Multimodal intraoperative monitoring (MIOM) during 409 lumbosacral surgical procedures in 409 patients

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Abstract A prospective study on 409 patients who received multimodal intraoperative monitoring (MIOM) during lumbosacral surgical procedures between March 2000 and December 2005 was carried out. The objective of this study was to determine the sensitivity and specificity of MIOM techniques used to monitor conus medullaris, cauda equina and nerve root function during lumbosacral decompression surgery. MIOM has increasingly become important to monitor ascending and descending pathways, giving immediate feedback information regarding any neurological deficit during the decompression and stabilisation procedure in the lumbosacral region. Intraoperative spinal- and cortical-evoked potentials, combined with continuous EMG- and motor-evoked potentials of the muscles, were evaluated and compared with postoperative clinical neurological changes. A total of 409 consecutive patients with lumbosacral spinal stenosis with or without instability were monitored by MIOM during the entire surgical procedure. A total of 388 patients presented true-

negative findings while two patients presented false negative and 1 patient false-positive findings. Eighteen patients presented true-positive findings where neurological deficit after the operation was intraoperatively predicted. Of the 18 true-positive findings, 12 patients recovered completely; however, 6 patients recovered only partially. The sensitivity of MIOM applied during decompression and fusion surgery of the lumbosacral region was calculated as 90%, and the specificity was calculated as 99.7%. On the basis of the results of this study, MIOM is an effective method of monitoring the conus medullaris, cauda equina and nerve root function during surgery at the lumbosacral junctions and might reduce postoperative surgical-related complications and therefore improve the long-term results.

Keywords Spine surgery · Lumbar spinal stenosis · Intraoperative monitoring · Sensitivity · Specificity

Introduction

The neurological complications of decompression surgery of degenerative lumbosacral spinal stenosis with or without instability, pseudospondylolisthesis, with or without instrumentation vary from 1 to 33% [1–5, 7, 8, 11]. The complications include transient or permanent nerve root palsy and transient or permanent radicular pain. Even if radiologically successful decompression and fusion is achieved, a neurological complication is extremely disturbing and negatively influencing the otherwise favourable reduction of radicular symptoms or spondylotic pain. Such a complication can occur as a result of nerve root compression, distraction or misplacement of pedicle screws [8].

In the past, several neurophysiological techniques were applied to alert surgeons to the possible neurological

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damage due to spinal canal and/or foraminal decompression or placement of instrumentation. Among these techniques, continuous EMG recording, somatosensory-evoked potentials and compound muscle action potentials by electrical stimulation of the motor cortex or the spinal cord are the most frequently used [2, 4, 6, 12, 13]. Bose et al. [2] concluded that continuous intraoperative electromyographic monitoring provided a real-time measurement of impending spinal nerve root injury during instrumented posteriolumbar fusion, allowing for timely intervention and minimizing the risk of nerve root damage.

The aim of the present study was to determine the sensitivity and specificity of multimodal intraoperative monitoring techniques used by an experienced team in complex surgical procedures in stenosis of lumbosacral region with or without instability.

Patient population and materials and methods

Patient population

The spine surgeons determined the usefulness or need for intraoperative monitoring on the basis of the complexity of the surgical procedure and the potential risk of iatrogenic neurological damage or where multimodal intraoperative monitoring (MIOM) was expected to aid the technical procedure, such as appropriate placement of pedicle screws. All 409 patients underwent spinal surgery between March 2000 and December 2005 and were selected from a large population of 11,536 patients who received spine surgery during the study period. The exclusion criteria are reported elsewhere [9]. All patients underwent preoperative clinical examination by the surgical spine team which included additional neurological and electrophysiological examinations by the first two authors. Following the operation all monitored patients were examined by both the

neurologist and the spine surgeon to assist possible new neurological deficits and to document the postoperative status. The same anaesthesia protocol was used in all cases as it was important not to use any substance which would significantly alter or abolish the evoked potentials [14]. The population consisted of 247 female, and 162 male patients with an average age of 62.5 years (range 13.7–87). The main diagnoses were degenerative spinal stenosis accompanied by pseudospondylolisthesis with or without deformities in 250 patients and multisegmental spinal stenosis alone in 159 patients.

Materials and methods

For this study, the methods of examination by applying the multimodal intraoperative monitoring as well as the anaesthesia protocol are described by Sutter et al. [9, 10]. The intraoperative monitoring was performed by the first two authors, experienced neurophysiologists specially trained in the different methods of MIOM.

