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Assessing The Role of Intraoperative Neurophysiological Monitoring (IONM) in Preserving Pelvic Floor Integrity During High-Risk Surgeries

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Introduction: Neural injuries during gynecological, urological, colorectal, and spinal surgeries affecting pelvic structures can result in life-altering dysfunction affecting bladder, bowel, and sexual health. Intraoperative neurophysiological monitoring (IONM) is a promising approach to mitigate surgical risks. In this systematic review with meta-analysis following PRISMA guidelines, we hypothesized that IONM could reduce postoperative deficits, maintain pelvic functions, and enhance improvement rates for high-risk procedures.

Methods: A systematic review of databases, including PubMed, ScienceDirect, and Scopus (1965-2024), was conducted per PRISMA guidelines. Studies were included if they reported post-operative outcomes in human subjects undergoing relevant surgeries, with at least ten patients per study. Case reports, conference abstracts, animal studies, and non-English publications were excluded. The IONM search included terms like "external urinary sphincter monitoring," "bladder EMG," "bladder motor evoked potential," "BCR," and "pudendal nerve SSEP." The non-IONM search encompassed keywords such as "hysterectomy," "colorectal surgery," "cauda equina surgeries," and "tethered cord release."

Results: Statistical analysis focused on spinal-related procedures due to insufficient comparative data in urological, colorectal, and gynecological subsections. Analysis included 771 patients, 482 receiving IONM, and 289 without IONM. Chi-square testing showed statistically significant variations in outcome distributions ($p < 0.0001$ for improvement, baseline maintenance, and deterioration). The odds ratio of 0.32 shows that IONM patients were 68% less likely to improve postoperatively, an unexpected finding requiring interpretation. Odds ratio for baseline function was 4.42, indicating that IONM patients were over four times more likely to maintain baseline function. IONM correlated with a 67% reduction in neurological deterioration risk.

Discussion: Our findings confirm that multimodality IONM is reliable for preserving neural function during high-risk surgeries. Lower improvement rates likely reflect its application in complex cases. Significant literature gaps persist regarding standardized pelvic-specific IONM protocols; future research is necessary.

INTRODUCTION

Quantifying the prevalence of neural injuries during surgeries involving delicate pelvic structures is challenging, but the impact can be significant. Even a small percentage of individuals affected by these injuries may face life-altering consequences, making it a critical concern in various surgical disciplines.

Surgical interventions in the pelvic region pose substantial risks to neural structures that control essential physiological functions, often leading to pelvic floor dysfunction (PFD). This condition affects urination, bowel movements, and sexual function. The pudendal nerve (S2-S4) regulates sphincter control and perineal sensation, with iatrogenic injury resulting in incontinence and sexual dysfunction [1]. The sacral plexus (L5, S1-S4) supports major pelvic neural pathways, and damage can lead to pelvic pain, lower limb weakness, and loss of bladder or bowel control [2]. The hypogastric (T12-L3) and pelvic splanchnic (S2-S4) nerves regulate autonomic functions, and their injury may result in voiding difficulties, constipation, and sexual dysfunction[3]. Managing these postoperative deficits often requires long-term interventions, such as transurethral catheterization, which increases the risk of infection and daily discomfort.

It is crucial to understand how these intraoperative injuries occur to minimize postoperative complications. Common mechanisms include direct surgical trauma, such as nerve transection or crush injury, stretch-related neuropathy from prolonged retraction, and ischemic damage due to vascular compromise [4].

To minimize surgical complications and post-operative deficits, Surgical teams enhance preparations through pre-operative imaging, such as MRI, and post-operative rehabilitation to mitigate these issues. Among these various forms of preventative measures, intraoperative neurophysiological monitoring (IONM) is a promising field that employs established techniques such as electromyography (EMG) and evoked potentials (EP), including somatosensory evoked potentials (SSEPs) and motor evoked potentials (MEPs with real-time feedback. These monitoring modalities enable continuous functional assessment of neural activity, improving detection of injuries and reducing intraoperative risks[5]. While its usage is essential for evaluating sensory and motor pathway integrity during neurosurgical and spinal procedures, such standard techniques require modification for pelvic operations due to the complex interactions between somatic and autonomic nerves involved.

Pelvic autonomic nerves, such as the hypogastric plexus, cannot be directly assessed with standard SSEPs. Consequently, modified techniques such as pudendal nerve SSEPs and MEPs for external urethral sphincter (EUS) and external anal sphincter (EAS) have been developed for functional assessment during pelvic surgeries [5]. Customization includes adapting traditional neuromonitoring approaches to accommodate the distinctive nerve structures within the pelvis. While EMG effectively monitors somatic nerve activity through compound muscle action potentials (CMAP), it cannot assess autonomic nerves controlling smooth muscle function [5].

To address this limitation, researchers have developed advanced techniques combining smooth muscle EMG with bladder manometry for intraoperative evaluation of pelvic autonomic nerves. These approaches involve direct nerve stimulation with simultaneous measurement of internal anal sphincter (IAS) responses and bladder pressure changes. Unlike conventional EMG, which detects rapid muscle contractions, this modified technique evaluates slow, wave-like contractions characteristic of smooth muscle, enhancing detection accuracy for pelvic autonomic nerves[6].

Despite such promising advances, pelvic-specific IONM still remains underutilized due to significant methodological challenges. Electrode placement in the pelvis is often difficult, and real-time monitoring is complicated by interference from adjacent anatomical structures. Limited awareness of pelvic neuromonitoring techniques among surgical teams results in inconsistent implementation. Financial constraints, including costs of specialized equipment and trained neurophysiologists, further restrict widespread adoption[7]. Addressing these barriers through standardized guidelines, advanced training, and enhanced technology is essential to maximize IONM efficacy for pelvic operations and improve patient outcomes.

Considering this, this systematic review will address the significant gap in literature by exploring the potential of Intraoperative Neurophysiological Monitoring (IONM) to preserve pelvic floor nerve integrity during surgery. We hypothesize that IONM can reduce postoperative nerve deficits, maintain essential functions, and enhance recovery rates. To test this, we conducted a comparative analysis of surgical outcomes with and without IONM and performed chi-square statistical testing.

The findings may contribute to developing a structured framework for improving clinical guidelines and enhancing individual patient outcomes.

MATERIALS AND METHODS

Study Design

This systematic review with meta-analysis followed PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. No a priori sample size calculation was performed, as is standard for systematic reviews which analyze all eligible literature meeting inclusion criteria. Statistical analysis included chi-square testing and odds ratio calculations to compare outcomes between IONM and non-IONM groups.

The literature search was conducted between January and April 2025, examining studies from PubMed, ScienceDirect, and Scopus published between 1948 and 2024. We conducted separate searches for intraoperative neurophysiological monitoring (IONM) and non-IONM studies using distinct keyword lists.

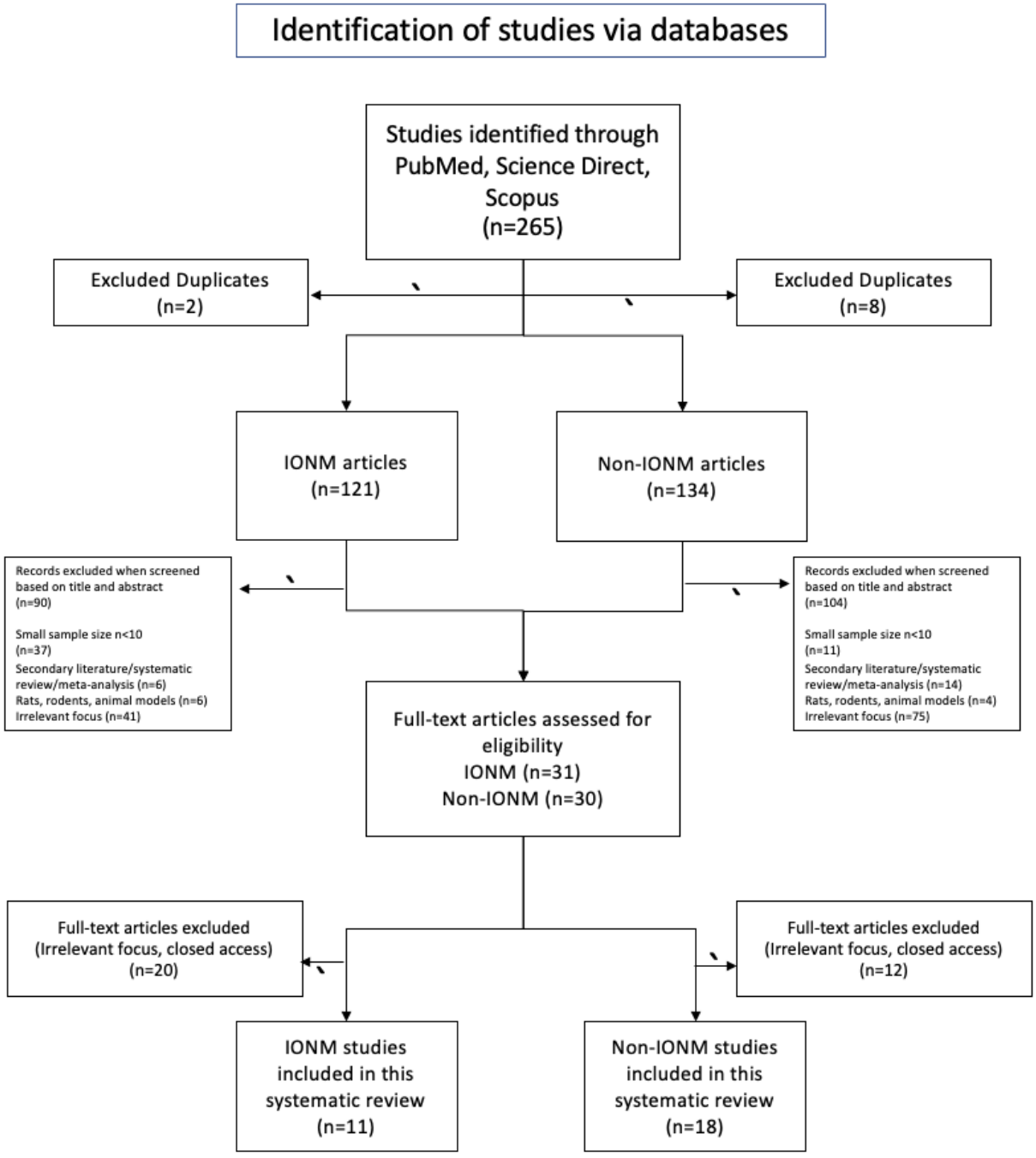

Figure 1. PRISMA Flow Diagram Study selection process showing identification, screening, eligibility assessment, and final inclusion of articles in this systematic review.

The IONM search included “external urinary sphincter monitoring,” “bladder EMG,” “bladder motor evoked potential,” “BCR,” and “pudendal nerve SSEP.” The non-IONM search used “hysterectomy,” “colorectal surgery,” “cauda equina surgeries,” “tethered cord release,” “pre-operative,” and “post-operative.”

