PAPER

False negative findings in intraoperative SEP monitoring: analysis of 658 consecutive neurosurgical cases and review of published reports

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Objectives: To determine the sensitivity of intraoperative monitoring in neurosurgical operations using somatosensory evoked potentials and to identify reasons for false negative findings and possible settings with an increased risk for monitoring failure.
Methods: SEP monitoring of 658 neurosurgical operations was analysed. The target of monitoring was the function of a hemisphere in 251 cases, the brain stem in 198 cases, and the spinal cord in 209 cases.
Results: In 27 cases (4.1%), monitoring was classified as false negative. Further analysis showed that five of these patients had experienced delayed neurological damage. Among the remaining 22 false negative cases, 14 had a minor neurological deficit and eight had severe neurological damage. Overall sensitivity and negative predictive value of SEP monitoring was 79% and 96%, respectively. For the detection of severe neurological damage the corresponding figures were 91% and 98%. Sensitivity of monitoring varied depending on the target of monitoring and the type of lesion. Monitoring was less likely to detect neurological damage in surgery for infratentorial tumours with brain stem compression, small lesions of the motor cortex, and small vessel damage during aneurysm surgery.
Conclusions: SEP monitoring has acceptable sensitivity for detecting neurological damage during different neurosurgical procedures. Distinct settings with an increased risk of monitoring failure can be identified. In these cases measures to enhance the sensitivity of monitoring should be considered.

Although there are no controlled randomised trials showing a favourable effect of intraoperative neurophysiological monitoring (IOM) on surgical outcome, there is much evidence that it is a useful tool to prevent neurological damage during different surgical procedures.[1–7] Consequently IOM is now widely used in clinical practice and it would hardly be considered ethical to carry out a randomised trial on its efficacy. Thus the collection of observational data appears to be the best way to deal with questions arising from clinical practice. In this paper we present a critical evaluation of a large neurosurgical series from a single institution using somatosensory evoked potentials (SEP), focusing on an analysis of monitoring failures. For the monitoring team it is of prime importance to be aware of the limitations of their method, and detailed knowledge of IOM failures may help to refine monitoring techniques and improve sensitivity.

METHODS

During a period of nine years (January 1992 to December 2001), 21 990 neurosurgical operations were done in our hospital. IOM was applied only in cases that were considered to carry a significant risk of neurological damage. Thus, based on the surgeon's decision, the type of lesion, and the availability of the monitoring team, some kind of neurophysiological monitoring was undertaken in 884 cases (4% of all operations). From this database 658 consecutive cases in which SEP monitoring was done were selected for further analysis. Cases confined to facial nerve monitoring, monitoring of motor evoked potentials, and monitoring involving spinal cord stimulation were excluded from the analysis in order to avoid confusion, as in modes other than SEP monitoring the criteria for monitoring alarms are different and somewhat ill defined. Some data on a subgroup of this population have been analysed and published elsewhere, with a focus on surgical interventions together with a detailed description of our techniques.[7]

The age of the patients ranged from 0.6 to 83.2 years (mean 45.8 years), and the male to female ratio was 1.3:1. The duration of monitoring ranged from 0.8 to 12.9 hours, with a mean of 3.3 hours. The patients' diagnoses were as follows: 282 intracranial tumours (156 infratentorial, 126 supratentorial), 158 extramedullary and 51 intramedullary spinal lesion, 139 intracranial vascular lesion, and 28 other non-tumour lesions. The target of monitoring—that is, the structure that was mostly exposed to damage during surgery—was a cerebral hemisphere in 251 cases, the brain stem in 198 cases, and the spinal cord in 209 cases. Median nerve somatosensory evoked potentials (M-SEP) were used for monitoring in 463 cases, and tibial nerve potentials (T-SEP) in 166. In 29 cases both modes were used.

