The incidence of Positioning-Related Intraoperative Neurophysiological Monitoring (IONM) Changes: A Review of 5894 Surgeries

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Abstract

Introduction: Patient positioning during various surgeries may cause stretching, compression, or ischemia of the peripheral nerves. Upper extremity nerves are more at risk, resulting in postoperative neuropathy. Somatosensory Evoked Potentials (SSEPs) and Transcranial Electrical Motor Evoked Potentials (TCeMEPs) can be beneficial in identifying positioning issues. Repositioning the limb can prevent nerve damage from occurring.

Methods: We retrospectively reviewed 5894 surgeries performed with neuromonitoring from 2016 through 2018 (52% female, 48% male). We utilized a multimodality approach including two or more of the following: SSEPs, TCeMEPs, and Electromyography (EMG).

Results: IONM data changes related to positioning were identified in 209 patients (female: 78, male: 131) with ages ranging from 19 to 86 years (median: 59 years). The incidence of positioning changes was 3.5% for all procedures. The signals returned to baseline with repositioning in 78% of the surgeries. Positioning changes occurred in 27.3% of hip, 5.1% of lumbar, 2.5% of thoracic, 2.2% of craniotomy, and 1.5% of cervical surgeries. The highest incidence of change was observed in upper SSEPs (86.7%), followed by lower SSEPs (5.7%), upper TCeMEPs (3.8%), lower TCeMEPs (1.9%), spontaneous EMG (1.4%), and upper TCeMEP and SSEP (0.5%) data. We observed that 82.3% of the changes identified were in upper SSEPs during lumbar surgery.

Conclusions: Multimodality IONM is a protective tool against neuropathy and positioning complications during various surgical procedures. Early identification of changes in signals can detect positioning issues. We highly recommend monitoring upper SSEPs for lumbar surgery due to the correlated incidence rate. The use of IONM to detect changes can minimize post-operative neurological deficit by repositioning.

Keywords: Positioning; Brachial Plexopathy; Ulnar Nerve Injury; Neuropathy; Intraoperative Neurophysiological Monitoring

Introduction

The proper positioning of the patient for surgery is vital for optimal operating site exposure and the patients' safety. Improper positioning can lead to complications such as perioperative peripheral nerve injury (PPNI) and postoperative visual loss (POVL) [1]. Contributors to PPNI include peripheral nerve stretch resulting in ischemia of nerve fibers and peripheral nerve compression. Ulnar neuropathy and brachial plexus injury are common sites of PPNI. In a study by Welch., et al. orthopedic (21%), general (18%), neurological (8.9%) and cardiac (7.1%) surgeries were related to PPNI [2]. Somatosensory Evoked Potentials (SSEP) and Transcranial Electrical Motor Evoked Potentials (TCeMEP) are common modalities used for Intraoperative Neurophysiological Monitoring (IONM) in orthopedic and neurological surgery to detect peripheral nerve conduction abnormalities caused by malposition, thus preventing PPNI [3,4].

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Injury type

Ischemia is a pathologic process in axonal injury, hyperesthesia, and Wallerian degeneration in animal models [5]. Nerve fiber ischemia due to nerve conduction slowing is one of the primary causes of PPNI. Sustained ischemia can result in permanent PPNI. Peripheral nerve stretch and compression also contribute to PPNI in perioperative patients. Positions, such as the prone (Superman) position, can stretch peripheral nerve fibers beyond their normal length. This promotes axon and vasa nervorum disruption. Compression may cause perfusion pressure reduction by increasing intraneural/extraneural pressure [6].

Injury site

Reports of PPNI is more common in the upper extremity than the lower extremity. Ulnar nerve injury consists of 28% of all anesthesia associated nerve injury malpractice, while brachial plexus injury makes up 20% [7]. Patients with ulnar nerve injuries often lose the ability to abduct or oppose the fifth digit and experience sensation loss on the fourth and fifth digits. This can occur with delayed onset two to seven days postoperatively. Compression and stretch of the ulnar nerve or median nerve can provoke brachial plexus injury. Posterior shoulder displacement, shoulder abduction greater than 90 degrees, and external arm rotation can hyperextend the brachial plexus [6].

High-risk factors

Middle-aged males have a higher tendency to develop PPNI. Certain positions, such as prone and lateral decubitus, have a higher incidence of upper extremity nerve injury than supine positions with the arms tucked or out and prone positions with the arms tucked [8]. Placing an axillary roll under the chest may decrease the incidence of brachial plexus injury. Patients with a history of upper extremity nerve injury are more prone to PPNI. Diabetes, hypertension, and tobacco use are the top three pre-existing patient history risk factors related to PPNI [2].