All included surgeries were conducted by fellowship-trained neurological and orthopedic spine surgeons, with neuromonitoring performed by board-certified neurophysiologists. Eligible studies involved human subjects undergoing colorectal, gynecologic, urologic, or spinal surgeries that could cause neurogenic bladder dysfunction, pudendal nerve damage, or pelvic floor-related neurological defects. Studies had to report post-operative clinical outcomes to compare IONM and non-IONM groups. To be included in the IONM group, neuromonitoring had to be a key component of the procedure. Only English-language studies with at least ten patients were considered.

We excluded systematic reviews, meta-analyses, case reports, conference abstracts, and studies using animal models. This review follows PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.

Anesthesia Protocol

Anesthesia is a crucial factor for successful pelvic neuromonitoring. Both neurophysiological signals like MEPs and BCR are sensitive to anesthetic drugs. The recommended technique for these procedures is the utilization of total intravenous anesthesia (TIVA) with agents. Another key factor is neuromuscular blockade management. Since EMG and MEP monitoring require intact neuromuscular transmission, muscle relaxants must be carefully managed. Additionally, the required utilization of Train of Four (TOF), monitors and records the abductor hallucis muscle to assess the depth of muscle relaxation. A 4/4 response must be ensured throughout the procedure.

Overview of Pelvic Intraoperative Neuromonitoring (pIONM)

Pelvic intraoperative neuromonitoring (pIONM) has emerged as an inestimable technique to aid surgeons in identifying and protecting pelvic nerves during procedures, thereby reducing postoperative neurological deficits. Potential postoperative deficits include urogenic issues, loss of bladder control, sexual dysfunction, and bowel control. Modern pelvic intraoperative neuromonitoring (pIONM) is a multimodal approach to surgical procedures, including gynecological, urological, colorectal, and spinal surgeries. Several neurophysiological modalities are used to monitor pelvic nerve integrity are as follows:

Somatosensory Evoked Potentials (SSEPs) assess the integrity of sensory (afferent nerves) pathways. Motor Evoked Potentials (MEPs) evaluate the integrity of motor pathways (efferent signals from motor cortex) function. Free running and Triggered Electromyography (EMG) detect nerve injury through electrical responses from muscles, either spontaneous or response to stimulation. The Bulbocavernosus Reflex (BCR) assesses the sacral spinal reflex which monitors the S2-S4 pathway. These various neuromonitoring modalities are implemented across many surgical procedures to preserve pelvic floor functionality.

Somatosensory Evoked Potentials (SSEPs)

Somatosensory Evoked Potentials (SSEPs) are utilized during pelvic procedures to evaluate the integrity of peripheral nerves in the pelvic region[8]. For the upper extremity, the ulnar nerve is stimulated at the wrist of the patient to assess signal conduction from the arm to the somatosensory cortex. For the lower extremity, the posterior tibial nerve is stimulated at the ankle to evaluate sensory integrity from the leg up to the somatosensory cortex[8]. Lastly, the pudendal nerve, located near the perianal area, is stimulated to evaluate the conduction from the sacral spinal cord to the somatosensory cortex. Electrical stimulation is applied percutaneously or transcutaneous in the perianal area via the pudendal nerve. Critical SSEP recording sites are identified by applying the 10-20 system. Primary cortical somatosensory sites include Cz'-Fz for cortical recording points and Cpi-CPc for transcortical recording [9]. Subcortical recording sites are located at FPz- Cv5, while the lumbar potential is located around T11/T12 or L2-IC and is not affected by anesthesia. For posterior tibial nerve SSEPs only, a recording at the popliteal fossa is used. In certain circumstances, alternative recording sites may be placed near the sacral nerves if necessary.

Table 1A

Stimulation Parameters for SSEP

Study	Pulse Width (µs)	Stimulation Rate (Hz)	Sweep (ms)	Locut (Hz)	Hicut (Hz)
Chen et al., 2010	N/A	N/A	N/A	N/A	N/A
Fan et al., 2024	N/A	N/A	N/A	N/A	N/A
Jahangiri et al., 2019 (1)	[1]Standard	[1]Standard	[1]Standard	[1]Standard	[1]Standard
Jahangiri et al., 2019 (2)	[1]Standard	[1]Standard	[1]Standard	[1]Standard	[1]Standard
Lee et al., 2009	N/A	N/A	N/A	N/A	N/A
Lim et al., 2024	N/A	N/A	N/A	N/A	N/A
Menezes et al., 2021	N/A	N/A	N/A	N/A	N/A
Sarkar and Rajshekhar, 2021	N/A	N/A	N/A	N/A	N/A
Steinbok et al., 1995	N/A	N/A	N/A	N/A	N/A
Vissarionov et al., 2018	N/A	N/A	N/A	N/A	N/A
Yang et al., 2024	N/A	N/A	N/A	N/A	N/A

Table 1A. Stimulation Parameters for Somatosensory Evoked Potentials (SSEPs). Technical specifications for SSEP stimulation across all included studies, including pulse width (µs), stimulation rate (Hz), sweep time, locut filter (Hz), hicut filter (Hz). (Table created by Sam Ayyoub).

Note: [1]Standard indicates standard protocol parameters where specific values were not reported in the original publication.

Recommended stimulation parameters for SSEPs require a pulse duration of 100-300 ms and a repetition rate at a required 2.66-3.79 Hz. Stimulation intensity varies among nerves: 15–75 mA for the pudendal nerve, 10–20 mA for the ulnar nerve, and 100–400 mA for the posterior tibial nerve [10]. Recording parameters require a mandatory 100 ms (10 ms/div) sweep. A Locut filter at 10 Hz, a Hicut filter at 5000 Hz, and the notch filter deactivated. The dynamic range, also known as input gain, should be set to 10-20 uV/div, and sensitivity set between 0.5-2 uV/div for maximum neuronal potential detection.

Table 1B

Recording Parameters for SSEP

Study	Locut (Hz)	Hicut (Hz)
Chen et al., 2010	N/A	N/A
Fan et al., 2024	N/A	N/A
Jahangiri et al., 2019 (1)	[1]Standard	[1]Standard
Jahangiri et al., 2019 (2)	N/A	N/A
Lee et al., 2009	N/A	N/A
Lim et al., 2024	N/A	N/A
Menezes et al., 2021	N/A	N/A
Sarkar and Rajshekhar, 2021	N/A	N/A
Steinbok et al., 1995	N/A	N/A
Vissarionov et al., 2018	N/A	N/A
Yang et al., 2024	N/A	N/A

Table 1B. Recording Parameters for Somatosensory Evoked Potentials (SSEPs). Technical specifications for SSEP recording across all included studies, including locut filter (Hz), and hicut filter (Hz). (Table created by Sam Ayyoub).

Note: [1]Standard indicates standard protocol parameters where specific values were not reported in the original publication.

Clinical Relevance

SSEP neuromonitoring is an indispensable modality in protecting neurological functionality during pelvic procedures. This modality aids in evaluating the integrity of the afferent sensory pathway from the pudendal nerve to the somatosensory cortex. Neurophysiologists highly consider implementing pudendal and lower extremity SSEPs in cases where the risk to neuronal structures is high [11]. The pudendal SSEP technique extends neuromonitoring coverage to the sacral plexus, which is crucial for preserving continence and sexual function in operations near the pelvic floor [12]. Monitoring these neural pathways using SSEP in intraoperative monitoring is essential for detecting nerve damage in pelvic procedures. Somatosensory

Evoked Potentials contribute to improving results by safeguarding the nervous system and decreasing postoperative deficits.

Alarm Criteria

Intervention is critical in recorded responses if there is a sign of a 50% decrease in amplitude or a 10% increase in latency[13]. These substantial shifts indicate potential abnormalities in the integrity of the sensory nervous system.

Motor Evoked Potentials (MEPs)

Motor Evoked Potentials (MEPs) is an intraoperative modality that assesses the integrity of the motor pathways, in this case, involved with lower limb functionality and pelvic floor control. To evoke motor responses during pIONM, Transcranial Electrical Stimulation (TES) is utilized for these pelvic procedures. Stimulating electrodes, such as corkscrew or needle electrodes, are placed on the scalp that targets the primary motor cortex. Implementing the 10-20 system, some montages perceived are the common interhemispheric setup (ex. C1-C2 or M1-M2) and a lateral montage (ex. C3-C4 or M3-M4)[14]. To overcome anesthetic suppression, a train of 5-7 monophasic pulses is delivered for each motor-evoked potential (MEP) [15]. Train pulses are separated by a 2.0-4.0 ms interstimulus interval (ISI) [16]. This ensures the continuation of the firing of lower motor neurons and aids in temporal summation. In some cases, the utilization of a double-train stimulation is necessary, also called the “2+7 protocol” (beginning with 2 pulses, then followed by a second burst of 7 pulses) [17]. Interpulse and intertrain intervals (ITI) are selected to balance summation an d axonal refractory periods; ISIs at ~2–4 ms and ITIs on the order of 30 ms are often used in TES protocols [17].

Motor evoked potentials (MEPs) require high stimulation intensities transcranially to trigger the motor pathways through the patient’s skull. Stimulator output setting ranges from 80- 400 V per train, to target certain muscles (adjustment based on patient response) [18]. For lower extremity and pelvic floor MEPs, high voltage is occasionally needed due to higher thresholds of the leg area motor cortex. Throughout the usage of MEPs, total intravenous anesthesia (TIVA) is used to enhance the MEPs stability. Also, no neuromuscular blocking agents should be administered after induction to receive muscle responses as intended [16].

MEP recording sites occur at multiple lumbosacral spinal cord muscle groups that are essential to pelvic procedures. These pelvic floor muscle channels directly reflect the integrity of the pudendal nerve motor outflow. To record, bipolar subdermal needle electrodes are placed 2-3cm apart within the belly area to record relevant compound action potentials from muscles. The following muscle groups were monitored bilaterally:

- Iliopsoas – Hip flexor innervated primarily by L2–L3 nerve roots (femoral nerve).
- Adductor Magnus – Hip adductor innervated by L2–L4 (obturator nerve, with a hamstring portion by sciatic nerve).
- Quadriceps Femoris (e.g. vastus lateralis) – Knee extensor innervated by L2–L4 (femoral nerve).
- Tibialis Anterior – Ankle dorsiflexor innervated by L4–L5 (deep peroneal branch of the sciatic nerve) [19].
- Medial Gastrocnemius – Ankle plantar flexor innervated by S1–S2 (tibial branch of the sciatic nerve).
- Abductor Hallucis (or flexor hallucis brevis) – Intrinsic foot muscle (great toe abductor/flexor) innervated by S1–S2 (tibial nerve via medial plantar nerve).
- External Anal Sphincter (EAS) – Skeletal muscle of the pelvic floor innervated by S2–S4 (pudendal nerve, via inferior rectal branch) [16].
- External Urethral Sphincter (EUS) – Pelvic floor muscle (urogenital diaphragm) innervated by S2–S4 (pudendal nerve via perineal branches, originating from Onuf's nucleus).

