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Intraoperative use of transcranial motor/sensory evoked potential monitoring in the clipping of intracranial aneurysms: evaluation of false-positive and false-negative cases (II)

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OBJECTIVE

Somatosensory and motor evoked potentials (SEPs and MEPs) are often used to prevent ischemic complications during aneurysm surgeries. However, surgeons often encounter cases with suspicious false-positive and false negative results from intraoperative evoked potential (EP) monitoring, but the incidence and possible causes for these results are not well established. The aim of this study was to investigate the efficacy and reliability of EP monitoring in the microsurgical treatment of intracranial aneurysms by evaluating false-positive and false-negative cases.

METHODS

From January 2012 to April 2016, 1514 patients underwent surgery for unruptured intracranial aneurysms (UIAs) with EP monitoring at the authors' institution. An EP amplitude decrease of 50% or greater compared with the baseline amplitude was defined as a significant EP change. Correlations between immediate postoperative motor weakness and EP monitoring results were retrospectively reviewed. The authors calculated the sensitivity, specificity, and positive and negative predictive values of intraoperative MEP monitoring, as well as the incidence of false-positive and false-negative results.

RESULTS

Eighteen (1.19%) of the 1514 patients had a symptomatic infarction, and 4 (0.26%) had a symptomatic hemorrhage. A total of 15 patients showed motor weakness, with the weakness detected on the immediate postoperative motor function test in 10 of these cases. Fifteen false-positive cases (0.99%) and 8 false-negative cases (0.53%) were reported. Therefore, MEP during UIA surgery resulted in a sensitivity of 0.10, specificity of 0.94, positive predictive value of 0.01, and negative predictive value of 0.99.

CONCLUSIONS

Intraoperative EP monitoring has high specificity and negative predictive value. Both false-positive and false-negative findings were present. However, it is likely that a more meticulously designed protocol will make EP monitoring a better surrogate indicator of possible ischemic neurological deficits.

KEY WORDS

unruptured intracranial aneurysms; evoked potential; false negative; false positive; diagnostic technique; vascular disorders

TABLE 1. Summary of clinical and demographic data and aneurysm characteristics for 1514 patients who underwent clipping of 1845 UIAs with EP monitoring

Variable	Value
Sex, n (%)	
Female	1061 (70.08%)
Male	453 (29.92%)
Mean age in yrs	57.14 ± 9.30
Hypertension, n (%)	150 (9.91%)
DM, n (%)	747 (49.34%)
History of CAD, n (%)	29 (1.92%)
Mean aneurysm size in mm	4.80 ± 3.38
Aneurysm location,* n (%), mean size in mm	
Anterior circulation	
ICA	
Cavernous	2 (0.11%), 23.00 ± 8.28
Paraclinoid	145 (7.86%), 5.91 ± 4.21
PCoA	209 (11.33%), 4.87 ± 3.00
AChA	143 (7.75%), 3.27 ± 1.65
ICA bifurc	85 (4.61%), 6.91 ± 7.51
ACoA	324 (17.56%), 4.89 ± 2.60
ACA	98 (5.31%), 4.13 ± 4.57
MCA	792 (42.93%), 4.60 ± 2.58
Posterior circulation	
Basilar top	19 (1.03%), 4.71 ± 2.92
PCA	2 (0.11%), 2.50 ± 0.28
SCA	13 (0.70%), 4.08 ± 2.72
AICA & PICA	13 (0.70%), 5.62 ± 3.50

ACA = anterior cerebral artery; ACoA = anterior communicating artery; AICA = anterior inferior cerebellar artery; bifurc = bifurcation; CAD = coronary artery disease; DM = diabetes mellitus; ICA = internal carotid artery; MCA = middle cerebral artery; PCA = posterior cerebral artery; PCoA = posterior communicating artery; PICA = posterior inferior cerebellar artery; SCA = superior cerebellar artery.
Data are from 1514 patients who underwent clipping of 1845 UIAs with EP monitoring. Means are presented with SDs.
* Aneurysm location indicates the originating artery of the aneurysm sac.