Results

The surgical procedures of the 409 patients with spinal deformities were planned and performed according to the pre-existing lumbosacral pathology. The distribution of lumbar segments, which were operated on, is shown in Fig. 1; the level most operated on was L4/L5. Most of the patients were operated on two levels ($n = 187$), or three levels ($n = 156$) (Fig. 2). The time of the intraoperative monitoring was on average 3.7 h (range from 1 till 21 h). During the surgical procedures, eight different test modalities were applied according to the actual situation taking the surgical procedure into account in order to assess the functional status of the conus, the cauda equina, and

Fig. 1 Frequency distribution of lumbar segments operated on

Table 1 Test applied to the patient population ($n = 409$) with lumbar stenosis and instabilities

Monitoring modality	Monitoring applied		Baseline recording	
	Out of 409 cases	Mean tests per patient	Normal	Abnormal/no potential
cm-EP	407 (99.5%)	2.43	130	276/1
sm-EP	49 (12.0%)	2.43	NVM	
cs-EP	19 (4.6%)	1	6	6/7
ss-EP	0		NVM	
nc-EP	385 (94.1%)	1.42	141	241/3
ns-EP	37 (9.0%)	1.14	NVM	
F wave	3 (0.7%)			
Cont. EMG	384 (93.9%)	2.43	No spontaneous activity	
Ped screw stim.	130 (31.8%)	2.62		

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

nerve roots. The different modalities, tests and their frequency of application during the surgery are summarized in Table 1.

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

Within the group of 409 patients undergoing decompression with or without instrumentation, 388 presented true-negative findings during the intraoperative monitoring, whereas two patients presented false-negative findings (Table 2). One 51-year-old female patient was operated for pseudarthrosis (fifth operation) with decompression and stabilisation. The corticomuscular-evoked potentials and the neurocortical-evoked potentials were pathological

although available during the entire procedure. There were no changes of potentials, however, after the operation there was a weakness of foot extension on the one side which completely recovered within 3 months. The other female patient (72-year-old) with severe degenerative stenosis and instability in quite reduced general condition, underwent a 4½-h dorsal decompression and fusion. Even though the baseline data presented pathological results, there were no changes during the operation but motor-evoked potentials to the anal sphincter were not tested and urinary and bowel incontinence of unknown reason was observed after the operation.

One patient presented false-positive findings as a radicular irritation was predicted by the monitoring; however, no clinical symptoms were seen (Table 3).

Eighteen patients presented true-positive findings with pathological changes of the monitoring parameters and new neurological deficit after the operation could be clinically confirmed. The detailed analysis of the cases is documented in Table 4. Of the 18 patients, 12 recovered completely within hours till 3 months; however, 6 patients recovered only partially with remaining symptoms.

Applying the standard formula, sensitivity of the intra-operative monitoring during decompression with and/or without fusion was calculated at 90% (95% confidence interval) and a specificity of 99.7% (95% confidence interval).

Discussion

The true incidence of the complication of decompression surgery of degenerative lumbar spinal stenosis with or without unstable pseudospondylolisthesis and instrumentation is not exactly known and according to the different studies, it varies from 1 to 33%. All the studies including

Fig. 2 The number of operations per segment

Table 2 Detailed description of false-negative cases in lumbar spine procedures

Patient	Region	Pathology	Surgery	Duration	IOM Modalities	IOM-baseline	IOM-changes	Neurological deterioration	Duration	Recovery
J.C., F, 51 years	L5–S1	Pseudo-arthrosis (5 operation)	Decompression and stabilisation	2.3 h	cm _{TA,AH} -EP, n _{TC} -EP	All available but pathologic	None	Weakness foot extension	3 months	Completely
R.S., F, 72 years	L2–L5	Degenerative stenosis and instability	Dorsal decompression and fusion	4.5 h	cm _{VM,TA,AH} EP, s _{1,2} m _{VM,TA,AH} EP, n _{PC} EP, cont EMG _{VM,TA,AH}	cmEP right not available, other EP severe pathologic	None	Urinary and bowel incontinence	Loss of follow-up/patient abroad	Loss of follow-up/patient abroad

Table 3 Detailed description of false-positive cases in lumbar spine procedures

Patient	Region	Pathology	Surgery	Duration	IOM modalities	IOM baseline	IOM changes	Expected neurological deficit
B.R., F, 59 years	L2–L3	Degenerative stenosis and instability	Dorsal decompression and fusion	5.5 h	cmP, VM, TA, AH-EP, EMG P, VM, TA, AH, nEP PN	All motor and sensory potentials pathological available	Screw L2 right pathological threshold	Radicular irritation L2 right