Recommended MEP recording parameters consist of acquiring baseline measurements after induction. A sweep time of 100-150 ms (10ms/div) per trial [20]. Locut filter is set at 10 Hz, Hicut filter set at 5000 Hz, and the notch filter is off. The amplifier bandpass filter is set to an estimate of 50-1,000Hz (occasionally 50-1,000Hz) and a sensitivity of 100-500 uV/div [21]. The amplifier gain (dynamic range) was adjusted so that the full scale could assist potentials on the order of a few millivolts. This allows for clear visualization of MEP amplitudes, which typically were in the 200-500 uV/div range. The high dynamic range ensures that even if large muscle responses (ex. quadriceps) occurred, they would not clip the amplifier, while still allowing small responses (ex. from sphincters) to be distinguished. Each recorded MEP was analyzed for its latency and amplitude. Neurophysiologists monitor for significant changes, generally using alarm criteria such as a 50% amplitude drop in any muscle's MEP or an absolute loss of response [16].

Monitoring these muscles provides an instant response on motor pathways, particularly for sacral nerves that control bowel and bladder continence [22]. Significant drops in MEP amplitudes can result in potential nerve injury.

Table 2A

Stimulation Parameters for MEP

Study	Pulse Width (µs)	Simulation Rate (Hz)	Sweep (ms)	Locut (Hz)	Hicut (Hz)
Chen et al., 2010	N/A	N/A	N/A	N/A	N/A
Fan et al., 2024	N/A	N/A	N/A	N/A	N/A
Jahangiri et al., 2019 (1)	50-75	N/A	N/A	N/A	N/A
Jahangiri et al., 2019 (2)	50-75	N/A	N/A	N/A	N/A
Lee et al., 2009	N/A	N/A	N/A	N/A	N/A
Lim et al., 2024	N/A	N/A	N/A	N/A	N/A
Menezes et al., 2021	N/A	N/A	N/A	N/A	N/A
Sarkar and Rajshekhar, 2021	N/A	N/A	N/A	N/A	N/A
Steinbok et al., 1995	N/A	N/A	N/A	N/A	N/A
Vissarionov et al., 2018	N/A	N/A	N/A	N/A	N/A
Yang et al., 2024	N/A	N/A	N/A	N/A	N/A

Table 2A. Stimulation Parameters for Motor Evoked Potentials (MEPs). Technical specifications for MEP stimulation across all included studies, including pulse width (µs), stimulation rate (Hz), sweep time, locut filter (Hz), hicut filter (Hz). (Table created by Sam Ayyoub).

Table 2B

Recording Parameters for MEP

Study	Locut (Hz)	Hicut (Hz)
Chen et al., 2010	N/A	N/A
Fan et al., 2024	N/A	N/A
Jahangiri et al., 2019 (1)	N/A	N/A
Jahangiri et al., 2019 (2)	[1]Standard	[1]Standard
Lee et al., 2009	N/A	N/A
Lim et al., 2024	N/A	N/A
Menezes et al., 2021	N/A	N/A
Sarkar and Rajshekhar, 2021	N/A	N/A
Steinbok et al., 1995	N/A	N/A
Vissarionov et al., 2018	N/A	N/A
Yang et al., 2024	N/A	N/A

Table 2B. Recording Parameters for Motor Evoked Potentials (MEPs). Technical specifications for MEP recording across all included studies, including locut filter (Hz), and hicut filter (Hz). (Table created by Sam Ayyoub).

Note: [1]Standard indicates standard protocol parameters where specific values were not reported in the original publication.

Electromyography (EMG)

Electromyography (EMG) is a neuro modality that assesses the electrical activity of muscles. EMG can detect nerve injury in real time and corresponds with improving postoperative nerve function [23]. There are two types of EMG, Spontaneous EMG (Free Running) and Evoked EMG (Triggered).

Spontaneous EMG displays continuous activity from muscles, detecting muscle bursts caused by surgical irritation such as heating, stretching, or nerve pressure. Spontaneous EMG is specifically invaluable for monitoring the sciatic nerve as it provides real-time feedback, unlike SSEPs which are occasionally impeded. However, false negatives can present themselves which is an apprising manner that will need immediate interference from the surgical team [24].

Evoked EMG includes two responses: triggered EMG mapping responses from direct stimulation and the MEP responses from transcranial stimulation. However, a failed elicit response in the targeted muscle is an alert that needs rapid attention. For transcranial MEPs, significant amplitude reduction or disappearance of the muscle CMAP signals from baseline is an alerting factor for the surgical team[25].

The protocol settings for transcranial MEP stimulation take place via scalp electrodes at C1-C2 and M1-M2, correlating to the motor cortex using the universal 10-20 system (alternative sites at C3/C4 or M3-M4)[25]. Transcranial electrical stimulation (TES) evokes action potentials in the aimed muscle groups to ensure corticospinal and peripheral nerve pathways are comprehensive. For direct nerve stimulation, a monopolar or bipolar stimulator probe is utilized to stimulate pelvic nerves or nerve roots at ris k[26]. The stimulation factor criteria are delivered by train of monophasic pulses for mapping these autonomic nerves (for both transcranial or direct nerve stimulation). With a pulse duration set to 200 μs, repetition rate (frequency) at 30 Hz, and an intensity ranging between 0.05- 5.0 mA [27].

The following limb and perineal muscle groups are monitored during innervation:

- Iliopsoas – Hip flexor innervated primarily by L2–L3 nerve roots.
- Adductor Magnus – Hip adductor innervated by L2–L4, manages thigh adduction.
- Quadriceps Femoris – Knee extensor innervated by L2–L4, in control of knee extension.
- Tibialis Anterior – Ankle dorsiflexor innervated by L4–L5, responsible for dorsiflexion (lifting the foot)
- Medial Gastrocnemius – Ankle plantar flexor innervated by S1–S2, in charge of plantarflexion (pointing of the foot).
- Abductor Hallucis – Foot muscle innervated by S1–S2, aids in the movement of the hallux (big toe).

The recommended electromyography (EMG) recording parameters typically include a locut filter to 10 Hz, hicut filter of 5000 Hz, and notch filter switched off. Two sweep time categories are employed: 300 ms (30 ms/div) for sEMG and 100 ms (10 ms/div) for tEMG. The dynamic range (input gain) is typically set to 200-500 uV/div, the sensitivity (gain) set to 100-200 uV/div[28]. Recording sites aim at perineal muscles supplied by the pudendal nerve (external urethral sphincter and external anal sphincters).

In conclusion, real-time monitoring of muscle activity throughout pelvic procedures ensures the protection of nerves at risk and preserves overall neuromuscular function [29].

Table 3A

Stimulation Parameters for EMG

Study	Pulse Width (µs)	Stimulation Rate (Hz)	Sweep (ms)	Locut (Hz)	Hicut (Hz)
Chen et al., 2010	1000	10	20	30	3,000,000
Fan et al., 2024	N/A	N/A	N/A	N/A	N/A
Jahangiri et al., 2019 (1)	N/A	N/A	N/A	N/A	N/A
Jahangiri et al., 2019 (2)	N/A	N/A	N/A	N/A	N/A
Lee et al., 2009	N/A	N/A	N/A	N/A	N/A
Lim et al., 2024	N/A	N/A	N/A	N/A	N/A
Menezes et al., 2021	N/A	N/A	N/A	N/A	N/A
Sarkar and Rajshekhar, 2021	N/A	N/A	N/A	N/A	N/A
Steinbok et al., 1995	100	50 (Tetanic)	N/A	N/A	N/A
Vissarionov et al., 2018	N/A	N/A	N/A	N/A	N/A
Yang et al., 2024	N/A	N/A	N/A	N/A	N/A

Table 3A. Stimulation Parameters for Electromyography (EMG). Technical specifications for EMG stimulation across all included studies, including pulse width (µs), stimulation rate (Hz), sweep time, locut filter (Hz), hicut filter (Hz). (Table created by Sam Ayyoub).

Table 3B

Recording Parameters for EMG

Study	Locut (Hz)	Hicut (Hz)
Chen et al., 2010	30	3,000,000
Fan et al., 2024	N/A	N/A
Jahangiri et al., 2019 (1)	N/A	N/A
Jahangiri et al., 2019 (2)	[1]Standard	[1]Standard
Lee et al., 2009	N/A	N/A
Lim et al., 2024	N/A	N/A
Menezes et al., 2021	N/A	N/A
Sarkar and Rajshekhar, 2021	N/A	N/A
Steinbok et al., 1995	N/A	N/A
Vissarionov et al., 2018	N/A	N/A
Yang et al., 2024	N/A	N/A

Table 3B. Recording Parameters for Electromyography (EMG). Technical specifications for EMG recording across all included studies, including locut filter (Hz), and hicut filter (Hz). Table created by Sam Ayyoub.

Note: [1]Standard indicates standard protocol parameters where specific values were not reported in the original publication.

Bulbocavernosus Reflex (BCR)

The Bulbocavernosus Reflex (BCR) is a hallmark modality in pIONM due to its clinical significance in preserving the sacral nerve function. The bulbocavernosus reflex stimulates the pudendal nerve by placing electrodes on the dorsal surface of the clitoris or dorsal penile shaft. In female patients, the cathode is placed on the clitoral dorsum, and the anode is placed on the labia majora. In male patients, electrodes are placed 2-3 cm apart along the penile dorsum [30]. Optimal stimulation settings are set to a 500 μs pulse width, interstimulus interval of 3 ms, and an intensity of 20 mA [30]. To evoke a reflex response, 4-5 pulses are delivered, with pulse frequency adjusted to 1 Hz respectively. For BCR recording, needle electrodes are positioned into the anal sphincter muscle. Two electrodes are placed 1 cm apart in each hemisphincter, with needles inserted 2.5 cm deep within the sphincter. BCR recording parameters are set to a sweep of 100ms (10 ms/div), however, if a double-train is utilized, the sweep criteria should be set to 200ms [31]. Locut filter is required to be set at 10 Hz, hicut filter at 5000 Hz, and the notch filter turned off. The dynamic range, also known as input gain, is set between 200-500 uV/div and sensitivity at 100-200 uV/div.

Table 4A

Stimulation Parameters for BCR

Study	Pulse Width (µs)	Stimulation Rate (Hz)	Sweep (ms)	Locut (Hz)	Hicut (Hz)
Chen et al., 2010	N/A	N/A	N/A	N/A	N/A
Fan et al., 2024	600	N/A	N/A	30	1500
Jahangiri et al., 2019 (1)	N/A	N/A	N/A	N/A	N/A
Jahangiri et al., 2019 (2)	N/A	N/A	N/A	N/A	N/A
Lee et al., 2009	N/A	N/A	N/A	N/A	N/A
Lim et al., 2024	N/A	N/A	N/A	N/A	N/A
Menezes et al., 2021	N/A	N/A	N/A	N/A	N/A
Sarkar and Rajshekhar, 2021	N/A	N/A	N/A	N/A	N/A
Steinbok et al., 1995	100	50 (Tetanic)	N/A	N/A	N/A
Vissarionov et al., 2018	N/A	N/A	N/A	N/A	N/A
Yang et al., 2024	300	2.3	N/A	N/A	N/A

Table 4A. Stimulation Parameters for Bulbocavernosus Reflex (BCR). Technical specifications for BCR stimulation across all included studies, including pulse width (µs), stimulation rate (Hz), sweep time, locut filter (Hz), hicut filter (Hz). (Table created by Sam Ayyoub).

