ORIGINAL ARTICLE

The Advantages of Using Intraoperative Neurophysiological Monitoring in Hip Surgeries: A Meta-Analysis.

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ABSTRACT

Various hip surgeries place peripheral nerves at risk of injury, such as those occurring during total hip arthroplasty, arthroscopic hip repair, and periacetabular osteotomy. In total hip arthroplasty, intraoperative neurophysiological monitoring (IONM) is focused on the sciatic nerve, which is particularly vulnerable due to its proximity to the surgical site. During arthroscopic hip repair, careful attention is paid to monitoring the femoral and lateral femoral cutaneous nerves to prevent traction and compression injuries. In periacetabular osteotomy, which involves cutting and realigning the hip socket, the primary focus of monitoring is on the sciatic and obturator nerves to minimize the risk of bone repositioning and fixation damage.

The use of IONM in hip surgeries is becoming increasingly popular to prevent neurological deficits associated with procedures such as total hip replacements and hip dysplasia corrections. This meta-analysis draws on data from 18 studies involving 522 patients, adhering to PRISMA guidelines, and utilizing techniques such as somatosensory evoked potentials (SEP), motor evoked potentials (MEP), electromyography (EMG), and train of four stimulation (TOF). The findings suggest that using multiple IONM techniques resulted in an alert rate of 61%, compared to 54% in single-modality IONM treatments. The results demonstrate that multimodal IONM improves the detection and prevention of nerve injuries, with combined modalities providing higher sensitivity and specificity than single-modality monitoring.

INTRODUCTION

Hip surgeries are a collection of medical procedures that aim to address various conditions that affect the hip joint. These procedures range from fixing acetabular fractures to total hip replacements, and they all aim to reduce pain and restore mobility in patients who suffer from hip-related ailments. Total hip replacements are done when a person experiences severe hip pain that impairs their regular activities (Figure 1). In this procedure, surgeons replace the damaged parts of the hip bone with implants. Hip arthroscopy, on the other hand, involves a surgeon using a small tubular instrument equipped with a camera to visually examine the hip joint, identify any trauma, determine the sources of pain, and assess any other lesions or abnormalities within the hip. The periacetabular osteotomy is another surgery used to treat hip dysplasia, which is an unstable hip joint caused by a hip socket that is too shallow. During this surgery, the hip socket is adjusted to stabilize the hip joint, and it is mostly done during a child's development. By 2006, the incidence of hip dysplasia in children was 1/1000 (0.001%), with 80% of affected children being female. In 2010, the incidence rate of total hip replacements in the United States was 0.83%, with an increase observed among females and individuals in older age brackets. Notably, for those aged 80 years and older, the incidence rate surged to 5.26% [1].

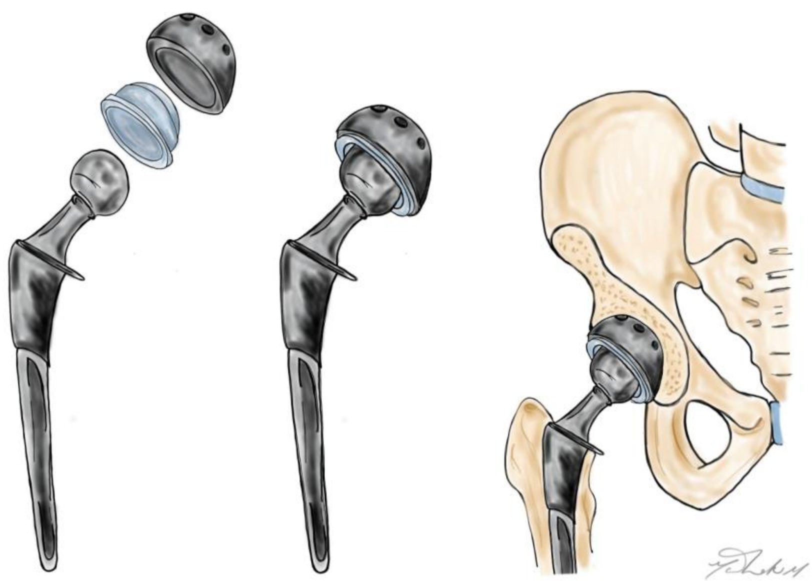

Figure 1. Left: Components utilized in a primary total hip replacement procedure. Middle: Integration of these components to form a cohesive implant. Right: Implant placement within the hip joint (Illustration by Mahek Mumtaz).

According to a study conducted in 2018, the incidence rate of hip arthroscopy in the United States was 13.54 cases per 100,000 patients [2]. It is important to note that if left untreated, a hip disorder can lead to several complications, including neurological deficits such as numbness, sciatica, weakness, paralysis, and other debilitating symptoms. In addition, patients undergoing surgical treatment for these disorders may be at risk of experiencing surgically induced neurological deficits. A recent study by Clement et al. (2020) revealed that during hip surgery, 5% of patients experienced irreversible postoperative neurological deficits related to the functional integrity of low-extremity peripheral nerves [3]. Another study by Kong et al. (2019) suggested that patients who had undergone previous hip surgery were more prone to post-operative nerve injury when monitoring femoral and sciatic nerves in total hip arthroplasty [4].

The use of Intraoperative neurophysiological monitoring (IONM) has become a widely accepted practice in the medical field to ensure the safety of nerves during surgical procedures. This technique provides surgeons with the ability to monitor neural pathways in real-time and evaluate the neurological function throughout the operation. With the integration of multimodality IONM techniques such as somatosensory evoked potentials (SEP), motor evoked potentials (MEP), electromyography (EMG), and train of four (TOF), distinct roles are played in identifying and preserving the integrity of neurological function in hip surgeries.

