Intraoperative Electromyographic Monitoring

Number: 0697

Policy
*Please see amendment for Pennsylvania Medicaid at the end of this CPB.

I. Aetna considers intra-operative electromyographic (EMG) monitoring of the facial nerve medically necessary for members undergoing any of the following intra-cranial neuro-otological surgeries:

A. Microvascular decompression of the facial nerve for hemifacial spasm; or
B. Surgery for acoustic neuroma, congenital auricular lesions, or cranial base lesions; or
C. Surgery for cholesteatoma, including mastoidotomy or mastoidectomy; or
D. Surgical excision of neuromas of the facial nerve; or
E. Vestibular neurectomy for Meniere's disease.

Policy History
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Review History

Definitions

Additional Information

Clinical Policy Bulletin Notes
Aetna considers the combined use of intra-operative EMG monitoring of facial nerve and intra-operative monitoring of somato-sensory evoked potentials not medically necessary.

II. Aetna considers intra-operative EMG monitoring of the facial nerve during cochlear implant surgery, parotid gland surgery, tympanoplasty without mastoidotomy or mastoidectomy, or maxillo-facial surgery experimental and investigational because its value for these indications has not been established.

III. Aetna considers intra-operative EMG monitoring during selective dorsal rhizotomy medically necessary when selection criteria for the procedure set in CPB 0362 are met.

IV. Aetna considers intra-operative EMG monitoring of any of the following cranial nerves medically necessary for surgical excision of neuromas of these cranial nerves.

- Abducens nerve
- Glossopharyngeal nerve
- Hypoglossal nerve
- Oculomotor nerve
- Recurrent laryngeal nerve
- Spinal accessory
- Superior laryngeal nerve
- Trochlear nerve

V. Aetna considers intra-operative EMG monitoring and neuromuscular junction testing during spinal surgery (including anterior cervical procedures) experimental and investigational because there is insufficient evidence that this technique provides useful information to the surgeon in terms of assessing the adequacy of nerve root decompression, detecting nerve root irritation, or improving the reliability of placement of pedicle screws at the time of surgery.

Aetna considers intra-operative EMG monitoring during intra-cranial tumor resections experimental and investigational (unless the resection involves a cranial nerve) because there is insufficient evidence that this technique provides useful information to the surgeon.
VI. Aetna considers intra-operative EMG monitoring of the recurrent laryngeal nerve/intra-operative neuromonitoring during thyroid and parathyroid surgery experimental and investigational because its clinical value has not been established.

VII. Aetna considers intra-operative EMG monitoring during aortic aneurysm repair, hip dysplasia surgery, hip replacement surgery, prostatectomy/prostate surgery, rectal cancer surgery, rotator cuff repair, tibial neurectomy, and wrist arthroscopy (not an all-inclusive list); or during placement of dorsal column stimulator experimental and investigational because its clinical value for these indications has not been established.

VIII. Aetna considers intra-operative surface EMG monitoring experimental and investigational because its clinical value has not been established.

IX. Aetna considers intra-operative EMG monitoring during decompression, neurectomy, radiosurgery or rhizotomy of the trigeminal nerve experimental and investigational because its clinical value for these indications has not been established.

See also **CPB 0181 - Evoked Potential Studies and CPB 0362 - Spasticity Management.**

**Background**

Electromyography (EMG) is a test that measures the electrical activity produced by a muscle contraction, to evaluate nerve and muscle function. It does not pertain to a nerve impulse traveling to or from the brain, but is an evaluation of the electrical activity of the muscle and the associated nerve.

Cranial nerves (CNs) can be damaged during various neurosurgical procedures. Intra-operative monitoring of the function of CNs by means of electromyography (EMG), compound nerve and muscle action potentials (MAP), and auditory evoked potentials (AEP) has been used to reduce the risk of injuries to these nerves. Intra-operative EMG monitoring of CNs entails electrical stimulation of the proximal (brain) end of the nerve and recording via EMG in the facial or neck muscles. Thus, the monitoring of CNs is done in the direction opposite to that of
sensory-evoked potentials, but the purpose is similar to verify the integrity of the neural pathway.

Electromyographic monitoring of the facial nerve (7th CN) is used to predict post-operative facial function after skull base surgery, which is associated with considerable risk to the functioning of the cerebral hemispheres, the brain stem and the CNs. This risk is due to problems associated with maintaining an adequate blood flow while exposing and removing the tumor, as well as direct or indirect trauma to the brain, perineural tissues and CNs.

**EMG Monitoring of Facial Nerve:**

Harner and associates (1987) compared with the results of patients who underwent acoustic neuroma resection with (n = 48) or without (n = 48) intra-operative monitoring of facial nerve. They reported that anatomical preservation of the facial nerve in patients with large tumors was substantially improved in the monitored patients (67 %) when compared with those without monitoring (33 %). Although no difference was noted in facial nerve function in the 2 groups of patients immediately post-operatively, the degree of improvement in the monitored group exceeded that observed for those who were not monitored at 3 months, particularly in those with medium-sized and large tumors.

Kwartler and colleagues (1991) compared a group of monitored translabyrinthine acoustic tumor removals (n = 89) to a similar un-monitored group (n = 155) in regard to facial nerve function. Function was assessed immediately post-operatively, at time of discharge, and at 1 year post-operatively using the House 6-point scale. Results were grouped as satisfactory, intermediate, or poor, and were analyzed by tumor size. Facial nerve results were better at all time intervals in the monitored groups, although the difference was not statistically significant at the 1-year interval. There was no difference between monitored and un-monitored patients in the subgroups with tumors smaller than 2.5 cm in diameter. The findings of this study supported the usefulness of intra-operative facial nerve monitoring in improving facial nerve results, especially in larger tumors.
Olds et al (1997) stated that “routine facial nerve monitoring is not considered the standard of care in most communities; however risk of facial nerve injury appears to be greatly reduced when this adjunctive technique is employed”. Spielholz (1997) stated that intra-operative facial nerve monitoring is especially helpful during removal of large (4 cm or greater) acoustic neuromas in which the incidence of facial weakness can reach 31%. Fabregas and Gomar (2001) noted that facial nerve monitoring for surgery of acoustic neuromas should be considered an absolute standard of care in neurosurgery. This is in agreement with the observation of Ingelmo et al (2003) who stated that intra-operative EMG monitoring of the facial nerve should be used routinely in acoustic neuroma surgery to reduce the degree of post-operative neurological impairment.

Wilson et al (2003) assessed the cost-effectiveness of intra-operative facial nerve monitoring during middle ear or mastoid surgery. The authors concluded that facial nerve monitoring is cost-effective, and its routine use should be adopted to reduce the risk of iatrogenic facial nerve injury during otologic surgery.

The American Academy of Otolaryngology-Head and Neck Surgery (1998) recognized the proven effectiveness of neurophysiologic monitoring of the facial nerve (7th CN), which may minimize the risk of injury to the nerve during surgical procedures in which the nerve is vulnerable due to site of lesion or extent of disease. The American Academy of Neurology (AAN, 1990; Lopez, 2004) stated that brainstem AEPs and cranial nerve EMG monitoring is safe and effective during surgeries performed in the region of the brainstem or inner ear. Nevertheless, clinical situations need to be chosen carefully, avoiding those in which the nervous system is only at low-risk.

A Tech Brief by the American Medical Association (1994) stated that the safety and effectiveness of intra-operative monitoring of the facial nerve by the use of either nerve conduction studies or EMG as a means of determining the integrity of the nerve during surgery for acoustic neuromas, cranial base lesions, or congenital auricular lesions were considered to be established by an expert panel. This is in agreement with the reviews by Harper (1998,
2004) who stated that there are controlled data to suggest that monitoring reduces the risk of injury to the facial nerve during resection of acoustic neuromas and other tumors in the posterior fossa.

The facial nerve is often embedded by fibrous tissues in recurrent tumor of the parotid gland. Studies have suggested that facial nerve-monitored patients undergoing parotidectomy for recurrent tumors have a 0 to 4 % risk of permanent facial paralysis. Dulguerov et al (1999) analyzed the incidence and factors responsible for post-parotidectomy facial nerve paralysis when the surgery is performed with the routine use of facial nerve monitoring (n = 70). The authors concluded that despite a stringent accounting of post-operative facial nerve deficits, the data compared favorably to the literature with or without the use of monitoring. An overall incidence of 27 % for temporary facial paralysis and 4 % for permanent facial paralysis was found. Although the lack of a control group precluded definitive conclusions on the role of EMG-based facial nerve monitoring in routine parotidectomy, the authors found its use very helpful. Brennan et al (2001) studied the effectiveness of continuous intra-operative EMG monitoring in patients who underwent parotidectomies, thyroidectomies, and parathyroidectomies (44 facial nerves, and 96 recurrent laryngeal nerves). These investigators concluded that continuous intra-operative nerve monitoring was associated with extremely low rates of temporary and permanent nerve paralysis. However, these reports were not randomized, controlled studies. Therefore, it remains unclear whether facial nerve monitoring significantly lowers the risk of facial nerve injury.

In a retrospective, case-controlled study, Terrell et al (1997) evaluated whether continuous facial nerve monitoring during parotidectomy is associated with a lower incidence of facial nerve paresis or paralysis compared with parotidectomy without monitoring (n = 117). The authors found that continuous EMG monitoring of facial muscle during primary parotidectomy reduced the incidence of short-term post-operative facial paresis, but did not change the incidence of permanent paralysis. Furthermore, Witt (1998) compared post-operative facial nerve
function after monitored (n = 20) and unmonitored (n = 33) parotid surgical procedures. No patient showed permanent facial paralysis. In 9 patients (17 %), transient nerve paralysis developed: 5 (15 %) of the 33 patients who underwent lateral parotidectomy without the use of a nerve-integrity monitor and 4 (20 %) of the 20 patients who underwent lateral parotidectomy with the use of a nerve-integrity monitor. Therefore, the clinical value of facial nerve monitoring during parotidectomy is still in question and its routine use in clinical setting awaits findings of well-designed randomized controlled studies.

In a prospective, controlled clinical two-center trial, Grosheva and colleagues (2009) analyzed the benefit of EMG neuromonitoring during primary surgery on benign parotid lesions for post-operative facial function compared to visual observation only. Using an operation microscope, 100 parotidectomies in 96 patients were performed: 50 procedures with a continuous EMG monitoring plus visual facial observation (EMG group), and 50 procedures with only visual facial control (control group). The rate of post-operative facial weakness was detected. Patients with post-operative facial paralysis were followed-up until total recovery or defective healing by repeated EMG examinations. A total of 79 superficial and 21 total parotidectomies were performed. Histological analysis found pleomorphic adenoma in 38 patients, cystadenolymphoma in 39, and chronic parotitis in 18. Immediate post-operative facial paralysis was evident in 41 patients. Six patients had permanent paralysis; in this group definitive defective healing was detected by EMG in 5 cases. Electromyography was not classifiable in 1 case. Intra-operative EMG monitoring had no significant effect on immediate post-operative or definitive facial outcome (p = 0.23 and p = 0.45, respectively). The duration of superficial, but not of a total parotidectomy, was diminished in the EMG group (p = 0.02 and p = 0.61, respectively). This result was independent of the specimen’s histology. The authors concluded that EMG monitoring in parotid surgery in addition to visual facial observation did not diminish either the incidence of post-operative facial paralysis or the final facial outcome. Nevertheless, the duration of surgery for superficial parotidectomy could be reduced by using EMG monitoring.
Shan et al (2014) analyzed the benefits of facial nerve EMG monitoring during parotid tumor surgery. In this study, 92 patients with parotid tumor who underwent surgery were surveyed. The study group consisted of 46 patients who underwent intra-operative EMG monitoring, and 46 patients served as the control group. The incidence of post-operative facial nerve weakness and the operation time were recorded. In primary parotid tumor resection, the operation time of the study group (6 cases) was (50.0 ± 9.1) mins, that of control group (7 cases) was (42.9 ± 5.2) mins (p = 0.064) when the facial nerve needed no dissecting; the operation time of the study group (32 cases) was (74.7 ± 28.0) mins, that of control group (33 cases) was (75.6 ± 29.8) mins (p = 0.893) when the facial nerve needed dissecting. For patients with revision surgery, the mean operation time in the study group [(117.5 ± 37.8) mins] was significantly lower than that of the control group [(175.0 ± 47.8) mins], p < 0.05. In the study group, 8 patients suffered from post-operative facial nerve weakness because of tumor characteristics; in the control group, 6 patients suffered from post-operative facial nerve weakness, with 4 cases because of tumor characteristic, and 2 cases because of operator error. The authors concluded that these findings suggested that continuous EMG monitoring of facial nerve during parotidectomy reduces the mean operation time in patients with revision surgery, but not the incidence of post-operative facial paralysis.

