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Scoping review Article: Focus on utility intraoperative neuro-monitoring in neurosurgery: Scoping review

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ABSTRACT

Intraoperative neuro-monitoring (IONM) is a crucial technique employed in neurosurgery to assess and preserve the functional integrity of the nervous system during surgical procedures. This scoping review aims to explore and summarize the existing literature on the utility of IONM in neurosurgery, focusing on its benefits, limitations, and current advancements. A comprehensive search of electronic databases was conducted, and relevant studies published between 2010 and 2023 were included. The review encompassed a wide range of neurosurgical procedures, including spinal, cranial, and peripheral nerve surgeries. The included studies predominantly focused on the application of various IONM modalities, such as somatosensory evoked potentials (SSEPs), motor-evoked potentials (MEPs), electromyography (EMG), electroencephalography (EEG), and brainstem auditory evoked potentials (BAEPs). The findings of this scoping review highlight the utility of IONM across different neurosurgical procedures. The use of IONM was consistently associated with a reduction in the incidence of postoperative neurological deficits, aiding in the prevention of nerve injuries and subsequent functional impairments. Furthermore, IONM was found to assist in identifying and localizing neural structures, guiding surgical approaches, and optimizing patient outcomes.

Introduction

Intraoperative neuro-monitoring (IONM) has revolutionized the field of neurosurgery by providing real-time feedback and guidance during complex surgical procedures involving the nervous system(fig 1) [1-3]. It is a specialized technique that involves monitoring and assessing the functional integrity of the nervous system, particularly the brain and spinal cord, while the patient is undergoing surgical intervention [4-6]. By employing advanced electrophysiological and neuroimaging techniques, IONM helps neurosurgeons make informed decisions,

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***Corresponding Author: Mansour Rezaei** (*M-Rezaei@yahoo.com*) minimize potential risks, and optimize surgical outcomes [7-9].

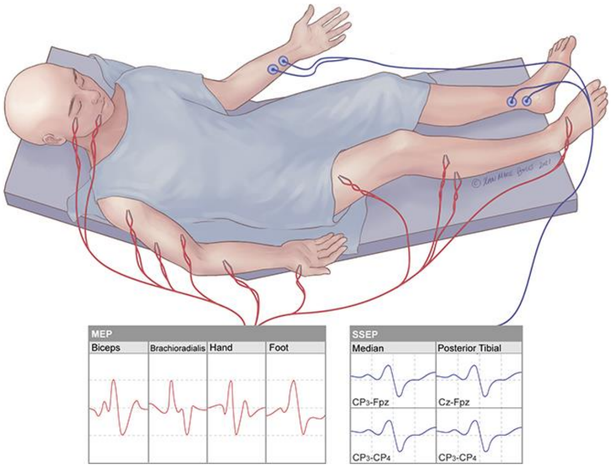

Figure 1: Intraoperative neuro-monitoring

The human nervous system is a complex network of interconnected structures responsible for transmitting and processing electrical signals that control various bodily functions [10-13]. When performing neurosurgical procedures, the delicate nature of the nervous system poses significant challenges to surgeons [14-16]. The proximity of critical neural structures, such as the brainstem, spinal cord, and motor pathways, requires utmost precision and caution to avoid irreversible damage and functional deficits. In this context, IONM has emerged as a vital tool in the neurosurgeon's armamentarium [17-19].

The primary goal of IONM is to identify and prevent injury to critical neural pathways, thereby preserving neurological function and enhancing patient safety [20-22]. Through the real-time monitoring of electrical signals, such as evoked potentials and electromyography, IONM enables surgeons to assess the functional status of nerves, monitor the integrity of neural pathways, and detect any changes that may occur during the surgical procedure [23-25]. This invaluable feedback empowers the surgical team to make immediate adjustments and take appropriate measures to mitigate potential risks [26-28].

IONM begins before the surgical incision, typically during the induction of anesthesia. Electrodes or sensors are strategically placed on specific sites of the patient's body to capture and record the electrical activity of the nervous system [29-31]. For instance, in procedures involving the spinal cord, electrodes may be positioned along the length of the spine to monitor motor and sensory functions. In surgeries involving the brain, electrodes may be placed on the scalp or directly on the cortical surface to record brainwave activity [32-35].

