ScientificScholar® Knowledge is power
Publisher of Scientific Journals

www.surgicalneurologyint.com

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: Triple intraoperative neurophysiological monitoring (IONM) should be considered the standard of care (SOC) for performing cervical surgery for ossification of the posterior longitudinal ligament (OPLL)

Nancy E Epstein[1], Marc A Agulnick[2]

[1]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, New York, United States, [2]Assistant Clinical Professor of Orthopedic Surgery, NYU Hospital Long Island c/o Dr. Marc Agulnick 1122 Franklin Avenue Suite 106, Garden City, NY, United States.

E-mail: *Nancy E Epstein - nancy.epsteinmd@gmail.com; Marc A Agulnick - marc_agulnick@yahoo.com

***Corresponding author:**
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, New York State, United States.
nancy.epsteinmd@gmail.com

Received: 24 August 2023
Accepted: 25 August 2023
Published: 15 September 2023

DOI
10.25259/SNI_710_2023

Quick Response Code:

ABSTRACT

Background: Triple Intraoperative Neurophysiological Monitoring (IONM) should be considered the standard of care (SOC) for performing cervical surgery for Ossification of the Posterior Longitudinal Ligament (OPLL). IONM's three modalities and their alerts include; Somatosensory Evoked Potentials (SEP: =/> 50% amplitude loss; =/>10% latency loss), Motor Evoked Potentials (MEP: =/> 70% amplitude loss; =/>10-15% latency loss), and Electromyography (loss of EMG, including active triggered EMG (t-EMG)).

Methods: During cervical OPLL operations, the 3 IONM alerts together better detect intraoperative surgical errors, enabling spine surgeons to immediately institute appropriate resuscitative measures and minimize/avoid permanent neurological deficits/injuries.

Results: This focused review of the literature regarding cervical OPLL surgery showed that SEP, MEP, and EMG monitoring used together better reduced the incidence of new nerve root (e.g., mostly C5 but including other root palsies), brachial plexus injuries (i.e., usually occurring during operative positioning), and/or spinal cord injuries (i.e., one study of OPLL patients documented a reduced 3.79% incidence of cord deficits utilizing triple IONM vs. a higher 14.06% frequency of neurological injuries occurring without IONM).

Conclusions: Triple IONM (i.e., SEP, MEP, and EMG) should be considered the standard of care (SOC) for performing cervical OPLL surgery. However, the positive impact of IONM on OPLL surgical outcomes critically relies on spinal surgeons' immediate response to SEP, MEP, and/or EMG alerts/significant deterioration with appropriate resuscitative measures to limit/avert permanent neurological deficits.

Keywords: Anterior cervical surgery, Anterior corpectomy fusion (ACF), Anterior diskectomy/fusion (ACDF), Intraoperative neural monitoring (IONM), Surgical errors, Negligence, Somatosensory evoked potentials (SEP), Motor evoked potentials (MEP): Electromyography (EMG), Neurological injuries, Spinal cord deficits, C5 Palsy, Brachial plexus injury

INTRODUCTION

Triple Intraoperative Neurophysiological Monitoring (IONM) should be considered the standard of care (SOC) for performing cervical surgery for Ossification of the Posterior Longitudinal

Ligament (OPLL). The three modalities of IONM and their alerts include; Somatosensory Evoked Potentials (SEP: =/> 50% amplitude loss; =/>10% latency loss), Motor Evoked Potentials (MEP: =/> 70% amplitude loss; =/>10-15% latency loss), and Electromyography (EMG: passive and active/triggered EMG (t-EMG)) [Table 1]. Any combination of these 3 alerts can signal the onset of intraoperative surgical errors/impending neurological injuries that can be limited/reversed/averted by spinal surgeons' immediate performance of appropriate resuscitative measures. This perspective focuses on how triple IONM (i.e., SEP, MEP, and EMG) should be considered part of the standard of care to limit/avert nerve root, brachial plexus, and spinal cord injuries from occurring during cervical OPLL surgery [Table 1].[1-20]

Early Evidence that MEP were Safe/Effective for Monitoring ACDF for Disk Disease/Spondylosis/ Cervical Spondylotic Myelopathy

Two early studies showed that MEP were safe and provided effective IONM for anterior cervical surgery (i.e., ACDF for disk disease/spondylosis/cervical spondylotic myelopathy (CSM)) [Table 1].[3,11] Darden *et al*. (1996) monitored 49 patients undergoing anterior cervical surgery with MEP (i.e., 38 had monoradiciulopathy); none exhibited new postoperative neurological worsening.[3] Interestingly, for those with preoperative deficits for under 1 year in duration, MEP helped predict postoperative improvement of motor function. In 1997, Gokaslan *et al*. using transcutaneously placed mid-thoracic epidural electrodes to monitor MEP during 16 ACDF found that no patients developed significant intraoperative changes/alerts, and that all were motor intact postoperatively.[11]

