

## Intraoperative electromyography monitoring in minimally invasive transforaminal lumbar interbody fusion

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**Object.** Minimally invasive transforaminal lumbar interbody fusion (TLIF) is an increasingly popular method for achieving lumbar decompression and fusion. The procedure is technically more demanding than open fusion, with correspondingly more theoretical risk of complication. The authors describe the use of intraoperative electromyography (EMG) as an adjunct to surgery to reduce the risk of complications.

**Methods.** Between August 2005 and April 2006, 25 consecutive patients underwent minimally invasive TLIF in which a total of 105 pedicle screws were placed. Intraoperative EMG was performed and included passive recordings during decompression and interbody graft placement, as well as active recording during the placement of the pedicle access needle and testing of the pedicle tap. A uniform protocol for active monitoring was used, with the pedicle access needle set at 7 mA. To assess hardware placement, all patients underwent postoperative radiography and 20 underwent postoperative computed tomography (CT) scanning.

In no patient did the authors observe significant EMG activation during decompression. In five cases, intermittent nerve root firing was noted after the interbody graft was placed, but this did not correlate with any postoperative deficits. Using the active stimulation protocol, 76.2% of screw placements required one or more changes to the trajectory of the pedicle access needle. With successful placement of the pedicle access needle, in all 105 screws, the pedicle tap nerve root stimulation threshold was greater than 15 mA. Postoperative radiography was performed in all patients and CT scanning was performed in 20 patients (with 85 screws being placed). Postoperative imaging revealed only three cases of pedicle breach. In all cases, the breach was at the lateral wall of the pedicle and not thought to be clinically relevant.

**Conclusions.** A continuous stimulation pedicle access needle alerts the surgeon to incorrect medial trajectories and may lead to safer pedicle cannulation. As a result of electrophysiological feedback, the pedicle access needle trajectory was altered in 76.2% of the reported cases. The use of the authors' protocol resulted in a 0% incidence of clinically relevant malpositioned hardware and a low overall neurological complication rate. Intraoperative nerve root monitoring is a useful adjunct to minimally invasive TLIF.

**KEY WORDS** • minimally invasive surgery • transforaminal lumbar interbody fusion • electromyography • nerve monitoring

**C**OMBINED posterior lumbar spinal decompression and instrumentation placement has been associated with a significant incidence of occasional complications, often due to malpositioned implants,<sup>1,6,10,11,28,36</sup> and intraoperative EMG monitoring has been proven to be a useful adjunct.<sup>3–5,7,9,25,29,31,39</sup> Various techniques of intraoperative nerve monitoring exist. The most useful modalities involve passive free-run monitoring of nerve roots to detect injury or irritation and active stimulation of pedicle

probes and the screws themselves to determine the threshold at which adjacent nerve root irritation occurs.<sup>18</sup> Electromyography monitoring has been shown to be more accurate in detecting malpositioned screws than intraoperative radiography and even direct visual inspection.<sup>7,16,17,37</sup>

Minimally invasive TLIF is a recently developed technique that is becoming increasingly popular.<sup>13,14,19,22,33</sup> This technique allows for decompression and fusion of the lumbar spine and is theoretically associated with advantages of reduced tissue and muscle trauma. Muscle injury in open fusion has been well documented and is postulated to be a cause of significant postoperative morbidity.<sup>20,21,27,34,35</sup> The minimally invasive technique, however, is more

Abbreviations used in this paper: AP = anteroposterior; CT = computed tomography; EMG = electromyography; PS = pedicle screw; TLIF = transforaminal lumbar interbody fusion.

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demanding than open decompression and fusion. The neural decompression and interbody fusion portions of the procedure may not be associated with a higher risk of neural injury than open surgery but the PS placement portion is. This is because screws are placed percutaneously, without the benefit of visual inspection of surgical landmarks or the opportunity to inspect the spinal canal and neural elements during or after placement. Without additional adjuncts, the surgeon relies on intraoperative fluoroscopy and tactile feedback to insert the screws safely and accurately.

We describe a technique that allows for neurophysiological feedback during minimally invasive lumbar decompression, interbody fusion, and especially during PS placement. Intraoperative electrophysiological monitoring during lumbar decompression and fixation has been reported on in conjunction with open surgery. To the best of our knowledge, however, ours is the first report of electrophysiological monitoring during minimally invasive lumbar fusion. Given the technically demanding nature of the procedure, it is critical to develop new techniques to reduce the complications of minimally invasive TLIF. The percutaneous insertion of instrumentation involves a different tool set and technique compared with open surgery. This requires modification of previously described equipment to allow the successful use of intraoperative nerve root monitoring. To this end, we describe the use of a system to provide electrophysiological feedback to increase the safety and improve the accuracy of the minimally invasive placement of instrumentation.

