eXtreme Lateral Interbody Fusion (XLIF®)

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Chapter 1 "Historical Background of Minimally Invasive Spine Surgery," by John J. Regan,
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Safety of XLIF® Afforded by Automated Neurophysiology Monitoring With NeuroVision®

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The innovative spinal surgery technique of extreme lateral interbody fusion, or XLIF, (NuVasive®, Inc., San Diego, CA) is a novel, minimally disruptive spine procedure that is directed laterally, or 90 degrees, off midline. The technique is described in more detail in Chapter 8. This chapter focuses on the safety of the procedure. XLIF provides the biomechanical benefit of preserving the anterior and posterior longitudinal ligaments. In addition, a large graft is placed, providing indirect decompression with excellent height restoration.[1-3] Historically, lateral approach surgery is not new[4-9]; however, a lateral approach surgery that is minimally invasive, safe, and reproducible in the hands of many surgeons *is* new. In a recent series by Bergey et al,[4] the authors reported positive results with a lateral approach, but with a significant complication rate. It is important to note that intraoperative neurophysiologic monitoring was not used during the transpsoas approach in that series.

The XLIF technique is unique in that the automated, surgeon-driven neurophysiologic guidance using the NeuroVision JJB System (NuVasive, Inc.) helps to ensure safety by avoiding neural injury. The safety and reproducibility of the XLIF procedure have been replicated in many centers.[1-3,10-13] The evolution of the surgical technique and experience has demonstrated that the following five cardinal principles are essential to making XLIF a safe, simple, and efficacious procedure:

1. Careful patient positioning
2. Gentle retroperitoneal dissection
3. Meticulous psoas traverse using NeuroVision
4. Complete disc removal, with release of the contralateral anulus and preparation of the fusion site
5. Appropriate-sized interbody implant placement

In this chapter, we discuss the third step—meticulous psoas traverse using NeuroVision, an automated neurophysiologic monitoring technology based on stimulated electromyography (EMG). Without reliable neurologic monitoring in real time, the lateral approach is fraught with risk.

Basic Neuroanatomy

Intraoperative neurophysiologic monitoring has been a part of spinal reconstruction surgeries since the early 1970s. Some of the earliest spinal cord monitoring in humans was done by Nash et al[14] during surgeries to treat patients with scoliosis and other spinal deformities. They monitored spinal cord function during spinal instrumentation procedures to minimize the chances of postoperative neurologic deficits. This early work evaluated only the sensory pathways by using somatosensory evoked potential (SSEP) monitoring. One clear drawback of this single-modality neurophysiologic monitoring was the likelihood of missing motor abnormalities during the procedure. The desire to monitor both the motor pathways in general and the nerve root–level characteristics led to the development of new neurophysiology monitoring modalities, such as stimulated EMG monitoring[15] and motor evoked potential (MEP) monitoring.[16-17]

TYPES OF INTRAOPERATIVE NEUROMONITORING

Fig. 9-1 presents the four main types of neuromonitoring—EMG, transcranial motor evoked potentials (TcMEPs), SSEPs, and dermatomal somatosensory evoked potentials (DSEPs). These are described as follows:

1. **EMG** assesses nerve root function by recording muscle activity during the surgical procedure. The general process involves locating the specific muscles or myotomes related to the root entry levels involved in the surgical procedure. Recording elicited myotome responses allows real-time assessment of nerve root irritation caused by electrical stimulation or triggered electromyography (trEMG), or mechanical irritation caused by spontaneous, free-run electromyography (SFrEMG). For trEMG, the amount of current required to depolarize the nerve root and elicit the peripherally innervated muscle to contract is recorded. Studies have indicated that direct, triggered stimulation of a healthy nerve root elicits a muscular response at approximately 2 mA.[18,19] One hallmark of trEMG is the ability to track a motor pathway to ensure continuous conduction, thus providing information concerning the integrity of the pathway.
2. **TcMEPs** generally allow tracking of the motor pathways along the anterior columns of the spinal cord to the peripheral muscles as a result of electrical or magnetic stimulation over the motor cortex. Magnetic stimulation is used under certain circumstances in the clinical laboratory, and electrical stimulation is generally used in the surgical environment. Responses can be recorded from the same muscle groupings as those in conjunction with trEMG or SFrEMG.