Evolution of IONM Techniques for Cervical OPLL Surgery From 1993-1998 Monitored with SEP/EMG to Combined SEP/EMG and MEP Monitoring by 2002-2014

For cervical OPLL surgery, Epstein documented the progression of IONM techniques from SEP/EMG monitoring alone from 1993-1998 to SEP/EMG and MEP techniques used together starting in 2002 [Table 1].[4-9] In 1993, Epstein performed 41 anterior cervical corpectomy/fusions (ACF) and 10 cervical laminectomies/fusion (LAM/F) for OPLL using SEP/EMG monitoring; these 2 modalities appeared to "... limit operative morbidity".[4] By 1998, SEP/EMG alone were still used to monitor 22 circumferential cervical OPLL procedures (i.e. including multilevel ACF with Posterior Fusions); postoperatively, patients improved an average of 3.0 postoperative Nurick grades, and the patients sustained no new postoperative cord deficits.[5] As of 2002, SEP/EMG and the option for MEP monitoring was not being used to supplement OPLL surgery; "...the option of undergoing MEP: "...for OPLL patients under 65 years of age with kyphosis being treated with single/multilevel ACF vs. laminectomies/posterior fusions if over 65 years of age with multilevel OPLL and a preserved lordotic curvature".[6] In 2003, Epstein's recommendations for performing cervical OPLL surgery included; "...continuous intraoperative somatosensory-evoked potential monitoring...", and EMG monitoring, but not yet routine MEP monitoring (i.e., along with awake intubation and awake positioning).[7] By 2014, Epstein's two studies focused on performing cervical OPLL surgery with routine intraoperative; "...somatosensory, motor evoked potentials, and electromyographic monitoring...", along with Total Intravenous Anesthesia (TIVA) to avoid interfering with IONM signals.[8, 9]

Utility of SEP in Cervical OPLL Surgery

Roh *et al*. (2007) Used SEP as Part of the Standard of Care in Cervical Surgery, Especially for OPLL

In 2007, Roh *et al*. utilized SEP during 809 consecutive cervical operations [Table 1].[16] Successful resuscitative maneuvers included removal of tape from the shoulders (8 patients) and release of traction; (4 patients). Two additional patients whose SEP changes failed to return to baseline prior to closing respectively recovered neurological function within 6 hrs, and 2 mos. postoperatively. The authors concluded that SEP monitoring; "....probably prevented neurological deficits in 15 (1.9%) of 809 patients..." They further commented that OPLL patients showed a; "...7-fold greater risk of intraoperative SEP degradation". Additional experience with IONM in this patient series led the authors to routinely incorporate SEP monitoring as part of their standard of care for performing cervical spine surgery.

Prolonged Preoperative SEP Latency Correlated with Intraoperative SEP/MEP Amplitude Losses and "Iatrogenic" Intraoperative and Postoperative Neurological Damage (PND)

Yoo *et al*. (2022) used SEP to reduce the incidence of intraoperative "iatrogenic damage" resulting in postoperative neurological damage (PND) observed in a series of 265 myelopathic patients undergoing cervical OPLL surgery [Table 1].[19] When they compared preoperative SEP (PreSEP) obtained 3 days prior to surgery with postoperative SEP obtained 48 hrs. and 4 weeks postoperatively, they found that; "... prolonged latency for PreSEP correlated with both intraoperative SEP (ioSEP) and intraoperative MEP (ioMEP) amplitude losses, that forecast PND at 48 hrs. and 4 weeks postoperatively".

SEP and TCeMEP Alerts Averted Brachial Plexus Injury in Anterior Cervical Surgery

While positioning for an anterior cervical procedure, Jahangir *et al*. (2011) found that SEP decreased, but TCeMEP were

Table 1: Ossification of the Posterior Longitudinal Ligament (OPLL) and The Necessity for Intraoperative Neural Monitoring (IONM).

