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Electrophysiological monitoring during surgery for cervical degenerative myelopathy and radiculopathy

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Object. The objective of this systematic review was to use evidence-based medicine to examine the diagnostic and therapeutic utility of intraoperative electrophysiological (EP) monitoring in the surgical treatment of cervical degenerative disease.

Methods. The National Library of Medicine and Cochrane Database were queried using MeSH headings and key words relevant to cervical spine surgery and EP monitoring. The guidelines group assembled an evidentiary table summarizing the quality of evidence (Classes I–III). The group formulated recommendations that contained the degree of strength based on the Scottish Intercollegiate Guidelines network. Validation was done through peer review by the Joint Guidelines Committee of the American Association of Neurological Surgeons/Congress of Neurological Surgeons.

Results. The reliance on changes in EP monitoring as an indication to alter a surgical plan or administer steroids has not been observed to reduce the incidence of neurological injury during routine surgery for cervical spondylotic myelopathy or cervical radiculopathy (Class III). However, there is an absence of study data examining the benefit of altering a surgical plan due to EP changes.

Conclusions. Although the use of EP monitoring may serve as a sensitive means to diagnose potential neurological injury during anterior spinal surgery for cervical spondylotic myelopathy, the practitioner must understand that intraoperative EP worsening is not specific—it may not represent clinical worsening and its recognition does not necessarily prevent neurological injury, nor does it result in improved outcome (Class II). Intraoperative improvement in EP parameters/indices does not appear to forecast outcome with reliability (conflicting Class I data).

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Key Words • **electrophysiological monitoring** • **myelopathy** • **radiculopathy** • **practice guidelines** • **spinal surgery** • **treatment outcome**

Recommendations

The reliance on changes in EP monitoring as an indication to alter a surgical plan or administer steroids has not been observed to reduce the incidence of neurological injury during routine surgery for CSM or cervical radiculopathy. Accordingly, its routine use in these circumstances is not recommended (quality of evidence, Class III; strength of recommendation, D). However, there may be circumstances in which the surgeon desires the added intraoperative diagnostic information that EP monitoring may confer.

Although the use of EP monitoring, including TcMEPs, may serve as a sensitive means of diagnosing potential neurological injury during anterior spinal surgery for CSM, the practitioner must understand that intraoperative EP worsening is not specific—it may not repre-

Abbreviations used in this paper: CSM = cervical spondylotic myelopathy; EMG = electromyography; EP = electrophysiological; MEP = motor evoked potential; SSEP = somatosensory evoked potential; TcMEP = transcranial MEP.

sent clinical worsening and its recognition does not necessarily prevent neurological injury, nor does it result in improved outcome (quality of evidence, Class II; strength of recommendation, C).

No recommendation may be given for the use of intraoperative improvement on EP parameters/indices as a means to forecast outcome with reliability because conflicting Class I data exist on this matter.

Rationale

Many practitioners have commonly used EP monitoring during spinal surgery. Use of such technology carries certain costs. Proponents of monitoring claim that the use of these techniques improves the safety and efficacy of surgery. The purpose of this evidence-based review is to establish whether EP monitoring improves the safety or efficacy of surgery performed for CSM. There are 2 questions considered in this manuscript. First, do abnormalities noted in intraoperative EP monitoring predict postoperative neurological deficits in patients with CSM? Second, does the use of EP monitoring increase the safety or efficacy of surgery for CSM?

Search Criteria

We searched the computerized database of the National Library of Medicine and the Cochrane Database (date range 1966–2007) using MeSH headings and the following keywords: "cervical myelopathy and somatosensory-evoked response," "cervical myelopathy and SSEPs," "cervical myelopathy and magnetic stimulation," "cervical myelopathy and MEPs," "cervical myelopathy and EMG," "cervical myelopathy and electromyogram," "cervical myelopathy and motor-evoked response," and "cervical myelopathy and muscle-action potential." The results were limited by the terms "decompression" or "surgery" and the search was restricted to the English language, resulting in an initial group of 868 papers. We reviewed the title and abstract of each paper and excluded duplicates, diagnostic studies, animal studies, and case reports. We then examined reference lists of reviewed articles to cull further references. We identified 39 references as providing relevant medical evidence and these provide the basis for this review. We ranked evidence using previously described methodology.[11] In this chapter, we have stratified papers into 2 groups: 1) those that examined alternations in monitoring as a diagnostic test for the development of permanent neurological deficits; and 2) those that considered the utility of monitoring to prevent neurological deficits as a therapy. The evidentiary table summarizes all papers providing relevant evidence (Table 1).