3. **SSEPs** are recorded from afferent fibers and long tract, dorsal column pathways. The earliest reported cases of surgical monitoring involved SSEPs.[14] Studies of this pathway have been widely reported. However, SSEP monitoring offers no information concerning individual nerve root function, and SSEP data are not a real-time measurement, because there is a delay while the response is averaged.[20]
4. **DSEPs** are methodologically identical to the previously discussed SSEPs, except that the stimulation site, rather than being a peripheral nerve, is a peripheral dermatomal patch on an extremity or other part of the body.[20] The information obtained is a sensory indication of conduction characteristics related to specific dermatomal regions rather than to large mixed nerves, as in SSEP recordings. Although a broad cross section of literature is available on SSEPs, this is not true for dermatomal responses. Generally speaking, dermatomal responses are smaller in amplitude and somewhat more difficult to obtain, particularly in patients who are obese or edematous.

The most appropriate type of monitoring for the XLIF procedure is stimulated EMG monitoring, which provides neurophysiologic information concerning the nerve roots and plexus during the transpsoas approach to the anterolateral lumbar disc.

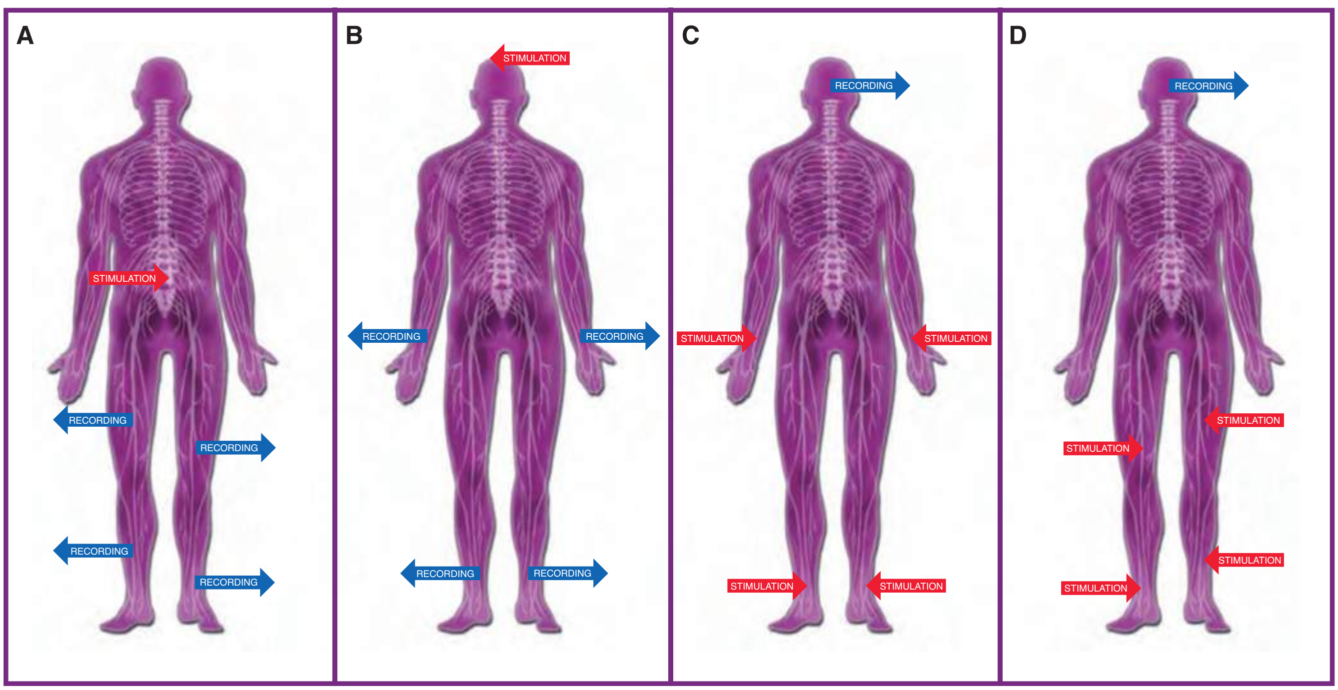


FIG. 9-1 Stimulation and recording for four types of monitoring. **A,** EMG. **B,** TcMEPs. **C,** SSEPs. **D,** DSEPs.