## Clinical Material and Methods

### Patient Population

Between August 2005 and April 2006, the authors performed minimally invasive TLIF in 25 consecutive patients. There were 10 men and 15 women whose mean age was 46 years. Demographic and treatment-related data are presented in Table 1.

### Surgical Technique

The patients were consecutively treated and prospectively identified in a database, although data analysis was performed retrospectively. Institutional review board approval was obtained. This series represents the first 25 minimally invasive TLIF procedures performed by the authors. The patients were treated in accordance with a uniform protocol. All patients underwent uni- or bilateral decompression, as clinically indicated, in which we used an expandable tubular retractor system (X-Tube, Medtronic, Inc.) with microscopic magnification, TLIF, and percutaneous PS fixation. Sextant PSs (Medtronic, Inc.) and a self-distracting polyetheretherketone cage (Capstone, Medtronic, Inc.) packed with local autograft and bone morphogenetic protein-2 (Infuse, Medtronic, Inc.) were used for all cases. Minimally invasive decompression and interbody fusion were performed using previously described techniques (see *Percutaneous PS Placement*). A unilateral decompression was required in 19 cases, and a bilateral decompression in six cases. Intraoperative EMG monitoring was used throughout the procedure. Ap-

TABLE 1

Summary of demographic and treatment-related data

Characteristic	No. of Cases
mean age (yrs)	46
male/female	10:15
indication for fusion	
spondylolisthesis	8
degenerative disc disease	15
recurrent disc herniation	2
previous decompressive op	6
no. of levels treated	
1	22
2	3

propriate muscles were monitored depending on the surgically treated level. Passive recording was used during neural decompression and interbody fusion. To allow EMG monitoring, patients were not given medication to induce paralysis during surgery. Although pharmacological paralysis is useful during muscle dissection and exposure in open lumbar decompression and fusion, we have not found the lack of paralysis to be a problem during this minimally invasive procedure.

### Percutaneous PS Placement

The surgical technique for percutaneous PS placement will be reviewed to explain the modifications that allow for improved nerve monitoring during hardware placement. Under AP and lateral fluoroscopic guidance, a pedicle access needle is placed onto the transverse process of the target pedicle, or the sacral ala (Fig. 1A). Very importantly, this needle is attached to a continuous stimulation current source. Our protocol involves delivering a continuous 7-mA current through the pedicle access needle. This threshold was determined based on clinical data from previous studies and our personal experience with intraoperative nerve monitoring during open lumbar fusion.<sup>7</sup> The continuously active pedicle access needle provides instant feedback of nerve root proximity through both EMG activation and actual muscle twitching in the affected leg. We have generally found it easier to use the same skin incision, but a separate, more lateral, fascial opening for PS placement than that used for the decompression and interbody fusion. The pedicle access needle is insulated, with only the metal tip exposed to prevent electrical grounding of the stimulation current. It is initially placed at the lateral portion of the appropriate transverse process. The needle is then “walked” medially to the junction of the transverse process and facet joint, using both tactile feedback and fluoroscopic visualization (Fig. 1A). The lateral-to-medial approach to needle placement prevents excessively medial placement of the needle, which in the setting of prior laminectomy and decompression could result in a potentially devastating neural injury.

The needle is placed at the appropriate entrance trajectory, at the junction of the facet joint and transverse process. The laterality of the needle is confirmed by AP fluoroscopy. A lateral image is then used to adjust the trajectory in the sagittal plane. The pedicle access needle is then advanced into the pedicle. At the settings used in

