Multimodality intraoperative monitoring during complex lumbosacral procedures: indications, techniques, and long-term follow-up review of 61 consecutive cases

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Object. The purpose of this study was to examine the neurological outcomes after complex lumbosacral surgery in patients undergoing multimodality neurophysiological monitoring.

Methods. Sixty-one patients were consecutively enrolled in this study. These patients underwent complex intra- and extradural lumbosacral procedures with concomitant intraoperative electromyography (EMG) monitoring of the lower-limb muscles, external anal and urethral sphincters (EAS and EUS), and lower-limb somatosensory evoked potentials (SSEPs). Long-term (minimum 2-year) clinical follow-up data were obtained in all cases.

Most patients were treated for spinal/spinal cord tumors (61%) or adult tethered cord syndrome (25%). Recordable lower-extremity SSEPs were reported in 54 patients (89%). New postoperative neurological deficits occurred in only three patients (4.9%), and remained persistent in only one patient (1.6%) at long-term follow-up examination. In only one of these cases was a significant decrease in SSEP amplitude detected. Spontaneous EMG activity was observed in the lower-extremity muscles and/or EAS and EUS in 51 cases (84%). Intraoperatively, EMG demonstrated activity only in the EUS in 5% of patients and only in the EAS in 28%. In seven patients (11%) spontaneous intraoperative EMG activity was observed in both the EAS and the EUS; however, in only three of these cases was EMG activity recorded in both sphincters simultaneously. In addition to spontaneously recorded EMG activity, electrically evoked EMG activity was also used as an intraoperative adjunct. A bipolar stimulating electrode was used to identify functional neural tissue before undertaking microsurgical dissection in 58 individuals (95%). In the majority of these patients, evoked EMG activity occurred either in one (33%) or in two muscles (9%) simultaneously. The presence of electrically evoked EMG activity in structures encountered during microdissection altered the plan of treatment in 24 cases (42%).

Conclusions. The authors conclude that the combined SSEP and EMG monitoring of lower-limb muscles, EAS, and EUS is a practical and reliable method for obtaining optimal electrophysiological feedback during complex neurosurgical procedures involving the conus medullaris and cauda equina. Analysis of the results indicates that these intraoperative adjunctive modalities positively influence decision making with regard to microsurgery and reduce the risk of perioperative neurological complications. Validation of the clinical value of these approaches, however, will require further assessment in a larger prospective cohort of patients.

KEY WORDS • intraoperative monitoring • lumbar spine • sacral spine • anal sphincter • urethral sphincter

Intraoperative neurophysiological monitoring, including SSEPs and EMG activity, is frequently used as an adjunctive modality during complex spinal surgery. Neurosurgical procedures within the lumbosacral spinal canal, particularly when performed to remove a tumor or to release a tethered spinal cord, are associated with a potential risk of new postoperative deficits including loss of urinary bladder or anal sphincter function or lower-extremity sensorimotor deficits. Recording of EMG activity in the EAS and/or EUS is commonly performed to monitor the integrity of the S2–4 spinal nerve roots; however, the simultaneous monitoring of both the EAS and EUS remains controversial. It is thought that monitoring of one is sufficient because the pudendal nerve, which runs from the S-2 to S-4 segments, innervates both sphincters. At our center we adhere to the belief that recording a combination of SSEPs and spontaneous/stimulated EMG activity will optimally reflect the integrity of afferent and efferent pathways that could otherwise be compromised during complex neurosurgical lumbosacral procedures. The data obtained in these studies become particularly important in cases in which spinal neoplasms significantly disturb the normal anatomy of the conus medullaris and cauda equina; intraop-

Abbreviations used in this paper: EAS = external anal sphincter; EMG = electromyography; EUS = external urethral sphincter; SSEP = somatosensory evoked potential.
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Intraoperative monitoring becomes particularly valuable to help reduce the risk of perioperative deficit. In these cases, EMG monitoring of the EUS and EAS allows for the simple and rapid detection of impending nerve root injury by providing the surgeon with immediate auditory feedback.

