

Electromyographic Monitoring and Its Anatomical Implications in Minimally Invasive Spine Surgery

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Study Design. Literature review.

Objective. The objective of this article is to examine current intraoperative electromyography (EMG) neurophysiologic monitoring methods and their application in minimally invasive techniques. We will also discuss the recent application of EMG and its anatomic implications to the minimally invasive lateral transpsoas approach to the spine.

Summary of Background Data. Minimally invasive techniques require that the same goals of surgery be achieved, with the hope of decreased morbidity to the patient. Unlike standard open procedures, direct visualization of the anatomy is decreased. To increase the safety of minimally invasive spine surgery, neurophysiological monitoring techniques have been developed.

Methods. Review of the literature was performed using the National Center for Biotechnology Information databases using PUBMED/MEDLINE. All articles in the English language discussing the use of intraoperative EMG monitoring and minimally invasive spine surgery were reviewed. The role of EMG monitoring in special reference to the minimally invasive lateral transpsoas approach is also described.

Results. In total, 76 articles were identified that discussed the role of neuromonitoring in spine surgery. The majority of articles on EMG and spine surgery discuss the use of intraoperative neurophysiological monitoring (IOM) for safe and accurate pedicle screw placement. In general, there is a paucity of literature that pertains to intraoperative EMG neuromonitoring and minimally invasive spine surgery. Recently, EMG has been used during minimally invasive lateral transpsoas approach to the lumbar spine for interbody fusion. The addition of EMG to the lateral approach has contributed to decrease the complication rate from 30% to less than 1%.

Conclusion. In minimally invasive approaches to the spine, the use of EMG IOM might provide additional safety, such as percutaneous pedicle screw placement, where visualization is limited compared with conventional open procedures. In addition to knowledge of the anatomy and image guidance, directional EMG IOM is crucial for safe passage through the psoas muscle during the minimally invasive lateral retroperitoneal approach.

Key words: extreme lateral interbody fusion (XLIF), psoas, lumbar plexus, neuromonitoring, electromyography (EMG), minimally invasive. **Spine 2010;35:S368–S374**

Spinal surgery includes a vast array of techniques and approaches to accomplish the intended goals of decompression, realignment, and stabilization. As with other surgical specialties, the recent trend has been to perform these procedures minimally invasively. Minimally invasive techniques require that the same goals of surgery be achieved, with the hope of decreased morbidity to the patient. Unlike standard open procedures, direct visualization of the anatomy is decreased. To increase the safety of minimally invasive spine surgery, neurophysiological monitoring techniques have been developed.

Intraoperative neurophysiological monitoring (IOM) methods, namely, somatosensory and motor-evoked potentials (SSEP and MEP, respectively) and free-run and evoked (triggered) electromyography (frEMG and tEMG, respectively), have aided in the intraoperative identification and correction of neural impingement while decreasing the prevalence of nerve injury.^{1–24} These methods are used to monitor the spinal cord (descending rostral column corticospinal and ascending dorsal column somatosensory tracts), spinal nerve roots, *cauda equina*, conus medullaris, and more recently, the lumbar plexus.^{8,10,20,21}

Nash *et al* introduced SSEP monitoring for nerve injury detection and avoidance during scoliosis surgery in 1977.²⁵ Subsequent publications have shown the sensitivity and specificity of multimodal neuromonitoring of the spinal cord and nerve roots during the surgical treatment of spinal trauma,^{26,27} tumors,^{28–33} degenerative and idiopathic scoliosis,^{15,16,19,25,34–38} placement of pedicle screws,^{2,3,9,39–42} and for testing the degree of nerve root function in posterior decompressive procedures.^{43,44} Advanced neurophysiologic monitoring has mainly been used in complex procedures, which are more commonly performed with open exposures.^{8,10,22,45} Outside of EMG screw testing in percutaneous pedicle screw placement,⁴¹ the role of intraoperative neurophysiologic monitoring in minimally invasive interbody fusion approaches has been less well studied or defined.^{46–48} The objective of this article is to examine current intraoperative EMG neurophysiologic monitoring methods and their application in minimally invasive techniques. The recent application of EMG to the minimally invasive lateral transpsoas approach to the spine is also discussed.

