Guidelines for the performance of fusion procedures for degenerative disease of the lumbar spine.

Part 15: electrophysiological monitoring and lumbar fusion

DIAGNOSTIC RECOMMENDATIONS

Standards. There is insufficient evidence to recommend a treatment standard.

Guidelines. Use of intraoperative SSEP or DSEP monitoring is recommended as an adjunct in those circumstances during instrumented lumbar spinal fusion procedures in which the surgeon desires immediate intraoperative information regarding the potential of a neurological injury. The occurrence of a postoperative neurological deficit is highly correlated with intraoperative changes in these monitoring modalities. An abnormal SSEP or DSEP during surgery, however, often does not correlate with a postoperative neurological injury because of a high false-positive rate.

Use of intraoperative evoked EMG recordings is recommended in those circumstances in which the operating surgeon wishes to confirm the lack of a neurological injury during pedicle screw placement. A normal evoked EMG response is highly predictive of the lack of a neurological injury. An abnormal EMG response during the surgical procedure may or may not be associated with a clinically significant injury.

Options. Intraoperative evoked EMG recording is recommended as an option during lumbar spinal fusion surgery in those situations in which the operating surgeon desires immediate information regarding the integrity of the pedicle wall, as a normal evoked EMG response is correlated with an intact pedicle wall.

THERAPEUTIC RECOMMENDATIONS

Standards. There is insufficient evidence to recommend a treatment standard.

Guidelines. There is insufficient evidence to recommend a treatment guideline.

Options. Intraoperative SSEP, DSEP, EMG, and/or evoked EMG monitoring are recommended only as adjunctive options during instrumented lumbosacral fusion procedures for degenerative spinal disease. The use of any of these modalities has not been convincingly demonstrated to influence patient outcome favorably.

Rationale

Intraoperative electrophysiological monitoring of spinal cord and nerve root function is used in a variety of clinical scenarios. Various techniques are thought to be useful for the detection and prevention of neurological deficits.
during surgery to repair aortic aneurysms, correct scoliotic or traumatic spinal deformities, and during resection of spinal cord tumors. \cite{11,13,29,30,38,45} Intraoperative monitoring for routine lumbosacral fusion for degenerative disease is also being performed. The primary justification for the use of these surgical adjuncts is the perception that the safety and efficacy of pedicle screw fixation is enhanced through the use of intraoperative electrophysiological monitoring. The purpose of this review is to examine the medical evidence concerning intraoperative monitoring to answer the following questions. 1) Does intraoperative electrophysiological monitoring of the nerve roots or spinal cord increase the safety of lumbar or lumbosacral instrumentation? 2) Does the use of intraoperative electrophysiological monitoring of the spinal cord and nerve roots influence patient outcomes following lumbar spinal surgery for degenerative disease?

Search Criteria

A computerized search of the database of the National Library of Medicine from 1966 to March 2003 was conducted using the search terms “electrophysiology and spinal surgery,” or “EMG and spinal surgery,” or “evoked potentials and spinal surgery.” The search was restricted to the English language and yielded a total of 1068 citations. The titles and abstracts of each of these references were reviewed and papers not concerned with the use of monitoring for lumbosacral fusion were discarded. References were identified that provided either direct or supporting evidence relevant to the use of monitoring for lumbar or lumbosacral fusion procedures. These papers were obtained and reviewed, and relevant references from the bibliographies of these papers were also identified. All papers providing Class II or better medical evidence regarding the use of electrophysiological monitoring for lumbar or lumbosacral fusion procedures are summarized in Table 1. Additional information is provided by other references listed in the bibliography.

Scientific Foundation

There are two potential uses for electrophysiological monitoring: an intraoperative diagnostic test for nerve injury during screw placement or a treatment tool to improve postoperative outcome. Because two different uses of monitoring are being considered, medical evidence was classified (as Class I, II, or III) separately when the evidence was used to support monitoring as a diagnostic study or when monitoring was used as a treatment modality. The level of evidence provided by a particular paper is therefore referred to as diagnostic, treatment, or both in Table 1.