Intraoperative neurophysiological monitoring (IONM)

A neurologic injury such as PPNI secondary to positioning is a frequent cause of patient injury during various surgeries including but not limited to orthopedic and neurological surgeries. In a study by Welch, et al. sensory neuropathies were more common than motor neuropathies [2]. SSEPs and TCeMEPs are reproducible, reliable during surgical procedures and are a vital tool for identifying positioning changes and preventing injury. SSEPs and TCeMEP are routinely used during surgeries to detect changes in electrophysiological conduction, if not corrected intraoperatively may lead to nerve damage. The brachial plexus function during surgeries is monitored during surgeries more commonly by SSEPs than TCeMEPs for minimizing any position-related nerve injuries [9,10].

Anterior cervical spine decompression and fusion

IONM can detect spinal cord and peripheral nerve conduction changes, and guide position adjustments pre-incision. Hyperextension of the neck with shoulder rolls in patients with instability, severe stenosis, and myelopathy may cause a loss of conduction in the central cord. Baseline signals should be recorded prior to the placement of a shoulder bump or tape on the shoulders. In one study, the right upper extremity SSEP amplitude decreased by more than 50% prior to incision. Further evaluation revealed that the right shoulder was tightly taped to the table. The tape was released, and the SSEP signal returned to baseline values. This may have prevented the right arm from developing neuropraxia [11]. In another case report, upper extremity SSEPs and TCeMEPs deteriorated after the tape was placed on the shoulders. The surgeon was notified, and the tape was removed completely. SSEPs and TCeMEPs recovered, and at two-months follow-up, the patient's upper extremity function was normal [12].

Lumbar spine procedures

Upper extremity SSEPs are helpful to detect positioning related changes due to brachial plexus injuries in lumbar spine procedures with the ability to localize and differentiate between the central and peripheral pathways. Several case studies have demonstrated that including SSEP monitoring of upper extremities is valuable to detect and prevent vascular and neural compromise of brachial plexus

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in lumbar spine surgery. Changes detected by upper and lower extremity SSEPs facilitate examination of the patient’s position and repositioning. This reposition can prevent postoperative neurological deficits [3].

Scoliosis

Ulnar nerve SSEP monitoring prevents impending brachial plexopathy during surgical scoliosis correction. In a study by Schwartz, et al. 18 limbs (15 patients) out of 500 patients presented with a significant reduction in the ulnar nerve SSEP. Arms or shoulders were repositioned, and no PPNI was reported postoperatively. One patient underwent scoliosis correction without neuromonitoring, and pressure on the axilla from the positioning frame induced brachial plexopathy [13].

Methods

Patient population

We retrospectively reviewed 5894 surgeries performed with neurophysiological monitoring from 2016 through 2018. This study was performed to identify the frequency and cause of positioning changes by utilizing multimodality IONM. The IONM data was collected by experienced neurophysiologists under the direct supervision of licensed neurologists via real-time monitoring. All the surgeries in which intraoperative positioning changes were documented were reviewed. In 209 patients (female: 78, male: 131) with ages ranging from 19 to 86 years (median: 59 years) IONM data changes related to positioning was identified. Procedures that did not involve monitoring for positioning changes such as thyroids and parotids were not included in this data. Out of the 5894 surgeries, 3157 were lumbar, 2350 were cervical, 237 were thoracic, 139 were craniotomy, and 11 were hip procedures.

Anesthesia protocol

The anesthetic regimen included Total Intravenous Anesthesia (TIVA) or a mix of inhalational agents and intravenous agents. A short-acting neuromuscular blocking agent was used for intubation in all patients. A train of four (TOF) monitoring technique was utilized by stimulating the posterior tibial nerve and recording from the corresponding abductor hallucis muscles [14]. A TOF of 4/4 was obtained and maintained after intubation for all the procedures with TCeMEP and EMG monitoring.

Intraoperative neurophysiological monitoring

We utilized a multimodality approach including two or more of the following: SSEPs, TCeMEPs, and Electromyography (EMG). A Train of Four (TOF) monitoring technique was also utilized by stimulating the peripheral nerve and recording from the corresponding hand or foot muscles to assess the level of muscle relaxation [14]. IONM methods for each procedure varied based on neural structures at risk and surgeon preferences. Typical monitoring consisted of bilateral SSEPs from the ulnar and posterior tibial nerves, sometimes also utilizing median, peroneal, and saphenous nerves, upper and lower extremities TCeMEPs, spontaneous EMG from the upper and lower extremities, and TOF testing [4]. Data for all procedures were recorded by the Cadwell Cascade Pro (Cadwell Industries Inc, Kennewick, WA, USA) and by the Medtronic E4 NIM-Eclipse (Medtronic, Inc., Minneapolis, MN, USA) IONM systems.