Recording technique

In the earlier cases, balanced anaesthesia with nitrous oxide and isoflurane was employed, while in the later cases total intravenous anaesthesia was used exclusively. Our recent anaesthetic protocol includes induction with propofol, remifentanil, and rocuronium and maintenance of anaesthesia by continuous infusion of remifentanil and propofol. M-SEP and T-SEP were elicited by stimulation of the nerve at the wrist or at the lower ankle, respectively, using square wave electrical pulses (100 ms duration, 20 mA intensity, 5.1 Hz stimulation rate). A stimulation rate of 3.1 Hz was

Abbreviations: BAEP, brain stem auditory evoked potential; IOM, intraoperative neurophysiological monitoring; M-SEP, median nerve somatosensory evoked potential; SEP, somatosensory evoked potential; T-SEP, tibial nerve somatosensory evoked potential

Table 1 Classification of intraoperative monitoring findings

Target of IOM	Total	True positives	False positives	False negatives	True negatives
Cerebral hemisphere	251	29	0	16	206
Brain stem	198	31	20	5	142
Spinal cord	209	45	6	6	152
Total	658	105	26	27	500

Values are numbers of cases.
IOM, intraoperative monitoring.

used in some cases, if the amplitudes of the baseline recordings were low. Stimulation and recordings were done using subcutaneous needle electrodes. For recording, the active electrodes were placed at C3′ and C4′ (M-SEP) or at Cz′ (T-SEP) with a reference electrode at Fz according to the international 10-20 system. Proximal recordings were made using either electrode at the second cervical vertebra, at Erb's point, or the first lumbar vertebra. An earth (ground) electrode was placed at the forehead. Resistance of all electrodes was kept below 5 kΩ. The time base was set to 50 or 100 ms and a filter bandpass of 30 to 3000 Hz was used. Depending on the quality of the recording, 250 to 500 trials were averaged.

The recordings were visually analysed for the presence of the main peaks N20–P25 and P40–N50, respectively, and peak to peak amplitudes as well as peak latencies were measured. After induction and with anaesthesia in steady state, intraoperative baseline values were established and the recording parameters were maintained throughout the surgical procedure. In patients with intraoperative events during IOM or unexpected neurological deficits, additional recordings were made postoperatively within the first days after surgery.

Collection of data

Criteria of an event—that is, a pathological finding in neurophysiological monitoring—were a 50% reduction in amplitude of the cortical complex and/or a 10% increase in peak latency compared with baseline if sustained for two consecutive trials. In all cases of monitoring events, several conditions were checked such as alterations to the anaesthesia regimen, physiological abnormalities, and surgical problems noted by the surgeon.

All patients had a neurological examination postoperatively, done by a member of the staff who was not involved in the monitoring procedure. Patients were classified as suffering from a neurological deficit if a new significant neurological dysfunction occurred corresponding to the monitoring target. For example, if surgery of an intracranial aneurysm was monitored using M-SEP or T-SEP, a new hemiparesis was considered to be a postoperative deficit. However, a patient with a new dysfunction of the oculomotor nerve was not admitted to this group, because monitoring was not targeted at this nerve. For spinal cord monitoring any motor or sensory function of the spinal cord was considered to be the target of monitoring. Thus all patients with new symptoms of spinal cord dysfunction postoperatively were assigned to the group with postoperative deficits.

Classification of IOM

For the purpose of this study patients were assigned to one of four groups corresponding to the information obtained from IOM, the intraoperative findings, and the postoperative neurological examination. These groups were:

- *True positives*—Patients were assigned to this group if a monitoring event occurred and a new neurological deficit corresponding to the target of monitoring was present. However, patients without a neurological deficit were also included if the surgeon identified and reacted

