Research Article

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Multimodal Neuromonitoring During Safe Surgical Dislocation of the Hip for Joint Preservation: Feasibility, Safety, and Intraoperative Observations

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Abstract

Introduction: Nerve injuries can occur from major hip surgeries, and some may be significant. Our goal was to assess the feasibility and safety of neuromonitoring during hip preservation surgery and the incidence of alerting events during such monitoring.

Methods: Twenty-five adult patients underwent surgical hip dislocation for femoroacetabular impingement. Upper and lower extremity somatosensory evoked potentials, lower extremity transcranial motor evoked potentials, and lower extremity electromyography were recorded.

Results: We observed a temporary reduction of the monitored parameters in twelve patients (48%) during surgery. There were no clinically significant neurological deficits postoperatively in any cases.

Discussion: Neuromonitoring did demonstrate events during hip surgery in our case series. Although it may not be practical to use neuromonitoring in all major hip surgeries, it may be prudent from the perspective of patient safety to use it in high-risk cases, including those requiring prolonged surgical time; in patients with high body mass index, excessive deformity correction, and preexisting neuropathy; and in revision cases, among others.

Joint preservation and improvement in musculoskeletal function have been the goals of orthopaedics since its inception as a specialty. Following its initial description by Ganz et al,[1] surgical hip dislocation has become a well-accepted, safe technique for hip preservation surgery. It offers close to 360° visualization of the femoral head-neck region and the acetabulum, which helps address various hip pathologies, including femoroacetabular impingement (FAI), traumatic labral tears, proximal femoral deformities, slipped capital femoral epiphysis, hip dysplasia, fractures (including those of the femoral head and neck and of the acetabulum), loose bodies, cartilage defects, and tumors. With widespread use of this approach to hip surgery, different complications have been reported.[2,3] Nerve injury is one such complication. Although infrequent, nerve injuries during hip surgeries can be devastating and life-changing events.

Intraoperative neurophysiologic monitoring (IONM) has proven its benefit in several surgical fields.[4–8] The senior author (H.S.H.) was mentored by some of the pioneers in spine monitoring during his orthopaedic training, including Denis Drummond, MD, and John Dormans, MD. As demonstrated in spine surgery, identifying early electrophysiologic changes, IONM can point toward risk factors for ongoing damage in the monitored nerves.[9] This information critically guides the surgeons during the surgical intervention, including extension of incisions, placement of implants, limb positioning, and retraction techniques that are invaluable in preventing permanent injury or damage to the nerve.

Currently, a multimodal technique is recommended to monitor the ascending nerve pathways by somatosensory evoked potentials (SSEPs) and the descending nerve pathways by transcranial motor evoked potentials (TcMEPs), and continuous spontaneous elicited electromyography (EMG).[10]

For hip joint surgery, IONM has been used for primary total hip arthroplasty,[11] total hip arthroplasty revisions,[11] periacetabular osteotomies (PAOs),[12,11] hip arthroscopy,[13,14] arthroscopic-assisted treatment of hamstring avulsion, and ischial tunnel syndrome.[15] However, to the best of our knowledge, there are no reports about intraoperative electrophysiologic changes in the sciatic and femoral nerve during surgical hip dislocation and manipulation of the limb in various positions for purposes of the several indications and requirements in joint-preserving surgery.

The goal of this study was to (1) prove the feasibility and safety of IONM during surgical hip dislocation for hip preservation surgery and (2) analyze the incidence of alerting events during the course of such intraoperative neuromonitoring, with an intention to limit or curtail certain surgical steps that put the nervous structures at a higher risk for possible injury.

Methods

Institutional review board approval was obtained before this study, and every patient provided written informed consent before participating.

