Brief Overview about Intraoperative Neurophysiological Monitoring

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Abstract

Intraoperative neurophysiological monitoring (IONM) measures neural function and integrity during surgical procedures. IONM is often associated with reducing the risk of postoperative neurological deficits in operations where the nervous system is at risk of being permanently injured. Reducing the risk of loss of function in portions of the nervous system is based on the observation that the function of neural structures usually changes in a measurable way before being permanently damaged . Reversing the surgical manipulation that caused the change within a certain time will result in a recovery to normal or near-normal function, whereas if no intervention had been taken, there would have been a risk that permanent postoperative neurological deficit would have resulted. Alerted to the loss of a neural signal, the surgeon has the opportunity to adjust the procedure to decrease the risk of long-lasting damage . There is a large range over which recovery can occur either totally or partially. To a certain degree of injury, there can be total recovery, but thereafter, the neural function might be affected for some time. After more severe injury, the recovery of normal function not only takes a longer time but the final recovery would only be partial, with the degree of recovery depending on the nature, degree, and duration of the insult.
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Introduction

IONM measures neural function and integrity during surgical procedures (1). IONM is often associated with reducing the risk of postoperative neurological deficits in operations where the nervous system is at risk of being permanently injured (2).

Alerted to the loss of a neural signal, the surgeon has the opportunity to adjust the procedure to decrease the risk of long-lasting damage. There is a large range over which recovery can occur either totally or partially. To a certain degree of injury, there can be total recovery, but thereafter, the neural function might be affected for some time. After more severe injury, the recovery of normal function not only takes a longer time but the final recovery would only be partial, with the degree of recovery depending on the nature, degree, and duration of the insult **(1)**.

Principle of IONM

The general principle of IONM is to apply a stimulus and then to record the electrical response from specific neural structures along the neural pathway that are at risk of being injured. This can be done by recording the near-field evoked potentials by placing a recording electrode on a specific neural structure that becomes exposed during the operation or, as more commonly done, by recording the far-field evoked potentials from, for instance, electrodes placed on muscles or the surface of the scalp **(3).**

Types of IONM

The importance of selecting the appropriate modality of intraoperative neurophysiological potentials for monitoring purposes cannot be overemphasized and making sure that the structures of the nervous system that are at risk are included in the monitoring is essential. Monitoring the wrong side of the patient's nervous system is, also, a serious mistake **(2).**

Among the primary modalities used are somatosensory evoked potentials (SSEPs), and transcranial motor evoked potentials (TcMEP) , Depth of anesthesia can be assessed by Spectral Edge Frequency (SEF) and Degree of muscle relaxant blockade by Train Of Four (TOF).

1- Monitoring of sensory system

Intraoperative monitoring of the function of sensory systems has been widely practiced since the middle of the 1980s. The earliest uses of IONM of sensory systems were modelled after the clinical use of recording sensory evoked potentials for diagnostic purposes **(4).**

Somatosensory evoked potentials (SSEPs)

Sensory systems are monitored by applying an appropriate stimulus and recording the response from the ascending neural pathway in dorsal column of spinal cord, usually by placing recording electrodes on the surface of the scalp to pick up far-field potentials from nerve tracts and nuclei in the brain (far-field responses) **(5).**

SSEPs has long been used during scoliosis surgery, and it is increasingly used in major spine and aortic surgery when the chance of spinal cord injury is significant. It has an additional advantage of detecting malposition of the upper limbs causing brachial plexus injury **(6).**

SSEPs are recorded after electrical stimulation of a peripheral mixed nerve. Stimulation is provided most commonly with surface electrodes (e.g., electrocardiogram electrodes) placed on the skin above the nerve or with fine needle electrodes. A square wave stimulus lasting 50 to 250 sec is delivered to the peripheral nerve and the intensity is adjusted to produce a minimal muscle contraction. Increasing the stimulus intensity beyond the sum of the motor and sensory threshold does not influence the amplitude or latency of the recorded evoked potential. However, SSEPs monitoring is often not initiated until after the patient is already anesthetized and paralyzed. In these cases, stimulus intensity is increased until no further increase in response size occurs at any recording site, typically constant current stimulation of 20 to 50 mA. For comparison, consider supra maximal stimulation used for the neuromuscular blockade monitor, commonly 80 mA. The rate of stimulation varies from 1 to 6 Hertz (Hz). The common sites of stimulation include the median nerve at the wrist, the common peroneal nerve at the knee, and the posterior tibial nerve at the ankle **(6).**