Methods

Review of the literature was performed using the National Center for Biotechnology Information databases using PUBMED/MEDLINE. Keywords included intraoperative, neurophysiologic, monitoring, somatosensory, motor, evoked potentials,

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multimodal, electromyography, triggered, spine, minimally invasive, percutaneous, spinal cord, nerve root, injury, and neurologic deficit. All articles in the English language discussing the use of intraoperative EMG monitoring and minimally invasive spine surgery were reviewed. A description of EMG monitoring in special reference to the minimally invasive lateral transposas approach and anatomy was also described with respect to literature findings.

■ Results

In total, 73 articles were identified that discussed the role of neuromonitoring in general spine surgery. Narrowing the search to EMG and spine surgery resulted in many articles discussing the use of IOM for safe and accurate pedicle screw placement.^{2,3,9,39,40,42,49} When limiting to articles that only address EMG monitoring and minimally invasive spinal approaches, 4 articles were identified. Three articles discussed the utility and accuracy of EMG for identifying malpositioned percutaneous pedicle screws^{41,47,48} and 1 discussed the use of EMG for verification of nerve root decompression during minimally invasive lumbar discectomy.⁴⁴ In general, there is a paucity of literature that pertains to intraoperative EMG neuromonitoring and minimally invasive spine surgery.

Recently, tEMG and frEMG have been used during the minimally invasive lateral transposas approach to the lumbar spine for interbody fusion.^{50–58} Its application is used to identify the location of the nerves of the lumbar plexus as the psoas muscle is traversed so as to potentially reduce any neural-related complications. The addition of EMG to the lateral approach has contributed to decrease the neural complication rate from 30% to less than 1%.^{58,59,59a}

■ Discussion

Neural injuries typically occur as the result of compressive or distractive forces, by laceration or shearing, or by ischemia, either through the natural history of a pathology or iatrogenically.¹ The early identification of such injuries intraoperatively is essential in allowing for changes in surgical plan to potentially reverse or attenuate the injury. Along with the potential avoidance of such injuries before occurrence, IOM is used intraoperatively to correct surgical events that elicit an IOM response and which may be causing injury to a nerve, otherwise unknownst to the operating surgeon.^{1,8,10,20,21,60}

Electromyography

EMG was first described by Dutch biologist Jan Swammerdam (1637–1680), after discovering that stroking of the innervating nerve of a frog's gastrocnemius resulted in muscle contraction. Jasper introduced the technology to human diagnostics and treatment, with the first electromyograph, in 1942. Since that time, the clinical and diagnostic applications of EMG have been widely studied. In general, EMG has a low positive predictive value (percentage of patients with postoperative neural deficit which correlated with an intraoperative alarm) with high sensitivity (the probability of an alarm signal detecting a neurologic injury), which is

particularly useful in the early detection and prevention of pending nerve injury.⁸ EMG is also regularly used as a supplement to SSEP and MEP monitoring in cervical and lumbar surgeries, where the exiting nerve roots are at risk.^{5,10–14,17,21,33,34,43,47,48,61–63} EMG can be used in 2 ways, either passively through frEMG or by stimulating nerves to elicit a response (tEMG). An initial set of 4 positive twitch tests before surgery confirms EMG responses and that anesthetic guidelines were followed (no paralytics).