Author [Ref] **Journal Date**	**Patient Population Study Aim**	**Results**	**Results**	**Results**	**Outcomes**
Epstein[4] J spinal Disord 1993	OR for OPLL 51 Pts	Severe Myelop MR CT, Myelo-CT	Document Full Extent of OPLL-Surgery: Anterior (ACDF/ACF), Posterior (Lam, LOP), Circ	51 OPLL Pts Superior Results -41 Anterior -10 Posterior	Continued IONM SEP Limit OR Morbidity
Darden[3] J Spinal Disord 1996	NMEP IONM 49 Anterior Cervical OR	Latency-Amplitude Median and Ulnar Baseline and Closure	38 Mono Rad Followed >1 yr-Results Good/Exc Odom's Criteria	No Worse NMEP-No New Neuro Deficits-Symptoms>1 yr-No sig Improved in NMEP	Intraop Improved NMEP May Predict Improved Outcome (Only if Symptoms <1 yr)
Gokaslan[11] J Spinal Disord 1997	IONM Cord Function with MEP Transcut Mid Thoracic-Epidural-Electrode After-Stim Transcranial	MEP in 16 pts ACDF-Myelop-Rad	No Sig. Change in Spinal MEP Intraop-All Intact Motor Postop-No AE from Electrodes	Safe to Monitor ACDF using Spinal MEP Transcut Epidural Electrodes MID Thoracic	MEP Intact During Surgery Correlated with Good Postop Motor Function
Epstein[5] J Spinal Disord 1998	Circ OR Cervical OPLL-Simult Anterior Posterior OR	DecompFus-1989-1996-22 Circ OR	Average 2.5 Level ACF-Avg 5 Level PWF- Severe Myelop-Avg Nurick Grade 3.5	Followed avg 22 mos (Rg 4-52 most)-Circ OR Time-Avg 9.l8 h-Avg 3.5 U Transfused	Postop Improved+3.0 Nurick Grades-Circ OR OPLL Successful In <10 h with Limited EBL
Epstein[6] Neurosurg Focus 2002	C-OPLL Progress Ossify HPLL to OPLL-CT Single, C, Double Layer Signs Dural Penetration-High Risk CSF Leak	< 65 yo: Direct Anterior Resection OPLL-ACF >65 Good Lordosis -LAM/Fus -LOP	Circ Surgery-Anesthesia Protocol-Awake Intubate-Awake Position-IONM SEP EMG MEP-Keep Intubated First Postop Night	3 or More Risk Factors Delay Extubation-Major Risks Factors-Anterior OR, >10 hrs,	Keep Intubated Major Risk Factors: 4 or >Levels, Obesity, Asthma, -Transfuse >4 U (250 cc/U)
Epstein[7] Spinal Cord 2003	Laminectomy +/- Fusion or LOP Address Cervical Stenosis OPLL and OYL	MR/CT OPLL Surgery-Use Awake Intubation Awake Positioning-Plus IONM	LAM-LAM/FOR or LOP for Cervical OPLL-Critical Careful Pt Selection	High Risk Factors:>70 yo-Long-Term Deficits- More Comorbidities	Correlate Deterioration Age >70- >Myelop-Recent Trauma-Best Multilevel C-OPLL Good Lordosis
Roh[16] Asian Spine J 2007	Use of SEP During Cervical OR-Does it Impact Outcome? -SEP Use-Tibial-Median Ulnar-809 Pts	Avg Age 52-472 M, -339 F-Studied Changes in SEP and Responses to Changes-17 (2.1%) of 809 SEP Loss Met Warning Criteria	Interventions Included: Release Shoulder Tape-Release Traction-Usual Result -SEP Improved	Failure SEP to Improve Correlated with New Neuro Deficit in 2 Pts But New Deficits-Resolved 6 hr. and 2 months Later. -OPLL-7 Times Greater Risk of Intraop SEP Loss	SEP Probably Prevented Deficits in 15 (1.9%) of 809 pts -If SEP Improve-Likely No Deficit-Conclude SEP in Standard of Care in OR Cervical Spine
Jahangiri[12] Am J Electro-neurodiagnos-tic Technol 2011	Prevent Position Related BP Injury-SEP and TCeMEP Anterior Spine OR-Benefit Sep TCeMEP Avoid Position-Related Injury 43 yo	During Draping SEP Decreased TCeMEP Loss APB-ADM Biceps Left Deltoid-Surgeon Informed Removed Shoulder Tape Arms on Boards	Tape Off-UE TCeMEP-Elicited-EP Improved-All SSEP TCeMEP Stable 3 hrs OR-2 Mos Postop Intact	Concluded IONM Identified and Reversed Impending Neural Injury-Sig Changes SEP TCeMEP	"...we recommend that TCeMEP monitoring be considered as an adjunct to SEP for prevention of injury to the brachial plexus"
Bhalodia[2] J Neurosurg Spine 2013	TC MEP and spEMG Acute v Delayed C5 Palsy-Cervical OR	229 pts/235 Levels-spEMG Detect Deltoid Wk C5 Injury Cervical OR	TCeMEP Sensitive Specific Detect C5 Injury-Cervical OR-C4 or C5 level 2006-2008-5.1% Periop Injury	Most Injury-2 ACF at Both C4, C5-All with C5 Palsy had Sig. TCeMEP Changes-100% Sensitive-99% Specific	spEMG Only 20% Sensitive-92% Specific-Neither-Identified Candidates Delayed C5 Palsy

(Contd...)