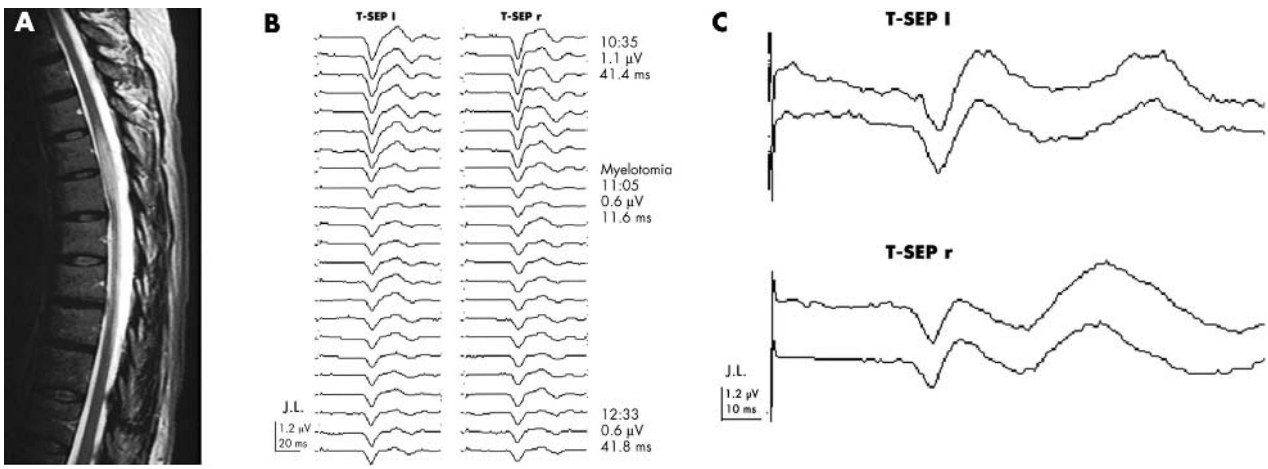

Figure 1 Case No 8 (158-97). This 49 year old man presented with mild ataxia. (A) Magnetic resonance scan showing an intramedullary tumour at D4–D6. Histological examination revealed a benign astrocytoma. (B) Intraoperative tibial nerve somatosensory evoked potential (T-SEP) recordings, showing attenuation of the T-SEP amplitude bilaterally when the tumour was approached through a midline myelotomy. These changes persisted until the end of surgery, but did not exceed the limit of a 50% attenuation, which is considered to be of clinical significance. Postoperatively the patient suffered from a new mild paraparesis and marked ataxia, but improved continuously and was able to walk independently within two weeks after surgery. (C) T-SEP recordings on the second day after surgery showing the preservation of T-SEP on both sides. This case illustrates how minor neurological deficits may be not detected with SEP monitoring.

Table 2 Cases of false negative intraoperative monitoring

Case No	Diagnosis	Target of IOM	Postoperative findings	Classification
1	Right MCA aneurysm	Cerebral hemisphere	Seizures and left hemiparesis 8 h postop, MCA ischaemia, marked attenuation of M-SEP postop	Delayed deficit
2	Intradural schwannoma C4-C6	Spinal cord	Increased sensorimotor paresis of the right arm, normal M-SEP postop	Minor deficit
3	Petroclival meningioma	Brain stem	Reversible, incomplete right hemiparesis, moderate attenuation of M-SEP postop	Minor deficit
4	Left temporal AVM	Cerebral hemisphere	Reversible, incomplete paresis of the right arm, moderate attenuation of M-SEP intraop, small ischaemic internal capsule lesion, unchanged M-SEP postop	Minor deficit
5	BA aneurysm	Brain stem	Delayed MCA ischaemia 18 h postop, complete loss of M-SEP	Delayed deficit
6	Pontine cavernoma	Brain stem	Right hemiparesis, normal M-SEP postop	Severe deficit
7	Left ICA aneurysm	Cerebral hemisphere	Delayed MCA ischaemia 12 h postop, complete loss of M-SEP	Delayed deficit
8	Intramedullary astrocytoma D4-D6	Spinal cord	Moderate T-SEP attenuation intraop, reversible mild paraparesis, unchanged T-SEP postop	Minor deficit
9	Left sphenoidal meningioma	Cerebral hemisphere	Right hemiparesis, partial MCA ischaemia, normal M-SEP postop	Severe deficit