Study Cohort

Between March 2015 and March 2016, a total of 25 patients (19 women, 6 men; mean age, 38.5 ± 12.9 years; range, 20–63 years) underwent surgical dislocation of the hip (14 right hips, 11 left hips). Eleven patients were diagnosed with a posttraumatic labral tear after motor vehicle accident injury, impact, or fall. Fourteen patients underwent surgery because of FAI (cam-, pincer-, or mixed-type FAI) with a labral tear. Before surgery, all patients underwent standard radiographs (anterior-to-posterior pelvis and modified Dunn view of the affected proximal femur) and an MRI arthrogram with radial neck sequence imaging to confirm labral pathology.

Anesthesia Protocol

Induction of general endotracheal anesthesia was performed with the use of midazolam 2 mg, fentanyl 3 mcg/kg, propofol 100 mg, and succinylcholine 100 mg, all by intravenous route. Maintenance of anesthesia was used with a propofol/ketamine (2 mg/mL) intravenous infusion ranging from 50 to 100 mcg/kg/min, desflurane inhalation at less than 1/2 minimal alveolar concentration, oxygen/air mixture; neuromuscular blockade was maintained with rocuronium 30 mg. Bispectral index monitoring was used to help guide depth of anesthesia. Muscle relaxant was allowed to wear off, and no reversal was required in any of the reported cases. All patients were prophylactically treated for nausea with dexamethasone 8 mg and ondansetron 4 mg. Hydromorphone 2 mg was titrated in at incremental doses at the conclusion of each case. Patients were extubated after meeting extubation requirements and then taken to the postanesthesia care unit. Notably, no spinal or peripheral pain catheters were used in any of the reported cases.

Neuromonitoring

All modalities used in this study follow the guidelines put forth by the American Clinical Neurophysiological Society.[16,17] With respect to the settings within the operating room, stimulator and preamplifier boxes (NIM-Eclipse; Medtronic) were placed near the foot of the operating table. The analysis was conducted with NIM-Eclipse NS Software (Version 3.5.354). Before positioning each patient in a lateral decubitus position, subdermal needle electrodes on the nonoperative leg, the hands, and the head were placed by the neurophysiologist. The electrodes for the operative leg were placed by the surgeon under sterile conditions. Subsequently, baseline recordings were obtained before the incision.

Cranial electrodes were placed according to the international 10-20

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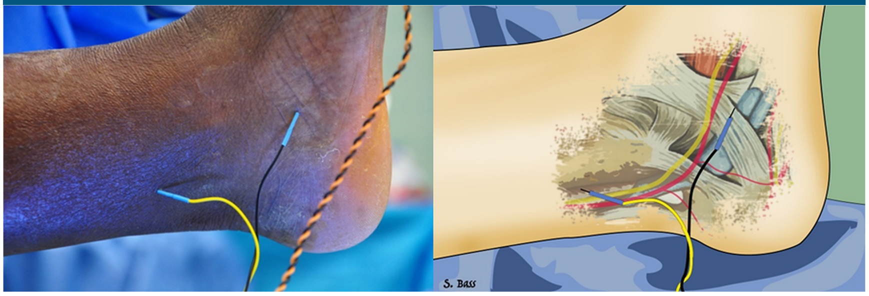
system.[18] Somatosensory evoked potentials were recorded from electrodes placed over FPZ, CPZ, CP3, CP4, and Cv after the ulnar nerve (upper extremity) and the posterior tibial nerve (lower extremity) (Figure 1) were stimulated with 25 mA (upper extremity) and 50 mA (lower extremity). The referential montage was Fpz − Cv; Fpz − CP4; and CP3 − CP4 for the left upper extremities and Fpz − Cv; Fpz − CP3; and CP4 − CP3 for the right upper extremities. The referential montage for the lower extremities was Fpz − Cv; Fpz − CPz; and CP4 − CP3 (left) and Fpz − Cv; Fpz − CPz; and CP3 − CP4 (right). The repetition rate was set to 2.79 stimulations per second for both upper and lower extremities, and the pulse width was 200 μsec. Thirty-Hz low-frequency filters and 500-Hz high-frequency filters were used. Throughout the surgery, SSEPs from the operative leg were compared with the contralateral leg and baseline values. A decrease of 50% or higher in amplitude or an increase of 10% or higher in latency was considered as an alerting event that might point out toward a transient nerve injury. Any chance of an alerting event was immediately communicated by the neurophysiologist.