Somatosensory Evoked Potential Monitoring

Intraoperative SSEP monitoring has been used in spinal surgery since the 1940s. \cite{2,12,20} Initially, SSEPs were used for assessing spinal cord function during scoliosis surgery, resection of spinal cord tumors, spinal cord decompression, or during vascular procedures with the potential to alter spinal cord blood flow. \cite{11,13,20,21,23,24,30,33,40,42,45,46} More recently, the use of this technique has been extended to patients being treated with lumbosacral fusion for degenerative disease. Balzer, et al.,\cite{1} reported their results from a group of 44 patients who were treated with lumbosacral fusion. All patients were studied with SSEP as well as spontaneous EMG and evoked EMG monitoring. Thirty-eight of these patients were surgically treated for degenerative spinal disease; postoperative S-1 radiculopathy developed in two. Intraoperative SSEPs were reported to be abnormal in one of these patients, despite repositioning of a screw. Intraoperative SSEPs were also reported to be abnormal in another patient who did not suffer a neurological deficit. In this patient, recordings normalized following adjustment of a cross-link. The sensitivity of SSEP monitoring for the detection of new deficits in this series was 50%.\cite{3} Although the NPV of normal SSEPs in this series was high (97%), the incidence of safe screw placement irrespective of SSEP monitoring was also high (95%). Bose and colleagues\cite{27} monitored continuous SSEPs as well as continuous EMG in a group of 61 patients being treated with instrumented posterolateral fusion procedures of the lumbosacral spine. These authors reported that SSEP monitoring was less useful than EMG monitoring for the detection of nerve injuries. Lencke, et al.,\cite{22} similarly used continuous SSEP as well as evoked EMG monitoring during placement of 233 lumbar pedicle screws. They reported that no useful information was provided by the SSEP monitoring. Reidy and colleagues\cite{29} noted that SSEPs were relatively insensitive to pedicle fracture during thoracic pedicle screw placement when compared with EMG monitoring. Mochida, et al.,\cite{28} compared SSEP monitoring with evoked EMG monitoring and found that the use of evoked EMG monitoring was more sensitive and specific for diagnosing intraoperative injury to nerve roots than were SSEPs.

Manninen\cite{26} reported his experience with continuous SSEP recording in a series of 309 patients who were treated with spinal surgery, 169 of whom underwent surgery for degenerative lumbar disease. He noted a 4.4% rate of false-positive changes in responses, a 1.1% incidence of false-negative changes in responses, a sensitivity of 57%, and a specificity of 95%. When the lumbar group was considered alone, the sensitivity of SSEP monitoring for detecting new deficits was 50%. Nishijima and colleagues\cite{31} noted significant SSEP changes in 11 of 58 patients they treated with thoracolumbar or lumbar surgery, yet none of these patients were noted to have a postoperative deficit. Meyer and colleagues\cite{23} compared their results with SSEP monitoring in a group of patients with traumatic injuries of the thoracolumbar spine. They compared two groups of patients who underwent surgical stabilization of the spine: 150 with monitoring and 145 without monitoring. These authors found that new neurological injuries occurred less frequently in the monitored group. They reported that six patients had significant changes in SSEP responses, only one of whom had a neurological deterioration (sensitivity 100%, specificity 96%, PPV 16%, NPV 100%). In the comparison group, 10 of 145 patients had new postoperative neurological deficits. There were, however, significant differences between the patient groups. The nonmonitored group was made up of a historical cohort combined with more severely injured patients in whom there were no reliable SSEPs preoperatively. The relevance of these findings to the current discussion is questionable because of disparities between the treatment groups, because the patient population treated was a trauma population, and because the

