Clinical study

Femoral nerve neuromonitoring for lateral lumbar interbody fusion surgery

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Abstract

BACKGROUND CONTEXT: The transpsoas lateral lumbar interbody fusion (LLIF) technique is an effective alternative to traditional anterior and posterior approaches to the lumbar spine; however, nerve injuries are the most reported postoperative complication. Commonly used strategies to avoid nerve injury (eg, limiting retraction duration) have not been effective in detecting or preventing femoral nerve injuries.

PURPOSE: To evaluate the efficacy of emerging intraoperative femoral nerve monitoring techniques and the importance of employing prompt surgical countermeasures when degraded femoral nerve function is detected.

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STUDY DESIGN/SETTING: We present the results from a retrospective analysis of a multi-center study conducted over the course of 3 years.

PATIENT SAMPLE: One hundred and seventy-two lateral lumbar interbody fusion procedures were reviewed.

OUTCOME MEASURES: Intraoperative femoral nerve monitoring data was correlated to immediate postoperative neurologic examinations.

METHODS: Femoral nerve evoked potentials (FNEP) including saphenous nerve somatosensory evoked potentials (snSSEP) and motor evoked potentials with quadriceps recordings were used to detect evidence of degraded femoral nerve function during the time of surgical retraction.

RESULTS: In 89% (n=153) of the surgeries, 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 increase in blood pressure from the anesthesiologist. All the cases where prompt surgical countermeasures were employed resulted in 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.

CONCLUSIONS: Multimodal femoral nerve monitoring 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. Our data also suggests that the common strategy of limiting retraction duration may not be effective in preventing iatrogenic femoral nerve injuries. © 2021 Elsevier Inc. All rights reserved.

Keywords: Saphenous nerve; Motor evoked potentials; Somatosensory evoked potentials; Femoral nerve; Lumbar lateral interbody fusion; Quadriceps; Nerve injury.

Abbreviations: LLIF, lateral lumbar interbody fusion; SSEPs, somatosensory evoked potentials; MEPs, motor evoked potentials; FNEPs, femoral nerve evoked potentials (snSSEP & MEPq); snSSEP, saphenous nerve somatosensory evoked potentials; MEPq, transcranial motor evoked potentials with quadriceps recordings; sEMG, spontaneous (free running) electromyography recordings; tEMG, triggered electromyography for nerve localization (mapping); PTN, posterior tibial nerve; pmSSEP, posterior tibial nerve somatosensory evoked potentials; TIVA, total intravenous anesthesia

Introduction

The transpsoas lateral lumbar interbody fusion (LLIF) technique is an effective alternative to traditional anterior and posterior approaches to the lumbar spine [1]. The advantages of the LLIF are well documented, however, injuries to the lumbar plexus are the most reported postoperative complication [2]. Injury to the neural elements of the lumbar plexus can range from low grade transient neuropraxia to high grade injuries with axonal damage and the potential for permanent disability. A high-grade femoral nerve injury is the most feared neurologic complication, with the suspected highest risk at the L4−L5 level where the variable path of the femoral nerve can run directly across the disc space [3]. Most nerve injuries associated with LLIF procedures should be classified as plexopathies, which have different prognostic, and management implications compared with radicular injuries that are associated with traditional posterior approaches to the lumbar spine where the nerve roots are most at risk [2]. This important anatomical distinction also applies to neuromonitoring protocols for the lumbar plexus and/or femoral nerve, which must be approached differently than those used to monitor the function of the spinal cord and nerve roots [4].

This publication provides an overview of emerging intraoperative femoral nerve monitoring techniques and a review of our results from a multi-center study conducted over the course of 3 years.

Materials and methods

Institutional review board approval was granted for this study and intraoperative monitoring data from 172 LLIF procedures (103 females and 69 males with a mean age of 66 years) consisting of 278 surgical levels (L1−L2=9; L2−L3=66, L3−L4=118, L4−L5=85) were prospectively collected and retrospectively analyzed. Fellowship trained orthopedic spine and neurologic surgeons performed all the LLIF procedures. Multimodal neurophysiological monitoring using somatosensory evoked potentials (SSEP), electromyography (EMG), and motor evoked potentials (MEPs) was performed by board certified surgical neurophysiologists with specialized training in femoral nerve monitoring techniques. The neuromonitoring data was reviewed and correlated to immediate postoperative examination findings.