Scientific Foundation

Multiple authors have reported that EP monitoring may detect intraoperative neurological injury.[4,6,7,16,20,28] The relative sensitivity and specificity of the various monitoring techniques differ depending on the patient's diagnosis and the procedure performed.[6] The purpose of this review was to establish the clinical utility of intraoperative EP monitoring for the avoidance of clinically relevant neurological injury during decompressive procedures performed for CSM. Authors of studies examining the utility of EP monitoring as a diagnostic or therapeutic tool have used "clinically relevant neurological injury" as the outcome measure.

Sebastian et al.[19] described a series of 210 patients who underwent SSEP monitoring during anterior decompressive surgery for CSM. These authors found that significant changes occurred in 84 patients, with 44 patients showing improvement in monitoring, and 40 showing significant worsening or unstable responses. The majority of the episodes of worsening were attributed to various systemic issues related to anesthesia, hypotension, or hypothermia. Thirteen episodes were thought to be the result of mechanical stress to the cord, and the surgeon made some sort of inspection or adjustment following the alert. No patient awoke with a relevant new deficit, and no correlation between SSEP improvement and functional outcome was described. This paper provided little useful information on the clinical utility of SSEP monitoring. There was no correlation between reported events (positive or negative) and outcome, and no way to determine whether the intraoperative adjustments were helpful or harmful.

May and colleagues[17] described their results in a series of 182 patients who underwent SSEP monitoring during a variety of decompressive procedures. Twenty-four patients had SSEP changes without new deficits, 9 patients had SSEP changes and a new deficit, and 1 patient had a new deficit undetected by SSEP. The authors reported that the sensitivity of SSEP for predicting a new deficit was 99% and the specificity was 27%. No mention was made of surgeon response (or lack thereof) to change in SSEP monitoring. Accordingly, the influence of SSEP monitoring on clinical outcome could not be determined. Because of the mixed patient population, this study was considered to provide Class II evidence for the use of SSEP as a diagnostic tool to detect injury.

Dennis and colleagues[5] reported on a mixed population of 31 patients who underwent intraoperative SSEP monitoring. Of 27 patients without new deficits, SSEP changes were observed in 6 (false positive). One of these patients showed improvement in SSEP recordings with adjustment of traction. Four patients' conditions deteriorated, and 2 of these patients had SSEP changes (sensitivity 50%, overall specificity 25%). The authors concluded that SSEPs were not specific for the detection of intraoperative neurological injury. This paper provided Class II evidence regarding the ability of SSEP monitoring to predict injury but did not provide evidence regarding the utility of SSEP monitoring for avoiding injury.

Smith et al.[21] performed a retrospective cohort comparison of 1037 patients who underwent anterior cervical discectomy for radiculopathy. Approximately half of these patients underwent intraoperative SSEP monitoring. There were 6 alerts in the monitored group, 5 thought to be caused by hypotension and 1 due to retractor position. None of these patients had a new postoperative deficit. Postoperative central cord syndrome developed in 1