Anatomic Considerations

The use of neurophysiologic guidance is particularly important when traversing the psoas muscle to avoid injury to the lumbar plexus and exiting nerve roots. Moro et al[21] conducted an anatomic study to assess the relationship between the position of the lumbar plexus and nerve roots relative to the lumbar vertebral body and the relationship between the genitofemoral nerve and the psoas muscle. In their study, 30 cadavers were examined. Six lumbar spine specimens were analyzed by sectioning the spine from L1 to the sacrum; the positions where the genitofemoral nerve emerged on the abdominal surface of the psoas major muscle were analyzed using the remaining 24 cadavers. Cuts were made parallel to the lumbar disc and then at the cranial third and caudal third of the vertebral body. Analyzing the relationship between the lumbar plexus and nerves involved defining the transverse section view in terms of six zones: zone A was anterior to the anterior margin of the vertebral body, and zone P was posterior to the posterior margin of the vertebral body. The area between the anterior and posterior borders of the vertebral body was divided into four zones: zone 1 was the anteriormost part, and zone 4 was the posteriormost part. For level L2-3 and above, all parts of the lumbar plexus and the nerves were located in the posterior fourth of the vertebral body or more dorsally. For L3-4 and L4-5, the lumbar plexus and the nerves were located in the posterior half of the vertebral body or more dorsally. The genitofemoral nerve was found to descend obliquely forward through the psoas muscle, emerging to its surface between L3 and L4. This anatomic study clearly demonstrates the importance of using neurophysiologic guidance to avoid motor injury when performing a transpsoas approach.

Bergey et al[4] reported on their clinical series, in which they used a lateral approach without neurophysiologic assessment. They reported a 30% complication rate associated with the approach. In contrast, several large reports[10-13] have shown that the XLIF technique is extremely safe when NeuroVision is used to guide the surgeon through a safe path in the psoas muscle.

Safety Provided by Automated Neurophysiology

The NeuroVision JJB System provides validated EMG information. In a recent study, Youssef and Salas[22] directly compared the automated NeuroVision system with a conventional system (Axon Epoch XP, Axon Systems, Inc., Hauppauge, NY) for testing pedicle screws. Clinical and numeric agreement between the two systems was high, and the authors commented that the key differentiating feature between the two systems was the manner in which the information was presented to the surgeon, with the automated system providing direct feedback to the surgeon. They concluded: "EMG testing has been shown in other studies to be a useful tool to help identify misplaced pedicle screws. Automated EMG systems may widen the availability of this technology."[22]

In addition, the NeuroVision JJB System provides capabilities that conventional neurophysiologic assessment does not, including a dynamic Detection mode to provide real-time information concerning proximity to nerves. The NeuroVision system uses a patented hunting algorithm that provides 5 pulses per second of increasing amplitude current until the appropriate myotome has responded (Fig. 9-2). Once the maximum current level to elicit a response is achieved, the current output is maintained at that level. The Detection mode uses evoked EMG to test the proximity of neural structures to prevent postoperative radicular irritation or injury from surgical instruments and implanted instrumentation. Obser-