Table 1: *(Continued).*

Author [Ref] **Journal Date**	**Patient Population Study Aim**	**Results**	**Results**	**Results**	**Outcomes**
Epstein[8] Surg Neurol Int 2014	Perspective-Select C-OPLL Evaluate Diagnose-MR/CT	CT Dural Penetration Single, C, Double Layer Signs	Surgery Significant Myelop Rad-Anterior -Posterior-Circ Anterior ACF-Loss Lordosis-Kyphosis	Anterior OR Risk CSF Leak-Vertebral Injury-Choose Posterior Surgery Adequate Lordosis-Multilevel-Decomp	NT Fiberoptic Intubation-Awake Positioning-IONM-TIVA Anesthesia
Epstein[9] Surg Neurol Int 2014	C-OPLL-OR Risks-Benefits-Alternatives -Pitfalls-Document Full Extent-MR/CT	Diagnose OPLL-MR Soft Tissue-CT Look for Dural Penetration-Single, C, and Double Layer Signs	Surgery-Anterior-Posterior -Circ-IONM-SEP-MEP-EMG	Anesthesia-Awake-Intubation Positioning	Critical to Diagnose Full Extent of OPLL with MR/CT-OR Use IONM -SEP MEP-EMG
Kobayashi[14] J Neurosurg Spine 2014	New Alarm -Gold-Standard Tc-MEP For SCM (IMSCT or EMSCT) JSSR-MM IONM More Accurate	48 True Positive Cases-Decrease MEP with New Neuro Deficit Postop-70% Decrease Amplitude ALARM-Tc-MEP	959 Cases Included Deformity, Spinal Tumor, OPLL (2010-2012)-18 Centers-JSSR Prospective Evaluation TcMEP Pre and Postop Motor Deficits	2 FN during IMSCT New Alarm-Tc-MEP Sensitivity 95% Specificity 91% IONM Accurate (Not True for IMSCT)	Recommend Routine Use-Tc-MEP Alarm Loss 70% Amplitude for Spinal Deformity OPLL and EMSCT
Kobayashi[15] J Neurosurg Spine 2018	Alarm-Br (E)-MsEP Loss Amplitude =/> 70% and =/> 10% Latency Specific+Reduced False +'s	83 Pts IONM-1640 Acceptable Baseline Muscle Extremities-9/83 New Postop Motor Deficits	Studied Relationship Postop Motor Deficits Use Loss Latency 15% or Reduce Amplitude (= or>70%)	15% Delay Latency-Sensitive 78% Specific 96% Predict Postop Deficits-Loss Amplitude and Delay Latency =/> 10% Sensitive 100% Specific 93%	False Positive Rate 7%-False Negative 0%-Positive Predictive Value 64%-Negative Predictive Value 100%
Yoshida[20] Spine 2019	IONM Alert Timing-Intervention-IONM High Risks Spine Surgery-OPLL-Study Does IONM Identify Prevent-Nerve Damage	2867 Cases High Risk Spine Cases-TcMEP-2010-2016-622 C-OPLL-1009 Deformity-249 T-OPLL-771 EMSCT-216 IM SCT	Alarm Threshold-Loss 70% TcMEP, TP 126, FP 234, TN 2362, FN 9-Rescue Cases 136-OPLL Post Decomp-Rescue rates (Pts Rescued after IONM Alerts-	TP Cases Plus Rescue Cases)-Cervical OPLL 82.1% (32/39)-Multicenter-Potential Nerve Damage 9.5% Cases	52% Rescue Cases Using IONM-Rescue Rates for T-OPLL and IMSCT Low IONM "...may present neural damage even in high-risk spinal surgeries".
Badhiwala[1] J Neurosurg Spine 2019	Ask Value IONM ACDF Safety/Cost-NIS Sample 141,007 ACDF-Not Apply to Complex Pathology Including OPLL	Concluded; No Sig. Association-with/without IONM and Neuro Deficits	Age >65-Multilevel Fusion-CCI >0-Emergency More Neuro-AE	Populations-ACDF-With IONM 9380-1.7% Deficits – vs. ACDF Without IONM 9380-0.22% Deficits- Total 18 Centers, 760-AE Similar	Similar LOS (19% IONM vs. 18% No IONM)-IONM Add $6843 To Cost of ACDF Without Documented Benefit Excluding OPLL
Shigematsu[17] J Orthop Sci 2021	Impact Non OR Factors of TES=MEP and OPLL Surgery-TES-MEP Not Identify Non-OR Factors	IONM Detects Neuro Damage Allowing To Avoid Permanent-Neuro Deficits	OR Alerts-Surgeon Acute Intervention Warranted to Avoid Neuro Deficits/ AE-Surgery: TP, FP Reflect Acute Postop New Deficits	1934 Pts-Deformity-Cord Tumor-OPLL-2017-2019-70% Loss Amplitude Alarm Threshold	251 Alerts TES=MEP-62 TP-189 FP IONM-158 non OR Factors; 22 TP and 136 FP-Non OR Related Factors Higher in FP vs. TP
Takahashi[18] Spine 2021	Valid Alarm Point IONM TCeMEP-Cord JSSR-1934 Cases	=/>70% Decrease Amplitude TCeMEP High Risk Surgery-16 Centers 2017-2018	High Risk (Group HR)-OPLL Included: Deformity-Cord Intramedullary Tumors vs. Common Risk (Group C) Other Cervical Surgery	HR Sensitive 94.4%-Specific 87.0%-C: Sensitive 63.6%, Specific 91.9%	HR Sensitive OPLL 100%-Specific 86.9%-No Significant Differences with Deformity or Cord Tumors