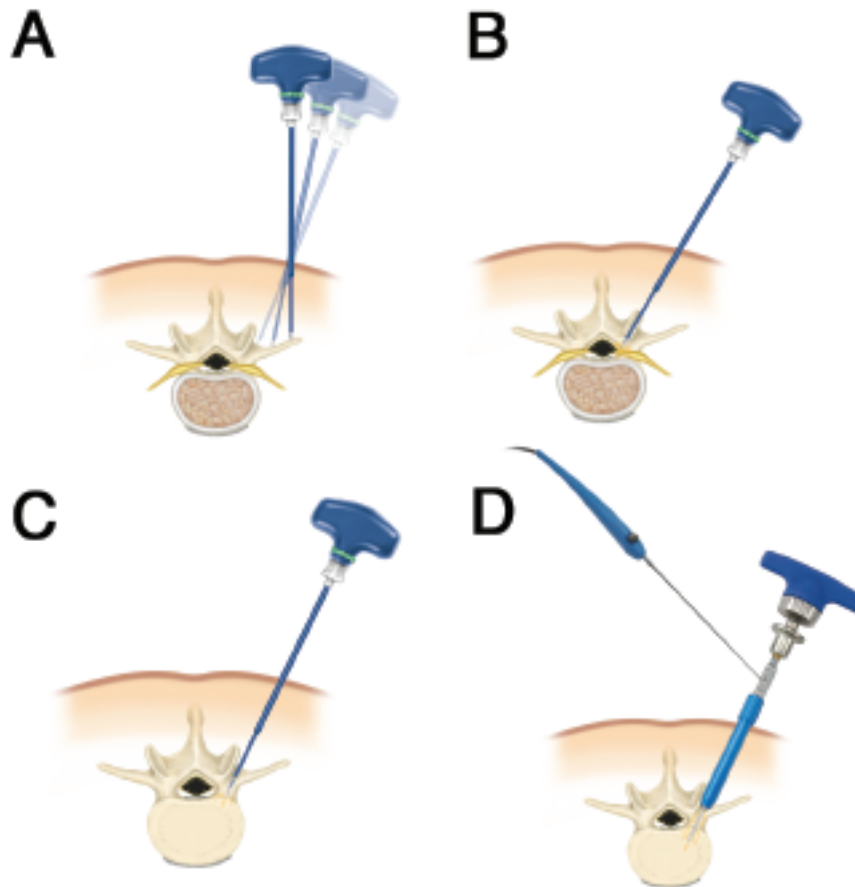


FIG. 1. Schematic illustrations. A: Depiction of the pedicle access needle being “walked” lateromedially along the transverse process to the appropriate entry point at the junction of the transverse process and facet joint. The lateromedial approach prevents inadvertent canal violation and neural injury. B: Pedicle access needle angled too medially to the pedicle cortex with nerve root stimulation detected on EMG. C: Pedicle access needle with correct trajectory and without nerve root activation. D: Pedicle tap in correct position with insulating sleeve, being electrically stimulated, without nerve root activation.

this study, EMG activation and myogenic leg twitching are instantly noted if an incorrect trajectory is used, prior to a pedicle breach (Fig. 1B). If activation occurs, fluoroscopic images are acquired. The needle is withdrawn from the bone, the trajectory readjusted, and the needle advanced again (Fig. 1C). After the pedicle and vertebral body are cannulated without EMG activation, a guidewire is placed through the needle and the needle is withdrawn. Two metal dilators are placed and an insulating sleeve is inserted over these instruments. The sleeve was originally designed as a metal soft-tissue barrier but has been modified to be composed of an insulating plastic. The dilators are removed, and a tap is placed through the sleeve and over the guidewire. The pedicle is tapped. The tap is then tested using an electrified ball probe, which is touched to the metal tap (Fig. 1D). The presence of the insulating sleeve is required to prevent the current from being grounded by surrounding the soft tissue. The maximum stimulation threshold at which no EMG activation occurs is recorded. The tap is removed and the PS placed over the guidewire. Because of the need for a metallic extension device and the resulting current grounding on surrounding

soft tissue, the screws themselves cannot be directly tested after implantation. In lumbar pedicles, a 6.5-mm-diameter screw was used in all cases, whereas a 7.5-mm-diameter screw was used for S-1.

## Results

Table 1 provides a summary of patient demographic and treatment-related data. Twenty-five patients were included in this study. Twenty-two patients underwent single-level fusion, and three underwent two-level fusion. In one patient undergoing two-level fusion, one of the six screws needed to be removed when we encountered difficulty in passing the connecting rod; thus, only five screws were placed. A total of 105 screws were assessed in this study.

As previously noted, intraoperative EMG monitoring was performed in passive, free-running, and active stimulus-evoked modes. A passive mode was used to detect nerve root irritation or injury manifesting as spontaneous firing. Active monitoring was performed by the continuously active pedicle access needle and by testing the pedi-

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cle tap. Both EMG modalities are very different, and therefore we will describe results of these modalities separately.