Leonetti et al (1990) noted that while identification of the intra-temporal portion of the facial nerve is mandatory in most otologic surgical procedures, inadvertent instrumentation, traction, or thermal injury may still result from inaccurate delineation, purposeful avoidance, or false protection of this critical structure. Improved functional preservation of the facial nerve has been achieved in acoustic neuroma surgery through the monitoring of evoked facial EMG activity. This technique may also be used during otologic procedures in which facial nerve manipulation is anticipated in the management of recurrent cholesteatoma, temporal bone trauma, congenital deformity, or purposeful access for cochlear implantation. The authors stated that intra-operative monitoring can assist the surgeon in isolating the facial nerve when chronic inflammation, traumatic injury, or
anomalous development has resulted in distortion or absence of micro-anatomic landmarks.

Selesnick and Lynn-Macrae (2001) identified the incidence of facial nerve dehiscence in patients undergoing surgery for cholesteatoma. An assessment of all cases performed by the senior author from 1991 to 1999 revealed 59 patients with adequate data available for analysis. These patients ranged in age from 3 to 92 years; a total of 67 surgical procedures. Main outcome measure was the presence of facial nerve bony dehiscence after exenteration of disease, and post-operative facial nerve function. In 33% of the total procedures analyzed, 30% of the initial procedures, and 35% of the revision procedures, patients were found to have facial nerve bony dehiscence. The dehiscence was present in the tympanic portion of the facial nerve in the vast majority of patients. Of the 97% of patients with normal pre-operative facial nerve function, all retained normal function post-operatively. The authors concluded that facial nerve dehiscence in this series was far greater than that reported in the literature, underscoring the fact that this is an under-appreciated condition. These findings suggested that surgeons should be highly vigilant when dissecting near the facial nerve. The authors stated that intra-operative facial nerve monitoring (FNM) has been shown to be of value in facial nerve preservation during acoustic neuroma resections, and may have a role during surgery for cholesteatoma.

In a prospective, non-randomized study, Di Martino et al (2005) investigated fallopian canal dehiscences in order to assess the risk of encountering an unprotected facial nerve during routine ear surgery. The intra-operative appearance of the facial canal in 357 routine ear operations was compared with 300 temporal bone specimens from 150 autopsies. Intra-operatively, a dehiscence was detected in 6.4% (23/357) of the operations, most frequently at the oval niche region (16/23 cases). The incidence increased with the number of operations (p < 0.0002). Cholesteatoma surgery had the highest relative risk (RR 4.6) of exposing an unprotected facial nerve. Post-operatively, no persistent facial paralysis was observed. In 4 of 5 cases with a transient facial palsy due to local anesthetics, a bony dehiscence
could be found. The anatomical study revealed fallopian canal
dehiscences in 29.3 % (44/150) of the autopsies. One-third
(15/44) of the individuals affected displayed bilateral findings;
thus resulting in 19.7 % (59/300) of temporal bones affected. A
total of 17/59 bones showed micro-dehiscences, and most
(55/59) were located at the oval niche. The actual prevalence of
fallopian canal dehiscences was significantly higher than intra-
operative findings suggested. The oval niche is the most affected
region. The authors stated that high-resolution computed
tomography is of diagnostic value only in selected cases. Facial
paralysis following local anesthesia is the most significant clinical
sign. Vigilance in acute facial palsy after local anesthetics and in
cholesteatoma surgery and adequate intra-operative exposure
help to prevent iatrogenic injury of the uncovered nerve. In
unclear cases, FNM can facilitate a safe outcome.

Jiang and associates (2006) studied the application of FNM and
estimated the therapeutic effectiveness of the total
decompression of facial nerve during the surgery for
cholesteatoma in petrous bone by middle cranial fossa-mastoid
process approach. A total of 8 patients who suffered from
chronic suppurative otitis media (cholesteatoma type) in petrous
bone were treated with open technique, 3 other cholesteatoma
cases whose tympanic membranes were intact was treated with
close technique. Monitoring for facial nerve integrity during
operation was applied. Total decompression of facial nerve was
performed in all patients. House-Brackmann grading system was
used to evaluate the recovery of facial nerve function. Facial
paralysis recovered gradually during the period of 3 to 6 months
after operation. After 6 to 12 months follow-up in 11 cases, 1
case regained basically normal status, 9 cases recovered to mild
facial paralysis and 1 case still needed further follow-up. There
was no recurrence of cholesteatoma in all patients. The authors
concluded that middle cranial fossa-mastoid process combining
approach technique is effective for cholesteatoma in petrous
bone and total decompression of facial nerve at the same stage.
They stated that FNM is helpful in orientating facial nerve during
operation and in preventing possible damage to the facial nerve.

Hu and colleagues (2014) stated that there is a growing trend for
the routine use of the FNM in chronic ear surgery. These investigators aimed to examine current patterns in the use of FNMs in chronic ear surgery. A 10-question survey was designed to identify level of training, scope of practice, specific otologic surgeries where monitoring was most used, and the opinion of respondents regarding the use of FNMs as standard of care for chronic and/or middle ear surgery. A randomized list of 2,000 board-certified members of the American Academy of Otolaryngology-Head and Neck Surgery was generated; A total of 1,000 subjects received a mailed survey with a self-addressed return envelope and 1,000 subjects received an emailed survey through SurveyMonkey.com. There were 359 (36%) surveys returned by mail and 258 (26%) surveys returned electronically -- 43% of respondents were in private practice, and 31% were fellowship-trained in otology/neurotology; 65% used a FNM in their training and 95% had regular access to a FNM. Revision mastoid surgery, cholesteatoma, canal wall down mastoidectomy, and facial recess approach were the settings where a FNM was most used. Forty-nine percent of respondents felt that a FNM should be used as the standard of care in chronic ear surgery; this represents an increase from 32% in a similar study done approximately 10 years ago. The authors concluded that there is a growing trend for routine facial nerve monitoring in the setting of chronic ear surgery.

Prell and colleagues (2017) stated that in vestibular schwannoma surgery, facial nerve injury with consecutive functional impairment is one of the most important complications. Intraoperative monitoring of facial nerve function has been developed in order to avoid this complication. These investigators evaluated the methods and their ability to achieve the goals of intraoperative monitoring. Intraoperative functional monitoring aims to identify and map the facial nerve in the surgical field during surgery. It also aims to identify potentially damaging events and allow for intraoperative prognosis of functional outcome. Available methods are direct electrical stimulation, free-running EMG, facial nerve EPs, and processed EMG. The authors concluded that identification and mapping of the facial nerve in the surgical field can be reliably achieved by direct electrical stimulation; potentially dangerous events can be
identified in real time by the free-running EMG and the processed
EMG, and almost in real time by facial nerve EPs. However, they
stated that intraoperative prognostics are hampered by false-
positive results with all available methods and have limited
reliability.

**EMG Monitoring of Recurrent Laryngeal Nerve:**

The recurrent laryngeal nerve (RLN) is one of the branches of the
vagus nerve (10th CN). After the RLN leaves the vagus nerve, it
travels into the chest and then loops back up to supply nerves to
the larynx. Injury to the RLN is rare but may occur as a
complication of surgery in the neck or chest. In this regard,
damage to the RLN remains one of the most devastating
complications of thyroid surgery. The nerve can also be injured
by tumors or swollen lymph nodes in the mediastinum. Damage
to the RLN causes laryngeal palsy on the affected side. Symptoms
include hoarseness, difficulty in speaking, and difficulty in
swallowing.

During thyroidectomy, the RLN is visually identified and dissected
away from the thyroid gland. It has been advocated that intra-
operative knowledge of the status of the nerve after dissection
could potentially provide the surgeon with important decision-
making information. However, it has not been established that
intra-operative EMG monitoring of the RLN reduces the incidence
of RLN injury during thyroidectomy. There are studies that have
calculated the positive-predictive value (PPV) and negative-
predictive value (NPV) of RLN monitoring during thyroid surgery.
Most recently, Beldi and co-workers (2004) reported that the NPV
of intra-operative RLN monitoring was 99 %, but the PPV was only
33 %. These results are similar to those of Otto and Cochran
(2002) who reported a NPV of 98.6 % and a PPV of 33.3 %. Beldi
et al (2004) concluded that although an intact nerve can be
verified by RLN monitoring, the loss of nerve function can not be
reliably identified, and that the incidence of RLN lesions was not
lowered by intra-operative monitoring. This is in agreement with
the findings of Robertson et al (2004) who reported that there
were no statistically significant differences in RLN paralysis,
paresis, or total injury rates between control and continuous
laryngeal nerve integrity monitoring among patients who underwent thyroidectomy (n = 165).

In a prospective study (n = 328 patients with 502 nerves at risk), Hermann et al (2004) examined the ability of neuromonitoring to predict post-operative outcome in patients undergoing thyroid surgery for different indications. These authors concluded that neuromonitoring is useful for identifying the RLN, in particular if the anatomical situation is complicated by prior surgery, large tissue masses, aberrant nerve course. However, neuromonitoring does not reliably predict post-operative outcome. Thus, the value of intra-operative EMG monitoring of the RLN has not been established.

Chiang et al (2008) determined the causes of RLN palsy and identified potentially reversible causes of RLN injury during thyroid surgery with the use of intra-operative neuromonitoring (IONM). A total of 113 patients with 173 nerves at risk were enrolled in this study. All operations were performed by the same surgeon. The 4-step procedure of IONM was designed to obtain EMG signals from the vagus nerve and RLN before and after resection of thyroid lobe. A total of 16 nerves had loss of EMG signals after thyroid dissection, and the causes of nerve injuries were well elucidated with the application of IONM. One nerve injury was caused by inadvertent transection, which led to permanent RLN palsy. Among the remaining 15 nerves, 1 injury was caused by a constricting band of connective tissue, which was detected precisely and released intra-operatively, 2 by inadvertent clamping of the nerve, and 12 by apparent over-stretching at the region of Berry's ligament (5 nerves regained signals before closing the wound, but 1 showed impaired cord movement. Another 7 nerves did not regain signals before closing the wound, and all developed temporary RLN palsy). The authors concluded that their 4-step procedure of IONM is useful and helpful in elucidating the potential operative pitfalls during dissection near the RLN. However, the rates of RLN palsy were not decreased in this study.

The National Institute for Health and Clinical Excellence's (NICE) guidance on intra-operative nerve monitoring during thyroid
surgery (2008) noted that the evidence raises no major safety concerns. However, only 2 of the 9 specialist advisers stated that this procedure is useful for teaching; while 1 adviser stated that there are significantly different opinions between surgeons as to whether this technology improves outcomes or whether it gives false reassurance to inexperienced surgeons.

The NICE (2008) assessment reported that 4 non-randomized studies of 16,448, 684, 639 and 136 patients (29,998, 1,043, 1,000 and 190 nerves) reported permanent rates of vocal cord paralysis ranging from 0% to 2% in the intra-operative nerve monitoring groups, compared with 0% to 1% in the control groups (visual recurrent laryngeal nerve identification or no recurrent laryngeal nerve identification). No statistically significant differences were seen between procedures undertaken with or without intra-operative nerve monitoring. The NICE assessment also found that 3 case series of 328, 288 and 171 patients reported rates of permanent vocal cord paralysis using intra-operative nerve monitoring in 3% (15/502), 1% (6/429) and 1% (2/271) of recurrent laryngeal nerves, respectively.

The NICE (2008) assessment also indicated that 4 non-randomized studies of 684, 639, 165 and 136 patients (1,043, 1,000, 236 and 190 nerves) reported rates of transient vocal cord paralysis ranging from 3% to 5% in the intra-operative nerve monitoring groups, compared with 3% to 4% in the control groups (none was statistically significant). The NICE assessment stated that another non-randomized study reported that vocal cord immobility was detected at 3-month follow-up in 6% (6/104) of patients when intra-operative nerve monitoring was used and 5% (5/100) of patients when intra-operative nerve monitoring was not used (p = 0.55). The 3 case series of 328, 288 and 171 patients reported rates of transient recurrent laryngeal nerve palsy as 9% (43/502), 9% (37/429) and 5% (13/271), respectively.

The NICE (2008) assessment stated that the non-randomized study of 639 patients (1,000 nerves at risk), which compared intra-operative nerve monitoring with visual identification of the recurrent laryngeal nerve, reported that intra-operative nerve
monitoring indicated no nerve damage in 10 out of 21 vocal cords that were paralyzed as a result of surgery. Conversely, intra-operative nerve monitoring indicated nerve damage in 27 out of 480 patients who were found to have normal post-operative vocal cord function.

Barczyński and colleagues (2009) tested the hypothesis that identification of the RLN during thyroid surgery reduces injury, and that IONM may be of additional benefit. A total of 1,000 patients scheduled to have bilateral thyroid surgery were randomized to standard protection or additional nerve monitoring. The primary outcome measure was prevalence of RLN injury. Of 1,000 nerves at risk in each group, transient and permanent RLN injuries were found respectively in 38 and 12 nerves without RLN monitoring (p = 0.011) and 19 and 8 nerves with RLN monitoring (p = 0.368). The prevalence of transient RLN paresis was lower in patients who had RLN monitoring by 2.9 % in high-risk patients (p = 0.011) and 0.9 % in low-risk patients (p = 0.249). The NPV and PPV of RLN monitoring in predicting post-operative vocal cord function were 98.9 and 37.8 %, respectively. The authors concluded that nerve monitoring decreased the incidence of transient but not permanent RLN paresis compared with visualization alone, particularly in high-risk patients.

