ORIGINAL ARTICLE

Femoral Nerve Monitoring During Lateral Spine Surgery

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ABSTRACT

Objective: To review evidence on the use of somatosensory evoked potentials (SSEP), transcranial electric motor evoked potentials (TCeMEP), electromyography (EMG), train of four (TOF), and multimodal intraoperative neurophysiological monitoring (mIONM) of the femoral and saphenous nerves in spinal procedures with a lateral approach.

Methods: A literature review was conducted to identify retrospective clinical studies with outcomes of patients who underwent lateral spine surgeries with intraoperative monitoring of the femoral and saphenous nerves. Postoperative neurologic sensory and motor deficits were analyzed. The efficacy and accuracy of SSEP, TCeMEP, EMG, TOF, and mIONM were investigated during lateral spine approach surgeries.

Results: TCeMEP monitoring is associated with a lower rate of postoperative neurologic deficits, both sensory and motor, compared to EMG monitoring only. Multimodal IONM strategies using TCeMEPs or saphenous SSEPs (SnSSEPs) may be promising. Distal saphenous nerve SSEPs (DSn-SSEPs) can optimize recordings during lateral lumbar procedures and improve outcomes.

Conclusion: When performing lateral spine surgeries, a multimodal approach that includes the use of EMG, TCeMEP, and SSEP may reduce the incidence of adverse postoperative findings and offer an opportunity to intervene in developing iatrogenic nerve injuries to femoral and/or saphenous nerves.

INTRODUCTION

The lumbar plexus (LP) is a complex neural network of nerves that arise partially out of the thoracic portion and primarily from the lumbar portion of the spinal cord. The ventral rami of L1-L5 and T12 nerves contribute to it. The LP consists of five nerve branches located in the lower spine. The femoral nerve is the largest of these five branches, composed of L2-4 coming together. The nerve provides motor function to the hips, legs, and feet while also providing sensory function, allowing the sense of touch, temperature, and pain for the hip, thigh, knees, and legs. The femoral nerve is a deep-running nerve that branches into the anterior and posterior divisions. The anterior portion helps to flex and move the hips and provides sensation to the anterior and medial portion of the thigh. The posterior portion controls the quadriceps muscle and courses down as the saphenous nerve, providing sensation to the knees and below. The saphenous nerve is the longest sensory branch of the femoral nerve, from L1, L2, and L3 nerve roots. It supplies sensation to the medial aspect of the leg and foot. The saphenous nerve courses in the LP and is part of the third and fourth lumbar roots [1].