Table 4B

Recording Parameters for BCR

Study	Locut (Hz)	Hicut (Hz)
Chen et al., 2010	N/A	N/A
Fan et al., 2024	30	1500
Jahangiri et al., 2019 (1)	N/A	N/A
Jahangiri et al., 2019 (2)	N/A	N/A
Lee et al., 2009	N/A	N/A
Lim et al., 2024	N/A	N/A
Menezes et al., 2021	N/A	N/A
Sarkar and Rajshekhar, 2021	N/A	N/A
Steinbok et al., 1995	N/A	N/A
Vissarionov et al., 2018	N/A	N/A
Yang et al., 2024	N/A	N/A

Table 4B. Recording Parameters for Bulbocavernosus Reflex (BCR). Technical specifications for BCR recording across all included studies, including locut filter (Hz), and hicut filter (Hz). (Table created by Sam Ayyoub).

Train of Four

Train of Four (TOF) technique serves to record the neuromuscular blockade during procedures. Particularly the muscle response from the abductor hallucis muscle, generally evaluated by stimulating the posterior tibial nerve. TOF monitoring supports the reliability of neuromonitoring modalities by aiding anesthesiologists to maintain an appropriate balance of muscle relaxation. Train of Four (TOF) mechanism requires the administration of four monophasic pulses at a stimulation rate of 2 Hz, a pulse width of 0.2 ms, and a 20 ms/division. The number of muscle twitches determines the level of neuromuscular blockade generated from four pulses: 0 twitches equate to 100% of the blockade, 1 twitch equates to 95% of the blockade, 2 twitches suggest 85% of the blockade, 3 twitches represent 65-75% of the blockade, and 4 twitches indicate to 5-75% of the blockade [32].

Beyond the Scope of Intraoperative Neuromonitoring

Internal Sphincter Assessment

Assessing the functionality of the internal sphincter is essential for detecting any indication of underlying issues. Two methods that can evaluate this are urodynamic exams, which determine how well a patient can hold and release urine from the bladder, and anorectal manometry, which determines the effectiveness of anal and rectal muscle control. The internal anal sphincter (IAS) and the detrusor (bladder muscle) are both smooth muscles controlled by the autonomic nervous system. Though these examinations are crucial, they are not used with the utilization of IONM and serve solely as diagnostic methods. This review focuses on intraoperative neuromonitoring techniques that assess the somatic nervous system and external sphincter function.

RESULTS

Study Cohort Characteristics

Our study encompassed a wide range of surgical interventions, including colorectal, urological, gynecological, and spinal procedures; however, meta-analysis was limited to spinal-related surgeries due to insufficient comparative data for other categories. This limitation was anticipated to some extent, as IONM has historically been most extensively adopted and studied in spinal procedures compared to other surgical fields. Despite our comprehensive dual-search strategy using identical terminology for both IONM and non-IONM searches, we found a significant disparity in available literature outside of spinal procedures. This finding itself highlights an important research gap in IONM applications for non-spinal pelvic surgeries.

Table 5A: Participant Demographics Across IONM Studies

Study	Sample Size (n)	Male (n)	Female (n)	Mean Age	Age Range	Country
Chen et al., 2010	20	0	20	44.1 Years *(Median)*	35 - 54 Years	China
Fan et al., 2024	105	61	44	40.9 ± 13.8 Years	27.1 - 54.7 Years	China
Jahangiri et al., 2019 (1)	10	5	5	49 Years *(Median)*	8 Months - 67 Years	United States, Saudi Arabia
Jahangiri et al., 2019 (2)	15	8	7	38.91 Years *(Median)*	8 Months - 66 Years	United States, Pakistan, Saudi Arabia
Lee et al., 2009	60	26	34	43 Years	17 - 72 Years	Canada
Lim et al., 2024	122	56	66	2.3 ± 3.9 Years	N/A	Singapore
Menezes et al., 2021	20	4	16	42.9 Years	20 - 77 Years	United States
Sarkar and Rajshekhar, 2021	59	40	19	N/A	N/A	India
Steinbok et al., 1995	77	N/A	N/A	N/A	N/A	Canada
Vissarionov et al., 2018	17	7	10	N/A	1 - 18 Years	Russia
Yang et al., 2024	52	30	22	48.6 ± 17.2 Years	N/A	China

Table 5B: Participant Demographics Across Non-IONM Studies

Study	Sample Size (n)	Male (n)	Female (n)	Mean Age	Age Range	Country
Baessler and Schuessler, 2001	33	0	33	61 Years	41 - 77 Years	Switzerland
Byvaltsev et al., 2022	59	39	20	Open: 41 Years MI: 38 Years	Open: 29 - 52 Years *(IQR)* MI: 30 - 53 Years *(IQR)*	Russia
Byvaltsev et al., 2023	46	25	21	DA: 35 Years FO: 32 Years	DA: 28 - 47 Years *(IQR)* FO: 25 - 43 Years *(IQR)*	Russia
Ceccaroni et al., 2019	160	0	160	36.1 Years	N/A	Italy
Cornips et al., 2012	25	8	17	8.3 Years	2 - 18 Years	Netherlands
Cundiff et al., 1997	19	0	19	55.5 ± 11.8 Years	32 - 71 Years	United States
Danzer et al., 2016	42	N/A	N/A	N/A *(Gestational Age)*	N/A	United States
Dubowitz et al., 1965	12	4	8	N/A	5 Weeks - 11 Years 9 months	England
Gakis et al., 2011	24	16	8	39 Years *(Median)*	13 - 63 Years	Germany, India, Netherlands
Gleave & Macfarlane, 1990	33	N/A	N/A	41.2 Years	23 - 67 Years	N/A
Gupta & Mahapatra, 2005	17	6	11	20.8 Months	2 Months - 5 Years	India
Iskandar et al., 2001	34	12	22	34 Years	18 - 70 Years	United States
Karrer et al., 1988	14	4	10	4.5 *(Median)*	<1 Month - 15 Years	United States
Meeks et al., 1994	110	0	110	54.5 ± 14.6 Years	N/A	United States
Mosiello et al., 2003	11	6	5	7 Years *(Median)*	2 - 4 Years	Italy
Poad & Arnold, 1994	66	0	66	N/A	20 - 60 Years	New Zealand
Sakai et al., 2009	20	14	6	40.3 ± 18.4 *(Median)*	6 - 64 Years	Japan
Theodore et al., 2020	20	5	15	36 Years	20 - 69 Years	United States

Table 5A-B. Participant Demographics Across Included Studies. Summary of sample size, sex distribution, age characteristics, and geographical distribution across studies with and without intraoperative neurophysiological monitoring (IONM). (Tables created by Sam Ayyoub).

Note: For Table 5B, combined data presented for Byvaltsev et al. (2022) includes both Open TLIF (n=59, mean age 41 years) and MI TLIF (Minimally Invasive Transforaminal Lumbar Interbody Fusion; n=57, mean age 38 years) groups. Combined data for Byvaltsev et al. (2023) includes DA (Depression Alone; n=46, mean age 35 years) and FO (Fusion Only; n=43, mean age 32 years) groups.

Table 6A. Distribution of Surgical Categories Across IONM Studies

Study	Total Number of Procedures (n)	Spinal Procedures (n)	Urological Procedures (n)	Gynecologic Procedures (n)	Colorectal Procedures (n)	Comments
Chen et al., 2010	20	N/A	N/A	20	N/A	Nerve-sparing radical hysterectomy (20)
Fan et al., 2024	105	105	N/A	N/A	N/A	Conus medullaris and cauda equina tumor surgery (105)
Jahangiri et al., 2019 (1)	10	10	N/A	N/A	N/A	Surgeries for intradural tumors (7) and tethered cord syndrome (3) including laminectomy, conus tumor resection, and tethered cord release
Jahangiri et al., 2019 (2)	15	15	N/A	N/A	N/A	Surgeries for conus/cauda tumors, tethered cord, and spinal stenosis (15)
Lee et al., 2009	60	60	N/A	N/A	N/A	Detethering surgery for caudal cord tethering (60)
Lim et al., 2024	122	122	N/A	N/A	N/A	Total/near-total resection of complex lumbosacral lipomas (122)
Menezes et al., 2021	20	20	N/A	N/A	N/A	Microsurgical untethering procedures for newly diagnosed adult TCS including filum sectioning (8), conus lipoma debulking (7), diastematomyelia spur removal (7), and cervical cord tethering release (2). All procedures utilized SSEP/EMG neuromonitoring with 1-30 year follow-up
Sarkar and Rajshekhar, 2021	59	59	N/A	N/A	N/A	Spinal intradural dermoid cyst surgery (59), predominantly in the lumbosacral region
Steinbok et al., 1995	77	77	N/A	N/A	N/A	Selective functional posterior rhizotomy (77)
Vissarionov et al., 2018	17	17	N/A	N/A	N/A	Septum resection surgeries for patients with diastematomyelia (17)
Yang et al., 2024	52	52	N/A	N/A	N/A	Surgical resection of distal intraspinal tumors (52)

Table 6B. Distribution of Surgical Categories Across Non-IONM Studies

Study	Total Number of Procedures (n)	Spinal Procedures (n)	Urological Procedures (n)	Gynecologic Procedures (n)	Colorectal Procedures (n)	Comments
Baessler and Schuessler, 2001	33	N/A	N/A	33	N/A	*Abdominal sacrocolpopexy (33)*
Byvaltsev et al., 2022	116	116	N/A	N/A	N/A	*Decompression and stabilization for cauda equina (116)*
Byvaltsev et al., 2023	89	89	N/A	N/A	N/A	*Decompression and lumbar interbody fusion (89)*
Ceccaroni et al., 2019	160	N/A	160	N/A	N/A	*Laparoscopic ureteroneocystotomy (160)*
Cornips et al., 2012	25	25	N/A	N/A	N/A	*Untethering for tight filum syndrome (25)*
Cundiff et al., 1997	19	N/A	N/A	19	N/A	*Abdominal sacral colpoperinopexy (19)*
Danzer et al., 2016	54	54	N/A	N/A	N/A	*Fetal myelomeningocele surgery (54)*
Dubowitz et al., 1965	12	12	N/A	N/A	N/A	*Cauda equina lipoma surgery (12)*
Gakis et al., 2011	24	N/A	24	N/A	N/A	*Latissimus dorsi detrusor myoplasty (24)*
Gleave & Macfarlane, 1990	33	33	N/A	N/A	N/A	*Surgery for lumbar disc prolapse (33)*
Gupta & Mahapatra, 2005	17	17	N/A	N/A	N/A	*Sac excision and detethering (17)*
Iskandar et al., 2001	34	34	N/A	N/A	N/A	*Spinal cord detethering (34)*
Karrer et al., 1988	14	N/A	N/A	N/A	14	*Abdominal perineal pull-through, anoplasty, ileostomy, colostomy, and pull-through procedures for anorectal malformations (14)*
Meeks et al., 1994	110	N/A	N/A	110	N/A	*Vaginal vault prolapse repair via suspension to iliococcygeus fascia (110)*
Mosiello et al., 2003	11	9	2	N/A	N/A	*Pelvic neoplasm resection (11)*
Poad & Arnold, 1994	66	N/A	N/A	66	N/A	*Pelvic floor surgery including colposuspension, vaginal/abdominal hysterectomy, and anterior repair (66)*
Sakai et al., 2009	20	20	N/A	N/A	N/A	*Myxopapillary ependymoma removal (20)*
Theodore et al., 2020	20	20	N/A	N/A	N/A	*Vertebral column osteotomy for recurrent TCS (20)*

Table 6A-B. Surgical Categories Across Study Populations. Distribution of surgical interventions among included studies with and without intraoperative neurophysiological monitoring (IONM), categorized by specialty (spinal, gynecological, urological, and colorectal). (Tables created by Sam Ayyoub).