10	Left MCA aneurysm	Cerebral hemisphere	Myocardial infarct 12 h postop, partial MCA ischaemia, right hemiparesis, marked M-SEP attenuation postop	Delayed deficit
11	Left parietal metastasis	Cerebral hemisphere	Reversible mild right hemiparesis and aphasia, normal M-SEP postop	Minor deficit
12	Spinal ependymoma D12 - S5	Spinal cord	Attenuated T-SEP preop, increased distal paraparesis, unchanged T-SEP postop	Minor deficit
13	Left parietal meningioma	Cerebral hemisphere	Attenuated M-SEP preoperatively, reversible mild right hemiparesis, unchanged M-SEP postop	Minor deficit
14	Right sphenoidal meningioma	Cerebral hemisphere	Progressive left hemiparesis 6 h postop, partial MCA ischaemia, marked attenuation of M-SEP postop	Delayed deficit
15	Left parietal glioblastoma	Cerebral hemisphere	Right hemiparesis, normal CT and M-SEP postop	Severe deficit
16	Left parietal astrocytoma	Cerebral hemisphere	Reversible, mild right hemiparesis, normal M-SEP postop	Minor deficit
17	Right MCA aneurysm	Cerebral hemisphere	Left partial hemiparesis, internal capsule ischaemia, normal M-SEP postop	Severe deficit
18	Intradural schwannoma L3-L5	Spinal cord	Reversible incomplete cauda syndrome, normal T-SEP postop	Minor deficit
19	Angioblastoma D11	Spinal cord	Reversible mild paraparesis, normal T-SEP postop	Minor deficit
20	Intradural meningioma D5-D6	Spinal cord	Reversible mild paraparesis and ataxia, no SEP recording postop	Minor deficit
21	Right parietal meningioma	Cerebral hemisphere	Reversible mild left hemiparesis, normal M-SEP postop	Minor deficit
22	Left CPA haemangiopericytoma	Brain stem	Incomplete right hemiparesis and cranial nerve dysfunction, normal M-SEP postop	Severe deficit
23	Left MCA aneurysm	Cerebral hemisphere	Aphasia, partial MCA ischaemia, normal M-SEP postop	Severe deficit
24	ACA aneurysm	Cerebral hemisphere	Right hemiparesis, left thalamic ischaemia, no SEP recording postop	Severe deficit
25	Bilateral cerebellar metastases	Brain stem	Right hemiparesis, left internal capsule ischaemia from presumed embolic insult, normal M-SEP postop	Severe deficit
26	Right parietal metastasis	Cerebral hemisphere	Reversible incomplete left hemiparesis, normal M-SEP postop	Minor deficit
27	Left MCA aneurysm	Cerebral hemisphere	Reversible aphasia, normal CT, normal M-SEP postop	Minor deficit