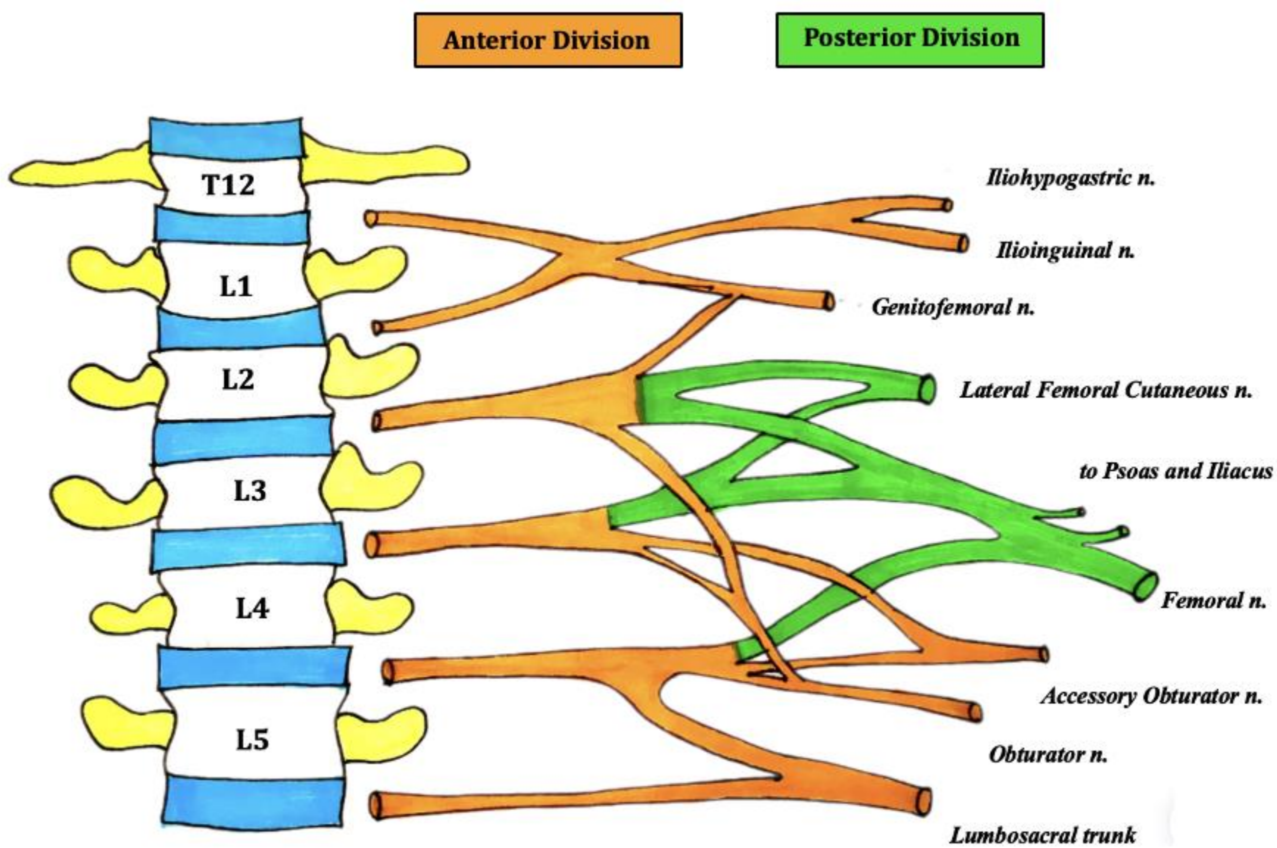

Fig 1. The lumbar plexus (LP) is a network of nerve fibers that innervates muscles and provides sensation to the lower limbs. It is formed by the anterior rami of T12 to L5 nerve roots.

Pathological conditions that can damage the lumbar spine or the nerves distal and proximal to it, like scoliosis, degenerative disc disease, lumbar disc herniation, spondylolisthesis, compressed nerves, or spinal stenosis [2], can be treated with lumbar interbody fusion. There are five main approaches to performing a lumbar interbody fusion: posterior lumbar interbody fusion (PLIF), transforaminal lumbar interbody fusion (TLIF), oblique lumbar interbody fusion/anterior to psoas (OLIF/ATP), anterior lumbar interbody fusion (ALIF), and lateral lumbar interbody fusion (LLIF). Among these approaches, LLIF has resulted in less tissue damage and postoperative pain, shorter hospital stays, and quicker recovery times compared to ALIF or PLIF techniques [3]. While traditional lumbar interbody fusion techniques require exposing the spine, allowing the surgeon to visualize anatomical structures directly, LLIF is a minimally invasive procedure where the vertebrae and intervertebral discs are accessed without opening muscles or shifting nerves around to access the surgical site. LLIF is performed via small incisions in the side of the spine. Although the lateral approach is minimally invasive, there are risks involved due to the surgeon operating without direct anatomical visualization, specifically risk to the nerves and nerve roots in the LP and damage to the psoas muscle [4]. Using multimodality intraoperative neurophysiological monitoring (mIONM), the risk of insulting nerves, nerve roots, and/or muscles at the lumbar plexus can be mitigated through continuous monitoring and intraoperative intervention when necessary. Monitoring the femoral and saphenous nerves during these procedures can reduce the risk of permanent damage.