### TABLE 1

**Summary of studies involving electrophysiological monitoring**

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>Class</th>
<th>Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herron, et al., 1987</td>
<td>III</td>
<td>30 patients w/ lumbar stenosis had intraop DSEP. Improvements in monitoring were seen postdecompression in all patients. No significant difference between patients w/ good &amp; fair or poor results. In 2 patients, lack of improvement led to further decompression. Contralateral responses improved somewhat w/ unilat procedures.</td>
<td>DSEPs improve after decompression but prognostic importance is unclear.</td>
</tr>
<tr>
<td>Meyer, et al., 1988</td>
<td>III treatment II diagnosis</td>
<td>25 patients underwent op for trauma &amp; were retrospectively analyzed. 150 w/ SSEP, 145 not monitored. New deficits more common in nonmonitored group. Nonmonitored group were patients in whom responses could not be elicited &amp; historical cases. 5 false-positive SSEP alerts.</td>
<td>SSEP monitoring is sensitive for detection of nerve root injury. Use of monitoring may improve safety of trauma surgery in thoracic &amp; thoracolumbar spine. Sensitivity 100%, specificity 97%, PPV 17%, NPV 100%, LR(+) 33, LR(−) 0.</td>
</tr>
<tr>
<td>Owen, et al., 1988</td>
<td>III</td>
<td>NMEPs monitored in 111 patients; successful in 90%. No mention of results. No patient had neurological injury. Mixed patient population.</td>
<td>NMEPs can be measured in most patients.</td>
</tr>
<tr>
<td>Gepstein &amp; Browning, 1989</td>
<td>III</td>
<td>Observational study of 41 patients w/ SSEPs w/ laminectomy for HNP or stenosis. Improvements in latency correlated w/ functional outcome at 3 mos but not 1 yr. All patients had improved latency.</td>
<td>Decompression of nerve roots is associated w/ improved SSEP latencies.</td>
</tr>
<tr>
<td>Cohen, et al., 1991a</td>
<td>III treatment</td>
<td>Very select group of 12 patients w/ preop weakness monitored w/ DSEPs for decompressive op. 9 had “complete normalization” of DSEPs &amp; recovered strength. 3 had “variable” normalization &amp; did not regain strength.</td>
<td>DSEPs may improve after nerve root decompression. Improvement is a favorable prognostic sign.</td>
</tr>
<tr>
<td>Cohen, et al., 1991b</td>
<td>III diagnosis</td>
<td>Pudendal nerve DSEP performed in 154 patients w/ sacral fixation. 1 patient lost responses. No patient had a deficit.</td>
<td>Pudendal nerve DSEP monitoring is possible in most patients. Utility is unclear.</td>
</tr>
<tr>
<td>Nishijima, et al., 1992</td>
<td>III</td>
<td>58 patients w/ lumbar spine op (10 fusion) monitored w/ SSEPs w/ double stimuli. Loss of 2nd response in 11 patients. No patient had detectable postop deficit.</td>
<td>Sacral EP measurements can be abnormal in patients w/ severe claudication. Improvement can occur after decompression.</td>
</tr>
<tr>
<td>Hiraizumi, et al., 1993</td>
<td>III</td>
<td>5 patients w/ severe claudication had preop &amp; intraop monitoring. Symptoms correlate w/ sacral EP measurements. 4 patients had op &amp; all had improvement in amplitude. Clinical results excellent in 2 patients &amp; good in 2.</td>
<td>Femoral nerve SSEPs can detect injury to upper lumbar roots. Sensitivity 100%, specificity 87%, PPV 40%, NPV 100%, LR(+) 7.7, LR(−) 0.</td>
</tr>
<tr>
<td>Robinson, et al., 1993</td>
<td>III treatment</td>
<td>26 patients w/ lumbar fractures studied w/ femoral nerve SSEPs. 5 patients had significant SSEP changes. 1 had postop deficit despite immediate action taken by the surgeon.</td>
<td>Femoral nerve SSEPs can detect nerve root injury. Sensitivity 66%, specificity 88%, PPV 18%, NPV 98%, LR(+) 5.5, LR(−) 0.39. Utility unclear.</td>
</tr>
<tr>
<td>Toleikis, et al., 1993</td>
<td>III diagnosis</td>
<td>80 patients had lumbar op w/ PS fixation monitored w/ DSEPs. 69 had “minimal” changes during op &amp; none had new deficit. 11 had DSEPs disappear during op. 2 had neurological deficits. 1 related to deep venous thrombosis, 1 to dural tear.</td>
<td>Femoral nerve SSEPs can detect nerve root injury. Sensitivity 66%, specificity 88%, PPV 18%, NPV 98%, LR(+) 5.5, LR(−) 0.39. Utility unclear.</td>
</tr>
<tr>
<td>Owen, et al., 1994</td>
<td>III</td>
<td>80 patients monitored w/ mechanically elicited EMG. 17.8% of nerve roots studied demonstrated some firing. In 1, firing led to removal of PS. No postop deficits reported.</td>
<td>Mechanically elicited EMG can detect nerve root irritation. Importance unclear.</td>
</tr>
<tr>
<td>Castello, et al., 1995</td>
<td>III</td>
<td>30 patients had decompressive op for HNP or l/r recess stenosis w/ SSEP. Responses generally improved after discectomy or foraminotomy. No clinical outcome given.</td>
<td>SSEPs may improve after decompression of nerve root.</td>
</tr>
<tr>
<td>Glassman, et al., 1995</td>
<td>III treatment III diagnosis</td>
<td>Prospective study of 512 PSs placed in 90 patients. All PSs stimulated w/ EMG &amp; CMAP. All patients underwent CT for PS position. 11 PSs adjusted based on EMG (repositioning did not improve threshold) &amp; 4 PSs adjusted based on imaging w/ normal EMG threshold (&gt;15 mA). Normal EMG threshold predicted no obvious PS malposition w/ an NPV of 98%. Downgraded to Class III due to methodological issues of CT assessment.</td>
<td>CMAP threshold of &gt;15 mA likely represents intrapedicular screw.</td>
</tr>
<tr>
<td>Lencke, et al., 1995</td>
<td>III</td>
<td>233 PSs placed in lumbar or sacral pedicles in 54 patients w/ continuous SSEP &amp; then triggered EMG w/ threshold measured. 229 screws were well placed &amp; 4 questionable. Only 1 postop deficit in a patient whose PS was not replaced &amp; whose deficit may not have anything to do w/ the PS. No CT data.</td>
<td>Authors propose threshold guidelines for assessment of pedicle wall integrity (4 mA, 4–8 mA, &gt;8 mA).</td>
</tr>
</tbody>
</table>
TABLE 1 Continued