Each patient was positioned in a lateral decubitus position and the transpsoas approach was performed as
described by multiple authors [1,5–6] To establish a safe surgical corridor to the disc space, common nerve mapping techniques using triggered electromyography (tEMG) were employed to detect motor nerve fibers in proximity to the tip of each of the surgical instruments (eg, dilators, retractor blade, hand-held probe), which are fitted with a monopolar stimulating electrode. Once a safe surgical corridor was established and the surgical retractors were deployed, the neurophysiologist switched their focus from nerve mapping to femoral nerve monitoring for the purpose of detecting any evidence of degraded femoral nerve function during surgical retraction.

Intraoperative neurophysiological monitoring methods

Baseline Femoral Nerve Evoked Potentials (FNEPs) including both saphenous nerve SSEPs (snSSEPs) and motor evoked potentials with quadriceps recordings (MEPqs) were acquired before skin incision. Baselines of control recordings (non–femoral nerve SSEPs and MEPs) were also acquired for comparison. The surgeon was advised of the quality of the baseline data as a measure of how effective the femoral nerve monitoring would be for that particular case, as the quality of FNEP data can be highly variable between patients and under different anesthetic conditions.

Alert criterion was defined as an isolated degradation in amplitude of the surgical side snSSEP and/or MEPq responses while the amplitudes from all other non–femoral nerve innervated evoked potential recordings (control recordings) remained unchanged. Alerts were also provided if any abnormal spontaneous electromyography (sEMG) activity was observed, with particular attention on the lumbar plexus innervated muscles.

Femoral nerve monitoring using femoral nerve evoked potentials (FNEPs)

FNEPs including both snSSEPs and MEPqs, were acquired near the time of incision to establish baseline amplitudes. The neurophysiologist provided the surgeon with a verbal report using three basic categories that subjectively describe the quality of the acquired snSSEP and MEPq baseline recordings:

- **Good**- repeatable responses with ample, consistent amplitudes, and stable waveform morphologies
- **Poor**- inconsistent, variable, or low amplitude responses
- **Unobtainable**- no viable, repeatable recordings can be acquired

Results

We were able to confidently monitor the sensory function of the femoral nerve by obtaining good quality snSSEP responses at baseline in 84% of the cases (144 patients) using electrical activation of the saphenous nerve at the distal medial thigh and recording the resultant cortical sensory evoked potentials with subdermal scalp electrodes. In 16% of the cases (28 patients), baseline snSSEP recordings were poor or unobtainable. We were able to confidently monitor the motor function of the femoral nerve with good quality baseline MEPq responses in 57% of the cases (98 patients) using transcranial electrical stimulation with at least two quadriceps muscle recording channels (ie, vastus medialis and vastus lateralis). Poor quality MEPq baselines were acquired in 30% of cases (52 patients) and there were 12% of cases (20 patients) where baselines were unobtainable. One percent (two patients) were omitted due to contraindications for MEP monitoring.

Detecting degraded FNEPs during surgical retraction

Our case series consisted of 172 surgeries with 278 surgical levels. In 89% (n=153) of the surgeries (248 surgical levels), there were no surgeon alerts as the FNEP response amplitudes remained relatively unchanged throughout surgical retraction and until closure (Negative group). The positive group included 11% of the cases (n=19) where the surgeon was alerted to an isolated deterioration of the surgical-side FNEP amplitudes during surgical retraction (Table 1). Degraded FNEPs were not observed in the one case in our series that was performed at the L1–L2 level. At the L2–L3 level, we detected FNEP amplitude degradation in three cases. We detected a greater number of degraded FNEPs at the L3–L4 level (nine cases) compared with the L4–L5 level (seven cases). In 17 of the 19 cases where degraded FNEPs were detected, the surgeons employed prompt surgical countermeasures that included loosening, adjusting, or removing surgical retraction, and/or requesting an increase in blood pressure from the anesthesiologist. All 17 of these cases where prompt surgical countermeasures were employed resulted in 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.