MATERIALS AND METHODS

Data Sources

This meta-analysis used PubMed, Google Scholar, and UT Dallas Eugene McDermott Library database sources.

Study Selection

Systematic reviews, narrative reviews, experimental studies, case-series studies, prospective and retrospective cohort studies, and observational studies were considered for examination. Only English language publications concerning the use of IONM in procedures involving the hip or pelvis were reviewed.

Search Strategies

Systematic searches were conducted using three databases from (dates of study range). Eight keywords were used for the search: sciatic nerve, palsy, hip, neuromonitoring, neurophysiology, pelvis, IONM, and femoral nerve.

Protocols and Registration

This meta-analysis was reported following the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) statement [5]. Figure 1 shows the PRISMA flowchart.

Intraoperative Neurophysiological Monitoring (IONM)

Somatosensory Evoked Potential (SEP)

The SEP stimulation electrodes are placed at the medial malleolus for the posterior tibial nerve and at the fibular head for fibular (peroneal) nerve stimulation (Figure 2 and 3). The saphenous nerve electrodes are placed at the medial surface of the tibia for monitoring [6] (Figure 4). Subdermal needle electrodes for recording are placed on the scalp according to the international 10-20 system at FPz, CPz, CP3, and CP4. Electrodes are also placed at Cv5 (cervical response), Erb's point (brachial plexus), and PF (popliteal fossa/peripheral response). Subdermal needle electrodes are placed at T12, L1, L2, and the contralateral iliac crest for recording lumbar potential (LP). A pulse width of 300 microseconds with an intensity of 15-25 milliamperes (upper extremities) and 40-100 milliamperes (lower extremities) is used for stimulation. A bandpass filter of 30-500 hertz, with a sweep of 50 milliseconds for the upper and 100 milliseconds for the lower limbs, is used

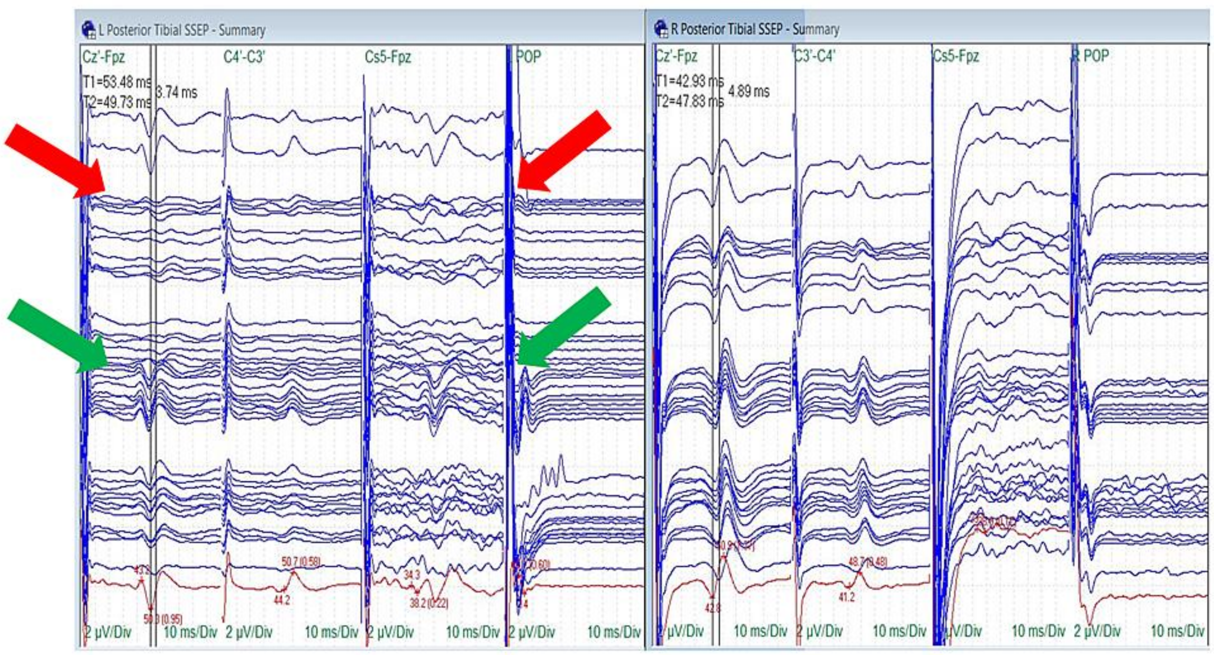

Figure 2. Posterior Tibial Nerve SSEP Stack. Loss (red arrows) and recovery (green arrows) of the ipsilateral posterior tibial nerve somatosensory evoked potentials (SSEPs) (cortical, subcortical, and popliteal fossa responses) with traction. The surgeon removed turns of traction to allow the SSEPs to recover. Electrode placement according to the international 10-20 system (Cz´: placed at CPz, C3´: placed at CP3, C4´: placed at CP4, Fpz placed at FPz), Cs5: placed at 5th cervical spine, POP: popliteal fossa, µV: microvolts, ms: milliseconds, Div: division [7].

for recording [8]. Alert criteria for nerve damage using SEPs involve a decrease in SEP amplitude of greater than 50% or an increase in the latency of SEPs of more than 10% from the baseline [9].

