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Efficacy of Intraoperative Neuromonitoring during the Treatment of Cervical Myelopathy

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Abstract

Objective The accuracy of intraoperative neuromonitoring (IONM) during surgery for cervical spondylotic myelopathy (CSM) to detect iatrogenic nervous system injuries while they are reversible remains unknown. We evaluated a cohort of patients who had IONM during surgery to assess accuracy.

Methods Patients who underwent surgical treatment of CSM that included IONM from January 2018 through August 2018 were retrospectively identified. A standardized protocol was used for operative management. Clinical changes and postoperative neurological deficits were evaluated.

Results Among 131 patients in whom IONM was used during their procedure, 42 patients (age 58.2 ± 16.3 years, 54.8% males) showed IONM changes and 89 patients had no change. The reasons for IONM changes varied, and some patients had changes detected via multiple modalities: electromyography ($n = 25$, 59.5%), somatosensory-evoked potentials ($n = 14$, 33.3%), motor evoked potentials ($n = 13$, 31.0%). Three patients, all having baseline deficits before surgery, had postoperative deficits. Among the 89 patients without an IONM change, 4 showed worsened postoperative deficits, which were also seen at last follow-up. The sensitivity of IONM for predicting postoperative neurological change was 42.86% and the specificity was 68.55%. However, most patients (124, 94.7%) in whom IONM was used showed no worsened neurological deficit.

Conclusion IONM shows potential in ensuring stable postoperative neurological outcomes in most patients; however, its clinical use and supportive guidelines remain controversial. In our series, prediction of neurological deficits was poor in contrast to some previous studies. Further refinement of clinical and electrophysiological variables is needed to uniformly predict postoperative neurological outcomes.

Keywords
- cervical spondylotic myelopathy
- degenerative cervical myelopathy
- electromyography
- intraoperative neuromonitoring

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Introduction

There has been increasing use of intraoperative neuromonitoring (IONM) for intraoperative evaluation of surgical correction as well as prediction of postoperative neurological changes.[1–10] One study showed 296% increase in the use of IONM between 2008 ($n = 31,762$) and 2014 ($n = 124,835$), along with substantial heterogeneity in clinical application.[11] Multimodality IONM (involving somatosensory evoked potentials [SSEPs], transcranial motor evoked potentials [tcMEPs], and electromyography [EMG]) is now used as a surgical adjuvant to help reduce neurological deficits by detecting neurologic injury while still reversible.[1,12] Despite its common use, recommendations about IONM are often conflicting.[12–15] A recent set of guidelines from the Joint Section of the American Association of Neurological Surgeons and Congress of Neurological Surgeons (AANS/CNS) suggested level I evidence for the use of IONM in a diagnostic (i.e., detection) capacity during spine surgery and level III evidence to support IONM in a therapeutic (i.e., reduction in patient deficits) or cost-effectiveness manner.[14] There also remains significant regional variability in the use of IONM as spine surgeons question its validity.[14,16] Because of the need to identify and treat intraoperative injuries to prevent postoperative neurological deficits in cervical spondylotic myelopathy (CSM), we investigated the clinical utility of using a standard care protocol with IONM to identify clinical changes and predict postoperative neurological deficits.

Methods

Patient Selection

With Institutional Board Review approval providing a waiver of informed consent, a retrospective analysis of patients who underwent surgical fusion for CSM and IONM was performed. Patients were included if they were at least 18 years old, underwent anterior or posterior cervical fusion during which IONM was used, had a preoperative diagnosis of CSM, and had complete preoperative and postoperative neurological examination information. Consecutive cases from January 2018 to August 2018 were evaluated. Patients with traumatic spinal cord injury or isolated thoracic myelopathy were excluded.

Patient Variables

Patients underwent standardized preoperative and intraoperative management during treatment via use of a multidisciplinary checklist (►**Table 1**). Various clinical variables were analyzed. Nurick classifications of myelopathy were analyzed (grade 0: roots only or normal; grade 1: signs of cord compression, normal gait; grade 2: gait difficulty but fully employed; grade 3: gait difficulty prevents employment, walks unassisted; grade 4: unable to walk without assistance; grade 5: wheelchair- or bedbound).[17]

Neuromonitoring Setup and Thresholds

IONM was performed in all patients by using SSEPs, tcMEPs, and spontaneous EMG activity of the nerve roots using Cascade Elite Pro equipment (Cadwell, Kennewick, Washington, United States).

