www.surgicalneurologyint.com

ScientificScholar® Knowledge is power
Publisher of Scientific Journals

Surgical Neurology International

Editor-in-Chief: Nancy E. Epstein, MD, Professor of Clinical Neurosurgery, School of Medicine, State U. of NY at Stony Brook.

SNI: Spine

Editor
Nancy E. Epstein, MD
Professor of Clinical Neurosurgery, School of Medicine, State U. of NY at Stony Brook

SNI® Open Access

Review Article

Perspective: Can intraoperative neurophysiological monitoring (IONM) limit errors associated with lumbar pedicle screw fusions/transforaminal lumbar interbody fusions (TLIF)?

Nancy E Epstein

Professor of Clinical Neurosurgery, School of Medicine, State University of NY at Stony Brook, and Editor-in-Chief Surgical Neurology International NY and c/o Dr. Marc Agulnick 1122 Franklin Avenue Suite 106, Garden City, NY 11530 ,United States.

E-mail: *Nancy E Epstein - nancy.epsteinmd@gmail.com

***Corresponding author:**
Nancy E Epstein, M.D., F.A.C.S., Professor of Clinical Neurosurgery, School of Medicine, State University of NY at Stony Brook, and Editor-in-Chief Surgical Neurology International NY and c/o Dr. Marc Agulnick 1122 Franklin Avenue Suite 106, Garden City, NY 11530, United States.
nancy.epsteinmd@gmail.com

Received: 08 August 2023
Accepted: 09 August 2023
Published: 08 September 2023

DOI
10.25259/SNI_671_2023

Quick Response Code:

ABSTRACT

Background: We evaluated whether intraoperative neural monitoring (IONM), including somatosensory evoked potential monitoring (SEP), motor evoked potential monitoring (MEP), and electrophysiological monitoring (EMG), could reduce operative errors attributed to lumbar instrumented fusions, including minimally invasive (MI) transforaminal lumbar interbody fusion (TLIF)/open TLIF.

Methods: Operative errors included retraction/stretch or cauda equina neural/cauda equina injuries that typically occurred during misplacement of interbody devices (IBD) and/or malpositioning of pedicle screws (PS).

Results: IONM decreased the incidence of intraoperative errors occurring during instrumented lumbar fusions (MI-TLIF/TLIF). In one series, significant loss of intraoperative SEP in 5 (4.3%) of 115 patients occurred after placing IBD; immediate removal of all IBD left just 2 patients with new neural deficits. In other series, firing of trigger EMG's (t-EMG) detected intraoperative PS malpositioning, prompted the immediate redirection of these screws, and reduced the need for reoperations. One t-EMG study required a reoperation in just 1 of 296 patients, while 6 reoperations were warranted out of 222 unmonitored patients. In another series, t-EMG reduced the pedicle screw breech rate to 7.78% (1723 PS) from a higher 11.25% for 1680 PS placed without t-EMG. A further study confirmed that MEP's picked up new motor deficits in 5 of 275 TLIF.

Conclusion: SEP/MEP/EMG intraoperative monitoring appears to reduce the risk of surgical errors when placing interbody devices and PS during the performance of lumbar instrumented fusions (MI-TLIF/TLIF).However, IONM is only effective if spine surgeons use it, and immediately address significant intraoperative changes.

Keywords: Transforaminal Lumbar Interbody Fusions, Surgical errors, Malpositioning Pedicle Screws, Interbody Devices, Retraction Neural Injuries, Intraoperative Monitoring, Somatosensory Evoked Potentials (SEP), Electromyography (EMG), Motor Evoked Potentials (MEP), Minimally Invasive (MI) TLIF

INTRODUCTION

Can intraoperative neurophysiological monitoring (IONM) limit surgical errors (i.e. particularly attributed to placing interbody devices (IBD), or pedicle screws (PS)) during instrumented pedicle/screw fusions, including open/minimally invasive (MI) transforaminal lumbar interbody fusions (MI-TLIF/TLIF)?[1-11] In this review, intraoperative somatosensory evoked

Table 1: Added Safety and Efficacy for Intraoperative Neural Monitoring (IONM) of Transforaminal Lumbar Interbody Fusion (TLIF).