In a retrospective case control study with 993 patients, Cavicchi et al (2009) examined the accuracy of neurostimulation with laryngeal palpation (NSLP) and IONM to predict the post-operative function of RLN in thyroid surgery. The control group (799 patients with 1,450 nerves at risk) included patients who underwent NSLP and the case group (194 patients with 354 nerves at risk) consisted of those who underwent NSLP in association with IONM. Sensitivity, specificity, PPV, NPV, and accuracy were calculated for NSLP and IONM, with nerve palsy as the target outcome. A significant difference in nerve injury between the case and the control group (p = 0.31) was not observed. The presence or absence of laryngeal twitch (LT) (p < 0.0001) and the acoustic response to electrical stimulation (p = 0.003) were significantly associated with nerve function at the end of the surgery. The authors concluded that these findings indicated that NSLP is a safe and reliable intra-operative method
of RLN monitoring. Moreover, these results confirmed that IONM is not a helpful tool to reduce the rate of palsy in thyroid surgery.

Harrison and Triponez (2009) reviewed the evidence regarding the use of intra-operative parathyroid hormone (PTH), radio-guided parathyroidectomy (RGP), methylene blue (MB), frozen section, and IONM during surgery for primary hyperparathyroidism (PHPT). A Medline keyword search of English-language articles led to the production of a draft document, subsequently revised by committee, containing levels of evidence and the grading of recommendations as proposed by the Agency for Healthcare Research and Quality. Literature review provided the basis for clear recommendations on the use of intra-operative PTH at surgery for PHPT. In contrast, there is little evidence to support the use of RGP, MB, routine frozen section, and IONM.

Kiviniemi and colleagues (2010) stated that the knowledge of the anatomy of the parathyroid and thyroid glands helps a surgeon to localize important details and lessen complications, especially laryngeal palsy and hypo-parathyroidism. The ligament of Berry and tuberculum Zuckerkandl cover the recurrent laryngeal nerve in the upper part of the thyroid lobes. The recurrent laryngeal nerve or its branches are exposed during the mobilization of these structures during total thyroidectomy. The upper parathyroid gland can be found on the upper part of the tuberculum Zuckerkandl behind the recurrent laryngeal nerve, whereas the lower parathyroid gland can be found in front of the nerve on the under surface of the thyroid lobe or in the thymus below. The tertiary branches of blood vessels are cut preserving the function of the parathyroid glands. If the parathyroid has lost its blood circulation, it is made into pieces and transplanted into the pockets of sternocleidomastoideus muscle. Exposing the recurrent laryngeal nerve during operation seems to decrease permanent recurrent laryngeal nerve injury. The authors noted that the role of neuromonitoring during parathyroid and thyroid surgery is still controversial.

Dionigi et al (2013) stated that IONM contributes in several ways to RLN protection. Notwithstanding these advantages, surgeons must be aware that the current, intermittent mode of IONM (I-
IONM) has relevant limitations. To overcome these I-IONM limitations, a continuous IONM (C-IONM) technology has been proposed. These investigators performed a PubMed indexed literature review of the current limitations of I-IONM and provided a commentary about C-IONM; presenting the preliminary results of research on this topic. These researchers concluded that RLN traction injury is still the most common cause of RLN injury and is difficult to avoid with the application of I-IONM in thyroid surgery. Continuous-IONM is useful to prevent the imminent traction injury by detecting progressive decreases in electromyographic amplitude combined with progressive latency increases; C-IONM seems to be a technological improvement. Likely, C-IONM by vagal nerve stimulation should enhance the standardization process, RLN intraoperative information, documentation, protection, training, and research in modern thyroid surgery. They stated that although C-IONM is a promising technology at the cutting edge of research in thyroid surgery, more studies to assess in an evidence-based way all its advantages are needed.

EMG Monitoring of Other Cranial Nerves:

Schlake et al (2001) reported that EMG is effective as a mapping tool for intra-operative localization and identification of ocular motor nerves -- the oculomotor nerve (3rd CN) and the abducens nerve (6th CN) in skull base surgery. However, the predictive value of conventional neurophysiological parameters for clinical outcomes appears to be rather poor. Further investigations on a larger number of patients are thus needed to develop new quantification techniques which enable an intra-operative prediction of ocular motor nerve deficits. More studies are also needed to extend this technique to the trochlear nerve (4th CN). Furthermore, in a review on the electrophysiological examination of CNs, Vial and Bouhour (2004) stated that intra-operative monitoring of various CNs can be useful but techniques still need to be validated.

There are no controlled studies that examined whether EMG monitoring of the oculomotor, trochlear, and abducens nerves during surgery in the middle cranial fossa reduces the risk of post-
operative ophthalmoplegia. Moreover, although there are reports of monitoring, either alone or in combination, of glossopharyngeal, laryngeal branches of the vagus (e.g., the superior laryngeal nerve and the recurrent laryngeal nerve), spinal accessory, and hypoglossal nerves during skull base surgeries such as surgical resection of tumors in the region of the foramen magnum, jugular foramen, hypoglossal foramen, and clivus, there are no controlled data to indicate that the risk of CN injury is reduced by monitoring (Harper, 2004). Thus, the clinical value of intra-operative monitoring of the oculomotor, trochlear, abducens, glossopharyngeal, laryngeal branches of the vagus, spinal accessory, and hypoglossal nerves has not been established.

**EMG Monitoring During Spinal Surgery:**

Spinal surgery is associated with a risk of injury to the spinal cord. Methods to intra-operatively monitor spinal function have been employed to minimize such risks. These neurophysiological techniques include somato-sensory evoked potentials (SSEP - see CPB 0181), dermatosensory evoked potentials (DSEP - see CPB 0181), and motor evoked potentials (MEP - see CPB 0181). This CPB specifically addresses the continuous, free-running monitoring of EMG activity and stimulus-triggered EMG activity from anatomically appropriate muscles done to detect injury to nerve roots during surgery. The main objective of intra-operative neurophysiological monitoring of spinal cord or nerve root function is to identify induced neurophysiological alterations so that they can be detected as they occur and corrected during surgery; thus avoiding post-surgical complications such as myelopathy or radiculopathy, as well as permanent injury.

Weiss (2001) discussed the application of intra-operative neurophysiological monitoring to surgical treatment of lumbar stenosis. The author noted that benefits of SSEP and MEP studies during surgical correction of spinal deformity are well known and documented. Continuous free-running and stimulus-triggered electromyography (EMG) monitoring during placement of pedicle screw is an accepted practice at many institutions. Moreover, the functional integrity of spinal cord, cauda equina, and nerve roots
should be monitored throughout every stage of surgery including exposure and decompression. Continuous free-running EMG provides feedback regarding the location and potential for surgical injury to the lumbo-sacral nerve roots within the operative field, while stimulus-triggered EMG can confirm that transpedicular instrumentation has been positioned correctly within the bony cortex. Continuous free-running EMG is monitored from muscles innervated by nerves or nerve roots considered to be at risk during spinal surgery. Surgical trauma to these nerve roots and motor nerves will produce high-frequency spikes or trains of motor unit potentials in monitored muscles. These neural discharges can be used to alert the surgeon of inadvertent trauma to nerve roots/peripheral nerves, and avoid more severe or irreversible injury. Multiple channels of continuous free-running EMG activity can be monitored simultaneously, providing real-time information regarding lumbosacral nerve root motor function throughout the operation (Holland, 2002).

Electro-stimulation of intact motor nerves will elicit compound muscle action potentials (CMAP) in innervated muscles. Intra-operative CMAP responses (all-or-none) are usually recorded by means of intra-muscular needle electrodes and submaximal stimulation, in contrast to those measured in diagnostic EMG laboratories where surface electrodes and maximal stimulation are employed. Electro-stimulation is usually performed by the surgeon using a hand-held monopolar or bipolar device within the operative field. The advantage of bipolar stimulation is that it evokes a localized stimulating current, thus avoiding unwanted current spreading to nearby nerves. This is especially useful during peripheral nerve or plexus surgeries, when multiple nerves lie in close proximity. Two examples of stimulus-triggered EMG monitoring are as follows: (i) the presence of a stimulus-triggered CMAP response can be used to differentiate nerve root from fibrous bands during surgical dissection for tethered cord release (Legatt et al, 1992), and (ii) the failure to produce a CMAP response from stimulation of pedicle screws and holes at a stimulus intensity of 7 to 11 mA is the electrophysiological criterion most commonly used to exclude a pedicular cortical perforation (Maguire et al, 1995). However, since the expected
finding is negative (i.e., no CMAP responses), it is always beneficial to test and document a positive control response to confirm the reliability of the test results. This is best achieved by directly stimulating an exposed nerve or nerve root at the same stimulus intensity (Holland, 2002).

Although intra-operative monitoring of EMG has been used to monitor spinal cord function during spinal surgery, there is disagreement regarding its clinical value.

In a clinical trial, Owen and colleagues (1994) examined the use of mechanically elicited EMG during placement of pedicle screws in patients undergoing surgery for spinal stenosis (n = 89). Mechanically elicited EMG was recorded in muscle groups innervated by cervical or lumbar nerve roots. Confirmation of surgical activity with the level of the EMG was correlated. Results of this study indicated that mechanically elicited EMG is very sensitive to nerve root irritation. Compared to other neurophysiological methods, EMG is a viable alternative. These authors concluded that mechanically elicited EMG is sensitive and specific to nerve root firings and should be considered for use during the dynamic phases of surgery.

In a case series study, Beatty et al (1996) discussed their experiences with the use of continuous intra-operative EMG recording during spinal surgery. A total of 150 patients underwent spinal surgery for radiculopathy (120 underwent lumbar surgery and 30 had cervical operations). All of the surgeries were performed to alleviate symptoms due to disc herniation, spondylosis, or both. During the surgical procedures, continuous intra-operative EMG recordings were taken from the muscle corresponding to the involved nerve root. In baseline recordings taken in the operating room 10 minutes before lumbar surgery, electrical discharge or firing was recorded from the muscle in 18 % (22 of 120 patients) of the cases. Once the nerve was decompressed, muscle firing ceased. Electrical discharges were produced with regularity on nerve root retraction. These authors concluded that continuous EMG monitoring can be accomplished easily and yields valuable information that indicates when the nerve root is adequately decompressed or when undue
retraction is exerted on the root. The findings of Owen et al (1994) as well as Beatty et al (1996) are in congruous with that of Limbrick and Wright (2005) who stated that surgeon-driven evoked EMG threshold testing may provide a simple, effective adjunct to lumbar microendoscopic diskectomy for intra-operative verification of nerve root decompression as well as that of Jimenez and co-workers (2005) who reported that the incidence of post-operative C-5 palsies was lowered from 7.3 to 0.9 % as a consequence of intra-operative continuous EMG monitoring. Jimenez et al (2005) also noted that no patient suffered a post-operative C-5 palsy when intra-operative evidence of root irritation was absent.

Continuous intra-operative EMG plus SSEP have also been used in spinal surgery to prevent neural injury. However, only limited data are available on the sensitivity, specificity, and predictive values of intra-operative electrophysiological changes with regard to the occurrence of new post-operative neurological deficits. Gunnarsson and colleagues (2004) retrospectively analyzed a prospectively accrued series of 213 consecutive patients who underwent intra-operative monitoring with EMG and SSEP during thoraco-lumbar spine surgery. The authors examined data on patients who underwent intra-operative monitoring with continuous lower limb EMG and SSEP. The analysis focused on the correlation of intra-operative electrophysiological changes with the development of new neurological deficits. A total of 213 patients underwent surgery on a total of 378 levels; 32.4 % underwent an instrumented fusion. Significant EMG activation was observed in 77.5 % of the patients and significant SSEP changes in 6.6 %. Fourteen patients (6.6 %) had new post-operative neurological symptoms. Of those, all had significant EMG activation, but only 4 had significant SSEP changes. Intra-operative EMG activation had a sensitivity of 100 % and a specificity of 23.7 % for the detection of a new post-operative neurological deficit, while SSEP had a sensitivity of 28.6 % and specificity of 94.7 %. These investigators concluded that intra-operative EMG activation has a high sensitivity for the detection of a new post-operative neurological deficit but a low specificity. In contrast, SSEP has a low sensitivity but a high specificity. They noted that combined intra-operative monitoring with EMG and
SSEP is helpful for predicting and possibly preventing neurological injury during thoracolumbar spine surgery.