SSEPs were performed after bilateral independent median and posterior tibial nerve stimulation through subdermal needles. Stimulation of the ulnar nerve was performed when C8-T1 nerve roots were thought to be at risk. Supramaximal and constant current stimulation was performed to elicit a visible muscle twitch in all extremities. Recording was performed through subdermal needles placed according to the international 10 to 20 classification system with two cortical channels ($C_{3/4}$ contralateral-midfrontal [MF] and $C_{3/4}$

Table 1 Standardized preoperative and intraoperative management of cervical spondylotic myelopathy patients

Timing of steps	Management steps
Preoperative	Arterial line placed
	Mean arterial blood pressure maintained >85 mm Hg throughout case
	Intravenous propofol and remifentanil with low-dose inhalational anesthetic used
	Surgical time out with surgical, anesthesiology, and IONM teams performed
Intraoperative management of IONM changes	Baseline IONM potentials performed before cervical traction
	Attention of surgical, anesthesiology, and IONM teams focused on timing and characteristic of change
	Mean arterial blood pressure verified and increased if necessary
	Anesthetic doses and concentrations verified
	Surgical maneuver reversed if possible (e.g., placement of interbody, reduction of distraction)
Postoperative evaluation	Debriefing of IONM change performed among surgical, anesthesiology, and IONM teams
	Patient monitored in neurocritical care unit if IONM change intraoperatively
	Rehabilitation consultation performed postoperatively

Abbreviation: IONM, intraoperative neuromonitoring.

contralateral-$C_{3/4}$ ipsilateral for upper extremities and Cz-MF and $C_{3/4}$ contralateral-$C_{3/4}$ ipsilateral for lower extremities), one subcortical channel (ipsilateral mastoid-MF for both upper and lower extremities), and ipsilateral Erb-contralateral Erb for peripheral potentials. Recording filters were a 30-Hz, low-frequency filter, and a 1000-Hz, high-frequency filter.

tcMEPs were performed through corkscrew needle electrodes positioned at M3-M4, or alternatively at M1-M2 when there was significant movement associated with stimulation with the former montage. A bite block was used in all cases. The most commonly used stimulation parameters for high-frequency pulse train stimulation were interstimulus interval of 2 millisecondsec, train of 6 stimuli, pulse width of 75 µsec, and a stimulation intensity varying between 80 and 400 V that would elicit a minimum of 30-µV tcMEP response from all sampled muscles on the contralateral side with acceptable patient movement. Our muscle sampling protocol involves trapezius, deltoid, biceps, triceps, extensor digitorum communis, abductor pollicis brevis, and abductor hallucis as the most commonly sampled muscles in neuromonitoring of cervical spine procedures. tcMEPs were performed as requested and allowed by the surgeon. All traces were automatically stored. Each recording trace included tcMEP responses from all monitored muscles with both cathodal and anodal stimulation. Spontaneous EMG activity was also monitored in all sampled muscles.

The criteria for noting change were defined by the American Clinical Neurophysiology Society guidelines.[18] For SSEPs, 50% amplitude decline or more than 10% latency increase of the N20 waveform was considered as a critical change. For tcMEPs, 80% amplitude decrease was considered a significant change by default when accompanied by a change in morphology from polyphasic to mono- or biphasic waveform or failure to improve despite an at least 100-V voltage increase. Occasionally, when baseline MEPs were impaired, or there was significant fluctuation because of change in anesthetic regimen, or neuromuscular blocking agents were used, then an all-or-none criterion was used. Rarely, when there was an isolated 50% tcMEP amplitude decrease from the deltoid muscle correlating with the critical portion of surgery, then the surgeon was advised of these findings.