ACA, anterior communicating artery; AVM, arteriovenous malformation; BA, basilar artery; CPA, cerebellopontine angle; CT, computed tomography; ICA, internal carotid artery; intraop, intraoperatively; IOM, intraoperative monitoring; MCA, middle cerebral artery; postop, postoperatively; preop, preoperatively.

to an intraoperative problem corresponding to the monitoring event in order to prevent neurological damage.

- *False positives*—Patients were assigned to this group if a monitoring event occurred, but corresponding intraoperative findings or problems were missing and the patient showed no postoperative deficit corresponding to the target of monitoring.
- *False negatives*—Patients were assigned to this group if monitoring was completely uneventful, but the patient

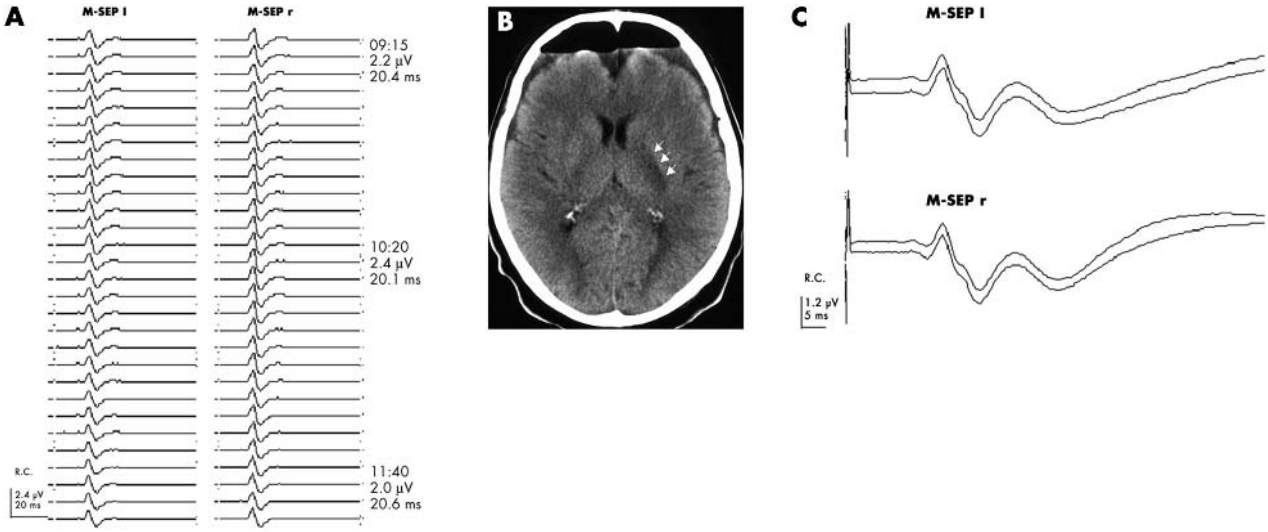

Figure 2 Case No 25 (77-01). This 62 year old man underwent resection of a cerebellar metastasis. Surgery was completely uneventful, but the patient awoke with a right sided hemiparesis. (A) Traces of intraoperative monitoring showing no significant changes of median nerve somatosensory evoked potentials (M-SEP) during surgery. (B) Postoperative computed tomography showed a left thalamic ischaemic lesion (arrows). (C) M-SEP recording done 22 hours postoperatively, showing normal traces over both hemispheres. This case illustrates the lack of sensitivity of M-SEP recording for detecting a motor deficit in cases of an isolated lesion of the motor pathways. We speculated that the patient had an embolic ischaemic insult during surgery, as transoesophageal echocardiography showed a left atrial thrombus.

suffered from a new postoperative deficit corresponding to the target of monitoring.

- *True negatives*—Patients were assigned to this group if monitoring was uneventful and no new postoperative deficits were found.

Database

The complete dataset of IOM including all recordings and amplitude and latency values were stored in a database. The dataset additionally comprises remarks on the stages of the surgical procedure and, if present, on special intraoperative events. The patient's preoperative recordings of evoked potentials and, if done, the postoperative recordings were also included. Furthermore the datasets were supplemented with remarks on the patient's postoperative course and the protocol of the surgical procedure. The database is designed to allow a meaningful retrospective analysis of each monitoring case.

RESULTS

In 527 of the total 658 cases (80%) monitoring was uneventful, and in 131 cases (20%) a monitoring event was noted. In 106 of the cases with a monitoring event, the alterations to the evoked potentials persisted throughout the surgical procedure, whereas they returned to normal during surgery in 25 cases. All the latter, except for four false positive cases, were assigned to the group of true positives. A new postoperative deficit was observed in 112 (17%) of the 658 cases. According to our criteria the patients were assigned to groups as follows: 105 (16%) true positives, 26 (3.9%) false positives, 27 (4.1%) false negatives, and 500 (76%) true negatives. A detailed overview is given in table 1.

Analysis of false negative findings

A summary of the findings in the 27 false negative IOM cases is given in table 2. A careful case by case analysis of these 27 patients identified three different groups with IOM failure. In the first group of five patients a thorough review of clinical, radiological, and neurophysiological findings presented convincing evidence that the neurological deficit has not occurred intraoperatively, but in the early postoperative period after termination of monitoring. There were four patients who underwent clipping of an intracranial aneurysm and one with a large meningioma of the skull base infiltrating the cavernous sinus and the wall of the intracavernous internal carotid artery. Early postoperative neurological examination on the intensive care unit was unequivocally normal in three patients. In two patients a mild deficit was suspected at the time of the first examination postoperatively, but both showed a clear step by step deterioration in the early postoperative period. In all five cases SEP monitoring was completely uneventful until the end of surgery, but all patients showed marked alterations of SEP when recordings were done postoperatively—on the same day in two cases or on the day after surgery in

Table 3 Sensitivity and negative predictive values

		Minor and severe deficits		Severe deficits only	
Target of IOM	No	Sensitivity	Negative predictive value	Sensitivity	Negative predictive value
Cerebral hemisphere	251	64%	95%	81%	98%
Brain stem	198	85%	97%	88%	98%
Spinal cord	209	88%	96%	100%	100%
Total	658	79%	96%	91%	98%

IOM, intraoperative monitoring.