The response is recorded either directly at exposed cortex or at the scalp of the primary somatosensory cortex at "C3" , "Cz" , and "C4" (according to the international 10-20 electroencephalogram (EEG) system in the form of latency and amplitude as in fig. (1) **(7).**

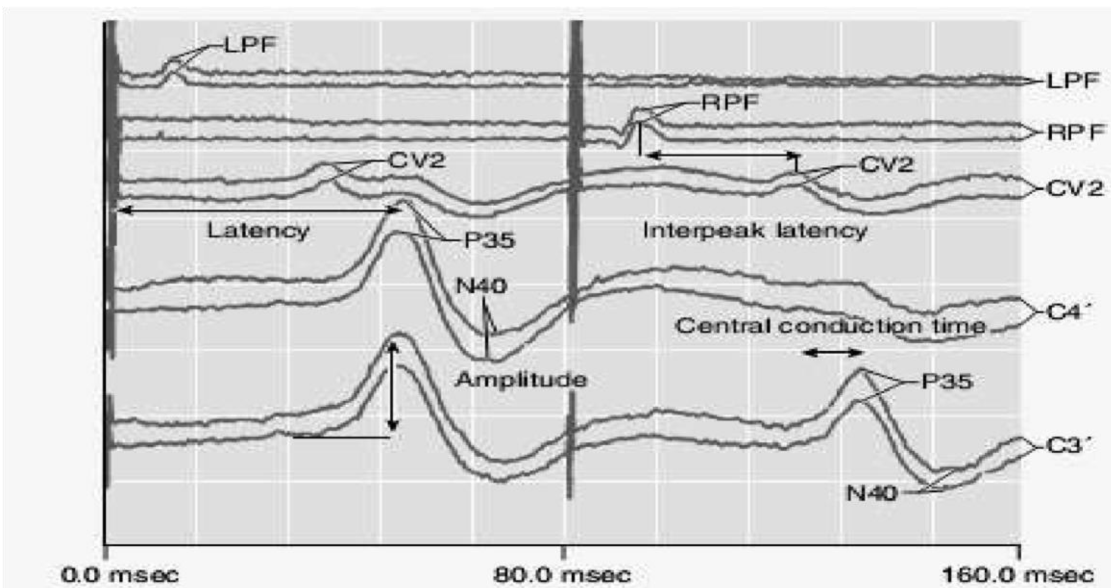

Figure (1) :Sensory-evoked responses are described in terms of latency and amplitude. Latency is the measured time between two peaks. The example shows a recording of posterior tibial somatosensory-evoked potentials. Each tracing is reproduced twice because reproducibility of a waveform helps distinguish signal from artifact. Left and right posterior tibial nerves are stimulated at 0 and 90 mSec, respectively. The first evoked response is recorded from the left and right popliteal fossa (LPF and RPF, respectively). The peak labeled CV2 represents the brainstem response recorded at the cranio cervical junction. As a far-field potential, the potential looks similar for right- and left-sided stimulation. The primary cortical responses are recorded from the contralateral hemisphere (labeled P35 and N40) (7).

Lower limb SSEPs (LLSSEPs): Stimulation of the tibial nerve at ankle, with recording at the popliteal fossae .

Upper limb SSEPs (ULSSEPs): Stimulation of the median/ulnar nerve at wrist, with recording at the cubital fossae and/or Erb's point. This will help better distinguish technical changes and arm positional changes.

Interpretation of SSEPs and effect on anesthetic drugs on it :

We can define predetermined SSEPs warning criterion that it is a significant repeatable change in amplitude and/or latency of the waveform which cannot be explained by reversible technical or anesthetic changes .Common SSEPs alert criteria include: Disappearance of waveform , Amplitude reduction (50% or more) , Latency increase (10% or more) or any change that cannot be explained technically or anesthetically. Compromised blood supply to the part of the spinal cord that generates the SSEPs (mainly the dorsal part) can be detected by monitoring SSEPs. Ischemia to parts of the brain that is involved in the generation of SSEPs can also be detected by monitoring SSEPs **(4).**

Advantages: It can be monitored while the patient is paralyzed by muscle relaxants, which may help to reduce signal interference. Because signals are run continuously without patient movement, detection of an alert is not dependent on the proximity to the last time the case was paused and signals were tested, as is the case for other modalities.