All interpretation was performed within the context of and considering changes in mean arterial pressure (MAP), anesthetics used, and administration timing of neuromuscular blocking agents. Baseline recordings were performed after induction of anesthesia. Baselines were obtained in supine position when there was vertebral column instability and a planned posterior approach to assess for any positioning-related compromise. Total intravenous anesthesia was used in most procedures. IONM changes were considered transient when final evoked potentials returned to baseline recordings.

Intraoperative and Postoperative Care

Several standardized measures were used at our institution during the treatment of patients with CSM (►**Table 1**). All patients routinely underwent placement of an arterial line and maintenance of MAPs more than 85 mm Hg for the duration of the case. Normothermia was targeted for all patients via Bair Hugger, and confirmation of reversal of neuromuscular blockade by train of four stimuli was achieved prior to IONM. Patients with IONM changes thought to be due to surgery were placed in an intensive care setting postoperatively for close monitoring for a minimum of 24 hours. Intravenous propofol and remifentanil along with low-dose inhalational anesthetics were routinely used. A surgical timeout was initiated before surgery in the presence of the surgical, anesthesiology, and IONM teams. Baseline potentials were obtained before any positioning, once further after positioning was acquired, and then throughout the case. After IONM changes were detected, there was collaborative troubleshooting by the surgeon, anesthesiologist, and IONM team on every case (►**Table 1**). The initial goals after IONM changes were identified were to raise MAPs if necessary, modify patient positioning or instrumentation if possible, and identify any other potentially reversible steps. The cases of patients with postoperative deficits were reviewed by the surgical and IONM teams jointly as part of a surgical debriefing. All myelopathic patients routinely underwent evaluation by physical medicine and rehabilitation physicians to assess eligibility for inpatient rehabilitation and other medical recommendations.

Postoperative neurological evaluation was performed immediately after surgery and on each subsequent day until discharge. A deficit was noted if a change from preoperative to postoperative neurological examination was documented prior to discharge. A deficit on follow-up was noted based on the patient's last clinical follow-up.

Analysis

Continuous and discrete variables are reported as means ± standard deviation and count (% total), respectively. The number of patients with persistent neurological changes who could be statistically analyzed was limited. Summary statistics were calculated using SPSS (V23.0, IBM).

Results

A total of 372 patients who had a diagnosis of degenerative myelopathy and whose case involved neuromonitoring were identified; 241 were excluded for various reasons, 42 patients showed an IONM change, and 89 showed no IONM change (►**Fig. 1**, ►**Tables 2** and **3**). Among the 42 patients with neuromonitoring changes, 3 patients (7.1%) showed postoperative neurological deficits (►**Table 4**). For the 89 patients without IONM changes, 4 patients (4.5%) showed some postoperative deficit that, although mostly mild, persisted up to last follow-up (►**Table 4**).

Sensitivity of 42.86%, specificity of 68.55%, positive predictive value of 7.14%, and negative predictive value of 95.51% were identified for IONM in predicting postoperative neurological changes (►**Table 3**). An overall accuracy for predicting neurological deficit of 67.18% (95% confidence interval [CI]: 58.43–74.12%) was observed. The majority of

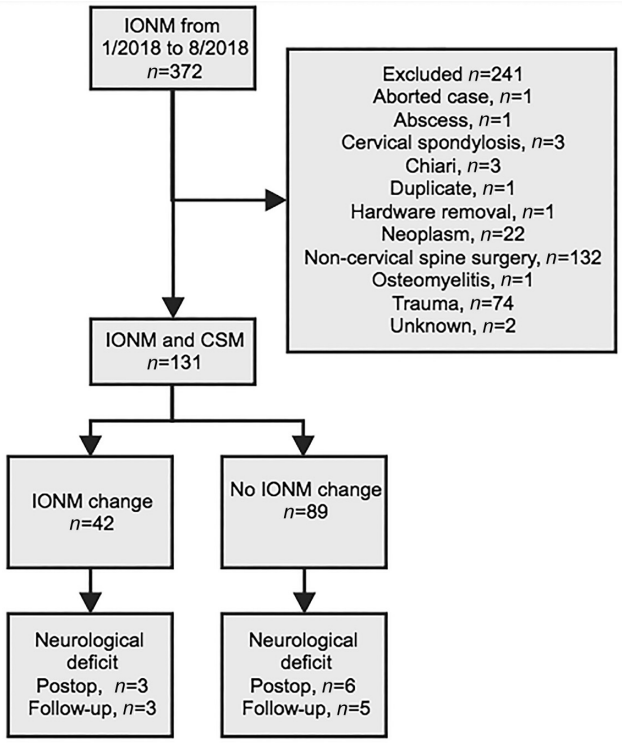

Fig. 1 Flowchart demonstrating selection of patients. CSM, cervical spondylotic myelopathy; IONM, intraoperative neuromonitoring.

