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Dynamically evoked, discrete-threshold electromyography in the extreme lateral interbody fusion approach

Clinical article

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Object. Because the psoas muscle, which contains nerves of the lumbar plexus, is traversed during the extreme lateral interbody fusion (XLIF) approach, appropriate nerve monitoring is needed to avoid nerve injury during surgery and prevent approach-related neural deficit. This study was performed to assess the effectiveness of dynamically evoked electromyography (EMG) to detect and prevent neural injury during the XLIF approach.

Methods. One hundred two patients undergoing XLIF at L3–4 and/or L4–5 were enrolled in a prospective, multicenter, nonrandomized clinical study. The EMG threshold values for each of the 3 successive dilators were recorded at the surface of the psoas muscle, mid-psoas, and on the spine. At each location, the dilators were rotated 360°, taking recordings immediately posterior, superior, anterior, and inferior. For each dilator, the authors noted the rotational position (the angle in degrees) at which the lowest threshold was found. Findings of pre- and postoperative neurological examinations were also recorded.

Results. Nerves were identified within proximity of the dilators (alert-level EMG feedback) in 55.7% of all cases during the XLIF approach. Although nerves were more commonly identified in the posterior margin (63%), there was significant variability in the location of nerves identified. Despite the fact that the posterior half of the disc space was targeted in 90% of cases, no significant long-lasting neural deficits were identified in any case; 27.5% experienced new iliopsoas/hip flexion weakness and 17.6% experienced new postoperative upper medial thigh sensory loss. Transient motor deficits were identified in 3 patients (2.9%), and all had resolved by the 6-month follow-up visit.

Conclusions. The ability to identify and report a discrete, real-time EMG threshold during the transpsoas approach helps to avoid nerve injury and is required for the safe performance of the XLIF procedure. Additionally, nerve location is variable, thus reinforcing the need for real-time directional and proximity information.
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Key Words • **neuromonitoring** • **psoas muscle** • **nerve injury** • **lateral approach**

The lateral approach to interbody fusion procedures has been reported as a way to mitigate the risks of direct anterior approaches and the morbidity associated with posterior approaches. Initial reports of the lateral-approach technique described retracting the psoas muscle posteriorly, putting pressure on the nerves of the lumbar plexus within the psoas muscle.[4,14] In these reports, traversing the psoas required either significant dissection of the muscle or use of nontraditional surgical tools such as optical trocars to access the vertebral column. These methods have been associated with neural complication rates as high as 30%.[4] Recent anatomical studies have demonstrated the importance of careful passage through the psoas muscle to avoid injury to the lumbar plexus and exiting nerve roots.[3,15,18] This is of special concern at the L4–5 level because it has been shown that the plexus migrates ventrally relative to the lumbar disc spaces from L-2 to L-5.[3,15,18] Pimenta and others have described a transpsoas lateral approach that uses stimulated EMG to detect nerves in the path of the approach, thereby significantly mitigating the risk of neural injury.[17,19,24] The current study was undertaken to determine the utility of this EMG monitoring in detecting nerves during the XLIF approach through the psoas muscle.

Methods

Surgical Technique

In preparation for neuromonitoring of the XLIF procedure, surface electrodes were placed overlying the myotomes corresponding to the bilateral vastus media-

Abbreviations used in this paper: ALIF = anterior lumbar interbody fusion; EMG = electromyography; TLIF = transforaminal lumbar interbody fusion; XLIF = extreme lateral interbody fusion.

lis, tibialis anterior, biceps femoris, and medial gastrocnemius muscles, effectively covering responses from the L2–S2 spinal nerves. Reference and return electrodes were placed on the patient's upper thigh and near the surgical site, respectively. Patients were then secured in the lateral decubitus position directly over the table break. After draping, a twitch test using the NeuroVision System (NuVasive, Inc.) was performed to determine the level of muscle relaxants in effect, specific to the lower extremities. Specifically, a train-of-4 stimulation was delivered either within the surgical site or peripherally via an electrode at the popliteal fossa, with the resulting threshold recorded at the tibialis anterior muscle. A fourth twitch with at least 75% of the strength of the first was required to ensure accurate and quantifiable EMG readings.

