree of contralateral stenosis				0.21
< 50%	92 (45)	7 (30)	85 (47)	
50%-70%	52 (26)	6 (26)	46 (26)	
70%-99%	46 (23)	9 (39)	37 (21)	
Occlusion	13 (6)	1 (4)	12 (7)	
ICA cross-clamping time (min)	24 (21-26)	27 (18-32)	24 (19-28)	0.47

BMI indicates body mass index; CEA, carotid endarterectomy; EP, evoked potential; ICA, internal carotid artery; IQR, interquartile range.

period did not differ between groups (Supplemental Digital Content 1: Supplementary Table 1, http://links.lww.com/JNA/A276—Changes in hemodynamics, $PaCO_2$, and hemoglobin concentration before, during, and after ICA clamping).

Correlation Between rSO_2 and EPs

There was a correlation between ΔrSO_2 and EP amplitude changes ($R^2 = 0.15$, $P = 0.02$). The mean (± SD) of ΔrSO_2 in patients with significant EP changes was 18.3% (± 8.8%) compared with 9.0% (± 5.5%) in the patients with nonsignificant EP changes ($P < 0.001$) (Table 2). In addition, the proportion of patients with $\Delta rSO_2 \geq 16\%$ was higher in those with significant EP change compared with those without significant EP change (69.5% vs. 9.4%, respectively, $P < 0.001$).

Diagnostic Performance of rSO_2 for Detecting Cerebral Hypoperfusion

Analysis of the ROC curve revealed an AUC of 0.82 (95% confidence interval: 0.76-0.87) for rSO_2 to predict the need for intervention for potential cerebral hypoperfusion compared with EP changes. The optimal cutoff value of ΔrSO_2 in predicting the need for intervention (ie, significant EP changes) was 16% with the largest sum of sensitivity and specificity. The sensitivity was 70.8%, the specificity was 91.1%, the positive predictive value was 48.5%, and the negative predictive value was 95.9% (Table 3).

TABLE 2. Value Range of ΔrSO_2 During ICA clamping

ΔrSO_2 (Relative Decrease)	All Patients (N = 203)	Significant EPs Changes (N = 23)	Nonsignificant EPs Changes (N = 180)	P
Mean values (SD)	10.1 (6.6)	18.3 (8.8)	9.0 (5.5)	0.002
Value range, n (%)				0.000
< 10%	124 (61.1)	4 (17.4)	120 (66.7)	
10%-15%	46 (22.7)	3 (13.1)	43 (23.9)	
16%-20%	17 (8.3)	7 (30.4)	10 (5.5)	
21%-40%	16 (7.9)	9 (39.1)	7 (3.9)	
Significant change≧16%, n (%)	33 (16.2)	16 (69.5)	17 (9.4)	0.000

ΔrSO_2 was calculated as the formula: (Baseline rSO_2 − minimum rSO_2)/baseline rSO_2.
EP indicates evoked potential; ICA, internal carotid artery; rSO_2, regional cerebral oxygen saturation.

False-positive Rate of rSO_2 Monitoring

The percentage of false-positive rate for ΔrSO_2 was evaluated according to the immediate postoperative motor outcome. A false-positive result was defined as a change in $\Delta rSO_2 \geq 16\%$ during ICA clamping that was not associated with an immediate postoperative motor deficit. In the 180 patients who did not receive interventions, there were 16 false positives (8.9%). In addition, 1 patient with nonsignificant EP changes developed motor deficit in the immediate postoperative period; this recovered within 3 days. The ΔrSO_2 during ICA clamping in that patient was 17%.