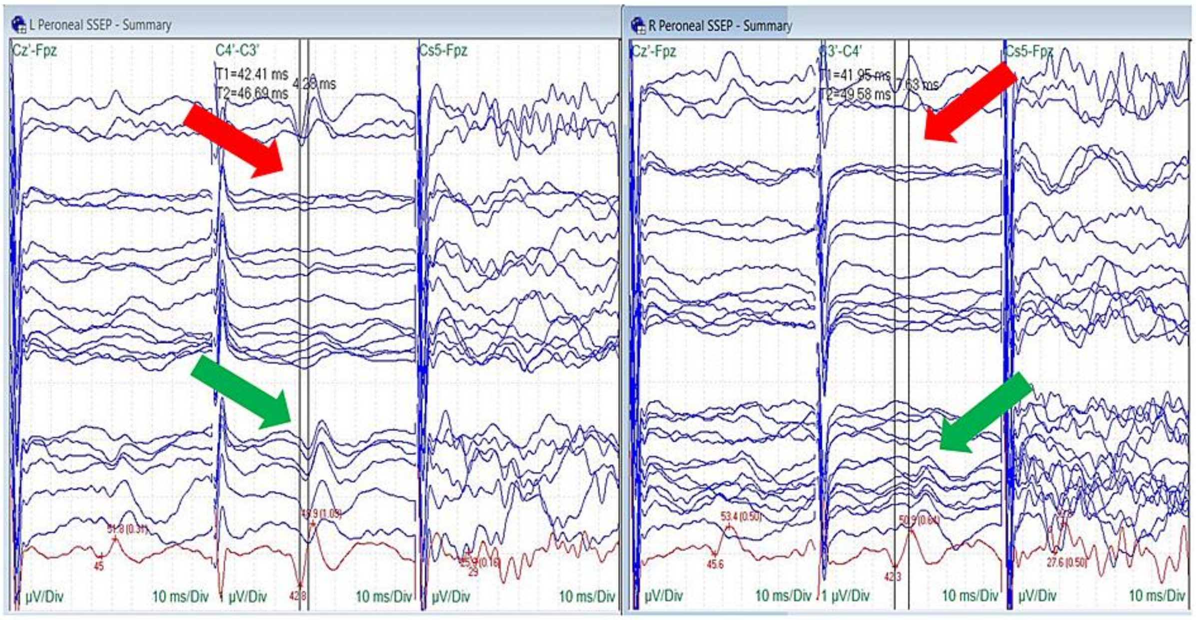

Figure 3. Peroneal Nerve SSEP Stack. Loss (red arrows) and recovery (green arrows) of the bilateral peroneal nerve somatosensory evoked potentials (SSEPs). Electrode placement according to the international 10-20 system (Cz´: placed at CPz, C3´: placed at CP3, C4´: placed at CP4, Fpz placed at FPz), Cs5: placed at 5th cervical spine, μV: microvolts, ms: milliseconds, Div: division [7].

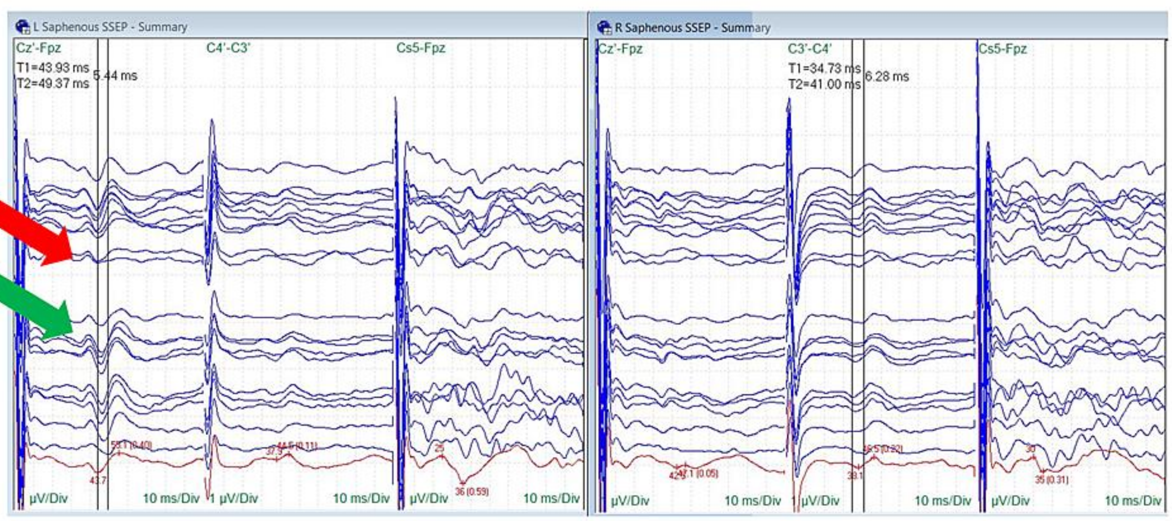

Figure 4. Saphenous Nerve SSEP Stack. Temporary amplitude decrease (red arrow) and recovery (green arrow) in ipsilateral saphenous nerve somatosensory evoked potentials (SSEPs) correlating with traction occurred in one surgery. The change occurred comorbidly with peroneal and posterior tibial nerve SSEP changes. Electrode placement according to the international 10-20 system (Cz´: placed at CPz, C3´: placed at CP3, C4´: placed at CP4, Fpz placed at FPz), μV: microvolts, ms: milliseconds, Div: division [7].

Electromyography (EMG)

The EMG is used to evaluate the electrical activity produced by skeletal muscles. Subdermal needle electrodes are placed in the lower extremity muscles for recording. Typically, the muscles used are the adductor brevis, quadriceps, tibialis anterior, gastrocnemius, and abductor hallucis (Figure 5). Handheld monopolar or bipolar probes can be used to stimulate the nerves during the triggered EMG (tEMG). Stimulation intensity gradually increased from 0.5 mA, reaching a maximum of 10 mA for nerve stimulation. A 200 microseconds pulse width with a 2-4 Hz repetition rate is used for stimulation. A band-pass filter of 10-5000 hertz with a recording of 100 milliseconds is used. The alert criteria are the presence of any abnormal EMG activity, such as train activity or neurotonic discharges [10].

