Evaluation with evoked and spontaneous electromyography during lumbar instrumentation: a prospective study

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The neuroanatomical structures that approximate the bony pedicles of the lumbar spine allow little room for technical error or compromise of the bone during pedicle screw insertion. Currently available neurophysiological monitoring techniques detect compromised bone and nerve root injury after it occurs. The purpose of this prospective study is to evaluate the reliability and efficacy of a unique neurophysiological monitoring technique. This technique provides immediate evaluation of pedicle cortical bone compromise in patients undergoing lumbar fusion with instrumentation by using electrified surgical instruments throughout the pedicle screw fusion procedure. Spontaneous electromyographic (EMG) activity was also monitored.

Intraoperative evoked EMG stimulation was performed using a pedicle probe and feeler as monopolar stimulators during the insertion of 164 pedicle bone screws in 32 patients. The EMG response to subthreshold stimulation intensities indicated cortical bone compromise. Immediate and conclusive feedback via evoked EMG activity using stimulating pedicle probes in appropriate muscle groups was successful in identifying pedicle cortical bone compromise in four patients. One false-negative evoked EMG study was noted but was identified via spontaneous EMG activity. Intraoperative EMG monitoring alerted the surgeon that redirection of the pedicle probe or screw was necessary to avoid nerve root irritation or injury and served as an early warning system.

Evoked EMG stimulation proved to be reliable and efficacious, especially when used in combination with spontaneous EMG. This technique may provide an added safeguard during implant placement procedures at centers where intraoperative neurophysiological monitoring is routinely performed.

KEY WORDS • electromyography • pedicle screw • intraoperative monitoring • spine fusion • pedicle probe

The indications for posterior lumbar spinal fusion with instrumentation include segmental spinal instability, spondylolisthesis, fractures, and instability after the resection of metastatic tumors. Although solid bone fusion is required to maintain long-term spinal stability, spinal implants are used to increase fusion rates and provide rigid internal fixation while the fusion mass forms. Recently, implant systems have been designed to include bone screws inserted through the pedicles into the vertebral bodies.

Insertion of pedicle screws requires anatomical localization of the pedicles, removal of laminar-facet cortical bone, and insertion of a metal probe or marker into the pedicle, followed by placement of the pedicle screw. Scar tissue, facet sclerosis, bone fracture, invasion by tumor, and osteoporosis increase the difficulty of screw insertion. The proximity of the nerve roots and thecal sac to the pedicles leaves little room for technical error or compromise of the bone. In light of the associated neuroanatomical considerations, it is not surprising that nerve root injury occurs in as many as 15% of operations.

In an effort to reduce the incidence of this complication, surgeons have used neurophysiological monitoring to detect bone or nerve root compromise. Many of these techniques provide either monitoring of somatosensory pathways or evoked electromyographic (EMG) recording in response to stimulation of pedicle screws that have already been placed in bone. Although somatosensory evoked potential (SSEP) monitoring is helpful, it may not detect subtle compromises in nerve root function. Determining EMG response after screw placement does not preclude the possibility of creating nerve root damage during probing or tapping of the pedicle or placement of the screw.

We have developed a technique that uses an electrified pedicle probe and feeler designed to provide immediate evaluation of pedicle integrity and probe position during preparation of the pedicle entry site and insertion of
Clinical Material and Methods

Approval for this study was obtained from the Institutional Review Board of the University of Pittsburgh Medical Center. Patients were first enrolled in July 1993 and the study ended in December 1995. All patients included in this study were evaluated pre- and postoperatively by a single surgeon (W.C.W.) and a single departmental physician’s assistant. All intraoperative neurophysiological testing was performed by members of the Center for Clinical Neurophysiology (R.D.R. or J.R.B.) using a standard protocol that will be described briefly.

TABLE 1
Clinical characteristics of 32 patients undergoing lumbar instrumentation with EMG monitoring

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Procedure</th>
<th>No. of Bone Screws</th>
<th>Intraop Spontaneous EMG</th>
<th>Intraop Evoked EMG</th>
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<td>4</td>
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* Act = activity, probe redirected; SA = spontaneous activity.
† Patient underwent two separate procedures.

def the implant screws. The evoked EMG protocol permits the detection of spontaneous EMG activity as well. The purpose of this prospective study was to evaluate the reliability and ease of use of this technique in the prevention of nerve root injury during pedicle screw placement.