TABLE 1: Evidentiary summary of studies on EP monitoring and outcomes*

Authors & Year	Description	Class	Conclusion
Lee et al.,1995	Case series of 8 patients who underwent MEP monitoring produced by magnetic stimulation. 3 patients had changes in monitoring, 2 resolved spontaneously & 1 did not. 1 patient whose changes did not resolve had a transient deficit. No patient had a permanent deficit. Patient population largely tumor.	II (diagnosis)	No relevance to CSM population.
May et al., 1996	SSEPs were recorded during 182 procedures for a variety of compressive lesions. 24 patients had SSEP changes & no new deficits, 9 patients had SSEP changes & new deficits, and 1 patient had a new deterioration w/o SSEP changes.	II (diagnosis)	Sensitivity of SSEPs for predicting new deficit 99%, specificity 27%. No mention made of surgeon response (or lack thereof) to change in SSEPs & subsequent clinical course. Downgraded to Class II because of mixed patient population.
Lee et al., 2006	1445 patients monitored w/ TcMEP, SSEP, & EMG. The population included an unclear proportion of patients w/ CSM, along w/ other patients (radiculopathy, tumor, & trauma). 267 patients had EP alerts. 8 surgeries were aborted due to alerts but no new deficits seen. 2 patients whose surgeries were not aborted (1 patient had BP increased & 1 patient had completion of decompression) had loss of signal & new deficits.	II (diagnosis) III (therapy)	Multimodality monitoring may detect the occurrence of a neurological injury; however, it is unclear if reaction to alerts has any effect on outcome. The authors recommend confirming electrophysiological changes w/ a wake-up test prior to aborting surgery in the unstable spine. Downgraded to Class II for diagnostic due to mixed patient population. The recommendation for a wake-up test in a patient undergoing a cervical decompression procedure is potentially unrealistic.
Jones et al., 2003	2 cases of quadriparesis following anterior discectomy despite normal SSEPs reported.	III (therapy)	Neurological injury can occur despite normal SSEP recordings.
Hilibrand et al., 2004	Comparison between TcMEP & SSEP in 427 patients undergoing cervical surgery (216 for CSM). 12 patients had significant changes in monitoring during surgery, 2 had new deficits. All significant changes were addressed by surgeon in stereotypical fashion including BP elevation, operative inspection, & steroids. TcMEP was more sensitive than SSEP.	II (diagnosis)	TcMEP was more sensitive than SSEP for detecting potential neurological deficits. Changes were more common in CSM group. If TcMEP improved following intervention, then no deficits observed. No information on efficacy of intervention. Downgraded to Class II because of mixed population; it is considered Class I for comparison between modalities.
Fukuoka et al., 2004	38 patients w/ cervical myelopathy evaluated w/ intraop TcMEP. Study was performed to predict which patients were able to be monitored.	I (therapy)	No safety or efficacy information provided. No data on outcomes. Class I for feasibility.
Fan et al., 2002	Authors evaluated utility of intraop multimodality (SSEP, TcMEP, & dermatomal evoked potentials) monitoring to detect iatrogenic C-5 radiculopathy during laminectomy for myelopathy. 200 total patients were monitored, 8 developed C-5 palsy. The addition of deltoid-specific monitoring improved sensitivity but did not affect likelihood of palsy (6/132 vs 2/68, p = NS).	III (therapy)	It is possible to detect electrophysiological evidence of C-5 root palsy during laminectomy procedures using deltoid specific TcMEP monitoring. Class III for utility of monitoring to prevent root injury (no false positives in entire group, no false negatives in deltoid-specific monitoring group); Class I for diagnosis regarding comparison of modalities.
Bouchard et al., 1996	Authors correlated SSEP responses & postop course in 32 patients w/ CSM. Of the 11 that had improvements intraop, all improved clinically. Of the 21 who did not have intraop improvement, 20 improved.	I (diagnosis)	There was no correlation between intraoperative improvement in SSEP & ultimate functional outcome.
Dennis et al., 1996	Mixed population of 31 patients operated upon w/ SSEP monitoring. 27 patients suffered no new deficits & 6 had SSEP changes. 4 patients deteriorated & 2 had SSEP changes. In 1 patient, adjustment of traction in response to SSEP change was felt to be helpful.	II (diagnosis)	SSEPs are sensitive but not specific for the detection of intraoperative neurological injuries. Class II due to mixed population including radiculopathy & tumors.

(continued)

TABLE 1: Evidentiary summary of studies on EP monitoring and outcomes* *(continued)*