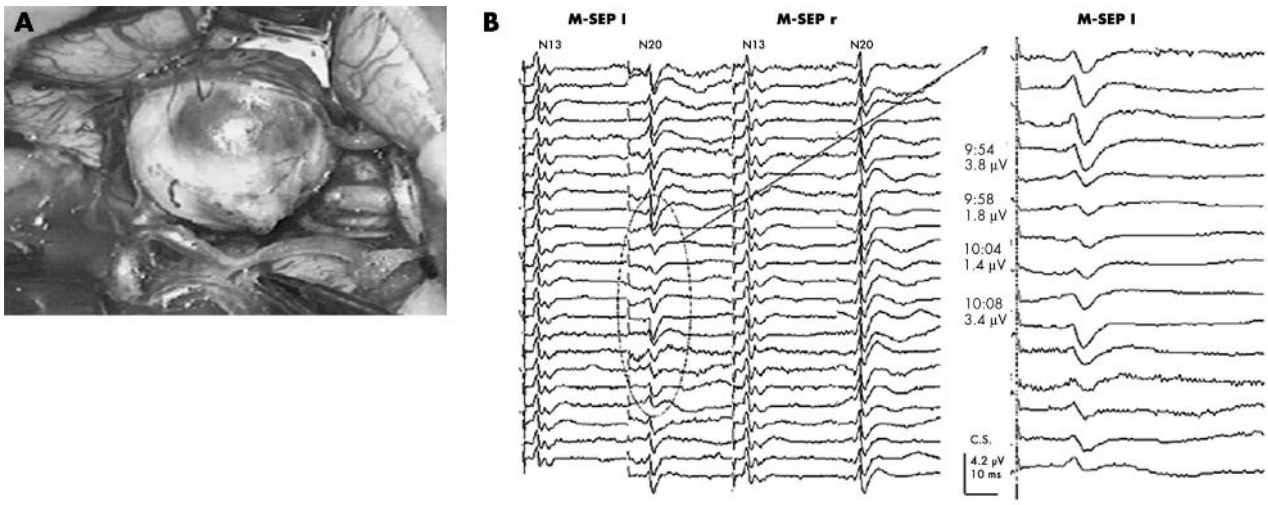

Figure 3 Example of a true positive event with intervention of the surgical team (case 124-97). (A) Intraoperative photograph showing a giant aneurysm of the right middle cerebral artery. (B) Intraoperative recordings showing median nerve somatosensory evoked potentials (M-SEP) traces for both sides. During dissection of the aneurysm neck amplitude decreased from 3.8 μV to 1.8 μV. Vasospasm of the M1 segment was identified by the surgeon. Dissection was ceased, papaverine was applied topically, and mean arterial blood pressure was increased from 70 to 100 mm Hg. After intervention the amplitudes recovered completely. The contralateral M-SEP remained stable. The patient awoke without a neurological deficit.

three. In all five cases computed tomography showed an ischaemic lesion that was related to the vascular territory of a vessel exposed during surgery. One may speculate that vasospasm or an embolic event as a consequence of surgical manipulation of the vessel wall was the underlying cause.

The second group comprised 14 patients with uneventful SEP monitoring who suffered from only mild postoperative

Table 4 Sensitivity and negative predictive value of intraoperative monitoring

	Type of surgery	No of cases	Sensitivity	Negative predictive value	Comment
Bejjani, 1998[15]	Skull base	224	58%	90%	Recommend IOM
Dawson, 1991[16]	Spinal deformity	33 000	72%	99.9%	Multicentre survey
Fisher, 1995[17]	Carotid TEA	3028	76%	99.7%	Meta-analysis
Forbes, 1991[10]	Spinal deformity	1168	100%	100%	Temporary changes included, one patient with delayed onset of deficit
Friedman, 1987[18]	Intracranial aneurysm	50	63%	90%	IOM not reliable in BA aneurysms
Friedman, 1991[19]	MCA aneurysms	53	80%	97%	Recommend IOM
Guerit, 1997[2]	Carotid TEA	205	92%	99%	One false negative
Haupt, 1992[20]	Carotid TEA	994	88%	99%	Complete SEP loss considered only
Henderson, 1994[11]	Spinal surgery	308	100%	100%	IOM may replace wake-up test
Linstedt, 1998[12]	Carotid TEA	146	20%	97%	Patients with preoperative neurological deficits
Little, 1987[13]	BA aneurysms	16	30%	70%	SEP and BAEP
Manninen, 1998[21]	Spinal surgery	309	70%	99%	Radicular lesions included
May, 1996[22]	Cervical spine	191	90%	99%	Technical failure considered
Mizoi, 1993[23]	Intracranial aneurysms	97	50%	95%	Temporary vessel clipping
Noonan, 2002[14]	Spinal deformity	134	100%	100%	Inconsistent findings in temporary changes
Nuwer, 1995 (9)	Spinal deformity	51 263	82%	99.9%	Multicentre survey, sensitivity increases to 92% if cases with intervention included
Schramm, 1990[6]	Intracranial aneurysms	113	81%	98%	IOM less reliable in BA aneurysms
Wiedemayer, 2002[7]	Intracranial and spinal surgery	423	81%	95%	Sensitivity increases to 85% if cases with intervention included