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>Class</th>
<th>Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maguire, et al., 1995</td>
<td>III</td>
<td>273 recordings made from nerve roots, drill bits, &amp; PSs during placement. Current thresholds more reliable than voltage thresholds for measurement purposes. 13 of 239 instrumentation measure &lt; 6 mA. 8 of 13 were incorrectly placed radiographically. 2 of 13 repositioned after direct inspection; 3 of 13 left in place after inspection. 1 patient w/ &gt; 6-mA threshold had a clearly misplaced screw on intraop radiographs. No CT data.</td>
<td>Authors suggest 6-mA threshold as being indicative of pedicle wall integrity.</td>
</tr>
<tr>
<td>Clements, et al., 1996</td>
<td>III treatment</td>
<td>25 patients received 112 PSs w/ EMG &amp; CMAP. PSs palpated or inspected visually. 12 PSs w/ stimulating threshold &lt; 11 mA broke through cortex. All cortical violations noted by palpation or inspection. 2 patients had a new postop (pain only) deficit.</td>
<td>EMG &amp; CMAP can detect pedicle violation. Effect on outcome unclear. For nerve injury, sensitivity 100%, specificity 90%, PPV 8%, NPV 100%, LR(+) 10, LR(−) 0.</td>
</tr>
<tr>
<td>Darden, et al., 1996</td>
<td>III</td>
<td>32 patients prospectively monitored w/ EMG. Patients w/o EMG response at EMG can detect nerve injury. Sensitivity 90%, specificity 45%, PPV 40%, NPV 91%, LR(+) 1.64, LR(−) 0.22. Unclear why Group 1 did worse than Group 3. Majority of EMG alarms led to no adjustments.</td>
<td>EMG can detect nerve injury. Sensitivity 90%, specificity 45%, PPV 40%, NPV 91%, LR(+) 1.64, LR(−) 0.22. Unclear why Group 1 did worse than Group 3. Majority of EMG alarms led to no adjustments.</td>
</tr>
<tr>
<td>Mochida, et al., 1997</td>
<td>III</td>
<td>“Train spinal stimulation” used in 34 patients w/ thoracic or thoracolumbar fusion. 10% latency delay that did not improve was associated w/ postop deficits. SSEPs did not detect any changes.</td>
<td>“Train spinal stimulation,” a form of CMAP, was found to be sensitive for the detection of postop deficits. SSEPs were not.</td>
</tr>
<tr>
<td>Tsai, et al., 1997</td>
<td>III</td>
<td>DSEPs in 33 patients w/ lumbar decompression. 58% of patients had reliable responses. All patients had improvement in responses postdecompression. Clinical results variable &amp; did not correlate w/ DSEP results.</td>
<td>DSEP monitoring is not feasible in many patients w/ lumbar nerve root compression. Improvement in DSEP criteria does not correlate w/ clinical outcome.</td>
</tr>
<tr>
<td>Balzer, et al., 1998</td>
<td>III</td>
<td>44 patients had op w/ SSEP &amp; EMG w/ CMAP. 6 instances of EMG abnormalities noted, all reported to surgeon. 2 of these patients had postop deficits. 2 instances of SSEP changes noted, 1 patient had postop deficit.</td>
<td>SSEP &amp; EMG monitoring were sensitive for intraop nerve root injury. Normal monitoring parameters were predictive of no new injury. Effect of monitoring on ultimate outcome unclear. Sensitivity specificity, NPV, PPV, LR(+), LR(−) for SSEP were 100%, 98%, 100%, 50%, 43, &amp; 0. The same values for EMG were 100%, 90%, 100%, 33%, 10.5, &amp; 0.</td>
</tr>
<tr>
<td>Darden, et al., 1998</td>
<td>III</td>
<td>Prospective comparison of impedance measurements, EMG &amp; CMAP to detect pedicle wall violation in 20 patients. 98 pedicle holes w/ PSs were tested w/ all modalities. All pedicle walls were inspected visually &amp; by palpation. 2 pedicles violated, both had abnormal EMG values. Impedance measurements unreliable. No clinical data given. No postop assessment of PS position.</td>
<td>Impedance measurements unreliable for assessing pedicle wall violation. EMG sensitive for detecting pedicle wall violation.</td>
</tr>
<tr>
<td>Manninen, 1998</td>
<td>II diagnostic</td>
<td>SSEP in 149 lumbar ops (disc &amp; stenosis). SSEP changes in 8 &amp; deficits in 4 patients. 2 false-negative SSEP studies &amp; 5 false positives. Nocross-Nechay, et al., 1999</td>
<td>Sensitivity of SSEP during lumbar surgery for diagnosing new deficit is 50%, specificity is 96%, NPV 98%, PPV 25%, LR(+) 12.5, LR(−) 0.52. SEPs can detect intraoperative nerve injuries. Sensitivity 100%, specificity 86%; PPV 25%, NPV 100%, LR(+) 7.14, LR(−) 0.</td>
</tr>
<tr>
<td>Norcross-Nechay, et al., 1999</td>
<td>III</td>
<td>70 patients monitored w/ SSEPs for lumbar stenosis op (a subset had fusion). 12 patients had intraop deterioration of SSEPs. 9 had no clinical sequelae. 3 had significant neurologic deficits postop. Op “adjustments” were made &amp; high-dose steroids were given to all w/ SSEP deterioration.</td>
<td>SSEP &amp; EMG monitoring were sensitive for intraop nerve root injury. Normal monitoring parameters were predictive of no new injury. Effect of monitoring on ultimate outcome unclear. Sensitivity specificity, NPV, PPV, LR(+), LR(−) for SSEP were 100%, 98%, 100%, 50%, 43, &amp; 0. The same values for EMG were 100%, 90%, 100%, 33%, 10.5, &amp; 0.</td>
</tr>
<tr>
<td>Reidy, et al., 2001</td>
<td>II</td>
<td>Prospective study of 95 PSs in thoracic spine w/ EMG &amp; SSEP. CT &amp; clinical FU performed. No changes in SSEPs, 90% of screws accurately placed.</td>
<td>EMG (CMAP) &amp; SSEP do not improve accuracy or safety of thoracic PS placement. Sensitivity of EMG for detecting pedicle breach was 50%, specificity 83%, NPV 94%, PPV 22%, LR(+) 2.9, LR(−) 0.6.</td>
</tr>
<tr>
<td>Bose, et al., 2002</td>
<td>III treatment</td>
<td>61 patients had op w/ SSEP &amp; EMG. 14 events in 13 (21%) patients. Events reported to surgeon who made changes. There was 1 postop deficit in patient w/ “sustained neurotrophic discharges” during retraction of thecal sac.</td>
<td>EMG &amp; SSEP sensitive for nerve injury. Effect of monitoring on ultimate outcome is unclear. Sensitivity 100%, specificity 80%, NPV 100%, PPV 8%, LR(+) 5, LR(−) 0.</td>
</tr>
<tr>
<td>Haghighi, 2002</td>
<td>III</td>
<td>41 patients w/ CMAPs for decompressive ops. No changes w/ decompression of nerve roots in 6 patients w/ radiculopathy.</td>
<td>CMAPS do not provide useful prognostic information after decompression of nerve roots.</td>
</tr>
</tbody>
</table>