Authors & Year	Description	Class	Conclusion
Tani et al., 1999	51 patients w/ CSM underwent introap SSEP monitoring. The authors noted that conduction blocks usually occurred at C3–4 or C4–5, & suggested that incremental monitoring may help locate areas of blockage.	III (therapy)	Conduction blocks to SSEPs are detectable intraoperatively.
Tanaka et al., 2006	62 patients who underwent laminoplasty were monitored w/ TcMEP. No patient demonstrated decrement of intraop recordings, but 3 had postop C-5 palsies.	I (diagnosis); III (therapy)	Intraop TcMEP monitoring does not protect against C-5 palsy after laminoplasty.
Tani et al., 1995	Case series of patients who underwent CSM surgery guided by conduction block detected by inserting needles into disc spaces & decompressing at those disc spaces. All patients improved.	III (therapy)	Intraop assessment of SSEP conduction blocks may help target decompressive procedures.
Cioni et al., 1995	3 patients noted to have transient postop deficits had changes in SSEPs following laminectomy.	III (diagnosis)	New neurological deficits may be correlated w/ SSEP changes following laminectomy.
Baba, et al., 1996	64 patients w/ CSM underwent decompression w/ intraop epidural SCEP monitoring. Improvements in monitoring following decompression. Extent of electrical abnormality correlated well w/ clinical condition. Improvement in intraop monitoring correlated w/ improvement in neurological status according to JOA scale.	I (diagnosis)	Patients w/ preop abnormal SCEP monitoring whose potentials return towards normal have a better chance of making a good recovery than those whose responses do not improve.
Spielholz et al., 1979	11 patients w/ traumatic, compressive lesions of the spinal cord were monitored intraop w/ SSEPs. 4 patients were noted to have improvements in monitoring intraop. There was no correlation between intraop improvement & functional outcome.	III (diagnosis)	Improvement in SSEPs following decompression does not predict functional improvement. This is a poor Class III due to population; small size may be NA.
May et al., 1996	191 patients w/ a variety of cervical lesions operated upon w/ intraop SSEP monitoring. 24 patients had SSEP changes & no deficits, 9 had SSEP changes & deficits, 1 patient had no SSEP changes & had new deficits. Sensitivity for detecting new deficit was 99%, specificity 27%.	II (diagnosis). NA for therapy.	SSEPs are sensitive for detecting neurological injury. Downgraded to Class II for diagnostics because of mixed population.
Ueta et al., 1998	Case series of patients monitored intraop w/ SCEP. Different patterns of abnormalities noted which usually correlated w/ MRI. Authors felt that monitoring provided useful information about the location of the compressive lesion.	III (therapy)	Intraoperatively SCEP may be helpful to localize physiological abnormalities in the spinal cord. There is no evidence presented to suggest that the addition of this modality improved patient outcome.
Gokaslan et al., 1997	Series of 16 patients who underwent transcutaneous MEP monitoring using percutaneous electrode. No patient had a change in monitoring; no patient had a new deficit.	III (diagnosis)	TcMEPs may be recorded w/ percutaneous electrode. Downgraded to Class III due to the absence of true or false positives.
Smith et al., 2007	Cohort comparison of 1037 patients undergoing ACDF for radiculopathy. Half were monitored & half not. No adverse events in unmonitored group. 6 alerts in monitored group w/ no deficits. 1 patient w/ deficit in monitored group w/ no change in SSEP developed a new central cord syndrome.	III (therapy)	SSEP monitoring does not improve safety of anterior discectomy. This is considered Class III due to a radiculopathy population as opposed to a myelopathy population.
Kitagawa et al., 1989	Case series of 20 patients who underwent surgery for a variety of indications w/ MEP monitoring. Signal deteriorated in 5 w/ no neurological worsening. Signal was lost completely in 1 patient who woke up quadriplegic. No false positives.	III (diagnosis)	MEP monitoring can indicate damage to the spinal cord. Study downgraded to Class III because of population—mostly patients w/ tumor & C1–2 instability.

(continued)

TABLE 1: Evidentiary summary of studies on EP monitoring and outcomes* *(continued)*