Author [Reference] Journal Year	Number/ Types of Cases	Levels of TLIF Type of TLIF	Results	Results	Outcomes
Devlin[3] J Am Acad Orthop Surg 2007	IONM During Spine OR	Find AE Neural Intraop	Early Intervene Avoid Deficits	Combined Use of Modalities to Limit Postop AE	Provide Critical Data to Operating Teams
Bindal[1] JNS Spine 2007	IONM 25 MI TLIF > Risk PS/AE vs. Open TLIF 2005-2006 105 PS EMG Decomp IBD, PS Test Tap PS	All Postop X-rays; 20/25 CT (85 PS) No Sig. Abnl EMG with Decomp	5 Cases EMG Intermit Firing with IBD Placed- No Correlate with Postop Deficit	Active Stimulation 76.2% PS Required 1 or > Changes in Trajectory All Pedicle Taps Normal 15 mA 25 X-rays/20 CT	3 Cases Breaches-Lateral Wall Not Clinically Relevant 0% Clinical Malposit PS
Gonzalez[5] Neurosurg Focus 2009	IONM Spine Surgery Review	At risk Cordially, Roots Vessels	SEP MEP EMG (spont Vs. t-EMG)	Key clinical Recommend	"_As many spinal surgeries ... evolve along ...pathway of MI, ... likely ... value of IONM will only continue to become more prominent"
Duncan[4] Spine 2012	IONM Decreased Amplitude of SEP in LE With IBD During TLIF EMR 115 Pts TLIF Using SEP MEP and EMG	Decrease SEP LE Due to Fusion Cage (IBD) Placement TLIF With No Alert on EMG	Used SEP MEP (Cord) EMG (Root) Injury	Followed 2 years 5 Intraop SEP Changes Due to IBD Placement All 5 Showed Reversal SEP Changes to Baseline After Removing Cages	3/5 No New Postop deficit Due to Intraop Cage Removal 2/5 New Postop Neuro Deficits SEP Alerts Associated with TLIF Without EMG Alert
Nixon[9] (Senior Author Dr. Fessler) Surg Neurol Int 2014	Bilateral Neuro Deficits After 4 Unilateral MI TLIF 340 TLIF 2002-2012 Fessler Series AE Low "New neurological postoperative complications may be underreported"	"...report... infrequent rate of MI-TLIF... complicated by postop weakness" (1.2%) AE Bilateral LE Weakness	Avg Age 65.6 (62-75) BMI Avg 25 3 F, 1 M All DS Grade I-II Unilateral Left MI TLIF-	Rates New Deficits Low 1.2% "...open discussion of this serious complication is important for surgeon education"	"...the specific etiology or pathophysiology behind these complications remains relatively unknown (e.g. direct neural injury, traction injury, hypoperfusion, positioning complications and others..."
Kaliya-Perumal[7] BMC Musculoskelet Disord 2017	Intraop EMG Monitor t-EMG Detect Potential PS Breaches/ Safer-Reduce Reop Rate Reduce Neural Injury Malposit PS	Use EMG Identify PS Malposit- Allow Intraop PS Reposit	PS L1-S1 Group I t-EMG (296 Pts; 1856 PS) Group II No t-EMG (222 Pts, 1256 PS)	518 Pts; 3112 PS L1-S1 Group I: 145 PS (8.7%) positive response t-EMG threshold Sensitive 93.3% Specificity 92.88%	1 Group I Pt Reop Sig. Decrease Malposit PS/ Neuro Deficits Reop Rate Group II 6 Reop Higher Reop
Schar[10] Eur Spine J 2017	Outcome L5 Rad After TLIF for High Grade L5S1 IS Role IONM Course Iatrogenic L5 Rad After TLIF	17 Pts 2005-2013 Avg Age 26.3 Mean Preop Slip 72% Reduced to 19%	Rate new L5 Rad Motor Deficit 29% -5 Pt 4 Full Recovery 3 mos., 1 Lost F/O	IONM Postop L5 Transient Deficits Sensitivity 20% Specificity 100% Recovery with IONM	If Intraop Full Recovery IONM Deficits Resolve in 3 mos.

(Contd...)