During the surgery, the recorded signals are continuously analyzed by a team of highly trained neurophysiologists who work in close collaboration with the surgical team. This multidisciplinary approach ensures that any deviations or abnormalities in the monitored signals are promptly detected and communicated to the surgeon [36-38]. The neurophysiologists interpret the data, identify potential risks, and provide real-time feedback to guide the surgeon's actions. This collaborative effort between the neurophysiologists and the surgical team forms the cornerstone of IONM and greatly enhances patient safety [39-41].

The applications of IONM in neurosurgery are vast and encompass a wide range of procedures. For instance, in brain tumor resections, IONM plays a crucial role in preserving neurological function by continuously monitoring brainwave activity and evoked potentials [42-45]. By closely monitoring the electrical signals, the surgical team can identify areas of the brain that are critical for motor, sensory, or language functions. This knowledge allows the surgeon to navigate the tumor resection with precision, minimizing the risk of damage to vital neural structures and reducing postoperative deficits [46-48].

In spinal surgeries, IONM is essential for monitoring the integrity of the spinal cord and nerve roots. By assessing motor and sensory functions, as well as somatosensory and motor-evoked potentials, IONM helps identify potential injury to the spinal cord during procedures such as spinal fusions, decompressions, and tumor resections. The ability to detect changes in neural function in real-time allows the surgeon to modify their approach, reposition instrumentation, or take other corrective measures to prevent permanent damage [49].

IONM is also valuable in complex vascular interventions, such as aneurysm surgeries and arteriovenous malformation (AVM) resections. By monitoring blood flow and evoked potentials, IONM helps detect any compromise to the blood supply of critical neural structures [50-53]. This information guides the surgeon in determining the optimal timing and approach for the intervention, ensuring that the patient's neurological function is preserved [54].

Furthermore, IONM has proven beneficial in the treatment of epilepsy and movement disorders. For patients undergoing epilepsy surgery, IONM allows the surgeon to precisely identify and spare functional brain regions responsible for vital functions, while effectively removing the epileptic focus [55-57]. In deep brain stimulation procedures for movement disorders like Parkinson's disease, IONM assists in locating the optimal target for electrode placement and ensuring accurate stimulation settings for optimal therapeutic outcomes [58-60].

The advancements in IONM have significantly improved patient outcomes in neurosurgery. By providing real-time feedback, IONM allows neurosurgeons to navigate complex anatomical structures with precision and confidence, ensuring optimal outcomes for their patients. It has become an essential component of modern neurosurgical practice, enhancing surgical safety and reducing the risk of postoperative complications [61-63].

In conclusion, intraoperative neuro-monitoring has emerged as an indispensable tool in neurosurgery, enabling surgeons to preserve neurological function, minimize complications, and enhance patient safety. Through the continuous monitoring of electrical signals, IONM provides real-time feedback that guides surgical decision-making and helps prevent potential damage to critical neural structures [64-66]. As technology continues to advance, thefuture of IONM holds the promise of further improving surgical outcomes and advancing the field of neurosurgery [67-69]. With ongoing research and innovation, IONM techniques may become more sophisticated, allowing for enhanced resolution and accuracy in monitoring neural function. This, in turn, will enable neurosurgeons to perform increasingly complex procedures with greater precision and confidence [70-73].

However, it is important to note that IONM is not a standalone solution but rather a complementary tool that works in conjunction with the surgical expertise of neurosurgeons. It requires a collaborative effort between the surgical team and neurophysiologists to effectively utilize the information provided by IONM and make critical decisions during surgery [74-76].

In conclusion, intraoperative neuro-monitoring has transformed the landscape of neurosurgery by providing real-time feedback and guidance during complex procedures involving the nervous system [77-79]. Through the continuous monitoring of electrical signals, IONM helps preserve neurological function, minimize risks, and optimize surgical outcomes. As technology and techniques continue to advance, IONM will likely play an increasingly significant role in neurosurgical practice, ultimately benefiting patients by improving surgical safety and enhancing overall patient care [80].