Outside of its use as a supplement to SSEP, MEP, or both monitoring methods, EMG has certain unique application specific to general spine surgery as well as minimally invasive techniques. The most widely used application of EMG monitoring in spine surgery is for testing of posterior pedicle screw breach. In 2002, Jutte and Castelein reported on 105 patients treated with bilateral transpedicular fixation and found an overall complication rate of 54% with 6.5% of patients having suboptimal pedicle screw placement with impingement of the *cauda equina* or nerve root.⁶⁴ EMG pedicle screw testing works by stimulating the placed screw and depending on the threshold needed to elicit a response from the corresponding myotome, an indication of pedicle breach can be determined. As the pedicle acts as an insulator, the higher the response threshold, the decreased likelihood of direct or near contact to the exiting nerve root. Typically, an EMG response threshold of <7 mA indicates a likely breach of the pedicle.^{9,39,61} Although this method is used in both open and minimally invasive placement of pedicle screws, its utility in percutaneous approaches is particularly useful as a validated safety measure which also decreases the use of intraoperative fluoroscopy.^{46,48} Approach instrumentation, including Jamshidi needles, have also been outfitted with EMG stimulators that can detect potential breaches before screw placement, thus facilitating early trajectory correction.

A second application in posterior spine surgery is to test for extent of nerve root decompression by comparing preoperative EMG recordings with intra- or postoperative readings. Chronically compressed nerves do not function as efficiently as decompressed nerves, which can cause the response threshold of tEMG to be more than 10 mA with direct contact, as opposed to the 7 or 5 mA thresholds described elsewhere.^{39,40,48,61} Thus, decompression of these nerves during surgery can result in a decreased stimulating EMG threshold to elicit a response. The extent of nerve root compression can be tested using EMG in 2 ways. First, using frEMG involves preoperative testing to determine the presence of existing neurotonic firing (typically at lumbar levels), indicating a compressed nerve root. Beatty *et al* reported that 18% of 150 patients being treated for degenerative conditions of the lumbar spine exhibited spontaneous electrical discharge or firing in myotomes related to levels being treated. In those 18% of patients, once the decompression had been performed the muscle firing ceased.⁴³ In the second application, Limbrick *et al* in 2005 showed

that high initial tEMG thresholds in compressed nerve root myotomes significantly decreased when posterior lumbar decompressions had been performed. In 2 patients in their series, a lack of change in tEMG threshold correlated with persistent symptoms and on subsequent decompression, tEMG thresholds decreased as well did their symptoms.⁴⁴ This application is currently used in both open decompressions as well as in microlumbar discectomies and percutaneous approaches for discectomy.^{39,43,44} Currently, intraoperative neuromonitoring of nerve roots during lumbar microdecompressions is not routinely being used, since direct visualization of nerves during the procedure typically provides sufficient information to avoid regular neural injury.

Minimally Invasive Lateral Transpsoas Approach

The lateral approaches to the lumbar spine require passage through the psoas muscle, which contains the nerves of the lumbar plexus that innervate the muscles of the lower extremities. The lateral approach to the lumbar spine was first reported in the late 1980s, but was not widely adopted as high incidences of neurologic injury were encountered because of the indeterminacy of the location of the lumbar plexus, which placed it at high risk for violation.^{65,66} In the early 21st century, a modification of the approach, with real-time, directionally stimulated, discrete threshold EMG IOM was developed to aid in the identification of intrapsoas nerves. The addition of EMG has allowed the surgeon to be able to determine the location (proximity) of and avoid intrapsoas nerves during the approach. Subsequent clinical and anatomic studies have shown the reproducibility of this model and approach.^{53,54,67–70}

This minimally invasive approach, extreme lateral interbody fusion (XLIF[®], NuVasive[®], Inc., San Diego, CA) using EMG IOM (NeuroVision[®] NuVasive, Inc.) approaches the spine with sequential dilators orthogonal to the disc space in a true lateral position which stimulate (tEMG) directionally and provide discrete threshold results of lower limb nerve root function (bilateral vastus medialis, tibialis anterior, biceps femoris, and medial gastrocnemius myotomes) while passing through and when positioned within the psoas muscle (Figure 1). As this system is now in its third generation, it includes multiple components of neuromonitoring, not only EMG. In addition, the system allows for frEMG when not using tEMG. Using discrete threshold, tEMG in directional orientations provides real-time feedback of the relative position of intrapsoas nerves with respect to the placed instrumentation as well as the approximate distance from the nerve, as measured by the threshold required to depolarize the nerve and elicit a response (Supplemental Digital Content, video, online only, available at: <http://links.lww.com/BRS/A490>). The dilators are designed to be integrated with EMG-stimulating capabilities unidirectionally, with an isolated stimulating surface on the dilator. Using tEMG, as the dilator is rotated within the psoas muscle, stimulating areas are localized circumferentially. Therefore, if the stimulating surface is facing anteriorly