Table 1: *(Continued).*

Author [Reference] Journal Year	Number/ Types of Cases	Levels of TLIF Type of TLIF	Results	Results	Outcomes
Kim[8] Oper Neurosurg 2019	Efficacy IONM Detect Postop Neuro Deficits for TLIF 2010-2014 SEP/MEP EMG for TLIF Best Combo	275 TLIF IONM New Postop Motor Sensory Deficits SEP+EMG 275 Pts 66 MEP	7 New Postop Deficits: 2 sensory 5 Motor MEP High 80% Sensitivity and 100% Specificity	SEP Failed to Detect Sensory Deficits EMG High False Positive Rates for Both Sensory (100%) and Motor deficits (97.3%)	MEP Should use for IONM Below L1 with TLIF High Sens and Spec Detect Postop Motor deficits
Hofler and Fessler[6] Neurodiagn J 2021	IONM and Lumber Instrum Use IONM Avoid AE SEP EMG	SEP Dorsal Columns-Posterior C/TH OR MEP/EMG Motor Nerve Function	Approach Lumbar Spine-Anterior Lateral Posterior	PS Direct Stim with t-EMG Detect Pedicle Cortex Breach	"...followed by accurate recognition of the cause for these changes and appropriate responses by the surgeon, anesthesiologists, and monitoring personnel to correct the change"
Chen[2] BMC Musculoskelet Disord 2021	Role Multimodal vs. Single IONM PE TLIF 113 Pts 2018-2020	12 (10.6%) IONM Alerts Sensit 100% Spec 96.2%	Minor deficit 6.2% (7 Pts) All AE Temp	Ability Single IONM Modality Detect Neuro AE Range 25-66% All Modalities 100%	Multimodal IONM More Effective Accurate vs. Unimodal Assess root Function During PE=TLIF Reduced Neuro AE and False Negatives
Yongjun[11] BMC Musculoskelet Disord 2023	Eval T-EMG) Reduce Breach PS + Revisions Posterior PS L1-S1 2015-2021	T-EMG (374 cases-1723 PS) vs. Non T-EMG (339 cases (1680 PS) 3 Spine Surgeons Eval Images	Subgroup PS Local Lat-Sup Med-Inf Degree Breach Minor Major Eval Demog PS Posit Reop	713 Pts (3403 PS Postop CT T-EMG reduced PS Breach rate 7.78% vs. non T-EMG 11.25% Med/Inf Breach Higher T-EMG6.27% vs. Non T-EMG 8.93%	Same results Lat/Sup Breaches T-EMG Valuable Improving Accuracy of PS Placement Reducing PS Revision Rate

IONM=Intraoperative Neural Monitoring, Comp=Complications, OR=Surgery, Pts=Patients, Intraop=Intraoperative, Place=Placement, TcMEP=Transcranial Motor Evoked Potentials, MEP=Motor Evoked Potentials, Def=Deformity, Sp=Spine, OPLL=Ossification Posterior Longitudinal Ligament, T-EMG=Triggered EMG, Lat=Lateral, Sup=Superior, Med=Medial, Inf=Inferior, Eval=Evaluate, Reop=Reoperations/Revisions, Posit=Position, Demog=Demographics, Malposit=Malposition, Reposit=Reposition, t-EMG=Trigger EMG, MI=Minimally Invasive, TLIF=Transforaminal Lumbar Interbody Fusion, AE=Adverse Events, PS=Pedicle Screws, Decomp=Decompression, IBD=Interbody Devices Sig=Significant, Abnl=Abnormal, Intermit=Intermittent, Comb=Combination, Sens=Sensitivity, Spec=Specificity, Instrum=Instrumentation, C=Cervical, Th=Thoracic, Stim=Stimulation, DJD=Degenerative Disease, Spont=Spontaneous, Rad=Radiculopathy, IS=Isthmic Spondylolisthesis, PE=Percutaneous Endoscopic, Temp=Temporary, DS=Degenerative Spondylolisthesis, Def. =Deficiency, LE=Lower Extremities, EMR=Electronic Medical Record, SEP=Somatosensory Evoked Potential Monitoring, F=Female, M=Male, F/O=Follow-up, mos=Months, Postop=Postoperative, Neuro-Neurological, BMI=Body Mass Index, avg=Average, combo=Combination

potential monitoring (SEP) largely monitored dorsal column dysfunction during cervical/thoracic surgery. However, even during lumbar surgery, motor evoked potential monitoring (MEP) best identified impending motor dysfunction, while electrophysiological monitoring (including triggered EMG (t-EMG)) most readily identified pedicle breaches. Real-time alerts provided by combinations of these 3 modalities helped surgeons limit/avert impending surgical errors/neurological damage (i.e., occurring due to excessive retraction, stretch, or compression requiring revision/removal of IBD and/or redirecting malpositioned PS) [Table 1]. Nevertheless, IONM is only effective if spine surgeons use it and expeditiously change/alter/modify their operative technique in response to IONM alerts.