* FU = follow up; HNP = herniated nucleus pulposus; LR = latency response; PS = pedicle screw.
Intraoperative monitoring

Medical and surgical treatment paradigm used in the study is outdated and not currently practiced.

Norcross-Nechay, et al.,32 monitored 70 patients they treated with lumbar decompression, instrumentation, and fusion with continuous SSEP monitoring and noted significant changes in 12 cases. In all 12 instances, immediate intraoperative “adjustments” were made and high-dose steroids (1.5 mg/kg dexamethasone intravenously) were given to those patients whose responses did not return to normal. Three patients had persistent deficits postoperatively. Therefore, the sensitivity of the SSEP monitoring for new injury was 100%, the specificity was 86%, the PPV was 25%, and the NPV was 100%. Similarly, Robinson, et al.,36 monitored femoral nerve SSEPs in 26 patients undergoing surgery for lumbar fractures and found that five patients had significant intraoperative recording changes, only one of whom had a postoperative deficit. The sensitivity, specificity, PPV, and NPV in this study (100%, 87%, 25%, and 100%, respectively) were similar to those noted by Norcross-Nechay, et al. Other supportive series from the scoliosis literature also indicate a significant false-positive rate and rare false-negative reports.17,36,46

Based on this information, it appears that SSEPs are able to detect many instances of nerve injury during thoracolumbar and lumbar surgery. Somatosensory evoked potential monitoring may be used to provide information to the surgeon regarding the occurrence of an intraoperative neurological injury. The majority of patients who awaken with deficits will have had abnormal SSEPs intraoperatively. There is, however, no evidence to suggest that a surgical response to SSEP changes influences patient outcome. Furthermore, there is a significant incidence of false alarms associated with the use of SSEPs that may cause the surgeon to make “adjustments” that are unnecessary and potentially harmful. These data do not, therefore, support the use of SSEP monitoring to improve outcome during thoracolumbar and lumbar fusion procedures in patients who undergo operation for degenerative disease.