BA, basilar artery; BAEP, brain stem auditory evoked potentials; IOM, intraoperative monitoring; MCA, middle cerebral artery; SEP, somatosensory evoked potentials; TEA, thrombendarterectomy.

neurological deficits, which were completely reversible in nine cases. In five patients an incomplete hemiparesis occurred after surgery for a supratentorial tumour in the vicinity of the motor cortex. Two patients suffered from mild deficits following vascular surgery. In two patients with surgery for an intradural spinal meningioma a mild paraparesis occurred postoperatively, and in another three patients with surgery for an intramedullary lesion (one astrocytoma, two angioblastomas) a pre-existing myelopathy was worsened. Furthermore, in one patient a minor lesion of a cervical nerve root occurred during resection of an intradural schwannoma, and in another patient mild signs of brain stem dysfunction were observed after removal of a meningioma of the cerebellopontine angle. An example for this type of IOM failure is given in fig 1.

In the third group of eight patients, severe neurological deficits were observed postoperatively although SEP monitoring was completely uneventful. This group comprised three aneurysm cases, two cases of infratentorial tumours with compression of the brain stem, and one patient each with a brain stem cavernoma, a supratentorial glioblastoma involving the motor cortex, and a supratentorial meningioma. An example from this group is given in fig 2.

For calculation of sensitivity and negative predictive value those five patients with convincing evidence of a delayed neurological deficit were excluded from the group of false negatives and the eight patients with severe neurological deficits were considered separately. A summary of the data is given in table 3.

DISCUSSION

The primary goal of IOM is to identify patients with impending neurological damage early during surgery, to enable the surgical team to react in time. Such an intervention by the surgical team following a monitoring alarm is potentially effective in preventing neurological deterioration in the patient. In our experience a cautious estimation is that successful interventions occur in about 5% of the cases monitored. A more detailed discussion of this topic is given elsewhere.[7] The rate of false positive findings appears to be relatively high in this series, particularly for cases of brain stem monitoring (table 2). This is a matter of concern because false positive alarms may disturb the progress of surgery. A detailed analysis suggests that false positive alarms are partly attributable to the patient's semi-sitting position used for different types of surgery at our institution and that there are ways to overcome this problem.[8]

Concerning false negative findings, published reports generally have to be read carefully because criteria for false negative findings are not always clearly defined. For example it is sometimes unclear whether SEP monitoring of the spinal cord is or is not required to detect a pure motor deficit. One could argue that a pure motor deficit with normal SEP monitoring is not a failure of monitoring if dorsal column function remains normal. Another example is cases where SEPs deteriorate intraoperatively and the patient wakes without a new neurological deficit, because the surgeon was able to react to the event successfully. These cases are sometimes considered false positives, but they are in fact correct predictions of an impending neurological deficit. In our opinion it seems reasonable to classify these types of events as true positives. An example is given in fig 3. If these cases were counted as correct predictions, the sensitivity of IOM would appear more favourable.[7 9] In most reported series the sensitivity of neurophysiological IOM is around 80%. However, if distinct subgroups are considered the sensitivity shows much more variation, ranging from 20% to 100%.[10–14] An overview is given in table 4.