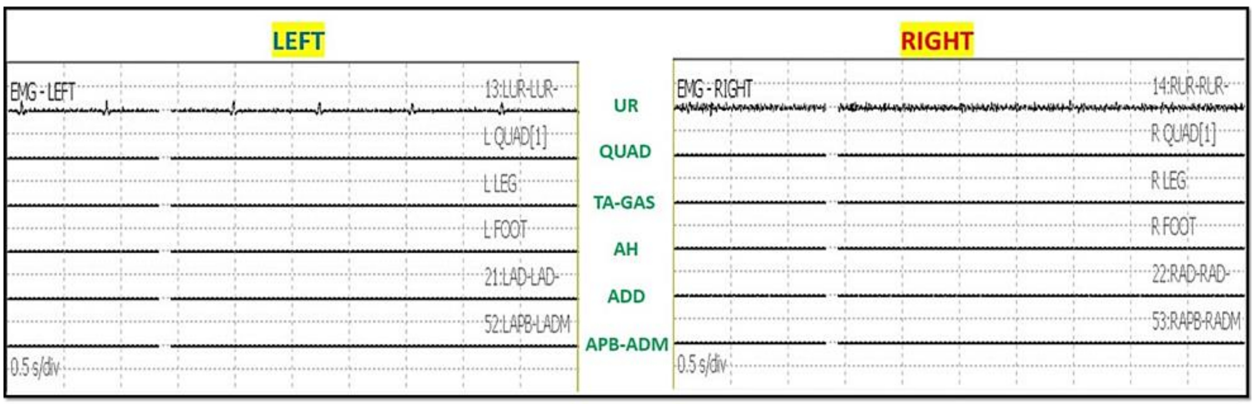

Figure 5. Electromyography (EMG). EMG was recorded from the upper extremities (control) and lower extremities at the baselines. No abnormal EMG signals were present at the baseline. UR: Upper Rectus Abdominis, QUAD: Quadriceps, TA: Tibialis Anterior, GAS: Gastrocnemius, AH: Abductor Hallucis, ADD: Adductor Magnus, Abductor Pollicis Brevis, ADM: Abductor Digiti minimi [11].

Train Of Four (TOF)

TOF stimulation assesses neuromuscular function during surgery, especially in patients under anesthesia with muscle relaxants. Stimulation parameters involve a monophasic square pulse (0.2 msec, 2 Hz, 4 pulses), with alert criteria requiring all four twitches present with less than 30% fade on T4. TOF compares T4 to T1 (Figure 6). Post-paralysis, facial muscles regain function first due to better vascular supply, followed by hands and feet [10]. It is recommended to stimulate the posterior tibial nerve at the medial malleolus and record from the abductor hallucis muscle in the foot for all cases[12].

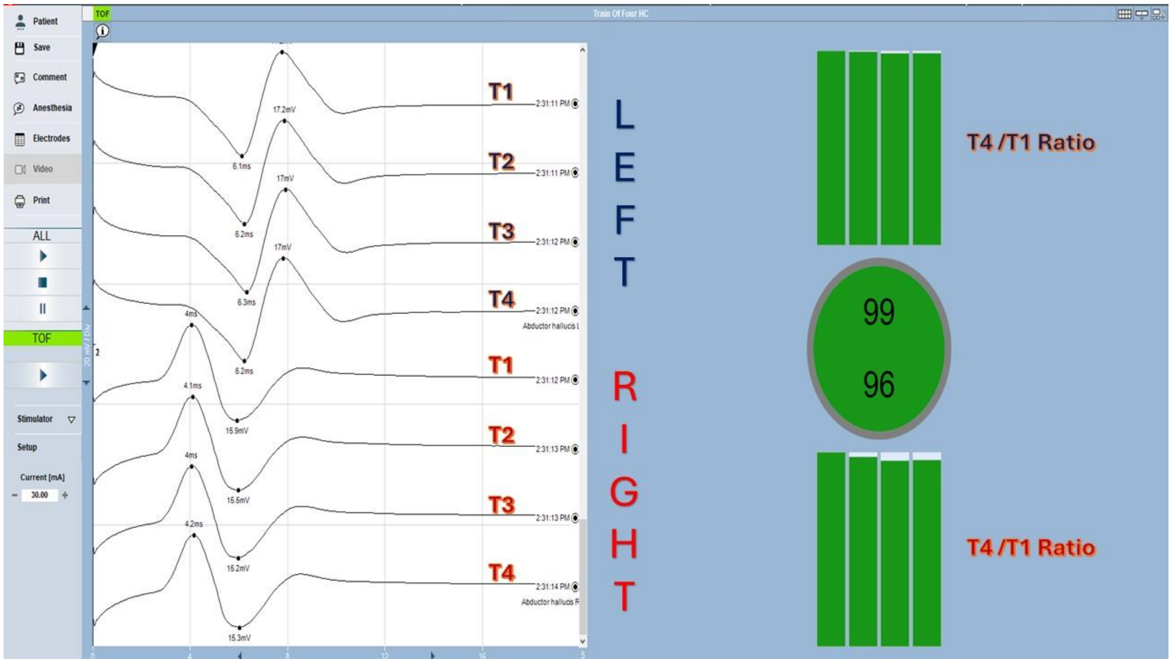

Figure 6. Train of Four (TOF). Bilateral TOF recordings at the baselines from the foot muscles (referenced Abductor Hallucis-Extensor Hallucis Brevis) lower extremities. Upper: left foot responses. Lower: right foot responses. AH: Abductor Hallucis, EHB: Extensor Hallucis Brevis. T1; Twitch 1, T2: Twitch 2, T3: Twitch 3, T4: Twitch 4. (Image by Faisal R. Jahangiri).