Despite the potential benefits of multimodality electrophysiological monitoring, several questions remain regarding its practical application to routine neurosurgical practice. How practical and feasible are these techniques? Does monitoring of both the EAS and EUS provide complementary information or do they add redundant data?
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FIG. 2. Photographs showing the urinary bladder (A) and anal (B) sphincter electrodes (Medtronic/Dantec). The recording electrode for the bladder sphincter EMG is available in two sizes (outer diameter 4.6 × 3.6 and 5.7 × 4.7 mm). The urethral electrode has two platinum leads and is mounted on a Foley catheter (No. 10 or 14). The recording electrode for anal sphincter EMG has two platinum leads separated by a sponge that is inserted into the anal canal.

Clinical Material and Methods

Study and Patient Details

The Research Ethics Board of the University Health Network approved the protocol for this study. We analyzed data in 61 consecutive patients, 31 females and 30 males ranging in age from 15 to 90 years (mean age 46.6 ± 17.4 years), who underwent surgery for complex lesions of the lumbosacral region while also undergoing neurophysiological monitoring. All patients were treated between 1998 and 2000 in the Division of Neurosurgery at the Toronto Western Hospital. Simultaneous EMG monitoring of EAS and EUS activity was conducted. Lower-limb muscle EMG activity and SSEPs were also recorded intraoperatively. Detailed neurological evaluations were performed for up to 2 years following surgery in all cases. Complete follow-up data were obtained in all patients.

Anesthesia Considerations

General anesthesia was administered in the following manner. Propofol and fentanyl were used for induction; muscle paralysis was achieved using a rocuronium bolus (or another intermediate-acting muscle relaxant) for induction and intubation. This was allowed to dissipate to facilitate EMG monitoring. No further dose of muscle relaxant was administered. All patients were placed prone. Anesthesia was maintained using an O.subscript.2/nitrous oxide ratio of 50:50 with one minimum alveolar concentration of isoflurane or desflurane. Intraoperative analgesia was maintained by an infusion of remifentanil or an intermittent fentanyl bolus. The arterial blood pressure electrocardiography activity, and level of O.subscript.2 saturation were continuously monitored in all patients. A peripheral nerve stimulator, usually placed over the ulnar nerve in the forearm, was used to check the patient’s level of paralysis intermittently until four twitches of a four-twitch train were obtained. Although two of four twitches will probably allow for adequate recording of intraoperative EMG activity, we decided to avoid neuromuscular paralysis because of the paucity of published data on this technique and the difficulty in maintaining partial paralysis through muscle relaxant infusion.

Electrophysiological Monitoring

A Viking Ile (Nicolet Biomedical, Madison, WI) or an Epoch 2000 (Axon Systems, Hauppauge, NY) monitor was used for intraoperative SSEP and EMG monitoring. Electrophysiological monitoring was conducted during the surgery and subdivided into the major stages of the procedure: postinduction baseline, intraoperative period, and closure.

Somatosensory Evoked Potentials

Grass E2 (Astro-Med, Inc., West Warwick, RI) platinum subdermal needle electrodes were used for both stimulating and recording the SSEPs. All electrodes were applied after induction of anesthesia and patient positioning. Electrode impedances were kept below 5 kΩ. Conventional lower-limb SSEPs were obtained by electrical stimulation of the posterior tibial nerves at the ankles, proximal cathode, halfway between the Achilles tendon and medial malleolus, and an anode located 2 to 3 cm distal. Stimulus parameters were as follows: the bilateral interleaving square wave stimulus pulse was 4.7 Hz for a 250-μsec duration; stimulus intensity was adjusted individually, ranging from 25 to 40 mAmp. Recording electrodes for SSEPs were positioned at the following sites using a previously published standard: Cv2-Fpz for the N31 subcortical response generated at the cervicomedullary junction and CPz-Fpz for the P37/N45 responses generated within the sensory cortex. The recording parameters used were 30- to 1000-Hz bandpass filter; 100-μsec analysis time; 10-μV/div gain. Somatosensory evoked potentials were acquired using continuous averaging of 500 to 1000 sweeps and were repeatedly compared with the baseline responses obtained soon after
patient positioning. Because of amplifier channel limitations in older electrophysiology recording equipment, preference was given to the recording of EMG responses with any remaining channels for SSEP recording. For example, when only one channel was available for SSEPs, then the Cv2-Fpz montage was used because of its reliability and resistance to physiological and anesthesia-related changes (Fig. 1).