(Contd...)

Table 1: *(Continued).*

Author [Ref] Journal Date	**Patient Population Study Aim**	**Results**	**Results**	**Results**	**Outcomes**
Kim[13] Clin Neurophysiol Pract 2021	IONM ACDF for OPLL-TcMEP, SEP-EMG-2009-2019	196 Pts v Controls-<u>Postop Deficits 3.79% IONM vs-14.06% non IONM Control</u>	IONM+Preop Myelop More Postop AE	23 Warning during IONM 17 TcMEP-84.2% Sensitive -6 EMG-Sensitive (84.2%) Specific (93.7%) IONM Warnings New Neuro deficits:	Multimodal IONM-Useful Detect Neuro Damage ACDF High Risk OPLL with Preop Myelop
Funaba[10] Spine 2022	IONM-336 OPLL 840 CSM TCeMEP JSSR->70% Loss Amplitude-Impact Treat Alert	Rescue Wave Recovery Treated Alerts -No Postop Neuro Deficits-Sensitive 71.4% OPLL-CSM 42.9%	C5 Palsy Sensitivity-66.7% OPLL vs 0% CSM-LE Palsy 100%-<u>Most TCeMEP Alerts During</u>-Decomp 63.16%-Screw 15.79%	<u>Rescue Rate</u> 58.3% OPLL-CSM 57.1%-Both TCeMEP-Best Detect Long Tract Injuries	Good C5 Palsy with OPLL-Rescue Rate >50% Right Treatment "...May have prevented postoperative neurological complications"
Yoo[19] J Clin Monit Comput 2022	IONM with OPLL-Preop SEP Evaluates Myelop-Use IONM Reduce Errors-(Iatrogenic Damage)	Studied Correlation PreSEP and IONM on PND in OPLL-265 Pts-Pre-SEP and IONM 2015-2019	3 Days Preop v 48 h and 4 wk Postop-Record PreSEP and ioSEP (Median/-Tibial Nerves	PreSEP Prolonged Latency Correlated with ioSEP and ioMEP Amplitudes-PND-Correlated at 4h h and 4 wk Postop with Prolonged Latency ioSEP	Worse with Increased EBL-PreSEP Predicted Sig Changes in ioSEP-Bleeding Control sig to Decrease PND in OPLL

