Transabdominal Motor Action Potentials (Tamap) for Lateral Approach Neurounmonitoring 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 neurounmonitoring 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 lateralis (L3/L4), and in 58% of right anterior tibialis recordings (L4/S). 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 neurounmonitoring 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 neurounmonitoring • 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 traction injury over the psoas that are not sufficiently avoided in exceedingly small operative fields [7,8].

Intraoperative neuropsychiological 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 neurounmonitoring. 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 TaMAP and standard neurologic monitoring that recorded triggered and free run EMG in large muscle groups of the lower extremities. This prospectively collected neurounmonitoring data, using TaMAP, 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 be 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 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 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
release 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
5 patients recordings (38%) saw a decrease in voltage of -2 mV (decrease in amplitude of 50 mV),
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)
showed no change in amplitude between the recordings while the other at -23 mV
(32-55mV) saw a decrease in 100 mA.

Right-sided
Vastus medialis measures were recorded in one patient receiving a right-
sided decompression. The right vastus lateralis recording changed by
9 mV (amplitude increased 100 mV). 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
temperature 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
-26mV (-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 neurapraxia 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 90-92% 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 to 7 of 11 cases. Given our control 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 [28]. One explanation for this discrepancy could be due to overlapping innervation. Aesthetic 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 studies, 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 of reducing mortality, morbidity 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