Electromyography Activity

Lower-extremity EMG activity was monitored using 25-mm Grass paired stainless steel needle electrodes (Medtronic Xomed, Inc., Jacksonville, FL). Recordings were obtained from the rectus femoris, tibialis anterior, and gastrocnemius muscles bilaterally, covering the L-2 to S-2 nerve root myotomes inclusively. The needle electrodes were inserted transdermally into the muscles after preparing the skin with a topical betadine solution. Electrode impedances were kept below 5 kΩ, and interelectrode impedances were maintained below 1 kΩ. The EMG values for the EUS and EAS were obtained using a urethral ring electrode and a sphincter electrode (Medtronic/Dantec, Jacksonville, FL [Fig. 2]). The urethral ring electrode was inserted into the urethra via a two-way French Foley catheter (No. 10 or 14); this was performed by medical staff appropriately trained in this technique. The ring electrode was placed over the catheter tip in a sterile fashion, to sit approximately 1 to 2 cm below the inflated balloon. Care was exercised, during the insertion of the catheter, to prevent the electrode from slipping down the catheter and erroneously recording from the distal urethra. By gently withdrawing the catheter with the balloon inflated, the recording contacts were placed in proximity to the EUS. After patient positioning, the anal sphincter electrode was manually inserted. Care was used to achieve contact between the electrodes and the sphincter muscle. Conductive gel was used on the two electrical contacts to reduce impedance. Electromyography recording parameters were as follows: 10- to 5000-Hz bandpass filter; 1.5- to 2-second analysis time; 200-μV/div gain. The neuromonitoring units were equipped with a loudspeaker that allowed immediate intraoperative audio feedback of EMG responses to the surgeon and technologist. Any significant intraoperative EMG activity, spontaneous and/or stimulated, was documented and printed. The surgical events that were responsible for the activation of muscle action potentials were also noted, including maneuvers such as suction, traction, coagulation, and use of cold irrigation fluid.

We performed electrical stimulation at the surgical site to identify nerve roots (stimulated EMG) by using a Karlroth Bipolar Stimulator Probe (Medtronic Xomed, Inc.). Current intensity started at 0.5 mAmp and was increased as necessary by using a monophasic square wave pulse (100 μsec, 3 Hz).

Statistical Analysis

A chi-square analysis was conducted to determine the influence of tumor location, spinal cord pathological entity, and baseline/intraoperative EMG recordings of the EAS and EUS on postoperative neurological outcome (immediate and ≈ 2 years of follow up). The amplitude and latency of different components of SSEPs were measured and compared using analyses of variance. Changes were considered statistically significant at p < 0.05. Data are presented as the mean ± standard deviation.

Results

All patients underwent lower-limb SSEP and continuous real-time EMG monitoring of the lower-extremity muscles and EAS and EUS intraoperatively. The various spinal or spinal cord pathological entities are summarized in Table 1. In a minority of patients (8%) spinal stenosis (developmental and/or acquired) or central disc herniation was present. Only those patients with severe cauda equina compression due to these degenerative lesions were included in the study. Eleven patients (16%) had previously undergone spinal surgery. Detailed clinical and neurological evaluations were conducted postoperatively in all cases for a minimum of 2 years after surgery.

The SSEP Findings

Assessment of the SSEPs elicited by posterior tibial nerve stimulation was based on the absolute latency and amplitude of the N31 and P37 components. Lower-extremity SSEPs were recorded in 54 patients (89%). In the other seven patients (11%) baseline SSEPs could not be interpreted, which corresponded with significant preoperative neurological deficits. The amplitude and latency of all SSEP components were stable during all stages of surgery in 53 patients (98% of those in whom SSEPs could be recorded). In three (6%, Cases 1–3; Table 2) of the 54 patients with recorded intraoperative SSEPs, new postoperative neurological deficits were found (Table 2). In one patient (Case 2 [2%]), a unilateral loss of the right lower-limb SSEP was detected during the resection of an intramedullary ependymoma of the conus medullaris (Fig. 3, Table 3).

