Transabdominal Motor Action Potentials (Tamap) for Lateral Approach Neuromonitoring in Spine Surgery: Novel Case Series of 51 Patients in Proof-of-Concept Demonstration

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Abstract

Background: Risk of nerve injury is well-documented in lateral approach spine surgery. Advanced intraoperative neuromonitoring techniques may improve false positive and false negative rates of traditional methods to decrease complications.

Objective: Determine the safety, sensitivity, and methodological validity of transabdominal motor action potentials (TaMAP) recordings in lateral access spine surgery.

Methods: Institutional Review Board approval was obtained for the prospective collection of patient data. Cathode and anode leads were placed on the posterior and anterior surfaces of back and abdomen, and motor responses were recorded by subdermal needle electrodes in 6 target muscles. Voltage and stimulation amplitude were measured at preoperative baseline, postoperative, and new baseline time points, and compared for muscle groups relevant to symptoms and operative approach.

Results: In a total of 51 cases of lateral approach surgery, stimulation sensitivity was 100% for vastus medialis, anterior tibialis, and adductor magnus, followed by 98% in biceps femoris, 95% in gastrocnemius, and 33% for vastus lateralis measures. Decompression at L5/S1 resulted in a decrease in voltage in right gastrocnemius in 80% of cases, 80% of right vastus medialis (L3/L4), and in 58% of right anterior tibialis recordings (L4/5). No postoperative neurological complications were observed.

Conclusions: TaMAP intraoperative monitoring is a safe, reliable, and sensitive MEP measure with ease-of-use that may serve as an alternative resource in neuromonitoring for spinal surgery. Sensitivity was observed to be as high as 100% for 3/6 muscle groups tested and with robust efficacy of decompression across a variety of procedures and pathologies, including degenerative spine disease and spinal tumor.

Keywords: Lateral interbody fusion • Lateral approach • Motor evoked potentials • Intraoperative neuromonitoring • Nerve injury • Trans-abdominal motor action potentials

INTRODUCTION

Incorporation of minimally invasive (MIS) procedures has increased across a variety of indications of spine surgery including, discectomy, stenosis, spondylolisthesis, laminectomy, and fusion. MIS lumbar spine surgery is associated with fewer postoperative complications, improved patient reported outcomes, shorter length of stay, and reduced blood loss compared to analogous open approach procedures [1,2]. While a narrow operative window has reduced cerebrospinal fluid (CSF) leak complications, soft tissue distraction, and postoperative recovery duration, one notable drawback is limited anatomical visualization during the procedure that may lead to increased nerve root compression injury and dysesthesia, especially in far lateral approaches [3,4]. Indeed, radiculitis is the most commonly reported complication following MI-transforaminal lumbar interbody fusion (TLIF), in as high as 57% of cases [5,6]. Traversing nerves may be particularly susceptible to distraction injury over the psoas that are not sufficiently avoided in exceedingly small operative fields [7,8].

Intraoperative neurophysiological monitoring (IONM) is used during spinal surgery to assess the integrity of descending motor and ascending sensory pathways to signal spinal cord or nerve compression through transcranial, spinal, and muscle motor evoked potentials [9,10]. However, guidelines for degenerative spine fusion cases highlight trials that have shown limited evidence for the success of traditional monitoring methods to reduce nerve injury or improve responses [11]. Mechanically elicited electromyography (EMG) has not been shown to be responsive to compression in animal studies.4 Even transcranial motor evoked potentials (Tc-MEPs), the most commonly used IONM method [12] and spontaneous EMG may not accurately detect intraoperative cervical palsy [13,14]. False positive and false negative reports of somatosensory evoked potentials (SEP) also challenge the reliability and validity of traditional IONM methods [15,16].

In the present single-center, single-surgeon, prospective study, we introduce transabdominal motor action potentials (TaMAP) that may serve as an alternative intraoperative motor evoked potential (MEP) monitoring technique that offers immediate, quantitative feedback that may signal impending injury or improved nerve functioning. Additionally, in a patient population with preoperative radiculopathy, TaMAP may offer an advantage in quantifying severity of nerve compression in this comorbid surgical cohort.