TABLE 2. Clinical and radiological outcome

Variable	No. of Cases (%)
Complications	75 (4.95)
Radiologically confirmed infarction	72 (4.76)
Asymptomatic infarction	52 (3.43)
Symptomatic infarction	18 (1.19)
Motor weakness	9 (0.59)
Confusion/delirium	5 (0.33)
Motor/sensory aphasia	2 (0.13)
Delayed infarction (after POD 3)	2 (0.13)
Hemorrhage	4 (0.26)
ICH & SAH	1 (0.07)
ICH	2 (0.13)
EDH	1 (0.07)
CN III palsy	3 (0.20)
Seizure	2 (0.13)
Vasospasm	2 (0.13)
Other	9 (0.59)
Functional outcomes	
GOS <5 at discharge	6 (0.40)
mRS ≥3 at 6 mos	1 (0.07)

CN = cranial nerve; EDH = epidural hemorrhage; POD = postoperative day. Some patients had more than 1 type of complication and are therefore represented in more than 1 category.

TABLE 3. False-positive cases

Case No.	Age (yrs), Sex	Aneurysm Characteristics: Location*	Aneurysm Characteristics: Size (mm)	Muscle Relaxant	MEP Cx: Persist	MEP Cx: Any	SEP Cx: Persist	SEP Cx: Any	Postop Motor Weakness	GOS†	mRS‡
1	52, F	PCoA	4	Contin	+	+	−	−	−	5	0
2	46, F	ACoA	6.3	Contin	+	+	−	−	−	5	0
3	69, F	ACoA	1.7	Contin	+	+	−	−	−	5	0
4	56, F	MCA	3.6	Single bolus	+	+	−	−	−	5	0
5	38, F	ACoA	5	Contin	+	+	−	−	−	5	0
6	65, M	MCA	2.06	Contin	+	+	−	−	−	5	0
7	56, M	MCA	5.8	Single bolus	+	+	−	−	−	5	0
8	55, F	MCA	3.2	Contin	+	+	+	+	−	5	0
9	60, F	MCA	5.3	Contin	+	+	−	−	−	5	0
10	54, M	MCA	3.7	Contin	+	+	−	−	−	5	0
11	53, M	MCA	2.3	Single bolus	+	+	−	−	−	5	0
12	47, M	MCA	3	Contin	+	+	−	−	−	5	0
13	43, M	MCA	2.4	Contin	+	+	−	−	−	5	0
14	56, F	ACA	4.58	Contin	+	+	−	−	−	5	0
15	61, M	ACoA	2	Single bolus	+	+	−	−	−	5	0

Contin = continuous; Cx = change(s); persist = persistent; + = EP change event; − = no EP change event.
* Aneurysm location indicates the originating artery of the aneurysm sac.
† GOS score at discharge.
‡ mRS score at 6 months' follow-up.

TABLE 4. False-negative cases

Case No.	Age (yrs), Sex	Aneurysm Characteristics: Location	Aneurysm Characteristics: Size (mm)	Muscle Relaxant	MEP Cx: Persist	MEP Cx: Any	SEP Cx: Persist	SEP Cx: Any	Periop Complications	Lesion Size (cm)*	Motor Grade: POD 0	Motor Grade: 1 Mo Postop	GOS†	mRS‡
1	46, F	Paraclinoid	5.6	Contin	−	−	−	−	Postop temp lobe ICH, SAH	2.5	4	5	5	0
2	75, F	MCA	13.2	Contin	−	−	−	−	Acute infarction in lt MCA terr	1.3	3	4	5	0
3	56, F	MCA	3	Contin	−	−	−	−	Acute infarction in lt lat LSA terr	3.8	2	5	5	0
		AChA	2											
		ICA bifurc	3											
4	72, F	MCA	7.1	Contin	−	−	−	−	Appearance of several DWI high-signal cortical lesions in lt paracentral lobule	0.6	4	5	5	0
5	69, F	PCoA	5	Contin	−	−	−	−	Rt AChA terr infarction	0.8	4	5	5	0
6	49, M	MCA	4.6	Contin	−	−	−	−	Recent infarction w/ hemorrhage in rt basal ganglia	4.7	4	4	4	1
7	71, F	AchA	4	Contin	−	−	−	−	Focal acute infarction, lt anteromedial thalamus	0.9	4	5	5	0
8	60, F	ACoA	18	Contin	−	−	−	−	Ischemic Cx in rt ACA terr → confusion	0.9	2	5	4	3
		MCA	2.9											
		AchA	2.8											