OPLL=(Cervical) Ossification Posterior Longitudinal ligament, MR=Magnetic Resonance Imaging, CAT=Computed Tomographic Imaging, yr=years, mos=months, d=days, yo=years old, IOM/IONM=Intraoperative Neural Monitoring, SEP=Somatosensory Evoked Potentials, TES-MEP/MEP/NMEP=Transcranial Electrical Stimulation of Motor Evoked Potentials/Neurogenic MEP, EMG=Electromyographic Monitoring, C=Cervical, Th=Thoracic, L=Lumbar, M=Male, F=Female, avg=Average, Lat=Latency, Amp=Amplitude, IMSCT=Intramedullary Spinal Cord Tumor, EMSCT=Extramedullary Spinal Cord Tumor, T-OPLL=Thoracic OPLL, C-OPLL=Cervical OPLL, TCeMEPs/TcMEP/NMEP=Transcranial Electrical Stimulation Motor Evoked Potential, Dec=Decrease, Inc=Increase, JSSR=Japanese Society for Spine Surgery and Related Research, TP=True Positive, TN=True Negatives, FN=False Negatives, FP=False Positives, HPLL=Hypertrophied Posterior Longitudinal Ligament, LAM=Laminectomy, LamFor=Laminoforaminotomy, LOP=Laminoplasty, Fus=Fusion, ACDF=Anterior Cervical Diskectomy/Fusion, CSF=Cerebrospinal Fluid, TIVA=Total Intravenous Anesthesia, U=Units of Red Blood Cells, Circ=Circumferential, ACF=Anterior Cervical Corpectomy/Fusion, BP=Brachial Plexus, MM=Multimodality, Myelop=Myelopathy, Rad=Radiculopathy, Myelo-CT=Myelogram CAT Scan, TPE=Transcutaneously Placed, Epi=Epidural, Elec=Electrode, NMEP=Neurogenic Motor Evoked Potential, MonoRad=Monoradiculopathy, C5=Cervical C5 Root, spEMG=Spontaneous Electromyography Monitoring, CAD=Coronary Artery Disease, PPV=Positive Predictive Value, NPV=Negative Predictive Value, AP=Alarm Point, WG=Monitoring Working Group, HR=High Risk, DCM=Degenerative Cervical Myelopathy, CSM=Cervical Spondylotic Myelopathy, BR[E]-MsEPs=Brain Evoked Muscle Action Potentials, preSEP=Preoperative SEP, PND=Postoperative Neurologic Deterioration, Post=Posterior, Decomp=Decompression, SCM=Spinal Cord Monitoring, Postop=Postoperatively, OR=Operative Risks/Operating Room, TIVA=Total Intravenous Anesthesia, Pts=Patients , Simult=Simultaneous, PWF=Posterior Wiring/Fusion, h=Hours, EBL=Estimated Blood Loss, NIS=Nationwide Inpatient Sample (Healthcare Cost and Utilization Project 2009-2013), CCI=Charlson Comorbidity Index, Transcut=Transcutaneous, APB=Abductor Pollicus Brevis, ADM=Abductor Digiti Minimi, Exc=Excellent, spEMG=Spontaneous, Periop=Perioperative, HR=High Risk Surgery Group, Group C=Common Risk Surgery Group, DCM=Degenerative Cervical Myelopathy, PND=Postoperative Neurologic Deterioration PreSEP=Preoperative SEP, ioSEP=Intraoperative SEP, ioMEP=Intraoperative MEP, PSD=Postoperative Sensory Deterioration, OYL=Ossification Yellow Ligament, Comorbid=Comorbidities, C=Common Risk, Stim=Stimulation, C-OPLL=Cervical OPLL. Sig=Significant, NT=Nasotracheal, AE=Adverse Events lost in the left upper extremity during draping for an anterior cervical procedure; the surgeon's removal of the shoulder tape, and placement of the arms on arm boards resulted in SEP improvement, and full TCeMEP recovery [Table 1].[12] Because of this case, the authors; "...recommend that TCeMEP monitoring be considered as an adjunct to SEP for prevention of injury to the brachial plexus..." for cervical spine surgery.

TCeMEP Detect Cord Injuries/C5 Palsies in Cervical OPLL/CSM Surgical Patients, While EMG's Were Less Accurate

Two studies documented TCeMEP detected cord/long tract motor deficits, and C5 palsies in patients undergoing cervical surgery for OPLL or CSM; EMG's were less accurate [Table 1].[2,10] Bhalodia *et al*. (2013) found that during 229 predominantly C4 and/or C5 ACF, most C5 root injuries were documented with TC-MEP (100% sensitive; 99% specific); however, spontaneous EMG were less accurate.[2] In 2022, Funaba *et al*. performed TCeMEP (i.e., alert > /= 70% loss of amplitude) in 336 OPLL patients vs. 840 operations for CSM, and found the; "Overall sensitivity was higher for OPLL (71.4%) vs. CSM (42.9%)".[10] In short, the sensitivity of TCeMEP for lower extremity paralysis/cord injuries for both groups was 100%. However, it's accuracy was reduced to 66.7% for segmental palsy/root injuries in OPLL patients, but was nil (i.e., 0%) for signaling root injuries in CSM patients. Interestingly, most TCeMEP changes occurred during decompressions (63.16%), or screw placements (15.79%).

Efficacy of IONM for ACDF in Patients with OPLL But Not Disc Disease/Spondylosis/CSM

IONM Not Effective in Anterior Diskectomy/Fusion (ACDF) Excluding OPLL Surgery

In 2019, Badhiwala *et al*. (2019) demonstrated that IONM did not limit/prevent neurological deficits when used in ACDF surgery performed for disc disease, spondylosis, or CSM patients; however, this series specifically excluded OPLL patients [Table 1].[1] Their NIS Sample (Nationwide Inpatient Sample Healthcare Cost and Utilization Project 2009-2013) showed comparable frequencies of new neurological injuries for ACDF performed with (i.e., 1.7% out of 9380 monitored ACDF) vs. without IONM (i.e., 0.22% out of 9380 unmonitored ACDF). Further, IONM cost an additional average of $6843.00 per ACDF case.