In this technique, as previously described,[17,19,22,24] psoas dilation and retraction are accomplished with a series of 3 sequential dilators, inserted from a position lateral and orthogonal to the disc through the retroperitoneal space. The first dilator was introduced through a lateral incision with the index finger escorting the dilator to the psoas muscle. With the dilator on the surface of the psoas muscle, its location was verified with a lateral fluoroscopic image, with the ideal location at the center, or just posterior to the center, of the disc space. A stimulation clip was then attached to the dilator, and the NeuroVision System was activated in detection mode. The stimulus was applied to the dilator, which is insulated except for an isolated electrode at the distal tip. This tip electrode continuously emits the stimulus while the EMG recording electrodes are monitored for a muscle response. The closer the tip electrode is advanced toward a nerve, the greater the current density surrounding the nerve, and the lower the resulting EMG threshold (Peloza J: Validation of neurophysiological monitoring of posterolateral approach to the spine via discogram procedure. E-Poster presented at the International Meeting on Advanced Spinal Technologies, Montreux, Switzerland, May 2002). The EMG threshold is the number of milliamperes required to depolarize the nerve, causing it to fire and produce a muscle contraction. With this continuous and real-time feedback, the dilator can be advanced and/or repositioned through the psoas muscle to detect and/or avoid nerve contact.

Observations made from direct nerve stimulation during instrumentation procedures have shown that clinically normal nerves elicit an EMG response ranging from 1 to 5 mA, with an average of about 2 mA.[5,13] The EMG thresholds will decrease with proximity to the nerve, with thresholds of 5 mA or less therefore indicating possible direct contact with the nerve. With this information, a color-coded red "alert" is displayed on the system screen and a corresponding audible tone is produced. Experience with lateral-approach procedures has shown that thresholds greater than 10 mA provide a distance from nerves that allows adequate exposure of the disc. Therefore, thresholds between 5 and 10 mA are color-coded yellow or "caution," and those greater than 10 mA are color-coded green or "acceptable," each with their respective audible tones from the NeuroVision System (Fig. 1).

Two additional dilators were introduced over the initial dilator, and a retractor was then placed over the final dilator. This retractor was rigidly fixed in position with an articulating arm that was attached to the surgical table. The retractor system (MaXcess, NuVasive, Inc.) was then opened in such a way that exposure of the disc space was gained by expanding the aperture through the psoas muscle in a preferentially anterior direction. In this way, injury to the posteriorly situated lumbosacral plexus is minimized. The MaXcess retractor can also be stimulated through its posterior blade to record EMG results.

Study Design

This was a prospective, multicenter, institutional review board–approved clinical study in which 102 consecutive patients gave informed consent and were enrolled across 9 US centers (Appendix 1). Study investigators included 5 orthopedic surgeons and 4 neurosurgeons. All patients had indications for the XLIF procedure at level(s) L3–4 and/or L4–5.

The EMG threshold values for each of the 3 sequentially larger dilators described in the surgical technique were recorded at 3 depths: 1) the surface of the psoas, 2) mid-psoas, and 3) on the spine. At each location, the dilators were rotated 360°, and threshold recordings were obtained immediately posterior (0°), superior (90°), anterior (180°), and inferior (270°) (Fig. 2).

Additionally, the rotational position (the angle in degrees) of each dilator at which the lowest threshold was found was recorded. Free-run (spontaneous) EMG activity during the course of each case was also recorded and the incidence of dilator and/or retractor repositioning was documented. Fluoroscopic images taken of the dilator's approach to the disc space were collected for targeting analysis.

Preoperative and immediate postoperative neurological examinations using the American Spinal Injury Association (ASIA) classification scale grading motor strength from 0 to 5, sensation from 0 to 2, and reflexes from 0 to 5 were performed on all patients to quantify new neural deficits and were correlated with intraoperative EMG findings. This immediate postoperative examination concluded each patient's participation in the study unless a new deficit was identified. Patients with new deficits were followed up until their symptoms resolved or stabilized.

Results

From May 2008 through January 2009, 102 patients (62 women and 40 men) ranging in age from 21 to 88 years (mean 63 years) gave consent for participation in this prospective, multicenter study. A total of 132 levels were treated: 24 at L3–4, 48 at L4–5, and 30 at both L3–4 and L4–5. Surgery was indicated in the study patients after at least 6 months of conservative treatment for back pain (96%), leg pain (89%), weakness (42%), and numbness (42%) as a result of 1 or more of the following pathological conditions: stenosis with instability (in 67 patients), spondylolisthesis (52), degenerative disc disease (51), loss of disc height (40), spondylosis (25), scoliosis (16), recurrent disc herniation (9), adjacent segment degeneration (9), postlaminectomy instability (6), and loss of lordosis (5). The average duration of surgery was 70