Table 4 Detailed description of true-positive cases in lumbar spine procedures

Patient	Region	Pathology	Surgery	Duration (h)	IOM modalities	IOM baseline	IOM changes	Neurological deterioration	Duration	Recovery
B.B., F, 50 years	L1–S1	Achondroplasia	Decompression and fusion dorsal	8.8	csEP, cmEP VM TA AH, smEP, nsEP, ncEP TN, ped screw stimulation, cont EMG	All available but pathologic	Deterioration of cmEP TA bilateral and ncEP TN left	Radiculopathy L5 bilateral and S1 left	3 years	Partial
S.H., F, 72 years	L3–L4	Rheumatoid arthritis with osteoporotic fracture	Decompression and fusion L2–S1	5.3	cmEP VM TA AH, ncEP PN, cont EMG	All available but pathologic	Deterioration of cmEP VM left and TA bilateral	Paraesthesia L4 left	1 day	Complete
D.R., F, 69 years	L3–L5	Degenerative instability with stenosis	Decompression and fusion dorsal	4.3	cmEP VM TA AH, smEP, csEP, ncEP PN, cont EMG	All available but pathologic	Deterioration cmEP and smEP VM&TA right	Mild deterioration of radiculopathy L4 right	1 week	Complete
M.L., F, 74 years	L3–L5	Degenerative instability with stenosis	Decompression and fusion dorsal	3.3	cmEP VM TA AH, ncEP FN PN, cont EMG	All available but pathologic	Alteration of cmEP VM right	Mild radiculopathy L4 right	1 day	Complete
B.P., M, 65 years	L3–L5	Degenerative instability with stenosis	Decompression and fusion dorsal	2.5	cmEP VM TA AH, ncEP PN, cont EMG	All available but pathologic	Alteration of cmEP VM right	Mild radiculopathy L4 right	1 week	Complete
C.H., M, 76 years	L3–S1	Degenerative instability with stenosis	Decompression and fusion dorsal	3.5	cmEP VM TA AH, ped screw stimulation, cont EMG, ncEP PN	All available but pathologic	Alteration of cmEP AH left	Mild paraesthesia S1 left	2 h	Complete
S.W., M, 70 years	L4–L5	Degenerative instability with stenosis	Decompression and fusion dorsal	3.3	cmEP TA AH, cont EMG, ncEP TN	All available but pathologic	During ped screwing L5 left alteration of cmEP TA and AH right due to shearing forces	Paraesthesia L5 right	6 h	Complete
K.K., F, 59 years	L4–L5	Degenerative instability with stenosis	Decompression and fusion dorsal	4.5	cmEP VM TA AH, cont EMG, ncEP PN	All available but pathologic	During ped screwing L5 left alteration of cmEP VM right due to instability	Paraesthesia L4 right	2 weeks	Complete
C.R., F, 57 years	L4–L5	Degenerative instability with stenosis	Decompression and fusion dorsal	3.7	cmEP VM TA AH, cont EMG, ncEP PN, ped screw stimulation	All available but pathologic	During ped screwing L5 left alteration of cont EMG and cmEP TA left, screw replaced	Paraesthesia L5 left	2 days	Complete
M.B., M, 60 years	L4–L5	Degenerative instability with stenosis	Decompression and fusion dorsal	2.5	cmEP VM TA AH, cont EMG, ncEP PN, ped screw stimulation	All available but pathologic cmEP	During nerve root decompression alteration cont EMG TA, cmEP TA and ncEP PN left. Normal ped screw stimulation	Paraesthesia L5 left	1 day	Complete
S.M., F, 63 years	L4–L5	Degenerative instability with stenosis	Decompression and fusion dorsal	3.8	cmEP VM TA AH, smEP, cont EMG, ped screw stimulation, ncEP PN	All available but pathologic	Loss of ncEP PN left during instrumentation	Radicular pain syndrome L5 left	6 months	Complete