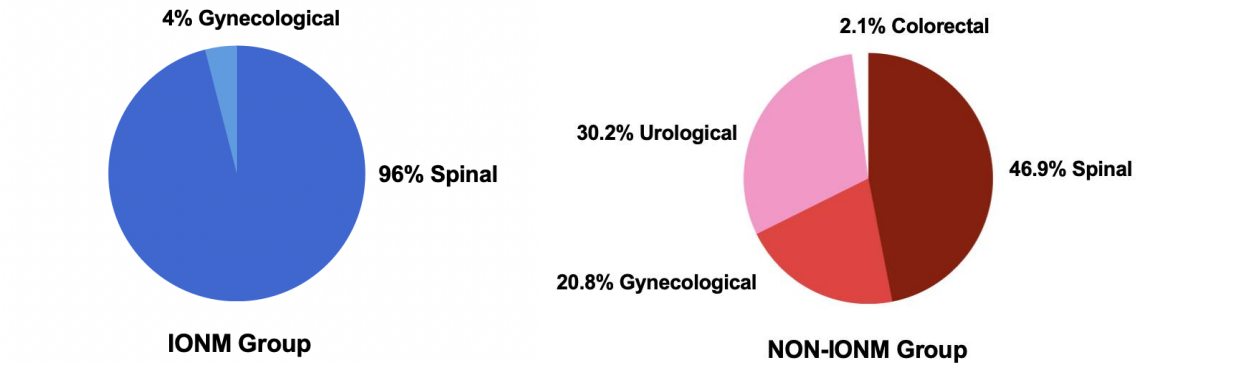

Figure 2. Surgical Category Distribution: IONM vs. Non-IONM Groups. Pie chart comparison illustrates the distribution of surgical categories between procedures utilizing intraoperative neurophysiological monitoring (IONM) and those conducted without monitoring (non-IONM), corresponding to data presented in Table 6.

Clinical Outcomes

Table 7A. Overall Clinical Outcomes Across All Surgical Categories for IONM Studies

Study	Surgical Category	Clinical Outcome			Patients Analyzed (n)
		Worsened (n)	Baseline (n)	Improved (n)	
Chen et al., 2010	Gynecologic	2	18	0	20
Fan et al., 2024	Spinal	16	89	0	105
Jahangiri et al., 2019 (1)	Spinal	0	5	1	6
Jahangiri et al., 2019 (1)	Spinal	0	4	0	4
Jahangiri et al., 2019 (2)	Spinal	0	8	1	9
Jahangiri et al., 2019 (2)	Spinal	0	3	1	4
Jahangiri et al., 2019 (2)	Spinal	0	2	0	2
Lee et al., 2009	Spinal	2	19	21	42
Lim et al., 2024	Spinal	41	95	2	122
Menezes et al., 2021	Spinal	0	7	12	19
Sarkar and Rajshekhar, 2021	Spinal	0	22	1	23
Steinbok et al., 1995	Spinal	8	68	0	76
Vissarionov et al., 2018	Spinal	1	12	4	17
Yang et al., 2024	Spinal	2	50	0	52

Table 7B. Overall Clinical Outcomes Across All Surgical Categories for NON-IONM Studies

Study	Surgical Category	Clinical Outcome			Patients Analyzed (n)
		Worsened (n)	Baseline (n)	Improved (n)	
Baessler and Schuessler, 2001	Gynecologic	13	10	8	31
Byvaltsev et al., 2022	Spinal	46	70	0	116
Ceccaroni et al., 2019	Urological	24	136	0	160
Cornips et al., 2012	Spinal	1	8	13	22
Cundiff et al., 1997	Gynecologic	0	11	8	19
Danzer et al., 2016	Spinal	31	11	0	42
Dubowitz et al., 1965	Spinal	9	3	0	12
Gakis et al., 2011	Urological	0	3	21	24
Gleave & Macfarlane, 1990	Spinal	0	7	26	33
Gupta & Mahapatra, 2005	Spinal	0	10	7	17
Iskandar et al., 2001	Spinal	1	6	11	18
Karrer et al., 1988	Colorectal	0	10	3	13
Meeks et al., 1994	Gynecologic	23	0	0	23
Mosiello et al., 2003	Spinal	6	3	0	9
Mosiello et al., 2003	Urological	2	0	0	2
Poad & Arnold, 1994	Gynecologic	31	24	0	55
Sakai et al., 2009	Spinal	2	2	6	10
Theodore et al., 2020	Spinal	2	2	6	10

Table 7A-B. Overall Clinical Outcomes Across All Surgical Categories

Comprehensive summary of postoperative outcomes (improved, baseline maintained, and worsened) for all procedures with and without intraoperative neurophysiological monitoring (IONM), categorized by surgical specialty (spinal, gynecological, urological, and colorectal). Tables created by Sam Ayyoub.

In total, we analyzed clinical outcomes for a cohort of 771 patients who had undergone spinal-related procedures, in which 482 received intraoperative neurophysiological monitoring (IONM) and 289 did not (NON-IONM).

Spinal-Related Postoperative Clinical Outcomes

The spinal interventions comprised tumor management procedures, tethered cord-related procedures, congenital malformation surgeries, and degenerative spine procedures. Given the limited sample sizes within individual subcategories for both monitored and unmonitored cohorts, we aggregated data across all spinal procedures. We classified three categories based on clinical outcomes regarding urinary and bowel function: improved, unchanged (baseline), and worsened.

Table 8A. Spinal-Related Clinical Outcomes Selected for Statistical Analysis for IONM Studies

Study	Surgical Sub-Category	Clinical Outcome			Patients Analyzed (n)
		Worsened (n)	Baseline (n)	Improved (n)	
Fan et al., 2024	*Tumor Management Procedures*	16	89	0	105
Jahangiri et al., 2019 (1)	*Tumor Management Procedures*	0	5	1	6
Jahangiri et al., 2019 (1)	*Tethered Cord-Related Procedures*	0	4	0	4
Jahangiri et al., 2019 (2)	*Tumor Management Procedures*	0	8	1	9
Jahangiri et al., 2019 (2)	*Tethered Cord-Related Procedures*	0	3	1	4
Jahangiri et al., 2019 (2)	*Degenerated Spine Procedures*	0	2	0	2
Lee et al., 2009	*Tethered Cord-Related Procedures*	2	19	21	42
Lim et al., 2024	*Tethered Cord-Related Procedures*	41	95	2	122
Menezes et al., 2021	*Congenital Malformation Surgeries*	0	7	12	19
Sarkar and Rajshekhar, 2021	*Tumor Management Procedures*	0	22	1	23
Steinbok et al., 1995	*Congenital Malformation Surgeries*	8	68	0	76
Vissarionov et al., 2018	*Tethered Cord-Related Procedures*	1	12	4	17
Yang et al., 2024	*Tumor Management Procedures*	2	50	0	52

Table 8B. Spinal-Related Clinical Outcomes Selected for Statistical Analysis for NON-IONM Studies

Study	Surgical Sub-Category	Clinical Outcome			Patients Analyzed (n)
		Worsened (n)	Baseline (n)	Improved (n)	
Byvaltsev et al., 2022	*Degenerated Spine Procedures*	46	70	0	116
Cornips et al., 2012	*Tumor Management Procedures*	1	8	13	22
Danzer et al., 2016	*Congenital Malformation Surgeries*	31	11	0	42
Dubowitz et al., 1965	*Congenital Malformation Surgeries*	9	3	0	12
Gleave & Macfarlane, 1990	*Degenerated Spine Procedures*	0	7	26	33
Gupta & Mahapatra, 2005	*Tethered Cord-Related Procedures*	0	10	7	17
Iskandar et al., 2001	*Tethered Cord-Related Procedures*	1	6	11	18
Mosiello et al., 2003	*Tumor Management Procedures*	6	3	0	9
Sakai et al., 2009	*Tumor Management Procedures*	2	2	6	10
Theodore et al., 2020	*Tethered Cord-Related Procedures*	2	2	6	10

Table 8A-B. Spinal-Related Clinical Outcomes Selected for Statistical Analysis. Detailed analysis of postoperative outcomes specifically for spinal procedures, comparing IONM versus non-IONM groups with statistical significance measures. (Table created by Sam Ayyoub).

The IONM group exhibited the following outcome distribution: improvement in 44 patients (9.1%), maintenance of baseline function in 368 patients (76.3%), and deterioration in 70 patients (14.5%). Comparatively, the NON-IONM group demonstrated improvement in 69 patients (23.9%), unchanged status in 122 patients (42.2%), and worsened condition in 98 patients (33.9%).

Statistical Analysis in Spinal-Related Procedures

Our meta-analysis using chi-square testing revealed a significant difference in improvement rates between the two groups ($\chi^2 = 31.41$, $p < 0.0001$). The calculated odds ratio (OR = 0.32) indicates that patients who received IONM-guided procedures were 68% less likely to show postoperative improvement for urinary and bowel functions than those in the NON-IONM cohort. This unexpected finding merits careful interpretation within the broader clinical context.

Analysis of baseline maintenance revealed substantial differences between groups ($\chi^2 = 90.88$, $p < 0.0001$). The corresponding odds ratio of 4.42 reflects that patients who received IONM were more than four times as likely to maintain their baseline neurological function following surgery. This stability pattern represents the most pronounced difference between the two cohorts.