IONM Effective in ACDF Performed for Cervical OPLL

Kim *et al*. (2021) documented that IONM using SEP, TcMEP, and continuous EMG monitoring effectively averted/limited surgical errors/new neurological injuries from occurring during ACDF performed in patients with cervical OPLL [Table 1].[13] They found the; "...rates of postoperative neurological deficits, neurophysiological warnings...", in 196 OPLL patients undergoing ACDF surgery (2009-2019) was reduced to 3.79% with IONM (23 warnings: 17 TcMEP, and 6 for EMG), vs. a significantly higher 14.06% incidence of new postoperative deficits in historical controls (i.e. ACDF without IONM performed 2003-2009). They concluded that utilizing all 3 modalities together; "...may be a useful tool to detect neurological damage in ACDF for high-risk conditions such as OPLL with pre-existing myelopathy".

MEP Alerts Warn of Surgical Errors/Impending Neurological Injury in Cervical OPLL and Other Cervical Surgery

Multiple studies effectively utilized IONM MEP alerts (i.e., set at =/> 70% decrease in amplitude; typically set at >/= 10% (i.e., subset set at >/= 15% decrease in latency)) to warn of surgical errors/impending neurological injuries occurring during OPLL, CSM and/or other cervical procedures [Table 1].[14,15,17,18,20] From 2010 to 2012, Kobayashi *et al*. (2014) set the Tc-MEP alert at =/> 70% decrease in amplitude for 959 patients undergoing cervical surgery for OPLL, spinal deformities, and spinal cord tumors.[14] This yielded a; "...high sensitivity (95%) and specificity (91%) for intraoperative spinal cord monitoring..."; there were just 2 false negatives (i.e. no intraoperative alerts occurring in 2 patients undergoing surgery for intramedullary cord tumors). In 2018, using Br[E]-MsEP alerts (Brain Evoked Muscle-Action Potentials; decrease =/> 70% in amplitude; =/> 10% to 15% increase in latency), Kobayashi *et al*. found that 9 of 83 patients undergoing spine surgery developed new postoperative motor deficits (i.e., true positives with a "sensitivity of 100% and specificity of 93%, with just 7% false positives, and 0% false negative rates) [Table 1].[15] They concluded that combining amplitude and latency alerts for Br[E]-MsEP provided highly sensitive and specific alerts, and; "...reduces false positive rates". Yoshida *et al*. (2019) confirmed the efficacy of TcMEP (i.e., loss of =/> 70% amplitude) in high-risk spine cases, including 622 with cervical OPLL [Table 1].[20] Most alerts occurred during; "...posterior decompression and dekyphosis in OPLL cases". The specific rescue rate (i.e., "...number of patients rescued with intervention after IONM alert/number of true positive cases + rescue cases...") for cervical OPLL cases was 82.1% (32/39 cases). With these findings, they concluded; "...appropriate intervention immediately after an IONM alert may prevent neural damage even in high-risk spinal surgeries". Takahashi *et al*. (2021) evaluated the impact of using Tc(E)-MEPs (=/> 70 decrease in amplitude) on 1934 patients undergoing high risk (HR) surgery (Group HR included cervical OPLL, deformity and spinal cord tumors) vs. common cervical surgery (Group C included more routine procedures); for OPLL, the sensitivity was 100%, and the specificity was 86.9%.[18] Shigematsu *et al*. (2021) studied the impact of non-surgery related factors resulting in TES-MEP changes (alert loss =/> 70% amplitude) for patients undergoing 1934 spinal surgeries including for OPLL, deformity, and spinal cord tumors (2017-2019).[17] There were 62 true positives, and 189 false positives; 150 of these were attributed to "non-surgical related factors" (i.e., "...22 (35.5%) true positives, and 136 (72%) false positive cases"). They concluded; "Although the surgeon should examine surgical procedures immediately after a TES-MEP alert, surgical intervention may not always be the best approach..."

CONCLUSION

This review indicates that triple IONM (i.e., SEP, MEP, and EMG) should be considered the standard of care (SOC) for performing cervical surgery for OPLL. Notably, using all 3 IONM modalities together better signaled intraoperative surgical errors that, if immediately addressed with appropriate resuscitative maneuvers, could limit/avert the onset of intraoperative/postoperative new neurological deficits (i.e. C5 and/or other root palsies, brachial plexus injuries, and/or new spinal cord deficits).