Authors & Year	Description	Class	Conclusion
Bouchard et al., 1996	Authors measured SSEPs & tried to correlate improvements w/ clinical outcome in 32 patients operated upon for CSM. 11 patients had immediate improvements & all had improvement in function. 20 of 21 patients w/ stable responses also improved.	II (diagnosis)	Improvements in SSEP do not predict better outcomes following decompression in CSM. Study downgraded to Class II because definition of improvement subjective.
Devlin et al., 2006	Review recommending monitoring as diagnostic tool to detect neural injury.	III (diagnosis)	Intraop monitoring can detect neural injury.
Urasaki et al., 1988	Case series of 24 patients monitored during surgery for a variety of indications. SSEP changes occurred in 9 patients, 4 of whom had postop deficits. None of these patients had CSM.	III (diagnosis)	SSEP monitoring can detect neural injury during spinal surgery.
Bose et al., 2004	119 patients underwent anterior surgery for radiculopathy or myelopathy (99 radiculopathy, 13 myelopathy, 7 other). SSEP & TcMEP monitoring were performed in every case. 6 alerts occurred. 1 of the 6 patients developed a postop deficit (SSEP remained normal, TcMEP changed). 2 other patients developed a deficit that was undetected due to difficulty w/ monitoring.	II (diagnosis)	SSEP likely not helpful for anterior surgery. TcMEP may be more helpful. Study downgraded because mostly radiculopathy population.
Epstein, 1993	Review of 51 patients w/ OPLL. 46 were operated on w/ continuous SSEP monitoring. The author felt that monitoring improved safety.	III (therapy)	SSEP monitoring felt to improve safety of surgery for OPLL. Study used a historical cohort; was downgraded due to select population not CSM; no data regarding frequency of alerts; patients w/ OPLL who underwent surgery w/o monitoring did not have deficits; no information on nature of cases in which injuries occurred in historical cohort.
Sebastian et al., 1997	SSEPs were recorded in 210 patients undergoing anterior decompression of the cord. SSEP abnormalities were noted in 84 (44 improved, 40 worsened or were unstable). In 13 cases, changes were thought to be caused by mechanical stress. Inspection was performed in these 13, & appropriate adjustments were made (not well described). No patient developed new neurological deficits.	III (therapy) III (diagnosis)	SSEP recordings may change due to a variety of intraop stresses including mechanical stress. The importance of these changes is not clear. Class III for therapy due to false end point. Class III for diagnosis because no deficits were observed & correlation w/ improvement was not described.

* ACDF = anterior cervical discectomy and fusion; BP = blood pressure; JOA = Japanese Orthopaedic Association; NA = not applicable; NS = not significant; OPLL = ossification of the posterior longitudinal ligament; SCEP = spinal cord–evoked potential.

patient despite normal intraoperative SSEP recordings. There were no neurological injuries in the nonmonitored group. Because there was only 1 neurological injury in the study, the ability of SSEPs to prevent neurological injury was inconclusive from this study. This paper provided Class III evidence (cohort study with radiculopathy population) indicating uncertainty regarding the ability of intraoperative SSEP monitoring to prevent neurological deficits during anterior decompression of the spinal cord.

Bouchard and colleagues[3] investigated the ability of SSEP improvements to predict improvement in clinical outcomes. They measured SSEP signals in a series of 32 patients undergoing decompression for CSM. Eleven patients had immediate improvement in their SSEP recordings, and all of these patients improved following surgery; however, 20 of 21 patients without SSEP improvement also recovered. This paper provided Class II evidence that improvements in SSEP recordings were not necessary for clinical recovery after decompression.[3] Spielholz et al.[23] came to a similar conclusion after evaluating their results in a series of 11 patients with traumatic compressive lesions, although the evidence from their paper is considered of lower quality due to the size of the patient population.

In contrast, Baba et al.[1] used intraoperative epidural spinal cord–evoked potential monitoring in a group of patients undergoing decompression for CSM. These authors found that improvements in intraoperative monitoring correlated with improvements in neurological status (as measured with the Japanese Orthopaedic Association scale). Therefore, it appears that the technique used to measure improvement may be important in terms of diagnostic accuracy. Epidural spinal cord–evoked potential recording has been used in a wide variety of patient series for assessment of the degree of deficit.[10,22,25,27] Spinal cord–evoked potential improvements do seem to be correlated with improved function. No evidence exists, however, to indicate that this modality improves patient safety, because no series reports the occurrence of a new neurological deficit or intervention performed in response to changes in EP monitoring.