We prospectively analyzed a series of minimally invasive lumbar procedures using TaMAP technique and traditional neuromonitoring. Baseline, immediate postoperative, and new baseline recordings in the intraoperative and perioperative settings were compared to assess the sensitivity and efficacy of this novel monitoring adaptation. We anticipate that a decrease in voltage represents a lower current necessary to reach threshold because of decompression. Given previous animal studies and translational capability [17] TaMAP monitoring may augment intraoperative decision-making with immediate, reliable feedback of specific nerve roots, resulting in fewer cases of postoperative radiculitis and nerve root injury.

Methods

University of California, San Diego Institutional Review Board (IRB) approval was obtained for the prospective collection of data. All cases were performed at University of California, San Diego Health System Jacobs Hospital or Hillcrest Hospital from January 2017 to December 1st, 2018. All cases of lateral approach for lumbar surgery were monitored with TMAP and standard neurologic monitoring that recorded triggered and free run EMG in large muscle groups of the lower extremities. This prospectively collected neuromonitoring data, using TMAP, was reviewed in cases in which an intraoperative decision was made after a change in stimulation thresholds. We evaluated these individual procedures with threshold changes to identify factors or neurological deteriorations that may correlate with these changes. Data retrieved from patient records included preoperative neuro exam, procedure name, surgical approach and laterality, and time of operation.

Intraoperative TaMAP Recordings

Cathode and anode leads were placed on the posterior and anterior surfaces of back and abdomen of human participants, as previously described. Motor responses were monitored and recorded from subdermal needle electrodes in 6 target muscles: adductor magnus, vastus medialis, vastus lateralis, anterior tibialis, biceps femoris, and gastrocnemius intraoperatively. Stimulation of abdominal leads was set at 450 mA and confirmed by evoked potentials measured distinct electrophysiological outputs for specific target muscles. Stimulation amplitude resulting in insufficient recording in distal electrode leads was subsequently increased in linear increments until sufficient mV threshold was reached or deemed to recordable. Baseline measures were recorded prior to operation, and a second recording in all muscles were recorded immediately postoperatively after the decompression and prior to closure. A third and final recording was measured to record a new baseline in the postoperative setting after closure.

Statistical Analysis

Standard measures of mean were calculated to report changes across patients for different levels.

Results

A total of 51 cases of lateral approach surgery were performed from 1/9/2017-9/25/2018, including 26 lumbar laminectomies, 8 hemilaminectomies, 2 endoscopic hemilaminotomies, 1 endoscopic discectomy, 2 extreme lateral interbody fusions (XLIF) procedures, 1 facetectomy, 1 revision open laminectomy, 1 MIS microdiscectomy, 2 MIS hemilaminotomies and discectomies, 1 transforaminal endoscopic discectomy, 1 facetectomy and resection of tumor, 1 posterior spinal fusion (PSF), and 4 uncategorized decompressions. Across all patients, levels of operation were: 1 case involving L1-2; 11 cases involving L2-3; 18 cases involving with L3-4; 33 cases involving L4-5; 8 cases involving L5-S1; and 7 cases with unknown levels. Bilateral approaches were used in 22 cases, unilateral right-sided was in 11 cases, and unilateral left-sided approaches in 8 cases. Of the 51 patients, 16 experienced pain only with no signs of radiculopathy while 30 patients had pain with at least intermittent or reproducible radiculopathy in the expected distribution of pathology.

Intraoperative TaMAP Recordings

Of the 6 target muscles, measures were identified in all attempted stimulation trials for vastus medialis, anterior tibialis, and adductor magnus recordings. Recordings failed to elicit a response in 3 of 51 (6%) gastrocnemius (2 left, 1 right) measures, 1 of 51 (2%) biceps femoris (right) measures, and in in 34 of 51 cases (67%) vastus lateralis recordings. An additional 5 patients did not have sufficient data in our records. Unknown subjects were not included in the tallies for muscle groups based on level of operation. For procedures in which a change greater than 100 milliamps (mA) was observed on the operative side in the distribution of the femoral nerve, effort was made to relieve nerve compression by releasing the retractor and/or concluding the surgery. No postoperative neurological complications were observed for all cases.

L1-2 Levels (Vastus medialis, vastus lateralis)

Bilateral

For the single patient who received decompression at L1-L5 for bilateral radiculopathy, increases in immediate postoperative baseline were seen in the left vastus medialis of 9 mV (amplitude change= 0), right vastus medialis of 60 mV (amplitude change= 0), and left vastus lateralis of 15 mV (amplitude change= 0).