Neurophysiological Evaluations

Intraoperative studies included SSEPs, evaluation of spontaneous EMG activity, and generation of threshold and suprathreshold EMG activity via stimulation of intact cortical bone of the pedicle, cancellous bone of the unroofed pedicle, and direct epineural root stimulation. Standardized intraoperative neurophysiological evaluations were performed in each patient by using a UNIX workstation (Hewlett-Packard, Boise, ID) linked to commercially available software (Neuro-Net 3.0; Computational Diagnostics Inc., Pittsburgh, PA). Subdermal needle electrodes were used for SSEP peripheral stimulation and scalp recording. Intramuscularly placed subdermal needle electrodes were used to record level-specific EMG activity (Fig. 1). The electrodes were placed after intubation and prior to patient positioning.

Spontaneous EMG activity was monitored from the lower-extremity muscle groups throughout the procedure (Table 1). The EMG thresholds were determined by using the pedicle probe and feeler as monopolar cathode (−) and suprathreshold intensities of stimulation are obtained. Gas = gastrocnemius; ham = hamstring; quad = quadriceps; tib = tibialis.

Patient Population

Thirty-two patients were enrolled in this study. Table 1 lists the diagnosis for each patient on admission, number of levels fused, and the number and location of pedicle screws placed. The patients were categorized as follows: thoracolumbar fusion (one patient), lumbar fusion with or without discectomy (eight patients), or lumbosacral fusion with or without discectomy (23 patients) using pedicle screws (VSP or Isola System; Acromed Corp., Cleveland, OH, or CCD System; Danek Group Inc., Memphis, TN). A short-acting muscle relaxant was administered at the time of anesthesia induction.

Fig. 1. Electromyelographic tracing showing selective direct stimulation of the left L-3 nerve root using a range of stimulation intensities. Note EMG activity on the left quadriceps muscle group allowing for confirmation of level and stimulation site. Both threshold and suprathreshold intensities of stimulation are obtained. Gas = gastrocnemius; ham = hamstring; quad = quadriceps; tib = tibialis.
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relate this activity with operative spinal levels. Square-wave DC pulses were delivered through the probe and feeler (3–6 Hz for 50–200 μsec at 1–150 V). Care was taken to prevent grounding of the surgical instruments during stimulation. Muscle relaxant was discontinued to allow EMG activity during the stimulation trials.

Each patient underwent midline exposure of the posterior vertebral elements, facet joints, and transverse processes. The pedicle entry sites were identified as described by An.2 Pedicle screws were not placed above the T-12 vertebral body in any patient.

The voltage threshold for detectable EMG activity was first determined on intact facet cortical bone, after which the cortical bone was removed. The cancellous bone of the pedicle was exposed and its voltage thresholds were determined. Both cortical and cancellous bone thresholds to elicit EMG response were determined on the initial pedicle to be probed in each patient. Half-voltage thresholds used for subsequent pedicle probe placements in pilot studies6,22 indicated that evoked EMG activity was typically obtained during bone stimulation at values more than two times greater than the nerve thresholds.

The pedicle was probed with the electrified instrument. Evoked EMG activity during the placement of the pedicle probe indicated that the probe was misplaced or that cortical bone compromise had occurred. In these cases the probe was redirected (usually more medially) or a new entrance site was selected. The position of pedicle entry holes was confirmed on a lateral radiograph prior to tapping and screw placement. The pedicles were tapped, and the electrified pedicle feeler was used to assess cortical integrity both manually and electrically. The EMG activity occurring at half-voltage threshold stimulation indicated that tapping had caused bone compromise, and the pedicles were reprobed and retapped as necessary.