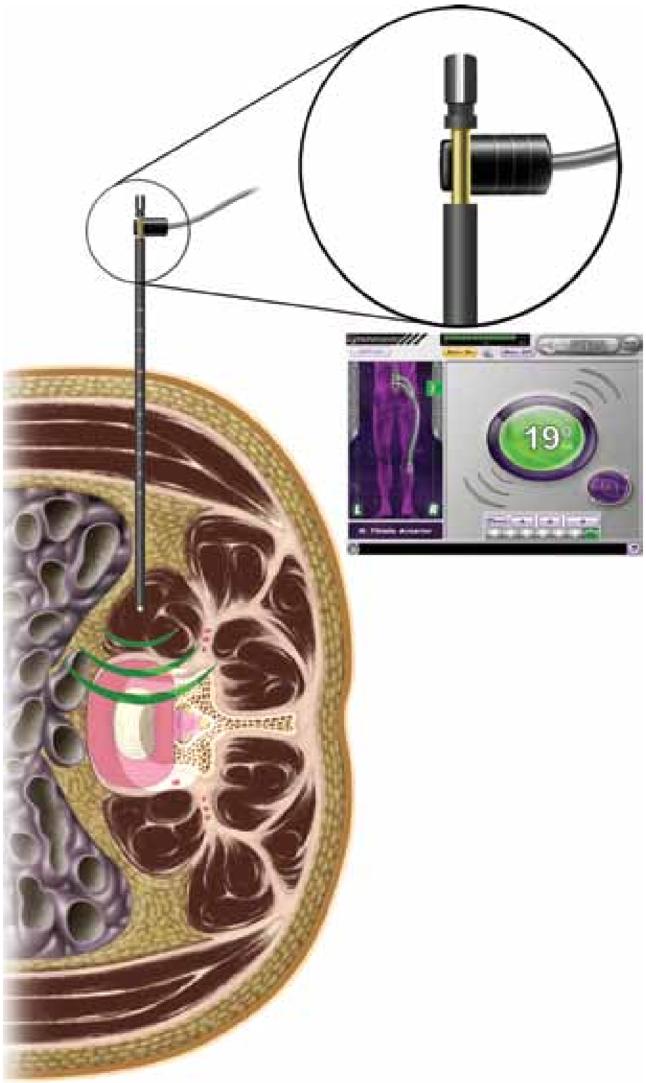

Fig. 1. The NeuroVision System's numerical and color-coded output as the psoas muscle is traversed.

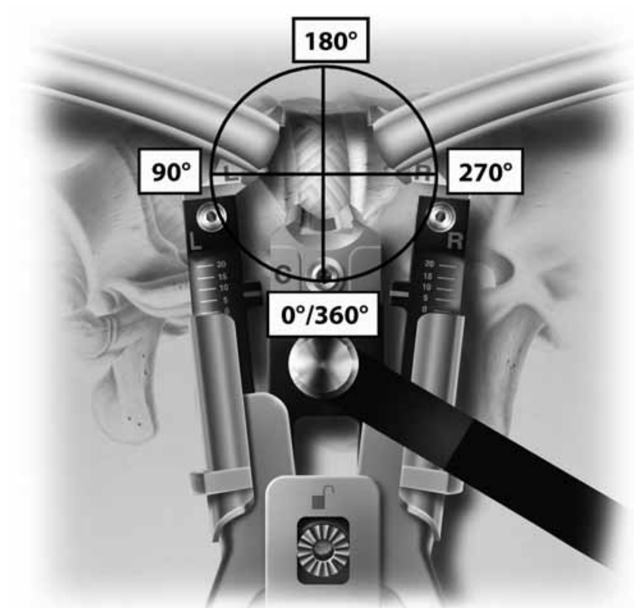

Fig. 2. Diagram illustrating how the rotational position of each dilator was determined.

minutes per level with a median follow-up period of 48 hours (ranging from 4 hours to 45 days). (These values for duration of follow-up do not include cases in which new deficits were observed.)

Nerve Detection/Identification

Alert-level EMG feedback was given (that is, a nerve was identified within the proximity of the dilators) in 53.9% of all cases—in 31.5% of approaches to the L3–4 level and in 53.8% of those to L4–5. The relative frequencies of the location of the lowest threshold found for all 3 dilators combined at each level are summarized in Fig. 3. Although nerves were identified more frequently in the posterior direction, there was significant variability in the location of the nerves identified.