L2-3 Levels (Adductor magnus, vastus medialis, vastus lateralis)

Bilateral

Of the 8 patients who received bilateral decompression at L2/3, recording of the left vastus medialis was observed to decrease by an average of -5 mV (-161-75 mV). Recordings for two of the 8 patients (25%) decreased in voltage by -7mV (49-42 mV, change in amplitude=0) and -161 (437-276, change in amplitude=0). Right vastus medialis saw an average increase of 5 mV (-9-32 mV). Three of the 8 patient recordings (38%) saw a decrease in voltage of -2 mV (decrease in amplitude of 50 mA), -9 mV (no change in amplitude), and -6 mV (no change in amplitude).

Left-Sided

Of the two patients with left-sided symptoms who received left-sided decompression approach, the left vastus medialis observed no change in voltage for one (amplitude change of +100) and an increase of 2 mV in the other (no change in amplitude), for an average of 1 mV (0-2 mV). One patient experienced a recording change for the left adductor magnus, demonstrating an increase in voltage of 43 mV from 113mV to 156mV at postoperative baseline (50 mA higher stimulation than baseline). The right adductor magnus for the same patient increased 44 mV (479-435 mV) at the same stimulation as baseline (500 mA).

L3-4 Levels (Adductor magnus, vastus medialis, vastus lateralis)

Bilateral

Recordings for the left and right adductor magnus were reported for bilateral laminectomy decompression in one of 5 patients receiving operation at bilateral levels. Left adductor magnus increased 16 mV (decrease in amplitude of 50 mA) and right adductor magnus increased 4 mV (decrease in amplitude of 50 mA).

For the left vastus medialis, an average increase of 92 mV (-115-306 mV) was observed. 2 of 5 recordings (40%) decreased at -4 mV (no change in amplitude) and -115 mV (decrease in amplitude of 50 mV). The right vastus medialis saw an average change of -6 mV (-30-33 mV). A total of 4 of 5 (80%) recordings decreased at -30 mV (decrease in amplitude of 50 mV), -11 mV(decrease in amplitude of 100 mV), -14 mV (no change in amplitude), and -8 mV (increase in amplitude of 100 mV).

Left-sided

For the left vastus medialis, an average change of -46 mV (-69- -23mV) was observed after surgical decompression. One value of -69mV (328-397 mV) had no change in amplitude between the recordings while the other at -23 mV (32-55mV) saw a decrease in 100 mA.

Right-sided

Vastus lateralis measures were recorded in one patient receiving a right-sided decompression. The right vastus lateralis recording changed by- 9 mV (amplitude increased 100 mA). Two patients received right-sided decompression for radiculopathy. Right vastus medialis recording changes were 128 mV (no change in amplitude) and -24 mV (decrease in amplitude of 50 mV).

L4-5 Levels (Anterior tibialis)

Bilateral

Bilateral approaches involving the L4/5 level were observed in 19 cases. Left anterior tibialis recordings averaged 88 mV (-74-1164 mV). Decreased voltage was observed in 6 of 19 cases (32%), involving -6 mV (no change in amplitude), -50 mV (decrease in amplitude of -150 mA), and -60 mV (decrease in amplitude of -50 mA), -27 (no change in amplitude), and -74 (no change in amplitude). Right anterior tibialis saw an average change of -63 mV (-1073-81 mV), with 11 of 19 cases (58%) showing a decrease in current postoperatively, including – 9 mV (no change in amplitude), -13 mV (decrease of -100 mA), -14 mV (increase of 50 mA), -34 mV (no change in amplitude), -14 mV (decrease of -50 mV), and -1073 (no change in amplitude).

Left-sided

3 recordings were taken for left-sided approaches at L4-5 for an average increase of 26 mV at left anterior tibialis (-4-56 mV). One of 3 recordings was found to decrease postoperatively with change of -4 mV (no change in amplitude).

Right-sided

5 recordings were observed for the anterior tibialis for an average change of -20mV (-76-42). 3 of the 5 (60%) saw decreases in voltage of -76 mV (decrease in 50 mA), -71 mV (no change in amplitude), and -1 (no change in amplitude).

L5-S1 Levels (Gastrocnemius)

Bilateral

Two patients received bilateral decompression at L5-S1. Left Anterior tibialis saw an increase in current at 24 mV (no change in amplitude) and right gastrocnemius saw a decrease of -14 mV (increase of 50 mA). In the other patient, left anterior tibialis saw an increase in 18 mV (decrease of 150 mA), while right anterior tibialis saw an increase in 70 mA (increase of 100 mA).