### Passive Monitoring

During decompression, in no case was EMG activation noted. In five cases, intermittent spontaneous firing of the nerve root was noted after placing the interbody graft. This firing occurred at infrequent intervals during the rest of the procedure, unrelated to continued work at that level and side. In none of these cases was this intermittent nerve firing associated with any postoperative neurological deficit. Therefore, the significance of this EMG activity is unclear.

### Active Monitoring

A total of 105 screws were placed in this study. In 80 (76.2%) of 105 screws, one or more changes in pedicle entry point or trajectory were made as a result of instant EMG and myogenic feedback from the pedicle access needle. In no case was a pedicle tapped until the pedicle access needle could be placed without producing EMG activity. The pedicle tap was tested initially at a threshold of 20 mA. If nerve root activation occurred, the threshold was progressively reduced in 1-mA increments until stimulation ceased. No tap provoked nerve activation at a stimulation threshold of less than 15 mA (Table 2). In no case did a patient suffer clinical nerve root injury due to minimally invasive decompression, interbody fusion, or PS placement.

### Postoperative Imaging

Postoperative AP, lateral, and flexion–extension x-ray films were obtained in all patients. Postoperative CT scanning was performed to assess 85 screws in 20 patients. For study purposes and to assess and improve our skills, we began, after the first 14 cases, to obtain postoperative CT scans in all patients prior to discharge from the hospital. We were able to acquire CT studies in eight of the first 14 patients in the series. All imaging studies were reviewed by an independent radiologist and the lead author. In no case did radiography clearly demonstrate evidence of a malpositioned screw. In three instances (three [3.5%] of 85 screws) CT scanning revealed pedicle violation. In all cases the pedicle violation was directed laterally. In no case was the complication clinically relevant, and good bone purchase was found in all cases (Fig. 2).

## Discussion

This is the first published study in which intraoperative EMG monitoring was used as an adjunct to minimally invasive TLIF. No significant neurological complications occurred. The use of a continuous stimulation pedicle access needle alerts the surgeon to incorrect trajectories and results in safe pedicle cannulation. As a result of the electrophysiological feedback, the trajectory of the pedicle access needle was altered in 76.2% of the cases. No cases of medial pedicle violation were noted on postoperative images. Only three cases (3.5%) of clinically insignificant

TABLE 2  
Results of active nerve root monitoring\*

Case No.	No. of Screws Placed	Treated Levels	PAK Needle Trajectory Changed†	Pedicle Tap EMG Activation Threshold‡	
				15–20 mA	>20 mA
1	4	L5–S1	4	—	4
2	4	L5–S1	4	1	3
3	4	L4–5	4	1	3
4	4	L5–S1	4	—	4
5	4	L5–S1	4	1	3
6	4	L2–3	4	—	4
7	4	L4–5	4	—	4
8	5	L4–S1	4	—	5
9	4	L4–5	3	—	4
10	4	L5–S1	4	1	3
11	4	L4–5	2	—	4
12	4	L5–S1	4	1	3
13	4	L4–5	3	—	4
14	4	L4–5	4	—	4
15	4	L4–5	3	—	4
16	4	L4–5	2	1	3
17	4	L4–5	4	—	4
18	4	L4–5	3	—	4
19	4	L5–S1	1	—	4
20	4	L4–5	4	—	4
21	4	L4–5	1	—	4
22	4	L4–5	3	—	4
23	4	L5–S1	1	—	4
24	6	L4–S1	3	1	5
25	6	L4–S1	3	—	6
total	105	28	80	7	98

\* PAK = pedicle access; — = not applicable.

† Changed because of EMG activation. The values represent the number of screws for which one or more alterations in the trajectory of the pedicle access needle was made as a direct result of intraoperative EMG activation.

‡ Indicates threshold at which EMG activation occurred with stimulation of the pedicle tap.

nificant lateral violation were noted on CT scans of 88 screws.

### Intraoperative EMG in Lumbar Instrumentation

There is a body of evidence in the literature on the use of intraoperative EMG in open lumbar fixation. Most of the literature deals with testing PSs after placement. In the lumbosacral spine, some authors have attempted to determine the threshold at which a PS may be considered “safe.” In a study of 512 PSs, Glassman et al.<sup>16</sup> determined that a stimulation threshold of 15 mA or greater was associated with a 98% probability that the screw was in the pedicle. Electromyography stimulation was found to be more accurate than intraoperative radiography. A stimulation threshold of less than 10 mA was associated with a high probability of pedicle violation. In a study in which 3409 screws were inserted, Toleikis et al.<sup>37</sup> found a direct correlation between stimulation threshold and the chance that a screw was medially displaced. After inspecting the screws again, they redirected 90% of those testing at less than 5 mA, compared with 41% of the screws testing at 5 to 7 mA and 24% of those testing at 7 to 10 mA. Screws testing at greater than 10 mA were not reinspected. Clements et al.<sup>9</sup> determined that cortical breakthrough occurred at a stimulation threshold of less than 11 mA.