The threshold values recorded as the initial dilator traversed the depth of the psoas muscle at L4–5 are summarized in Table 1. On average, EMG threshold values decreased from the surface to mid-psoas, with the lowest overall thresholds found posteriorly, as expected. Threshold values then increased slightly as the dilator reached the intervertebral disc space. This threshold trend was not observed at L3–4, where values steadily decreased as the dilator descended within the muscle.

The results of intraoperative fluoroscopy were analyzed to identify differences in disc space targeting and correlation with EMG values (Fig. 4). Four "zones" were used to quantify the approach and the results are summarized in Table 2. No disc space was targeted within "Zone 4."

No statistically significant difference was found between the zones (p = 0.4282, ANOVA), even when analyzed individually by level (that is, neither at L3–4 nor at L4–5). Additionally, there was no correlation between targeted zone and incidence of postoperative motor neural deficit.

Complications

Intraoperatively identified complications were few: 2 minor perforations of the peritoneum occurred in 102 patients (1.96%). Neither perforation required repair.

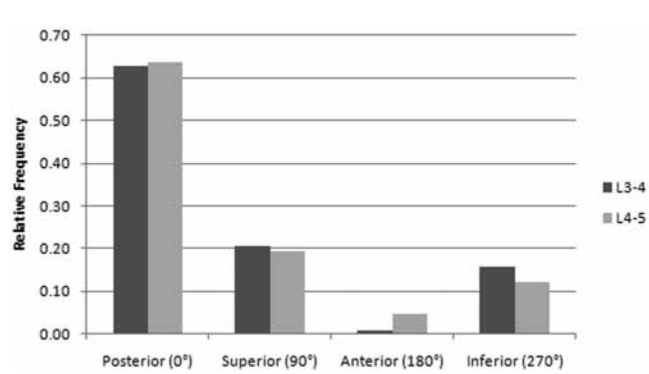

Fig. 3. The relative frequency of the location of the lowest threshold found for all 3 dilators combined at each operative level.

TABLE 1: Average EMG threshold values for the first dilator at 3 depths within the psoas muscle at the L4–5 level

	L4–5 Average Threshold Values (mA)		
Dilator Orientation	At Psoas Surface	Midpsoas	On Spine
posterior	20.5	14.9	15.7
superior	20.3	16.3	17.8
anterior	21.0	17.7	18.9
inferior	21.2	16.5	18.5

Postoperatively, 28 patients (27.5%) experienced new iliopsoas/hip flexion weakness, most commonly with a Medical Research Council grade of 4/5. Eighteen patients (17.6%) experienced new postoperative upper medial thigh sensory loss; most commonly with a grade of 1/2. Postoperative neurological examination identified new postoperative motor neural deficits in 3 patients (2.9%): 1 case of foot dorsiflexion weakness (Grade 4/5) and 2 cases of quadriceps/knee extension weakness (Grade 3/5 in 1 and Grade 4/5 in the other).

Thresholds Versus Complications

In the first of the 3 cases of new postoperative motor weaknesses, a single-level left-sided L4–5 procedure in a 71-year-old woman, with an operative time of 1 hour and 44 minutes, showed no alert-level thresholds in any direction relative to the dilators during the transpsoas approach, the lowest value being 14 mA in the posterior direction, deep to the psoas muscle. A ball-tipped probe was used to locate the nerve, which was confirmed in a position posterior to the retractor at 11 mA. Spontaneous or free-run EMG was noted on the left anterior tibialis myotome briefly during the removal of the implant trials (sizers). A left-sided deficit of the anterior tibialis (Grade 4/5) was noted at the 2-week postoperative visit and had resolved by the 6-month follow-up.

In the second case, a single-level left-sided L4–5 procedure in a 68-year-old man, with an operative time of 1 hour and 32 minutes, red alert-level thresholds were found during the transpsoas approach at 3 mA in the posterior direction relative to the initial dilator, found mid-psoas, increasing to 6 mA deep/flush with the spine. Yellow 10-mA recordings in the inferior direction (also mid-psoas) and green 11- and 13-mA recordings superior and anterior to the dilators, respectively, were noted. The second and third dilators confirmed the first, with 1-mA thresholds posteriorly, as did the ball-tipped probe, with 2.5 mA in the posterior margin of the exposure. The patient awoke with a left-sided deficit of the quadriceps muscle (Grade 3/5) that had resolved by the 6-month follow-up.