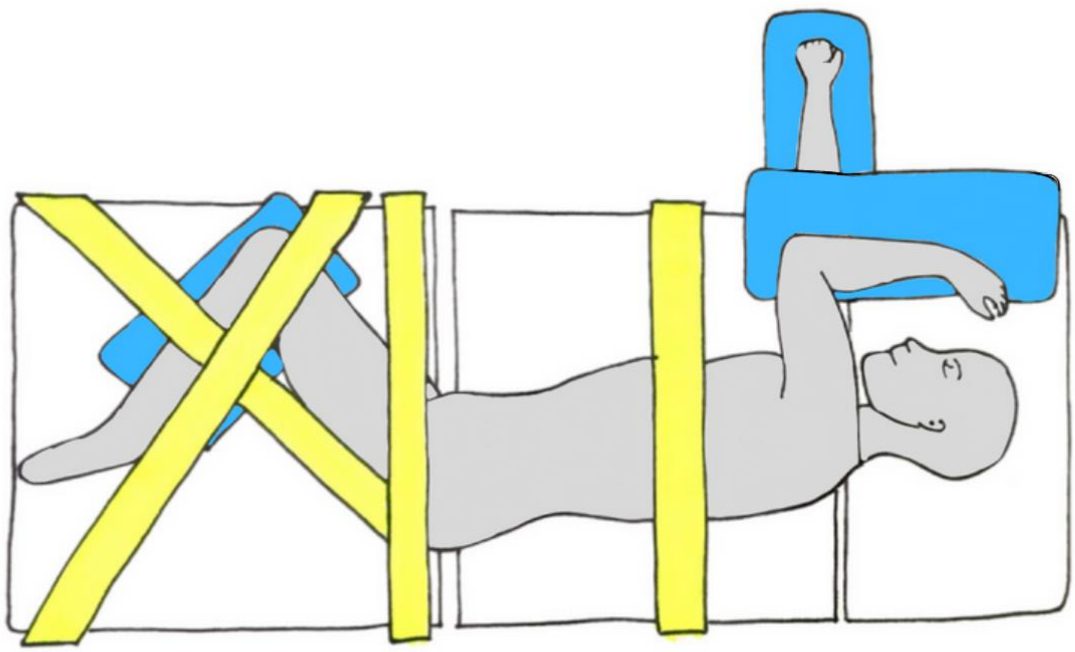

Fig. 2. Typical patient positioning for the lateral lumbar approach is the lateral decubitus position. The patient's arms are supported by padding. The table can be flexed at the lumbar level to allow easier access. The patient is secured to the table by taping. The top leg is gently flexed at the hip to relax the psoas.

Intraoperatively, the femoral nerve can be monitored using somatosensory evoked potentials (SSEP), transcranial motor evoked potentials (TCeMEP), spontaneous electromyography (S-EMG), and triggered electromyography (T-EMG). However, EMG modalities only measure free-running or triggered electrical activity of muscles and nerves. They do not assess variations in nerve function due to ischemia or compression; EMG is also limited in sensitivity and specificity. While SSEPs provide information about ischemic changes, due to the deep-seated location of the femoral nerve, SSEPs in lateral spine surgeries do not provide indications of ischemic changes in the upper lumbar spine as they only provide information regarding the lower lumbosacral plexus (L4–S2). In the distal thigh, the saphenous nerve becomes superficial between the tendons of the sartorius and gracilis muscles, making it easily accessible for SSEP monitoring [5]. Originating from L3 and L4, the saphenous nerve is the largest cutaneous branch of the femoral nerve [6], and due to its superficial location along the anterior portion of the leg, monitoring the saphenous nerve during lateral lumbar procedures for sensory function has proven to produce more favorable outcomes [7].

Various IONM modalities can be utilized to ensure the integrity of the nervous system, such as the motor and sensory functions. Any deficits can be localized to a specific point in the surgery or establish that it was not an iatrogenic injury. Because of the risk LLIF has to the LP and psoas muscle, femoral nerve evoked potentials (FNEP), saphenous nerve somatosensory evoked potentials (SnSSEP), transcranial electrical motor evoked potentials (TCeMEP) and quadricep recordings with electromyography (EMG) provide optimal measures of degraded femoral nerve potentials and consequently, a good measure of the integrity of the LP and psoas muscle during the LLIF [7]. Therefore, using multiple IONM modalities enhances the ability to assess the integrity of the spinal cord, peripheral nerves, and nerve roots during spinal procedures.