Spontaneous EMG activity was recorded from the quadriceps femoris muscle to monitor the femoral nerve, from the tibialis anterior, extensor hallucis longus, and short head of biceps femoris muscles for the peroneal nerve, and from the gastrocnemius and long head of the biceps femoris muscles for the tibial nerve (Figure 2). The time base for recordings was 15 ms/division (150 ms time base total). Filter settings were adjusted to 30 Hz for low frequency and 500 Hz for high frequency with up to 500-sweep average. Tibialis anterior and gastrocnemius EMGs from the nonoperative leg were obtained to serve as a control.

Figure 1



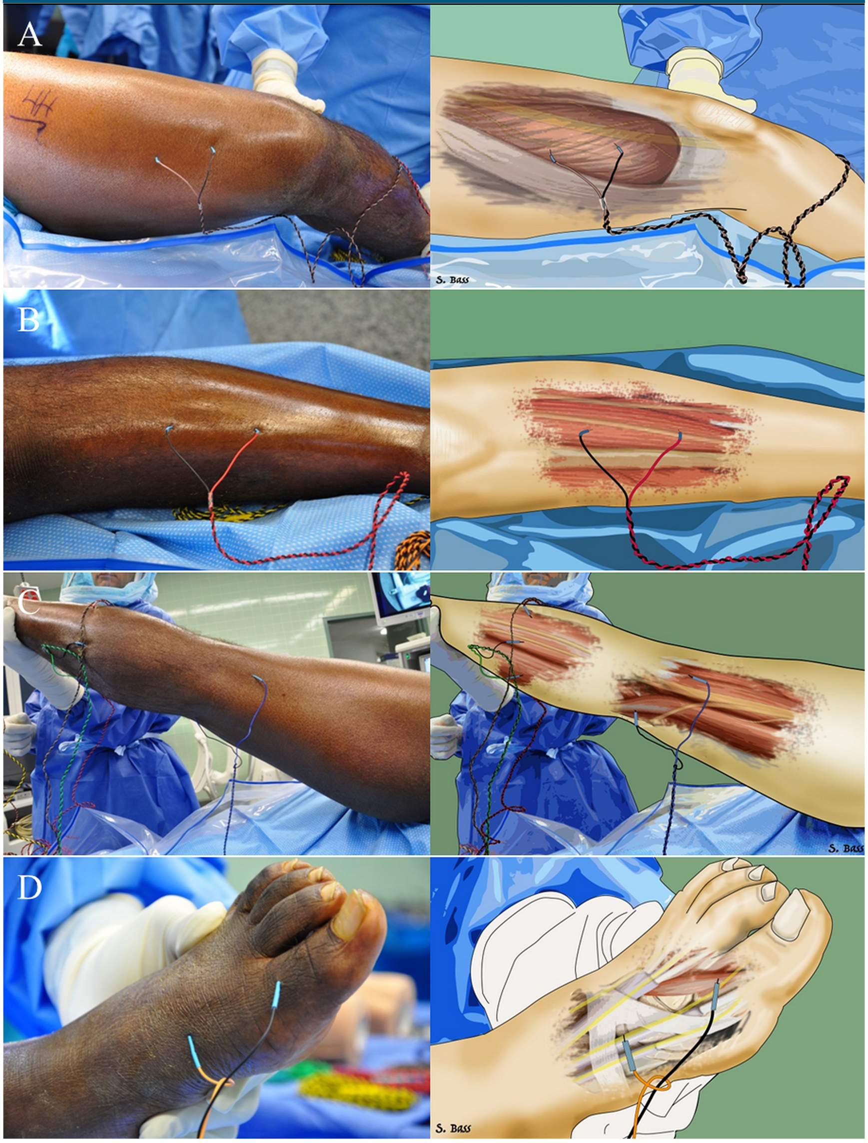
Subdermal needle electrodes were placed around the medial malleolus for stimulation (50 mA) of the posterior tibial nerve. After stimulation, somatosensory evoked potentials were recorded from the operative leg and compared with the contralateral leg and baseline values. A decrease of 50% or higher in amplitude or an increase of 10% or higher in latency were considered as an alerting event.