Somatosensory-evoked potentials

Somatosensory-evoked potentials (SSEPs) are a valuable neurophysiological tool used in neurosurgery to assess the integrity of the somatosensory pathways and monitor the functional status of the nervous system during surgical procedures. SSEPs provide real-time feedback about the transmission of sensory signals from peripheral nerves to the brain, aiding neurosurgeons in preserving neurological function and minimizing the risk of postoperative deficits(fig 2) [81].

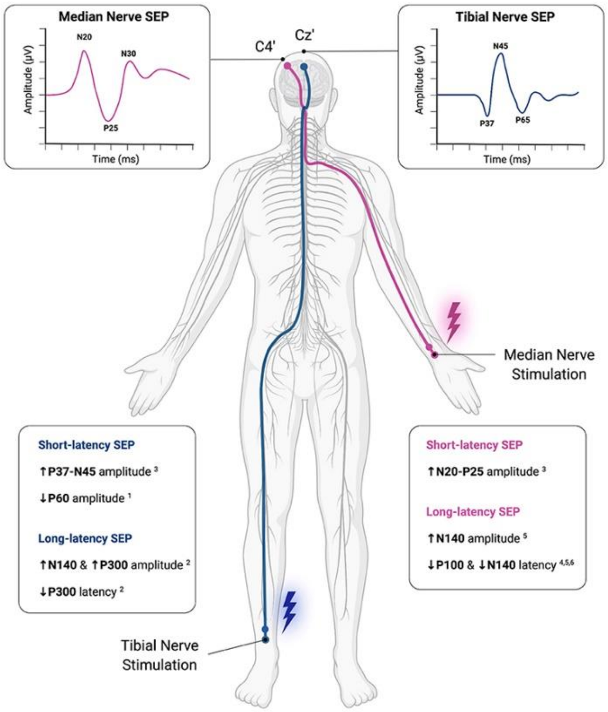

Figure 2: Somatosensory-evoked potential (SEP) application and summarized results

The somatosensory system is responsible for the perception of touch, pressure, temperature, and pain. It involves a complex network of sensory fibers that transmit signals from the periphery to the brain. During neurosurgical procedures, particularly those involving the spinal cord or peripheral nerves, the manipulation or compression of these structures can potentially lead to damage or compromise the transmission of somatosensory information. SSEPs play a crucial role in helping surgeons identify and prevent such injuries.

SSEPs are generated by stimulating peripheral nerves and recording the resulting electrical activity at various points along the somatosensory pathway. The stimulation is typically performed by delivering a brief electrical impulse to a specific peripheral nerve, such as the median nerve in the upper extremity or the tibial nerve in the lower extremity. The electrical impulse travels along the nerve fibers, through the spinal cord, and finally reaches the somatosensory cortex in the brain, generating a characteristic waveform that can be measured and analyzed.

The SSEP waveform consists of several components, including the N20, P25, N30, P40, and N60 waves. These waves represent different stages of the neural processing along the somatosensory pathway. The N20 wave corresponds to the arrival of the sensory signal at the primary somatosensory cortex, while the subsequent waves reflect the subsequent processing and integration of the sensory information. By analyzing the amplitude, latency, and morphology of these waves, neurophysiologists can assess the functional integrity of the somatosensory pathway and detect any abnormalities or changes that may occur during surgery.

During a neurosurgical procedure, SSEPs are typically monitored by placing electrodes on the scalp overlying the somatosensory cortex, as well as on other strategic locations along the pathway, such as the spinal cord or peripheral nerves. The recorded SSEP signals are continuously analyzed by a team of neurophysiologists who work alongside the surgical team. Any significant changes or deviations in the SSEP waveform are immediately communicated to the surgeon, who can then modify their approach or take corrective measures to prevent potential damage to the somatosensory system.