Generally, several different reasons for failure of IOM can be identified. For example, an event leading to neurological damage may occur after termination of monitoring. In this series such a delayed deficit was responsible for monitoring failure in five of our 27 cases (19%). A stringent definition of false negative findings should not include this type of failure.[24] Furthermore, a failure to monitor the pathway at risk seems to be a not uncommon mistake.[25] If, for example, M-SEPs are used to monitor surgery of an anterior communicating artery aneurysm, then ischaemia in the territory of the anterior cerebral artery is beyond the scope of monitoring. T-SEPs have to be used in addition in these cases. Another example is the use of bilateral stimulation of the tibial nerve for spinal cord monitoring, which may easily overlook a unilateral lower extremity weakness.[26] Furthermore, brain stem auditory evoked potentials (BAEP) are sometimes used to monitor brain stem function, but may prove insensitive to lesions of the upper brain stem.

A different reason for monitoring failure is difficulty in adequately interpreting SEP changes. Temporary changes in evoked potentials after vascular clamping, for example, are sometimes judged to be false negatives if the potentials return to baseline following reperfusion during surgery but the patient wakes with new neurological damage. For a correct interpretation of this finding one has to take into account the fact that white matter is more resistant to ischaemia than grey matter. Thus following temporary hypoperfusion white matter pathways may recover completely with restitution of evoked potential conduction, but grey matter areas may suffer damage, leading to neurological deficits. Consequently, one must bear in mind that restitution of evoked potentials does not guarantee normal postoperative function.[15 23 25 27 28]

Finally, there are failures of neurophysiological monitoring that are obviously unavoidable. Basic physiological knowledge suggests that with SEP monitoring only parts of the lemniscal system are covered. Thus it is not unexpected that SEPs are insensitive to isolated damage to structures outside the lemniscal system such as the motor pathways. This is a fundamental concern about SEP monitoring, because in the clinical setting it is usually desirable to monitor function in larger anatomical areas such as the whole spinal cord, the brain stem, or the motor cortex. Nevertheless, for practical clinical use SEP monitoring is acceptable because monitoring of the confined lemniscal system functions as an indicator of damage to the larger adjacent area at risk during surgery. The practical value of this basic principle is supported by our findings of an overall sensitivity of 79%, and a 91% sensitivity for severe neurological deficits.

Analysis of our data suggests that circumscribed lesions outside the monitored pathways are the main reason for monitoring failure. In most of our false negative cases neurological morbidity was mild, probably because the majority of lesions were small, as documented by postoperative radiological findings. In this series this was true for 14 patients with mild neurological deficits, which were completely reversible in nine cases. On the other hand, if the lesion is located in an eloquent area, severe permanent neurological deficits may occur. This latter type of severe monitoring failure occurred in eight patients in this series.

In practice it important to identify the clinical settings that are at increased risk of monitoring failure. Our data suggest that such settings are indeed identifiable. These were: surgery of intracranial aneurysms with a risk of damage to small vessels causing ischaemia in the area of the basal ganglia; some cases of brain stem damage in infratentorial tumours, possibly caused by damage to small perforating vessels; and cases with confined damage to the motor cortex in supratentorial tumours. These findings are supported by

observations of other investigators reporting results of surgery for aneurysms[6 13 29] or skull base tumours.[15]

Finally, if the monitoring team is aware of an increased risk of monitoring failure the question about the consequences arises. In these cases measures to enhance the sensitivity of IOM should be considered. A first approach may be to monitor both M-SEP and T-SEP, on the basis that an enlarged area monitored within the lemniscal system will provide better sensitivity. However, we are at present unable to provide evidence that this approach is effective, and we are currently investigating it at our institution. In cases where isolated damage to the motor cortex is of concern, monitoring of motor evoked potentials in addition to SEP seems a good suggestion.[30] If damage to the brain stem is the main risk, then a simultaneous recording of SEPs and BAEPs should be considered. The latter suggestion is based on the findings of Manninen *et al*,[31] who showed that in surgery for posterior fossa aneurysms combined monitoring increases the sensitivity from 47% and 37%, respectively, to 84% for both SEP and BAEP. But the surgeon needs to take into account that there are certain types of damage occurring during surgery that may not be detected by IOM.

Conclusions

The use of SEP monitoring should be accompanied by an awareness of its possible limitations. Certain clinical settings can be identified where there is an increased risk of monitoring failure. In these cases additional measures to enhance the sensitivity of monitoring should be considered.

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