To monitor TcMEPs, stimulating transcranial electrodes were placed over C3 and C4. We used trains of 7 to 10 stimuli with a 75-μsec pulse duration and an interstimulus interval of 4 ms. Stimulation intensities ranged from 200 V to 500 V. The time base for recording was set to 12.5 ms/division (125 ms total time base). Transcranial motor evoked potentials were noted from the same muscle groups as EMG recordings (Figure 2) at the beginning of surgery, then routinely after surgical milestones, and after muscle relaxants wore off.

Surgical Technique

All surgical hip dislocations were performed by the same orthopaedic surgeon with extensive experience in hip preservation surgery. For each case, key surgical milestones were entered together with the corresponding time into the neuromonitoring log by the attending neurophysiologist. All patients underwent surgery in the lateral decubitus position on a radiolucent Jackson table and stabilized with Stulberg hip positioners. The surgical technique used was similar to that described by Ganz et al.[1] The modified Gibson approach was used, and trochanteric flip osteotomy was performed while protecting the vascularity of the femoral head (including the medial circumflex femoral artery and its branches). The capsule was dissected through the interval between the piriformis and gluteus minimus muscles. After the Z capsulotomy, the hip was dislocated anterosuperiorly with external rotation, adduction, and flexion maneuver. Intra-articular issues were appropriately addressed (eg, labral tear repair and osteochondroplasty) in each individual patient, while the leg was held in this position and gently manipulated with rotations and abduction/adduction and flexion/extension as needed. Meanwhile, double-angled Hohmann retractors and/or Steinman pins were placed around the superior aspect of the acetabular rim to allow for a complete visualization of the acetabulum and labrum. Of note, during this step, no retractors were placed near the sciatic or femoral nerve directly. After addressing the intra-articular issues appropriately (on a case-to-case basis), the hip was eventually relocated and the capsule repaired; the trochanteric fragment was positioned back on the femur and fixated with two 3.5-mm cortical screws, followed by layered closure of the wound without a drain.

Figure 2



Electromyography activity and transcranial motor evoked potentials were recorded from different muscle groups from the operative leg. The femoral nerve was monitored from the quadriceps femoris muscle (**A**). The peroneal nerve was monitored from the tibialis anterior (**B**), short head of the biceps femoris (**C**), and extensor hallucis longus (**D**) muscles. The tibial nerve was monitored from the gastrocnemius and long head of the biceps femoris muscles (**C**). Tibialis anterior and gastrocnemius recordings from the nonoperative leg served as a control.