Our study revealed an 11% alert rate and a 1% rate of femoral nerve injury that only occurred in the two cases where no prompt surgical countermeasures were employed following an alert of degraded FNEPs.

Spontaneous electromyography (sEMG)

Continuous sEMG recordings were closely observed during surgical retraction to detect any evidence of abnormal spontaneous muscle activity (ie, neurotonic discharges) that might be considered suggestive of nerve stretch, compression or irritation. Continuous sEMG recordings of
<table>
<thead>
<tr>
<th>Case</th>
<th>Sex</th>
<th>Procedure</th>
<th>Level of FNEP degradation</th>
<th>snSSEP</th>
<th>MEPq</th>
<th>Retraction time to FNEP conduction failure in min</th>
<th>Surgical countermeasure</th>
<th>FNEP recovery by closure</th>
<th>Postop exam</th>
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<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>L2−L5 LLIF</td>
<td>L4−L5</td>
<td>Loss</td>
<td>Unobtainable</td>
<td>40</td>
<td>Increase BP and retractor removal</td>
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<td>Neuro Intact</td>
</tr>
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<td>2</td>
<td>M</td>
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<td>L2−L3</td>
<td>Unobtainable</td>
<td>Loss</td>
<td>1</td>
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<td>Yes</td>
<td>Neuro intact</td>
</tr>
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<td>L4−L5</td>
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<td>Loss</td>
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<tr>
<td>4</td>
<td>M</td>
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<td>L3−L4</td>
<td>Loss</td>
<td>Loss</td>
<td>12</td>
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<td>5</td>
<td>M</td>
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<td>Loss</td>
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<td>Retractor Removal</td>
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<td>L3−L4</td>
<td>Degraded Amplitude</td>
<td>Loss</td>
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<td>Retraction removal</td>
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<td>L2−L3</td>
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<td>Loss</td>
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<tr>
<td>8</td>
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<td>L4−L5 LLIF</td>
<td>L4−L5</td>
<td>Loss</td>
<td>Loss</td>
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<td>No</td>
<td>Femoral nerve sensorimotor deficit</td>
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<td>L4−L5</td>
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<td>Loss</td>
<td>26</td>
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<tr>
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<tr>
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<tr>
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<td>L4−L5</td>
<td>Loss</td>
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<td>21</td>
<td>Hastened Procedure</td>
<td>Yes</td>
<td>Neuro Intact</td>
</tr>
<tr>
<td>14</td>
<td>F</td>
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<td>L4−L5</td>
<td>Loss</td>
<td>Loss</td>
<td>5</td>
<td>Retractor removal</td>
<td>Yes</td>
<td>Neuro Intact</td>
</tr>
<tr>
<td>15</td>
<td>F</td>
<td>L3−L4 LLIF</td>
<td>L3−L4</td>
<td>Loss</td>
<td>Loss</td>
<td>30</td>
<td>Retractor Removal</td>
<td>Yes</td>
<td>Neuro Intact</td>
</tr>
<tr>
<td>16</td>
<td>M</td>
<td>L3−L4 LLIF</td>
<td>L3−L4</td>
<td>Loss</td>
<td>Loss</td>
<td>14</td>
<td>Retractor removal</td>
<td>Yes</td>
<td>Neuro Intact</td>
</tr>
<tr>
<td>17</td>
<td>F</td>
<td>L3−L4 LLIF</td>
<td>L3−L4</td>
<td>Unobtainable</td>
<td>Loss</td>
<td>26</td>
<td>No Intervention</td>
<td>No</td>
<td>Femoral nerve sensorimotor deficit</td>
</tr>
<tr>
<td>18</td>
<td>M</td>
<td>L1−L3 LLIF</td>
<td>L2−L3</td>
<td>Loss</td>
<td>Loss</td>
<td>7</td>
<td>Retractor removal</td>
<td>Yes</td>
<td>Neuro Intact</td>
</tr>
<tr>
<td>19</td>
<td>M</td>
<td>L3−L4 LLIF</td>
<td>L3−L4</td>
<td>Loss</td>
<td>Loss</td>
<td>24</td>
<td>Retractor loosening</td>
<td>Yes</td>
<td>Neuro Intact</td>
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</table>
The results of our study suggest that multimodal femoral nerve monitoring utilizing FNEPs is highly effective for detecting hyperacute femoral nerve conduction failure during surgical retraction in LLIF procedures. Our study revealed a high predictive value with a 100% correlation between well-preserved FNEP amplitudes at the time of surgical closure resulting in good postoperative outcomes (Fig. 1). Poor outcomes were also accurately predicted in the two patients (1%) where degraded FNEP recordings did not recover by the time of surgical closure (Fig. 2).