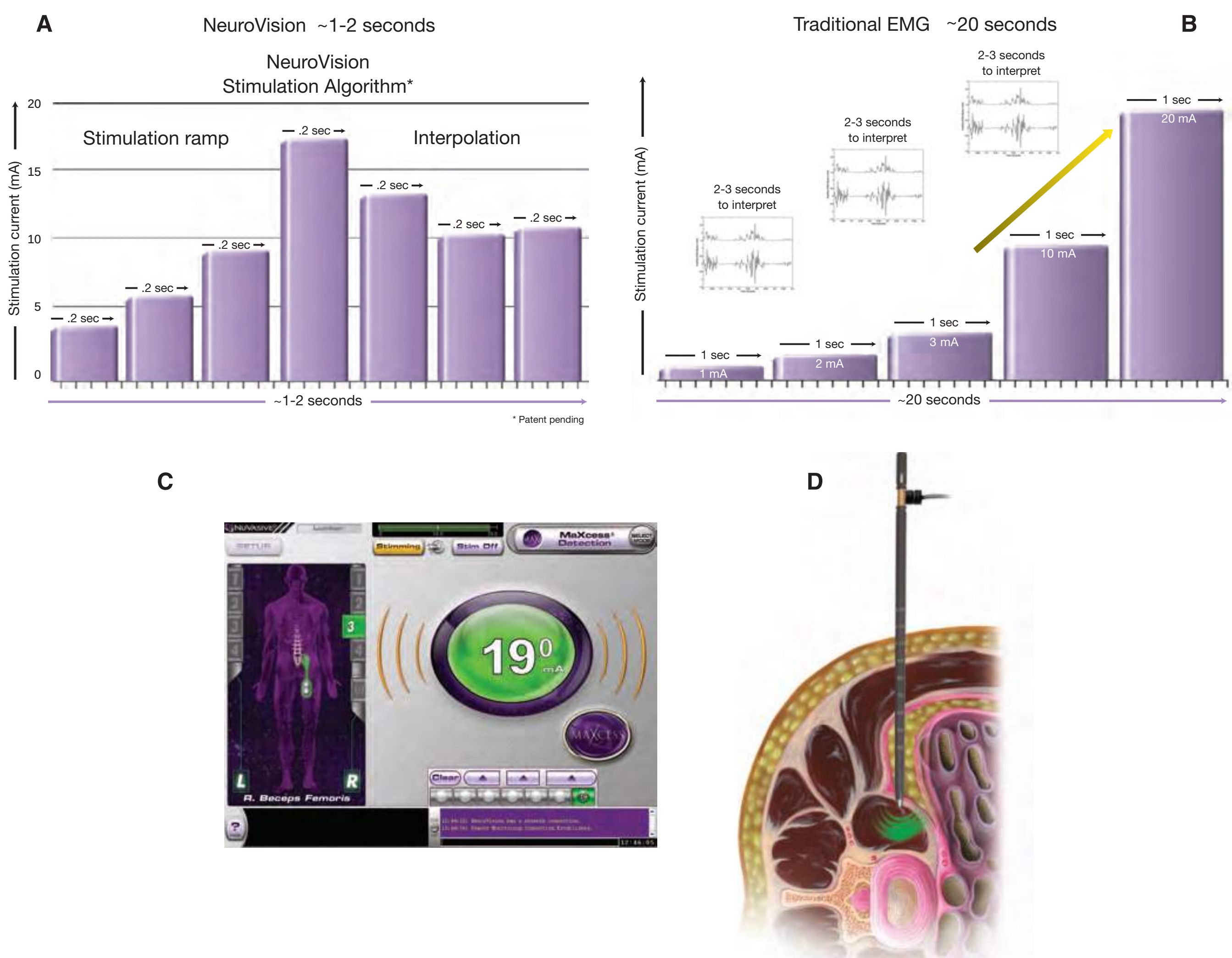


FIG. 9-2 **A** and **B,** Comparison of the NeuroVision hunting algorithm with traditional EMG monitoring. The NeuroVision system applies stimulation in a nonlinear fashion to quickly (1 to 2 seconds) determine the EMG threshold for nerve roots in proximity of the surgical instrument. Automation of this process allows real-time results to be delivered directly to the surgeon precisely when needed. **C** and **D,** XLIF Nerve Detection. NeuroVision provides directional nerve proximity information, true trajectory of the nerve with directed stimulation values, and safe and reproducible passage through the psoas muscle.

NUMERIC READING	COLOR CORRESPONDENCE	INTERPRETATION
11 mA or Greater	GREEN 	Acceptable
5-10 mA	YELLOW 	Caution
Less than 5 mA	RED 	Alert

FIG. 9-3 Interpretation of color-coded results for NeuroVision's Detection mode, which is essential for safe and reproducible passage through the psoas muscle.

vations made from direct nerve stimulation during instrumentation procedures indicate that clinically normal nerves elicit an EMG response under an applied stimulus ranging from 1 to 5 mA, with an average of approximately 2 mA.[18,19] Therefore the closer the proximity of the nerve, the closer the threshold is to 2 mA. Experience with lateral approach procedures has shown that thresholds are divided into the following three groupings (Fig. 9-3):

1. Acceptable (green) thresholds are those greater than 10 mA.
2. Caution (yellow) thresholds are those between 5 and 10 mA.
3. Alert (red) thresholds are those less than 5 mA.

In the Detection mode of the NeuroVision JJB System, the stimulus is applied with the Dynamic Stimulation Clip to the MaXcess® Dilators (NuVasive, Inc.). The Dilators are insulated, except for a triangular-shaped electrode at the distal tip. This tip continuously emits the stimulus while the EMG electrodes are monitored for a myotome response. Insulating the Dilators is important to concentrate the electrical current at the desired location. The closer that tip electrode is to a nerve, the lower the resulting EMG threshold will be. Also, by judiciously rotating the tip of the exposed electrode portion in different directions, the surgeon can determine the general anatomic relationship between the Dilator and the adjacent nerves. With this feedback, the Dilator can be advanced and/or repositioned to avoid nerve contact and to determine proximity.