The clinical applications of SSEP monitoring in neurosurgery are vast. In procedures involving the spinal cord, such as spinal fusions or tumor resections, SSEPs provide critical information about the integrity of the sensory pathways. By monitoring SSEPs, surgeons can assess the impact of their manipulations on the spinal cord and take immediate action to prevent irreversible damage. For instance, if a significant decrease in SSEP amplitude or an increase in latency is observed, it may indicate spinal cord compression or compromise, prompting the surgeon to adjust their surgical technique or relieve the pressure on the spinal cord.

SSEPs are also invaluable in surgeries involving peripheral nerves, such as nerve decompressions or tumor resections. By stimulating the peripheral nerves and monitoring the evoked responses, surgeons can determine the functional status of the nerves and ensure their preservation during the procedure. SSEP monitoring helps identify any inadvertent nerve injuries, such as traction or compression, and guides the surgeon in taking appropriate measures to prevent permanent damage.

Furthermore, SSEPs have proven to be particularly useful in surgeries involving the posterior fossa region of the brain, where critical structures, such as the brainstem or cranial nerves, are located. By monitoring SSEPs during these procedures, neurosurgeons can detect any potential compromise to the sensory pathways or brainstem function and adjust their surgical approach accordingly, minimizing the risk of postoperative deficits.

In conclusion, somatosensory-evoked potentials (SSEPs) play a vital role in neurosurgery by providing real-time feedback about the functional integrity of the somatosensory pathways. By monitoring the transmission of sensory signals from peripheral nerves to the brain, SSEPs help neurosurgeons identify and prevent potential injuries and optimize surgical outcomes. SSEP monitoring is particularly valuable in procedures involving the spinal cord, peripheral nerves, and posterior fossa region of the brain. With ongoing advancements in neurophysiological techniques, SSEP monitoring continues to evolve, enhancing patient safety and improving the overall quality of neurosurgical interventions.

Motor-evoked potentials

Motor-evoked potentials (MEPs) are a crucial neurophysiological tool used in neurosurgery to assess the functional integrity of the motor pathways and monitor the status of the nervous system during surgical procedures. MEPs provide real-time feedback about the transmission of motor signals from the brain to the muscles, aiding neurosurgeons in preserving motor function and minimizing the risk of postoperative deficits(fig 3).

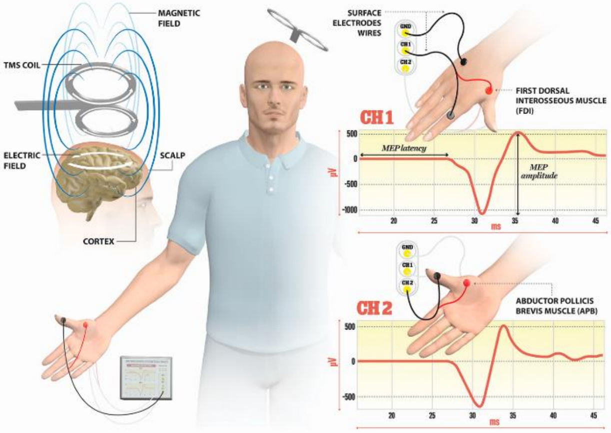

Figure 3: Illustration of the direction of current flows in a magnetic coil and the induced current in the brain tissue

The motor system is responsible for initiating and controlling voluntary muscle movements. It involves a complex network of motor fibers that transmit signals from the motor cortex in the brain to the muscles throughout the body. During neurosurgical procedures, particularly those involving the brain or spinal cord, the manipulation or compression of these structures can potentially lead to damage or compromise the transmission of motor information. MEPs play a crucial role in helping surgeons identify and prevent such injuries.

MEPs are generated by stimulating the motor cortex of the brain using a non-invasive technique called transcranial electrical stimulation (TES) or by applying direct electrical stimulation to the exposed cortical surface during surgery. The stimulation triggers an electrical impulse that travels along the motor pathways, through the spinal cord, and finally reaches the muscles, resulting in a muscular response that can be measured and analyzed.

The MEP waveform consists of several components, including the initial negative deflection called N1, followed by a positive deflection labeled P1. These components reflect the activation of the motor pathways and the subsequent generation of the muscular response. By analyzing the amplitude, latency, and morphology of MEPs, neurophysiologists can assess the functional integrity of the motor pathways and detect any abnormalities or changes that may occur during surgery.