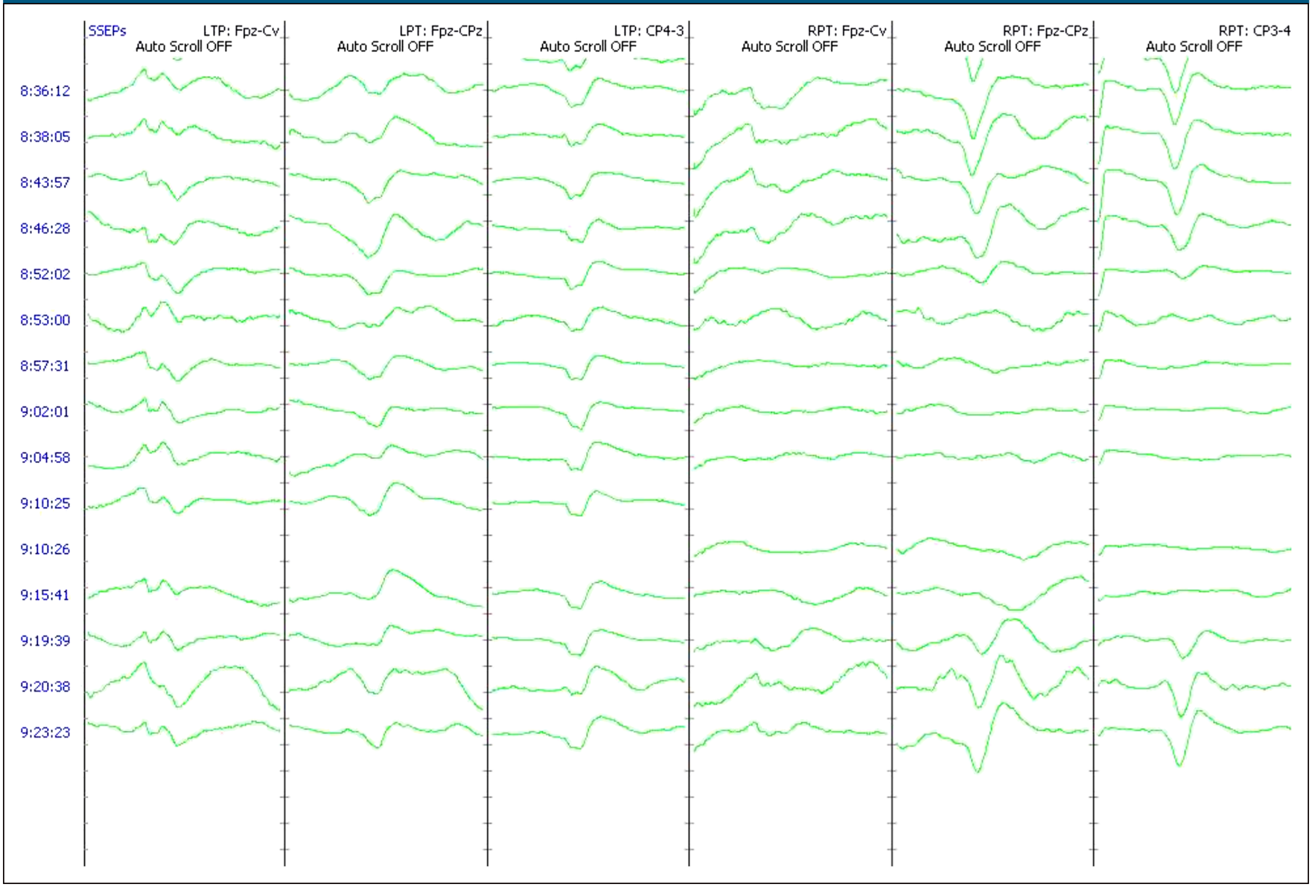
Baseline monitoring was obtained in all cases before initiating the surgical procedure. In the case of an alerting event during surgery, our approach was to initially quickly assess whether there were any nonsurgical factors, such as hypothermia, hypotension, other anesthesia-related factors, or technical issues with the neuromonitoring equipment, such as lead contacts, that could have biased the monitoring. If this initial checklist did not reveal a possible cause for the electrophysiologic changes and the event still existed, our approach was as follows: (1) best possible changes in limb positioning were undertaken to allow seamless continuation of the procedure as much as possible; (2) repositioning and adjusting the traction on retractors; and (3) relocation of the hip immediately or as quickly as possible as permitted from the steps/stage of the surgery.

The chief surgeon and the entire team never left the operating suite in any case until the IONM team had reestablished and reconfirmed the return of all the signals and monitoring to the baseline. After the surgery, each patient spent at least 1 night in the hospital and was seen by the attending surgeon immediately postoperative in the postanesthesia care unit, each day until discharge, and on a regular basis during the postoperative follow-up.