Table 4 continued

Patient	Region	Pathology	Surgery	Duration (h)	IOM modalities	IOM baseline	IOM changes	Neurological deterioration	Duration	Recovery
B.D., M, 42 years	L4–S1	Degenerative instability with stenosis	Decompression and fusion dorsal	5.5	cmEP VM TA AH, csEP, ped screw stimulation, cont EMG, ncEP PN TN	All available but pathologic	During ped screwing alteration of cont EMG, cmEP TA and ncEP PN right. Threshold ped screw 3 mA. Screw replaced.	Paraesthesia L5 right	1 week	Complete
V.N., F, 14 years	L5–S1	Lysis L5, olisthesis 3°	Decompression, correction and fusion, dorsal-ventral-dorsal	9	csEP, cmEP TA AH, smEP, cont EMG, ncEP PN	All available	Deterioration of cmEP and smEP TA right and ncEP PN right	Sensomotor radiculopathy L5 right	2 years	Partial
S.H., M, 42 years	L5–S1	Lysis L5, olisthesis 3°	Correction and fusion dorsal and ventral	7	cmEP TA AH, smEP, csEP, nsEP PN	All available	Massive alteration of sm- and cmEP TA and AH left, nsEP PN left, associated with bleeding and compression to lumbosacral plexus left	Sensomotor deficits of lumbosacral plexus left	3 years	Partial
A.N., F, 29 years	L5–S1	Lysis L5, ptosis	Decompression and fusion dorsal	14.3	cmEP VM TA AH, ncEP PN TN, cont EMG, ped screw stimulation	All available	Alteration cmEP TA right during reposition	Sensomotor radiculopathy L5 right	1 year	Partial
M.U., F, 56 years	L4–L5	Pseudarthrosis postoperative	Decompression and fusion dorsal	3.8	cmEP VM TA AH, cont EMG, ncEP PN, ped screw stimulation	All available but pathologic	After ped screwing L5 right alteration of cont EMG and deterioration of cmEP TA&AH right. Threshold screw stimulation L5 right 4.8 mA, screw replaced	Sensomotor radiculopathy L5 right	1 year	Partial
G.V., F, 50 years	L4–S1	Stenosis and instability	Decompression and fusion dorsal	4.8	cmEP VM TA AH, ncEP PN, cont EMG	All available but pathologic	Associated with pedicular screwing alteration of cont EMG and cmEP TA and AH right	Paraesthesia L5&S1 right	3 months	Complete

ours suffer from selection bias. In our patient population, we selected 409 patients for MIOM which compares to approximately 10% of all patients operated on the spine during the study period. The choice was made due to the complexity of the procedure and/or where potential risk of complication was expected, considering that the complications include transient or permanent nerve root palsy radicular pain. Such complications can occur as a result of nerve root compression, distraction or misplacement of pedicle screws. Several neurophysiological techniques have been applied to alert surgeons to the possible neurological damage among those continuous EMG recording sensory-evoked potential and compound muscle actual potentials by electrical stimulation of the motor cortex or the spinal cord [2, 4, 6, 12, 13].

In our institution, we introduced a multimodal intraoperative monitoring with sensory and motor-evoked potentials and particularly selective nerve root monitoring for each miotom in a side-by-side comparison. The monitoring tests and their application have been adapted according to the surgical procedure taking the treated level into account. Majority of our patient population were decompressed at two or three levels, but also 49 patients at four levels and 11 at five and 5 patients at 6 levels. Analyzing the two false-negative cases in a patient with a postoperative occurrence of urine incontinence the monitoring could be considered retrospectively as incomplete as sphincter ani MEP were not monitored. In the second case where weakness for foot extension occurred, we could not find an explanation in spite of the normal potentials during the entire duration of the operation; luckily the patients recovered completely after 3 months for these patients with pseudoarthrosis at the lumbosacral junction that was the fifth consecutive operation at the same level.

In one false-positive case operated for degenerative stenosis and instability at the level of L2-L3 all motor and sensory-evoked potentials were pathological. Even though L2 neurological deficit or radicular irritation was expected the patient was postoperatively absolutely pain free without any neurological deficit.

Eighteen patients presented true-positive findings considered as mild and/or moderate complications of which most of them recovered completely (Table 4). And that means 20 patients presented postoperative complications, 18 true positive and 2 false negative which account for 4.9% of complication incidence in the highly selective patient population for the intraoperative monitoring during lumbar spine procedure. In this respect, we are of the opinion that for complex lumbar spine surgical procedure intraoperative monitoring is a helpful aid to identify possible surgical problems. It remains a hypothesis and maybe even a speculation that without monitoring in the complex surgical cases minor complication would have been worse

while the surgeon was not alerted in time to alter his or her surgical procedure. In summary from our experience, the SEP for monitoring the lumbar nerve roots are less important, however, the continuous EMG from the related miotoms and the motor-evoked potentials to the muscles being innervated by the operated nerve root are of crucial importance. Due to technical reasons L1 and L2 nerve roots are very difficult to monitor.

Finally, the stimulation of pedicle screws to determine the appropriate positioning of the screws requires special attention and is not covered in this study.

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