patients ($n = 124/131$, 94.7%) showed no worsened neurological deficit after surgery involving the use of multimodal IONM.

Case 1

A 51-year-old man presented with a 3-year history of worsening peripheral neuropathy and severe myelopathy in the setting of severe alcoholism, recurrent pneumonias, and osteomyelitis/discitis (►**Fig. 2**). Preoperatively, he showed some weakness in the upper and lower extremities, decreased sensation greater in the upper extremities, and mildly diminished rectal tone. He underwent a two-stage surgical procedure, including a partial C3/4 corpectomy with placement of polyetheretherketone cage, C5/6 anterior cervical discectomy and fusion, and C3–6 anterior cervical fusion, followed by a C2–6 posterior spinal fusion 2 days later. During the stage 1 procedure, neuromonitoring demonstrated widespread bilateral and asymmetric EMG irritation. There were no accompanying SSEP or tcMEP changes during stage 1 and no neurophysiologic change was seen in the stage 2 of the procedure. His postoperative course was complicated by dysphagia with worsened sensory and bowel issues, but he was able to discharge home.

Discussion

Study Results

In this study, we evaluated the ability of modern, multimodal IONM to predict new postoperative deficits and its utility in surgical decision-making. In regard to function evaluated by IONM, three patients had unexpected new postoperative deficits after IONM changes. Overall, the sensitivity of IONM for detecting postoperative deficits in CSM was limited and specificity was moderate. These results are not

Table 2 Baseline characteristics and IONM findings for 42 patients with cervical myelopathy and IONM changes

Variable	Value
Age (years)	58.1 ± 16.1
Sex (male)	23 (54.8%)
Pathogenesis of myelopathy	
Degenerative	40 (95.2%)
Neoplastic	1 (2.3%)
Infection	1 (2.3%)
Nurick grade	
1	21 (50.0%)
2	15 (35.7%)
3	4 (9.5%)
4	1 (2.3%)
Case time (hh:mm)	3:03 ± 1.09
IONM tech time (hh:mm)	4:29 ± 1.22
Length of stay (days)	3 ± 3
Follow-up time (months)	3.9 ± 2.3
Fusion approach	
Anterior	26 (61.9%)
Posterior	14 (33.3%)
Anterior & posterior	2 (4.8%)
Level of fusion	
Occiput	2 (4.8%)
C1	5 (11.9%)
C2	14 (33.3%)
C3	21 (50.0%)
C4	30 (71.4%)
C5	28 (66.7%)
C6	26 (61.9%)
C7	17 (40.5%)
T1	11 (26.2%)
T2	3 (7.1%)
Number of fusion levels	3.7 ± 1.9
Corpectomy	7 (16.7%)
Intraoperative neuromonitoring change	
EMG	25 (59.5%)
SSEP	14 (33.3%)
MEP	13 (31.0%)

Abbreviations: EMG, electromyography; IONM, intraoperative neuromonitoring; MEP, motor evoked potentials; SD, standard deviation; SSEP, somatosensory evoked potentials.
Data are presented as mean ± STD or count (% total).