Motor Evoked Potentials (MEPs)

MEPs can be utilized during surgical procedures to assess the functional status of the corticospinal tract. These recordings can be obtained from the same muscles utilized for EMG, with stimulation corkscrew electrodes placed on the scalp using the international 10-20 system at C1, C2, C3, and C4 (Figure 7). It's important to note that MEP muscle responses are highly sensitive to inhalational anesthesia, and therefore require the use of total intravenous anesthesia (TIVA) without muscle relaxant. Stimulation parameters typically involve 5-7 pulses, an inter-stimulus interval (ISI) of 2.1-4.1-, and an 80-600 volts intensity. A band-pass filter of 10-5000 hertz with a recording sweep of 100 milliseconds is also employed. The MEP alert criteria consist of a 70-80% decrease in amplitude, a change in waveform morphology, or an increase in stimulation threshold of more than 100 volts [13].

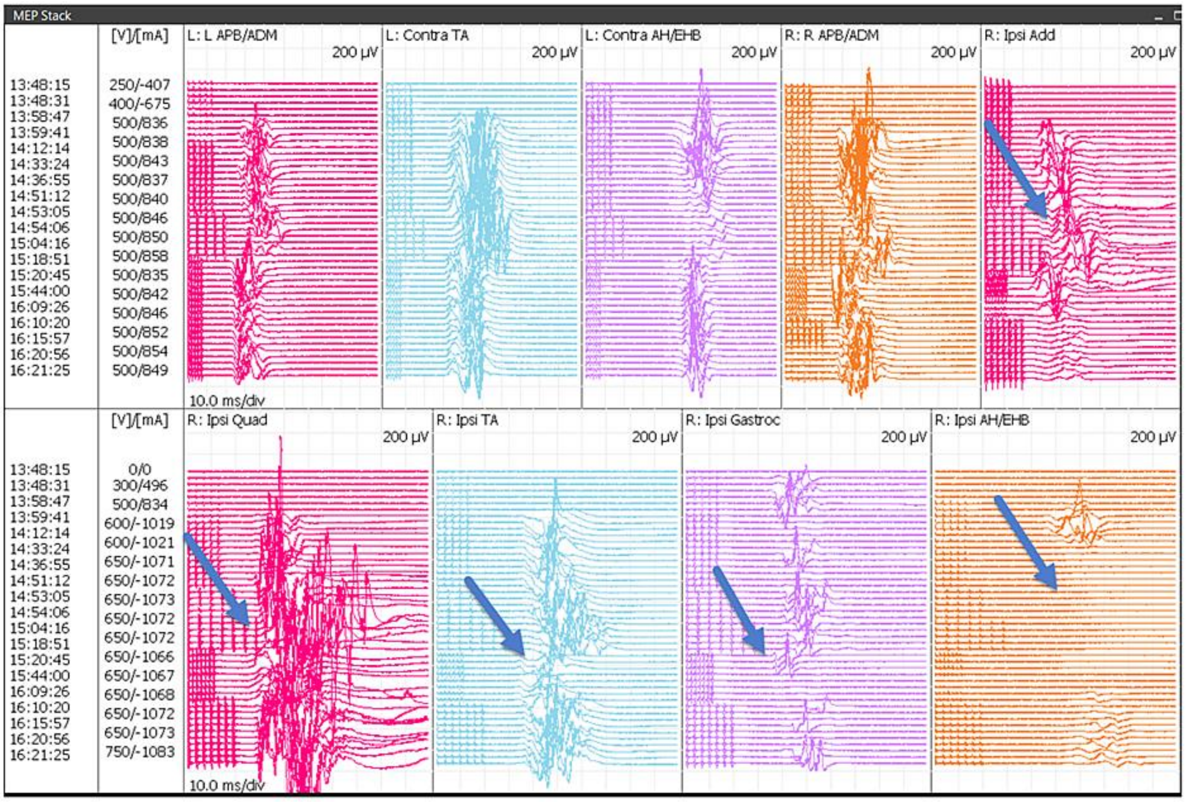

Figure 7. Bilateral Upper and Lower TCeMEP Stack. Transcranial Electrical Motor Evoked Potentials (TCeMEP) data showing loss and recovery of motor responses in the ipsilateral adductors, quadriceps, tibialis anterior, gastrocnemius, and abductor hallucis muscles (blue arrows). L: left, R: right, Ipsi: ipsilateral, Conta: contralateral, APB: abductor pollicis brevis, ADM: abductor digitiminimi, AH: abductor hallucis, EHB: extensor hallucis brevis, Add: adductor brevis, Quad: quadriceps, TA: tibialis anterior, Gastroc: gastrocnemius, V: volts, µV: microvolts, ms: milliseconds, mA: milliamperes, Div: division [7].

RESULTS

Inclusion Criteria

The PRISMA flowchart provides our paper's exclusion and inclusion criteria (Figure 8). To ensure relevance, papers not about IONM, hip surgery, or IONM in hip surgery were excluded, as well as any duplicates. Of the remaining papers, 18 met our criteria and were included in the flowchart. Our assessment included a total of 522 patients.