Right-sided

Right gastrocnemius recordings were observed in 6 patients who received decompression at L5-S1. Postoperative measurements decreased from baseline in 4 of 5 (80%) for an average of -29.8 mV (-233-83 mV). Decreases were observed to be -5 mV (no change in amplitude), -3 mV (decrease of -100 mA), and -233 mV (no change in amplitude).

Discussion

Risk of nerve injury is as high as four times more likely in minimally invasive procedures of the spine, ranging from naurapraxia to axonotmesis [18]. Intraoperative neuromonitoring reduces the risk of nerve injury with reliable feedback of nerve compression, stretching, or ischemia. Somatosensory evoked potential (SEP) monitoring has been reported to reduce paraplegia in 60% of spinal surgery cases [19]. While SEPs have traditionally been used in spine surgery, motor evoked potentials (MEP) offer a direct assessment of descending motor pathway function and include transcranial motor evoked potentials and spontaneous EMG [20,21].

Sensitivity of SSEP has been reported to be as high as 90%,22 while Tc-MEP is from 78%-91%, and differing upon muscle groups [23,24]. The present study represents a novel paradigm of TaMAP in spine surgery across a host of different pathologies (e.g. spinal stenosis, degenerative disc disease, tumor). Recordings elicited a response in all cases (100%) for 3 of the 6 muscle groups. Cases involving the gastrocnemius (95%) and biceps femoris (98%) were also highly sensitive; however, vastus lateralis was the lowest in successfully eliciting a response in 33% of cases. Given the overlap of the femoral nerve innervation to vastus medialis and vastus lateralis, identification of the higher lumbar nerve roots may be best achieved through recordings of the vastus medialis which achieved response in 100% of cases.

TaMAP recordings represent another form of MEP that do not require an averaging and are immediately available, unlike those of somatosensory evoked potentials that may take minutes to determine latency and amplitude [25]. Additionally, quantitative TaMAP recordings do not involve interpretation of waveform as in other forms of MEP that may have lower inter-rater reliability and require interpretative expertise. Thus, TaMAP may introduce streamlined interpretation that overcomes challenges of traditional SSEP and MEP monitoring methods. Quantitative readings may also give more indication of the type or severity of compression or stretch injury to allow swift adjustments intraoperatively.

Efficacy of decompressive surgery is presumed to result in an increase in voltage from lower or similar stimulation amplitude [26]. We found that decompression at the level of L5/S1 resulted in a decrease in voltage in the recording of right gastrocnemius in 80% of cases. Similarly, postoperative current measures of the right vastus medialis decreased in 80% of bilateral cases for the L3/L4 level, and decreased in 58% of right anterior tibialis recordings bilateral decompression L4/5. These decompressed lumbar nerve roots corresponded to the side of chief complaint, neuro exam findings, and other indications of pathology at level of decompression such as preoperative MRI as anatomically expected. These findings support the argument that a decrease in voltage may underlie successful relief of nerve compression and represent an immediate form of intraoperative feedback. It is often reported that decreased amplitude signifies a compression of the nerve and may correlate with motor deficits postoperatively [27] However, few reports have suggested interpretation of recorded voltage from stimulation. It is possible that a decrease in voltage from a similar stimulation current may indicate lower resistance and successful decompression or reduction in resistance. Notably, conflicting conclusions exist on interpretation of even established methods of IONM [28] Reliable interpretation of TcMEP thresholds has proven controversial, and may result in false negatives that result in motor deficit despite no discernable changes in recording.14 One explanation for this discrepancy could be due to overlapping innervation. Anesthetic use may further alter the threshold for nerve conduction and synapse transmission [29] and may require higher stimulation amplitude recordings and subsequent physiologic interpretation, especially in myelopathy patients [30]. However, several studies have reported minimal change to IONM recordings related to anesthetic administration [31,32].

TaMAP also offers an ease-of-use, applying two electrodes, and distal electrodes similar to transcranial monitoring, without scalp and facial electrode placement. Reduction in preoperative and postoperative setup is significant, given reduction in number of electrodes. During the stimulation trials, no cases of tissue injury to the patient or operating room personnel were reported. Given the benefit of a multi-modal neuromonitoring (MIOM) platform in complex spinal cases and correction for scoliosis [33]. TaMAP brings unique and unparalleled advantages that may particularly complement the armamentarium of IONM methods in spinal surgery.