During a neurosurgical procedure, MEPs are typically monitored by placing electrodes on the scalp overlying the motor cortex, as well as on the muscles being evaluated. The recorded MEP signals are continuously analyzed by a team of neurophysiologists who work in close collaboration with the surgical team. Any significant changes or deviations in the MEP waveform are immediately communicated to the surgeon, who can then modify their approach or take corrective measures to prevent potential damage to the motor system.

The clinical applications of MEP monitoring in neurosurgery are diverse. In procedures involving the brain, such as tumor resections or epilepsy surgeries, MEPs provide critical information about the functional status of the motor pathways. By monitoring MEPs, surgeons can assess the impact of their manipulations on the motor cortex and take immediate action to prevent irreversible damage. For instance, if a significant decrease in MEP amplitude or an increase in latency is observed, it may indicate motor pathway compression or compromise, prompting the surgeon to adjust their surgical technique or relieve the pressure on the motor cortex.

MEPs are also invaluable in surgeries involving the spinal cord, such as spinal fusions or tumor resections. By stimulating the motor pathways and monitoring the evoked responses in the muscles, surgeons can determine the functional status of the motor nerves and ensure their preservation during the procedure. MEP monitoring helps identify any inadvertent nerve injuries, such as traction or compression, and guides the surgeon in taking appropriate measures to prevent permanent motor deficits.

Furthermore, MEPs have proven to be particularly useful in surgeries involving the spinal cord or the posterior fossa region of the brain, where critical motor structures, such as the corticospinal tracts or the brainstem, are located. By monitoring MEPs during these procedures, neurosurgeons can detect any potential compromise to the motor pathways or brainstem function and adjust their surgical approach accordingly, minimizing the risk of postoperative motor deficits.

In some cases, MEP monitoring is also utilized during functional neurosurgical procedures, such as deep brain stimulation (DBS) surgeries for movement disorders like Parkinson's disease or essential tremor. By monitoring MEPs during the placement of electrodes in specific brain regions, surgeons can ensure accurate targeting and minimize the risk of motor side effects.

In conclusion, motor-evoked potentials (MEPs) play a crucial role in neurosurgery by providing real-time feedback about the functional integrity of the motor pathways. By monitoring the transmission of motor signals from the brain to the muscles, MEPs help neurosurgeons identify and prevent potential injuries and optimize surgical outcomes. MEP monitoring is particularly valuable in procedures involving the brain, spinal cord, or posterior fossa region. With ongoing advancements in neurophysiological techniques, MEP monitoring continues to evolve, enhancing patient safety and improving the overall quality of neurosurgical interventions.

Electromyography

Electromyography (EMG) is a vital component of intraoperative neuro-monitoring (IONM) in neurosurgery. It is a diagnostic technique that measures and records the electrical activity produced by skeletal muscles. In the context of neurosurgical procedures, EMG is used to monitor the functional integrity of the peripheral nerves and muscles, providing real-time feedback to the surgical team and helping to prevent potential nerve injuries and postoperative deficits.

During neurosurgery, particularly procedures involving the spinal cord, peripheral nerves, or brainstem, the manipulation or compression of neural structures can potentially lead to nerve damage or compromise. EMG is utilized to assess the functional status of the peripheral nerves and muscles, allowing the surgical team to identify and mitigate any potential injuries.

EMG involves the placement of small needle electrodes into the target muscles. These electrodes detect the electrical signals generated by the muscle fibers during contraction or relaxation. The recorded electrical activity is displayed as a waveform on an EMG monitor and can be analyzed by trained neurophysiologists.

In the context of IONM, EMG serves multiple purposes:

Nerve Localization: EMG helps identify and localize the peripheral nerves during surgery. By stimulating the nerves with a mild electrical impulse and recording the resulting muscle response, the surgeon can confirm the location and integrity of the nerves, guiding their dissection and minimizing the risk of inadvertent nerve injury.