Contrary to expectations, we detected a slightly greater number of degraded FNEPs at the L3–L4 level (nine cases) compared with the L4–L5 level (seven cases). Cadaveric anatomical investigations describe considerable anatomical variability in the formation and branching patterns of the lumbar plexus including prefixed and postfixed lumbar plexuses [37–40]. Our study results suggest that surgeons and neurophysiologists should be attentive to the FNEPs at the levels rostral to the L4–L5 level which has traditionally been suspected to be the level of highest risk.

Surgeons should appreciate the technical obstacles, pitfalls, limitations, and strengths of femoral nerve monitoring to use the information most effectively for surgical decision-making.

Table 2
Muscles used for sEMG, tEMG, and MEP recordings.

<table>
<thead>
<tr>
<th>Lumbar plexus muscle recordings</th>
<th>Muscle recording channel</th>
<th>Root/Plexus/Peripheral nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdominals</td>
<td>T12, L1 / Lumbar Plexus / Subcostal nerve (T12), Illiodygapogastric Nerve (L1) &amp; Elioinguinal Nerve (L1)</td>
<td></td>
</tr>
<tr>
<td>Adductors</td>
<td>L2, L3, L4 / Lumbar Plexus / Obturator nerve</td>
<td></td>
</tr>
<tr>
<td>Quadriceps - at least two muscle recording channels (ie, vastus medialis &amp; vastus lateralis)</td>
<td>L2, L3, L4 / Femoral nerve</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sacral plexus (control recordings)</th>
<th>Muscles used for sEMG, tEMG, and MEP recordings.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibialis Anterior</td>
<td>L4, L5 Sacral Plexus / Sciatic/Peroneal nerve</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>S1–S2/ Sacral Plexus / Sciatic / Posterior Tibial Nerve</td>
</tr>
<tr>
<td>Abductor Hallucis</td>
<td>S1, S2, S3 / Sacral Plexus / Sciatic / Posterior Tibial Nerve</td>
</tr>
</tbody>
</table>
Widespread adoption of femoral neuromonitoring techniques may be slow due to technical challenges and the limited number of qualified neurophysiologists with the ability to successfully acquire useful data and provide the surgeon with an appropriate interpretation. The quality of the FNEP data can vary significantly between patients and can be influenced by several factors including anesthetic levels, technical factors, physiological factors, and comorbidities. At the time of incision, the neurophysiologist should provide a detailed verbal report describing the quality of the baseline FNEPs to the surgeon. The report should include qualitative descriptions of both the snSSEPs and MEPq data (ie, good, poor, absent) that will provide the surgeon with a level of confidence in their ability to monitor femoral nerve function for that particular patient. The quality of the acquired FNEP data is different for each case, and effective communication between the surgeon, neurophysiologist and anesthesiologist is essential. If the baseline snSSEPs are poor, the surgeon must solely rely on the MEPq data to assess femoral nerve function, and thus MEPq data must be acquired more often throughout the procedure. The snSSEP data can be acquired continuously throughout surgical retraction, most often without any disruptive patient movement from the electrical stimulation. In contrast, MEPq data must be acquired intermittently as the electrical stimulation often causes a short burst of patient movement that can be disruptive to the surgery. It is often possible for the neurophysiologist to acquire MEPq data intermittently at opportune times when the surgeon is clear of the surgical field (eg, during fluoroscopy).