Dermatomal Sensory Evoked Potential Monitoring

Dermatomal sensory evoked potential monitoring has been reported to be a more specific means of intraoperative nerve root monitoring than SSEP monitoring,4,45 and has been used to provide feedback to the surgeon during lumbar fusion procedures. Toleikis, et al.,41 monitored 80 patients they treated with lumbar spinal surgery and pedicle screw fixation and reported that DSEP responses were lost in 11 patients. Two of these 11 patients had postoperative deficits, one of whom had a deficit related to deep vein thrombosis but unrelated to screw placement. The second patient with a deficit was noted to lose responses immediately following a dural tear. Cohen, et al.,4 followed pudendal DSEPs in 154 patients. One patient was noted to have a deterioration in the DSEP response. This patient did not experience a postoperative neurological deficit. It appears that DSEPs are capable of detecting nerve injury and are likely similar to SSEPs in terms of diagnostic accuracy. There are, however, fewer publications to review concerning this monitoring modality. The neurological abnormalities described in the available series were either irrelevant to surgical manipulation, falsely positive, or simply a marker of damage already done. These data do not support the use of DSEP monitoring for improvement of patient outcome following lumbar fusion for degenerative disease.

Electromyographic Monitoring

Electromyography provides information regarding the motor function of the nerve roots and spinal cord. It has been used in many forms as a monitoring method during decompression and instrumentation procedures in the lumbar spine. Electromyographic monitoring techniques can be divided into those measuring mechanically elicited action potentials or those elicited by electrical stimulation of tissue or instruments. Various terms are used to describe these responses depending on the stimulus used to provoke a response from the nerve and the techniques used to measure the response. Some of the more common terms include evoked or elicited EMG, the CMAP, the NMEP, and persistently electrified pedicle screw instrumentation. The following discussion concerns the use of all modalities of EMG. Important differences in recording and stimulating techniques used in the studies will be discussed individually.

Balzer, Rose, and colleagues published a series of papers detailing their use of continuously electrified surgical instruments during the placement of pedicle screws during lumbar spinal surgery. These authors recorded both spontaneous (mechanically elicited) and evoked EMG activity (using a variable voltage threshold of stimulation determined intraoperatively) in patients being treated with instrumented lumbar fusion procedures. In six of 44 cases reported by Balzer, et al.,1 persistent spontaneous EMG activity was noted and “immediate measures” were undertaken to alleviate nerve root irritation. Two of these patients had new radicular complaints following surgery despite intraoperative adjustments. Bose and colleagues15 used a similar protocol (although they used a current threshold of 7 mA as a cutoff for pedicle breach as opposed to an intraoperative voltage measurement). In a series of 61 consecutive patients, “significant neurophysiological events” occurred in 13 patients (21%). Sustained neurotonic discharges in response to retraction of the thecal sac were seen in five of 40 patients being treated with interbody fusion. One of these patients had a postoperative deficit (temporary paraparesis). The sensitivity, specificity, PPV, and NPV for EMG monitoring in this series were 100%, 94%, 25%, and 100%, respectively.

Clements, et al.,6 prospectively studied the efficacy of evoked and spontaneous EMG in a series of 25 patients who were treated with instrumented lumbar fusion procedures. One hundred twelve screws were placed in patients. These authors found that a pedicle breach was predicted with 100% accuracy when the stimulating threshold was less than 11 mA. Pedicle breach was confirmed by visualization or palpation of the medial pedicle wall at the time of surgery. One patient with a pedicle breach experienced postoperative radiculopathy. Because the abnormal EMG responses were all noted after the pedicle had already been breached and because all pedicle breaches were detected by visualization and palpation, it is unclear if the use of EMG contributed useful data to the surgeon. Owen, et al.,8 recorded mechanically elicited EMG in 89 patients being treated with surgery for stenosis (80 lumbar and

nine cervical. They noted abnormal responses in 85 (17.8%) of 476 nerve roots monitored. No information was provided regarding the clinical consequences of this frequently noted activity.