The EMG Findings

Spontaneous EMG Activity. Intraoperatively, spontaneous EMG activity was recorded from the lower-extremity muscles, EAS, and EUS in 51 patients (84%). Intraoperative EMG responses were often seen in spike, burst, and train patterns (Figs. 1 and 4). The intra- and intercase amplitude, frequency, and duration of EMG responses varied significantly, and any increase in each of these criteria was

<table>
<thead>
<tr>
<th>Lesion</th>
<th>No. of Cases (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>tethered cord</td>
<td>15 (25)</td>
</tr>
<tr>
<td>central disc herniation w/ cauda equina syndrome</td>
<td>2 (3)</td>
</tr>
<tr>
<td>spinal stenosis w/ severe cauda equina compromise</td>
<td>3 (5)</td>
</tr>
<tr>
<td>tumors involving the lumbar cord, cauda equina, or lumbar spinal nerves</td>
<td></td>
</tr>
<tr>
<td>intramedullary (conus)</td>
<td>3 (5)</td>
</tr>
<tr>
<td>intradural</td>
<td>30 (49)</td>
</tr>
<tr>
<td>extradural</td>
<td>4 (7)</td>
</tr>
<tr>
<td>intra- &amp; extradural</td>
<td>2 (3)</td>
</tr>
<tr>
<td>tumor &amp; tethered cord</td>
<td>2 (3)</td>
</tr>
</tbody>
</table>
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Baseline SSEPs

Intraoperative loss of right SSEPs

SSEPs at closure

FIG. 3. Case 2. Intraoperative SSEP recordings during resection of an intramedullary ependymoma of the conus medullaris. Well-defined baseline SSEPs were recorded during stimulation of the left (Trace 1) and the right (Trace 2) posterior tibial nerves in this case (N31 components are indicated by arrows). During resection of the tumor, however, a significant reduction in the right-sided SSEP (intraoperative Trace 2) was detected. Partial recovery of amplitude of the right N31 component was noted at the time of closure. Postoperatively, mild weakness of eversion and dorsiflexion of the right foot was noted. (Calibrations: time 10 msec, amplitude 0.1 µV).

TABLE 2
Summary of details in cases with new postoperative neurological deficits in the immediate postoperative period

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Diagnosis</th>
<th>Motor</th>
<th>Sensory</th>
<th>EAS &amp; EUS</th>
<th>EMG</th>
<th>SSEPs</th>
<th>2-Yr Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>57, F</td>
<td>intradural/extradural schwannoma</td>
<td>L-3 distribution</td>
<td>none</td>
<td>none</td>
<td>no changes in SSEPs</td>
<td>no changes in SSEPs</td>
<td>no changes in SSEPs</td>
</tr>
<tr>
<td>2</td>
<td>37, M</td>
<td>intramedullary ependymoma</td>
<td>rt L-2 down distribution</td>
<td>none</td>
<td>none</td>
<td>unilateral loss of SSEPs</td>
<td>unilateral loss of SSEPs</td>
<td>unilateral loss of SSEPs</td>
</tr>
<tr>
<td>3</td>
<td>30, M</td>
<td>tethered spinal cord</td>
<td>rt L-2-5 distribution</td>
<td>none</td>
<td>none</td>
<td>significant spontaneous EMG activity in EAS &amp; EUS</td>
<td>significant spontaneous EMG activity in EAS &amp; EUS</td>
<td>significant spontaneous EMG activity in EAS &amp; EUS</td>
</tr>
</tbody>
</table>

* LE = lower-extremity; min = minimal; TA = tibialis anterior.

Thought to be indicative of potential nerve root injury. Any surgical events, such as suction, traction, coagulation, and the use of cold irrigation fluid, potentially responsible for the activation of these muscle action potentials in lower-extremity muscles and the EAS or EUS were noted. It was also noted that, in general, the EMG activity recorded in the lower-extremity muscles was significantly greater in amplitude (range 500–2000 µV) than that observed in the EAS or EUS (range 100–500 µV; Figs. 1 and 4).

Stimulated EMG Activity. A bipolar probe for electrical stimulation was used when recording stimulated EMG ac-
In 58 individuals (95%). In these cases, the electrically evoked EMG was registered, with low strength of stimulus, usually in one muscle (19 patients [33%]) and occasionally in several monitored muscles simultaneously (five patients [9%]) with a short latent period following the stimulus artifact. This evoked EMG activity was used to prevent nerve root injury or to establish functional continuity during the surgical procedures (to identify viable neural tissue, or nerve root identification, tumor removal, detethering, and terminal filum identification).