The aforementioned study by Gunnarson, et al. (2004) was one of two studies of intraoperative EMG that met inclusion criteria in the recent systematic evidence review of intraoperative neuromonitoring for spinal surgery by Fehlings, et al. (2010). The other study, by Kelleher, et al. (2008), looked at the predictive value of intraoperative EMGs and evoked potentials in cervical spine surgery. The aforementioned study by Gunnarsson, et al. (2004) reported on EMGs and SSEPs in 213 patients undergoing thoracolumbar surgery. EMG activation occurred in more than three-fourths of patients, including all of 14 patients who were found to have new or exacerbated neurologic symptoms postoperatively. The authors found that intraoperative EMG had a negative predictive value of 1.0 but a positive predictive value of 0.085. The authors posited that the low specificity of intraoperative EMG may be because the surgeon was able to avoid injury by changing the surgical strategy based upon the monitoring. However, the study did not report whether and what type of changes in surgical strategy were made as a result of EMG neuromonitoring. Significant limitations of this study include retrospective analysis, lack of standardized method of case ascertainment, and lack of blinding of clinical outcome assessment. Nonobjective outcomes are particularly problematic for assessing the usefulness of intraoperative neuromonitoring because of the potential for diagnostic suspicion bias. Without masked clinical outcome assessment and a standardized method of case ascertainment, patients with a positive EMG result could be more thoroughly evaluated for neurologic deficits than persons with a normal intraoperative neuromonitoring result. This bias would tend to exaggerate the usefulness of intraoperative EMG.

Available studies of intraoperative EMG for pedicle screw placement (e.g., Raynor, et al., 2007; Toleikis, et al., 2000) focus on the relationship between threshold testing to hardware position, but include no data on clinical outcomes. In addition, studies have not examined the clinical consequence of unnecessary screw revisions or removal. Considering that a false-
positive finding can result in the temporary removal of a pedicle screw to evaluate the screw tract, performing a laminotomy to check screw position, repositioning or complete removal of a pedicle screw, or aborting a planned portion of the procedure, the potential for significant adverse effects on outcome exists. There is yet to be any published data showing reduced postoperative neurologic deficit or improved clinical outcomes from using intraoperative EMG to confirm satisfactory placement of pedicle screws at any spinal level to justify the time, effort and potential adverse consequences involved. Additional prospective study of these recordings is recommended to further specify the relationship of electrophysiological breach to clinical outcomes.

In a prospective clinical study, Raynor et al (2002) assessed the sensitivity of recording rectus abdominis-triggered EMG to evaluate placement of thoracic screw. A total of 677 thoracic screws were inserted into 92 patients. Screws placed from T-6 and T-12 were evaluated using an ascending method of stimulation until a CMAP was obtained from the rectus abdominis. Threshold values were compared both in absolute terms and also in relation to other intra-patient values. Screws were divided into 3 groups: (i) group A (n = 650 screws) had thresholds greater than 6.0 mA and intra-osseus placement, (ii) group B (n = 21) had thresholds less than 6.0 mA but an intact medial pedicle border on re-examination and radiographical confirmation, and (iii) group C (n = 6) had thresholds less than 6.0 mA and medial wall perforations confirmed by tactile and/or visual examination. Thus, 3.9 % (27 of 677) of all screws had thresholds less than 6.0 mA. Only 22 % (6 of 27) had medial perforation. Group B screws averaged a 54 % decrease from the mean as compared with a 69 % decrease for group C screws (p = 0.016). There were no post-operative neurological deficits or radicular chest wall complaints. These investigators concluded that for assessment of thoracic pedicle screw placement, triggered EMG thresholds of less than 6.0 mA, coupled with values 60 to 65 % decreased from the mean of all other thresholds in a given patient, should alert the surgeon to suspect a medial pedicle wall breach. These investigators further stated that although this retrospective analysis of electrophysiological observations and subsequent guidelines are not currently
validated, this electrophysiological approach can be used in conjunction with precise surgical techniques, careful pedicle tract palpation, as well as intra-operative biplanar fluoroscopy and/or radiography to create the safest environment for placement of thoracic screw. They noted that further investigations of these guidelines will be carried out to validate this electrophysiological approach.

It is interesting that the conclusion of the study by Raynor et al (2002) was directly opposite to that by Reidy et al (2001), who, in a prospective study, examined the use of inter-costal EMG monitoring as an index of the accuracy of the placement of pedicle screws in the thoracic spine. A total of 95 thoracic pedicle screws in 17 patients were studied. Prior to insertion of the screw, the surgeon recorded his assessment of the integrity of the pedicle track, and then stimulated the track using a K-wire pedicle probe connected to a constant current stimulator. A CMAP was recorded from the appropriate inter-costal or abdominal muscles. Post-operative computed tomography (CT) was performed to establish the position of the screw. The stimulus intensity needed to evoke a muscle response was correlated with the position of the screw on the CT scan. There were 8 unrecognized breaches of the pedicle. Using 7.0 mA as a threshold, the sensitivity of EMG was 0.50 in detecting a breached pedicle and the specificity was 0.83. Thoracic pedicle screws were accurately placed in more than 90% of patients. These investigators concluded that EMG monitoring did not significantly improve the reliability of placement of the screw.

Regarding the observations by Raynor and colleagues (2002), Finkelstein (2003) stated that “the value of a screening test should be such that the outcome could be altered by the prediction of an adverse event. The protocol of the study by Raynor et al would suggest that the damage of a medially placed screw would have already occurred by the time the screws were tested for CMAP and then compared to the other screws, determining an “average“ of all other thresholds. Aside from improving the radiograph, it would seem to have little clinical utility”. Finkelstein also noted that the utility of a screening test is defined by its sensitivity and specificity, as well as its positive
predictive value. These were assessed in the study by Reidy and associates, and deemed unable to improve the accuracy beyond an experienced surgeon's knowledge of well described anatomical landmarks.

In a review on intra-operative EMG monitoring during thoracolumbar spinal surgery, Holland (1998) stated that this approach has a number of potential limitations, including: (i) EMG is sensitive to blunt lumbosacral nerve root irritation or injury, but may provide misleading results with “clean” nerve root transaction, (ii) EMG must be recorded from muscles belonging to myotomes appropriate for the nerve roots considered at risk from surgery, (iii) EMG can be effective only with careful monitoring and titration of pharmacological neuromuscular junction blockade, (iv) when transpedicular instrumentation is stimulated, an exposed nerve root should be stimulated directly as a positive control whenever possible, (v) pedicle holes and screws should be stimulated with single shocks at low-stimulus intensities when pharmacological neuromuscular blockade is excessive, and (vi) chronically compressed nerve roots that have undergone axonotmesis (wallerian degeneration) have higher thresholds for activation from electrical and mechanical stimulation. Hence, whenever axonotmetic nerve root injury is suspected, the stimulus thresholds for transpedicular holes and screws must be specifically compared with those required for the direct activation of the adjacent nerve root (and not published guideline threshold values).

Krassioukov et al (2004) examined the neurological outcomes after complex lumbo-sacral surgery in patients undergoing multi-modality neurophysiological monitoring. A total of 61 patients were consecutively enrolled in this study. These subjects underwent complex intra- and extra-dural lumbosacral procedures with concomitant intra-operative EMG monitoring of the lower-limb muscles, external anal and urethral sphincters (EAS and EUS), and lower-limb SSEP. Long-term (minimum of 2 years) clinical follow-up data were obtained in all cases. Most subjects were treated for spinal/spinal cord tumors (61 %) or adult tethered cord syndrome (25 %). Recordable lower-extremity SSEP were reported in 54 patients (89 %). New post-
operative neurological deficits occurred in only 3 patients (4.9 %), and remained persistent in only 1 patient (1.6 %) at long-term follow-up examination. In only 1 of these cases was a significant decrease in SSEP amplitude detected. Spontaneous EMG activity was observed in the lower-extremity muscles and/or EAS and EUS in 51 cases (84 %). Intra-operatively, EMG demonstrated activity only in the EUS in 5 % of patients and only in the EAS in 28 %. In 7 patients (11 %) spontaneous intra-operative EMG activity was observed in both the EAS and the EUS; however, in only 3 of these cases was EMG activity recorded in both sphincters simultaneously. In addition to spontaneously recorded EMG activity, electrically evoked EMG activity was also used as an intra-operative adjunct. A bipolar stimulating electrode was used to identify functional neural tissue before undertaking microsurgical dissection in 58 individuals (95 %). In the majority of these patients, evoked EMG activity occurred either in 1 (33 %) or in 2 muscles (9 %) simultaneously. The presence of electrically evoked EMG activity in structures encountered during microdissection altered the plan of treatment in 24 cases (42 %). The investigators concluded that the combined SSEP and EMG monitoring of lower-limb muscles, EAS, and EUS is a practical and reliable method for obtaining optimal electrophysiological feedback during complex neurosurgical procedures involving the conus medullaris and cauda equina. Analysis of the results indicates that these intra-operative adjunctive modalities positively influence decision making with regard to microsurgery and reduce the risk of peri-operative neurological complications. Moreover, the authors noted that validation of the clinical value of these approaches, however, will require further assessment in a larger prospective cohort of patients.

In a review on electrophysiological intra-operative monitoring for spinal surgeries, Slimp (2004) stated that the advent of equipment capable of performing SSEP, MEP, and EMG in a multiplexed fashion, and in a timely manner brings a new level of monitoring that far exceeds the previous basic monitoring done with SSEP only. However, the author noted that whether this more comprehensive monitoring will result in greater protection of the nervous system awaits future analysis. It is also interesting to note that when Erickson and co-workers (2005) from the
technology assessment unit of the McGill University Health Center developed a report on the use of intra-operative neurophysiological monitoring during spinal surgery, they only examined the use of SSEP and MEP. These investigators recommended that combined SSEP/MEP should be available for all cases of spinal surgery for which there is a risk of injury to the spinal cord.

The American Association of Neurological Surgeons/Congress of Neurological Surgeons' guidelines for the performance of fusion procedures for degenerative disease of the lumbar spine (Resnick et al, 2005) stated that there does not appear to be support for the hypothesis that any type of intra-operative monitoring improves patient outcomes after spinal surgery such as lumbar decompression or fusion procedures for degenerative spinal disease. The report noted that evidence does indicate that a normal evoked EMG response is predictive for intra-pedicular screw placement (high negative predictive value for breakout); while the presence of an abnormal EMG response does not, however, exclude intra-pedicular screw placement (low PPV). The majority of clinically apparent post-operative nerve injuries are associated with intra-operative changes in SSEP and/or DSEP monitoring. Thus, changes in DSEP/SSEP monitoring appear to be sensitive to nerve root injury. However, there is a high false-positive rate, and changes in DSEP and SSEP recordings are often not associated with nerve injury. A normal study has been shown to correlate with the lack of a significant post-operative nerve injury. There is insufficient evidence that the use of intra-operative monitoring of any kind provides clinically useful information to the surgeon in terms of assessing the adequacy of nerve root decompression at the time of surgery. Furthermore, the authors stated that a randomized prospective study comparing clinical and radiographical outcomes in similar groups of patients undergoing lumbosacral fusion with or without intra-operative monitoring would provide Class I evidence (well-conducted randomized prospective trials) supporting or refuting the hypothesis that the added expense associated with the use of intra-operative monitoring is justified by a clinical benefit.

In a prospective analysis, Paradiso and colleagues (2006)
evaluated the sensitivity, specificity, as well as PPV and NPV of multi-modality intra-operative neurophysiological monitoring in surgery for adult tethered cord syndrome. The results of multi-modality intra-operative neurophysiological monitoring were compared with the "gold standard" (neurological outcomes). Multi-modality intra-operative neurophysiological monitoring included posterior tibial nerve SSEPs, continuous EMG monitoring of the L2 to S4 myotomes, and evoked EMG. Follow-up neurological evaluations were performed for at least 1 year. A total of 44 consecutive patients, including 19 males and 25 females (aged 43 +/- 15 years), who underwent microsurgery for adult tethered cord syndrome were evaluated. After surgery, new neurological deficits, including 1 transient and 1 permanent, developed in 2 patients. There was 1 patient who had persistent posterior tibial nerve SSEP amplitude reduction following microsurgical manipulation. In 1 patient, a transient posterior tibial nerve SSEP amplitude reduction prompted a change in microneurosurgical strategy. This patient awoke with no new post-operative neurological deficits. For SSEPs, the sensitivity was 50 % and specificity 100 %. Electromyographical bursts were recorded in 36 patients (82 %). The 2 patients with post-operative neurological worsening had EMG activity in the myotomes, where their new deficits presented. Continuous EMG had a sensitivity of 100 % and a specificity of 19 %. The authors concluded that this was the largest series to date reporting the use of multi-modality intra-operative neurophysiological monitoring in the surgical management of adult tethered cord syndrome. Posterior tibial nerve SSEPs have high specificity, but low sensitivity, for predicting new neurological deficits. In contrast, continuous EMG showed high sensitivity and low specificity. Evoked EMG accurately identified functional neural tissue. The combined recording of SSEPs in concert with continuous and evoked EMGs may provide a useful adjunct to complex microsurgery for adult tethered cord syndrome.