Figure 1. Intraoperative photograph of triggered electromyography (tEMG) during a lateral transpsoas approach using the NeuroVision M5 neuromonitoring platform.

only within the psoas muscle while stimulating and no threshold response is observed, it indicates that the position of motor nerves are likely not anterior to the dilator. Conversely, if the stimulating surface is oriented posteriorly and a response is elicited, the relative position of the motor nerves is likely to be in the posterior orientation (Supplemental Digital Content, video, online only, available at: <http://links.lww.com/BRS/A490>). In general, tEMG thresholds for response below 5 mA indicate direct contact, between 5 and 10 mA indicate close proximity (little, but some, soft tissue between the instrumentation and the nerve), and >11 mA indicates farther proximity from intrapsoas nerves. The directional capabilities as well as the discrete threshold responses simultaneously provide information about the orientation and distance of instrumentation with respect to motor nerve location.

A report from 2004 of the use of the lateral transpsoas approach without this type of IOM found postoperative paresthesia rates as high as 30%.⁷¹ In the largest series reported to date using the approach with this monitoring, Rodgers *et al* showed a 0.7% neural injury rate (3 quadriceps femoris weakness, 1 tibialis anterior weakness) which all resolved by 3 months postoperative in 600 consecutively treated XLIF patients. No lasting neurologic deficits were reported.^{59a} Although NeuroVision was used in each case, EMG IOM was not an independent variable in the article. In a separate study of NeuroVision in a prospective, multicenter clinical study of 102 XLIF patients treated for degenerative conditions with interbody fusion at L3–L4 and L4–L5, the authors found that 55.7% of cases (43.6% at L3–L4, 62.9% at L4–L5) elicited alert-level (<5 mA) feedback from tEMG during dilator passage through the psoas muscle and during the operation with retractors expanded.⁵⁶ The most frequent location of nerves during psoas muscle passage was posterior to the instrumentation and there was no correlation between zone of instrumentation placement (disc divided into quadrants from anterior to posterior) and postoperative motor deficit. New postoper-

ative motor deficits were observed in 2.9% of patients including 1 dorsiflexion weakness and 2 instances of quadriceps femoris weakness. Other small series reports of XLIF and other lateral transposas approaches have reported higher levels of neural injury. One such report by Tormenti *et al* showed 8 patients treated for scoliosis correction with XLIF exhibited a 75% transient thigh symptoms (sensory or motor), although the experience of the surgeon, the role of IOM, and the conclusions able to be made from an 8 patient series are unknown.⁵⁹ Unlike MIS TLIF and microlumbar decompressions where neuromonitoring may add a benefit but is not essential to the procedure, neuromonitoring during the lateral transposas approach is essential for reproducible results. As with any procedure, however, the use of a safety measure, in this case neuromonitoring, does not eliminate such complications, but rather decreases their prevalence, as was evidenced in the studies of Bergey *et al*⁷¹ and Rodgers *et al*.^{59a}

Anatomic Considerations

In addition to image guidance, patient positioning, and EMG IOM, a thorough knowledge of the regional anatomy of the lumbar plexus is required for safe passage through the psoas muscle. To entirely benefit from the use of EMG IOM during the XLIF approach, one must understand the relationship of the lumbar plexus relative to the psoas muscle and disc spaces. This has prompted several anatomic studies regarding the lumbar plexus and lateral approach.^{67,68,70,72}