TABLE 5. Sensitivity, specificity, PPV, and NPV

Characteristic	SEP Cx (95% CI): Persist	SEP Cx (95% CI): Any	MEP Cx (95% CI): Persist	MEP Cx (95% CI): Any	Overall EP Cx (95% CI)
Sensitivity	0.000 (0.000–0.287)	0.000 (0.000–0334)	0.000 (0.000–0.315)	0.000 (0.000–0.332)	0.100 (0.005–0.454)
Specificity	0.995 (0.995–0.997)	0.973 (0.973–0.975)	0.990 (0.990–0.992)	0.976 (0.976–0.978)	0.941 (0.940–0.943)
PPV	0.000 (0.000–0.359)	0.000 (0.000–0.081)	0.000 (0.000–0.210)	0.000 (0.000–0.092)	0.011 (0.001–0.050)
NPV	0.993 (0.993–0.995)	0.993 (0.993–0.995)	0.993 (0.993–0.995)	0.993 (0.993–0.995)	0.994 (0.993–0.996)

TABLE 6. Comparison of characteristics of previously published studies and the present study

Authors & Year	No. of Cases (w/ MEP data)	Dx	Op	Type of Stim	Electrode Location	Type of EP	Stim Ampl (MEP)	Alert Criteria	Sensitivity* (95% CI)	Specificity* (95% CI)	FP*	FN*	Preop EP Eval	Remark
Suzuki et al., 2003	108	SAH & UIA	Clipping	DCS	Subdural, motor cortex (hand)	MEP	2 mA above threshold level (8–16 mA)	>50% ampl decr over 3 consec trials	0.200 (0.011–0.200)	1.000 (0.991–1.000)	0	0	−	ICA aneurysms
Horiuchi et al., 2005	53	SAH & UIA	Clipping	DCS	Subdural, motor cortex (hand)	MEP & SEP	2 mA above threshold level	>50% ampl decr over 3 consec trials	0.250 (0.014–0.250)	1.000 (0.981–1.000)	0	0	−	
Szelényi et al., 2006	113	SAH & UIA	Clipping	TES &/or DCS	C1, C2 (Cz & Fz for some pts)	MEP & SEP	<33 mA (DCS); <240 mA (TES)	>50% ampl decr; >20 mA threshold incr (TES)	0.364 (0.144–0.450)	0.990 (0.964–0.999)	0	7	−	
Irie et al., 2010	110	SAH & UIA	Clipping	TES	C3/Cz, C4/Cz	MEP	Approximately 500 V	>50% ampl decr over 3 consec trials	0.467 (0.009–0.167)	1.000 (0.991–1.000)	0	4	−	
Yeon et al., 2010	55	UIA	Clipping	TES	C3, C4	MEP & SEP	300–400 V	>50% ampl decr	0.000 (0.000–0.000)	1.000 (1.000–1.000)	0	0	−	Ant circ aneurysms
Motoyama et al., 2011	48	UIA	Clipping	DCS & TES	Subdural, motor cortex (hand) for DCS, C3/C4 for TES	MEP	140–250 V	>50% ampl decr over 3 consec trials	0.000 (0.000–0.000)	1.000 (1.000–1.000)	0	0	−	
Dengler et al., 2013	30	Aneurysm, ICA occlusion	EC-IC bypass	TES	C3, C4	MEP & SEP	Max of 400 V	>50% ampl decr; >10% incr in peak latency	0.500 (0.028–0.500)	1.000 (0.970–1.000)	0	0	−	
Takebayashi et al., 2014	50	UIA	Clipping, trapping, bypass	DCS	Subdural, motor cortex (hand)	MEP	<18 mA	Compl loss	0.400 (0.169–0.400)	1.000 (0.942–1.000)	0	0	−	Large & giant MCA aneurysms
Yue et al., 2014	89	SAH & UIA	Clipping, bypass	TES	C3, C4	MEP & SEP	100–400 V	>50% ampl decr 1st stage; >90% (wave loss) 2nd stage	0.200 (0.011–0.200)	1.000 (0.945–1.000)	0	1† (1.1%)	−	MCA aneurysms
Suzuki et al., 2014	5	UIA	Clipping (awake craniotomy)	DCS	Subdural, motor cortex (hand)	MEP	5–15 mA	NR	0.000 (0.000–0.000)	1.000 (1.000–1.000)	0	2 (40%)	−	AChA aneurysms
Present study, 2017	1514	UIA	Clipping, EC-IC bypass	TES	C3, C4	MEP & SEP	<300 V	>50% ampl decr	0.000 (0.000–0.315)	0.990 (0.990–0.992)	15 (0.99%)	8 (0.53%)	+	