Spontaneous Lower-Extremity Muscle EMG Activity. In 48 patients (79%), EMG electrodes were positioned in six lower-extremity muscles (rectus femoris, tibialis anterior, and gastrocnemius muscles bilaterally). Because of limitations of available recording channels in older equipment, in 13 patients (21%), EMG electrodes were positioned in only four muscles (tibialis anterior and gastrocnemius muscles bilaterally). Lower-extremity muscle EMG activity was observed in 10 patients (16%) soon after the effect of muscle relaxants wore off (baseline activity). In two of these cases, EMG activity was recorded in two muscles simultaneously. In 18 patients (30%) lower-extremity muscle EMG activity, evoked by surgical manipulation, was recorded. This activity was observed simultaneously in two muscles in nine cases and in one muscle only in eight cases. In 10 cases (16%) no EMG activity was recorded in any muscle or sphincter intraoperatively. In eight patients (13%) lower-extremity EMG activity was recorded at the time of closure. In the three patients in whom new neurological deficits occurred, two suffered new motor deficits (Table 2). Prolonged, high-amplitude lower-extremity EMG activity was observed in only one of these patients (Case 1; Fig. 1). In this patient, large bursts of EMG activity were recorded in the left rectus femoris muscle (Fig. 1B and C). During this phase of surgery, a complete resection of a large, invasive nerve sheath tumor involving the left L-3 root was undertaken. There was no spontaneous EMG activity observed in any monitored muscles at the beginning of the surgery (Fig. 1A).

External Urethral and Anal Sphincter Spontaneous EMG Activity. For both the EUS and EAS, EMG recording electrodes were placed in all 61 patients. In one patient (1.5%) baseline spontaneous EMG activity was observed in the EUS and in three patients (5%) baseline EMG activity was demonstrated in the EAS (Fig. 4). Intraoperatively, EMG activity which could be evoked only in the EUS was observed in three patients (5%), and in 17 (28%) EMG activity occurred only in the EUS. In seven patients (11%) spontaneous EMG was observed intraoperatively in both the EAS and EUS during different stages of surgery; however, this was recorded in both sphincters simultaneously in only three of these cases. At the time of closure, spontaneous EMG activity was observed in the EUS in one patient (1.5%) and in the EAS in eight patients (13%).

Concurrent EAS, EUS and Lower-Extremity Spontaneous EMG Activity. We also analyzed the incidence of the spontaneous sphincter-based EMG activity that occurred in association with lower-extremity EMG activity. Intraoperatively, EMG activity in the EAS and EUS occurred together with the lower-extremity EMG activity in 21 cases (34%); the greatest incidence was in the gastrocnemius muscles (15 cases). In only five (8%) of the cases was sphincter-based EMG activity recorded in the absence of lower-extremity EMG activity. In 25 cases (41%), lower-extremity EMG data were recorded in the complete absence of sphincter-based EMG activity. In 10 cases (16%) no EMG activity was recorded in any muscle or sphincter during surgery.

Intraoperative Electrically Evoked EMG Activity. Intraoperative electrical stimulation was used to identify neural structures or nerve roots in 58 cases (95%) (Fig. 5). In 34 (59%) of these cases no stimulated EMG activity was recorded in any of the monitored muscle, either in the lower limb or sphincters; however, in 24 cases (41%) evoked EMG activity was elicited either in one muscle (19 cases [33%]) or simultaneously in two of the monitored muscles (five cases [9%]). Evoked EMG activity was recorded solely in the EAS in two cases (3.4%), solely in the EUS in two cases (3.4%), and solely in one lower-extremity muscle in 16 cases (28%). In four cases (7%), stimulated EMG activity was simultaneously recorded in the EAS and EUS (Fig. 5; Case 4), and in one case (1.7%) simultaneously in the EAS and gastrocnemius (S-1) muscles. These electrophysiological data were used to direct and modify the microsur-
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**Case 1**

This 57-year-old woman underwent resection of a large L2–3 intradural/extradural schwannoma (Fig. 6); well-defined baseline SSEPs were noted (Fig. 1). No changes in SSEPs occurred intraoperatively (Table 3); however, new
sient L-3 deficit, related to dissection of the tumor, intra-
recovery by 6 months.