Bose et al.[2] described 119 patients who underwent anterior decompression for radiculopathy or myelopathy with continuous multimodality monitoring. Six alerts occurred, and 1 of the 6 patients developed a new deficit. Changes were seen on TcMEPs but not SSEPs in this patient. The authors concluded that TcMEPs are more sensitive for the detection of neurological deficits during anterior decompression than are SSEPs. Because of the mixed patient population, this study was deemed to provide Class II evidence suggesting that TcMEP is superior to SSEP for the detection of injury during anterior decompression for CSM. Other authors have also described the occurrence of significant neurological injury in the absence of SSEP changes.[13,29]

In 2004, Hilibrand et al.[12] used both SSEP and TcMEP monitoring in 427 consecutive patients who underwent cervical spine surgery. Of these patients 216 had CSM and 22 had ossification of the posterior longitudinal ligament. Intraoperative alerts were provided to the surgical team when unilateral or bilateral amplitude changes of at least 60% were noted to persist over a 10-minute period. All alerts were treated with augmentation of blood pressure and high dose (NASCIS protocol) steroids. Furthermore, in selected cases, removal of bone graft or instrumentation was performed. Significant changes on monitoring were noted in 12 patients, and 2 of these awoke with new neurological deficits. The authors noted that SSEP changes were absent in 1 of these patients and delayed in the other. The authors assumed that all 12 events were clinically significant and calculated sensitivity and specificity values for both modalities. The reported sensitivity and specificity for SSEP monitoring was 25 and 100%, respectively, whereas TcMEP was reported to be 100% sensitive and specific. The authors concluded that TcMEP monitoring should be used to prevent neurological injury in patients undergoing surgery for CSM. This recommendation was particularly strong for those with ossification of the posterior longitudinal ligament, as the incidence of alerts was higher in this population. This paper was considered to provide Class I evidence for the comparison between SSEP and TcMEP monitoring in patients undergoing anterior cervical spine surgery. The evidence was downgraded to Class II specifically for the CSM population due to the mixed overall population; however, the vast majority of alerts did occur in the CSM population. Transcranial MEPs appeared to be more sensitive for detecting potential or actual injury than SSEPs in this situation. However, the authors used changes in TcMEPs as a false end point with regard to assessing the ability of either modality to predict neurological injury. Because a stereotypical response of uncertain benefit was performed every time there was an EP event, the meaning of the 10 alerts not associated with neurological injury was uncertain. This paper, therefore, did not provide convincing evidence to suggest that the addition of monitoring improved neurological outcomes.[12]

Two years later, the same group reported on their experience in a much larger cohort of patients.[15] This manuscript described the results of multimodality monitoring in 1445 patients undergoing ventral cervical surgery. Two hundred and sixty-seven patients were reported to have had either minor or major EP alerts, with the criteria for a major alert being identical to the criteria described above.[15] Major EP alerts occurred in 16% of operations performed for CSM. Of the 93 major alerts in the CSM population, 44 occurred during surgery, 25 occurred during shoulder taping, and 13 occurred during neck taping. Response to these alerts was variable and included occasional steroid administration. Two patients (presumably the same as described in 2004) suffered neurological injury; 1 patient received steroids and the other did not. In 8 patients, the surgery was aborted because of persistent EP abnormalities despite intervention; none of these patients had a new neurological deficit (4 received steroid therapy). Seven patients eventually returned to the operating room within a few days; however, 1 patient was unable to receive definitive surgery and was instead treated with a halo vest. This report raised serious issues regarding the meaning of TcMEP alerts in patients with CSM. It was also considered a Class II diagnostic study for the ability of multimodality monitoring to diagnose the occurrence of new neurological injuries; however, the specificity was substantially lower than in the previous study, and the potential for harm due to reaction to false positive alerts was illustrated. This study provided Class III evidence suggesting that monitoring should not be relied on to provide the sole impetus for substantial alterations in the surgical plan.

Electromyography and TcMEP monitoring have also been used as pre- and intraoperative assessment tools to predict or prevent C-5 palsy after laminoplasty. Tanaka et al.[24] used TcMEPs in the intraoperative monitoring of 62 patients. A C-5 palsy developed in 3 patients despite normal recordings. Fan et al.[8] recorded SSEPs, TcMEPs, and dermatomal-evoked potentials in 200 patients who underwent laminoplasty. These authors found that the addition of deltoid-specific TcMEP monitoring increased the sensitivity for detecting injury, but did not affect the likelihood of a postoperative palsy. Sasai and colleagues[18] used preoperative EMG recordings to identify patients at potential risk for C-5 palsy. Any patient with a preoperative abnormality underwent a C4–5 foraminotomy in addition to the laminoplasty. These authors found a lower incidence of C-5 palsy in the group of patients who underwent foraminotomy. It was difficult to draw any firm conclusions from this information except that C-5 injury may be detected with deltoid-specific TcMEP recording. The use of EMG in selected patients undergoing foraminotomy is an intriguing concept. However, because all patients with abnormalities were treated differently from those without abnormalities, it was impossible to discern whether the difference in C-5 palsies was attributable to the foraminotomy.