Postoperative neurological deterioration occurred at significantly lower rates in patients who underwent monitoring ($\chi^2 = 39.85$, $p < 0.0001$). The odds ratio (OR = 0.33) indicates a 67% reduction in deterioration risk for patients who received neuromonitoring during procedures. This finding aligns with the presumed protective function of neurophysiological monitoring during high-risk interventions.

Table 9A. Contingency Table - Improved in Spinal Procedures

	Improved Clinical Outcomes		
Procedural Group	**Yes**	**No**	**Total**
IONM	44	438	482
NON-IONM	69	220	289
Total	113	658	771

Table 9B. Contingency Table - Baseline in Spinal Procedures

	Baseline Clinical Outcomes		
Procedural Group	**Yes**	**No**	**Total**
IONM	368	114	482
NON-IONM	122	167	289
Total	490	281	771

Table 9C. Contingency Table - Worsened in Spinal Procedures

	Worsened Clinical Outcomes		
Procedural Group	**Yes**	**No**	**Total**
IONM	70	412	482
NON-IONM	98	191	289
Total	168	603	771

Table 9A-C. Contingency Tables for Clinical Outcomes. Distribution of clinical outcomes (improved, baseline maintained, and worsened) in spinal-related procedures between IONM and non-IONM groups in spinal procedures, showing frequency counts and row totals. Tables created by Sam Ayyoub.

Table 10. Statistical Analysis: Spinal-Related Clinical Outcomes for IONM vs NON-IONM Cohort

Variable	χ^2	p-value	Odds Ratio (95%)
Improved	31.41	p < 0.0001	0.32 (0.22, 0.47)
Baseline	90.88	p < 0.0001	4.42 (3.23, 6.06)
Worsened	39.85	p < 0.0001	0.33 (0.23, 0.47)

Table 10. Statistical Analysis: Clinical Outcomes for IONM vs NON-IONM Cohort. Chi-square test results, p-values, and odds ratios with 95% confidence intervals for improved, baseline, and worsened clinical outcomes from spinal-related procedures only. (Table created by Sam Ayyoub).

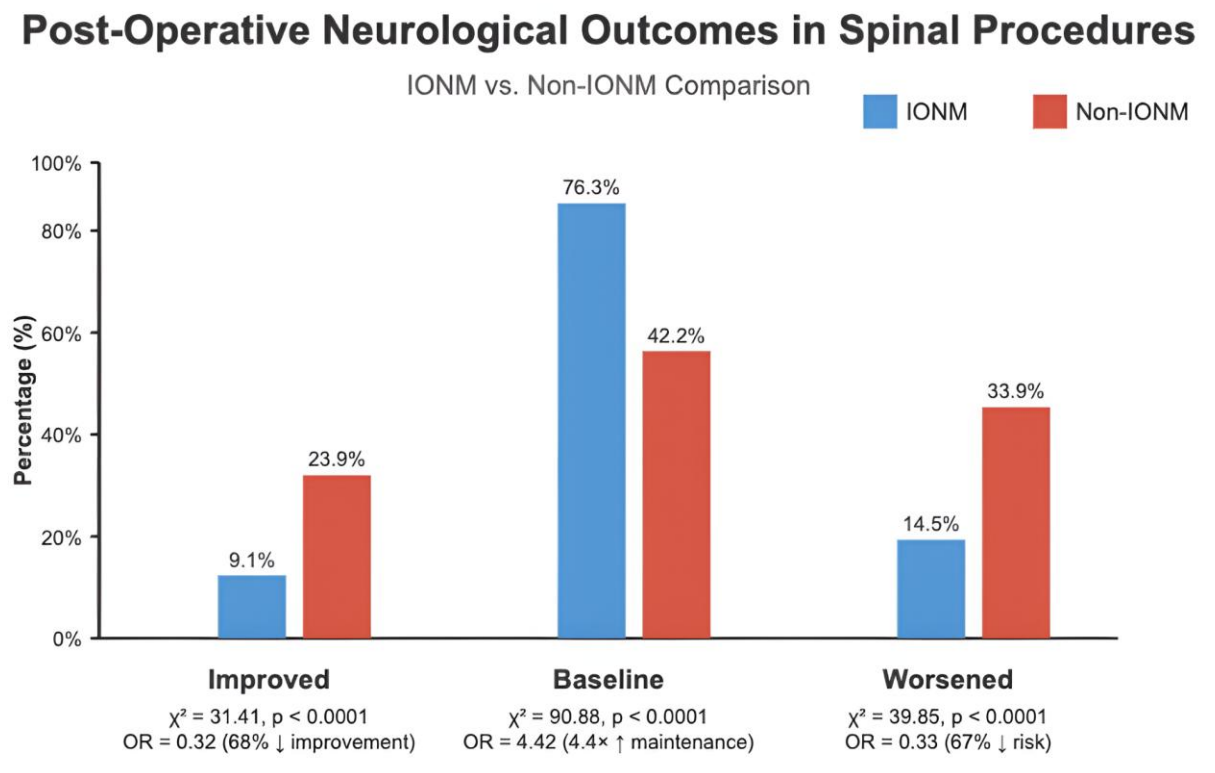

Figure 3. Postoperative Neurological Outcomes in Spinal Procedures. Bar chart comparing postoperative outcomes (improved, baseline maintained, and worsened) between IONM-monitored (blue) and non-monitored (red) spinal-related procedures, visualizing data from Table 8.

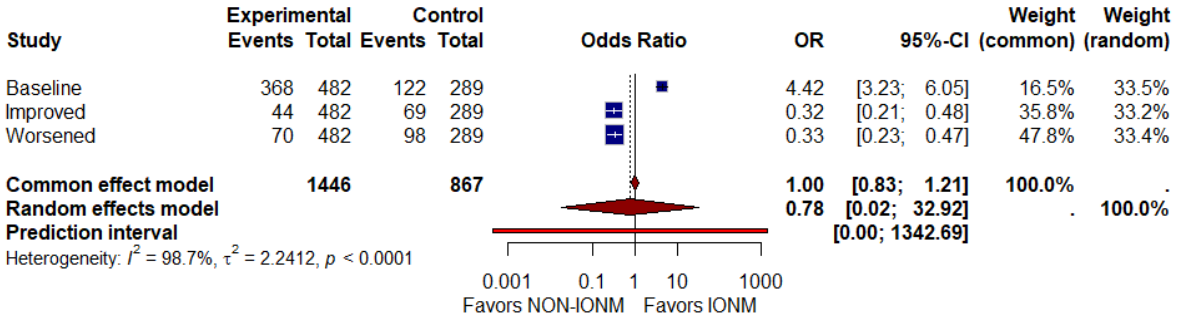

Figure 4. Forest Plot of Outcome Odds Ratios. Forest plot illustrates the statistical heterogeneity and odds ratios for clinical outcomes from spinal-related procedures between IONM and non-IONM groups. Figure created by Sam Ayyoub.

Due to the insufficient number of IONM studies in gynecological, colorectal, and urological fields, our focus shifted to addressing the statistical analysis on spinal-related procedures, where there was sufficient data for both non-IONM and IONM groups. In order to address the variability across the studies that were included for our statistical analysis, we performed a heterogeneity test. The results indicated a substantial degree of heterogeneity (I^2 = 98.7%), indicating that the variability between the studies included highly likely influenced the overall findings. Such variables may include but not be limited to study methods, patient populations, types of spinal procedures, and possibly monitoring techniques across analyzed studies. Therefore, it would be necessary to draw broad conclusions from this statistical analysis with caution, given that variability across the spinal-related procedures may compromise our results' validity and applicability.

Other Surgical Categories

Although limited, the comprehensive analysis of urological and gynecological surgical procedures revealed distinctive outcomes across multiple interventions. In the urological domain, three non-IONM studies provided critical insights. The laparoscopic ureteroneocystostomy (n=160) indicated 15% (24/160) of patients experiencing neurological complications, with 85% maintaining baseline status and no improvement observed.

The latissimus dorsi detrusor myoplasty (n=24) demonstrated a different outcome profile, with 12.5% (3/24) of patients presenting neurological complications while 87.5% (21/24) achieved the primary surgical objective of bladder function improvement. Alternatively, the pelvic neoplasm resection procedure (n=11) revealed more significant neurological challenges, with 72.7% (8/11) of patients experiencing neurological deterioration and 27.3% (3/11) maintaining preoperative neurological status.

Gynecological procedure analysis integrated one IONM study and four non-IONM studies. The IONM-guided radical hysterectomy (n=20) exhibited 10% (2/20) worsened outcomes and 90% (18/20) baseline

neurological preservation. Aggregated non-IONM studies (n=128) revealed 52.3% (67/128) improvement, 35.2% (45/128) baseline function maintenance, and 12.5% (16/128) neurological decline.

Intraoperative Neuromonitoring (IONM) Alerts

Included Studies

Our systematic review found 11 studies that used intraoperative neuromonitoring (IONM) across various surgical procedures with a cohort of 502 patients. Almost half of the studies (5/11, 45.5%) had a sample size of less than 30 patients, which may limit the generalizability of our findings.

IONM Modalities

As shown in Table 11, there was heterogeneity in the utilization of IONM modalities across a wide range of surgical procedures comprised in our studies. EMG was the most used modality (n=196, 25.4% of all procedures), used in 7 out of 11 studies, followed by BCR (n=157, 20.4%), MEP (n=126, 16.3%), and SSEP (n=91, 11.8%). Only 2 studies had a more comprehensive approach, with Yang et al. (2024) using SSEP, MEP, and BCR in all 52 procedures.

Table 11. Intraoperative Neuromonitoring (IONM) Modalities Used Across Studies

Study	Total (n) Procedures	EMG (n)	SSEP (n)	MEP (n)	BCR (n)
Chen et al., 2010	20	20	N/A	N/A	N/A
Fan et al., 2024	105	N/A	N/A	N/A	105
Jahangiri et al., 2019 (1)	10	10	10	N/A	N/A
Jahangiri et al., 2019 (2)	15	15	15	15	N/A
Lee et al., 2009	42	42	42	N/A	N/A
Lim et al., 2024	122	122	122	122	N/A
Menezes et al., 2021	24	24	24	N/A	N/A
Sarkar and Rajshekhar, 2021	59	59	N/A	59	N/A
Steinbok et al., 1995	77	28	N/A	N/A	N/A
Vissarionov et al., 2018	17	17	N/A	N/A	N/A
Yang et al., 2024	52	N/A	52	52	52

Table 11. Intraoperative Neuromonitoring (IONM) Modalities. Frequency distribution of monitoring techniques (EMG, SSEP, MEP, BCR) utilized across included studies with total procedure counts. (Table created by Sam Ayyoub).