DISCUSSION

Our study showed that ΔrSO_2 during ICA clamping had a positive relationship with EP changes, which is consistent with previous findings.[10] Uchino et al[11] reported a significant correlation between changes in MEP amplitude and reduction in rSO_2 during ICA clamping. Thus, a relative change in rSO_2 could be used as a reference indicator for cerebral hypoperfusion during ICA clamping. However, previous studies have defined ΔrSO_2 cutoff values for the detection of cerebral hypoperfusion that vary between 11.7% and 25%.[5]

Due to small sample sizes and varied reference standards, previous studies have cast considerable doubt on the relevant cutoff value of ΔrSO_2 compared with other neuromonitors during CEA under general anesthesia.[12] The most reliable cutoff value for cerebral ischemia was obtained in conscious patients operated under local anesthesia.[6] Our study attempted to identify the diagnostic performance of rSO_2 to detect cerebral hypoperfusion during CEA under general anesthesia. The AUC represents the overall performance of the diagnostic test, and should be at least 0.75 to be clinically valuable.[13] We found that ΔrSO_2 of 16% had the optimal diagnostic performance in differentiating cerebral hypoperfusion on the basis of ROC (AUC = 0.82, 95% confidence interval: 0.76-0.87).

In other studies, Mauermann et al[10] used a ΔrSO_2 cutoff value of 10% and reported a sensitivity of 75% and

TABLE 3. Diagnostic Statistics for rSO_2 Monitoring in Predicting for Cerebral Hypoperfusion

Parameter	Cutoff Value (%)	Sensitivity (95% CI) (%)	Specificity (95% CI) (%)	Positive Predictive Value (95% CI) (%)	Negative Predictive Value (95% CI) (%)
ΔrSO_2	16	70.8 (48.8-86.6)	91.1 (85.6-94.6)	48.5 (31.2-66.5)	95.9 (91.4-98.2)

ΔrSO_2 was calculated as the formula: (Baseline rSO_2−minimum rSO_2)/baseline rSO_2.
CI indicates confidence interval; rSO_2, regional cerebral oxygen saturation.

a specificity of 84%, whereas Rigamonti et al[14] reported that a decrease in rSO_2 of 15% or greater had a sensitivity of 44% and a specificity of 82% in predicting the need for shunt placement during CEA. In the current study, the cutoff value of 16% was associated with a higher specificity (91.1%) than that reported in these previous studies, and a sensitivity >70%. Furthermore, the negative predictive value in our study was higher (95.9%) than the positive predictive value (48.5%). This is consistent with the findings of Friedell et al,[12] who compared the efficacy of rSO_2 with electroencephalography and SSEP in determining the need for shunt placement during CEA and reported positive predictive and negative predictive values of 47% and 98%, respectively. Thus, ΔrSO_2 appears to have a high negative predictive value for cerebral hypoperfusion, but a low positive predictive value and specificity. These findings confirm that, although harmful desaturation events would rarely go undetected, rSO_2 monitoring might result in some patients undergoing unnecessary treatment because of the false-positive rates. In association with previous findings, the false-positive rate of 8.9% for detecting postoperative neurological outcomes in our study suggests that rSO_2 monitoring in isolation may have insufficient clinical reliability for assessing cerebral perfusion during CEA.

There are several limitations to our study. First, this was a prospective single-center study and our results need to be validated in larger multicenter studies, particularly in centers that routinely apply shunts during ICA clamping. Second, both the number of patients enrolled and the number with significant EP changes were relatively small. Third, we only evaluated motor deficits immediately after surgery, which may have led to an underestimation of the incidence of longer term neurological deficits. However, neurological deficits occurring immediately after surgery have been closely associated with ICA clamping-related ischemia.[15] Finally, the criteria for predicting cerebral ischemia during ICA clamping differed between SSEP and MEP monitoring. Currently, SSEP and MEP are considered monitors for cerebral hypoperfusion, but the corresponding cutoff criterion in the MEP varies among studies. However, loss of MEP is widely used as warning criteria during CEA.[3,4,8,16,17]

In summary, ΔrSO_2 during ICA clamping was significantly associated with EP monitoring evidence for intraoperative cerebral hypoperfusion. ΔrSO_2 of 16% can serve as a warning criterion in determining the presence of ICA clamping-associated hypoperfusion during CEA. However, relying on rSO_2 alone might lead to unnecessary therapeutic interventions, and increase the risk of shunt-related complications. Further multicenter studies are needed to identify the combined diagnostic performance of EPs and rSO_2 in monitoring patients during CEA under general anesthesia.