Summary

Currently, there is no Class I evidence that demonstrates the ability of EP monitoring to improve safety and functional outcome. Conversely, there have been no studies appropriately designed to demonstrate that EP monitoring does not improve outcome or safety. The use of intraoperative SSEP monitoring does not appear to provide useful diagnostic or therapeutic information during anterior surgery for CSM, and the role of SSEP monitoring in posterior procedures is not well defined. Transcranial MEP monitoring may be more useful in the diagnosis of neurological injury during anterior decompression; however, there is no evidence to suggest that the use of such monitoring substantially improves the safety of surgery in the majority of patients with CSM. There is some evidence to suggest that exclusive reliance on TcMEP monitoring may lead to surgeon behavior that may be detrimental to patient welfare. Spinal cord–evoked potentials may be helpful for the localization of the level of neurological compromise in cases of multiple levels of compression on MR imaging; however, the utility of this monitoring technique for altering surgical strategy is unclear. Preoperative EMG may be useful for the identification of patients at high risk for C-5 root palsy after laminoplasty, but the data to support this are of relatively poor quality.

Future Areas of Investigation

A blinded, randomized study would require recording of responses in all patients with randomized reporting of events to the surgeon, a situation that would have significant ethical issues. A cohort comparison of patients undergoing surgery for CSM with multimodality EP monitoring and another without such monitoring stratified by operative approach would allow an assessment of the utility of such techniques for the improvement of patient safety and clinical outcomes, and could potentially provide Class II evidence in support of/not in support of EP monitoring in this population.

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References

1. Baba H, Maezawa Y, Imura S, Kawahara N, Tomita K: Spinal cord evoked potential monitoring for cervical and thoracic compressive myelopathy. **Paraplegia 34:**100–106, 1996
2. Bose B, Sestokas AK, Schwartz DM: Neurophysiological monitoring of spinal cord function during instrumented anterior cervical fusion. **Spine J 4:**202–207, 2004
3. Bouchard JA, Bohlman HH, Biro C: Intraoperative improvements of somatosensory evoked potentials: correlation to clinical outcome in surgery for cervical spondylitic myelopathy. **Spine 21:**589–594, 1996
4. Cioni B, Meglio M, Pentimalli L, Visocchi M: Spinal somatosensory potential monitoring in three cases of neurological deterioration after laminectomy for cervical spondylotic myelopathy. **J Neurol Neurosurg Psychiatry 58:**113–114, 1995
5. Dennis GC, Dehkordi O, Millis RM, Cole AN, Brown DS, Paul OA: Monitoring of median nerve somatosensory evoked potentials during cervical spinal cord decompression. **J Clin Neurophysiol 13:**51–59, 1996
6. Devlin VJ, Anderson PA, Schwartz DM, Vaughan R: Intraoperative neurophysiologic monitoring: focus on cervical myelopathy and related issues. **Spine J 6 (6 Suppl):**212S–224S, 2006
7. Epstein N: The surgical management of ossification of the posterior longitudinal ligament in 51 patients. **J Spinal Disord 6:**432–454, 1993
8. Fan D, Schwartz DM, Vaccaro AR, Hilibrand AS, Albert TJ: Intraoperative neurophysiologic detection of iatrogenic C5 nerve root injury during laminectomy for cervical compression myelopathy. **Spine 27:**2499–2502, 2002
9. Fukuoka Y, Komori H, Kawabata S, Ohkubo H, Mochida K, Shinomiya K: Transcranial electrical stimulation as predic-