The bone screws were placed and stimulated at intensities below the bone threshold. Again, if EMG activity occurred, indicating that the screw had caused compromise of the pedicle cortical bone, lateral radiographs were repeated, the pedicles were reprobed and tapped, and the screws were redirected. The additional time required to stimulate the facet cortex, intramedullary bone, and screw was approximately 2 minutes per pedicle.

The screws were connected to plates or rods to complete the implant. Autogenous iliac crest bone was preferentially used for fusion in the facet joint line and over the decorticated transverse processes. Autogenous blood and a cell-saver transfusion system were used in most cases.

Postoperative anteroposterior and lateral radiographs were obtained in all patients undergoing fusion. Except for the four cases discussed, all studies demonstrated appropriate intraosseous placement of the pedicle screws.

Results

One hundred sixty-four pedicle screws were placed in 32 patients during 33 operations. There was one permanent nerve root deficit in the immediate postoperative period (Case 20). Four screws required repositioning during the surgery and are discussed below.

Intraoperative Findings and Postoperative Results

Bone threshold readings were generated at the pedicle cortex and/or in the intramedullary pedicle bone in all patients. Bone thresholds were greater than 25 V in all patients and were typically approximately 40 V.

Spontaneous EMG activity was noted during four pedicle probe placements in four patients (Cases 2, 6, 18, and 20). Two of these patients (Cases 2 and 20) displayed new evidence of nerve root irritation in the immediate postoperative period. The patient in Case 18 had minimal resolution of her preoperative radicular symptoms post-surgery. The patient in Case 6 had excellent resolution of his radicular symptoms in the immediate postoperative period.

There were no cases in this study of evoked EMG activity without pedicle cortical bone compromise. Cortical bone compromise occurred during the insertion of four pedicle screws in four fusion operations (Cases 7, 15, 20, and 22). Bone compromise was confirmed by the surgeon via visual inspection, palpation using the pedicle probe or feeler, or radiographs. The presence of evoked EMG activity was detected in appropriate muscle groups in each of these cases, thereby rendering this technique extremely specific to the detection of cortical bone compromise. Such EMG activity was noted during any further attempts at reinsertion of the stimulated probe. The nonstimulated probe was redirected in each of the pedicles and bone screw placement was successful in three of the four compromised pedicles (Cases 7, 15, and 22). Stimulation of the redirected screws was performed in Cases 15 and 22, and no evoked EMG activity was noted. These three patients did not develop new neurological deficits.

One patient with osteoporosis and a small right-sided L5–S1 disc bulge (Case 20) underwent successful redirection of the probe in the left L-5 pedicle. During placement of the screw, the pedicle was disrupted medially and the screw was removed. Because of the osteoporosis, we used sacral screws to obtain bicortical sacral purchase. Spontaneous EMG activity was noted in the right S-1 nerve root during the procedure. There was no evidence of evoked responses in the right S-1 muscle groups. This patient developed an exacerbation of right-sided S-1 sciatica after discharge. Myelography and postmyelographic computerized tomography as well as plain x-ray films were obtained prior to implant removal. The left L-4 screw pulled out of the pedicle, the right S-1 screw appeared to have advanced further into the anterior sacral cortex, and a small disc rupture was noted at L₅–S₁ on the right side. The patient underwent implant removal via right L₅–S₁ laminectomy and discectomy. There was no evidence that the right S-1 screw had broached the pedicle, although it did penetrate further through the anterior sacral cortex. The patient’s symptoms improved immediately after instrumentation removal but had not fully resolved 26 months later.

The patient in Case 2 underwent L₅–S₁ fusion for segmental spinal instability. Nonlocalizing spontaneous EMG activity was noted, although no EMG responses were evoked at subthreshold voltages during pedicle probing. The patient awoke with new right-sided S-1 radicular symptoms. Intra- and postoperative radiographs revealed that the right S-1 bone screw was angled slightly more inferiorly than the left and was approximating the S-1 foramen but appeared to be solidly within bone (Fig. 2). Because of the persistent symptoms, the patient under-
Somatosensory Evoked Potential Monitoring Techniques

Constant Voltage Versus Constant Current in Evoked EMG Techniques

Discussion

Inaccurate placement of pedicle screws can cause nerve root injury or irritation. Neurological complications related to pedicle screw placement are more common in a surgeon’s early experience with spinal instrumentation, but even surgeons with extensive experience may encounter difficulty with screw insertion or neurological compromise, particularly in cases in which surgery has been performed previously.