Nerve Integrity Monitoring: EMG provides continuous monitoring of the peripheral nerves throughout the surgical procedure. By monitoring the EMG activity, the surgical team can detect any changes or abnormalities in the electrical signals, such as decreased amplitude or increased latency, which may indicate nerve compression, traction, or injury. This early warning system allows the surgeon to take immediate action to prevent further damage.

Muscle Function Assessment: EMG can assess the functional status of the muscles during surgery. By evaluating the electrical activity generated by the muscles, the surgical team can determine if the muscle is functioning properly or if there is any compromise due to nerve injury or manipulation. This information aids in planning the surgical approach and helps prevent postoperative motor deficits.

Nerve Decompression Confirmation: In procedures involving nerve decompression, such as carpal tunnel release or nerve entrapment syndromes, EMG can be used to confirm the success of the procedure. By comparing the pre- and post-decompression EMG activity, surgeons can assess the improvement in nerve function and ensure the effectiveness of the surgical intervention.

Facial Nerve Monitoring: EMG is particularly valuable in surgeries involving the facial nerve, such as acoustic neuroma resections or facial nerve decompressions. By monitoring the electrical activity of the facial muscles, surgeons can identify any potential damage or compromise to the facial nerve and take immediate action to preserve its function.

Multimodality intraoperative neuromonitoring

Multimodality intraoperative neuromonitoring (IONM) is an advanced technique used in neurosurgery to monitor multiple aspects of the nervous system simultaneously during surgical procedures. It combines various neurophysiological modalities to provide real-time feedback about the functional integrity of the central and peripheral nervous systems, aiding in the preservation of neurological function and minimizing the risk of postoperative deficits(fig 4).

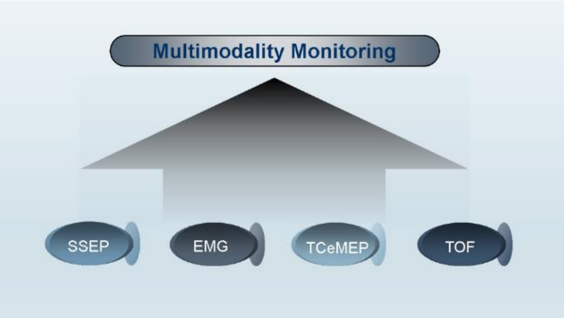

Figure 4: Multimodality intraoperative neuromonitoring steps

Traditionally, IONM involved the use of a single neurophysiological modality, such as somatosensory evoked potentials (SSEPs) or electromyography (EMG), to monitor specific aspects of the nervous system. However, with the advancements in technology and the understanding of neurological pathways, multimodality IONM has emerged as a more comprehensive and effective approach.

Multimodality IONM typically integrates a combination of the following neurophysiological techniques:

Somatosensory Evoked Potentials (SSEPs)

SSEPs involve the stimulation of peripheral nerves and recording of electrical signals generated by the sensory pathways in response to the stimulation. By monitoring SSEPs, which typically include the peripheral nerve action potentials and cortical responses, neurophysiologists can assess the functional integrity of the sensory pathways during surgery. Changes in SSEPs can indicate potential nerve compression or compromise, allowing the surgical team to take immediate action to prevent permanent sensory deficits.

Motor-Evoked Potentials (MEPs): MEPs involve the stimulation of the motor cortex or motor pathways and recording of the resulting electrical signals in the muscles. By monitoring MEPs, neurophysiologists can assess the functional integrity of the motor pathways, detect any abnormalities or changes during surgery, and help prevent motor deficits. MEP monitoring is particularly valuable in procedures involving the brain, spinal cord, or posterior fossa region.

Electromyography (EMG): EMG measures and records the electrical activity produced by skeletal muscles. It is used to monitor the functional integrity of the peripheral nerves and muscles during surgery. EMG can help identify and localize the peripheral nerves, assess muscle function, and detect any potential nerve injuries or compromise.

Electroencephalography (EEG): EEG measures and records the electrical activity of the brain. In multimodality IONM, EEG is used to monitor the overall brain function and detect any changes or abnormalities in the electrical signals, such as seizures or ischemia, which may require immediate intervention.