Strengths and Limitations

Some recordings may be underestimated by decreased stimulation amplitude to achieve voltage. As shown in previous animal model study, a positive correlation is observed between stimulation amplitude and measured voltage. Certain recordings may therefore not reflect the degree of decompression or restoration of nerve function based on our quantitative measures. Specificity measures may also be pursued for TaMAP in additional analyses. Lack of a control group may also limit the generalizability of our findings and would be beneficial for future studies analyzing TaMAP technique. Future studies may incorporate other surgeons and facilities that may use TaMAP to validate its efficacy, as well as postoperative complication profiles to determine efficacy in reducing neurapraxia and other forms of nerve injury. It may also be beneficial to parse out the use of TaMAP in patients with pacemakers, defibrillators, or pulse generators in the chest, abdomen, or subclavicular locations to determine local stimulation effect on these devices and possible contraindications for cardiac history. TaMAP may also be used in scoliosis surgery separately or as part of a MIOM regimen given the higher risk of complication to the spinal cord and traditional reliance on IONM.

CONCLUSIONS

TaMAP intraoperative monitoring is a safe, reliable, and sensitive MEP measure with ease-of-use that may serve as an alternative resource in neuromonitoring for spinal surgery. Sensitivity was observed to be as high as 100% for 3/6 muscle groups tested and with robust efficacy of decompression over a variety of procedures and pathologies, including degenerative spine disease and spinal tumor. Future studies may explore postoperative outcome measures following TaMAP to obtain specificity, comparative analyses to other monitoring techniques, and a broader scope of utilization across surgeons, institutions, and patient populations susceptible to complication.

Conflict of Interests

The authors hereby declare there is no conflict of interests associated with this study or any of the procedures and materials used for the purpose of the study.

References

1. Khan NR, et al. Surgical Outcomes for Minimally Invasive vs Open Transforaminal Lumbar Interbody Fusion: An Updated Systematic Review and Meta-analysis. *Neurosurgery* 77. 6 (2015): 847-874.
2. Xie Q, et al. Minimally invasive versus open Transforaminal lumbar Interbody fusion in obese patients: a meta-analysis. *BMC Musculoskelet Disord* 9 (2018): 15.
3. Epstein NE. More nerve root injuries occur with minimally invasive lumbar surgery: Let's tell someone. *Surg Neurol Int* 7. Suppl 3 (2016): S96-S101.
4. Valone F, et al. Efficacy of transcranial motor evoked potentials, mechanically elicited electromyography, and evoked electromyography to assess nerve root function during sustained compression in a porcine model. *Spine (Phila Pa 1976)* 39. 17 (2014): E989-993.
5. Pereira C, et al. How Does Minimally Invasive Transforaminal Lumbar Interbody Fusion Influence Lumbar Radiologic Parameters? World. *Neurosurg* 116 (2018): e895-e902.
6. Weiss H, et al. A Systematic Review of Complications Following Minimally Invasive Spine Surgery Including Transforaminal Lumbar Interbody Fusion. *Curr Rev Musculoskelet Med* (2019): 328-339.
7. Uribe JS, et al. Electromyographic monitoring and its anatomical implications in minimally invasive spine surgery. *Spine (Phila Pa 1976)* 35. 26 Suppl (2010): S368-S374.
8. Youssef JA, et al. Minimally invasive surgery: lateral approach interbody fusion: results and review. *Spine (Phila Pa 1976)* 35. Suppl 26 (2010): S302-S311.
9. Fehlings MG, et al. The evidence for intraoperative neurophysiological monitoring in spine surgery: does it make a difference? *Spine (Phila Pa 1976)* 35. Suppl 9 (2010): S37-S46.
10. Lall RR, et al. Intraoperative neurophysiological monitoring in spine surgery: indications, efficacy, and role of the preoperative checklist. *Neurosurg Focus* 33. 5 (2012): E10.
11. Sharan A, et al. Guideline update for the performance of fusion procedures for degenerative disease of the lumbar spine. Part 15: electrophysiological monitoring and lumbar fusion. *J Neurosurg Spine* 21 (2014): 102-105.
12. Stecker MM. A review of intraoperative monitoring for spinal surgery. *Surg Neurol Int* 3. Suppl 3 (2012): S174-S187.
13. Bhalodia VM, et al. Efficacy of intraoperative monitoring of transcranial electrical stimulation-induced motor evoked potentials and spontaneous electromyography activity to identify acute-versus delayed-onset C-5 nerve root palsy during cervical spine surgery: clinical article. *J Neurosurg Spine* 19. 4 (2013): 395-402.
14. Iwasaki H, et al. Efficacy and limitations of current methods of intraoperative spinal cord monitoring. *J Orthop Sci* 8. 5 (2003): 635-642.
15. MacDonald DB, et al. Monitoring scoliosis surgery with combined multiple pulse transcranial electric motor and cortical somatosensory-evoked potentials from the lower and upper extremities. *Spine (Phila Pa 1976)* 28. 2 (2003): 194-203.
16. Gunnarsson T, et al. Real-time continuous intraoperative electromyographic and somatosensory evoked potential recordings in spinal surgery: correlation of clinical and electrophysiologic findings in a prospective, consecutive series of 213 cases. *Spine (Phila Pa 1976)* 29. 6 (2004): 677-684.
17. Hoshide R, et al. Novel Transabdominal Motor Action Potential (TaMAP) Neuromonitoring System for Spinal Surgery. *Cureus* 8. 6 (2016): e655.
18. Lykissas MG, et al. Nerve injury after lateral lumbar interbody fusion: a review of 919 treated levels with identification of risk factors. *Spine J* 14. 5 (2014):749-758.