METHODS AND ANALYSIS

The study design included a review of PubMed and UT Dallas Eugene McDermott Library databases published between 2014 and 2022; search terms included “lateral spine surgery,” “femoral nerve monitoring,” “saphenous nerve monitoring,” “lateral lumbar interbody fusion,” “transpsoas lumbar interbody fusion,” “LLIF,” “TLIF.” Key findings from the studies assessing the efficacy of neuromonitoring SSEP, saphenous n. SSEP (SnSSEP), EMG, spontaneous EMG (S-EMG), triggered EMG (T-EMG), TCeMEP, or mIONM approach during LLIF were included. Inclusion criteria involved patients who required LLIF surgery. Research studies were included based on the following criteria: Retrospective cases in which neuromonitoring modalities were used during LLIF surgery from 2014 to 2022 were included.

The anesthetic regimen included total intravenous agents (TIVA) with propofol and remifentanil. TIVA is preferred when utilizing TCeMEP and SSEP modalities. A train of four (TOF) is used from the abductor hallucis muscles in the feet to measure the depth of muscle relaxants during the entire surgical procedure.

Somatosensory Evoked Potentials (SSEP)

SSEPs are performed by bilaterally stimulating nerves in the upper and lower extremities. A ground electrode is placed on the stimulated limb between the stimulation site and the first recording site.

Monophasic rectangular pulses are delivered at a pulse width of 100-300ms duration with intensity set to 15-25 mA for upper extremities and 40-100 mA for lower extremities between a frequency of 3-5 Hz. Supramaximal stimulation should elicit repeatable responses, especially in peripheral nerve pathologies, edema of lower extremities, etc. Stimulation rates that are multiples or dividends of 60Hz were not used to avoid synchronization between responses and electrical noise. Common lower extremity SSEP sites stimulated are the ulnar, posterior tibial, common peroneal, femoral, saphenous, or pudendal nerve, depending on the spinal segment that requires surgery.

Recording electrodes are placed along the sensory pathway to record peripheral, subcortical, and cortical responses. Peripheral recording sites include ipsilateral Erb's point for upper extremity SSEPs and ipsilateral popliteal fossa for lower extremity SSEPs. Subdermal needle electrodes are placed at CP3, CP4, CPz, and FPz scalp locations for cortical responses determined by the International 10-20 system. Subcortical responses are recorded by placing a subdermal needle electrode at Cv5. System bandpass filters are typically set at 30-500 Hz for cortical recordings and 30-1500 Hz for spinal/peripheral recordings. Analysis time or sweep is set to 5-7.5ms/division for upper extremities and 10-12ms/division for lower extremities. These may need to increase depending on the conduction level of the patient. SSEPs are small amplitude signals. Hence, they require averaging, which is required to record the signal against biological and ambient noise. SSEPs require 200-300 averages to keep signal to noise ratio low. Alarm criteria for SSEPs are ≥ 50% decrement in amplitude and/or ≥ 10% increment in latency.

Transcranial electrical Motor Evoked Potentials (TCeMEP)

TCeMEPs are conducted by placing corkscrew stimulation electrodes on the scalp at sites C1, C2, C3, and C4, directly above the primary motor cortex, according to the International 10-20 system, which allows for activation of upper and lower extremity muscle groups. Alternatively, electrodes can be placed on the scalp at M1, M2, M3, and M4 locations. Stimulation is delivered at 50 or 75 µs pulse width with increasing intensity until myogenic responses are generated in target muscles or the intensity reaches 600V. Frequency is typically set between 200-500Hz. Train count is set to 5-7 pulses for the spine and 3-5 pulses for craniotomies.