Alert Thresholds and Diagnostic Accuracy

Table 12 highlights the literature gap in the reporting of IONM alert criteria and diagnostic performance metrics. Only 1 of 11 studies (9.1%)—Yang et al. (2024)—provided a clear alert criterion ("bilateral disappearance of response with stimulus at 2-3× threshold") and complete diagnostic accuracy data for BCR[33]. This study showed a time-dependent sensitivity that increased from 20% at 1 week to 100% at 6

months post-op, with a specificity of 100%. Only 2 of 11 studies (18.2%)—Jahangiri et al. (2019)—reported sensitivity values: 100% for transcranial MEP in their 2019 study[34] and 93% for transcranial MEP (sphincter) in their 2019 study[35]. However, neither of these studies reported specificity values or alert criteria. The remainder of the studies (72.7%) failed to report diagnostic accuracy metrics or alert criteria for their chosen IONM modalities.

Table 12. Intraoperative Neuromonitoring (IONM) Alerts Across All IONM Studies

Study	IONM Modality	Sensitivity (%)	Specificity (%)	Alert Criteria
Chen et al., 2010	Bladder EMG	N/A	N/A	N/A
Fan et al., 2024	BCR	N/A	N/A	N/A
Fan et al., 2024	EMG	N/A	N/A	N/A
Fan et al., 2024	MEP	N/A	N/A	N/A
Fan et al., 2024	SSEP	N/A	N/A	N/A
Jahangiri et al., 2019 (1)	Transcranial MEP	100%	N/A	N/A
Jahangiri et al., 2019 (1)	Upper/Lower Limb SSEP	N/A	N/A	N/A
Jahangiri et al., 2019 (1)	Triggered EMG (Sphincter/LE)	N/A	N/A	N/A
Jahangiri et al., 2019 (1)	Free-running EMG (Sphincter/LE)	N/A	N/A	N/A
Jahangiri et al., 2019 (2)	Transcranial MEP (Sphincter)	93%	N/A	N/A
Jahangiri et al., 2019 (2)	SSEP	N/A	N/A	N/A
Jahangiri et al., 2019 (2)	EMG	N/A	N/A	N/A
Jahangiri et al., 2019 (2)	TOF	N/A	N/A	N/A
Jahangiri et al., 2019 (2)	Sphincter MEP	N/A	N/A	N/A
Lee et al., 2009	Free-running EMG (Sphincter/LE)	N/A	N/A	N/A
Lee et al., 2009	SSEP	N/A	N/A	N/A
Lim et al., 2024	SSEP	N/A	N/A	N/A
Lim et al., 2024	MEP	N/A	N/A	N/A
Lim et al., 2024	EMG	N/A	N/A	N/A
Menezes et al., 2021	SSEP	N/A	N/A	N/A
Menezes et al., 2021	EMG	N/A	N/A	N/A
Sarkar and Rajshekhar, 2021	Triggered EMG	N/A	N/A	N/A
Sarkar and Rajshekhar, 2021	Free-running EMG	N/A	N/A	N/A
Sarkar and Rajshekhar, 2021	Transcranial MEP	N/A	N/A	N/A
Steinbok et al., 1995	EMG	N/A	N/A	N/A
Vissarionov et al., 2018	EMG	N/A	N/A	N/A
Yang et al., 2024	BCR	20% (1 week) 33.3% (2 months) 66.7% (4 months) 100 % (6 months)	100%	Bilateral disappearance of response with stimulus at 2-3× threshold
Yang et al., 2024	Transcranial MEP	N/A	N/A	N/A
Yang et al., 2024	SSEP	N/A	N/A	N/A

Table 12. Intraoperative Neuromonitoring (IONM) Alerts Across All IONM Studies. Analysis of alert criteria, threshold values, and response protocols across all IONM-monitored procedures, including sensitivity and specificity data where available.(Table created by Sam Ayyoub).

Notations used: BCR = Bulbocavernosus Reflex; EMG = Electromyography; MEP = Motor Evoked Potential; SSEP = Somatosensory Evoked Potential; TOF = Train of Four; LE = Lower Extremity; N/A = Not Available.

Technical Parameters

There was also a limitation in the reporting of technical parameters. As shown in Tables 1A-4A, most studies failed to report any stimulation parameters. For SSEP and MEP, only Jahangiri et al. reported pulse width (50-75 μs), and all other parameters were not reported in any of the studies. For EMG, only 2 of 11 studies (18.2%) reported specific technical parameters: Chen et al. noted all 5 parameters (pulse width: 1000 μs; stimulation rate: 10 Hz; sweep: 20 ms; low-cut filter: 30 Hz; high-cut filter: 3000 Hz) and Steinbok et al. reported pulse width (100 μs) and stimulation rate (50 Hz tetanic). For BCR, only Fan et al. (2024) reported parameters partially (pulse width: 600 μs; low-cut filter: 30 Hz; high-cut filter: 1500 Hz).

Modality Performance Comparison

While a comprehensive comparison is limited due to reporting gaps, the available data show significant modality performance differences. Yang et al. (2024) found BCR has 100% specificity but time-dependent sensitivity so it's more useful as a prognostic indicator rather than immediate detector of neurological injury[33]. The highest sensitivity values were from transcranial MEP (100% and 93% in the Jahangiri studies) so this modality might be more sensitive to neurological changes. However, without specificity data or alert criteria the clinical utility of these findings is unclear. Despite EMG being the most used modality (7 studies) none of the studies reported sensitivity, specificity or alert criteria for EMG monitoring which is a big gap given its widespread use.

Reporting Quality Assessment

Our systematic review found that none of the 11 studies provided the complete technical profile to implement and reproduce IONM. This critical gap includes missing or incomplete reporting of diagnostic accuracy (90.9% of studies), missing alert threshold (90.9% of studies) and insufficient documentation of stimulation and recording parameters (90.9% of studies). These findings highlight the need for standardized reporting protocol in IONM research to allow meaningful comparison between studies and clinical implementation. The wide variation in modality usage and inconsistent reporting of technical parameters and performance metrics hinders evidence-based selection of monitoring technique for specific surgical procedure.

DISCUSSION

The uneven distribution of IONM studies across surgical specialties in our meta-analysis reflects the current state of research in this field. While IONM is well-established in spinal surgery with substantial evidence supporting its use, there remains a significant gap in the literature regarding its application in gynecological, urological, and colorectal procedures. This disparity persisted despite our comprehensive search strategy, suggesting a true limitation in the current research landscape rather than a methodological

shortcoming. Identifying this research gap represents an important finding of our systematic review and underscores the need for expanded investigation in these surgical specialties.

Building on this identified research gap, we evaluated the role of intraoperative neurophysiological monitoring (IONM) in preserving pelvic floor integrity through the comparative analysis of worsened, unchanged, and improved clinical outcomes of surgical procedures performed with and without IONM. According to our inclusion criteria, our study included up to four surgical categories: spinal, gynecological, urological, and colorectal. However, only spinal-related procedural outcomes were included for comparative analysis due to insufficient studies for gynecological, urological, and colorectal procedures in the IONM group, further confirming the research disparity we identified.

With a total cohort of 771 patients who had undergone spinal-related procedures, the results showed significant differences across all postoperative outcome categories between the IONM group (N = 482) and the non-IONM group (N = 289). The results affirm our initial hypothesis that there is an increase in the likelihood of preserving neural function and a decrease of post-operative neurological deterioration such as urinary dysfunction, bowel dysfunction, and/or sexual dysfunction in the intraoperative neuromonitoring group compared to the control group. Specifically, for unchanged outcomes, the chi-square test showed significant difference between two groups with ($\chi^2 = 90.88$, $p < 0.0001$) and odds ratio 4.42. This indicates that IONM is four times more likely to preserve neural function relating to the pelvic floor compared to non-IONM counterparts for spinal-related surgeries. Likewise, for worsened outcomes, IONM significantly reduced deterioration risk by up to 67% indicated by the calculated odds ratio (OR = 0.33) and ($\chi^2 = 39.85$, $p < 0.0001$).

Interestingly, however, our results show a significant difference in clinical improvement rates in which IONM-guided procedures were 68% less likely to show postoperative improvement for urinary and bowel functions than those in the NON-IONM cohort. This finding rejects our initial hypothesis in which IONM increases the likelihood of improving clinical post-operative outcomes compared to non-IONM counterparts. This paradoxical outcome suggests potential confounding variables that warrant further investigation. For example, Gleave & Macfarlane (1990) demonstrated the incidence of improved clinical outcomes with an astonishing rate of 26 out of 33 cases (78.8%)[36]. It is important to consider potential case complexity bias as IONM will typically be utilized in high-risk cases with inherently limited potential for improvement compared to the straightforward disc decompressions that are performed in this study including non-IONM cohorts.

The analysis of different subcategories of spinal-related procedures reveals patterns that support our overall paradoxical findings as shown in Table 8. For tumor management, IONM procedures showed high preservation of baseline clinical outcomes (83-96.1%) but low rates of improvement (0-16.6%), whereas non-IONM cases had higher improvement rates (59-60%) but lower baseline preservation in clinical outcomes of (20-36.4%). This suggests that IONM is crucial in preventing deterioration in high-risk tumor cases, though it is less commonly associated with functional improvement, possibly due to the nature of

these surgeries. Likewise, tethered cord procedures paired with IONM had moderate improvement rates (23.5-50%) compared to higher rates in non-IONM cases (41.2-61.1%). Most strikingly, congenital malformation surgeries paired with IONM showed moderate improvement potential (up to 63.1%) with good preservation, while non-IONM cases showed no improvement and very high deterioration rates (73.9-75%). These procedure-specific differences reveal that intraoperative neuromonitoring mitigates against worsening in high-risk procedures, while the apparent lower improvement rates in IONM cases are likely not the direct correlation from the monitoring itself but due to confounding variables that require further exploration.

To have a better understanding of our findings in context, we examine below different complementary factors such as the underrepresentation of pelvic floor monitoring, intraoperative monitoring effectiveness analysis, and clinical implementation aspects. We aim to provide a more comprehensive assessment of the role of intraoperative neurophysiological monitoring (IONM) in preserving pelvic floor integrity during high-risk surgeries across different surgical categories while also considering the complex interplay of contributing factors of clinical outcomes.

The Current State of Pelvic IONM Practice

Despite advancements in intraoperative neuromonitoring (IONM), its usage in pelvic floor procedures is underrepresented compared to its well-established role in brain, spine, and peripheral nerve surgeries [37]. Historically, IONM has been used to assess neurological function in these areas, with techniques expanding to include brainstem reflexes, corticospinal tract mapping, and fascicular mapping [38].

Nonetheless, the integration of IONM in pelvic surgeries has been delayed due to various anatomical challenges, such as the delicate nature of pelvic autonomic nerves, and their similarity to surrounding connective and scar tissue, making identification difficult [39]. Furthermore, standardization in pelvic neuromonitoring remains limited, as the only widely available commercial systems include electromyography (EMG) of the internal anal sphincter and bladder manometry [40].

While these techniques provide valuable feedback, they present challenges such as procedural interruptions due to bladder filling requirements and difficulties in signal interpretation (particularly in bladder manometry) where respiratory rate dependency can lead to unstable pressure readings [41]. Alternative methods, including threshold-based signal evaluation, have been explored. However, they remain susceptible to random signal fluctuations and false positives [39].