Brainstem Auditory Evoked Potentials (BAEPs): BAEPs involve the stimulation of the auditory pathways and recording of the resulting electrical responses in the brainstem. BAEP monitoring is particularly useful in procedures involving the brainstem or acoustic nerve, such as acoustic neuroma resections. It helps assess the functional integrity of the auditory pathways and aids in the preservation of hearing function.

By combining these neurophysiological modalities, multimodality IONM provides a comprehensive assessment of the central and peripheral nervous systems during surgery. The simultaneous monitoring of sensory, motor, and brain function allows for a more accurate evaluation of the neural structures' integrity and helps guide the surgical team in real-time decision-making.

The information obtained from multimodality IONM is continuously analyzed and interpreted by a team of trained neurophysiologists who work closely with the surgical team. Any significant changes or deviations in the monitored signals are immediately communicated to the surgeon, who can then modify their approach or take corrective measures to preserve neurological function.

Multimodality IONM has revolutionized neurosurgery by enhancing patient safety and improving surgical outcomes. By providing a comprehensive assessment of the nervous system's functional integrity, it helps minimize the risk of neurological deficits and optimize surgical interventions.

Who can carry out neuromonitoring?

Neuromonitoring, also known as intraoperative neurophysiological monitoring (IONM), is a specialized technique performed during surgical procedures to monitor the integrity and function of the nervous system in real-time. It requires a multidisciplinary team of professionals with specific expertise in neurophysiology and neurosurgery. The following are the key individuals who play a role in carrying out neuromonitoring:

Neurophysiologist: A neurophysiologist is a highly trained specialist who plays a central role in the execution of neuromonitoring. They are responsible for setting up and operating the neurophysiological equipment, analyzing the data, and providing real-time feedback to the surgical team. Neurophysiologists interpret the signals recorded from various modalities, such as somatosensory evoked potentials (SSEPs), motor-evoked potentials (MEPs), electromyography (EMG), electroencephalography (EEG), and brainstem auditory evoked potentials (BAEPs). They communicate any significant changes or abnormalities in the monitored signals to the surgical team, enabling prompt intervention to prevent potential nerve injuries or deficits.

Neurosurgeon: The neurosurgeon is the primary surgical specialist responsible for performing the procedure and coordinating the overall surgical team. They work closely with the neurophysiologist and rely on their expertise to guide the surgical approach based on the neuromonitoring findings. The neurosurgeon collaborates with the neurophysiologist to interpret the data and make surgical decisions that aim to preserve neurological function and minimize the risk of postoperative deficits.

Anesthesiologist: The anesthesiologist plays a crucial role in neuromonitoring by ensuring the patient's overall well-being and administering the appropriate anesthesia during the surgical procedure. They work in coordination with the neurophysiologist to maintain stable physiological conditions for accurate neurophysiological recordings. The anesthesiologist monitors the patient's vital signs and adjusts anesthesia levels as necessary to optimize the reliability of the neuromonitoring data.

Surgical Team: The surgical team, which includes nurses, surgical technicians, and other supporting staff, assists the neurosurgeon and neurophysiologist during the procedure. They help prepare the patient, set up the equipment, and ensure a sterile surgical environment. The surgical team follows the instructions provided by the neurophysiologist regarding patient positioning, electrode placement, and any necessary adjustments to maintain optimal neuromonitoring conditions.

It's important to note that the specific requirements and regulations for performing neuromonitoring may vary depending on the country or healthcare system. In some cases, additional certifications or specific training may be required for individuals involved in neuromonitoring. The expertise of the neurophysiologist is particularly critical, as they are responsible for operating the equipment, interpreting the data, and communicating with the surgical team in real-time.

Conclusion

Neuromonitoring is a collaborative effort involving a multidisciplinary team. The neurophysiologist, neurosurgeon, anesthesiologist, and surgical team work together to ensure the accurate monitoring of the nervous system during surgery and make informed decisions to protect neurological function. Their collective expertise and communication are vital in achieving successful outcomes and minimizing the risk of postoperative complications.

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