Surface or needle electrodes are inserted in specific muscles, depending on the surgery site and nerve roots that may be at risk. Bandpass filters are set at 10Hz to 5.0kHz. Recordings should be a bipolar montage; typically, sweep settings are at 10ms/division with sensitivity at 200- 500µV/division. The impedance of recording electrodes should be <5 kOhms. Typical recording sites in lumbar surgeries for upper extremities are abductor pollicis brevis and abductor digiti minimi as controls. For lower extremities, typical recording sites are the iliopsoas, adductor magnus, vastus lateralis, vastus medialis, tibialis anterior, peroneus longus, gastrocnemius, extensor hallucis brevis, and abductor hallucis. Recording electrodes can also be placed in the anal sphincter and external urethral sphincter for pudendal nerve recording. Alarm criteria for TCeMEPs are ≥ 70-80% decrement in amplitude, change in signal morphology, and/or increase in the threshold of > 100V.

Electromyography (EMG)

Spontaneous (S-EMG) and triggered (T-EMG), both conducted for stimulation, are used to monitor motor nerve root and spinal cord function. They provide instantaneous feedback of motor nerves and nerve roots. Triggered EMG (T-EMG) is used to identify nerves, provide information regarding their functional integrity, and test pedicle screws during and after placement. EMGs are also utilized during spinal stenosis decompression, tumor removal, and a range of various cranial nerve procedures. Subdermal needles are placed over the belly of the muscle. Active and reference electrodes are placed 3 cm apart. Abnormal EMG activity is often due to nerve root irritation and includes train activity, abnormal neurotonic discharge, spikes, and bursts resulting from mechanical, electrical, or thermal insult.

Meanwhile, EMG often monitors the same muscles as TCeMEPs for lateral spine procedures. Bandpass filters are set at 10Hz to 5.0kHz. When recording S-EMGs, sweep settings are at 100-300ms/division. The impedance of recording electrodes should be < 5kOhms. For T-EMGs, bipolar, monopolar, and tripolar stimulation can be used with sweep settings at 10ms/division. Direct nerve stimulation should be performed at a pulse width of 200 µs with a 2-4 Hz stimulation rate at 0.05-5 mA intensity for direct nerve and 1.0-30 mA for pedicle screw stimulation. Alert criteria include abnormal train activity or prolonged neurotonic discharges for S-EMG, and for pedicle screw T-EMG, alert criteria include a threshold less than 8mA.

Train of Four (TOF)

TOF monitoring was utilized by stimulating the posterior tibial nerve and recorded from the abductor hallucis muscle in the foot. Parameters required when performing TOF intraoperatively are as follows: a monophasic square pulse of four pulses is delivered at a stimulation rate of 2 Hz. Pulse width is set to 0.2ms with sweep settings at 20 ms/division. Sensitivity depends upon the signal size and intensity of the stimulation. When four pulses of stimulation are delivered, zero twitches observed indicate 100% neuromuscular blockade, one twitch observed indicates 95% neuromuscular blockade, two twitches observed indicate 85% neuromuscular blockade, three twitches observed indicate 65-75% neuromuscular blockade, and lastly, four twitches observed indicates 5-75% neuromuscular blockade.

DISCUSSION

SSEPs are monitored to assess and maintain the function and integrity of the dorsal column medial lemniscus (DCML) pathway. SSEPs also assess the perfusion of the sensory pathways. Stimulation sites for the DCML pathway are a mix of peripheral nerves of the upper and lower extremities. Peripheral nerves are stimulated using surface adhesive or subdermal needle electrodes placed commonly at the ulnar nerves at the wrist for upper SSEPs and at the posterior tibial nerve at the medial malleolus for lower SSEPs. Recommended standards by the American Clinical Neurophysiology Society (ACNS) suggest contact impedance to be < 5 kOhms.

TCeMEPs are electrical signals generated by stimulation at the motor cortex; these responses are then recorded from muscles peripherally. TCeMEPs monitor descending motor pathways responsible for voluntary, reflexive, and rhythmic motor pattern-like movements. They provide crucial information about the motor neurons, the neuromuscular junction, the CST, and muscle integrity. TCeMEPs also assess the integrity and perfusion of motor pathways.