Table 3 Sensitivity and specificity of IONM for predicting neurological deficits in CSM

	Deficits absent	Deficit present	Totals
Change in IONM	39	3	42
No change in IONM	85	4	89
Totals	124	7	131
	Value	**95% CI lower limit**	**95% CI upper limit**
Sensitivity	42.86	11.8	79.76
Specificity	68.55	59.51	76.42
Positive predictive value	7.14	1.86	20.55
Negative predictive value	95.51	88.26	98.55

Abbreviations: CI, confidence interval; CSM, cervical spondylotic myelopathy; IONM, intraoperative neuromonitoring.

surprising given the known challenges in clinical and electrographic diagnosis of myelopathy, as well as the unpredictable clinical progression and surgical response of the disease. However, the strong negative predictive ability for IONM could be reassuring for surgeons and patients. Most patients (94.7%) showed no worsened deficits postoperatively, and this could be interpreted as the expected course of multimodal IONM, modern surgical techniques, and multidisciplinary management. These findings highlight a need for better interpretation of IONM findings with respect to pre-existing disease burden and surgical steps being performed. Further study, using prospective, multicenter data would be necessary to optimize surgical management from IONM results.

Best Practices for IONM

Multiple guidelines, including those by the Joint Section of the AANS/CNS,[12,14] position statements by the American Society of Neurophysiological Monitoring,[18] and individual reviews/meta-analyses[13,15] have yielded conflicting findings. Although good evidence supports the use of IONM to detect neurological changes, translating these findings to improvement of patient outcomes remains challenging.[14] Our current results show limited sensitivity for IONM in predicting postoperative recovery. Our study shows one method of using a multidisciplinary protocolized approach toward using IONM in patients with CSM.

Several recent meta-analyses have suggested that patient heterogeneity and IONM technique variation may account for the varying impact of IONM in reducing postoperative deficit. Thirumala et al[13] reviewed two studies that used IONM during CSM surgery. The use of IONM was associated with a lower rate of worsening myelopathy or quadriplegia compared with studies where IONM was not used (0.91 vs. 2.71%). Variation in use of the Nurick scale, Japanese Orthopedic Association score, or modified Medical Research Council muscle grading was seen among these studies, as well as a high interstudy heterogeneity index. C5 root and deltoid palsies were common among neurological deficits, with a rate of 4.56% (3.74% transient and 0.74% permanent) in patients without IONM compared with 0.84% rate in patients with IONM. Dysphagia was seen in 6.23% of patients without IONM and was not present in patients with IONM. The conclusion of this study was that "no evidence exists to refute or support the use of [IONM] to reduce neurological complications during anterior cervical procedures." One important point is that C5 root and pharyngeal monitoring are not part of routine IONM, requiring additional equipment and/or expertise. Daniel et al[15] reviewed six studies in which IONM was used during spine surgery. Significant interstudy heterogeneity was noted. The pooled odds ratio of IONM to reduce postoperative deficit was not significant (0.1993; 95% CI: 0.0384, 1.035; $p = 0.055$). Limitations of studies evaluating IONM in CSM include the small sample size, occasional reliance on a single IONM modality (e.g., MEP), patient heterogeneity, and lack of comparison group.

Sensitivity and Specificity for IONM in CSM

In contrast to our study, others have shown very high sensitivity and specificity for IONM. Among 140 patients with CSM studied, Clark et al[19] found 16 (11%) showed intraoperative MEP decrements and 8 (6%) had postoperative deficits. Among the 8 postoperative deficits, 6 were C5 root palsies and 2 were paraparesis. The sensitivity of IONM was calculated to be 75% and specificity 98%, with differences depending on patient age and comorbidities as well as increased sensitivity in patients with preoperative motor deficits. A follow-up study by Clark et al[20] in 144 patients compared 102 patients with degenerative CSM and 42 patients with nondegenerative causes (24 extra-axial tumors, 12 infectious processes, 5 traumatic fractures, and 1 rheumatoid arthritis) who had IONM used during their surgery. For degenerative versus nondegenerative cases, a sensitivity/specificity of 71%/94% versus 33%/74% was identified respectively. This improved accuracy for IONM in degenerative cases contrasted with both from our study and relied predominantly on MEPs to determine intraoperative changes. The use of SSEPs and EMG in our study could also have increased false positives and lowered accuracy compared with other studies. Lastly, heterogeneity in spine populations may impact outcomes and population of spine disease in studies by Clark et al.