tor of elicitation of intraoperative muscle-evoked potentials. **Spine 29:**2153–2157, 2004
10. 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 10:**299–303, 1997
11. Hadley MN, Walters BC, Grabb PA, Oyesiku NM, Przybylski GJ, Resnick DK, et al: Guidelines for the management of acute cervical spine and spinal cord injuries. **Clin Neurosurg 49:**407–498, 2002
12. Hilibrand AS, Schwartz DM, Sethuraman V, Vaccaro AR, Albert TJ: Comparison of transcranial electric motor and somatosensory evoked potential monitoring during cervical spine surgery. **J Bone Joint Surg Am 86:**1248–1253, 2004
13. Jones SJ, Buonamassa S, Crockard HA: Two cases of quadriparesis following anterior cervical discectomy, with normal perioperative somatosensory evoked potentials. **J Neurol Neurosurg Psychiatry 74:**273–276, 2003
14. Kitagawa H, Itoh T, Takano H, Takakuwa K, Yamamoto N, Yamada H, et al: Motor evoked potential monitoring during upper cervical spine surgery. **Spine 14:**1078–1083, 1989
15. Lee JY, Hilibrand AS, Lim MR, Zavatsky J, Zeiller S, Schwartz DM, et al: Characterization of neurophysiologic alerts during anterior cervical spine surgery. **Spine 31:**1916–1922, 2006
16. Lee WY, Hou WY, Yang LH, Lin SM: Intraoperative monitoring of motor function by magnetic motor evoked potentials. **Neurosurgery 36:**493–500, 1995
17. May DM, Jones SJ, Crockard HA: Somatosensory evoked potential monitoring in cervical surgery: identification of pre- and intraoperative risk factors associated with neurological deterioration. **J Neurosurg 85:**566–573, 1996
18. Sasai K, Saito T, Akagi S, Kato I, Ohnari H, Iida H: Preventing C5 palsy after laminoplasty. **Spine 28:**1972–1977, 2003
19. Sebastian C, Raya JP, Ortega M, Olalla E, Lemos V, Romero R: Intraoperative control by somatosensory evoked potentials in the treatment of cervical myeloradiculopathy. Results in 210 cases. **Eur Spine J 6:**316–323, 1997
20. Shukla R, Docherty TB, Jackson RK, Weller RO, Sedgwick EM: Loss of evoked potentials during spinal surgery due to spinal cord hemorrhage. **Ann Neurol 24:**272–275, 1988
21. Smith PN, Balzer JR, Khan MH, Davis RA, Crammond D, Welch WC, et al: Intraoperative somatosensory evoked potential monitoring during anterior cervical discectomy and fusion in nonmyelopathic patients: a review of 1039 patients. **Spine J 7:**83–87, 2007
22. Spetzler RF, Selman WR, Nash CL Jr, Brown RH: Transoral microsurgical odontoid resection and spinal cord monitoring. **Spine 4:**506–510, 1979
23. Spielholz NI, Benjamin MV, Engler GL, Ransohoff J: Somatosensory evoked potentials during decompression and stabilization of the spine. Methods and findings. **Spine 4:**500–505, 1979
24. Tanaka N, Nakanishi K, Fujiwara Y, Kamei N, Ochi M: Postoperative segmental C5 palsy after cervical laminoplasty may occur without intraoperative nerve injury: a prospective study with transcranial electric motor-evoked potentials. **Spine 31:**3013–3017, 2006
25. Tani T, Ushida T, Yamamoto H: Surgical treatment guided by spinal cord evoked potentials for tetraparesis due to cervical spondylosis. **Paraplegia 33:**354–358, 1995
26. Tani T, Yamamoto H, Kimura J: Cervical spondylotic myelopathy in elderly people: a high incidence of conduction block at C3-4 or C4-5. **J Neurol Neurosurg Psychiatry 66:**456–464, 1999
27. Ueta E, Tani T, Taniguchi S, Ishida K, Ushida T, Yamamoto H: Diagnostic value of cervical somatosensory evoked potentials recorded from the intervertebral discs after median and ulnar nerve stimulation in cervical spondylotic myelopathy. **J Spinal Disord 11:**514–520, 1998
28. Urasaki E, Wada S, Matsukado Y, Yokota A, Matsuoka S: Monitoring of short-latency somatosensory evoked potentials during surgery for cervical cord and posterior fossa lesions—changes in subcortical components. **Neurol Med Chir (Tokyo) 28:**546–552, 1988
29. Wenger M, Braun M, Markwalder TM: Post-traumatic cervical kyphosis with surgical correction complicated by temporary anterior spinal artery syndrome. **J Clin Neurosci 12:**193–196, 2005

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