In a systematic review, Fehlings and colleagues (2010) examined if intra-operative monitoring (IOM) is able to sensitively and specifically detect intra-operative neurologic injury during spine surgery and to assess whether IOM results in improved outcomes for patients during these procedures. A review of the English
language literature was undertaken for articles published between 1990 and March 2009. MEDLINE, EMBASE, and Cochrane Collaborative Library databases were searched, as were the reference lists of published articles examining the use of IOM in spine surgery. Two independent reviewers assessed the level of evidence quality using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) criteria, and disagreements were resolved by consensus. A total of 103 articles were initially screened and 32 ultimately met the predetermined inclusion criteria. These researchers determined that there is a high level of evidence that multi-modal (SSEP and MEP) IOM is sensitive and specific for detecting intra-operative neurologic injury during spine surgery. There is a low level of evidence that IOM reduces the rate of new or worsened peri-operative neurologic deficits (a grade of "low" means that further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate). There is very low evidence that an intra-operative response to a neuromonitoring alert reduces the rate of peri-operative neurologic deterioration (a grade of "very low" means that any estimate of effect is very uncertain). The authors concluded that based on strong evidence that multi-modality intra-operative neuromonitoring is sensitive and specific for detecting intra-operative neurologic injury during spine surgery, it is recommended that the use of multi-modality intra-operative neuromonitoring be considered in spine surgery where the spinal cord or nerve roots are deemed to be at risk, including procedures involving deformity correction and procedures that require the placement of instrumentation. Furthermore, they stated that there is a need to develop evidence-based protocols to deal with intra-operative changes in multi-modality intra-operative neuromonitoring and to validate these prospectively. Intra-operative EMG monitoring was not recommended as a means of neurophysiological monitoring during spinal surgery.

Kundnani et al (2010) reported the analysis of prospectively collected intra-operative neurophysiological monitoring data of 354 consecutive patients undergoing corrective surgery for adolescent idiopathic scoliosis (AIS) to establish the efficacy of multi-modal neuromonitoring and to evaluate comparative
sensitivity and specificity. The study group consisted of 354 patients (45 males and 309 females) undergoing spinal deformity corrective surgery between 2004 and 2008. Patients were monitored using electrophysiological methods including SSEP and MEP simultaneously. Mean age of patients was 13.6 years (+/- 2.3 years). The operative procedures involved were instrumented fusion of the thoracic/lumbar/both curves. Baseline SSEP and neurogenic MEP (NMEP) were recorded successfully in all cases. Thirteen cases expressed significant alert to prompt reversal of intervention. All these 13 cases with significant alert had detectable NMEP alerts, whereas significant SSEP alert was detected in 8 cases. Two patients awoke with new neurological deficit (0.56 %) and had significant intra-operative SSEP and NMEP alerts. There were no false-positives with SSEP (high specificity) but 5 patients with false-negatives with SSEP (38 %) reduced its sensitivity. There was no false-negative with NMEP but 2 of 13 cases were false-positive with NMEP (15 %). The specificity of SSEP (100 %) is higher than NMEP (96 %); however, the sensitivity of NMEP (100 %) is far better than SSEP (51 %). Due to these results, the overall sensitivity, specificity and PPV of combined multi-modality neuromonitoring in this adult deformity series was 100 %, 98.5 % and 85 %, respectively. The authors concluded that NMEP monitoring appears to be superior to conventional SSEP monitoring for identifying evolving spinal cord injury. Used in conjunction, the sensitivity and specificity of combined neuromonitoring may reach up to 100 %. Multi-modality monitoring with SSEP and NMEP should be the standard of care.

In a cross-sectional study of non-consecutive cases (level III evidence), de Bla et al (2012) reported the findings of a series of young patients with thoracic scoliosis who were treated with pedicle screw constructs. Data obtained from triggered EMG (t-EMG) screw stimulation and post-operative computed tomographic scans were matched to find different threshold limits for the safe placement of pedicle screws at the concavity (CC) and convexity (CV) of the scoliotic curves. The influence of the distance from the medial pedicle cortex to the spinal cord on t-EMG threshold intensity was also investigated at the apex segment. A total of 23 patients who underwent posterior fusions
using 358 pedicle thoracic screws were reviewed. All patients presented main thoracic scoliosis, with a mean Cobb angle of 58.3 degrees (range of 46 to 87 degrees). Accuracy of the screw placement was tested at surgery by the t-EMG technique. During surgery, 8 screws placed at the CC showed t-EMG threshold values below 7 mA and were carefully removed. Another 25 screws disclosed stimulation thresholds within the range of 7 to 12 mA. After checking the screw positions by intraoperative fluoroscopy, 15 screws were removed because of clear signs of mal-positioning. Every patient underwent a pre-operative magnetic resonance imaging examination, in which the distances from the spinal cord to the pedicles of the concave and convex sides at 3 apex vertebrae were measured. Post-operative computed tomographic scans were used in all patients to detect screw mal-positioning of the final 335 screws. According to post-operative computed tomographic scans, 44 screws (13.1 %) showed different mal-positions: 40 screws (11.9 %) perforated the medial pedicle wall, but only 11 screws (3.2 %) were completely inside the spinal canal. If these researchers considered the 23 screws removed during surgery, the true rate of misplaced screws increased to 18.7 %. In those screws that preserved the pedicle cortex (well-positioned screws), EMG thresholds from the CC showed statistically significantly lower values than those registered at the CV of the deformity (21.1 ± 8.2 versus 23.9 ± 7.7 mA, p < 0.01). In the concave side, t-EMG threshold values under 8 mA should be unacceptable because they correspond to screw mal-positioning. Threshold values above 14 mA indicate an accurate intrapedicular position with certainty. At the convex side, threshold values below 11 mA always indicate screw mal-positioning, and values above 19 mA imply accurate screw placement. At the 3 apex vertebrae, the average pedicle-spinal cord distance was 2.2 ± 0.7 mm at the concave side and 9.8 ± 4.3 mm at the convex side (p < 0.001). In well-positioned screws, a correlation between pedicle-dural sac distance and t-EMG threshold values was found at the concave side only (Pearson r = 0.467, p < 0.05). None of the patients with misplaced screws showed post-operative neurological impairment. The authors concluded that independent of the screw position, average t-EMG thresholds were always higher at the CV in the apex and above the apex regions, presuming that
the distance from the pedicle to the spinal cord plays an important role in electrical transmission. They stated that the t-EMG technique has low sensitivity to predict screw malpositioning and can not discriminate between medial cortex breakages and complete invasion of the spinal canal.

Also, an UpToDate review on “Treatment and prognosis of adolescent idiopathic scoliosis” (Scherl, 2012) mentions the use of intra-operative SEP and MEP monitoring; but not intra-operative EMG monitoring.

In a prospective study, Glassman and colleagues (1995) performed an analysis of intra-operative EMG monitoring of pedicle screw placement with CT scan confirmation. A total of 90 patients underwent lumbar pedicle screw instrumentation; 512 screws were tested intra-operatively using electrical stimulation. The accuracy of this technique was verified after surgery by CT. Screws (total, 512) in 90 patients were stimulated intra-operatively, and stimulation threshold was recorded. Computed tomographic scans were taken after surgery to document pedicle screw position; EMG thresholds and CT data were evaluated independently and compared to evaluate the accuracy of the EMG stimulation technique. Intra-operative screw stimulation was extremely accurate in confirming the adequacy of screw position. A stimulation threshold greater than 15 mA provided a 98% confidence that the screw was within the pedicle. In 8 of 90 patients (9%), EMG monitoring detected a screw mal-position that was not identified on lateral radiograph. The authors concluded that screw stimulation monitoring is a valuable and effective adjunct to lumbar pedicle screw instrumentation. They stated that a stimulation threshold greater than 15 mA reliably indicated adequate screw position. A stimulation threshold between 10 and 15 mA was generally associated with adequate screw position, although exploration of the pedicle is recommended; a stimulation threshold of less than 10 mA was associated with a significant cortical perforation in most instances. The main drawback of this study was that it focused on the relationship between EMG threshold testing to hardware position, but lacked data on clinical outcomes.
In a retrospective, controlled clinical study, Ovadia and associates (2011) evaluated the contribution of an electronic conductivity device (ECD) to the safety of pedicle screw insertion in pediatric scoliosis surgery. Pedicle screw insertion was analyzed in 248 pediatric scoliosis patients (idiopathic, congenital, neuromuscular, syndromatic). Group I included 150 procedures without the aid of the ECD and group II included 98 ECD-aided procedures. The 2 groups were matched by age, sex, etiology, Cobb angle, and surgical criteria. Data on screw position and concomitant neuro-monitoring alarms were compared. Group I consisted of patients operated with both the hybrid construct and pedicle screw instrumentation, while group II consisted of patients operated solely with pedicle screws. Both groups were operated on by a single surgeon with the same neurophysiologic methodology. Clinically relevant misplaced pedicle screws were established by intra-operative monitoring alarms concomitant with pedicle screw insertion. A total of 1,270 pedicle screw placements were analyzed in group I and compared with 1,400 pedicle screw placements in group II. Neuro-monitoring alarms concomitant with screw placement occurred in 10 procedures in group I (6.6 %) compared with 3 in group II (3.0 %). The contribution of the electronic device to reducing the number of neurophysiologic alarms was significant (p = 0.048, Fisher exact test); 9 of the 13 monitoring alarms (69 %) were associated with implantation adjacent to the apex of the spinal curve. The authors concluded that the use of an ECD significantly reduced the incidence of clinically relevant misplaced screws in a variety of scoliosis patients, thereby increasing the safety of pedicle screw implantation. This study did not appear to provide evidence for intra-operative EMG.

Lee and associates (2015) noted that triggered EMG (t-EMG) for pedicle screw placement was introduced to prevent the misplacement of screws; however, its diagnostic value is still debated. These researchers attempted to clarify the diagnostic value of t-EMG and to compare thresholds. They searched Medline, Embase, and the Cochrane Library, and 179 studies were identified. Among them, 11 studies were finally enrolled. The pooled sensitivity, specificity, diagnostic odds ratio (DOR), and summary receiver operating characteristics (SROC) plots were
The enrolled studies included 13,948 lumbar and 2,070 thoracic screws. The overall summary sensitivity/specificity/DOR values of t-EMG were 0.55/0.97/42.16 in the lumbar spine and 0.41/0.95/14.52 in the thoracic spine, respectively, indicating a weak diagnostic value. However, subgroup analysis by each threshold value showed that the cut-off value of 8 mA in the lumbar spine indicated high sensitivity (0.82), specificity (0.97), and DOR (147.95), thereby showing high diagnostic accuracy of identifying misplaced screws. The authors concluded that the most useful application of t-EMG may be as a warning tool for lumbar pedicle screw mal-positioning in the presence of positive stimulation at a threshold of less than or equal to 8 mA.

Mikula and colleagues (2016) determined the ability of t-EMG to detect misplaced pedicle screws (PSs). These investigators searched the U.S. National Library of Medicine, the Web of Science Core Collection database, and the Cochrane Central Register of Controlled Trials for PS studies. A meta-analysis of these studies was performed on a per-screw basis to determine the ability of t-EMG to detect misplaced PSs. Sensitivity, specificity, and ROC area under the curve (AUC) were calculated overall and in subgroups. A total of 26 studies were included in the systematic review. These researchers analyzed 18 studies in which t-EMG was used during PS placement in the meta-analysis, representing data from 2,932 patients and 15,065 screws. The overall sensitivity of t-EMG for detecting misplaced PSs was 0.78, and the specificity was 0.94. The overall ROC AUC was 0.96. A t-EMG current threshold of 10 to 12 mA (ROC AUC 0.99) and a pulse duration of 300 µsec (ROC AUC 0.97) provided the most accurate testing parameters for detecting misplaced PSs. Screws most accurately conducted EMG signals (ROC AUC 0.98). The authors concluded that t-EMG has very high specificity but only fair sensitivity for detecting mal-positioned PSs.

In a prospective, randomized study, Bernhardt and co-workers (2016) evaluated the impact of intra-operative pedicle screw monitoring on screw positioning. These investigators enrolled 22 patients and they were split into 2 equal groups: (i) dorsal instrumentation was supplemented with intra-operative nerve root monitoring using the INS-1-System (NuVasive, San Diego,
CA), and (ii) screws were inserted without additional pedicle monitoring. All patients underwent mono-segmental instrumentation with "free hand implanted" pedicle screws; a total of 44 screws were inserted in each group. The screw position was evaluated post-operatively using CT scans. The position of the screws in relation to the pedicle was measured in 3 different planes: (i) sagittal, (ii) axial and (iii) coronal. The accuracy of the screw position was described using the Berlemann classification system. Screw position is classified in 3 groups: (i) type 1 correct screw position, (ii) type 2 encroachment on the inner cortical wall, and (iii) type 3 pedicle cortical perforation. Screw angulation and secondary operative criteria were also evaluated. The use of neuro-monitoring did not influence the distance between the center of the screws and the pedicle wall. Distances only depended on the implantation side (right and left) and the height of implantation (caudal or cranial screw). Because of the low number of cases, no conclusion could be reached about the influence of root monitoring on the correct positioning of the screws. There was at least a non-significant trend towards more frequent perforation of the pedicle in the monitor group. In the present study, these researchers showed that root monitoring had a significant effect on the scattering of transversal angles. These were increased compared to the control group. Otherwise, the implantation angle was not shown to depend on the use of neuro-monitoring. They noted that neuro-monitoring did not influence blood loss or operative time. The authors concluded that the data did not permit any conclusion as to whether this technique can minimize the frequency of pedicle screw mal-position. The 4 coronal plane distances did not depend on the use of neuro-monitoring. The inclination angle was also unaffected by neuro-monitoring. The only parameter for which the authors found any effect was the transverse angle. The mean values were similar in both groups, but the variances were not equal. They stated that the effect of monitoring on the only parameter which could not be evaluated by fluoroscopy is thus rather unfavorable.