operative stimulation and recording were used to retain
spontaneous EMG activity in the left rectus femoris mus-
root injury. Prolonged high-frequency and high-amplitude
elicited during the identification of the left L-3 and L-4
lower-extremity muscles and EAS was observed intraoper-
tion of the tumor, although none was elicited from the left
tibial nerve (Table 3, Fig. 3). Some EMG activity in the
postoperative L-3 sensory and motor deficits were
observed (mild weakness of the left quadriceps muscle
Table 2)), which gradually resolved during the 2-year fol-
the absence of SSEP changes was interpreted as a false-negative finding, and thus emphasizes the
importance of EMG recording to detect isolated nerve root injury. Prolonged high-frequency and high-amplitude spontaneous EMG activity in the left rectus femoris muscle was observed during tumor resection and nerve root manipulation (Fig. 1). Intraoperatively, it was determined that significant EMG activity in the left rectus femoris was elicited during the identification of the left L-3 and L-4 roots when a bipolar stimulation probe was applied. No EMG activity in the EAS or EUS was observed during the surgery in this case. Although this patient suffered a transient L-3 deficit, related to dissection of the tumor, intraoperative stimulation and recording were used to retain sufficient integrity of the L-3 nerve to allow an excellent recovery by 6 months.

Case 2

This 37-year-old man underwent resection of an intra-
medullary ependymoma of the conus medullaris. Although well-defined baseline SSEPs were recorded, significant reduction of the right-sided SSEP was detected during resec-
tion of the tumor, although none was elicited from the left tibial nerve (Table 3, Fig. 3). Some EMG activity in the lower-extremity muscles and EAS was observed intraopera-
tively. With the reduction in the right lower-limb SSEP, the microsurgical technique was altered. At the time of clo-
ure, the right SSEP amplitude recovered to 27% of the baseline amplitude and latency increased by approximately 5 msec (15% increase from the baseline). Postoperatively this patient presented with sensory deficits within the L-2 to S-2 dermatomes on the right. Moderate weakness of
eversion and dorsiflexion of the right foot and right great
toe extension accompanied these sensory changes. During
the 2-year follow-up period, the sensory deficit improved
(residual, partial loss of light touch and pinprick sensation
from L4–S2), and the motor deficit improved (mild [Grade
4+/5] residual L-5 distribution weakness). The SSEP changes were considered to be true-positive changes.
Accordingly, although a mild residual right lower-limb sens-
orimotor deficit persisted, the change in microsurgical technique necessitated by the observed electrophysiologi-
changes likely averted a much more serious neurologi-
cal outcome. In this case, a radical microsurgical resec-
tion was achieved, lower-limb function was excellent, and bowel and bladder function were controlled.

Case 3

This 30-year-old man underwent release of a tethered
cord and repair of a lipomyelomeningocele. Significant baseline asymmetry of SSEPs was noted (Table 3). There was an intraoperative decrease in the amplitude (25%) of the right SSEP, but this did not meet our criteria for signif-
icant change (≥ 50% drop in amplitude). There was min-
imal spontaneous EMG activity detected in the left and right tibialis anterior muscles. Electrically stimulated anal and bladder sphincter-based EMG activity was observed
during nerve root identification; however, no spontaneous EMG activity was present in either sphincter during the
surgery. The patient awoke with numbness in the upper lateral thigh and dorsum of the foot on the right, which re-
solved entirely within a 3-month period. Although by strict criteria the SSEP changes were determined to be a false-
egative result, a nonsignificant amplitude reduction of the SSEPs did occur.

Case 4

This 30-year-old man presented with a 2-month history of low-back pain and a recent onset of difficulty initiating urination. Examination revealed subtle right-sided extensor hallucis longus muscle weakness and a decrease in perianal sensation (S2–3 distribution). Magnetic resonance imaging demonstrated a cystic lesion at the level of the conus medullaris. This patient underwent a T11–L2 laminectomy with decompression of the spinal cord cyst. No changes in SSEPs occurred intraoperatively. Spontaneous EMG activ-
ity was recorded in the right gastrocnemius muscle and both the EAS and EUS during the microsurgical dissection and drainage of the cyst. The EMG activity in these muscles did not occur simultaneously; however, with bipolar stimulation to identify viable neural tissue during cyst decompression and detethering, stimulated EMG activity was recorded simultaneously in the EAS and EUS (Fig. 7). These intraoperative findings led to a change in microsur-
gical strategy to avoid injury to the conus medullaris. No new neurological deficits were observed in this patient.
Moreover, at the first follow-up examination the patient was pain free and experienced improved urinary symp-
toms. Long-term follow-up evaluation at 2 years revealed normal motor status in the lower extremities and normal urinary function, with complete bladder emptying; howev-
er, there was slight persistent numbness in the S2–3 distri-

Fig. 5. Bar graph demonstrating results of an analysis of cases in which intraoperative electrical stimulation was used to identify functional neural structures. In most cases (34 patients) no EMG activity was elicited, which confirmed the neurosurgeon’s impres-
ation of absence of critical neural structures; however, in 24 cases myogenic or sphincter EMG activity was elicited that influenced microsurgical technique.