Ampl = amplitude; ant = anterior; circ = circulation; compl = complete; consec = consecutive; DCS = direct cortical stimulation; decr = decrease; Dx = diagnosis; EC = extracranial; FN = false negative; FP = false positive; IC = intracranial; incr = increase; NR = not reported; pts = patients; stim = stimulation; TES = transcranial electric stimulation.
* Data were reevaluated and/or analyzed to match the criteria for false-positive and false-negative cases to the present study.
† SEP change was noted without MEP change.

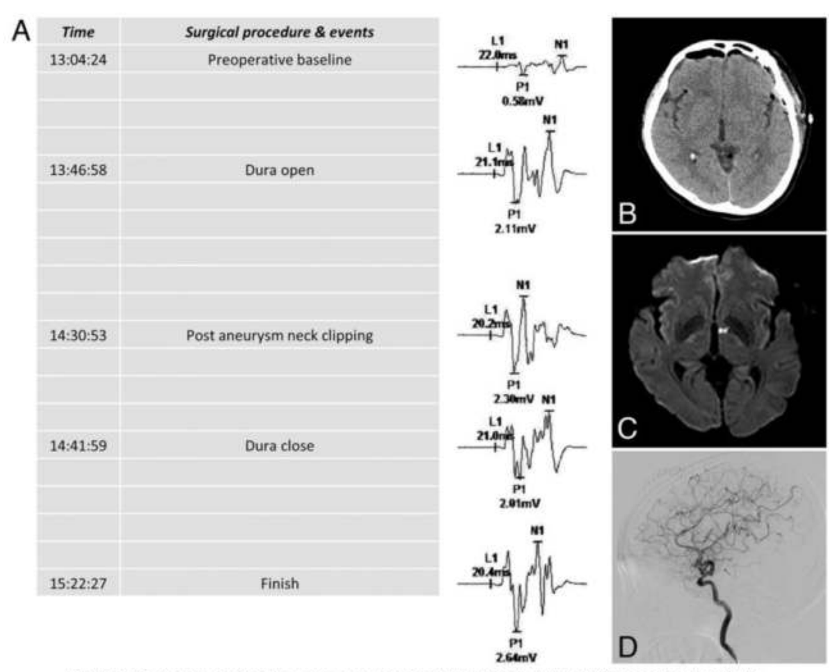

FIG. 1. This 71-year-old woman had a 4-mm aneurysm at the origin of AChA (case 7 in Table 4). ICG videoangiography and MVD sonography confirmed the patency of the internal carotid artery and AChA. There was no significant EP change during the operation (**A**); however, the patient showed grade 4 motor deficits in the right upper and lower extremities. Brain CT scans performed immediately after surgery and 1 day postoperatively revealed nothing abnormal (**B**), but the patient's motor weakness did not resolve. Thus, diffusion-weighted imaging was performed 3 days postoperatively and revealed a focal acute infarction at the left anteromedial thalamus (**C**). However, the AChA was shown to be patent by postoperative DSA immediately following the diffusion-weighted imaging study (**D**).