In the third case, a 2-level left-sided L3–5 procedure in a 67-year-old man, with an operative time of 5 hours and 19 minutes (operative time includes posterior fusion/instrumentation and TLIF at L5–S1), no alert-level thresholds were found in any direction relative to the dilators at either level during the transpsoas approach. All responses were recorded as > 30 mA, including the use of the ball-tipped probe, which is used to identify and locate the nearby nerve(s). Free-run EMG was noted on the left quadriceps myotome briefly during the impaction of the trial (sizer) and implant. A left-sided decrease in quadriceps strength (Grade 4/5) was noted immediately postoperatively, but had resolved by the 6-week follow-up.

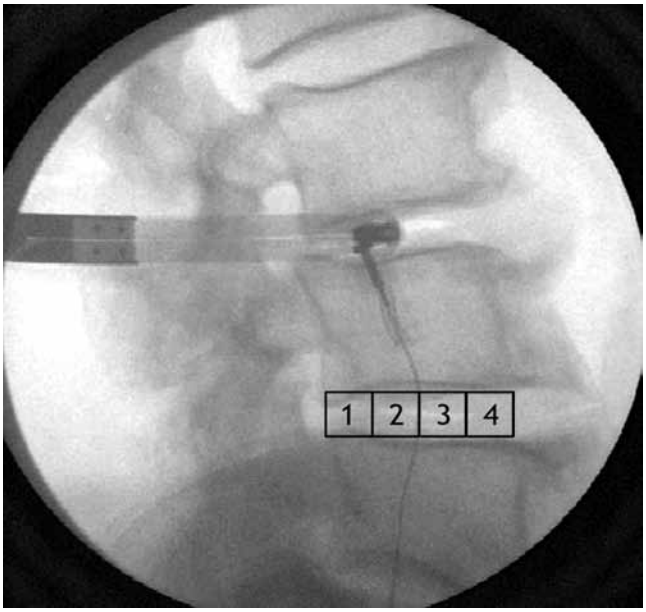

Fig. 4. Intraoperative fluoroscopic image with a diagram illustrating how the disc space was divided by quadrant, from posterior (Zone 1) to anterior (Zone 4).

Discussion

As a minimally invasive lateral approach to lumbar interbody fusion, XLIF offers many advantages over traditional techniques. It has been shown to result in less blood loss, lower complication rates, shorter hospital stays, and quicker recovery and return to daily activities.[17,23–25] By approaching the spine laterally, the risks associated with anterior and posterior approaches are reduced. Because the most concerning risk of a lateral approach is injury to the nerves of the lumbar plexus as the psoas muscle is traversed, it is imperative that reliable real-time nerve monitoring be used. The current study was performed to document the utility of a specifically designed intraoperative monitoring system for the lateral approach through the psoas muscle and the clinical safety of the procedure when it is used.

Several anatomical studies have provided better insight to the location of the lumbosacral plexus within the psoas muscle, specifically when considering a retroperitoneal or lateral approach to the lumbar spine. In their cadaveric study, Moro et al.[15] concluded that a safety zone exists within the psoas muscle at L4–5 and above and suggest that a more anterior approach to the intervertebral disc space be taken to prevent nerve injury. Most recently, Benglis et al.[3] found the lumbosacral plexus is most dorsally positioned at the posterior endplate of L1–2, and then makes a general trend of ventral migration relative to the disc space from L-2 to L-5. They concluded that posterior positioning of the dilator and/or retractor

TABLE 2: Frequency and mean lowest threshold for each of the 4 zones within the disc space*

Zone	Relative Frequency (%)	Mean Lowest Threshold (mA)
1	20.5	10
2	69.9	9.7
3	9.6	13.8
4	0	NA

* In 90.4% of cases, the target was in the posterior half of the disc space. Abbreviation: NA = not applicable.

may result in nerve injury, especially at L4–5. In the current study, the posterior half of the disc space was targeted in 90% of cases, and there were no significant or long-lasting transpsoas approach–related neural complications. This suggests that with appropriate neuromonitoring, safe navigation near these critical structures can be accomplished. Almost 56% of all cases in this study had some degree of alert-level feedback (≤ 10 mA) from the NeuroVision System. As supported by these anatomical reports, the lowest EMG threshold was most commonly identified posteriorly (63% of cases). However, in 37% of cases, neural structures were identified in other orientations, indicating a relatively high level of variability and supporting the need for dynamic, real-time neuromonitoring, which allows for the identification of the proximity and directionality of the neural structures and facilitates repositioning of the dilators as necessary.

