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Review Article

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Intraoperative Neuromonitoring During Lateral Lumbar Interbody Fusion

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Objective: To review the evidence for the use of electromyography (EMG), motor-evoked potentials (MEPs), and somatosensory-evoked potentials (SSEPs) intraoperative neuromonitoring (IONM) strategies during lateral lumbar interbody fusion (LLIF), as well as discuss the limitations associated with each technique.
Methods: A comprehensive review of the literature and compilation of findings relating to clinical studies investigating the efficacy of EMG, MEP, SSEP, or combined IONM strategies during LLIF.
Results: The evidence for the use of EMG is mixed with some studies demonstrating the efficacy of EMG in preventing postoperative neurologic injuries and other studies demonstrating a high rate of postoperative neurologic deficits with EMG monitoring. Multimodal IONM strategies utilizing MEPs or saphenous SSEPs to monitor the lumbar plexus may be promising strategies based on results from a limited number of studies.
Conclusion: The use of traditional EMG during LLIF remains without consensus. There is a growing body of evidence utilizing multimodal IONM with MEPs or saphenous SSEPs demonstrating a possible decrease in postoperative neurologic injuries after LLIF. Future prospective studies, with clear definitions of neurologic injury, that evaluate different multimodal IONM strategies are needed to better assess the efficacy of IONM during LLIF.

Keywords: Lateral lumbar interbody fusion, Intraoperative neuromonitoring, Electromyography, Somatosensory, Motor-evoked potentials

INTRODUCTION

Lateral lumbar interbody fusion (LLIF) is a minimally invasive technique that can improve patient-reported outcomes, while possibly reducing the risks associated with anterior, oblique-lateral, or posterior interbody approaches to the spinal column.[1,2] Compared to posterior approaches, LLIF allows for preservation of the posterior ligamentous complex and indirect decompression of spinal stenosis.[3] Additionally, a larger cage can be placed which may allow for greater improvement in sagittal alignment and foraminal height, and a more favorable biomechanical environment for arthrodesis.[4,5] When compared to anterior or oblique-lateral interbody techniques, the LLIF may be associated with a lower risk of vascular injury as the working corridor is further away from the major abdominal vessels.

Despite these advantages, LLIF is associated with a unique set of complications secondary to traversing the psoas muscle with dilators and retractors, which is avoided in anterior and oblique-lateral approaches. This transpsoas approach can result in a high incidence of nerve complications due to direct injury or prolonged retraction of the lumbar plexus. Some studies have reported motor weakness in up to 33.6% of patients and sensory complications in up to 75% of patients postoperatively after LLIF.[6-10] Although the majority of nerve injuries during LLIF result in transient postoperative symptoms, permanent motor and sensory deficits from femoral nerve injury are a significantly feared complication which can result in marked morbidity for patients.[10-13]

Possible reasons for the high incidence of reported neurologic complications in some studies include less direct anatomical visualization compared to traditional anterior or posterior approaches to the lumbar interbody space, anatomic variability of the lumbar plexus, and transitional lumbosacral anatomy. In most patients, the lumbar plexus includes the T12–L4 nerves which exit posteriorly in the foramen and migrate ventrally and caudally relative to the lumbar disc spaces. Multiple prior studies have demonstrated that, at the upper lumbar levels, the lumbar plexus nerves are typically posterior to the surgical approach resulting in a relatively large safe zone for LLIF,[14-18] but this safe zone becomes progressively smaller at more caudal lumbar levels and, at L4–5, the safe zone may be less than 50% the width of the disc, significantly increasing the risk for nerve injury.[14,17]

Given the required traversing of the lumbar plexus during LLIF, the approach has traditionally been marketed to require intraoperative neuromonitoring (IONM) to potentially minimize the risk of neurologic injury caused by direct interaction with the lumbar plexus or indirect injury secondary to stretching or compression. To date, several studies have investigated the use of electromyography (EMG), motor-evoked potentials (MEPs), and somatosensory-evoked potentials (SSEPs) as well as multimodal IONM techniques. In this paper, we will review the evidence for the use of each IONM modality as well as discuss the limitations associated with each technique.

