

Multimodal intraoperative monitoring (MIOM) during cervical spine surgical procedures in 246 patients

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Accepted: 7 May 2007 / Published online: 4 July 2007
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Abstract A prospective study of 246 patients who received multimodal intraoperative monitoring during cervical spine surgery between March 2000 and December 2005. To determine the sensitivity and specificity of MIOM techniques used to monitor spinal cord and nerve root function during cervical spine surgery. It is appreciated that complication rate of cervical spine surgery is low, however, there is a significant risk of neurological injury. The combination of monitoring of ascending and descending pathways may provide more sensitive and specific results giving immediate feedback information and/or alert regarding any neurological changes during the operation to the surgeon. Intraoperative somatosensory spinal and cerebral evoked potentials combined with continuous EMG and motor-evoked potentials of the spinal cord and muscles were evaluated and compared with postoperative clinical neurological changes. A total of 246 consecutive patients with cervical pathologies, majority spinal stenosis due to degenerative changes of cervical spine were monitored by means of MIOM during the surgical procedure. About 232 patients presented true negative while 2 patients false negative responses. About ten patients presented true positive responses where neurological deficit after the operation was predicted and two patients presented false positive findings. The sensitivity of MIOM applied during cervical spine procedure (anterior and/or posterior) was 83.3% and specificity of 99.2%. MIOM is an effective method of monitoring the spinal cord functional integrity during cervical spine surgery and can help to reduce the

risk of neurological deficit by alerting the surgeon when monitoring changes are observed.

Keywords Cervical spine surgery · Intraoperative monitoring · Sensitivity · Specificity

Introduction

Anterior cervical discectomy followed by fusion is a safe procedure with low rate of neurological complication. Intraoperative SEP monitoring is not helpful when performing routine anterior cervical discectomy and fusion [11]. In a mixed population of patients with radiculopathy due to cervical disc herniation, myelopathy, tumors and traumatic dislocation of vertebrae a potential utility of intraoperative SEPs and the transcranially elicited MEPs for detection changes in spinal cord functional integrity during anterior cervical fusion has been illustrated [1]. In 6 out of 119 patients operated anteriorly on the cervical spine based upon the monitoring results, true positive findings for neurophysiological alerts that prompted surgeon's and/or anaesthesiologist's intervention. Two alerts were related to sudden decreases in blood pressure, two as a result of hyperextension of the neck and one observed as a result of arm positioning during surgery. One alert occurred during single-level discectomy and five occurred during multilevel decompression.

Epstein [3] established the efficacy of SEP monitoring for more complex cervical spine surgery comparing in a historical study 218 unmonitored with 100 monitored patients. In the unmonitored group 8 patients (5%) became quadriplegic and 1 patient died. In the monitored group no quadriplegia or death occurred. The incidence of postoperative radicular deficit was not different between the groups.

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Epstein's observations document the potential high risk of neurological deficit including quadriplegia during complex surgical procedures. A recent report by Khan [5] analyzed 508 patients where SEP monitorings were performed during cervical spine corpectomy. The overall incidence of new postoperative neurological deficit in this series was 2.4%, About 11 with nerve root injury, and 1 with quadriplegia. The calculated sensitivity and specificity of intraoperative SEP monitoring for detecting impending or resultant intraoperative iatrogenic neurologic injury were 77 and 100%, respectively. From the nerve root injuries the C5 injury was the most common. In a prospective cohort study 161 patients with anterior surgery were monitored including in 116 procedures continuous C5 EMG from the deltoid muscle. In cases in which spontaneous C5 activity occurred an appropriate change in operative procedure was made. A historical control group consisted of retrospective review of 55 procedures that were monitored using conventional SEP techniques. The incidence of postoperative C5 palsies was reduced from 7.3 to 0.9% due to intraoperative continuous EMG monitoring. No patients suffered a postoperative C5 palsy when intraoperative evidence of root irritation was absent [4]. Also intraoperative evoked EMG monitoring was shown as a valuable tool in posterior cervical instrumentation using pedicle screws [2]. The intraoperative electrical stimulation was accurate in verifying screw position with 99% of positive predictive value. Patients with skeletal congenital malformations or dysplasia who are positioned for the surgical procedure in anaesthesia can lead to disappearance of evoked potentials simply by positioning of the head [6] while correction of the position lead immediately to the occurrence of the potentials. In this respect alteration in the surgical plan resulted in successful spinal surgery.