Disadvantages: SSEPs can be affected by other causes like changes in temperature and blood pressure so maintaing physiologic temperature and mean arterial pressure greater than 60 mmHg are compatible with normal SSEPs . Also delay in signal detection and isolated monitoring of the dorsal sensory tract. Although signals are monitored continuously with SSEPs, the results are summed over time. There can be a delay in the detection of the neurologic insult, which has been estimated at between 5 and 33 minutes. There are neurologic insults that may not be detected by SSEPs, such as those caused by occlusion of the anterior spinal artery **(7)**

2- Monitoring of motor system

Transcranial Motor evoked potentials (TcMEPs) are generated by transcranial electrical stimulations (TES) may directly activate axons of cortical motor neurons, there by producing descending discharge by corticospinal and corticobulbar tracts **(6).**

Based on the site of stimulation or recording , intraoperative electrical MEPs can be further classified as MEPs that can be recorded over muscle or over the spinal cord . Direct wave (D wave) and indirect wave (I wave). D wave result from direct activation of pyramidal axons, I wave probably reflect indirect activation of pyramidal cells **(8).**

TcMEPs is used in major spine and intracranial surgeries to detect mechanical or ischemic injury along the tract or at the end motor nerve. It is often used in conjunction with SSEPs for spinal cord monitoring, as together they grossly cover the spinal cord antero posteriorly **(5).**

Electrode Placement

The electrode placement on the skull is based on the international 10–20 EEG system. For stimulation of upper extremities, the electrodes should be placed at C3-C4 locations and at C1C2 for lower extremities. It is generally assumed that anodal (positive) current applied to the surface of the cortex is more effective than cathodal (negative) current for activating descending motor tracts because cathodal current elicits a more variable response and the threshold is higher.

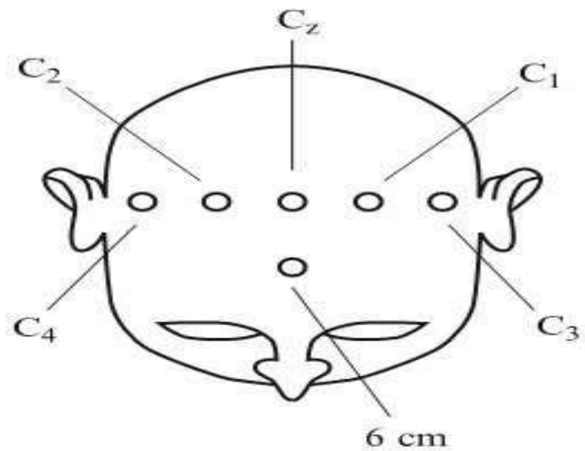

Figure (2): Electrode placement for TES of the cerebral motor cortex (9).

Since the anode is the effective stimulating electrode, at least for weaker stimulation, it should be placed on C1 or C3 to elicit a response in the right limbs, and C2 or C4 for activating muscles on left limbs. Stimulation at these locations elicits clear D and I wave from the corticospinal tract as seen when recorded from the spinal cord. Electrode placement with the anode at the vertex (Cz) , and the cathode at a location that is 6 cm anterior to the anode emphasizes the I waves and produces D waves of a lower amplitude than stimulation with electrodes placed at C1-C2 and C3-C4 **(4).**

Corkscrew electrodes are commonly used for transcranial electrical stimulation because of their secure placement and low impedance or more recently subdermal electrodes have come into favor . Although gold cup EEG electrodes may be used fixed with collodium , they are impractical and their placement is time-consuming. The only exception for its use , is for young children in whom the fontanel still exists to avoid penetration of the fontanel by cork screw-like electrodes **(9).**

There are two types for Transcranial electrical stimulation:

1- Single Pulse Stimulation Technique:

A single-pulse stimulating technique involves a single electrical stimulus applied transcranially or over the exposed motor cortex while the descending volley of the cortical tract is recorded over the spinal cord as a direct wave (D wave).