Results

The overall mean duration of surgery (incision to skin closure) was 112.4 ± 12.7 minutes (range, 78-178 minutes). The mean time interval between hip dislocation and hip reduction/relocation was 53 ± 11 minutes (range, 38-75 minutes). In 12 patients (48%; 10 women, 2 men), we noted a temporary change of neurophysiologic activity during surgery. Of these 12 patients, 10 (83.3%) showed a reduction of the amplitude of SSEPs in the operated leg while the hip was dislocated (Figure 3). The mean time interval between hip dislocation and the surgeon's notification of an alerting event by the neurophysiologist was 36.7 ± 13.9 minutes in these patients. After reduction of the hip, SSEPs returned to baseline within 6.7 ± 4.9 minutes (range, 1–17 minutes) in all 10 patients. Of note, in one of these patients, a decrease of the SSEPs occurred 23 minutes after dislocating the hip, which prompted an immediate reduction. Four minutes after the hip was reduced, SSEPs returned to baseline. After the second

Figure 3



Intraoperative somatosensory evoked potential (SSEP) recordings from a 38-year-old female patient who underwent open surgical hip dislocation due to a posttraumatic labral tear in her right hip. Twenty minutes after the hip dislocation, SSEPs from her right lower extremity were reduced (8:52:02). Four minutes after the hip was reduced, SSEPs returned back to baseline (9:19:39).

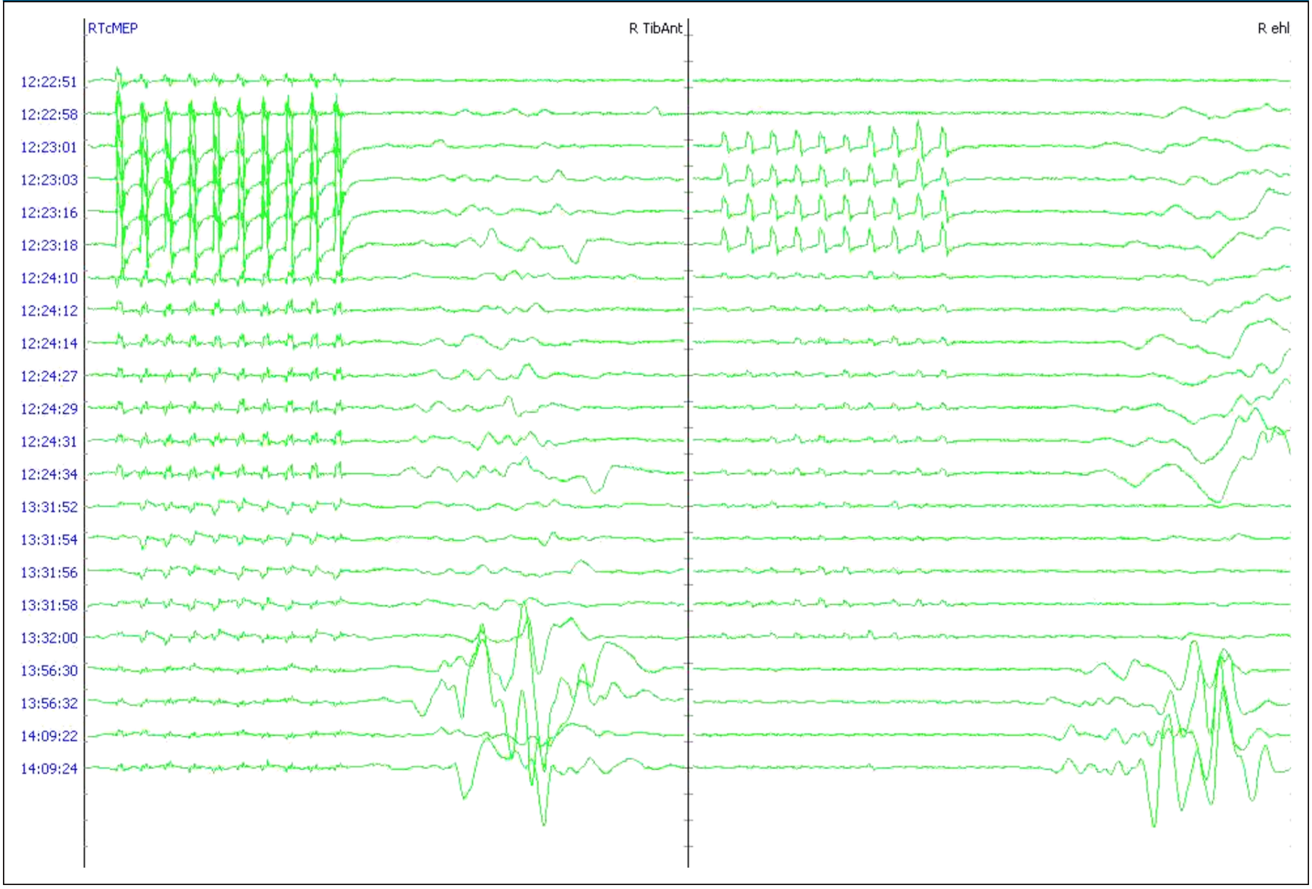
dislocation, SSEPs decreased again after 14 minutes and returned to baseline 5 minutes after the second reduction. In two patients (8%), we observed a reduction of the TcMEPs amplitude (Figure 4). In one patient, this was noted 44 minutes after the hip was dislocated and returned to baseline 29 minutes after the hip was reduced. In the second patient, a decrease of TcMEPs was seen 12 minutes after the hip was reduced while the screws for the greater trochanter osteotomy were placed. In this case, TcMEPs spontaneously returned to baseline after 15 minutes.