The aim of the current study was to determine the sensitivity and specificity of multimodal intraoperative monitoring as described by Sutter et al. [9, 10] used to monitor spinal cord and nerve root function during complex cervical spine surgeries.

Patient population and method

About 246 consecutive patients prepared for cervical spine surgical procedure were selected for multimodal intraoperative monitoring from March 2000 to December 2005 due to the potential risk of neurological damage as the result of the complex surgical procedure. The clinical diagnosis are shown in Table 1 and the surgical approach, anterior, posterior 360° approach is summarized in Fig. 1. The patients were informed about the procedure after the neurological examination. There were 112 females and

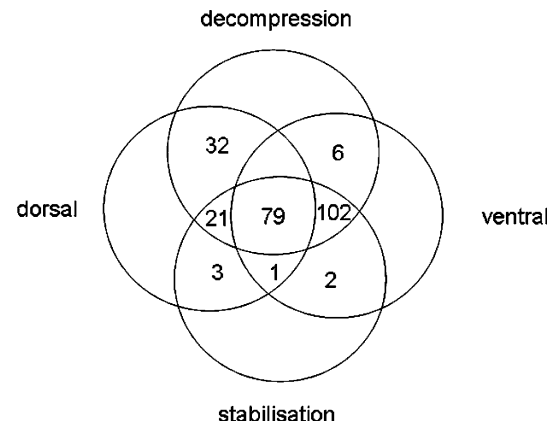


Fig. 1 Presentation of surgical approaches on 246 patients with cervical spine disorders

134 males of mean age 57.9 years (range from 1 to 83 years). The general inclusion and exclusion criteria as well as the method of examination of the multimodal intraoperative neurophysiological monitoring as well as the anaesthesia protocol have been described by Sutter et al. [9, 10]. All MIOM during this period of time were performed by the first two authors, experienced neurophysiologists specially trained in the different methods of MIOM.

Results

The surgical procedure of the 246 patients with cervical spine pathologies mainly resulting in cervical myelopathy were planned and performed according to the pre-existing pathology, by experienced and skilled spine surgeons. The mean time of intraoperative monitoring was 4.3 h ranging from 0.8 to 17 h. During the surgical procedure the tests of the multimodal intraoperative monitoring as described by Sutter [9, 10] were applied according to the actual situation taking the surgical procedure into account in order to assess the functional status of spinal cord, i.e. the motor and sensory pathways. If required, due to the selective nerve root decompression, monitoring of the nerve roots were included. The different tests and their frequency of application during the surgical procedure is summarized in Table 2.

The surgeon was informed about the changes of the potentials particularly if the trend justified an alert so the surgeon could adapt the procedure accordingly.

Within the group of 246 patients undergoing the cervical spine surgery 232 presented true negative while 2 patients false negative findings. The two false negative cases are summarized in Table 3: fortunately both patients with postoperative C5 radiculopathy recovered completely

Table 1 Diagnostic groups of patients operated on cervical spine with the aid of MIOM ($n = 246$)

Diagnostic characteristics	
Congenital anomaly	16
Degenerative	176
Disc herniation	20
Fractures/instability	7
Rheumatoid arthritis	17
Miscellaneous	10
Total	246

Table 2 Test applied to the patient population ($n = 246$) with cervical spinal stenosis

Monitoring modality	Monitorings applied		Baseline recording	
	Out of 246 cases	Mean tests per patient	Normal	Abnormal/No potential
cm-EP	241 (98.0%)	2.6	58	180/3
Sm-EP	7 (2.8%)	2.4	NVM	
cs-EP	104 (42.3%)	1.0	16	74/14
ss-EP	2 (0.8%)		NVM	
nc-EP	231 (93.9%)	1.4	67	163/1
ns-EP	27 (11.0%)	1.1	NVM	
F-Wave	2 (0.8%)		NVM	
EMG	219 (89.0%)	2.6	No Spontaneous Activity	

Tests: recorded muscle pairs or stimulated nerve pairs in a given modality, NVM normative value missing

cm-EP Cerebro-muscular evoked potentials, *cs-EP* cerebro-spinal evoked potentials, *ns-EP* neuro-spinal evoked potentials, *nc-EP* neuro-cerebral evoked potentials, *sm-EP* spino-muscular evoked potentials, *ss-EP* spino-spinal evoked potentials

within 1, respectively 6 weeks. Both were not monitored by continuous EMG from the deltoid muscle as proposed by Jimenez [4].

There were two false positive cases (Table 4) while ten patients presented true positive findings (Table 5).