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Discussion

In this study we analyzed our experience with multimodality intraoperative electrophysiological monitoring, including lower-limb SSEPs, lower-limb muscle EMG, and anal and bladder sphincter EMG during complex lumbosacral surgery. One of the major concerns during detethering of the spinal cord or tumor resection is the difficulty in recognizing viable neural tissue when a pathological process distorts the normal anatomy. Thus, intraoperative electrophysiological monitoring could be very useful in minimizing iatrogenic neurological injury and in assessing the physiological integrity of the spinal cord and its nerves during surgery. The results of this study provide evidence that multimodality electrophysiological monitoring is a practical and useful adjunct during complex neurosurgical procedures involving manipulation of the spinal cord, cauda equina, or individual lumbosacral nerve roots.

Anal and Urethral Sphincter EMG Monitoring

The pudendal nerve arises from the S-2 to S-4 spinal nerves and innervates both the anal and urethral sphincters.2,19 Previously it was thought that bladder sphincter function could be extrapolated by monitoring of the EAS alone.9 For example, Kothbauer, et al., have suggested that monitoring of the EAS alone could provide a sufficiently indirect assessment of the EUS and detrusor muscles. A number of authors, however, have shown that monitoring of the EAS alone does not provide a sufficient comprehensive neurophysiological assessment of EUS and detrusor function.3,9 Indeed, detailed electrophysiological investigations have revealed that innervation of these two sphincters can be both variable and distinct among patients.3,14 For example, Deletis, et al., showed that a single variable sacral root could carry the majority of motor fibers for the EUS.

Although EMG activity in the EAS and EUS was recorded intraoperatively in 27 patients in this study, simultaneous EMG activity was recorded from both sphincters in only three cases. Therefore, these observations indicate that, although the pudendal nerve innervates both sphincters, some branches have primarily EAS or primarily EUS innervation. Isolated EMG activity in one sphincter only indicates that both sphincters should be monitored for adequate coverage.

Some investigators have performed other techniques to monitor sacral nerve function during surgery. For example, in addition to conventional urinary bladder and anal sphincter EMG, Shionomiya and coauthors18 also used vesicle pressure measurements intraoperatively. Pang and Casey16 described the use of anal pressure monitoring during surgery involving the sacral spinal cord and nerve roots. These techniques, however, may not allow for adequate simultaneous monitoring of all sensory and motor segmental levels. Accordingly, based on our results, we advocate simultaneous, continuous monitoring of EMG activity in the EAS and EUS.

Somatosensory Evoked Potentials and Lower-Extremity EMG Activity

The SSEPs derived from the posterior tibial nerve, stimulated at the ankle, ascend the leg via the sciatic nerve and contribute to the cauda equina through the L-4 to S-1 nerve roots. The predominant contributors are the L-5 and S-1 nerve roots. This technique allows for monitoring of only a small portion of the spinal roots and the spinal cord above the S-1 nerve root entry zone. A combined multimodality approach involving intraoperative EMG record-
ings from the EAS, EUS, and lower limbs increases the possibility of monitoring nerve root integrity derived from the L2–S4 spinal segments.

In our study, baseline SSEPs could not be acquired in seven patients (11%). Previously, it was reported at our center that of 309 consecutive patients baseline SSEPs were unrecordable in 11%. Even with the absence of baseline SSEPs, we continued to monitor spontaneous and stimulated EMG activity in the lower limbs and in both sphincters to assess the integrity of the lumbosacral nerve roots in these individuals.