In the current study, 27.5% of patients experienced iliopsoas/hip flexion weakness, most commonly with a grade of 4/5. This weakness was short-lived, and a temporary postoperative change expected and associated with trauma to the psoas muscle during the approach and not due to neural injury, given that the procedures were performed at the L3–4 and/or L4–5 levels and the nerves innervating the psoas muscle originate more cranially. The psoas weakness was transient in all 28 patients, typically resolving within approximately 2 weeks after surgery, consistent with normal recovery from muscle dissection. Similarly, all 18 patients who experienced new postoperative upper medial thigh sensory loss also had resolution of symptoms within approximately 2 weeks after surgery.

Three cases in this series resulted in motor neural deficit. In the first case, the NeuroVision System reported high, non–alert-level EMG threshold values during the transpsoas approach, as well as noted but unremarkable (isolated, unsustained) free-run EMG activity. The patient had a normal postoperative course in the hospital and normal results on neurological examination prior to discharge. At her first follow-up visit 2 weeks later, she was noted to have weakness in foot dorsiflexion (Grade 4/5). The patient had not noticed any weakness but the examining physician discovered the deficit during the neurological examination. At this time, radiographs showed implant subsidence at L4–5. The patient was never sufficiently symptomatic to justify further intervention, presenting only with mild weakness and no pain. It is difficult to determine whether the slight weakness was due to surgical events or the postoperative subsidence. Her postoperative course remained uneventful with complete resolution of the weakness at the 6-month follow-up.

The second case of new motor deficit involved a patient who presented with quadriceps/knee extension weakness (Grade 3/5) immediately after surgery. The procedure was a technically demanding revision of a nonunion after prior ALIF using bone dowels. Therefore, the more posterior operative corridor was purposefully used to allow for removal of the old grafts. The patient had undergone several previous surgeries at the L4–S1 levels with significant epidural/perineural scarring from previous laminectomies and instrumentation failure. The operating surgeon felt that the plexus lacked its usual mobility and was more resistant to retraction during the procedure. In this case, the NeuroVision System recorded values as low as 3 mA and alerted the surgeon to nerve proximity and its location dorsally. Although a deficit did occur, it proved to be transient, resolving by the 6-month follow-up visit.

The third patient presented with quadriceps/knee extension weakness (Grade 4/5) within 24 hours of surgery. Similar to the first case discussed, this case also experienced high, non–alert-level EMG threshold values reported during the transpsoas approach. It should be noted that significant free-run EMG activity was documented during trial (sizer) and implant impaction, which correlated to the left quadriceps myotome. The attending surgeon theorized that the free-run activity detected was due to concussive injury to the neural structures during the impaction. Because the patient also underwent L2–S1 pedicle screw instrumentation and an L5–S1 TLIF, compressive neuropraxia from the posterior procedures could also be a contributing factor toward this weakness. However, definite etiology cannot be determined. Symptoms were resolved at the 6-week follow-up.

Although it cannot be said for certain that these 3 deficits did not occur during the transpsoas approach, we believe that the NeuroVision System provided important and useful information during the initial approach in each of these, as well as the other 99 uneventful cases.

By way of comparison of complication rates, a larger single-center series reports the rate of motor deficit following XLIF to be less than 1%.[23,25] (Note that this report includes surgeries at the L-1 through L-5 levels, whereas the current study evaluated only L3–4 and L4–5 approaches.) Relative to other approaches, it should be noted that neither anterior nor posterior approaches are without risk of neural injury. Permanent motor deficits have been reported in 0.8%–3.6% of instrumented posterolateral fusions,[6–8,10] 0.4%–6.1% of posterior lumbar interbody fusions,[2,9,12,16] 4.1% of minimally invasive TLIFs,[27] 6.5% of endoscopic ALIFs,[4] 0.4% of open ALIFs,[26] and 0.5% of minimally invasive surgical decompressions.[20] The results of this study suggest that the rate of motor neural injury in fusion procedures from a lateral approach (2.9%) is comparable to that of an anterior approach and significantly less than that of a posterior approach.