The NeuroVision JJB System displays the stimulus responses on a color-coded, numeric, graphical user interface, or GUI. The responses are accompanied by an audio feature where-

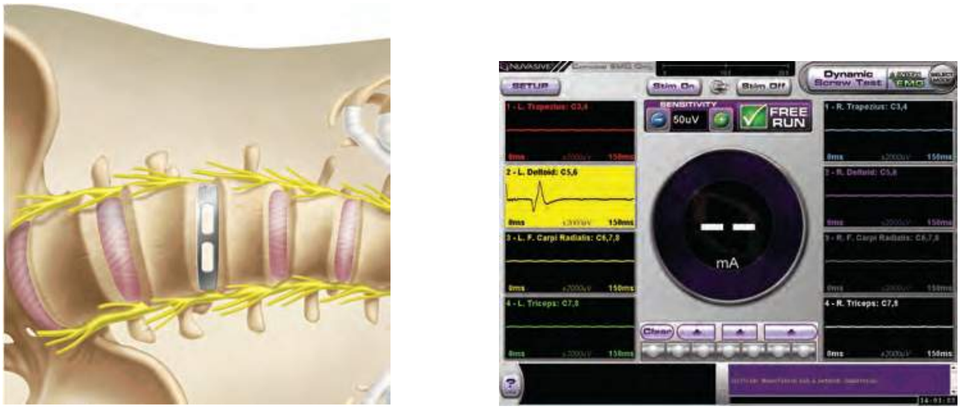


FIG. 9-4 Free-run EMG. Continuous monitoring of multiple spinal nerves warns the surgeon of neurologic insult from mechanical stimuli, such as when the disc space is distracted. NeuroVision provides both visual and audio alerts to free-run activity.

by changes in tone indicate the change in color coding, allowing the surgeon the freedom to focus on the surgical site instead of the screen (see Fig. 9-3). This feature provides near instantaneous feedback in real time and allows neural protection.

In addition to the safety provided by the electrophysiologic monitoring while in the Detection mode, the NeuroVision JJB System can be set to display free-run events, which are typically associated with mechanical stimulation of the cauda equina or exiting nerve roots.[20] Free-run monitoring is especially helpful while restoring disc height, because of the neural stretch that is inherent with height restoration (Fig. 9-4).

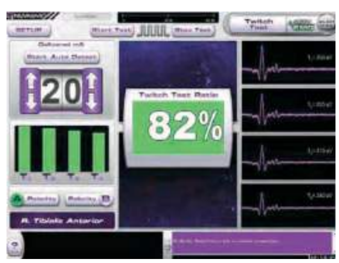
Meticulous Psoas Traverse Using NeuroVision

It is impossible to overemphasize the importance of reliable, timely monitoring of the neural elements while the surgeon traverses the psoas. Visual identification of the lumbar plexus is challenging, even with an extensive surgical exposure, and is essentially impossible in any minimally disruptive procedure. Thus it is essential that the plexus be protected by using an automated electrophysiology technology. The NeuroVision System, in Detection mode, provides information concerning the direction of the neural structures, because the stimulating electrode can be oriented to direct the current. By rotating the electrode 360 degrees, different current values corresponding to the recording myotome are displayed, providing information about the spatial orientation of the neural structures. Once the maximum current level required to elicit a response is achieved, the current output stabilizes.

Anesthesia Requirements

Effective and accurate intraoperative neurophysiologic monitoring requires careful collaboration with the anesthesia personnel. The wide varieties of available anesthetic agents have differing effects on the neuromonitoring modalities. In general, if EMG monitoring is used, all muscle relaxants must be cleared from the patient's system before traversing the psoas muscle. One of the best ways to evaluate the muscle relaxant clearance is the so-called Twitch Test, which is more accurately known as the "train of four" neuromuscular junction transmission testing (Fig. 9-5). This test is used to assess the residual effect of paralytic agents used during intubation by electrically stimulating the temporalis muscle. If such stimulation evokes four muscle twitches in response, the paralytic agents have been cleared from the patient's system and it is safe to proceed.