The use of EMG in preventing postoperative neurologic injuries is a mixed bag. Some studies show the efficacy of EMG [8-11], while others demonstrate a high rate of postoperative neurologic deficits [12-13]. Additional studies suggest the efficacy of integrating EMG into stimulation probes or finger electrodes in preventing or decreasing postoperative nerve deficits after LLIF. Multimodal IONM strategies using TCeMEPs or SnSSEPs may be promising. TCeMEP monitoring is associated with a lower rate of postoperative neurologic deficits, both sensory and motor, compared to EMG monitoring only [14]. SSEPs demonstrate sensitivity and specificity in detecting postoperative femoral nerve complications [15].

A study by Chaudhary et al. (2015) proposed a modified IONM protocol for LLIF surgery that includes TCeMEP in addition to spontaneous and triggered EMG [16]. The study found that stand-alone EMG nerve monitoring is inadequate for trans-psoas surgery, and the addition of TCeMEP may improve the sensitivity of IONM during transpsoas surgery. The study correlated postoperative neurological outcome with IONM findings and found loss of quadriceps TCeMEP signals occurred during LLIF at L4/L5 in all cases with prolonged retraction. Two patients had postoperative quadriceps weakness concordant with TCeMEP data. The study suggests that multimodality IONM may reduce the incidence of adverse postoperative findings and offer the opportunity to intervene in evolving iatrogenic nerve injuries.

Overzet et al. (2021) analyzed the usefulness of an additional stimulation site for monitoring Sn-SSEP data in lateral lumbar surgeries [17]. Sn-SSEPs provide a continuous way to monitor the femoral nerve to prevent injury, which is a well-reported complication in lateral spine surgeries. Posterior tibial nerve SSEPs are most used in IONM. However, this study shows that utilizing DSn-SSEPs as an adjunct to femoral nerve monitoring is valuable. In this study, stimulation electrodes were placed distally below the knee and medial to the tibia bone, and a viable DSn-SSEP waveform was obtained in 87% of these surgeries. The average amplitude across all procedures where the DSn-SSEP was obtained was 0.48 µV. The average latencies for P and N were 41.1 ms and 49.5 ms, with a peak-to-trough latency of 8.4 ms on average. Stimulation electrode placement is easy to palpate with clear anatomical borders, and muscle artifacts and patient movement from stimulation do not affect waveform morphology, allowing for more continuous and reliable monitoring. The study recommends including DSn-SSEPs to optimize recordings during lateral lumbar procedures [17]. A similar study that aimed to technically optimize the methodology for SnSSEPs proposed for monitoring upper lumbar roots in the operating room supports that distal stimulation for SnSSEP has advantages over proximal stimulation, including simplicity, lack of movement, and higher amplitude responses. Using two derivations (CPz–cCP, CPz–Fz) optimizes SnSSEP recording. The study had two groups. In the first group, the saphenous nerve was consecutively stimulated in two locations: proximal in the thigh and distal close to the tibia. Three different recording derivations (10–20 International system) to distal saphenous stimulation were tested in the second group. Distal stimulation yielded a higher SnSSEP amplitude (mean±SD) than proximal: 1.36±0.9 μV versus 0.62±0.6 μV, ($p<0.0001$). Distal stimulation evoked either higher (73%) or similar (12%) SnSSEP amplitude than proximal in most nerves. The recording derivation CPz–cCP showed the highest amplitude in 65% of the nerves, followed by 24% in CPz–Fz [18].