Using the standard formula the sensitivity of the MIOM for the cervical spine surgical procedure was calculated to be 83.3% and the specificity 99.2%. It has to be clearly stated that none of the 246 patients who underwent complex cervical spine procedure sustained a permanent deterioration of pre-existing symptoms or any new occurring symptoms.

The following short case documents the close collaboration between the spine surgeon and the neurophysiologist resulting in a successful management of impending complications in cervical spine surgery. A 55-year-old male had to undergo ventro-dorsal decompression and stabilisation for compressive myelopathy due to cranio-

cervical dyssegmentation (Figs. 2, 3). During reposition of the head we almost lost the motor-evoked potentials (Fig. 4). After release of the reposition the evoked potentials recovered almost to the baseline, so that the surgeon could carry on after adapting the surgical procedure (Fig. 5). The patient had the same neurological deficits postoperatively.

Discussion

The true incidence of complications of surgical procedures of cervical spine is unknown. The recently introduced spine tango, a multi-centre study initiated by the Spine Society of Europe, might in future offer reliable information on the outcome of treatment of the different pathologies of cervical spine with incidence of surgically induced complications. However, the data has not been released to date. The study of Epstein in a historical study of 218 unmonitored and 100 monitored patients, as followed by monitoring of SEP, revealed an incidence of 4% of severe neurological complication (quadriplegia) while none in the monitored group. This observation documents the potential high risk of neurological deficit however at that time only SEP was used. Meanwhile it is well established in the literature that SEP alone do not offer reliable information about the function of the descending corticospinal tract nor about the motor pathways of the nerve roots. Therefore the study by Taunt [11] does not really add any new information while using SEPs to monitor patients with radiculopathy due to cervical disc herniation. In our study population only 20 patients were operated on disc herniation however, being accompanied by additional bony degenerative changes at the operated level. In a mixed population of cervical spine surgical procedures Bose [1] presented the sensory and motor-evoked potentials for detection of spinal cord function during anterior cervical fusion and the advantage of having to alert the surgeon when pathological alteration of the potentials suddenly occurs. A very recent report by Khan [5] which analyzed 508 with SEP monitoring during cervical spine corpectomy is in spite of the current body of knowledge [7, 8] of very little value considering the anterior approach in corpectomy the descending pathways are the prime focus for the monitoring techniques. Khan calculated the sensitivity as 77% and specificity 100% only by using SEP. In the presented population of 246 patients with cervical spine surgical procedure of mixed population with majority degenerative changes and cervical spine canal stenosis based upon our findings we found a sensitivity of 83% and specificity of 99%. The application of the available monitoring tests has been constantly adapted according to the procedure the

Table 3 MIOM of false negative cases ($n = 2$) out of 246 Patients operated on cervical spine

Patient	Region	Pathology	Surgery	Duration (h)	IOM modalities	IOM-baseline	IOM-changes	Neurological deterioration	Duration (week)	Recovery
F, 55 years	C2–C5	Spondylotic cervical myelopathy and deformity (SLCT)	Corpectomy C3 + C4, Correction and Fusion, dv	9.3	cs _{C8} -EPcm _{BB,ADM} -EP _{MNC} -EPcont EMG _{BB,ADM}	All potentials available, but pathologic	Loss of all potentials after C4/5 distr., recovered after reduction	Radiculopathy C5 left	6	Complete
F, 70 years	C5–C7	Spondylotic cervical myelopathy (SLCT)	Dorsal decompression	3.3	cs _{T1} -EPcm _{ADM, AH} -EP _{MNC} -EPcont EMG _{ADM, AH}	All Potentials available, but pathologic	None	Radiculopathy C5 left	1	Complete

Table 4 MIOM of false positive cases ($n = 2$) out of 246 Patients operated on cervical spine

Patient	Region	Pathology	Surgery	Duration	IOM modalities	IOM-baseline	IOM-changes	Expected neurological deficit
F, 69 years	C0–T1	Congen. Malformation with sek. compressive Myelopathy (SLCT)	Dorsal decompression and fusion	3.8 h	csT5-EPcmEP BR, ADM _{MNC} -EPEMG BR,ADM	Pathological motor and sensory potentials on both sides	Alteration of cmEP ADM left	Radiculopathy C8 left
F, 83 years	C6–C7	Spondylotic cervical myelopathy (SLCT)	Ventral and dorsal decompression and fusion	5.3 h	csT12-EPcmEP BR,ADM _{MNC} /ns-EP MN, TNEMG BR,ADM	Motor and sensory evoked potentials severely pathological	Alteration of ncEP MN left	Ataxie left Arm