METHODOLOGY

The study design included a review of MEDLINE and PubMed databases for human clinical studies restricted to the English language published between 2010 and 2020; the search terms included “lateral lumbar interbody fusion neuromonitoring,” “lateral lumbar interbody fusion electromyography,” “lateral lumbar interbody fusion motor evoked potentials,” and “lateral lumbar interbody fusion somatosensory evoked potentials.” We included all studies assessing the efficacy of EMG, MEP, or SSEP IONM during LLIF. The references cited in the articles that met inclusion criteria after screening were reviewed to identify potential studies not captured by the initial database queries. We did not include studies assessing neuromonitoring in anterior, oblique, transforaminal, or posterior lumbar interbody fusion techniques. We did not exclude studies based on small sample

Table 1. Clinical studies evaluating EMG utilization during LLIF

Study	Sample size; treatment; study design	Key findings—benefits of EMG	Key findings—limitations of EMG
Tohmeh et al.[19] (2011)	102 Patients; LLIF at L3–4 and/or L4–5; Prospective, multicentered	No significant long-lasting neurological deficits in any patients with dynamic, discrete-threshold EMG; 3 new postoperative motor neural deficits that all resolved by 6-month follow-up.	
Uribe et al.[20] (2015)	323 Patients; LLIF at L4–5; Prospective, multicentered	Positive relationship between change in triggered EMG thresholds and postoperative symptomatic neuropraxia.	Triggered EMG specificity to detect nerve injury was low but increased with longer retractor time. Monitoring of triggered EMG motor nerves does not predict sensory function outcomes.
Bendersky et al.[21] (2015)	107 Patients; LLIF at any level; Prospective, single-centered	No postoperative motor deficits seen with free-run EMG.	Transient anterior thigh sensory symptoms in 17.75% of patients, all of which resolved by 3-month follow-up.
Sofianos et al.[10] (2012)	45 Patients; LLIF at any level; Retrospective case series	-	40% Rate of complications in the setting of normal dynamic, discrete-evoked EMG readings.
Cahill et al.[11] (2012)	118 Patients; minimally invasive LLIF at any level; Retrospective review	No femoral nerve injuries at any disc level except at L4–5.	4.8% Rate of femoral nerve injuries performed at L4–5 level with continuous EMG monitoring
Cummock et al.[29] (2011)	59 Patients; minimally invasive LLIF at any level; Retrospective review of prospectively collected data	-	62.7% Rate of thigh symptoms with continuous EMG monitoring, 90% of which resolved by 1 year following surgery.

EMG, electromyography; LLIF, lateral lumbar interbody fusion.

size or short duration of follow-up as the literature on neuromonitoring during LLIF is sparse and the purpose of this paper was to summarize the available evidence regarding IONM during LLIF, as opposed to focused systematic review.

In this literature review, we summarize the key findings from the included studies evaluating EMG, MEP, and saphenous SSEP use during LLIF. The study design, patient numbers, and key findings for studies included in the literature review are also presented in Tables 1-3.

ELECTROMYOGRAPHY

EMG is commonly used during LLIF in part due to historical precedent, but also because EMG has been the most researched IONM modality during LLIF (Table 1).[1] Free-run EMG allows for monitoring muscle activity throughout the entire LLIF procedure, and mechanical stimulation of a lumbar nerve root or the lumbar plexus can result in repetitive EMG discharges, signaling potential nerve injury. Triggered EMG in specific directions within the psoas muscle provides data on the direction and, possibly, the proximity of the lumbar plexus with respect to the dilation probes or retractor blades used during LLIF.

Tohmeh et al.[19] conducted one of the first studies validating the use of free-run and triggered EMG during LLIF in a prospective, multicenter study enrolling 102 patients. Across the 102 patients, no significant long-last neural deficits were identified and all transient deficits had resolved by the 6-month follow-up visit.[19] In a similar study, Uribe et al.[20] conducted a prospective, multicenter EMG validation study in 323 patients undergoing LLIF at L4–5. In this study, they assessed the efficacy

Table 2. Clinical studies evaluating MEP utilization during LLIF

Study	Sample Size, treatment, study design	Key findings—benefits of MEP	Key findings—limitations of MEP
Riley et al.[33] (2018)	479 Patients; LLIF with or without posterior decompression and fusion at any level; Retrospective review	Patients who received additional transcranial electric MEP (tcMEP) monitoring had a lower rate of postoperative neurologic deficits compared to patients receiving EMG monitoring only. tcMEP monitoring was associated with decreases in both sensory and motor deficits; tcMEP has potential to monitor sensory function indirectly via monitoring of mixed sensory-motor nerves.	-
Berends et al.[34] (2016)	23 Patients; LLIF at various levels from L1–4; Prospective, single-centered	In 9% of patients, MEP amplitude decreased due to psoas retractor deployment, without a corresponding change in EMG signals.	-
Chaudhary et al.[35] (2015)	3 Patients; LLIF at L4–5; Case series	Intraoperative MEP changes detected without corresponding abnormal EMG activity.	-
Houten et al.[25] (2011)	2 Patients; LLIF at L3–5; Case series	-	Postoperative motor deficits not detected by either EMG or MEP. Motor potentials may vary depending on depth and choice of anesthetic agents.

MEP, motor-evoked potential; EMG, electromyography; LLIF, lateral lumbar interbody fusion.