Several other studies highlight the potential of SnSSEP monitoring in identifying and preventing nerve injury during spine surgery. In a case series aimed at investigating the use of SSEPs in monitoring the saphenous nerve, of the 41 patients undergoing transpsoas surgical exposures of the lumbar spine, intraoperative changes of the SnSSEPs were observed in five patients which were focal to the saphenous nerve only. The changes occurred after the retractor was placed and opened at the level of L4-L5. In one case, the SSEP was attenuated on the approach side, which was resolved by adjusting the retractors, and the patient woke up neurologically intact. However, in the other four cases, changes in the SSEP data persisted, and three patients woke up with postoperative deficits [19]. These results are replicated in another study that utilized Sn-SSEP in 56 patients who underwent lateral lumbar interbody fusion (LIF). The study concluded that SnSSEP monitoring is dependable and provides actionable feedback highly predictive of neurological events during LLIF [9].

Jain et al. (2021) studied 62 patients undergoing LLIF surgery. Reliable SnSSEPs were recorded on the LLIF approach side in 52/62 patients [5]. Persistent SnSSEP reduction of amplitude of >50% in 6 cases was observed during expansion of the tubular retractor or the procedure, two of 6 patients postoperatively had femoral nerve sensory deficits, and 5 of 6 patients had mild femoral nerve motor weakness, all of which resolved at an average of 12 weeks postoperatively (range 2-24 weeks). One patient had SnSSEP changes but demonstrated intraoperative recovery and had no postoperative clinical deficits. In this study, SnSSEPs demonstrated 52% to 100% sensitivity and 90% to 100% specificity for detecting postoperative femoral nerve complications. The results supported the finding that SnSSEPs can detect electrophysiological changes to prevent femoral nerve injury during LLIF, and intraoperative SSEP recovery after amplitude reduction or loss may be a prognostic factor for the final clinical outcome [5].

In addition to SSEPs, there has been increasing research on the utility of TCeMEPs during spine surgery; TCeMEP monitoring is more specific to motor injury than SSEP. However, TCeMEP shows greater sensitivity to anesthetic agents and a much larger amplitude variability over time than SSEP. TCeMEPs have been advocated and widely used for monitoring spinal cord function during surgical correction of spinal deformity and surgery of the cervical and thoracic spine but have had limited acceptance for use in lumbar procedures. This is due to the theoretical possibility that TCeMEP recordings may not be sensitive in detecting an injury to a single nerve root, considering there is overlapping muscle innervation of adjacent root levels.

Data from some studies suggests that TCeMEP recordings may not be sensitive in detecting an injury to a single nerve root, considering there is overlapping muscle innervation of adjacent root levels. However, Block et al. (2015) propose a theory and technique to utilize TCeMEP to protect the femoral nerve, which is at risk in LLIF procedures [20]. In LLIF procedures, the surgeon is more likely to encounter LP elements than nerve roots. Within the substance of the psoas muscle, the L2, L3, and L4 nerve roots combine in the LP to form the trunk of the femoral nerve. When the nerve roots become the trunk of the femoral nerve, there is no longer any alternative overlapping innervation to the quadriceps muscles. Insult to the fully formed femoral nerve, which completely blocks conduction in motor axons, should theoretically abolish all TCeMEP responses to the quadriceps muscles. On multiple occasions over the past year, their neuro-monitoring groups have observed significantly degraded amplitudes of the femoral motor and/or sensory evoked potential limited to only the surgical side. Most of these degraded response amplitudes rapidly returned to baseline values with surgical intervention (i.e., prompt removal of surgical retraction).

A functional assessment of the femoral nerve cannot be obtained with T-EMG due to the possibility of false negative responses. Over the last year, a multimodality approach to monitoring femoral nerve function during LLIF procedures has been advocated; this approach utilizes information obtained from TCeMEP recordings of the quadriceps muscles in conjunction with information from saphenous nerve SSEPs (SnSSEPs)