Table 5 MIOM of true positive cases ($n = 10$) out of 246 patients operated on cervical spine

True positive cases of cervical									
Patient	Region	Pathology	Surgery	Duration IOM (h)	IOM-baseline	IOM-changes	Neurological deterioration	Duration	Recovery
F, 44 years	C0–C7	Rheumatoid arthritis	Decompression and fusion, ventral and dorsal	6	csEP, cmEP BR ADM, nsEP, ncEP MN, TN, cont EMG	Deterioration of pyramidal tract and dorsal tract function left arm	Central paresis left arm	After 2 days reoperation	Complete
F, 77 years	C1–C6	Rheumatoid arthritis	Decompression and fusion C0–T1	3.8	csEP, cmEP BR ADM	All available, but pathologic	Alteration of csEP and cmEP left arm	3 months	Complete
M, 40 years	C3–C4	Spondylotic cervical myelopathy	Decompression and fusion ventral	2.8	cmEP BR ADM, ncEP MN, cont EMG	All available, but pathologic	Sensomotor radiculopathy C5 right	2 months	Complete
M, 79 years	C3–C5	Degenerative stenosis and instability	Decompression and fusion ventral and dorsal	4.8	csEP, cmEP BR ADM, ncEP MN, cont EMG	All available, but pathologic	Proprioceptive deficits arm right	1 day	Complete
M, 66 years	C3–C5	Spondylotic cervical myelopathy	Decompression dorsal	3.5	csEP, cmEP BR ADM, ncEP MN TN, nsEP, cont EMG	All available but pathologic	Deterioration of cmEP arm and leg right	2 months	Complete
F, 61 years	C5–C6	Spondylotic cervical myelopathy	Decompression and fusion ventral and dorsal	3.3	csEP, cmEP BR ADM, ncEP MN, cont EMG	All available but pathologic	Deterioration of cmEP ADM right at end of decompression	1 day	complete
M, 78 years	C3–C7	Spondylotic cervical myelopathy	Laminoplasty C3–C7	3.8	cmEP BR ADM, ncEP MN, cont EMG	All available but pathologic ncEP	Deterioration of cmEP and ncEP left	1 day	Complete
F, 56 years	C4–6	Spondylotic myelopathy and radiculopathy C6 bilateral	Decompression and fusion, ventral	3.5	cmEP BB TM TA, ncEP MN, cont EMG	All available but pathologic	Deterioration of all cmEP right	3 months	Complete
m, 73 y	C4–C6	Spondylotic cervical myelopathy	Decompression and fusion ventral	4.8	cmEP DM BB TA, cont EMG, ncEP MN TN	All available but pathologic	Deterioration of cmEP DM left	1 month	Complete
M, 65 y	C4–C7	Spondylotic cervical myelopathy	Decompression and fusion ventral	6	cmEP DM BR ADM, cont EMG, ncEP MN TN	All available but pathologic	Deterioration of cmEP DM left	5 months	Complete

advantage to the continuous EMG monitoring as proposed by Jimenez [4] as being most probably a more sensitive finding. The one case with a false positive result was a patient with severe pathological changes of cervical spine and based upon the pathological findings of SEP of median nerve an expected ataxia of the left arm was documented however, no neurological findings was observed postoperatively after the surgeon performed control in situ without finding any unusual alteration in the surgical environment.

Out of the ten true positive cases six were attributed to a lesion of spinal cord while four to the nerve root. In this respect we could document and foresee in the very complex patient population with severe pathology of the cervical spine a rate of minor neurological complication of 5% and all recovered to the preoperative status. It has to be clearly stated that none of the 246 patients who underwent complex cervical spine procedure sustained a permanent deterioration of pre-existing symptoms or any new occurring symptoms.

Even though we have no historical comparable group and out of obvious reasons a prospective randomized study was not initiated as clearly explained by Sala et al. [7, 8]. We are of the opinion that looking at our results the MIOM is an effective method of monitoring the spinal cord and nerve root function during cervical spine surgery and can help to reduce the risk of neurological deficit by alerting the surgeon when monitoring changes are observed in complex surgical procedures.

Acknowledgments Dr. Lote Medicus fund for the financial support of the development of MIOM at the Schulthess Clinic. Dave O’Riordan and Charles McCammon for helping with the manuscript. Anne Mannion PhD for the critical review of the manuscript. A special thanks to professor Arnaldo Benini who supported the study with his patients.

Conflict of interest statement None of the authors has any potential conflict of interest.

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