19. Nuwer MR. Spinal cord monitoring. *Muscle Nerve* 22. 12 (1999): 1620-1630.

20. Nash CL, Jr., et al. Spinal cord monitoring during operative treatment of the spine. *Clin Orthop Relat Res* 126 (1977): 100-105.

21. Dawson EG, et al. Spinal cord monitoring. Results of the Scoliosis Research Society and the European Spinal Deformity Society survey. *Spine (Phila Pa 1976)* 16 Suppl 8 (1976): S361-S364.

22. Nuwer MR, et al. Somatosensory evoked potential spinal cord monitoring reduces neurologic deficits after scoliosis surgery: results of a large multicenter survey. *Electroencephalogr Clin Neurophysiol* 96 (1995): 6-11.

23. Miller SM, et al. Transcranial motor-evoked potentials for prediction of postoperative neurologic and motor deficit following surgery for thoracolumbar scoliosis. *Orthop Rev (Pavia)* 11 (2019): 7757.

24. Thirumala PD, et al. Diagnostic accuracy of motor evoked potentials to detect neurological deficit during idiopathic scoliosis correction: a systematic review. *J Neurosurg Spine* 26. 3 (2017): 374-383.

25. Park JH & Hyun SJ. Intraoperative neurophysiological monitoring in spinal surgery. *World J Clin Cases* 3. 9 (2015): 765-773.

26. Yan JG, et al. Intraoperative electrophysiological studies to predict the efficacy of neurolysis after nerve injury-experiment in rats. *Hand (N Y)* 3. 3 (2008): 257-262.

27. Hilibrand AS, et al. Comparison of transcranial electric motor and somatosensory evoked potential monitoring during cervical spine surgery. *J Bone Joint Surg Am* 86. 6 (2004): 1248-1253.

28. Tsutsui S & Yamada H. Basic Principles and Recent Trends of Transcranial Motor Evoked Potentials in Intraoperative Neurophysiologic Monitoring. *Neurol Med Chir (Tokyo)* 56. 8 (2016): 451-456.

29. Calancie B, et al. Isoflurane-induced attenuation of motor evoked potentials caused by electrical motor cortex stimulation during surgery. *J Neurosurg* 74. 6 (1991): 897-904.

30. Lyon R, et al. Progressive suppression of motor evoked potentials during general anesthesia: the phenomenon of "anesthetic fade". *J Neurosurg Anesthesiol* 17 (2005): 13-19.

31. Holdefer RN, et al. A comparison of the effects of desflurane versus propofol on transcranial motor-evoked potentials in pediatric patients. *Childs Nerv Syst* 30. 12 (2014): 2103-2108.

32. Liu HY, et al. Comparison of the effects of etomidate and propofol combined with remifentanil and guided by comparable BIS on transcranial electrical motor-evoked potentials during spinal surgery. *J Neurosurg Anesthesiol* 24. 2 (2012): 133-138.

33. Chang SH, et al. Monitoring of Motor and Somatosensory Evoked Potentials During Spine Surgery: Intraoperative Changes and Postoperative Outcomes. *Ann Rehabil Med* 40. 3 (2016): 470-480.

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