Darden and colleagues\textsuperscript{9,10} published two papers that provide useful information regarding EMG monitoring during placement of pedicle screws. In a 1996 paper,\textsuperscript{9} they prospectively evaluated the insertion of pedicle screws in a series of 132 consecutive patients being treated with instrumented lumbar spinal fusion procedures. They analyzed their data by using arbitrary threshold cutoffs of 20 and 40 V. Patients were divided into three groups: Group 1, consisting of patients in whom no positive EMG responses to stimulation were seen; Group 2, consisting of patients in whom a positive response was noted but no corrective action was undertaken; and Group 3, patients in whom corrective action was undertaken following a positive response. Using a 40 V threshold as a cutoff, 35% of patients were in Group 1 (changes were reported to the surgeon in 65% of cases). In approximately two thirds of the cases with abnormal responses, the surgeon elected not to take any corrective action and in one third of the cases the surgeon took corrective actions. Ten percent of patients in Group 1 had postoperative deficits. Fifteen percent of patients in Group 2 had postoperative deficits, and none of the Group 3 patients had a postoperative deficit. The sensitivity, specificity, PPV, and NPV for this threshold level for predicting a neurological deficit were 90%, 45%, 40%, and 91%. Using a 20 V stimulus, 68% of patients were in Group 1, 16% of patients were in Group 2, and 16% were in Group 3. The sensitivity was 64%, the specificity 83%, the PPV 67%, and the NPV 90%. Computerized tomography scans were obtained in some patients. In 2.1% of Group 1 and 3.3% of Group 2 patients studied with CT scanning demonstrable screw malposition was revealed.\textsuperscript{10} The authors recommend that screws with stimulation thresholds less than 20 V be subject to corrective action. It is noteworthy that there was a 10% rate of new injuries in the group of patients with threshold values greater than 40 V. In a 1998 follow-up paper,\textsuperscript{9} these authors demonstrated that elicited EMG (using a 20-V threshold) was more specific and sensitive for pedicle wall violation than screw hole impedance measurements.

Another potential clinical outcome measure that may be affected by the use of electrophysiological monitoring is the assessment of pedicle wall integrity. Several studies were identified in which the absence of a pedicle breach or screw malposition was used as the primary outcome measure. The technique for placing a lumbar pedicle screw and the desired anatomical outcome is the same for cases involving screw fixation for scoliosis or degenerative disease. Therefore, it is reasonable to include data concerning lumbar pedicle screw placement for these disorders in this review. Lencke, et al.,\textsuperscript{21} performed a prospective study of evoked EMG monitoring during lumbar pedicle screw placement in a mixed patient population made up primarily of adolescents with scoliosis. In this study, 233 screws were placed, 220 of which were believed to be within the pedicle by clinical and EMG criteria. The majority (93%) of the well-placed screws had thresholds greater than 8 mA and all had thresholds greater than 4 mA. Three of the four screws that were known to be malpositioned had thresholds less than 4 mA. There was one patient with a screw threshold potential of 4.7 mA who awoke with radicular symptoms. These authors concluded that a threshold potential of greater than 8 mA is highly predictive of intraosseous placement. This paper is weakened by the lack of postoperative imaging studies with which to assess screw location. Maguire, et al.,\textsuperscript{22} reviewed their experience with evoked EMG monitoring and pedicle screw placement in a series of 29 patients treated with 144 pedicle screws. They stimulated drill bits, probes, and screws. Using a 6-mA threshold, they noted that stimulation of five screws with subthreshold parameters resulted in a measurable response. All five screws were thought to be in an acceptable position based on intraoperative radiographs. These screws were explored and two were eventually repositioned. The other three screws were thought to be in good position and were left alone. Conversely, one screw was found to have a normal EMG response (threshold > 6 mA) but was clearly malpositioned based on intraoperative radiographs. No patient suffered a root injury.\textsuperscript{25} This study also lacked an objective, consistent postoperative assessment of screw position.

Glassman, et al.,\textsuperscript{15} published a prospective analysis of intraoperative EMG monitoring compared with postoperative CT assessment of screw position in a series of 90 patients treated with 512 pedicle screws. The authors reported an NPV of 98% for evoked EMG thresholds greater than 15 mA. There were 11 screws that were repositioned based primarily on EMG threshold, and four screws were repositioned based on radiographic criteria despite a threshold greater than 15 mA. Fifteen screws were noted to have thresholds less than 15 mA and were explored. None of the 15 demonstrated minimal penetration of the pedicle wall; all penetrations were thought to be clinically insignificant. The remaining six pedicles were explored and found to be intact. None of the screws was repositioned. Therefore, 25 screws were found to have stimulation thresholds less than 15 mA. Of these 25, 11 were repositioned. Twenty-two screws were found to be in good position, and three screws (12%) were thought to be malpositioned.\textsuperscript{15} This compares with 10 screws that were malpositioned despite normal EMG responses (2%). This paper is considered to provide Class III medical evidence due to methodological concerns related to CT acquisition and grading criteria. The authors used CT scans with 5-mm cuts and used a grading system that considered screws that could not be well visualized to be in the “well-positioned” group. The clinical consequences of screw malposition in this series were not discussed. Reidy, et al.,\textsuperscript{26} performed a prospective assessment of thoracic pedicle screw placement by using EMG and postoperative CT assessment of screw position. They found, in contrast to the previous study, that the use of intraoperative EMG recordings to predict screw position was not useful in the clinical setting. In this study in which a 7-mA threshold was used, the sensitivity of EMG for detection of screw breakout was 50%, the specificity was 83%, the PPV 22%, and the NPV 94%.\textsuperscript{37} It should be emphasized that this study was performed in thoracic pedicles and therefore may not be directly relevant to this discussion because the use of EMG monitoring in the thoracic spine may be less reliable compared with the lumbar spine. Overall, the medical evidence derived from the literature...
Intraoperative monitoring

indicates that the lack of a recordable EMG response following pedicle screw stimulation is highly predictive of acceptable placement of the pedicle screw. There is no evidence to suggest, however, that the safety or efficacy of lumbar pedicle screw fixation is improved with the use of intraoperative EMG monitoring.