Somatosensory evoked potentials (SSEPs)

Stimulation surface adhesive electrodes or subdermal needles were placed at the wrists for ulnar nerve or median nerve SSEPs, and at the medial ankles for posterior tibial nerve SSEPs. Peroneal nerve SSEP electrodes were placed at either the dorsal surface of the foot or at the fibular head. Saphenous SSEPs were stimulated at the medial thigh with 19 millimeters (mm) subdermal electrodes. A supramaximal electrical stimulation (ulnar: 15 - 25 mA; median: 15 - 40 mA; posterior tibial: 40 - 100 mA; peroneal: 40 - 100 mA; saphenous: 20 - 75 mA), was used for SSEP stimulation. Subdermal 13 mm needle electrodes were placed for SSEP recordings on the scalp at FPz, CPz, CP3, CP4, and Cs5 (5th cervical spine vertebra). Recording electrodes were placed at Erb’s point, and the Popliteal Fossa (PF) for SSEPs as well (Figures 1 and 2). To alert the surgeon about a possible intraoperative neurophysiological change, the SEP alarm criteria was set to a 10% increase in the latency and/or 50% decrease in the amplitude.

Transcranial electrical motor evoked potentials (TCeMEPs)

Corkscrew or subdermal needle electrodes were placed on the patient’s scalp at C1, C2 and/or C3, C4 for TCeMEP stimulation. A train stimulation of 3 - 9 pulses was utilized (120 to 600 volts, pulse width 50-75 µsec). For TCeMEP and EMG recordings, 13 mm subdermal...
needle electrodes were placed bilaterally in the muscles of the upper extremities (trapezius, deltoid, biceps, triceps, flexor carpi radialis, abductor pollicis brevis and abductor digituminim) and muscles of the lower extremities (adductor brevis, vastus lateralis, rectus femoris, tibialis anterior, gastrocnemius, and abductor hallucis). Longer needle electrodes were often used for the quadriceps muscles ranging from 18 mm to 37 mm to ensure that the electrode reached the muscle (Figure 3). The alarm criteria used for TCEMEP was a combination of 70% or more decrease in amplitude, change in the morphology and/or change in the stimulation threshold of 100 Volts (V) or more [15,16].
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Figure 3: Stack display of Transcranial electrical Motor Evoked Potentials (TcMePs) recorded from right upper and lower extremity muscles. Recording electrodes were placed in trapezius (TRAPEZIUS), deltoid (DELTOID), biceps brachii (BICEPS), abductor pollicis brevis-abductor digitominimi (APB/ADM), and abductor hallucis (AH) muscles of the arms and legs. The red arrow representing a loss of TcMePs in hand muscles (APB/ADM) whereas blue arrow represents a return of TcMePs after arm repositioning. The data was recorded during an anterior cervical discectomy and fusion procedure.

Results

The total patients consisted of 52% females and 48% males. We identified 209 out of 5894 total surgeries with changes in neurophysiological data due to patient positioning. Of the 209 patients, 78 were female (37%), and 131 were male (63%) with ages ranging from 19 to 86 years (median: 59 years) (Figure 4). The total incidence of positioning effects was 3.5% for all procedures. The incidence rate for males was higher (4.6%) compared to females (2.6%).

Figure 4: Positioning related neurophysiological data changes with sex distribution. The female patients were more than males but the incidence rate for males was higher at 4.6% as compared to females at 2.6%.

The signals returned to baseline with repositioning in 78% of the surgeries (Figure 5). In the majority of the 22% remaining patients the signal did not return to the baseline because the changes occurred near the end of the surgical procedure. The recovery time was delayed in patients depending on the severity of the injury and presence of any associated medical conditions (such as, diabetes mellitus, hypotension, arteriosclerosis, multiple sclerosis, chronic alcoholism, and pernicious anemia). The total percentage of patient population for each surgery type was 53.5% in lumbar, 39.9% in cervical, 4% in thoracic, 2.4% in craniotomy and 0.2% in hip procedures. Of the 209 patients who demonstrated positional neurophysiological data changes, 77.5% were identified in lumbar, 16.8% in cervical, 2.9% in thoracic, 1.4% in hip, and 1.4% in craniotomy surgeries. The highest incidence of change occurred in upper SSEPs (86.7%), followed by lower SSEPs (5.7%), upper TCeMEPs (3.8%), lower TCeMEPs (1.9%), spontaneous EMG (1.4%), and upper TCeMEP and SSEP (0.5%) data (Figure 6).