Lateral-approach surgery has been performed without the use of specialized neuromonitoring, but this has been largely through an anterolateral exposure and retraction of the muscle posteriorly rather than traversing it.[3,14,21] These resulted in what the authors considered unacceptably high rates of neuropraxia due to compression injury of the nerves. Studies describing the transpsoas approach using variable monitoring feedback report rates of motor injury ranging from 3.4% to 8.3% and sensory deficits from 10.3% to 25%.[1,11] The NeuroVision System provides both proximity and directionality information to help avoid injury during the transpsoas approach. The low rates of complications reported to date[23,25] using the system support the results of this study and the utility of this form of EMG monitoring. However, it should be recognized that injury can occur after the exposure has been achieved, and there are recommended methods for using the discrete thresholding features of NeuroVision to detect injury throughout exposure of the disc.

Surgical Considerations

In contrast to posterior lumbar interbody fusion and TLIF procedures, in which the nerve roots are routinely visualized, XLIF does not provide direct visibility of the nerves; this should not give the operating surgeon a false sense of security. In the current study, EMG threshold values recorded at L4–5 indicated a slight decrease in threshold mid-psoas. This suggests that the nerves of the lumbar plexus are more commonly found mid-psoas at L4–5 rather than at the surface of the spine. Therefore, cautionary thresholds (< 10 mA) found mid-psoas may not be cause for immediate redirection. However, it is important to note that safely passing the nerve mid-psoas but then compressing it through muscle retraction during the procedure can also cause injury. In these situations where the operative corridor may be within the plexus, the directionality information provided by the NeuroVision System can help to identify the location of the nerve so that the operating surgeon can safeguard it from this type of injury.

The MaXcess retractor used in the XLIF procedure is designed to open from its locked dorsal blade forward, thereby minimizing posterior compression of the nerves behind the retractor blade. The posterior retractor blade contains an electrode, which can be used to periodically run an evoked-EMG test to quantify changes in threshold to those nerves in the posterior muscle throughout the surgery. An increase in stimulated threshold values can indicate an ongoing compression or ischemic injury, and retraction of the muscle should be released to allow for recovery. This may not be a significant consideration in short procedures but would be important in revision and deformity cases or particularly where nerves are visually detected and retracted. Evoked EMG is especially useful because spontaneous (free-run) EMG monitoring is relatively insensitive to sustained retraction of nerve roots. Future studies are needed to investigate the role of EMG monitoring during retraction.

Performing a check using evoked EMG with the NeuroVision probe before inserting the posterior shim is also recommended. If, by necessity, the MaXcess retractor cannot be repositioned after low EMG thresholds are identified, careful gentle dissection and protection of the nerve may be needed. Especially true at L4–5, this can be achieved with the use of laparoscopic dissectors (Kittners) and bayoneted Penfields along the visible course of the nerve while using the NeuroVision probe to help localize the nerve superiorly and inferiorly. The operating surgeon should always be acutely aware of the magnitude and duration of the retraction. These factors can be partially reduced by flexing the table only enough to expose the interbody space (especially at L4–5), positioning the MaXcess retractor just posterior enough to be able to perform the procedure, and returning the table to a flatter position as soon as the interbody device is inserted.

Study Limitations

This study is limited by the lack of long-term follow-up. However, this study was designed to provide educational information about the utility and reliability of intraoperative monitoring and was not meant to draw conclusions about long-term outcomes, including fusion rates.

Conclusions

Real-time neuromonitoring using the NeuroVision System does help minimize the risk of injury by providing reliable, real-time information about the proximity and directionality of the lumbosacral plexus during the transpsoas approach, as demonstrated by the 97% of cases where no neural injury occurred; this is despite the fact that 90% of the approaches targeted the posterior half of the disc space. Dynamic, discrete-threshold EMG is an integral and necessary part of the XLIF procedure.

Appendix 1

The following centers participated in this study: Indiana Center for Neurosurgery; University of California, San Francisco; Southern Oregon Orthopedics; Spine Midwest, Inc.; Georgetown University; University of California, San Diego; Northwest Orthopaedic Specialists, P.S.; West Augusta Spine Specialists; and Emory University.

Disclosure

Funding for this study was provided by NuVasive, Inc. All authors are consultants for NuVasive, Inc.

Author contributions to the study and manuscript preparation include the following. Acquisition of data: all authors. Analysis and interpretation of data: Tohmeh. Drafting the article: Rodgers. Critically revising the article: Tohmeh. Reviewed final version of the manuscript and approved it for submission: all authors.

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