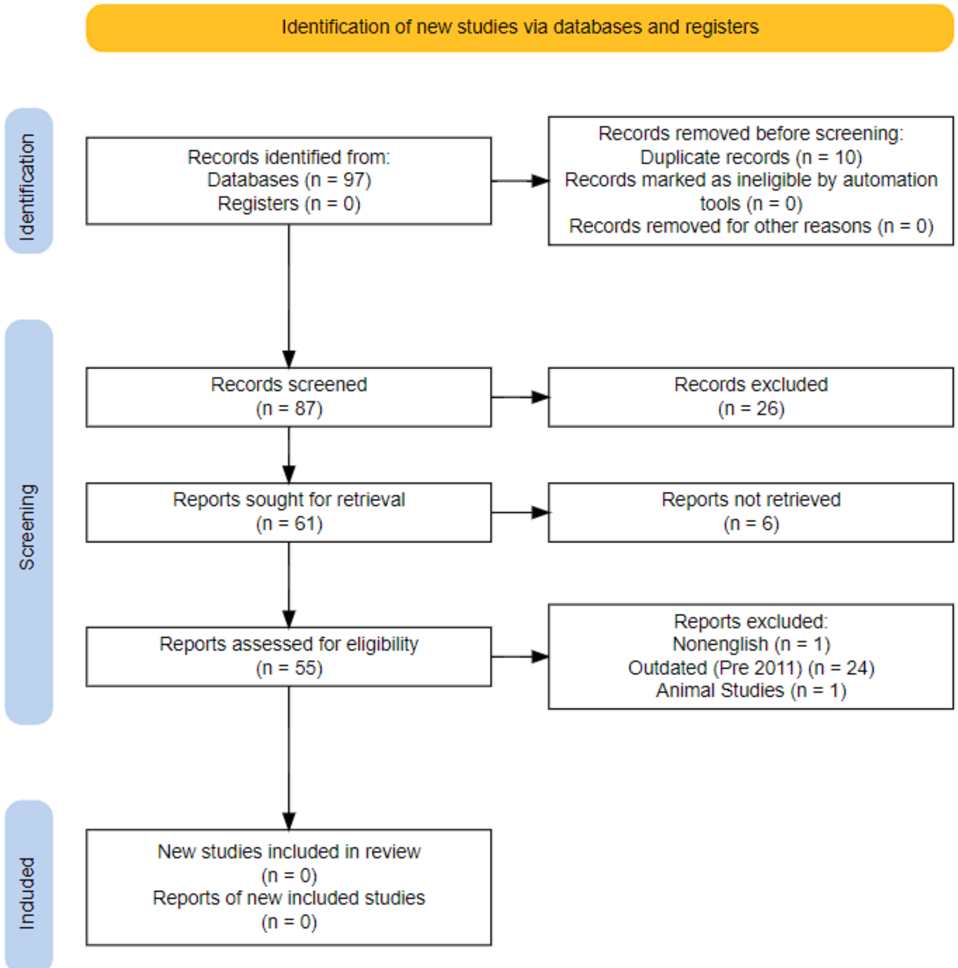

Figure 8. PRISMA Flow Chart.

Study Characteristics

The total cohort consisted of 522 patients, with 459 receiving IONM as part of their surgical procedure. The outcomes were assessed based on postoperative neurological deficits (Table 1). About 400 patients (76.6%) with IONM changes had postoperative recovery (Figure 9). Notably, 11 cases (2.1%) of permanent neurological deficits were reported across the entire cohort. The patients in our cohort underwent various hip procedures, including total hip arthroplasty (30.5%), arthroscopic hip repair (25.7%), periacetabular osteotomy (6.5%), and other hip surgeries (37.4%).

Study	Overall Sample Size (n)	IONM		Postoperative Deficits	
		Sample Size (n)	Technique Utilized	RECOVERED	PERMANENT
Bayram et al., 2020	16	16	SEP, MEP	N/A	N/A
Climent et al., 2020	100	100	SEP, MEP, f-EMG, ARMR, PRMR	95	5
Dikmen et al., 2019	20	20	ARMR, f-EMG	20	0
Gundogdu et al., 2023	10	10	EMG, f-EMG, TCeMEP, CMAP	10	0
Hesper et al., 2017	25	25	SEP, EMG, TCeMEP	25	0
Kong et al., 2019	91	35	N/A	85	6
Novais et al., 2017	34	34	SEP, EMG, TCeMEP	34	0
Ochs et al., 2012	35	35	SEP	N/A	N/A
Overzet et al., 2018	10	10	SEP, EMG, TCeMEP, TOF	10	0
Porat et al., 2013	60	53	SEP, EMG, TCeMEP	N/A	N/A
Shelton et al., 2022	89	89	SEP, EMG	89	0
Shemesh et al., 2017	9	9	N/A	9	0
Turan et al., 2023	23	23	SEP, MEP	23	0
Total	**522**	**459**	**N/A**	**400**	**11**

Table 1. Overview of the overall and IONM sample sizes, with the technique(s) utilized in each surgery, as well as outcomes regarding post-operative recovery (fully recovered cases and permanent deficits) [3-4, 13-23]. (SEP: somatosensory evoked potentials; MEP: motor evoked potentials; f-EMG: free-running electromyography; ARMR: anterior root muscle response; PRMR: posterior root muscle reflex; TCeMEP: transcranial motor evoked potentials; CMAP: compound muscle action potentials; TOF: train-of-four). (Created by Salam Ayyoub).