Hussain (2015) stated that while prospective data regarding the clinical utility of IOM are conspicuously lacking, retrospective analyses continue to provide useful information regarding
surgeon responses to reported waveform changes. Data regarding clinical presentation, operative course, IOM, and post-operative neurological examination were compiled from a database of 1,014 cranial and spinal surgical cases at a tertiary care medical center from 2005 to 2011. Intra-operative monitoring modalities utilized included SSEP, transcranial MEP, pedicle screw stimulation, and EMG. Surgeon responses to changes in IOM waveforms were recorded. Changes in IOM waveforms indicating potential injury were present in 87 of 1,014 cases (8.6 %). In 23 of the 87 cases (26.4 %), the surgeon responded by re-positioning the patient (n = 12), re-positioning retractors (n = 1) or implanted instrumentation (n = 9), or by stopping surgery (n = 1). Loss of IOM waveforms predicted post-operative neurological deficit in 10 cases (11.5 % of cases with IOM changes). In the largest IOM series to-date, the authors reported that the surgeon responded by appropriate interventions in over 25 % of cases during which there were IOM indicators of potential harm to neural structures. Moreover, they stated that prospective studies remain to be needed to adequately evaluate the utility of IOM in changing surgeon behavior.

Spitz et al (2015) stated that although advances have been made in surgical technique and IOM, the rate of post-operative C5 palsy remains the same. These researchers attempted to define characteristics which may predict risk of developing post-operative C5 palsy. Retrospective chart review identified 644 patients undergoing cervical procedures. Anterior cervical discectomy and fusion was performed in 456, anterior cervical corpectomy and fusion (ACCF) in 78, posterior laminectomy and fusion (PLF) in 106, and posterior open-door laminoplasty in 4 patients. All patients had neurophysiologic monitoring (SSEP, spontaneous EMG, and/or MEP). Post-operative C5 root palsy occurred in 5 (2 with ACCF and 3 with PLF) cases (1.4 %). In all cases, there were no changes in intra-operative neurophysiologic monitoring; C5 palsy did not occur before post-operative day 2. The authors concluded that patients undergoing cervical decompression remain at risk for C5 root palsy despite use of IOM. They stated that given that all patients experienced delayed onset of C5 palsy, MEP, SSEP, and EMG may not be sensitive enough to assess the risk of developing C5 palsy.
Thirumala and colleagues (2016) conducted a systematic review of reports of patients with cervical spondylotic myelopathy and evaluated the value of IOM, including SSEP, transcranial MEP and EMG, in anterior cervical procedures. A search was conducted to collect a small database of relevant papers using key words describing disorders and procedures of interest. The database was then shortlisted using selection criteria and data was extracted to identify complications as a result of anterior cervical procedures for cervical spondylotic myelopathy and outcome analysis on a continuous scale. In the 22 studies that matched the screening criteria, only 2 involved the use of IOM. The average sample size was 173 patients. In procedures done without IOM a mean change in Japanese Orthopaedic Association score of 3.94 points and Nurick score by 1.20 points (both less severe post-operatively) was observed. Within our sub-group analysis, worsening myelopathy and/or quadriplegia was seen in 2.71 % of patients for studies without IOM and 0.91 % of patients for studies with IOM. Variations persisted in the existing literature in the evaluation of complications associated with anterior cervical spinal procedures. The authors concluded that based on the review of published studies, sufficient evidence does not exist to make recommendations regarding the use of different IOM modalities to reduce neurological complications during anterior cervical procedures. However, they stated that future studies with objective measures of neurological deficits using a specific IOM modality may establish it as an effective and reliable indicator of injury during such surgeries.

In a large, single-institution, case-series study involving all levels of the spinal column and all spinal surgical procedures, Raynor and associates (2016) categorized and evaluated IOM failure to detect neurologic deficits occurring during spinal surgery. Multi-modality IOM included SSEPs, descending neurogenic evoked potentials (DNEPs), transcranial MEP, DSEP, and spontaneous electromyography (spEMG) and t-EMG. These investigators reviewed 12,375 patients who underwent surgery for spinal pathology from 1985 to 2010. There were 7,178 females (59.3 %) and 5,197 males (40.7 %); 9,633 (77.8 %) primary surgeries and 2,742 (22.2 %) revisions. Procedures by spinal level were: cervical 29.7 % (3,671), thoracic/thoracolumbar 45.4 % (5,624) and
lumbosacral 24.9% (3,080). Age at surgery was: greater than 18 years 72.7% (8,993), less than 18 years 27.3% (3,382); 45 of the 12,375 patients (0.36%) had false negative outcomes. False negative results by modality were as follows: spEMG (n = 22, 48.8%), t-EMG (n = 8, 17.7%), DSEP (n = 4, 8.8%), DNEL (n = 4, 8.8%), SSEP (n = 3, 6.6%), DSEP/spEMG (n = 3, 6.6%), t-EMG/spEMG (n = 1, 2.2%); 37 patients had immediate post-operative deficits unidentified by IOM; 30 (81%) involved nerve root monitoring, 4 had spinal cord deficits, and 3 had peripheral sensory deficits; 8 patients had permanent neurologic deficits, 6 (0.048%) were nerve root and 2 (0.016%) were spinal cord in nature. The authors concluded that despite correct application and usage, IOM data failed to identify 45 (0.36%) patients with false negative outcomes out of 12,375 surgical patients; 8 (0.064%) of these 45 patients had permanent neurologic deficits, 6 were nerve root in nature and 2 were spinal cord. They stated that although admittedly small, this represented the risk of undetected neurologic deficits even when properly using IOM. Deficits were at a higher risk to remain unresolved when not detected by IOM. (Level of Evidence = IV)

In summary, there is insufficient scientific evidence that intraoperative monitoring of EMG during spinal surgery provides useful information to the surgeon in terms of assessing the adequacy of nerve root decompression, detecting nerve root irritation, or improving the reliability of placement of pedicle screw at the time of surgery.

In a retrospective study, Kaliya-Perumal and colleagues (2017) investigated the effectiveness of intraoperative EMG monitoring to detect potential pedicle breach and examined if re-operation rates were significantly reduced. Patients who underwent posterior stabilization with pedicle screws for various pathologies were analyzed and those with screws among L1 to S1 levels were short-listed. They were divided into 2 groups: Group 1 included patients in whom t-EMG was used to confirm appropriate screw placement, and Group 2 included those in whom it was not used. Responses to t-EMG and corresponding stimulation thresholds were recorded for Group 1 patients. The sensitivity and specificity of the test was calculated. Re-operation rates due to
post-operative neurologic compromise caused by mal-positioned screws were compared between both the groups. A total of 518 patients had 3,112 pedicle screws between L1 to S1 levels. Among Group 1 \([n = 296; \text{ screws } = 1,856]\), 145 screws (7.8 \%) showed a positive response for t-EMG at stimulation thresholds ranging between 2.6 to 19.8 mA. The sensitivity and specificity of t-EMG to diagnose potential pedicle breach was found to be 93.33 \% and 92.88 \% respectively. Only 1 patient among Group 1 needed re-operation. However, among Group 2 \([n = 222; \text{ screws } = 1,256]\), 6 patients needed re-operation. This indicated a significant decrease in the number of mal-positioned screws that caused neurologic compromise \([p = 0.02]\), leading to subsequent decrease in re-operation rates \([p = 0.04]\) among Group 1 patients. The authors concluded that these findings suggested that t-EMG can be considered highly sensitive and specific for identifying potential pedicle breach by a mal-positioned screw that can cause neurologic compromise; but, undetected breaches may still exist. However, t-EMG monitoring in combination with palpatory and radiographic assessment will aid safe and secure pedicle screw placement. It can also reduce re-operation rates due to neurologic compromise provoked by a mal-positioned screw.

These researchers noted that this analysis may be subject to secular influences regarding certain factors due to the retrospective nature of this study. Regarding selection of samples, these investigators only included patients with pedicle screws among L1 to S1 segments, excluding dysmorphic pedicles. However, it should be understood that, not all pedicles are anatomically similar and there can be variants or anomalies. The underlying pathology for which the surgery was done may have affected the pedicle anatomy. The pedicles of patients in one group may be more prone for a breach when compared to the other group. This may have influenced the analysis of re-operation rates. The overall number of screws and the number of screws per patient in Group 1 was significantly higher than that of Group 2. Besides that, the decision to use intraoperative EMG was purely based on availability. These factors may have contributed for a selection bias and could have influenced these findings.
Grabb and colleagues (1997) reviewed the results of continuous intra-operative EMG monitoring of muscles innervated by cranial nerves in 17 children whose pre-operative imaging studies showed compression or infiltration of the 4th ventricular floor by tumor to determine how intra-operative EMG activity correlated with post-operative cranial nerve morbidity. Bilateral lateral rectus (6th) and facial (7th) nerve musculatures were monitored in all children. Cranial nerve function was documented immediately post-operatively and at 1 year. Of the 68 nerves monitored, 9 new neuropathies occurred in 6 children (6th nerve in 4 children and 7th nerve in 5 children). In 5 new neuropathies, intra-operative EMG activity could be correlated in 1 of 4 6th nerve injuries and 4 of 5 7th nerve injuries. Electromyographic activity could not be correlated in 4 children with new neuropathies. Of 59 cranial nerves monitored that remained unchanged, 47 had no EMG activity. Twelve cranial nerves (3 6th nerves and 9 7th nerves) had EMG activity but no deficit. Of 4 children with lateral rectus EMG activity, 3 had new 7th nerve injuries. Lateral rectus EMG activity did not predict post-operative abducens injury. The absence of lateral rectus EMG activity did not assure preserved abducens function post-operatively. Likely because of the close apposition of the intrapontine facial nerve to the abducens nucleus, lateral rectus EMG activity was highly predictive of 7th nerve injury. The authors noted that although facial muscle EMG activity was not an absolute predictor of post-operative facial nerve dysfunction, the presence of facial muscle EMG activity was associated statistically with post-operative facial paresis. The absence of facial muscle EMG activity was rarely associated with facial nerve injury. The authors speculated that EMG activity in the facial muscles may have provided important intra-operative information to the surgeon so as to avoid facial nerve injury.

Kombos et al (2000) stated that intra-operative cranial nerve monitoring has improved the preservation of facial nerve function following surgery in the cerebello-pontine angle (CPA). Facial EMG was performed in 60 patients during CPA surgery. Pairs of needle electrodes were placed subdermally in the orbicularis oris...
and orbicularis oculi muscles. The duration of facial EMG activity was noted. Facial EMG potentials occurring in response to mechanical or metabolic irritation of the corresponding nerve were made audible by a loudspeaker. Immediate (4 to 7 days after tumor excision) and late (6 months after surgery) facial nerve function was assessed on a modified House-Brackmann scale. Late facial nerve function was good (House-Brackmann 1 to 2) in 29 of 60 patients, fair (House-Brackmann 3 to 4) in 14, and poor (House-Brackmann 5 to 6) in 17. Post-manipulation facial EMG activity exceeding 5 minutes in 15 patients was associated with poor late function in 5, fair function in 6, and good function in 4 cases. Post-manipulation facial EMG activity of 2 to 5 minutes in 30 patients was associated with good late facial nerve function in 20, fair in 8, and poor in 2. The loss of facial EMG activity observed in 10 patients was always followed by poor function. Facial nerve function was preserved post-operatively in all 5 patients in whom facial EMG activity lasted less than 2 minutes. The authors concluded that facial EMG is a sensitive method for identifying the facial nerve during surgery in the CPA. EMG bursts are a very reliable indicator of intra-operative facial nerve manipulation, but the duration of these bursts do not necessarily correlate with short- or long-term facial nerve function despite the fact that burst duration reflects the severity of mechanical aggression to the facial nerve.

Furthermore, UpToDate reviews on "Clinical manifestations and initial surgical approach to patients with malignant gliomas" (Batchelor and Curry, 2012) and "Overview of the management of central nervous system tumors in children" (Lau and Teo, 2012) do not mention the use of intra-operative EMG.