2- Multipulse Stimulation Technique:

A multipulse stimulating technique involves a short train of five to seven electrical stimuli applied transcranially or over the exposed motor cortex while muscle MEPs from limb muscles in the form of compound muscle action potentials (CMAPs) are recorded. This latter technique differs essentially from the Penfield technique in that it calls for only five to seven stimuli with a stimulating rate of up to 2 Hz. Penfield's technique calls for continuous stimulation over a period of a few seconds with a frequency of stimulation of 50–60 Hz, and only in the cases when the motor cortex is surgically exposed **(10).** Motor evoked potentials can be recorded using needle electrodes from the foot muscles (abductor digiti minimi and abductor hallucis), leg muscles (gastrocnemius and tibialis anterior) and thigh muscles (hamstrings or quadriceps femoris). At least one upper limb muscles (first dorsal interossei , biceps brachii or deltoid) from each side was sampled for control and comparison in children with thoraco-lumbar surgeries **(10).**

Interpretation of MEPs and the effect of anesthetic drugs on it:

Anesthesia inhibits I waves and lower motor neuron (LMN) excitability, usually there is insufficient excitatory post synaptic potential (EPSP) summation and no muscle MEP but there may be small responses with light anesthesia. Pulse trains evoke a series of D waves and recruit some I waves , thereby generating enough EPSP summation to make some LMNs fire **(10).**

Various anesthetic drugs may influence MEP recordings. Especially inhalation agents like sevofurane cause more suppression of lower motor neuron excitability in comparison with total intravenous anesthesia . Previously, using muscle relaxant in such surgeries with the need for MEPs monitoring was excluded as muscle relaxants can abolish the waves hindering the monitoring but now using partial muscle relaxant can be done without affecting those waves **(11).**

3- Monitoring of depth of anesthesia by EEG:

Till now many anesthesiologists rely on parameters regarding the autonomic nervous system like blood pressure and heart rate to pick if a patient is sufficiently anaesthetized or not . However, the relationship between autonomic responses and cerebral activity has not been well characterized during an operation especially when using drugs that affect sympathetic nervous system . However, one needs to be cautious with processed EEG parameters **(11).**

Monitoring the EEG is usually useful in one of four perioperative uses:

1. It helps to identify inadequate blood flow to the cerebral cortex that is caused surgically or by anesthetic induced reduction in blood flow or retraction on cerebral tissue.
2. It is used to guide an anesthetic induced reduction of cerebral metabolism either in anticipation of a loss of cerebral blood flow (CBF) or in the treatment of high intracranial pressure, when a reduction in CBF and blood volume is desired.
3. It may be used to predict neurologic outcome after a brain insult.
4. Finally, the EEG may be used to gauge the depth of the hypnotic state of the patient under general anesthesia **(11).**

There are multiple quantitative techniques to monitor the depth of anesthesia , one of the most important technique is Spectral Edge Frequency (SEF).

Spectral Edge Frequency :

This monitor updates values faster (1s) than other modalities so facilitating more individualized EEGs, which provides superior precision in detecting an individual's anesthetic state than a multivariate model as used by the bispectral index monitor (BIS) **(12).**

Also SEF is superior to BIS as in patients undergoing general anesthesia with muscle relaxants , BIS levels diminished with decreased electromyography activity and this has been interpreted as electromyography noise affecting BIS algorithms **(13).**

Cortex activity, shown by oscillations on the spectrogram, is affected by hypnotics used to obtain adequate depth of anesthesia. This spectrogram uses four frequency bands: alpha, beta, delta and theta, representing 8–12 Hz, 12–30 Hz, 0.5–4 Hz and 4–8 Hz, respectively. The SEF value and the effect in every frequency band can be calculated from these frequencies. It also involves calculating the frequency in which the effect is greatest, by determining the frequency in which 90% or 95% of brain activity takes place **(14).**

In a previous study, SEF was used for reference to determine an adequate depth of anesthesia; and the authors used the frequency band of 8–13 Hz, which is alpha activity. The authors suggested that there was risk of beta activity more than 13 Hz in addition to the alpha activity, which is equivalent to lighter sedation. The authors also took the view that a SEF value < 8 Hz was associated with a higher overdose risk. This narrative review was undertaken to examine the available research evidence on the effect and reliability of SEF for assessing the depth of anesthesia in adult patients under general anesthesia **(12).**