Table 3. Clinical studies evaluating saphenous SSEP utilization during LLIF

Study	Sample size, treatment, study design	Key findings—benefits of saphenous SSEPs	Key findings—limitations of saphenous SSEPs
Silverstein et al.[30] (2014)	41 Patients; LLIF at any level; Retrospective case series	In 5 patients, SSEP changes were noted after retractor expansion, without associated EMG changes; 3 of these patients had postoperative femoral nerve deficits. No false-negative SSEP alerts.	Signals may be affected by anesthetic agents, body habitus, depth of saphenous nerve, and medical comorbidities.
Jain et al.[37] (2020)	62 Patients; LLIF at any level; Retrospective review	Saphenous SSEPs demonstrated 52%–100% sensitivity and 90%–100% specificity in detecting postoperative femoral nerve complications.	Saphenous SSEP could not be reliably established in 16% of patients.

SSEP, somatosensory-evoked potential; LLIF, lateral lumbar interbody fusion; EMG, electromyography.

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of triggered EMG thresholds in response to posterior retractor blade stimulation and EMG values collected every 5 minutes throughout retraction.[20] The authors found a positive relationship between the change in triggered EMG thresholds and postoperative symptomatic neuropraxia; however, triggered EMG specificity to detect nerve injury was low but increased with longer retractor time.[20] In a third study, Bendersky et al.[21] used a free-run EMG protocol specifically designed to monitor every branch of the lumbar plexus and reported zero motor deficits postoperatively. Additional studies have found the efficacy of integrating EMG into stimulation probes or finger electrodes in preventing or decreasing postoperative nerve deficits after LLIF.[22,23]

Although several studies have demonstrated the efficacy of EMG use during LLIF, there are several limitations. First, EMG has low specificity due to both false-positive and false-negative readings which can be misleading, particularly when using triggered EMG for anatomical mapping of the lumbar plexus. Additionally, EMG is not a test of neural integrity, it may not detect compression, stretch, or focal ischemia resulting in nerve injury. EMG may also be unreliable at estimating a distance from a nerve as higher values may not always correspond to a safe zone, and it cannot reliably monitor sensory-specific nerves.[6,24-28] Given these limitations, several studies have concluded that the use of only EMG for IONM during LLIF is likely inadequate and there may be a high rate of postoperative nerve complications in the setting of normal IONM EMG readings (Table 1).[10,11,29,30]

MOTOR-EVOKED POTENTIALS

The potential limitations of EMG as a unimodal IONM strategy have led to recent studies investigating the additive benefit of MEP to monitor the integrity of the lumbar plexus during LLIF (Table 2). Transcranial MEPs are action potentials generated by transcranial brain stimulation via electrode placement. MEPs allow for monitoring of motor pathways and spinal cord function. The use of MEPs during traditional posterior approaches to the lumbar spine has been limited because MEP changes may not be sensitive in detecting injury to a single lumbar nerve root; however, MEPs may be able to accurately monitor fully formed peripherals nerves of the lumbar plexus which innervate the quadriceps muscle.[31,32]

In one of the largest studies to date, Riley et al.[33] analyzed the rate of postoperative neurologic deficits in 479 patients undergoing LLIF in which either EMG only or EMG and MEP IONM strategies were utilized. Analysis of their results demonstrated that patients who received additional MEP monitoring had a lower rate of postoperative neurologic deficits compared to patients only receiving EMG monitoring.[33] Further analysis revealed that MEP monitoring decreased both sensory and motor deficits and the authors suggested that MEPs can provide an indirect assessment of sensory nerve fiber integrity by monitoring mixed sensory-motor nerves that originate off the lumbar plexus.[33] In a smaller study, without a control group, Berends et al.[34] reviewed 23 patients undergoing LLIF who were monitored with EMG and MEPs, and found that in 9% of patients MEP amplitude decreased due to psoas retractor deployment, without a corresponding change in EMG signals. However, whether additive MEP changed postoperative neurologic outcomes was unclear. Lastly, in a case series, Chaudhary et al.[35] reported 3 patients with intraoperative MEP changes without corresponding abnormal EMG activity during LLIF, and 2 of these patients had postoperative quadriceps weakness.