A retrospective analysis report that evaluated the efficacy of emerging intraoperative femoral nerve monitoring techniques and the importance of employing prompt surgical countermeasures when degraded femoral nerve function is detected reported out of 172 surgeries, in 89% (n=153), there were no surgeon alerts as the FNEP response amplitudes remained relatively unchanged throughout the surgery (negative group). The positive group included 11% of the cases (n=19) where the surgeon was alerted to a deterioration of the FNEP amplitudes during surgical retraction. Prompt surgical countermeasures to an FNEP alert included loosening, adjusting, or removing surgical retraction and/or requesting an increased blood pressure from the anesthesiologist. All the cases where prompt surgical countermeasures were employed resulted in the recovery of the degraded FNEP amplitudes and no postoperative femoral nerve injuries. In two cases, the surgeons were given verbal alerts of degraded FNEPs but did not employ prompt surgical countermeasures. In both cases, the degraded FNEP amplitudes did not recover by the time of surgical closure, and both patients exhibited postoperative signs of sensorimotor femoral nerve injury, including anterior thigh numbness and weakened knee extension [7].

The data suggested that the common strategy of limiting retraction duration may not be effective in preventing iatrogenic femoral nerve injuries, and a multimodal approach can provide surgeons with a timely alert to hyperacute femoral nerve conduction failure, enabling prompt surgical countermeasures to be employed that can mitigate or avoid femoral nerve injury. Additionally, it reiterated that a multimodal approach provides the surgeon with a comprehensive intraoperative assessment of femoral nerve function throughout the procedure.

SSEPs for the femoral nerve offer a continuous monitoring approach to prevent injury, a known complication in lateral spine surgeries. While posterior tibial nerve SSEPs are commonly used in IONM, this study demonstrates the value of incorporating Dual Stimulation (DSn)-SSEPs as an adjunct to femoral nerve monitoring.

Furthermore, aside from SSEPs, there has been an increased focus on applying TCeMEP in spine surgery. TCeMEP monitoring is more specific in detecting motor injury compared to SEP. However, TCeMEPs exhibit greater sensitivity to anesthetic agents and higher variability in amplitude over time compared to SSEP. Despite being widely used for monitoring spinal cord function during surgical correction of spinal deformities and cervical and thoracic spine surgeries, TCeMEPs have limited acceptance in lumbar procedures. As per theoretical considerations, TCeMEP recordings may not be sensitive enough to detect injuries to a single nerve root due to overlapping muscle innervation of adjacent root levels.

TOF monitoring is crucial to avoid missing S-EMG activity and, more importantly, to avoid false negatives. Additionally, patients respond to NMBAs differently; hence, it is important to assess the depth of anesthesia intraoperatively to alter anesthetic levels or administer reversal agents so neurophysiologists can not only monitor continuously but also monitor critical points during surgery to ensure large variations are addressed within the therapeutic window. TOF involves stimulation involving four consecutive pulses to a peripheral nerve to evaluate the level of neuromuscular blocking agents (NMBA) or depth of anesthesia. A peripheral nerve is stimulated, and the corresponding innervated muscle is recorded. The corresponding observed muscle twitch/contraction is used to assess the level of neuromuscular blockade. For spinal procedures with lateral approach, lower extremity nerves and muscles monitored are the sciatic nerve at the popliteal fossa, which innervates the gastrocnemius; peroneal nerve, which innervates the tibialis anterior; and the posterior tibial nerve, which innervates the abductor hallucis. TCeMEP and EMG modalities are dependent on intact neuromuscular junctions (NMJ) to get a contraction. Therefore, ensuring is no NMBA onboard when assessing with TOF is crucial.

CONCLUSION

In conclusion, the use of EMG to prevent postoperative nerve injury in spine surgery is controversial. While some studies demonstrate efficacy, others show a high rate of postoperative neurologic deficits. Multimodal IONM that uses TCeMEPs and SnSSEPs in addition to EMG may be promising in reducing adverse postoperative outcomes. Additionally, studies have shown that distal stimulation for SnSSEP has advantages over proximal stimulation. SnSSEP monitoring is more efficient and reliable and provides actionable feedback that highly predicts neurological outcomes during lateral spine procedures. Overall, a multimodality approach that includes the use of EMG, TCeMEP, and SSEP may reduce the incidence of adverse postoperative findings and offer an opportunity to intervene in developing iatrogenic nerve injuries during spinal surgery.

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