C5 nerve root palsies remain challenging to detect, especially in CSM. Oya et al[21] evaluated 131 cases of CSM in which the patients had IONM during surgery, showing that while IONM alerts were quite nonspecific for reporting postoperative C5 root palsy with some false negatives, MEP alerts in the deltoids or biceps showed the best accuracy (sensitivity: 100%, specificity: 98.4%). On the other hand, Fan et al[22] evaluated 200 patients undergoing cervical laminectomy with IONM for compressive myelopathy and found good accuracy for identifying C5

Table 4 Summary of patients with persistent neurological changes

Case	Age (years)/sex	Preoperative findings	Preop Nurick grade	Surgical procedure	IONM change	Postoperative findings	Follow-up exam
Patients with persistent neurological changes detected intraoperatively ($n = 3/42$)							
1	51.4/M	B, T: 4; HF, KE, KF: 4; Right DF: 2; Right PF: 4; Decreased sensation upper > lower extremities; mildly decreased rectal tone	3	C3/4 corpectomy, C5/6 discectomy, C2–6 ACF, C2–6 PSF	EMG activity from bilateral triceps muscles (right > left) during placement of the cage. No SSEP or tcMEP changes.	Stable motor; worsened sensory level, bowel incontinence	Stable motor exam and bowel incontinence; worsened sensory level
2	76.0/M	Neck and C7 arm pain, right C6/7 numbness	1	C2-T1 laminectomy and PSF	>80% amplitude decline of left APB tcMEP. Improved to noncritical range by end of procedure (remained 72% decreased). No accompanying SSEP changes.	C7 arm pain; WE, WF, G: 4	Persistent C7 hyperesthesia
3	39.2/F	Neck pain, C5 radiculopathy, subjective arm weakness	1	C5/6 ACDF, C7/1 ACDF, C2-T1 laminectomy and PSF	Sensory change in right upper extremity	D: 2; B, T: 4	Improved pain; D, B, T: 4+
Patients with persistent neurological changes not detected intraoperatively ($n = 4/89$)							
1	55.8/F	Neck pain, bilateral C8 radiculopathy and numbness	1	C4–6 plate removal, C7/T1 corpectomy and cage, C6-T2 fusion		G: 5-	Right C8 radiculopathy and mild numbness
2	73.0/M	D/B/T: 5-; WF/WE/G: 4 + ; numbness in upper extremities; wheelchair bound	5	C5/6 laminectomy, extension of fusion to T2		D/B/T: 4; G: 3; H/PF/DF: 5; wheelchair bound	D: 4-; B: 4; T/WE/WF: 5-; wheelchair bound
3	55.4/M	B: 4; left deltoid numbness	1	C3–6 decompression and fusion		D: 2; B: 3; T: 4	D: 4; B: 3; T: 4
4	61.9/M	T: 3; WE: 4; G: 2; HF/KE/KF: 3–4	4	C4–6 ACF, C5 corpectomy, C4–5 laminectomy, C3–7 fusion		D/B: 4; T:2; G: 0; HF/KE/KF: 3–4	T/G: 4; HF/KE/KF: 3–4

Abbreviations: ACDF, anterior cervical discectomy and fusion; ACF, anterior cervical fusion; APB, abductor pollicis brevis; B, biceps; D, deltoid; DF, dorsiflexion; EMG, electromyography; F, female; G, grip; HF, hip flexors; IONM, intraoperative neuromonitoring; KE, knee extension; KF, knee flexion; M, male; MEP, motor evoked potential; PF, plantar flexion; PSF, posterior spinal fusion; SSEP, somatosensory evoked potential; T, triceps; tcMEP, transcranial motor evoked potential; WE, wrist extensors; WF, wrist flexors.