Multimodal IONM Limits Postoperative Deficits and Reoperation Rates

Multiple rather than single IONM modalities utilized during instrumented lumbar pedicle screw fusions (PS) utilized during MI-TLIF/TLIF, better identify impending intraoperative neural injury/surgical errors; however they must prompt surgeons to perform immediate intraoperative resuscitative maneuvers to limit/avoid new postoperative neurological deficits [Table 1].[1-11] Gonzalez *et al*. (2009) stated multimodality IONM can; "...maximize the diagnostic efficacy in regard to sensitivity and specificity in the detection of impending neural injury; their hypothesis was that it would prove even more useful with more MI procedures being performed in the future.[5] Nixon *et al*. (2014) observed that 4 (1.2%) of 340 TLIF cases (primary surgeon Dr. Fessler) developed postoperative paraparesis, and stated; "Nonetheless, acknowledgment and open discussion of this serious complication is important for surgeon education". However, these "complications" were most probably surgical errors.[9] Hofler and Fessler (2021) subsequently advocated using multimodal IONM to; "...aid with the avoidance of neurologic complications during lumbar instrumented fusions".[6] However, they noted that IONM must be; "...followed by accurate recognition of the cause for these changes and appropriate responses by the surgeon, anesthesiologists, and monitoring personnel to correct the change".

Passive and Active t-EMG Limits Errors of Lumbar PS Fusions (MI-TLIF/Open TLIF)

Passive and active EMG (i.e., trigger EMG (t-EMG)) alerts increased the accuracy for detecting intraoperative PS misplacement, often prompting immediate screw redirection, and reducing the incidence of postoperative reoperations required to address malpositioned screws [Table 1].[1,7,11] Bindal *et al*. (2007) performed 25 MI TLIF placing 105 PS.[1] "Passive EMGs" yielded no alerts during spinal decompressions, but did identify five alerts of; "...intermittent nerve root firing..." following placement of IBD; interestingly, none of these patients exhibited new postoperative neural deficits. They observed; "Using... the active stimulation protocol *(t-EMG)* 76.2% of screw placements required one or more changes to the trajectory of the pedicle access needle". [1] With t-EMG, 25 postoperative X-rays and 20 CT scans (i.e., including.... visualization of 85 PS) showed only 3 lateral breaches which were clinically irrelevant. Kaliya-Perumal *et al*. (2017) documented that t-EMG used for 296 Group I patients to place 1856 PS yielded 145 (8.7%) screw alerts; PS were immediately repositioned, and just 1 patient required a second operation for a malpositioned screw.[7] Alternatively, 6 of their 222 Group II patients whose 1256 PS were placed without t-EMG required additional surgery. Yongjun *et al*. (2023) also found fewer (7.78%) misplaced PS using t-EMG monitoring in 374 patients to place 1723 PS vs. a higher 11.25% of misplaced PS occurring in 339 patients undergoing 1680 PS placement without the benefit of t-EMG.[11]

Significant SEP Decreases/Alerts During IBD Placement in 5 of 115 TLIF Patients Prompted Immediate IBD Removal and Averted Deficits in 3 Patients

When Duncan *et al*. (2012) performed 115 TLIF, 5 patients developed significant decreases (alerts) in SEP amplitude without EMG changes following the placement of IBD [Table 1].[4] All 5 devices were immediately removed, and SEP changes reverted to normal (i.e., returned to baseline) prior to closing. Removing IBD due to these SEP alerts, therefore likely avoided neurological injuries in 3 patients, limiting postoperative neural deficits to just 2 patients.

IONM Reduces Errors Occurring in MI-TLIF/Open TLIF Surgery

MI-TLIF/Open TLIF studies documented the reduction of intraoperative errors utilizing IONM [Table 1].[2,6,8-10] Nixon *et al.* (2014) found that 4 (1.2%) of 340 patients undergoing unilateral MI-TLIF (2002-2012) sustained new bilateral postoperative weakness/neurological deficits.[9] The authors concluded; "... the specific etiology or pathophysiology behind these complications remains relatively unknown (e.g., direct neural injury, traction injury, hypoperfusion, positioning complications, and others...)." Nevertheless, they likely mislabeled the 4 new postoperative instances of paralysis as "complications", whereas they were probably due to surgeon error. With IONM**,** Schar *et al*. (2017) identified 5 (29%) new L5 radicular motor deficits in 17 patients (2005–2013) undergoing instrumented high-grade fusions for L5S1 isthmic spondylolisthesis; 4 of 5 patients fully recovered within 3 postoperative mos. (e.g., 1 was lost to follow-up).[10] They concluded that without IONM, more of these deficits would likely have been permanent/irreversible.[10] Kim *et al*. (2019) looked at the impact of using SEP/EMG to perform 275 TLIF vs. utilizing SEP/EMG with MEP for 66 TLIF.[8] They found MEPs were 80% sensitive/100% specific for the five new postoperative motor deficits. SEP failed to detect the 2 postoperative sensory deficits, and EMG had high false positive rates for either motor or sensory neural injuries; they, therefore, recommended adding MEP to SEP/EMG when performing TLIF to best detect impending motor injuries.[8] In 113 patients undergoing percutaneous endoscopic TLIF (PE-TLIF), Chen *et al*. (2021) found 12 (10.6% alerts) utilizing multimodal vs. single IONM; when alerts were immediately addressed intraoperatively, they resulted in just 7 transient minor postoperative neurological deficits.[2] It is worth repeating Hofler and Fessler's conclusions in 2021 regarding the need to respond to significant IONM changes for PS placement.[6] They commendted that these changes should be; "...followed by accurate recognition of the cause for these changes and appropriate responses by the surgeon, anesthesiologists, and monitoring personnel to correct the change".[6]