**Figure 5:** Graph showing the percentage of signals returned to the baseline. In 162 patients (78%) the changes in the neurophysiological data returned to the baseline. In the remaining 47 patients (22%) data either partially recovered or did not return to baseline.

**Figure 6:** The incidence of positioning changes by each modality in 209 patients.
Of the 209 cases with positional changes, 82.3% were identified in upper SSEPs during lumbar surgery. The incidence of upper SSEP changes in different surgical procedures was distributed as 72.9% in posterior lumbar; 8.3% in anterior cervical; 5% in 360 lumbar; 3.9% in posterior cervical; 2.8% in thoracic; 2.2% in lateral lumbar; 2.2% in anterior lumbar; 1.7% in craniotomy; 0.6% in 360 cervical and 0.6% in hip surgeries (Figure 7). The incidence of upper SSEP changes was also analyzed by incidence specific to each surgery type. In summary, upper SSEP changes observed were 9.09% in hip; 4.73% in the lumbar; 2.16% in craniotomy; 2.11% in thoracic; and 0.98% in cervical surgeries (Figure 8 and Table 1).

Discussion

It has been identified and documented that the improper position of the arm and shoulder can result in brachial plexopathy while the patient is positioned on the operating table for surgery. This study identifies the incidence of possible position related neurophysiological...
changes in various surgical procedures. There are various factors that may lead to changes in neurophysiological data intraoperatively, such as, a decrease in Mean Arterial Pressure (MAP), hypothermia, changes in CO₂ levels, increase in intracranial pressure (ICP), increase in depth of anesthesia, muscle relaxants, technical or equipment related problems, etc.

Each patient data was reviewed in detail. To confirm the neurophysiological changes were due to patient limbs or shoulder malpositioning all other causes were ruled out. The factors identified that were responsible for nerve stretch and/or compression and caused the position related data changes under general anesthesia were obesity, tape on shoulders, additional traction of brachial plexus due to tucking of the upper limbs, exaggerated abduction of limbs, pressure on nerves, etc. Identifying the position related IONM data changes and allowing the patients’ limbs to naturally rest or reposition can lead to the complete or partial recovery of the neurophysiological data.

Various studies have reported the incidence of intraoperative position related nerve injuries during various surgeries. In 1973, Parks reported an incidence of brachial plexopathy in 38% of cases [17]. In 1990, Kroll, et al. reported anesthesia-related nerve injuries with ulnar neuropathy at 33% followed by brachial plexus injuries at 23% [18]. Cheney, et al. also reported ulnar neuropathy and brachial plexopathy as the two major categories of anesthesia-related nerve injuries [7]. Other studies have also reported position related peripheral nerve injuries due to improper positioning, ischemia of the nerve fibers, peripheral nerve stretching, and compression [1,2,5]. Intraoperative SSEP and TCeMEP changes due to positioning related peripheral nerve injury to the brachial plexus have been reported in the literature [12,19].

In 2006, Schwartz, et al. reported a higher incidence in males than females and described an injury to the brachial plexus as the most frequent cause of position related changes in SSEP and TCeMEP data. The second most frequent cause reported was neck extension for proper surgical positioning [9]. In our study, males had a 63% incidence compared to 37% in females.

This study demonstrated the benefits of utilizing a multimodality IONM method for identifying and preventing possible position related nerve injuries in different types of surgical procedures. It shows the importance of timely identification in SSEP and TCeMEP changes and quick intervention with repositioning of the limbs. This can aid in the full recovery of the IONM data and prevent any possible postoperative neural deficits.

Conclusions
Intraoperative multimodality IONM is a protective tool against neuropathy and positioning complications during various surgical procedures. In our study, there were 209 surgeries (3.5%) with intraoperative events. These 209 cases changed the course of the surgical procedure and prevented possible post-operative deficits. We highly recommend monitoring upper SSEPs for lumbar surgery as well as other surgeries for position related neuropathies. Neurophysiological monitoring must be started as early as possible and should be continuously performed during all stages of the surgical procedures to identify any changes in IONM data immediately. Early identification of changes in SSEP, TCeMEP, and sEMG signals during surgery can detect positioning issues. This allows for intraoperative repositioning, thus minimizing any post-operative neurological deficits.

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