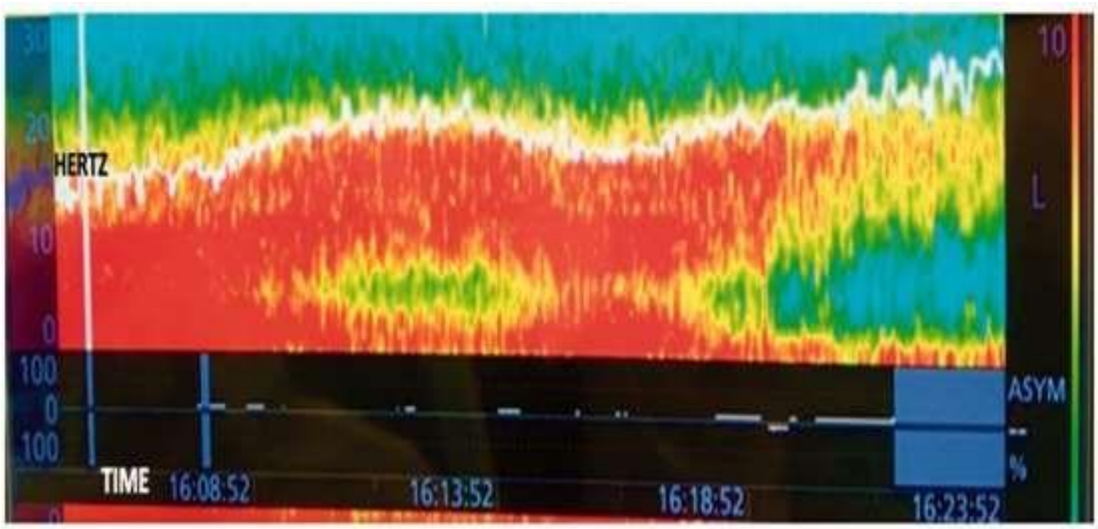

Figure (3): presents a typical screenshot showing a two-dimensional spectrogram where the y-axis represents frequency in Hz and the x-axis represents time. The area below the upper white line shows the SEF and it also represents the SEF value. The y-axis represents the frequency (Hz) and the x-axis shows the time (h:min:s). The colour version of this figure is available at: http://imr.sagepub.com_ (12).

Interpretation of EEG and SEF and effect of anesthetic drugs on it :

Burst suppression occurs when very deep levels of anesthesia are reached in the EEG. It is characterised by periods of electrical silence of the EEG interspersed by periods of high activity (bursts). Some anesthetic drugs such as barbiturates are able to suppress these bursts at high doses until the EEG is completely suppressed. Administration of higher doses of anesthetics in order to reduce the spectral edge frequency to 'less awake' levels may result in overdosing of patients. These changes apply more or less to all general anesthetics, however, one has to be aware that different anesthetics have different effects on the EEG activity making it impossible to relate directly the effect of an anesthetic on the EEG to a physiological effect **(12).**

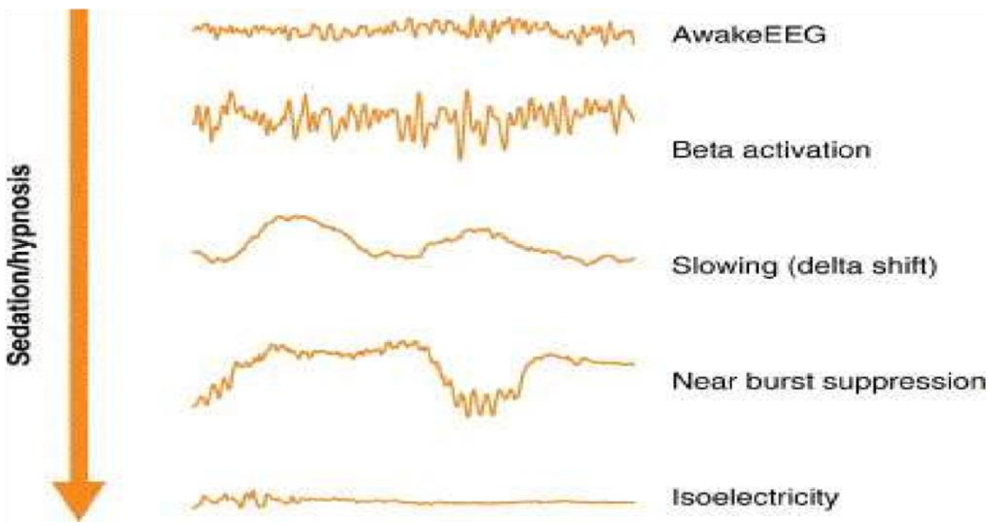

Figure (4): Changes in the electroencephalogram (EEG) dependent on sedation/hypnosis.