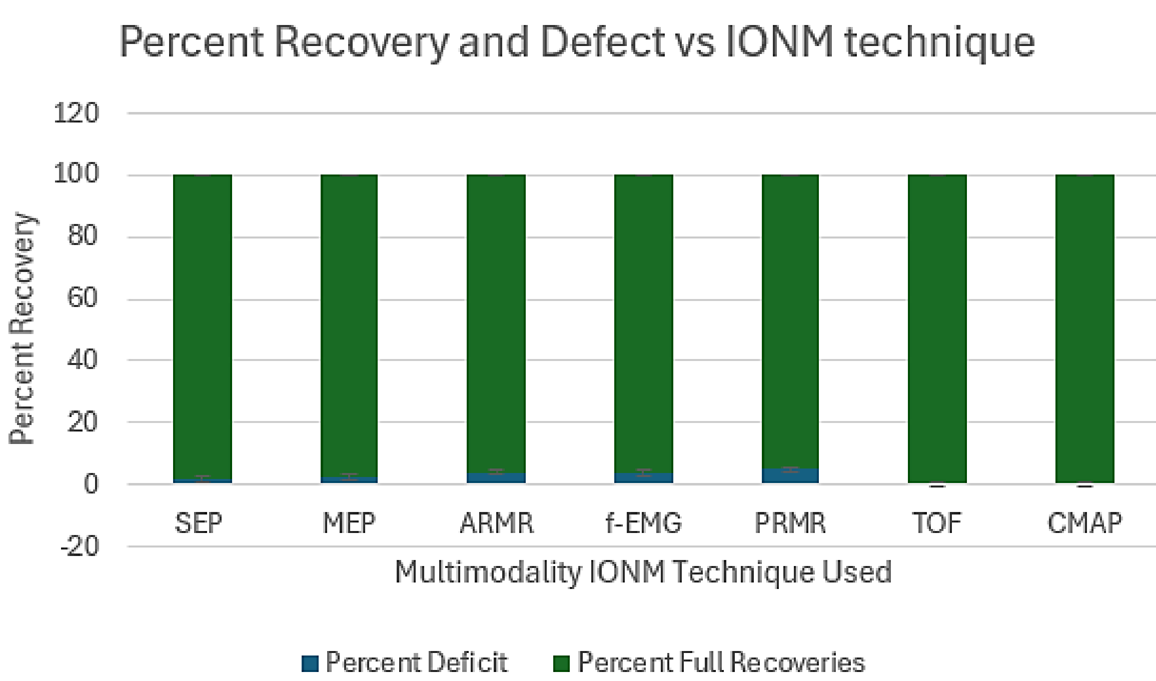

Figure 9. Overview of percent recoveries in hip surgery patients following particular multimodality IONM techniques. [3-4, 14-26]. (SEP: somatosensory evoked potentials; MEP: motor evoked potentials; ARMR: anterior root muscle response; f-EMG: free-running electromyography; PRMR: posterior root muscle reflex; TOF: train-of-four; CMAP: compound muscle action potentials). (Created by Rishab Parapperi and Salam Ayyoub).

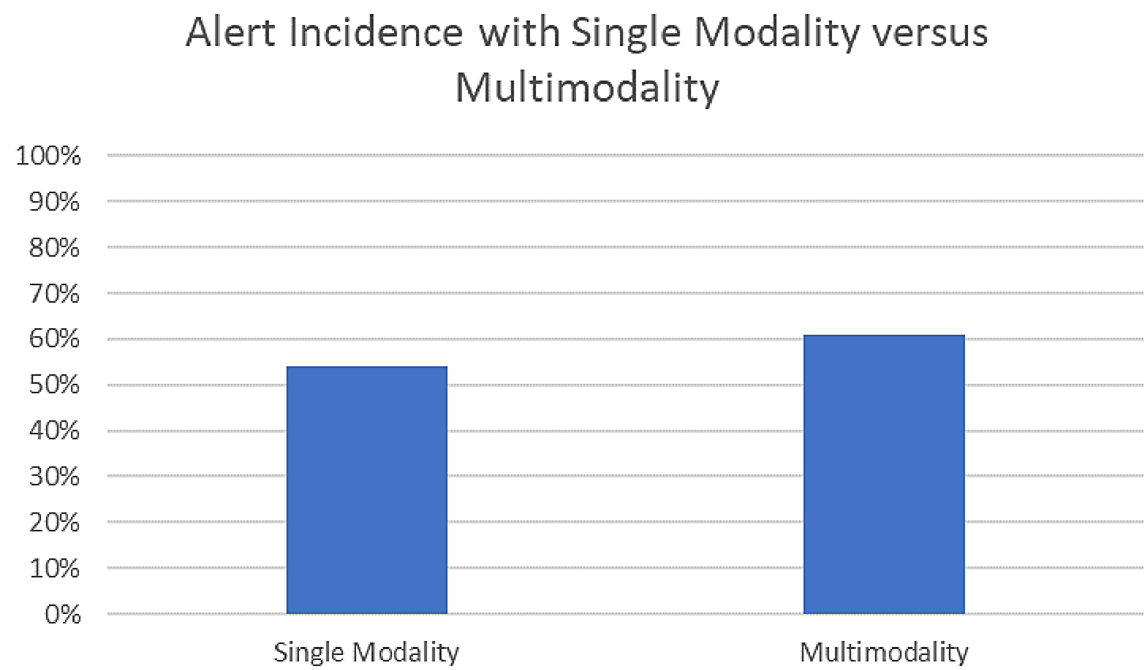

Figure 10. Comparison of the alert incidence in single versus multimodality IONM. [17-18]. Created by Rishab Parapperi and Salam Ayyoub).