It is acceptable to use small quantities of rapidly cleared relaxants during intubation, but it is imperative that the patient be tested to ensure that the "train of four" twitches have returned before proceeding. In our experience, psoas traversal begins less than 1 minute after the skin incision is made, thus it is our practice to ask the anesthesia provider to confirm the return of twitches before we incise the skin. No further muscle relaxants are permitted. It is important to emphasize this rule with each anesthesia provider during an XLIF procedure. In addition, TcMEP has been used for XLIF in the thoracic region, and it is important to note that testing for relaxants in the upper body may not be indicative of their effect in the lower limbs.



COLOR	RESULT	COMMENT
RED	0%-30%	Little or no muscle response
YELLOW	30%-75%	Marginal muscle response
GREEN	75%-100%	Good muscle response

FIG. 9-5 NeuroVision Twitch Test (also known as the "train of four") provides real-time information about the patient's muscle relaxants with out reliance on anesthesia.

Experience With NeuroVision

Since the NeuroVision JJB System was introduced to spine surgeons in 2002, this automated, neurophysiology technology has been used in over 70,000 spine surgery procedures. The applications range from pedicle screw testing to the dynamic monitoring of pedicle screw pilot holes, spinal cord monitoring using TcMEP, and the dynamic monitoring of the transpsoas approach during XLIF.

The records of 903 XLIF surgeries were reviewed to determine how often nerve identification occurred during the lateral approach through the psoas muscle (these records, obtained from cases performed between January and June 2007, contained no patient or other case-related information). The number of times an EMG threshold value fell within an "Alert" range category was documented. The time during which NeuroVision Nerve Detection dynamic-evoked EMG was active was also documented. From these numbers, the frequency of positive nerve proximity feedback was determined (Table 9-1).

Of the 903 cases evaluated, positive nerve proximity (that is, a myotome response was found at a value below the maximum stimulus intensity, usually set at a default of 20 mA) was identified in 758/903 (84%). "Acceptable" responses (green) occurred in 80% of all cases, 60% of all cases had "Caution" responses (yellow), and "Alert" responses (red) were detected in 50% of all cases.

TABLE 9-1 Intraoperative Data from 903 XLIF Surgeries Using the NeuroVision JJB System Monitoring

	Alert Range Category			
	Red	**Yellow**	**Green**	**Any**
	Alert 0.5 to 4.5 mA	Caution 5 to 10 mA	Acceptable 11 to 20 mA	
Percentage of all cases with nerves detected	49.8%	60.2%	80.4%	83.9%
Average number of detections per surgery	2.76	5.26	17.26	25.28
Average number of detections per hour of monitoring	4.57	6.90	21.60	33.06

SIGNIFICANCE OF FINDINGS

The XLIF approach offers the surgeon a safe pathway through the psoas muscle, because it is performed anterior to the nerves that tend to lie in the posterior third of the muscle.[21] However, it is clear from the values reported in Table 9-1 that nerve proximity during the approach is not only variable—and detectable—in the vast majority of cases (84%), but has been detected at values that should cause at least caution in more than half of the cases (60%). “Caution” responses (yellow) should encourage careful examination during the approach. It is generally recommended, however, that the path of the approach through the psoas muscle be redirected if the responses fall within the “Alert” (red) range, based on the direct nerve-stimulation values of 1 to 5 mA reported in the literature.[19,21,22] The findings from the data presented in Table 9-1 imply that pathway redirection may be necessary in as many as 50% of cases to avoid nerve injury. The low incidence of neural complications attributable to the monitored XLIF approach underscores the safety that NeuroVision Nerve Detection brings to this procedure. It is the only system that can provide real-time neurophysiologic information.

CONCLUSION

The utility of XLIF for multiple indications is becoming increasingly recognized. However, the safety of minimally invasive lateral spine surgery remains a point of discussion. It is incumbent on surgeons to ensure that the procedure is performed proficiently and with a minimal level of risk of neural or visceral injury. By following the five cardinal principles, safe and successful completion of the procedure is ensured. Of the five principles, the reliance on real-time neurologic monitoring has most often been neglected in previously reported series. It is not surprising that blind passage through the psoas results in neural injury. In our own series of more than 250 XLIF procedures using NeuroVision guidance, we have noted only two transient neurapraxias (0.7%).[11] Similar results are seen in other series using NeuroVision monitoring.[1,10,12,13] XLIF is a safe technique when it is carried out properly. NeuroVision neurophysiologic monitoring is a required part of the procedure.

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