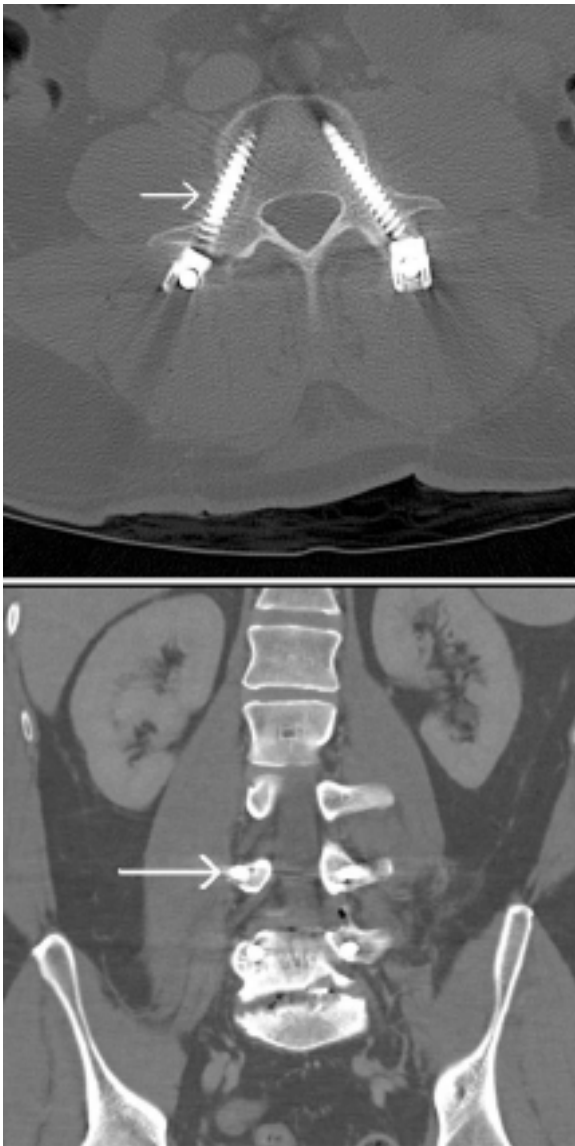


FIG. 2. Radiographic examples of minimal lateral pedicle violation (arrows).

There are limited published data on continuously active instruments used for pedicle access. Using continuously electrified instruments for pedicle probing, tapping, and screw placement, Calancie and associates<sup>7</sup> found that an activation threshold of less than 7 mA was associated with pedicle perforation or instrument malposition. They found that this threshold was associated with false-positive stimulation but preferred to err on the side of caution. Electromyography stimulation was found to be more sensitive than even direct inspection of the pedicle. Maguire et al.<sup>26</sup> found that a threshold of less than 6 mA occurred in cases of misplaced drill bits and violation of the cortex by PSs.

It is possible that the threshold values used in the present study are not optimal. Although the incidence of medially or inferiorly malpositioned PSs was 0% when we used a 7-mA level of activation for the pedicle access needle, it is possible that similar results may have been

achieved using a lower threshold. In 76.2% of PSs placed, the pedicle access needle had to be redirected at least once when EMG stimulation activated leg muscle twitching. It is likely that in many of these cases the trajectory was actually acceptable and that a false-positive activation occurred. We have no way of determining this, however. We had no cases of false-negative activation. By using a lower threshold, we may have caused fewer false positives. It may, however, also have caused false-negative activations, which would not be acceptable. The 7-mA threshold was selected to yield a minimal rate of false negatives. The 7-mA threshold resulted in a 0% incidence of EMG activation of the tap when less than 15 mA was delivered. Most published clinical data have been derived from the testing of the screw itself. We are not aware of data correlating pedicle tap thresholds to screw thresholds. A 15-mA threshold, however, is associated with well-positioned screws in all published studies. Examination of the results in our study suggests that this threshold for the pedicle tap is also associated with excellent screw placement relative to the nerve root.