CONCLUSION

Significant intraoperative IONM alerts prompted immediate intraoperative resuscitative maneuvers (i.e. reduction of retraction, stretching, IBD removal and/or PS redictection/repositioning) to limit operative errors attributed to instrumented lumbar PS fusions (MI-TLIF/Open TLIF) [Table 1]. Appropriate responses to significant IONM alerts limited/avoided many postoperative neurological deficits, and reduced reoperation rates for compressive IBD and malpositioned screws [Table 1].[1-11]

Declaration of patient consent

Patients' consent not required as patients' identities were not disclosed or compromised.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-Assisted technology for manuscript preparation

The author(s) confirms that there was no use of Artificial Intelligence (AI)-Assisted Technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

REFERENCES

1. Bindal RK, Ghosh S. Intraoperative electromyography monitoring in minimally invasive transforaminal lumbar interbody fusion. J Neurosurg Spine 2007;6:126-32.
2. Chen Y, Luo C, Wang J, Liu L, Huang B, Li CQ, *et al.* Roles of multimodal intra-operative neurophysiological monitoring (IONM) in percutaneous endoscopic transforaminal lumbar interbody fusion: A case series of 113 patients. BMC Musculoskelet Disord 2021;22:989.
3. Devlin VJ, Schwartz DM. Intraoperative neurophysiologic monitoring during spinal surgery. J Am Acad Orthop Surg 2007;15:549-60.
4. Duncan JW, Bailey RA, Baena R. Intraoperative decrease in amplitude of somatosensory-evoked potentials of the lower extremities with interbody fusion cage placement during lumbar fusion surgery. Spine (Phila Pa 1976) 2012;37:E1290-5.
5. Gonzalez AA, Jeyanandarajan D, Hansen C, Zada G, Hsieh PC. Intraoperative neurophysiological monitoring during spine surgery: A review. Neurosurg Focus 2009;27:E6.
6. Hofler RC, Fessler RG. Intraoperative neuromonitoring and lumbar spinal instrumentation: Indications and utility. Neurodiagn J 2021;61:2-10.
7. Kaliya-Perumal AK, Charng JR, Niu CC, Tsai TT, Lai PL, Chen LH, *et al.* Intraoperative electromyographic monitoring to optimize safe lumbar pedicle screw placement-a retrospective analysis. BMC Musculoskelet Disord 2017;18:229.
8. Kim JH, Lenina S, Mosley G, Meaike J, Tran B, Kim JS, *et al.* The efficacy of intraoperative neurophysiological monitoring to detect postoperative neurological deficits in transforaminal lumbar interbody fusion surgery. Oper Neurosurg (Hagerstown) 2019;16:71-8.
9. Nixon AT, Smith ZA, Lawton CD, Wong AP, Dahdaleh NS, Koht A, *et al.* Bilateral neurological deficits following unilateral minimally invasive TLIF: A review of four patients. Surg Neurol Int 2014;5:S317-24.
10. Schär RT, Sutter M, Mannion AF, Eggspühler A, Jeszenszky D, Fekete TF, *et al.* Outcome of L5 radiculopathy after reduction and instrumented transforaminal lumbar interbody fusion of high-grade L5-S1 isthmic spondylolisthesis and the role of intraoperative neurophysiological monitoring. Eur Spine J 2017;26:679-90.
11. Yongjun T, Yuntian Z, Biao C, Zenghui J. Intraoperative triggered electromyographic monitoring of pedicle screw efficiently reduces the lumbar pedicle breach and re-operative rate-a retrospective analysis based on postoperative computed tomography scan. BMC Musculoskelet Disord 2023;24:535.

How to cite this article: Epstein NE. Perspective: Can intraoperative neurophysiological monitoring (IONM) limit errors associated with lumbar pedicle screw fusions/transforaminal lumbar interbody fusions (TLIF)? Surg Neurol Int 2023;14:314.