The purpose of this prospective study was to evaluate the reliability and ease of use of a neurophysiological technique designed to provide immediate evaluation of pedicle integrity and probe position during preparation of the pedicle hole and insertion of the implant screws. Intraoperative techniques that identify neurological compromise, including bone impedance monitoring (unpublished data), motor evoked potential monitoring and intermittent neurophysiological stimulation, may provide the surgeon with powerful neurophysiological tools. Neurophysiological evaluation methods that have been used to determine suboptimum pedicle screw placement include SSEP and EMG monitoring. We can postulate that deficits were prevented because we performed the EMG stimulation techniques, used in this method, but this remains unproven.

Spontaneous EMG Activity

The neurophysiological technique used here featured an electrified pedicle probe and feeler to prevent nerve root injury during fusion implant surgery. Pedicle probe, feeler, and bone screw stimulation were used in 33 operations for the placement of 164 bone screws. Two patients (Cases 2 and 20) developed evidence of new nerve root irritation in the immediate postoperative period without intraoperative evoked EMG activity at the appropriate spinal level and side.

Constant Voltage Versus Constant Current in Evoked EMG Techniques

The advantages of constant voltage stimulation over constant current stimulation with respect to evoked EMG of the facial nerve have been discussed in depth by Moller. Constant current stimulation gained popularity because of its relative indifference to changes in electrode impedance, and such stimulation has distinct advantages for producing SSEPs. Therefore, constant current stimulators are available in many institutions and are sufficient for pedicle stimulation protocols. For example, Calancie, et al., who used a constant current stimulation method, suggested that 200-μsec stimuli of 7 mA were insufficient to evoke EMG activity through intact pedicle bone. Clements, et al., selected stimuli of 200 μsec and 11 mA in a similar protocol.

With evoked EMG stimulation, however, changes in impedance (similar to resistance in the clinical setting) are likely caused by changes in the small amounts of fluid between the active and reference electrodes. This fluid can shunt current away from the target area. According to Ohm’s law (V = IR), when current is maintained at a constant level, decreases in resistance, such as one might see...
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with fluid around a pedicle probe, decrease the voltage that would be applied to the target area. Neuronal activation occurs via voltage-dependent sodium channels in neuronal cell membranes. For these reasons, we believed that it would be preferable to use constant voltage stimulation.

In contrast to constant-stimulus-intensity protocols that used single set stimulus values for pedicle evaluation, we determined stimulus thresholds for individual pedicles. The theoretical advantages of the protocol used in the present study include individual thresholds for each pedicle, constant voltage stimulation, and persistent stimulation throughout hole preparation and screw implantation.

Conclusions

Evoked EMG activity was successful in identifying cortical bone compromise in each of four cases. Immediate and conclusive feedback was available, and this feedback warned the surgeon that redirection of the pedicle probe or screw was necessary, to avoid nerve root irritation or injury. This information was useful in preventing complications in the patients who required redirection of the pedicle probe. This technique may be most useful to surgeons early in their implant experience1,14 or during particularly technically difficult operations.

No major shortcomings of this technique were identified. Little time was added to the operations for the generation of EMG thresholds. The technique did not result in increased blood loss, and because the normal operative technique was used there was no increase in surgical manipulation. Anesthetic technique was important during the stimulatory phase of the operation, and careful preoperative planning and intraoperative communication among the surgeon, anesthesiologist, and neurophysiologist were crucial.

Advantages of this technique include the potential for reduced neural injury rates by providing the surgeon with an early warning system, confirmation of cortical bone compromise, and electrophysiological verification of successful pedicle screw placement. Other potential advantages are the reduced use of intraoperative radiography to confirm appropriate screw placement and the reduced need for implant adjustment. Furthermore, this technique appears to be both specific and sensitive and provides a simple and efficacious method to reduce nerve root injury.

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References


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