Data Analysis

Based on the studies, most patients who received multimodality intraoperative neuromonitoring (IONM) experienced complete recovery from post-surgery neurological deficits. However, recovery outcomes varied depending on the specific modality used. The recovery rates reported for each modality were as follows: 98.2% for SEP, 97.5% for MEP, 95.8% for Anterior Root Muscle Response (ARMR), 96.2% for f-EMG, 95% for Posterior Root Muscle Reflex (PRMR), and 100% each for TOF and CMAP (as illustrated in Figure 3). These results suggest that multimodality IONM procedures can lead to high recovery rates in patients undergoing surgery (Figure 8-10). Moreover, when multimodality IONM was used, which explicitly includes EMG, SEP, and TCeMEP, 61% of cases had alerts during surgery. In contrast, when only SEP was used in the single-modality approach, there was a 54% incidence of alerts (Figure 10).

DISCUSSION

Intraoperative neurophysiological monitoring (IONM) comprises several modalities that play a critical role in preserving neural function and guiding surgical decision-making. Sensory evoked potentials (SEPs) evaluate the functional status of sensory pathways, while motor evoked potentials (MEPs) assess the integrity of motor pathways. Electromyography (EMG) focuses on skeletal muscle activity, detecting electrical potentials to gauge muscle function and integrity. While SEPs and MEPs provide insights into sensory and motor pathways, respectively, EMG offers real-time monitoring of muscle activity, aiding in identifying nerve injury or compression during surgery.

The use of IONM has expanded to other surgical specialties, including orthopedics and trauma surgery. For example, hip surgeries, which encompass a range of procedures from arthroscopic interventions to total hip replacements, often benefit from IONM due to the inherent risks to nearby neural structures. During hip surgeries, the sciatic nerve courses near the hip joint, and any accidental damage can lead to debilitating complications such as lower limb weakness or sensory deficits. Similarly, the femoral nerve, responsible for motor function and sensation in the anterior thigh and knee, is susceptible to injury during hip surgeries. The proximity of these vital nerves underscores the significance of employing IONM in these procedures.

In a study conducted by Porat et al. (2013), the efficacy of different modalities of IONM in detecting impending nerve injury during pelvic and acetabular fracture fixation surgery was compared. The modalities that were investigated included MEPs, peroneal nerve SEPs, and EMGs. The study involved 60 patients who underwent operative fixation for pelvic or acetabular fractures. Of these, 53 patients were monitored, with the primary focus on safeguarding sciatic nerve function. The study revealed that MEP monitoring was the most reliable modality, with 100% sensitivity and 86% specificity in detecting neurological compromise. Peroneal nerve SEPs showed a sensitivity of 75% and a specificity of 94%. However, EMG monitoring, either alone or in combination with SEPs, was found to be unreliable, with a sensitivity of only 20%. It is recommended that a multimodality neuromonitoring approach using TCeMEP and SEPs is effective in detecting impending nerve injury during pelvic and acetabular surgery. EMG monitoring alone is not recommended due to its low sensitivity and inability to assess nerve function accurately. [22]

Two significant studies highlight the efficacy of IONM in total hip arthroplasty for developmental dysplasia of the hip (DDH), specifically Crowe types 3 and 4 hips. IONM has shown promising outcomes in preventing nerve palsy and reducing the need for femoral shortening osteotomy, which traditionally aimed to prevent nerve injury. In a study by Kong et al. (2019), IONM identified ten nerve alerts during total hip arthroplasty, leading to no neural complications post-operatively, unlike the control group where six patients experienced neural complications. Although not statistically significant, the monitoring group trended towards lower nerve injury rates, underlining the potential benefit of IONM in reducing nerve injury risk during total hip arthroplasty for DDH patients [4]. Similarly, in a different study by Turan et al. (2023), IONM was routinely employed in total hip arthroplasty procedures for Crowe types 3 and 4 hips, resulting in no nerve palsy occurrences post-operatively in the study cohort. Remarkably, only a fraction (13%) of the hips required femoral shortening osteotomy, suggesting that IONM helped avoid additional surgical interventions aimed at preventing nerve injury [25].

Two comprehensive studies were conducted to investigate the use of IONM during hip arthroscopy. The studies revealed significant findings regarding postoperative complications and the effectiveness of a multimodality approach. Overzet et al. (2018) conducted the first study, which demonstrated that during anterior arthroscopic hip surgeries, SEP changes were prevalent in the sciatic, peroneal, and posterior tibial nerves. However, recoveries were observed in most cases, indicating the utility of SEPs as an indicator of nerve integrity during traction. The study also recorded EMG activity in various nerves, which showed minimal post-operative deficits. The second study by Shelton et al. (2019) focused on pediatric patients undergoing hip arthroscopy and revealed that SEP changes >50% occurred in the peroneal and posterior tibial nerves in most cases, alongside EMG activity indicating nerve stimulation [22]. Clinical neurapraxia occurred in nearly 20% of patients, but it resolved within days post-operatively. Longer surgery and traction times were associated with higher neurapraxia rates.

CONCLUSION

Incorporating multimodal intraoperative neurophysiological monitoring (IONM) techniques, including SEPs, MEPs, and EMG, has been shown to significantly enhance the detection and prevention of nerve injuries in various hip surgeries. Studies have demonstrated that utilizing a combination of these methods can achieve sensitivities and specificities as high as 100% and 86%, respectively. These findings highlight the superiority of a multimodal approach over single-modality monitoring. For instance, in surgeries for pelvic and acetabular fracture fixation, the multimodality approach utilizing MEPs and SEPs has proven effective in identifying impending nerve injury, whereas EMG alone was found to be unreliable. Furthermore, in the case of hip arthroscopy, combining SEPs and EMG has facilitated real-time assessments, allowing for immediate corrective actions, and reducing the incidence of post-operative neurological deficits, ultimately leading to improved patient outcomes.

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