EMG Monitoring During Placement of Dorsal Column Stimulator:

Shils and Arle (2012) demonstrated that spinal cord stimulators (SCSs) may be placed safely and accurately under general anesthesia (GA) and that the proposed evaluation method activates structures predominantly in the dorsal columns. Data were retrospectively analyzed from 172 electrodes implanted with spinal cord SCSs at the Lahey Clinic between September 2008 and July 2011. All patients had their SCS placed under GA.
Electromyography was recorded from upper or lower limb muscle groups related to the placement of the stimulator electrode. Lateralization was performed based on electromyographic responses and electrode pairs stimulated. In a select group of patients, standard neurophysiologic tests, paired pulse, and collision studies were performed to demonstrate that the pain stimuli were activating the dorsal columns. A total of 155 patients had standard thoracic or cervical SCS placement. Preoperatively this cohort of patients had a visual analog score (VAS) of 7.51 ± 1.93, while post-operatively the VAS was 3.63 ± 2.43 (a reduction of 52.11 %). Based on the electromyographic recording technique, the electrodes were re-positioned intra-operatively in 15.9 % of patients. The recovery time (initial approximately 70 msec and complete approximately 150 to 300 msec) in both the paired-pulse tests and the collision studies showed that the stimulation used to elicit the compound muscle action potentials came from antidromic activation of the dorsal columns and not from the cortico-spinal tract. The authors concluded that GA-SCS is safe and appears to be at least as accurate and efficacious as using the awake-SCS placement technique based on a 50 % improvement in the VAS. In addition, the technique presented herein demonstrated that the test stimuli activate the same fiber tracts as that of the therapeutic stimulation.

Mammis and Mogilner (2012) noted that placement of spinal cord stimulating paddle leads has traditionally been performed under local anesthesia with intravenous sedation to allow intraoperative confirmation of appropriate placement. It may be difficult to maintain appropriate sedation in certain patients because of medical co-morbidities. Furthermore, patients undergoing lead revision frequently have extensive epidural scarring, requiring multi-level laminectomies to place the electrode appropriately. These investigators reported their technique of neurophysiologic monitoring that allows these procedures to be performed under GA. Data from 78 patients who underwent electromyography during laminectomy for paddle lead placement were retrospectively reviewed; 70 patients presented for first-time permanent system placement after a successful trial, and 8 were referred for revision or replacement of previously functioning systems. Surgeries were
performed under GA with fluoroscopic guidance. Electromyography was used to help define the physiological midline of the spinal cord and to guide appropriate lead placement. Somatosensory evoked potentials were used as an adjunct to minimize the possibility of neural injury. Immediately post-operatively, 75 of 78 patients reported that the paresthesia coverage was as good as (or better than) that of the spinal cord stimulation trial. At the long-term follow-up, 1 system was removed for infection, and 6 systems were explanted for lack of efficacy. A total of 64 of the 78 implanted patients reported continued pain relief with stimulator use. Revision surgery was performed in 9 patients. The authors concluded that the use of intra-operative electrophysiology for the placement of spinal cord stimulation paddle leads under GA is a safe and efficacious alternative to awake-surgery.

Also, an eMedicine review on “Intraoperative Neurophysiological Monitoring” lists the following clinical uses of intra-operative EMG: (http://emedicine.medscape.com/article/1137763-overview#aw2aab6b4)

- Facial nerve/other cranial nerve monitoring
- Pedicle screw placement
- Selective dorsal rhizotomy
- Tethered spinal cord release

Placement of spinal cord stimulator is not one of the listed indications.

Manuals of implantation of SCSs provide no recommendations for EMG neuromonitoring.


EMG Monitoring During Surgical Intervention of the Trigeminal Nerve:

Brock et al (2004) reported the findings of the first 45 consecutive patients undergoing microvascular decompression (MVD) surgery for trigeminal neuralgia, studied with peri-operative brainstem auditory evoked potentials (BAEPs) and EMG. These researchers observed a good correlation between the intra-operative BAEP modifications and post-operative hearing function. BAEP monitoring was useful in identifying the maneuvers that may compromise cochlear nerve function. This improved the surgical technique in the subsequent cases and reduced the incidence of iatrogenic hearing deficits after the learning period. There were no correlations between the entity of the intra-operative EMG discharges and the post-operative facial and trigeminal function. The authors noted that intra-operative EMG monitoring can be useful during the period of learning as a means of identifying the different nerves in the cisternal tract.

Minahan and Mandir (2011) noted that the trigeminal and facial nerves are placed at risk in a number of surgical procedures. The use of EMG, nerve conduction studies, SSEPs, MEPs, and other techniques were described. Application to specific surgical types and the associated evidence for impact on surgical outcomes were discussed. The authors discussed the use of intra-operative evoked potential studies of the trigeminal nerve; but not intra-operative EMG.

Furthermore, an UpToDate review on “Trigeminal neuralgia” (Bajwa et al, 2015) does not mention intra-operative EMG monitoring during surgical interventions (e.g., MVD, peripheral neurectomy, radiosurgery, and rhizotomy) of trigeminal neuralgia.

Hip Dysplasia Surgery:

Pring and colleagues (2002) stated that peri-acetabular
osteotomy (PAO) has become the procedure of choice in many centers for the treatment of symptomatic hip dysplasia. Intra-operative real-time nerve monitoring has been advocated during acetabular fracture repair and complex total hip arthroplasties to prevent iatrogenic sciatic nerve injury. To the authors' knowledge there is no information concerning the use of intra-operative EMG monitoring during PAO. These researchers examined the use of intra-operative continuous EMG monitoring during PAO in a relatively large consecutive series of patients as a mechanism to prevent nerve injury during surgery and as a prognostic indicator of neurologic function after PAO. From September 1992 to July 1999, a total of 140 consecutive PAOs were performed in 127 patients at the authors' institution. There were 96 women and 31 men, with an average age of 32 years at the time of surgery. All patients had intra-operative EMG monitoring of femoral and sciatic innervated muscles. All patients were followed-up for a minimum of 1 year, until complete resolution of neurologic deficits, or both; 36 patients (26 %) had abnormal EMG activity recorded during surgery; 7 patients (5 %) had peroneal nerve deficits post-operatively including extensor hallucis longus and tibialis anterior weakness with loss of sensation in the first web space. Abnormal EMG activity was observed intra-operatively in 5 of the 7 patients with post-operative deficits; 6 of the 7 injuries resolved completely; 1 patient with intra-operative EMG activity (0.7 %) had a post-operative foot-drop that persisted for greater than 1 year. There were no femoral, tibial, or obturator nerve deficits observed. The authors concluded that intra-operative EMG monitoring appeared to provide prediction of post-operative neurologic deficit.

Commenting on the afore-mentioned study, Sierra and colleagues (2012) noted that “Pring et al [2002] specifically studied nerve injuries after PAO at one institution and reported an incidence of 5 %, of which 0.7 % of injuries were permanent. They recommended the use of intraoperative EMG to decrease the risk of nerve injury and as a prognostic tool in cases when injury had occurred. Its use during PAO, however, has been debatable and is currently surgeon-dependent. Its drawbacks include cost and the fact that it requires specialized personnel present for its interpretation during the case. It also has certain limitations
because it cannot identify all nerve irritation or trauma. A sharp laceration of the nerve, for example, may not produce neurotonic discharges and may not be recorded. The presence of EMG could potentially provide the surgeon a false sense of safety that could lead to inadvertent injury to the nerve. It may be useful in surgery, however, because it may identify situations in which the nerve is at risk, such as during placement of retractors in inappropriate locations and it may identify over-lengthening of the extremity. It also could help the surgeon in determining whether exploration of the nerve may be warranted, such as in cases when the EMG fires during a specific maneuver that may injure the nerve”.

Novais and associates (2017) noted that sciatic nerve palsy after PAO is a serious complication. These researchers examined if a multi-modal sciatic monitoring technique allows for identification of surgical steps that place the sciatic nerve at risk. Transcranial electrical motor evoked potentials (TcMEPs), SSEPs, and spontaneous EMG were monitored in a consecutive series of 34 patients (40 hips) who underwent PAO for the treatment of symptomatic hip dysplasia between January 2012 and November 2014. There were 29 females (85 %) and 5 males (15%) with an average age of 19 years (range of 12 to 36 years) at the time of surgery. These investigators detected 8 temporary sciatic nerve monitoring alerts in 6 patients (incidence of 15 %). The events included decrease in amplitude of the TcMEPs related to the position of the hip during incomplete ischium osteotomy and placement of a retractor in the sciatic notch during the posterior column osteotomy (n = 3), generalized bilateral decrease in TcMEPs during fragment manipulation and fixation in association with acute blood loss (n = 2), and a change in SSEPs during a superior pubic osteotomy and supra-acetabular osteotomy (n = 1). At the end of the procedure, TcMEPs and SSEPs were at baseline and there was no abnormal pattern on EMG in all patients. Post-operatively, at 2, 6, 12 weeks, and 6 and 12 months, no motor weakness or sensory deficits were noted. The authors concluded that multi-modal neuro-monitoring allowed for identification of intra-operative steps and maneuvers that potentially place the sciatic nerve at higher risk of injury.
**Prostatectomy/Prostate Surgery:**

An UpToDate review on “Radical prostatectomy for localized prostate cancer” (Klein, 2017) does not mention intraoperative EMG monitoring.

**Rectal Cancer Surgery:**

Walega and colleagues (2017) presented their preliminary experience with intra-operative neuro-monitoring during rectal resection. These investigators qualified 4 patients (2 women, 2 men; age of 42 to 53 years) with rectal cancer for surgery with intra-operative neuro-monitoring. In all patients, functional tests of the anorectal area were performed before surgery. Action potentials from the sphincter complex in response to nerve fiber stimulation were recorded with electrodes implanted before surgery. Moreover, these researchers inserted a standard, 18FR Foley’s urinary catheter to which a T-tube was connected to allow urine outflow and measurement of pressure changes in the bladder induced by detrusor contractions during stimulation. Setting up neuro-monitoring prolonged surgery time by 30 to 40 minutes, or even by 60 to 80 minutes in the case of the first 2 patients. Neuro-monitoring itself took additional 20 to 30 minutes during surgery. In all patients, these investigators stimulated branches of the inferior hypogastric plexus in their anatomical position during dissection. In 3 patients, these researchers evoked responses both from the bladder and the sphincter in all planes of stimulation. In 1 patient, there was no response from the left side of the bladder, and in the same patient, these investigators observed symptoms of neurogenic bladder. Based on the available literature and their own experience, the authors stated that monitoring of bladder pressure and EMG signals from rectal sphincters enabled visualization and preservation of autonomic nervous system structures, both sympathetic and parasympathetic. They noted that intra-operative signals appeared to be correlated with clinical presentation and functional examinations after surgery. They stated that in order to objectify their findings, it is necessary to perform functional examinations before and after surgery in a larger group of patients.
Rotator Cuff Repair:

An UpToDate review on “Management of rotator cuff tears” (Martin and Martin, 2017) does not mention intraoperative EMG monitoring.

Tibial Neurectomy:

Sitthinamsuwan et al (2013) stated that selective tibial neurotomy (STN) is an effective neurosurgical intervention for treating ankle spasticity. These investigators used intraoperative EMG for selecting targeted fascicles and determined the degree of fascicular resection in STN. Participants who underwent STN with utilization of intraoperative EMG were recruited. Modified Ashworth Scale (MAS), passive range of motion (PROM) of the ankle in plantar flexion and dorsiflexion, Massachusetts General Hospital Functional Ambulatory Classification (MGHFAC) and ability to attain full plantigrade stance were assessed pre- and post-operatively. A total of 21 STNs were performed in 15 patients. The mean pre- and post-operative MAS and PROM were 2.8 and 0.4 (p < 0.001), 39.5(o) and 66.0(o) (p < 0.001), respectively. The mean level of MGHFAC was improved from 3.3 pre-operatively to 4.9 post-operatively (p < 0.01); 6 non-ambulators had significant amelioration in MGHFAC level. Post-operatively, 19 of 21 lower limbs achieved full plantigrade, and 6 patients could perform selective voluntary motor control of the ankle. The authors concluded that STN is an effective procedure for spastic ankle in well-selected cases; intraoperative EMG aided in selection of targeted fascicles, increased objectivity in neurotomy and prevents excessive denervation. This was a small, uncontrolled study; the clinical value of intraoperative EMG in this setting needs to be further investigated.