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. Badhiwala JH, Nassiri F, Witiw CD, Mansouri A, Almenawer SA, da Costa L, *et al.* Investigating the utility of intraoperative neurophysiological monitoring for anterior cervical discectomy and fusion: Analysis of over 140,000 cases from the National (Nationwide) Inpatient Sample data set. J Neurosurg Spine 2019;31:76-86.
2. Bhalodia VM, Schwartz DM, Sestokas AK, Bloomgarden G, Arkins T, Tomak P, *et al.* Efficacy of intraoperative monitoring of transcranial electrical stimulation-induced motor evoked potentials and spontaneous electromyography activity to identify acute-versus delayed-onset C-5 nerve root palsy during cervical spine surgery: Clinical article. J Neurosurg Spine 2013;19:395-402.
3. Darden BV 2nd, Hatley MK, Owen JH. Neurogenic motor evoked-potential monitoring in anterior cervical surgery. J Spinal Disord 1996;9:485-93.
4. Epstein NE. The surgical management of ossification of the posterior longitudinal ligament in 51 patients. J Spinal Disord 1993;6:432-54.
5. Epstein NE. Circumferential surgery for the management of cervical ossification of the posterior longitudinal ligament. J Spinal Disord 1998;11:200-7.
6. Epstein NE. Ossification of the cervical posterior longitudinal ligament: A review. Neurosurg Focus 2002;13:ECP1.
7. Epstein NE. Laminectomy for cervical myelopathy. Spinal Cord 2003;41:317-27.
8. Epstein NE. Cervical surgery for ossification of the posterior longitudinal ligament: One spine surgeon's perspective. Surg Neurol Int 2014;5:S88-92.
9. Epstein NE. What you need to know about ossification of the posterior longitudinal ligament to optimize cervical spine surgery: A review. Surg Neurol Int 2014;5:S93-118.
10. Funaba M, Kanchiku T, Yoshida G, Imagama S, Kawabata S, Fujiwara Y, *et al.* Efficacy of intraoperative neuromonitoring using transcranial motor-evoked potentials for degenerative cervical myelopathy: A prospective multicenter study by the monitoring committee of the Japanese society for spine surgery and related research. Spine (Phila Pa 1976) 2022;47:E27-37.
11. Gokaslan ZL, Samudrala S, Deletis V, Wildrick DM, Cooper PR. Intraoperative monitoring of spinal cord function using motor evoked potentials via transcutaneous epidural electrode during anterior cervical spinal surgery. J Spinal Disord 1997;10:299-303.
12. Jahangiri FR, Holmberg A, Vega-Bermudez F, Arlet V. Preventing position-related brachial plexus injury with intraoperative somatosensory evoked potentials and transcranial electrical motor evoked potentials during anterior cervical spine surgery. Am J Electroneurodiagnostic Technol 2011;51:198-205.
13. Kim JE, Kim JS, Yang S, Choi J, Hyun SJ, Kim KJ, *et al.* Neurophysiological monitoring during anterior cervical discectomy and fusion for ossification of the posterior longitudinal ligament. Clin Neurophysiol Pract 2021;6:56-62.
14. Kobayashi S, Matsuyama Y, Shinomiya K, Kawabata S, Ando M, Kanchiku T, *et al.* A new alarm point of transcranial electrical stimulation motor evoked potentials for intraoperative spinal cord monitoring: A prospective multicenter study from the Spinal Cord Monitoring Working Group of the Japanese Society for Spine Surgery and Related Research. J Neurosurg Spine 2014;20:102-7.
15. Kobayashi K, Ando K, Shinjo R, Ito K, Tsushima M, Morozumi M, *et al.* A new criterion for the alarm point using a combination of waveform amplitude and onset latency in Br(E)-MsEP monitoring in spine surgery. J Neurosurg Spine 2018;29:435-41.
16. Roh MS, Wilson-Holden TJ, Padberg AM, Park JB, Daniel Riew K. The utility of somatosensory evoked potential monitoring during cervical spine surgery: How often does it prompt intervention and affect outcome? Asian Spine J 2007;1:43-7.
17. Shigematsu H, Yoshida G, Kobayashi K, Imagama S, Ando M, Kawabata S, *et al.* Understanding the effect of non-surgical

factors in a transcranial motor-evoked potential alert: A retrospective cohort study. J Orthop Sci 2021;26:739-43.

18. Takahashi M, Imagama S, Kobayashi K, Yamada K, Yoshida G, Yamamoto N, *et al*. Validity of the alarm point in intraoperative neurophysiological monitoring of the spinal cord by the monitoring working group of the Japanese society for spine surgery and related research: A prospective multicenter cohort study of 1934 Cases. Spine (Phila Pa 1976) 2021;46:E1069-76.
19. Yoo M, Park YG, Cho YE, Lim CH, Chung SY, Kim D, *et al*. Intraoperative evoked potentials in patients with ossification of posterior longitudinal ligament. J Clin Monit Comput 2022;36:247-58.
20. Yoshida G, Ando M, Imagama S, Kawabata S, Yamada K, Kanchiku T, *et al*. Alert timing and corresponding intervention with intraoperative spinal cord monitoring for high-risk spinal surgery. Spine (Phila Pa 1976) 2019;44:E470-9.

How to cite this article: Epstein NE. Perspective: Triple intraoperative neurophysiological monitoring (IONM) should be considered the standard of care (SOC) for performing cervical surgery for ossification of the posterior longitudinal ligament (OPLL). Surg Neurol Int 2023;14:336.