In all patients, SSEPs and TcMEPs had returned to baseline values at the end of the surgery, and no abnormal EMG pattern was observed. In none of these reported cases, any clinical neurologic deficit was noted at any time postoperatively. Notably, no complications concerning the neuromonitoring setup and needle placement (eg, infection, bleeding, abnormal scar formation) were noted.

Discussion

In this study, we report our intraoperative observations in 25 patients who underwent hip preservation surgery through safe surgical hip dislocation with IONM of the femoral and sciatic nerves to identify surgical steps and maneuvers that might place these structures at risk. None of the patients in this series had any direct injury to these nerves in the form of any true neuropraxia, axonotmesis, or neurotmesis. In 48% of the patients, we observed a transient change of neurophysiologic activity in the operated extremity, mostly related to positioning of the femur while addressing the intra-articular issues. Shortly after hip reduction/relocation (6.7 ± 4.9 minutes; range. 1–17 minutes), neurophysiologic activity returned to baseline. Before leaving the operating room, all monitoring signals were confirmed to be normal and at

Figure 4



Intraoperative transcranial motor evoked potential (TcMEP) recordings from a 42-year-old female patient who underwent open surgical hip dislocation due to femoroacetabular impingement with a labral tear in her right hip. Forty-four minutes after the hip dislocation, TcMEPs were reduced in the tibialis anterior muscle and (more pronounced) in the extensor hallucis longus muscle (13:31:52). Twenty-nine minutes after the hip was reduced, TcMEP returned back to baseline (13:56:30).

baseline, and no clinical neurologic deficits were observed postoperatively.

Although other complications, such as heterotopic ossifications, deep infections, and deep vein thrombosis, have been described more frequently, nerve injury (sciatic in particular) has been reported as a major complication after surgical hip dislocation.[3] Direct injury to the substance of the nerve is a complication and certainly should be avoided by the operating surgeon using all precautions during dissection and the use of bovie cautery and thermocautery, placement of retractor pins, and other instruments. In our study, none of the signal alterations was related to direct injury to the substance of the nerve or instrument pressure. We noticed that our observations of alterations in nerve function, despite all precautions to avoid direct nerve injury, occurred mainly due to leg positioning and possible nerve traction (occasionally nonphysiologic) during hip dislocation and positioning maneuvers. These findings are in accordance with similar observations during hip arthroscopy, where traction on the operated leg for purposes of hip subluxation and visualization of the joint with arthroscopy instruments can cause nerve injury or neurophysiologic events. Monitoring SSEPs, Ochs et al[13] observed alerting events (the same definition as applied in this study: decrease of 50% or higher in amplitude or an increase of 10% or higher in latency) in 54% of the reported 36 hip arthroscopies. Somewhat similar to our observations, after releasing the traction on the operated leg and allowing the hip joint to reduce/relocate completely, SSEPs returned to baseline within 11 minutes in 77% of their patients, which points toward the effects of acute traction lengthening of nerves on SSEP alterations.