### Additional surgical applications for femoral nerve monitoring

Emerging femoral nerve monitoring techniques may have additional beneficial surgical applications. For example, snSSEPs may prove useful for routine intraoperative monitoring of the L3–L4 lumbar nerve roots. Commonly used peroneal and tibial nerve SSEPs may be unable to detect more rostral L3–L4 nerve root compromise as they predominantly assess the function of the L5 and S1 nerve roots, respectively [41,42]. FNEPs may also be useful in high-risk total hip arthroplasty (THA) surgery, especially for revisions, dysplasia or complex cases where the risk for femoral nerve injury is increased. Published management

<table>
<thead>
<tr>
<th>Saphenous Somatosensory Evoked Potentials</th>
<th>Motor Evoked Potentials- qudriceps recordings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Left snSSEP</strong></td>
<td><strong>Left MEPq</strong></td>
</tr>
<tr>
<td>Baseline recordings</td>
<td>Incision</td>
</tr>
<tr>
<td>Retractors placed</td>
<td>Realert - complete loss of left FNEPs</td>
</tr>
<tr>
<td>Degraded left side FNEPs detected</td>
<td>Surgical retraction removed</td>
</tr>
<tr>
<td>Alert - recovery of FNEPs</td>
<td></td>
</tr>
<tr>
<td>Well preserved FNEPs at closure</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. Case Example 1- Hyperacute femoral nerve conduction failure during surgical retraction detected and corrected. A “waterfall” view shows the FNEP data chronologically from the beginning of the L4–L5 LLIF procedure (top) until surgical closure (bottom). This was the first documented case where hyperacute femoral nerve conduction failure was detected concurrently in both the surgical side snSSEPs and MEPq while all control evoked potential recordings remained unchanged. (A) The baseline snSSEP amplitude (green) on the left (surgical side) begins to degrade (yellow) during surgical retraction until the signal is completely lost (red). Following release of the surgical retraction, the degraded signals quickly recover to near baseline amplitudes (green). In contrast, the right (non-surgical side) snSSEP response amplitudes remained unchanged throughout the procedure. (B) The left side motor evoked potential quadriceps recordings (MEPq) confirmed failing femoral nerve function with degraded response amplitudes (yellow) followed by a complete loss of the response (red), while the right sided responses remained unchanged. Like the degraded left snSSEP responses, the degraded left MEPq responses also rapidly recovered to near baseline amplitudes following prompt removal of the surgical retraction. The left sensory and motor femoral nerve evoked potential responses remained within normal limits at the time of surgical closure and this patient did not experience any postoperative neurologic deficits (Color version of the figure is available online.).
guidelines for THA surgery have reported an incidence of femoral nerve injury ranging from 0.1% to 2.4% [43].

**Conclusion**

Femoral nerve monitoring techniques include intraoperative functional assessments of both the sensory (snSSEPs) and motor (MEPq) components of the femoral nerve. Both sensory and motor evoked potential recordings should be used as the quality of the baseline data can be highly variable, and it is not uncommon to have poor or unobtainable data from one of the two monitoring modalities. Femoral nerve monitoring is technically challenging and requires a skilled and knowledgeable neurophysiologist with specialized training who can acquire useful data and interpret it appropriately. Acquisition of quality baseline evoked potential data is essential so that evidence of degraded femoral nerve function can be detected, assessed, and reported in a timely manner. Our study results suggest that the common strategy of limiting retraction duration is not effective in preventing iatrogenic femoral nerve injuries. In contrast, multimodal femoral nerve monitoring can provide surgeons with a timely alert to hyperacute femoral nerve conduction failure, so that prompt surgical countermeasures can be employed to reduce the strain on the femoral nerve during the critical period where the conduction failure is reversible.

**References**