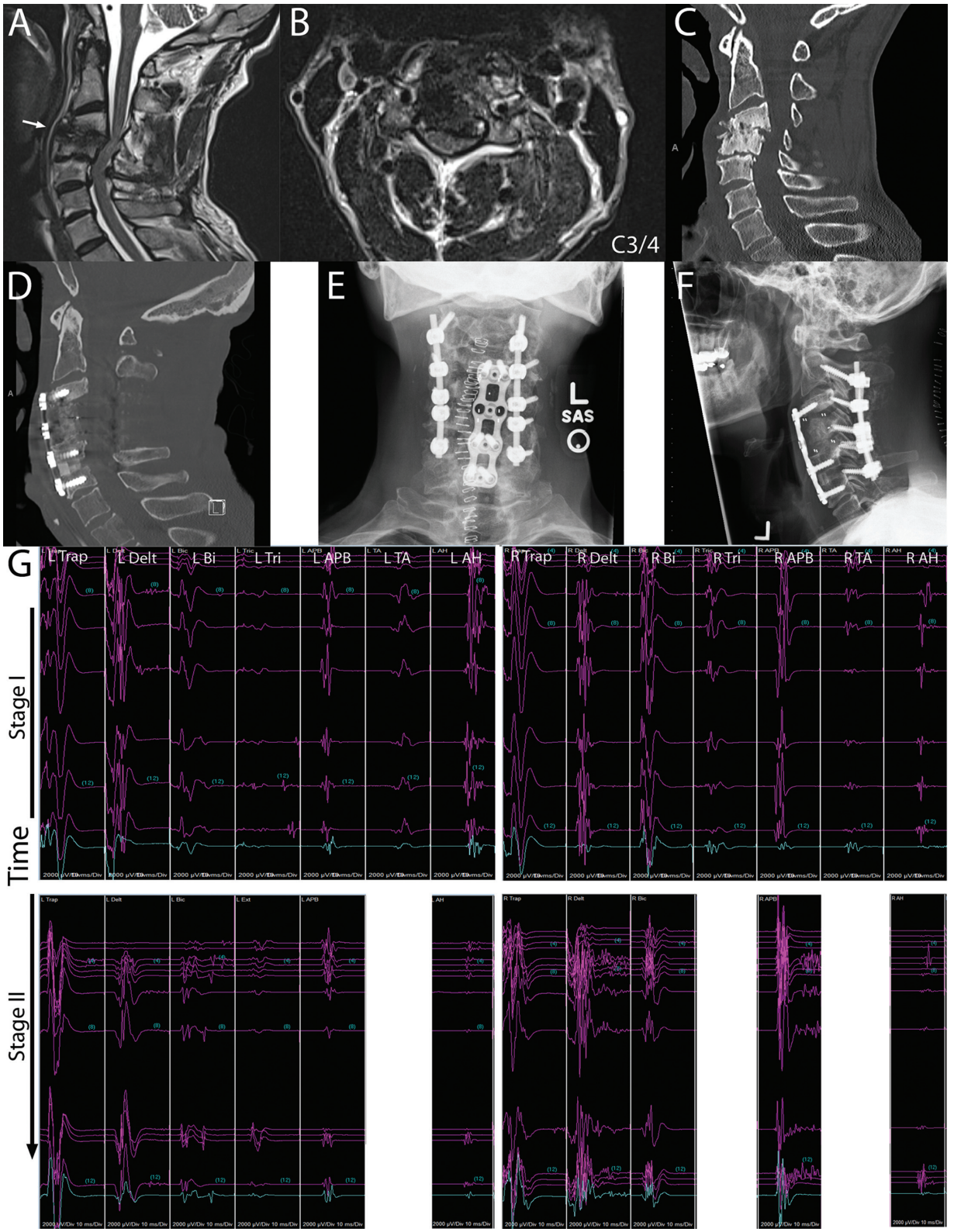

Fig. 2 Case 1. Preoperative (**A**) sagittal and (**B**) axial cervical T2-weighted MRIs demonstrating severe compression worse at C3/4 (arrow) along with cord signal change. (**C**) Preoperative midsagittal CT of the cervical spine demonstrating collapse of C3/4 disc space, osteophytic disease, and loss of cervical lordosis. (**D**) Postoperative midsagittal CT demonstrating the partial C3/4 corpectomy with PEEK implant. Postoperative (**E**) anteroposterior and (**F**) lateral X-rays showing the final anterior C3/4 PEEK cage, C5/6 PEEK interbody, C3–6 ACF, and C2–6 PSF. (**G**) tcMEP responses after anodal stimulation during stage 1 (top set) and stage 2 (bottom set) of the procedures (gain 2,000 µV/Div). There were no tcMEP changes. There was EMG activity from the bilateral triceps muscles during placement of the cage (not shown). APB, abductor pollicis brevis; ACF, anterior cervical fusion; AH, abductor hallucis; Bi, biceps; CT, computed tomography; Delt, deltoid; EMG, electromyography; L, left; MRI, magnetic resonance imaging; PEEK, polyetheretherketone; PSF, posterior spinal fusion; R, right; TA, tibialis anterior; tcMEP, transcranial motor evoked potential; Trap, trapezius; Tri, triceps.