Previously published experimental studies have suggested and postulated that an elongation of >6% is likely to cause nerve damage.[19] Given the fact that smaller individuals with shorter limbs may therefore have shorter nerve structures and hence less tolerance to total nerve lengthening, female patients (if shorter than their male counterparts) might generally be more prone to alerting events than male patients (10 versus 2 individuals in our study), although this is a hypothesis. In addition to the physical lengthening of the nerve, an animal study of Ogata and Naito[20] demonstrated that an average stretching of more than 15.7% caused a complete arrest of blood flow in the sciatic nerve. Of note, the recorded decrease in SSEPs in our study might also represent temporary signal change but were all reversible, likely nonischemic nerve changes.

Postoperative sciatic nerve damage has been associated with limb lengthening after total hip arthroplasty[21,22] in addition to other modalities of injury involved during the surgery. But such obvious changes in the anatomy are not alone likely to cause IONM alerts. In the study of Sutter et al,[11] 69 patients who underwent complex hip surgery (29 patients with complex hip replacement, 15 revision total hip replacements, 4 femoral osteotomies, 18 PAOs, 3 miscellaneous) were monitored intraoperatively by means of multimodal IONM. Alerting events were found in 28% of the complex hip replacement cases, 20% of revision total hip replacements, and 61% of PAOs. For PAO cases, 36.4% IONM alerts were associated with leg positioning, whereas the remaining cases were related to pelvic osteotomy or mobilization of the acetabular fragment.

We acknowledge several limitations of our study. With a sample size of 25 patients, this rather small study group does not allow for proof of reliability of IONM to predict permanent impairments of nerve function during this particular procedure, as sciatic nerve injury with postoperative deficiency in neuromuscular function has been described in <1% of cases after surgical hip dislocation.[3] Furthermore, as alerting events apparently seem to be dependent on leg positioning while the hip is dislocated, different surgical assistants (who were holding the legs during these cases) might have possibly biased our results. However, all surgeries were performed by one single surgeon, and efforts were made to ensure similar patient positioning during each case. Because of the need of muscle relaxants for endotracheal intubation, ease of dislocation and surgical exposures, and less tension on muscle structures, intraoperative EMG and TcMEP evaluation done during the usage of muscle relaxants might have been impaired. Until the relaxants wore off, SSEPs were the predominant predictor of nerve injury. However, evaluation of SSEPs are based on calculated averages that are recorded, and therefore, transient nerve injury might have sometimes occurred several minutes before notification.[23] In a study of Hilibrand et al,[24] changes in SSEPs were shown to occur with an average delay of 16 minutes after alterations in motor evoked potentials were noted. With respect to our findings, these results indicate that—in case of an alerting event—transient sciatic nerve injury might occur earlier than the average time of 36.7 ± 13.9 minutes that was noted in this study and should likely be considered as such in dealing with the event. However, because no patient exhibited a postoperative deficit in neuromuscular function, it seems unlikely that irreversible neurological injury had occurred at that point, that is, within the time span of an event in our patients.

In conclusion, this study demonstrates the feasibility and safety of IONM during surgical hip dislocation for hip preservation surgery in adults. This study certainly outlines the frequency of intraoperative events when monitoring changes are noticeable although not found to be clinically relevant in terms of sustained deficit. No surgeon expects or hopes to have any sustained event or deficit, and therefore any intraoperative marker or pointer that would help modify patient positioning, retractor placement, or point toward swifter completion of the remaining part of the procedure would always be appreciated by the operating surgeon, first assistant, and the entire operating team. Several young surgeons are working toward learning and mastering this procedure and approach. Irrespective of the surgeon's individual training and experience in this technically demanding procedure, IONM remains an effective modality of guidance and additional safety and prevention to help achieve the best possible outcome for each patient.

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