Monitoring During Decompression

Review of the literature revealed a series of papers in which the issue of using electrophysiological monitoring to determine the adequacy of nerve root decompression or to predict improvement in function following surgery was examined. For example, Castello and colleagues5 followed SSEPs during nerve root decompression in patients treated for a herniated disc. They found that SSEPs generally improved more with decompression of the lateral recess than with discectomy alone. There was no correlation with clinical outcome, however.3 Gepstein and Brown4 recorded SSEPs in a group of 41 patients they treated with lumbar nerve root decompression. Although there was an early correlation of improved SSEP latency with improved clinical outcome at 3 weeks following surgery, this association was not present 1 year following surgery. These authors reported performing further exploration in six patients because of a failure to obtain improvements in SSEP latency. In all six patients, a second compressive lesion was found. Haghighi16 recorded motor evoked potentials in six patients with radiculopathy who underwent lumbar decompression and fusion. No improvements in the potentials were noted and no clinical outcome data were presented.

Cohen, et al.,7 retrospectively reviewed a very select group of 12 patients (in a total population of 150) with weakness due to compression of lumbar nerve roots. Nine of the patients had complete normalization of DSEP potentials following decompression and had improved strength postoperatively. The other three patients had “variable improvement” in DSEPs and did not recover strength. Clearly, a chronically damaged nerve may not return to normal function even after adequate decompression. Therefore, although complete normalization of responses may be a positive predictor of improved function, the value of information provided by a “variable improvement” is less clear. Herron and colleagues8 recorded DSEPs in 30 patients who were treated with decompression for lumbar stenosis. Patient outcomes were graded as good in 21 patients, fair in seven, and poor in one patient (based on a nonvalidated outcome scale). Patients with good outcomes had a mean decrease in latency of 9.9 msec compared with a mean decrease in latency of 8.2 msec in the fair group and 6 msec in the patient with the poor outcome. There was a noted improvement in latencies on the unoperated side in patients with unilateral symptoms as well (mean 3.4 msec, range 0–7.6 msec). In two patients, failure of improvement in DSEPs led to further exploration, and a compressive lesion was found in one. Although this paper suggests a modest association between improvement in DSEP latency and outcome, there was no clearcut threshold of improvement to guide the surgeon. Tsai, et al.,44 also followed DSEP potentials during lumbar decompression surgery in 33 patients and correlated intraoperative changes in DSEP responses to clinical outcome. The DSEPs were recordable in 19 (68%) of 33 patients.

The authors reported complete normalization in DSEP latencies in every surgically treated patient who had a detectable baseline abnormality (13 of 19). There was no correlation between normalization of DSEP responses and clinical outcome.44

Summary

Based on the medical evidence provided by the literature reviewed, there does not appear to be support for the hypothesis that any form of intraoperative monitoring improves patient outcomes following lumbar decompression or fusion procedures for degenerative spinal disease. Evidence does indicate that a normal evoked EMG response is predictive for intrapedicular screw placement (high NPV for breakout). The presence of an abnormal EMG response does not, however, exclude intrapedicular screw placement (low PPV). The majority of clinically apparent postoperative nerve injuries are associated with intraoperative changes in SSEP and/or DSEP monitoring. For this reason, changes in DSEP/SSEP monitoring appear to be sensitive to nerve root injury. There is a high–false positive rate, however, and changes in DSEP and SSEP recordings are frequently not related to nerve injury. A normal study has been shown to correlate with the lack of a significant postoperative nerve injury. There is no substantial evidence to indicate that the use of intraoperative monitoring of any kind provides useful information to the surgeon in terms of assessing the adequacy of nerve root decompression at the time of surgery.

Future Research Directions

The main issues addressed in this review are the contribution of intraoperative monitoring to the clinical safety and effectiveness of lumbar spinal fusion procedures for degenerative spinal disease. No studies reviewed provided more than suggestive evidence on these issues. A randomized prospective study comparing clinical and radiographic outcomes in similar groups of patients undergoing lumbar spinal fusion either with or without intraoperative monitoring would provide Class I evidence supporting or refuting the hypothesis that the added expense associated with the use of intraoperative monitoring is justified by a clinical benefit.

References