REFERENCES

1. Rothwell PM, Gutnikov SA, Warlow CP. European Carotid Surgery Trialist's Collaboration. Reanalysis of the final results of the European Carotid Surgery Trial. *Stroke*. 2003;34:514–523.
2. Ferguson GG, Eliasziw M, Barr HW, et al. The North American Symptomatic Carotid Endarterectomy Trial: surgical results in 1415 patients. *Stroke*. 1999;30:1751–1758.
3. Alcantara SD, Wuamett JC, Lantis JC, et al. Outcomes of combined somatosensory evoked potential, motor evoked potential, and electroencephalography monitoring during carotid endarterectomy. *Ann Vasc Surg*. 2014;28:665–672.
4. Malcharek MJ, Kulpok A, Deletis V, et al. Intraoperative multimodal evoked potential monitoring during carotid endarterectomy: a retrospective study of 264 patients. *Anesth Analg*. 2014;120: 1352–1360.
5. Li J, Shalabi A, Ji F, et al. Monitoring cerebral ischemia during carotid endarterectomy and stenting. *J Biomed Res*. 2016;30:11–16.
6. Whiten C, Gunning P. Carotid endarterectomy: intraoperative monitoring of cerebral perfusion. *Curr Anaesth Crit Care*. 2009;20: 42–45.
7. Li Y, Meng L, Peng Y, et al. Effects of dexmedetomidine on motor- and somatosensory-evoked potentials in patients with thoracic spinal cord tumor: a randomized controlled trial. *BMC Anesthesiol*. 2015;16:51.
8. Malcharek MJ, Herbst V, Bartz GJ, et al. Multimodal evoked potential monitoring in asleep patients versus neurological evaluation in awake patients during carotid endarterectomy: a single-centre retrospective trial of 651 patients. *Minerva Anestesiol*. 2015;81: 1070–1078.
9. Unal I. Defining an optimal cut-point value in ROC analysis: an alternative approach. *Comput Math Methods Med*. 2017;2017: 3762651.
10. Mauermann WJ, Crepeau AZ, Pulido JN, et al. Comparison of electroencephalography and cerebral oximetry to determine the need for in-line arterial shunting in patients undergoing carotid endarterectomy. *J Cardiothorac Vasc Anesth*. 2013;27:1253–1259.
11. Uchino H, Nakamura T, Kuroda S, et al. Intraoperative dual monitoring during carotid endarterectomy using motor evoked potentials and near-infrared spectroscopy. *World Neurosurg*. 2012; 78:651–657.
12. Friedell ML, Clark JM, Graham DA, et al. Cerebral oximetry does not correlate with electroencephalography and somatosensory evoked potentials in determining the need for shunting during carotid endarterectomy. *J Vasc Surg*. 2008;48:601–606.
13. Olsson C, Thelin S. Regional cerebral saturation monitoring with near-infrared spectroscopy during selective antegrade cerebral perfusion: diagnostic performance and relationship to postoperative stroke. *J Thorac Cardiovasc Surg*. 2006;131:371–379.
14. Rigamonti A, Scandroglio M, Minicucci F, et al. A clinical evaluation of near-infrared cerebral oximetry in the awake patient to monitor cerebral perfusion during carotid endarterectomy. *J Clin Anesth*. 2005;17:426–430.

15. Huibers A, Calvet D, Kennedy F, et al. Mechanism of procedural stroke following carotid endarterectomy or carotid artery stenting within the International Carotid Stenting Study (ICSS) Randomised Trial. *Eur J Vasc Endovasc Surg*. 2015;50:281–288.
16. Marinò V, Aloj F, Vargas M, et al. Intraoperative neurological monitoring with evoked potentials during carotid endarterectomy versus cooperative patients under general anesthesia technique: a retrospective study. *J Neurosurg Anesthesiol*. 2018;30:258–264.
17. Malcharek MJ, Hesse J, Hesselbarth K, et al. Warning criteria for MEP monitoring during carotid endarterectomy: a retrospective study of 571 patients. *J Clin Monit Comput*. 2019;50: 281–288.