It is important to recognize that intraoperative EMG will only help to detect malpositioned screws in proximity to the lumbar nerve roots; screws that are laterally or superiorly malpositioned will not likely be detected. Certainly the vast majority of clinically relevantly malpositioned screws will be detected. In our series, postoperative CT scanning demonstrated three malpositioned screws, but in all cases the malpositioning was oriented laterally. There is CT-derived evidence in the literature that PSs can be accurately placed in open surgery without EMG monitoring.<sup>2,8,12,15,23,24,30,38,40</sup> In the literature, it is clear that most misplaced screws are medially malpositioned in the lumbar spine. The fact that we found only laterally malpositioned screws is likely due to the use of intraoperative EMG monitoring. Certainly there appears to be a learning curve to percutaneous screw placement. Therefore, the fact that the present series represents the first 25 procedures performed by the authors biases the results against us. With greater experience, the pedicle access needle and PS accuracy may improve.

#### *Minimally Invasive TLIF*

In 2002 both Foley and Gupta<sup>13</sup> and Khoo et al.<sup>22</sup> described the use of minimally invasive posterior lumbar interbody fusion. In their initial descriptions of the procedure the authors reported performing either intertransverse fusion or bilateral posterior lumbar interbody fusion via tubular retractors. The same authors have since described additional technical refinements involving unilateral TLIF, also using tubular retractors.<sup>14,19</sup> Almost all published clinical reports to date, limited as they are, involve one of the two author groups that originally described the procedure. One theoretical advantage of minimally invasive fusion over open surgery is reduced muscle trauma. Muscle injury in open fusion has been well documented and is postulated to be a cause of significant postoperative morbidity.<sup>20,21,27,34,35</sup> The authors of a recent clinical report suggested that minimally invasive TLIF is associated with decreased blood loss, reduced postoperative narcotic usage, fewer perioperative complications, and a shorter hospital stay.<sup>19</sup> There is limited evidence in the literature

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on neurological complications or hardware malposition in patients who have undergone minimally invasive fusion.

## Accuracy of PS Placement

The authors of cadaveric and postoperative CT studies have determined that the use of anatomical landmarks and radiographic guidance in open PS placement in the spine is associated with a high incidence of screw malposition.<sup>2,8,12,15,32,38</sup> Cortical violation occurs in up to 20% of the cases, even in the hands of very experienced spine surgeons.<sup>32</sup> In the lumbar spine, the evidence is clear that most screw violations occur medially,<sup>2,8,12,15,23,24,30,38,40</sup> which poses clinical danger, even though most screws that violate the cortex are asymptomatic.<sup>32</sup> In minimally invasive surgery, the surgeon lacks the ability to see anatomical landmarks, and must rely only on tactile feedback and fluoroscopy. There is no opportunity to inspect the clinically critical medial and inferior pedicle walls. Clearly, without surgical adjuncts one would expect the incidence of screw malpositioning to be higher than in open surgery. Because of the proximity of neural structures, intraoperative EMG monitoring can only reduce the incidence of medial and inferior pedicle wall breaches. In the present study, there was a 0% incidence of medial and inferior pedicle wall breaches. Although we would like to think this is the result of technical brilliance on our part, it seems likely that our results may not have been possible without intraoperative EMG monitoring.

Both groups of authors originally reporting the minimally invasive fusion procedure initially described using stereotactic guidance to assist with PS placement.<sup>13,22</sup> Stereotactic guidance has been shown to improve the accuracy of PS insertion.<sup>2,23,24,30</sup> The disadvantages of this technique include the need for a separate midline incision and the exposure and removal of the muscle from the spinous process to be used as an anchoring point for the reference array. The equipment is relatively expensive and not available at all institutions. There is also a small increase in operative time associated with attaching the array and the process of registration. Additionally, these systems are still associated with a chance of PS malposition, even during open surgery. Neurophysiological monitoring is simple, comparatively inexpensive, and is associated with minimally increased operative time. Direct, immediate feedback is given. Certainly, the use of either or both surgical adjuncts would be reasonable to reduce complication rates.

## Conclusions

This study is, to the best of our knowledge, the first to describe the use of intraoperative EMG as an adjunct to minimally invasive TLIF. A continuous stimulation pedicle access needle alerts the surgeon to incorrectly medial trajectories and may result in safer pedicle cannulation. As a result of electrophysiological feedback, the pedicle access needle trajectory was altered in 76.2% of the cases. Our protocol resulted in a 0% incidence of clinically relevant malpositioned hardware and a low overall neurological complication rate. Intraoperative nerve root monitoring is a useful adjunct to minimally invasive TLIF.

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## Disclaimer

The authors have no financial interest in the devices described in this paper.

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