Moro *et al* analyzed 6 lumbar spines in the axial plane to study the distribution of the lumbar plexus in relation to the psoas muscle so as to prevent nerve injuries during endoscopic spine surgery. They concluded that the “safety zone,” excluding the genitofemoral nerve, is at L4–L5 and above.⁶⁷ Benglis *et al* dissected the lumbar plexus in a total of 3 specimens using the lateral position. They noted a general trend of progressive ventral migration of the plexus at the lower lumbar segments. The authors recommended avoiding placement of the dilator/retractor in a posterior position on the disc spaces to prevent injury to large conjoined nerve roots.⁷² Park *et al* suggested that the intrapsoas nerves are at a safe distance from the radiographic center of the intervertebral disc in a majority of cases. However, they recommend use of neuromonitoring for safe passage through the psoas.⁶⁸ Uribe *et al* dissected 20 lumbar segments and studied the relationship between the disc spaces, psoas muscle, and the lumbar plexus. They described the safe anatomic zone/corridor for passage through the psoas muscle at each disc space level.⁷⁰

Complication Avoidance

Electrophysiological monitoring is a necessary tool to prevent nerve injury while traversing the psoas muscle and during placement of the retractor. We believe that electromyography systems with hunting algorithms, dis-

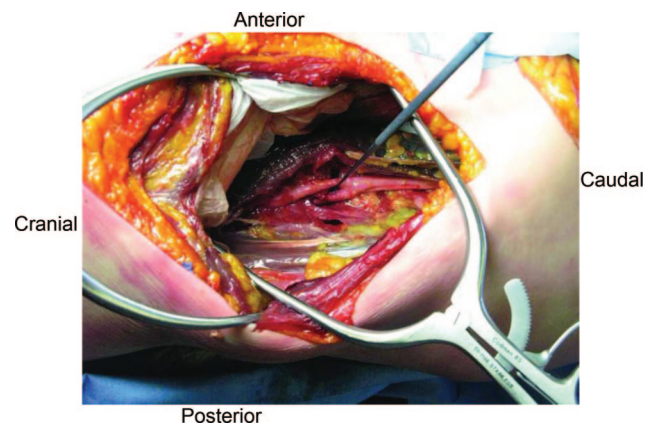


Figure 2. Cadaveric photograph of instrumentation splitting neural elements in the lumbar plexus.

crete-threshold results, in directional orientations provide the most useful information about the location of the main motor components of the lumbar plexus because they give you geographical information on the basis of presence and intensity of EMG response thresholds, not through binary measurement. By rotating the continuously firing electrode, information about the spatial orientation of the neural structures in reference to the dilator is obtained. For example, obtaining stimulation (low thresholds) of muscle groups during directional electromyographic stimulation both anteriorly and posteriorly should prompt the surgeon to change the dilator position to a more anterior one, so as not to split the neural elements (Figure 2). Whereas, if anteriorly you obtain high thresholds and posteriorly stimulation provokes muscle activity (low threshold), opening the retractor would retract the nerves posteriorly, which is favorable (Figure 3).

In addition, some nerves have mixed motor and sensory fibers, such as the femoral nerve, which carries the fibers of the anterior femoral cutaneous nerve. Neuro-monitoring using EMG will not directly assist in detection or localization of sensory nerves; however, based on the authors' experience, locating the femoral nerve will

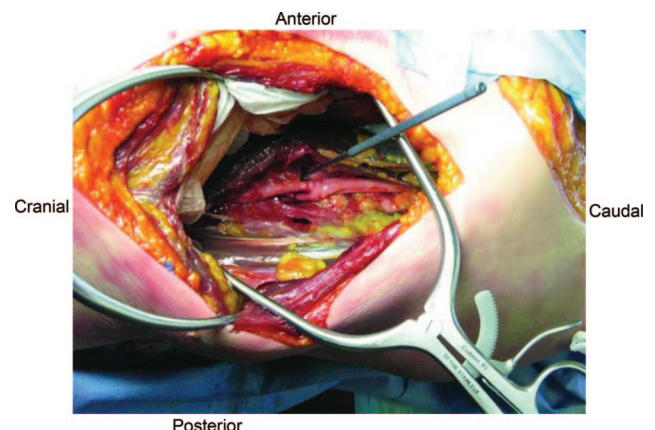


Figure 3. Cadaveric photograph of instrumentation anterior to the nerves of the lumbar plexus.