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<tr>
<th>CPT Codes / HCPCS Codes / ICD-10 Codes</th>
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<tr>
<td>Information in the [brackets] below has been added for clarification purposes. Codes requiring a 7th character are represented by &quot;+&quot;:</td>
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<tr>
<td>Intra-operative electromyographic (EMG) monitoring of cranial nerves:</td>
</tr>
<tr>
<td>CPT codes covered if selection criteria are met:</td>
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95867 Needle electromyography; cranial nerve supplied muscle(s), unilateral
95868 cranial nerve supplied muscles; bilateral
95887 Needle electromyography, non-extremity (cranial nerve supplied or axial) muscle(s) done with nerve conduction, amplitude and latency/velocity study (List separately in addition to code for primary procedure)
+95940 Continuous intraoperative neurophysiology monitoring in the operating room, one on one monitoring requiring personal attendance, each 15 minutes (List separately in addition to code for primary procedure)

**HCPCS codes covered if selection criteria are met:**

G0453 Continuous intraoperative neurophysiology monitoring, from outside the operating room (remote or nearby), per patient, (attention directed exclusively to one patient) each 15 minutes (list in addition to primary procedure)

**CPT codes for surgery where intra-operative EMG of cranial nerves is covered:**

61591 Infratemporal post-auricular approach to middle cranial fossa (internal auditory meatus, petrous apex, tentorium, cavernous sinus, parasellar area, infratemporal fossa) including mastoidectomy, resection of sigmoid sinus, with or without decompression and/or mobilization of contents of auditory canal or petrous carotid artery

61595 Transtemporal approach to posterior cranial fossa, jugular foramen or midline skull base, including mastoidectomy, decompression of sigmoid sinus and/or facial nerve, with or without mobilization

61597 Transcondylar (far lateral) approach to posterior cranial fossa, jugular foramen or midline skull base, including occipital condylectomy, mastoidectomy, resection of C1-C3 vertebral body(s), decompression of vertebral artery, with or without mobilization

69145 Excision soft tissue lesion, external auditory canal

69501 Transmastoid antrotomy (simple mastoidectomy)
Mastoidectomy

Petrus apicectomy including radical mastoidectomy

Revision mastoidectomy

Revision mastoidectomy

Tympanoplasty with antrotomy or mastoidotomy

Tympanoplasty with antrotomy or mastoidotomy (including canalplasty, atticotomy, middle ear surgery, and/or tympanic membrane repair)

Tympanoplasty with mastoidectomy (including canalplasty, middle ear surgery, tympanic membrane repair)

Labyrinthectomy; with mastoidectomy

CPT codes not covered when combined with intra-operative monitoring of facial nerve:

Short-latency somatosensory evoked potential study, stimulation of any/all peripheral nerves or skin sites, recording from the central nervous system; in upper limbs

in lower limbs

in the trunk or head

CPT codes for intra-cranial tumor resection surgery where intra-operative EMG is not covered:

Craniectomy for excision of brain tumor, infratentorial or posterior fossa; except meningioma, cerebellopontine angle tumor, or midline tumor at base of skull

Craniectomy for excision of brain tumor, infratentorial or posterior fossa; meningioma

Cerebellopontine angle tumor

Midline tumor at base of skull

Craniectomy bone flap craniotomy, transtemporal (mastoid) for excision of cerebellopontine angle tumor

Combined with middle/posterior fossa craniotomy/craniectomy

Craniotomy for excision of craniopharyngioma
62164 Neuroendoscopy, intracranial; with excision of brain
tumor, including placement of external ventricular
catheter for drainage

**CPT codes not covered for indications listed in the CPB [intra-
oporative EMG monitoring of the facial nerve are not covered
with]:**

21010 - Surgery of skull, facial bones, and temporomandibular
21499  joint
42300 - Surgery of salivary gland and ducts
42699

61450 Craniectomy, subtemporal, for section, compression,
or decompression of sensory root of gasserian
ganglion [trigeminal nerve]

61458 Craniectomy, suboccipital; for exploration or
decompression of cranial nerves [trigeminal nerve]

61450 for section of one or more cranial nerves [trigeminal
nerve]

61796 Stereotactic radiosurgery (particle beam, gamma ray,
or linear accelerator); 1 simple cranial lesion
[trigeminal nerve]

+61797 each additional cranial lesion, simple (List separately
in addition to code for primary procedure) [trigeminal
nerve]

61798 1 complex cranial lesion [trigeminal nerve]

+61799 each additional cranial lesion, complex (List
separately in addition to code for primary procedure)
[trigeminal nerve]

+61800 Application of stereotactic headframe for stereotactic
radiosurgery (List separately in addition to code for
primary procedure) [trigeminal nerve]

64600 Destruction by neurolytic agent; trigeminal nerve;
supraorbital, infraorbital, mental, or inferior alveolar
branch

64605 second and third division branches at foramen ovale

64610 second and third division branches at foramen ovale
under radiologic monitoring
64742 Transection or avulsion of; facial nerve, differential or complete [trigeminal nerve]

69631 - Tympanoplasty without mastoidectomy
69633

69930 Cochlear device implantation, with or without mastoidectomy

**ICD-10 codes covered if selection criteria are met:**

C30.1 Malignant neoplasm of middle ear

C44.201 - Other and unspecified malignant neoplasm of skin of ear and external auricular canal
C44.299

C47.0 Malignant neoplasm of peripheral nerves of head, face, and neck

C49.0 Malignant neoplasm of connective and soft tissue of head, face, and neck

D04.20 - Carcinoma in situ of skin of ear and external auricular canal
D04.22

D14.0 Benign neoplasm of middle ear, nasal cavity and accessory sinuses

D21.0 Benign neoplasm of connective and other soft tissue of head, face, and neck

D22.20 - Benign neoplasm of skin of ear and external auditory canal
D22.22
D23.20 -
D23.22

G51.0 - Facial nerve disorders and disorders of other cranial nerves
G52.9

H71.00 - Cholesteatoma of middle ear
H71.93

H74.40 - Polyp of middle ear
H74.43

H81.01 - Meniere's disease
H81.09

H95.00 - Recurrent cholesteatoma of postmastoidectomy cavity
H95.03

**ICD-10 codes not covered for indications listed in the CPB:**
C71.0 - Malignant neoplasm of brain
C71.9
C76.0 - Malignant neoplasm of head, face, and neck
C79.31 - Secondary malignant neoplasm of brain and cerebral meninges
C79.32
D33.0 - Benign neoplasm of brain, cranial nerves, or cerebral meninges
D33.3
D43.0 - Neoplasm of uncertain behavior of brain
D43.3
G50.0 - Disorders of trigeminal nerve
G50.9
H70.001 - Mastoiditis and related conditions, other disorders of tympanic membrane, and other disorders of middle ear and mastoid
H70.93,
H72.00 -
H74.399,
H74.8X1 -
H75.83,
H95.111 -
H95.199
K11.0 - Diseases of the salivary glands
K11.9
M26.00 - Dentofacial anomalies, including malocclusion
M26.9
S02.400+ - Fracture of mandible, malar, and maxillary bones
S02.42x+
S02.600+ -
S02.69x+
S03.00x+ - Dislocation of jaw
S03.02x+

Intra-operative EMG monitoring during spinal surgery:

CPT codes not covered for indications listed in the CPB:

51784 Electromyography studies (EMG) of anal or urethral sphincter, other than needle, any technique
51785 Needle electromyography studies (EMG) of anal or urethral sphincter, any technique
95860 Needle electromyography; one extremity with or without related paraspinal areas
95861 two extremities with or without related paraspinal areas
95863 three extremities with or without related paraspinal areas
95864 four extremities with or without related paraspinal areas
95869 thoracic paraspinal muscles (excluding T1 or T12)
95870 limited study of muscles in one extremity or non-limb (axial) muscles (unilateral or bilateral), other than thoracic paraspinal, cranial nerve supplied muscles, or sphincters
95885 Needle electromyography, each extremity, with related paraspinal areas, when performed, done with nerve conduction, amplitude and latency/velocity study; limited (List separately in addition to code for primary procedure)
95886 complete, five or more muscles studied, innervated by three or more nerves or four or more spinal levels (List separately in addition to code for primary procedure)
95887 Needle electromyography, non-extremity (cranial nerve supplied or axial) muscle(s) done with nerve conduction, amplitude and latency/velocity study (List separately in addition to code for primary procedure)
95937 Neuromuscular junction testing (repetitive stimulation, paired stimuli), each nerve, any 1 method

HCPCS codes not covered for indications listed in the CPB:
G0453 Continuous intraoperative neurophysiology monitoring, from outside the operating room (remote or nearby), per patient, (attention directed exclusively to one patient) each 15 minutes (list in addition to primary procedure)

CPT codes covered for spinal surgery where intra-operative EMG is covered:
63185  Laminectomy with rhizotomy; 1 or 2 segments
       [selective dorsal rhizotomy]
63190  Laminectomy with rhizotomy; more than 2 segments
       [selective dorsal rhizotomy]

**CPT codes for spinal surgery where intra-operative EMG is not covered:**

22010 -  Surgery of musculoskeletal system, spine (vertebral column)
22865  
62263 -  Surgery of spine and spinal cord
63182, 63191 - 
63746  
64633  Destruction by neurolytic agent, paravertebral facet joint nerve(s) with imaging guidance (fluoroscopy CT); cervical or thoracic, single facet joint
64634  cervical or thoracic, each additional facet joint (List separately in addition to code for primary procedure)
64635  lumbar or sacral, single facet joint
64636  lumbar or sacral, each additional facet joint (List separately in addition to code for primary procedure)
64470 - 64484  Injection, anesthetic agent and/or steroid, paravertebral facet joint or facet joint nerve; or transforaminal epidural
64561  Percutaneous implantation of neurostimulator electrode array; sacral nerve (transforaminal placement) including image guidance, if performed
64581  Incision for implantation of neurostimulator electrodes; sacral nerve (transforaminal placement)
64622 - 64627  Destruction by neurolytic agent, paravertebral facet joint nerve; lumbar or sacral; cervical or thoracic
64772  Transection or avulsion of other spinal nerve, extradural

**HCPCS codes for spinal surgery where intra-operative EMG is not covered:**
S2348  Decompression procedure, percutaneous, of nucleus pulposus of intervertebral disc, using radiofrequency energy, single or multiple levels, lumbar

S2350 - S2351  Diskectomy, anterior, with decompression of spinal cord and/or nerve root(s), including osteophytectomy; lumbar, single interspace or each additional interspace (list separately in addition to code for primary procedure)

_Intra-operative EMG monitoring of the recurrent laryngeal nerve/intraoperative neuromonitoring during thyroid and parathyroid surgery:_

_CPT codes not covered for indications listed in the CPB:_

- 95867  Needle electromyography; cranial nerve supplied muscle(s), unilateral
- 95868  cranial nerve supplied muscles; bilateral
- 95887  Needle electromyography, non-extremity (cranial nerve supplied or axial) muscle(s) done with nerve conduction, amplitude and latency/velocity study (List separately in addition to code for primary procedure)
- +95940  Continuous intraoperative neurophysiology monitoring in the operating room, one on one monitoring requiring personal attendance, each 15 minutes (List separately in addition to code for primary procedure)

_Other CPT codes related to the CPB:_

- 60000 - 60512  Thyroid and parathyroid surgery

_HCPCS codes not covered for indications listed in the CPB:_

- G0453  Continuous intraoperative neurophysiology monitoring, from outside the operating room (remote or nearby), per patient, (attention directed exclusively to one patient) each 15 minutes (list in addition to primary procedure)

_ICD-10 codes not covered for indications listed in the CPB:_

Too many to list

_Intra-operative EMG monitoring during hip replacement surgery:_
CPT codes not covered for indications listed in the CPB:

95870 Needle electromyography; limited study of muscles in one extremity or non-limb (axial) muscles (unilateral or bilateral), other than thoracic paraspinal, cranial nerve supplied muscles, or sphincters

Other CPT codes related to the CPB:

27130 Arthroplasty, acetabular and proximal femoral prosthetic replacement (total hip arthroplasty), with or without autograft or allograft

The above policy is based on the following references:

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7. American Academy of Otolaryngology - Head and Neck


18. Neff BA, Ting J, Dickinson SL, Welling DB. Facial nerve


**Monitoring of Recurrent Laryngeal Nerve:**


2. Horn D, Rotzsch VM. Intraoperative electromyogram monitoring of the recurrent laryngeal nerve: Experience


12. Dackiw AP, Rotstein LE, Clark OH. Computer-assisted evoked electromyography with stimulating surgical


**Monitoring of Other Cranial Nerves:**


**Monitoring During Spinal Surgery:**


14. Limbrick DD Jr, Wright NM. Verification of nerve root


22. Scherl SA. Treatment and prognosis of adolescent idiopathic scoliosis. Last reviewed June 2012. UpToDate Inc.


Monitoring During Intra-Cranial Tumor Resections:

3. Batchelor T, Curry WT. Clinical manifestations and initial surgical approach to patients with malignant gliomas. Last reviewed April 2012. UpToDate Inc. Waltham, MA.
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Monitoring During Placement of Dorsal Column Stimulator:


EMG Monitoring During Surgical Intervention of the Trigeminal Nerve:

1. Brock S, Scaioli V, Ferroli P, Broggi G. Neurovascular decompression in trigeminal neuralgia: Role of intraoperative neurophysiological monitoring in the
EMG Monitoring During Various Indications:


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Amendment to
Aetna Clinical Policy Bulletin Number: 0697 Intraoperative Electromyographic Monitoring

There are no amendments for Medicaid.