Addressing these limitations is crucial for improving the safety and efficacy of pelvic surgeries, highlighting the need for further research and coordination in this field.

Monitoring Effectiveness Analysis

It is known that rectal surgeries and other surgeries of the pelvic floor still have high rates of surgical complications, such as postoperative urinary incontinence, fecal incontinence, and sexual dysfunction, which is why nerve-sparing procedures through IONM have grown increasingly important [42]. Trials such as the NEUROmonitoring System (NEUROS) double-armed randomized, controlled, multicentered trial of 189 patients undergoing total mesorectal excisions (TMEs) for rectal cancer, have shown that pelvic IONM has the potential to significantly improve functional outcomes and is safe [43]. Another clinical trial in Germany, where thirty patients underwent nerve-sparing rectal surgery using pelvic IONM, indicated that there was a reliable identification of the pelvic autonomic nerves during the surgery and were hence spared [42]. However, the number of clinical trials and observational studies is still very limited, and the evidence of their benefit is still not very well established.

A systematic review of five studies identified the diagnostic accuracy of pelvic IONM following rectal surgery in detecting urogenital and anorectal dysfunction and concluded that IONM can be routinely used in clinical practice [44]. Another systematic review of 32 studies, however, concluded that the use of IONM during hip and pelvic surgery is debatable and that the review results were insufficient to support the routine use of IONM in hip and pelvic surgery. It stated that different IONM techniques have peculiar pros and cons and differences in sensitivity and specificity without clear evidence of superiority of any [45].

Another review on the use of IONM during pelvic peritonectomy stated that the use of IONM during surgery is technically feasible, but the definitive value is yet to be established [46]. A critical appraisal of published studies by a meta-analysis of six comparative studies (one randomized trial and three retrospective and two prospective studies) on 489 patients, undergoing rectal resections concluded that IONM may reduce the risk of anorectal dysfunction, but the outcomes related to urinary and sexual dysfunction seem to be unchanged [47].

Large scale studies are warranted to definitively establish the use of IONM in different surgical procedures and to help establish a set of guidelines and protocols for the incorporation of IONM into routine surgeries where their benefits outweigh their pitfalls and help improve patient outcomes.

Clinical Implementation

Cost-Benefit Considerations

The use of IONM in numerous surgical procedures has been somewhat controversial for numerous reasons. We live in a cost-conscious healthcare climate, and deciding where surgeons battle whether to use IONM for all types of surgeries, including uncomplicated cases or cases of low and moderate difficulty, to help reduce and contain costs for third-party payers and patients [48]. A study by Ney PJ et al. revealed that the use of multimodal IONM reduced the relative risk of postoperative neurological complications by approximately 49.4% ($p < 0.001$) at a cost of $63,387 (95%CI $61,939–$64,836) for every neurological

deficit that was prevented [48]. The technical, operator, and instruments cost with the use of IONM increased the cost of an already expensive surgery by another $1,535 per case [48].

According to another study by Garces J et al., patients who underwent surgeries using IONM cost, on average, an additional $4,000 dollars per case, which was statistically significant (P=0.008) when compared to the group of patients who underwent surgery without IONM [49]. Additionally, surgeries using IONM took longer on average, 49.54 minutes, which was a statistically significant difference too (P=0.009) between both groups and hence, they concluded that they did not see any benefit of the monitoring in their series [49].

Conversely, a study by Kombos T et al. argued that inpatient rehabilitation costs have risen considerably in the last few decades, and keeping the financial situation in mind, it is necessary to reduce postoperative morbidity and the cost that it involves [50]. IONM is known to reduce morbidity, and hence, the calculated costs of IONM are justified in its routine application in view of the socioeconomic consequences and even legal issues that surgery-related neurological complications may follow [50].

So, given the current climate of cost-conscious healthcare, the development of an effective evidence-based algorithm for determining which surgical procedures should be monitored is very crucial. However, many surgeons want to monitor every case if they could do so if it could potentially benefit the patient. This warrants large-scale cost-effectiveness analyses to make conclusive remarks since there will be an increase in the demand for these analyses in the rapidly expanding field of value-based medicine [51].

Technical Challenges and Accuracy

Apart from the cost, another barrier to the utilization of IONM is the failure of SSEPs to detect significant spinal cord injury in multiple well-documented cases. These cases were regarded as false negatives by Pajewski TN et al. [52]. Significant variability arises from the differences in IONM and surgical staff expertise, and institution-specific guidelines, warranting a response should systematically address potential sources of disturbance.

Signal disturbance thresholds have received criticism, too, since a surgeon or an inexperienced operator may not recognize signal disturbances due to a developing neurological injury referencing a certain threshold marker compared to an experienced IONM operator or surgeon who is more familiar with the technology [53]. This is one of the reasons for the large number of false positives associated with IONM use as evidenced by a retrospective cohort study of 207 patients where fifty-two patients (25%) were initially considered to have experienced signal drops, but eventually fifty of these fifty-two cases (96%) eventually turned out to be false positives [54].

Hence, efforts are being made to standardize IONM protocols and optimize signal processing to minimize artifacts and improve signal reliability, as judged by their amplitudes. Another pitfall is the variability in

the signal waveform insults and consequent troubleshooting protocols after signal disturbances. Other factors contributing to the signal disturbances include the effect of inhaled anesthetics, technical malfunctions, other surgical techniques, and surgical positioning [55-57].

A survey was carried out in 2022, and 20 different surgical scenarios were shown to 193 surgeons to assess which modalities they would use. The findings showed that one main reason for implementing IONM was medical and legal reasons rather than complication avoidance in patients [58]. This suggests that the need for defense against malpractice lawsuits can influence IONM utilization. Additionally, many surgeons have also been hesitant to use IONM during surgeries due to the lack of standardization of protocols for patient safety and in optimal modality combinations[59].

Team Expertise and Professional Qualifications

The expertise and training level of the neuromonitoring team significantly influences postoperative outcomes, particularly in complex pelvic surgeries. Studies, including research from the experienced neuromonitoring team at UCLA, demonstrate that centers with highly trained personnel report postoperative deficits in less than 50% of cases. Notably, outcomes improve with increasing team experience, with neuromonitoring teams involved in over 300 surgeries reporting fewer deficits compared to teams with experience in only 100 procedures.

In addition to experience, specific certifications play a critical role in ensuring optimal monitoring performance. Best outcomes are associated with teams that include technologists certified as CNIM (Certified in Neurophysiologic Intraoperative Monitoring) through ABRET.org and professionals holding the D.ABNM (Diplomate of the American Board of Neurophysiologic Monitoring) credential. These certifications ensure both technical proficiency in data acquisition and advanced expertise in real-time interpretation, contributing to improved patient safety and functional preservation.

Future Directions and Recommendations

Future research in pelvic intraoperative neurophysiological monitoring must address several important aspects to advance clinical practice. First, emerging modalities such as pudendal SSEPs require specific validation studies to determine standardized stimulation parameters, recording parameters, and alarm criteria for pelvic surgery. These studies must correlate intraoperative signal changes with functional outcomes to prove predictive validity across surgical specialties.

Researchers must develop and test standardized multimodal protocols that combine traditional modalities with newer modalities such as bladder MEPs and enhanced BCR monitoring. These protocols would establish the modality pairs most appropriate for optimal neural monitoring during the different phases of surgery in gynecologic, urologic, colorectal, and spine surgeries. As suggested in our discussion, IONM is underrepresented in these surgical fields despite the rates of postoperative pelvic floor dysfunction. Technological development would be aimed at reducing the invasiveness of recording, automated signal

analysis software to reduce false positives, and integrated visual systems for anatomical correlation in real time.

Prospective multicenter trials involving large numbers will be necessary to ascertain whether the use of standardized pelvic IONM reduces postoperative dysfunction rates in heterogeneous groups of patients and operations. Such trials will need to stratify by case complexity and consider the aim of the procedures to clarify our paradoxical finding of improvement rates for monitored and unmonitored cases. Studies also need to examine our paradoxical finding of significantly lower rates of improvement in spinal-related cases of IONM and note whether this phenomenon correlates with the severity of the case, technical limitations of interpreting signals, or altered surgical strategy when monitored.

In addition, health economic analyses need to quantify the direct costs of IONM implementation from prevented complications and reduced rehabilitation needs, establishing a comprehensive cost-benefit framework to guide clinical adoption of pelvic-specific IONM protocols. Standardization of IONM monitoring protocols, alert criteria, and outcome measures will be necessary to provide a more comprehensive comparative analysis while addressing high false positive rates commonly reported in the literature.

By conducting this research with appropriately qualified surgical teams, we can develop evidence-based guidelines for the application of IONM to preserve pelvic floor function across surgical specialties.

LIMITATIONS

In this systematic review, we evaluated the role of intraoperative neurophysiological monitoring (IONM) in preserving pelvic floor integrity through the comparative analysis of worsened, unchanged, and improved clinical outcomes of surgical procedures performed with and without IONM. According to our inclusion criteria, our study included up to four surgical categories: spinal, gynecological, urological, and colorectal. However, only spinal-related procedural outcomes were included for comparative analysis due to insufficient studies for gynecological, urological, and colorectal procedures in the IONM group.

The uneven distribution of IONM studies across surgical specialties in our meta-analysis reflects the current state of research in this field. While IONM is well-established in spinal surgery with substantial evidence supporting its use, there remains a significant gap in the literature regarding its application in gynecological, urological, and colorectal procedures. This disparity persisted despite our comprehensive search strategy, suggesting a true limitation in the current research landscape rather than a methodological shortcoming. Identifying this research gap represents an important finding of our systematic review and underscores the need for expanded investigation in these surgical specialties.

While the non-IONM group had a nearly even distribution of gynecological, colorectal, urological, and spinal-related procedures, the IONM group had the majority, including spinal-related procedures. As such, we were unable to conduct a more comprehensive comparative analysis across all surgical subspecialties to assess the differences in clinical outcomes. Despite efforts to employ a uniform dual-search strategy for our literature search using identical search terminology, with the addition of specific IONM-related keywords for our IONM group the lack of sufficient IONM studies in gynecological, colorectal, and urological surgery remains a limitation to the current analysis. This lack of balance limits the generalizability of our findings to these specific surgical specialties.

CONCLUSION

Intraoperative neurophysiological monitoring (IONM) offers substantial clinical benefits in preserving neural integrity during surgeries involving pelvic structures. Our systematic analysis demonstrates that IONM implementation significantly enhances preservation of baseline neurological function while diminishing deterioration risk. A paradoxical finding in our analysis was that IONM-associated cases showed lower rates of functional improvement. This likely reflects both a selection bias toward more complex cases and the differing primary aims of each surgical category. Despite demonstrated efficacy in spinal procedures, IONM remains underutilized in pelvic surgeries due to anatomical complexity and inconsistent monitoring protocols. We advocate for the broader adoption of multimodal IONM in pelvic procedures and recommend rigorously designed multicenter trials using standardized protocols.

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