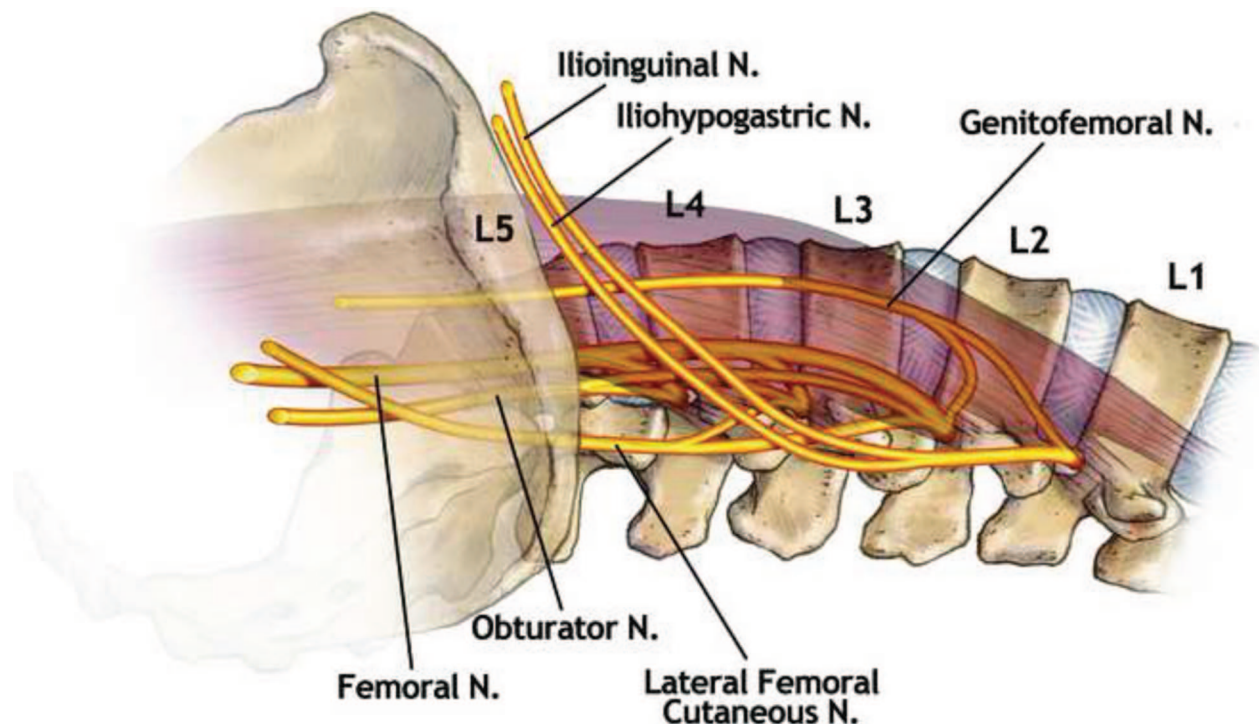


Figure 4. Illustration of the position of the nerves relevant to a lateral transpsoas approach.

indirectly indicate the location of the sensory fibers of the anterior femoral cutaneous nerve (Figure 4).

Conclusion

In minimally invasive approaches to the spine, the use of IOM may provide additional safety where visualization is limited compared with conventional open procedures. In some minimally invasive applications, such as percutaneous pedicle screw placement, the use of EMG IOM is well established. In addition to knowledge of the anatomy and image guidance, directional EMG IOM is crucial for safe passage through the psoas muscle. As the realm of minimally invasive spine surgery grows, the utility of IOM will increase.

Key Points

- Intraoperative neuromonitoring during minimally invasive spine surgery is used to increase the safety of the procedure.
- EMG has mainly been used for increasing the safety and accuracy of posterior pedicle screw placement.
- In addition to image guidance, patient positioning, and EMG IOM, a thorough knowledge of the regional anatomy of the lumbar plexus is required for safe passage through the psoas muscle during the minimally invasive lateral transpsoas approach.

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