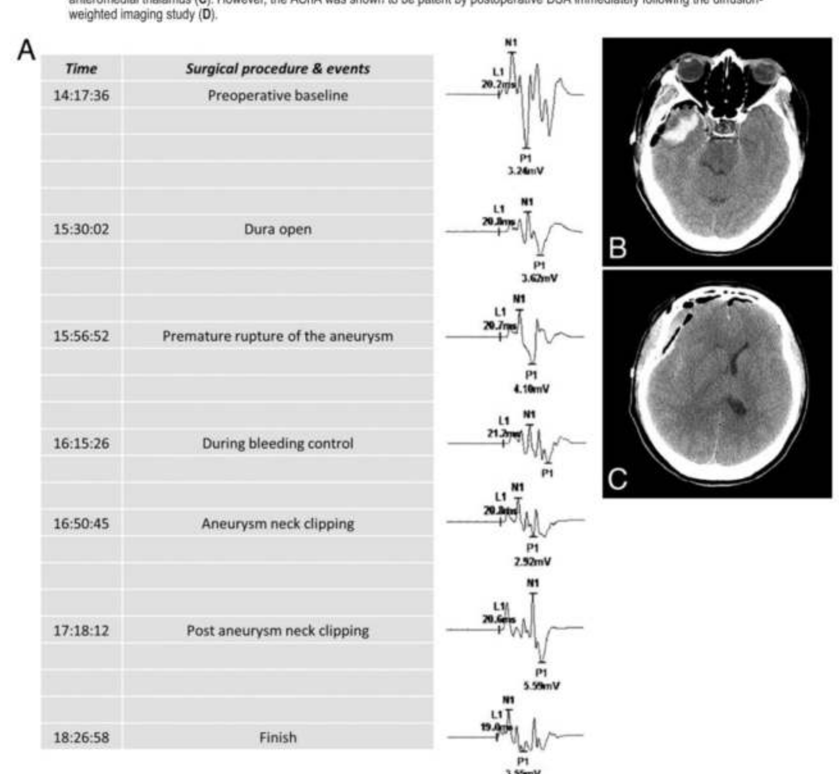

FIG. 2. This 46-year-old woman had a 5.6-mm paraclinoid aneurysm (case 1 in Table 4). During the intradural removal of the anterior clinoid process, the surgical high-speed drill injured the medial temporal lobe. The paraclinoid aneurysm was clipped after the bleeding was brought under control. ICG videoangiography and MVD sonography confirmed the patency of the internal carotid artery and its branches, and there were no significant EP changes observed during surgery (**A**). However, the patient had grade 4 motor deficits in the left upper and lower extremities with ipsilateral ptosis. Postoperative brain CT revealed an ICH in the temporal lobe and an SAH with midline shift toward the contralateral side (**B and C**).

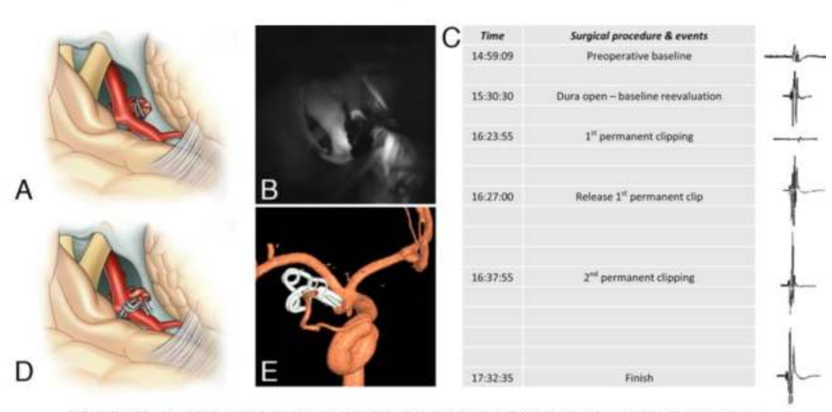

FIG. 3. This 72-year-old woman had a 7.4-mm right AChA aneurysm at the point of branching from the right distal internal carotid artery. Two standard clips were applied, leaving enough space from the AChA, which was severely stenotic. However, one of the aneurysm clips had to be placed over a perforating vessel, as the perforator was severely adhered to the aneurysm dome (**A**). ICG videoangiography confirmed the patent blood flow of AChA (**B**). However, the EP amplitude dropped more than 50%, but the EP results soon normalized after release of the previously applied aneurysm clips (**C**). Thus, the aneurysm was partially clipped to preserve the small perforator (**D and E**). The remnant aneurysm sac was secured with endovascular coiling. Panels A and D copyright Asan Medical Center. Published with permission. Figure is available in color online only.