While EMG and MEP multimodal IONM during LLIF may prevent intraoperative neurologic injury to the lumbar plexus, the addition of MEPs is not without its own set of limitations. The utilization of MEPs requires intravenous anesthesia as opposed to inhalational agents, and long-acting paralytics cannot be used, making positioning, exposure, and retraction more possibly challenging; thus, the choice of anesthesia technique can have a significant effect on MEP interpretation and reliability. Additionally, MEP monitoring is evoked at a certain point in time and does not allow for continuous neuromonitoring, thereby possibly delaying detection of injury to the lumbar plexus. Lastly, the interpretation of MEP data requires extensive training, is highly subject to variability, is dependent on establishing accurate and reproducible baseline MEP responses, and can be subject to both false-positive and false-negative alerts. These limitations of MEP monitoring may in part explain why some studies have demonstrated nerve injury during LLIF even when utilizing MEPs.[25]

SOMATOSENSORY-EVOKED POTENTIALS

SSEP in addition to EMG may provide an alternative multimodal IONM strategy during LLIF. SSEPs allow for monitoring of sensory transmission through the dorsal column pathways. SSEP signals allow for continuous monitoring and are thought to be sensitive to ischemic changes.[36] However, traditional SSEP techniques only track the lower lumbosacral plexus (L4–S2) by monitoring the posterior tibial or peroneal nerves. SSEP monitoring of the saphenous nerve may allow monitoring of the upper lumbar plexus as the saphenous nerve, a continuation of the posterior division of the femoral nerve, is a purely sensory nerve that is superficially found between the sartorius and gracilis muscles.

Two studies have examined the utility of saphenous SSEP monitoring during LLIF (Table 3).[30,37] Silverstein et al.[30] monitored saphenous SSEPs in 46 consecutive patients undergoing LLIF. In 5 patients, they noted SSEP changes after retractor expansion, without associated EMG changes; 3 of these patients had postoperative femoral nerve deficits, and there were no false-negative SSEP alerts.[30] A similar study by Jain et al.[37] monitored saphenous SSEPs in 52 patients, in addition to EMG and MEPs. In this study, saphenous SSEPs demonstrated 100% sensitivity (95% confidence interval, 52%–100%) and 100% specificity (95% confidence interval, 90%–100%) in detecting postoperative femoral nerve complications.[37] However, the authors did not provide an analysis of the additive utility of saphenous SSEPs compared to the use of EMG and/or MEPs. Given the lack of an additive utility analysis and control group, it is currently unclear whether saphenous SSEP monitoring definitively can prevent femoral nerve complications.

While saphenous SSEPs represent a promising approach to multimodal IONM during LLIF, they are associated with their own set of limitations. In the studies by Silverstein et al.[30] and Jain et al.,[37] reliable saphenous SSEP signals could not be established in 11%–16% of patients. The ability to establish reliable signals can be affected by anesthetic agents, similar to MEP monitoring, as well as body habitus, limb length, depth of the saphenous nerve, and medical comorbidities.

CONCLUSION

Lateral lumbar interbody fusion is an evolving technique and is currently used to treat a wide array of spinal pathology ranging from degenerative spinal stenosis, adult deformity, tumor, and infection. While LLIF continues to grow in popularity, the safety of the technique needs to continue to improve. The LLIF approach was originally designed to be executed with concurrent EMG surveillance. However, subsequent studies demonstrated a high rate of postoperative neurologic deficits, even with EMG monitoring.[10,11,29] Targeted EMG specifically designed to evaluate the lumbar plexus may be a more efficacious unimodal monitoring strategy during LLIF.[21] Additionally, a multimodal IONM strategy utilizing MEPs or saphenous SSEPs to monitor the lumbar plexus may be promising strategies based on results from a limited number of studies.[30,33,34,37] However, the additive benefit of multimodal IONM during LLIF remains without consensus and whether the increased cost of multimodal IONM justifies the unknown clinical benefit is without consensus. Ultimately, prospective studies, with clear definitions of postoperative neurologic injury, that evaluate different unimodal or multimodal IONM strategies are needed to accurately assess the efficacy of IONM during LLIF.

CONFLICT OF INTEREST

Sheeraz Qureshi -- Royalties: Stryker K2M, Globus Medical, Inc.; Globus Medical, Inc.: HS2, LLC; Private Investments: Tissue Differentiation Intelligence; Consulting: Stryker K2M, Globus Medical, Inc.; Speaking and/or Teaching Arrangements: AMOpportunities, Globus Medical, Inc.; Board of Directors: Society of Minimally Invasive Spine Surgery; Scientific Advisory Board/Other Office: International Society for the Advancement of Spine Surgery, Cervical Spine Research Society, Lumbar Spine Research Society, North American Spine Society, Association of Bone and Joint Surgeons, Simplify Medical, Inc., LifeLink.com Inc., Society of Minimally Invasive Spine Surgery, Minimally Invasive Spine Study Group, Spinal Simplicity, LLC, Contemporary Spine Surgery, Annals of Translational Medicine. Raymond Hah -- Nuvasive: Paid consultant; Clinical Spine Surgery: Editorial or governing board Global Spine Journal: Editorial or governing board Lumbar Spine Research Society: Board or committee member; North American Spine Society: Board or committee member.

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