root injuries. A total of 8 patients showed C5 root injuries, which were predicted by deltoid/biceps MEP and EMG alerts. No false-negative or false-positive results were seen. Kim et al[23] evaluated 52 patients undergoing surgical treatment for CSM with 6 patients showing an MEP alert (>80% loss of amplitude). Only 1 patient was correctly predicted to have postoperative deficits (MEP: sensitivity 100%, specificity 90%; SSEP: sensitivity 0%, specificity 100%).

Another point of view may be that better patient stratification is needed to improve prediction of outcomes. Lin et al[24] evaluated 152 patients with cervical compressive myelopathy and found that abnormal preoperative spinal cord T2 hyperintensity with T1 hypointensity was more likely in patients with IONM changes. The integration of imaging findings into preoperative stratification and prediction of outcomes in conjunction with IONM may be an interesting avenue of exploration in future studies. Our study did not show differences in patient comorbidities (e.g., preoperative Nurick grade) improving predictability of outcomes, although the overall sample size of patients with neurophysiologic changes was small.

IONM for Intraoperative Decision-Making

One potential strategy for use of IONM may be intraoperatively as an early warning system to reduce provocative maneuvers during surgery. Here, surgeons can aim to maximize patient benefit while accepting the potential for false-negative findings from IONM. Several groups have described the used of checklists for IONM,[25,26] and a specific checklist for CSM has been presented.[27] Our results show limited sensitivity (42.86%) for IONM to predict postoperative deficits and moderate specificity (68.55%) with mixed results in other studies. The use of IONM alone was not enough to prevent neurological decline in our series. Disease progression or surgical trauma may be a possibility in the treatment of such patients regardless of best practices. However, most patients (94.7%) showed safe surgical outcomes. The strategy of a protocol and checklists may be the most appropriate for using IONM as a surgical adjunct to improve patient outcomes rather than as a perfect method to prevent postoperative deficits. Our approach was to use a standardized multidisciplinary, collaborative approach among various physician teams aimed to improve patient outcome in this manner, with IONM playing a central role in surgical monitoring.

Limitations

Several limitations of this study include its retrospective nature, resulting in unblinded, retrospective analysis of preoperative and postoperative neurological findings. Another limitation is the small sample size, which reduced our ability to perform subgroup analysis. Identifying the specific IONM changes (i.e., tcMEP, SSEP, and EMG) and thresholds that would predict postoperative neurological deficits was not possible in this study. Moreover, a comparative group of CSM patients treated surgically who did not have IONM was not available at our institution. Also, with our current checklist bundle, it is unclear which specific component is the most impactful on patient outcomes. Despite these limitations, strengths of this study were the high granularity of neurological changes evaluated and correlation with IONM findings.

Conclusion

Multiple studies have suggested the challenges of integrating IONM into prediction of neurological outcomes. Our study showed that IONM was efficacious as a surgical adjunct but showed limited accuracy in predicting postoperative outcome in contrast to some previous studies. Moreover, we describe how a standardized multidisciplinary collaboration using the best available evidence may serve as the most effective method to optimize patient care in light of the limitations and controversies of IONM.

Conflict of Interest

A.T.D. reports being a consultant for Zimmer Biomet and K2M; receiving support for non–study-related clinical or research work he oversees; and receiving an honorarium from AO North America. E.F.B. is the recipient of a grant from PCORI, receives fellowship funding from Globus, is a consultant for MiRus, and has stock ownership in nView. The remaining authors have no conflicts of interest to declare.

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