There was one case with true-positive changes in the SSEPs (Case 2) and two cases with false-negative results (Cases 1 and 3) in our series of patients. It is generally accepted that a decrease in SSEP amplitude of more than 50% is an indication of possible postoperative neurological deficits. In our series, in Case 2 (Tables 2 and 3) a significant unilateral degradation of the amplitude of the SSEPs occurred. By the time of closure, incomplete recovery of the amplitude of the N31 component was accompanied by a significant increase in response latency (25%). In this case the SSEPs never returned to their baseline values. In Case 3, the unilateral decrease in the amplitude of the N31 component did not meet the criteria for a significant change (≤ 50% decrease in amplitude). Even though we classified this as a false-negative change, one should be suspicious of nerve root injury in cases of sudden or unilateral amplitude degradation in the SSEP response that coincides with a surgical event. It is important to consider that SSEPs elicited by the stimulation of the posterior tibial nerve ascend to the spinal cord predominantly through the L5–S1 spinal roots. It is possible that injury to one of these roots may not produce what is considered a significant change. Therefore, injury to other nerve roots during surgery may not be detected by SSEP changes alone. For example, in Case 1 SSEP monitoring failed to detect intraoperative injury during the removal of an L-3 root schwannoma; however, in this case the main value in SSEP monitoring was to minimize the risk of a cauda equina injury because of the large size of the tumor.

To date, there are no conclusive data on the quantitative analysis of intraoperative EMG activity and its ability to predict postoperative neurological deficits. Auditory feedback of all EMG activity, however, is a useful, technically simple adjunct during complex lumbosacral surgery. This methodology provides the surgeon real-time feedback to assist with surgical decision making. Indeed in our series there were many instances of spontaneous and evoked EMG activity that alerted the surgical team of critical neural structures. In the majority of these cases the surgeon either reevaluated the immediate surgical interventions or continued manipulation to separate viable neural tissue. In most cases, excellent clinical outcomes with no incidence of new neurological deficit were observed. As illustrated in Case 4 the detethering procedure was not undertaken until the viable roots (in this case innervating both EAS and EUS) were freed from the terminal filum. Moreover, there was a significant improvement postoperatively in all three patients with new neurological deficits. Preoperative and first follow-up neurological data are summarized in Table 2.

**Time Considerations and Practicality of Intraoperative Monitoring Setup**

There is often a concern about the time involved in setting up and preparing for intraoperative neurophysiological monitoring. In our center, careful planning and coordination by all personnel involved in the surgery ensured that the monitoring setup, including placement of electrodes and intraoperative stimulation, proceeded seamlessly and with minimal delay. It is common practice that the technologist will start preparing the patient soon after induction of anesthesia. Electrodes will first be placed in areas close to the surgical field or areas that will eventually be draped. Minimal additional time (5 minutes) is needed for the insertion of the urinary sphincter electrode, although it should be noted that the electrode cannot remain indwelling postoperatively and needs to be removed, with a new catheter inserted if necessary. An additional 1 to 2 minutes is necessary for the insertion and securing of the anal sphincter electrode. Preparation of the surgical field can commence immediately thereafter. During this time cortical and subcortical recording ele-
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trodes will be placed and baseline recordings will be obtained before the skin incision. The total time required for the electrophysiological setup described in this study is 15 to 20 minutes in the hands of experienced personnel, and most of this preparation is concurrent to the required surgical and anesthetic preparation. Moreover, from the surgeon’s point of view, the electrophysiological setup will save time intraoperatively by facilitating decision making and will provide a safer, controlled environment for tissue identification and dissection.

Conclusions

Complex intraoperative neurophysiological monitoring combining SSEP and EMG recordings is a valuable and practical tool that can be used to protect neural structures during complex lumbosacral surgery, particularly when the conus medullaris or cauda equina nerve roots are at risk. The results of our study indicate that lower-extremity SSEP monitoring alone does not provide adequate neurophysiological information during procedures involving the conus medullaris and cauda equina. Intraoperative EMG recording is a reliable and rapid method of nerve root identification as well as for detecting impending nerve root injury. Effective monitoring of EAS and EUS function is best achieved using simultaneous EMG monitoring of the EAS and EUS. This modality is not time consuming and is relatively easy to use. We believe that when these methods are used in combination, clinically useful monitoring of the nerve roots and spinal cord can be achieved; however, further validation of the clinical value of multimodality electrophysiological monitoring as an adjunct to the operative management of complex disorders of the lumbar spine, conus medullaris, and cauda equina requires prospective examination in a large cohort of patients. Moreover, our data do not provide evidence to support the routine electrophysiological monitoring during low-risk lumbar spine procedures.

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References