4- Degree of neuromuscular blockade Train of Four monitoring (TOF) :

Mostly we use muscle relaxant intra-operatively for adequate intubation, adequate surgical exposure and to improve mechanical ventilation . **Ali et al., (15)** developed and published the technique of TOF monitoring. TOF pattern was developed for assessing neuromuscular block in the anesthetized patient. TOF was developed as a stimulation pattern that did not require a comparison to a control response before administration of a neuromuscular blocking agent. It was done by stimulating the ulnar nerve with a TOF supra-maximal twitch stimuli:

- Frequency = 2 Hz for two seconds.
- Train frequency = 0.1 Hertz (every 10 seconds).
- Comparing T1 (1st twitch) to T0 (control)
- Comparing of T4 (4th twitch of the TOF) to T1 (known as the TOF ratio) **(16).**

All patients who receive any neuromuscular blocking agents should be monitored for neuromuscular function during the surgeries. Face muscles are the first one to get paralyzed by muscle relaxants because they have better vascular supply followed by hand and feet. Face muscles are the first one to get four twitches back because of higher venous drainage as compared to hand

and feet. Feet muscles are the last one to get paralyzed by muscle relaxants & the last one to get four twitches back **(17).**

Effect of Rocuronium on TOF :

Non depolarizing muscle relaxant (NDMR) is a competitive antagonist that blocks conduction by acting on alpha subunit of acetylcholine (Ach) receptor decreasing twitch response to a single stimulus. NDMR produces fade (unstained response) to continuous stimulus. For NDMR the TOF ratio is less than 0.7 (T4 is less than 70% amplitude of T1) . partial muscle relaxant effect can be considered when this ratio become 0.5 **(18).**

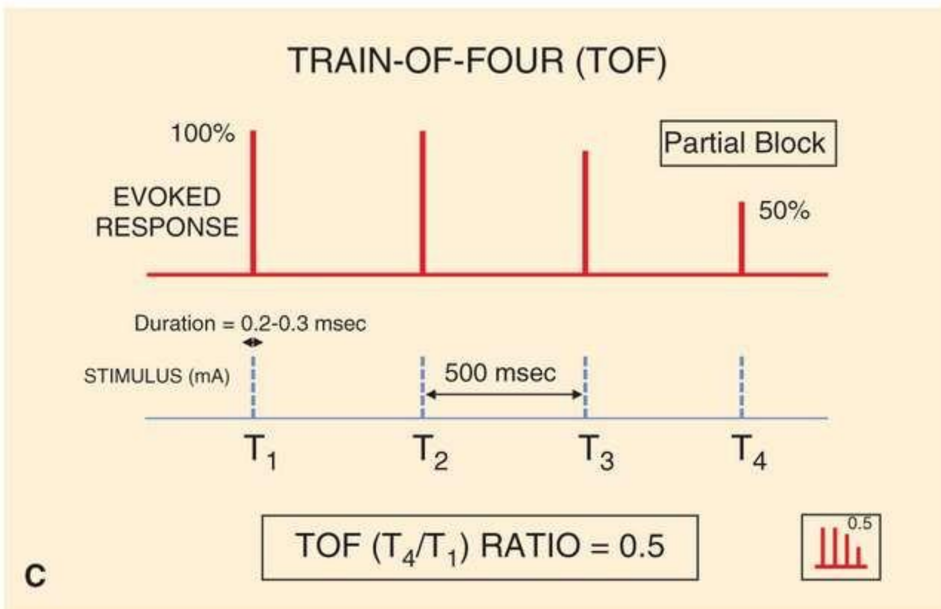

Figure (5): partial block explained by TOF

https//:slidesharetrick.blogspot.com/2019/11/train-of-four-monitoring.html

We monitor Neuromuscular Junction (NMJ) for many reasons such as:

Variable individual response to muscle relaxants.
The narrow therapeutic window.
There is no detectable block until 65 to 75% of receptors are occupied.
Paralysis is complete at 90 to 95% receptor occupancy.

Therefore, adequate muscle relaxation corresponds to a narrow range of 85 to 90% receptor occupancy. **(18).**

Clinical applications of the level of muscle relaxation are surgical Relaxation at >90% , Intubation facilitated at 95% and Total Flaccidity at 99%.There are different types of neuromuscular stimulators like Single Twitch, Tetanic Stimulation and Train of Four Stimulation.

In TOF we always setup the most distal muscle, Make sure your stimulation and recording setup is correct, if you are not getting TOF from one side we can try the contralateral side ,TOF should be done throughout the surgical procedure and Keep the intensity to a minimum **(18).**

Factors affecting TOF :

1. Calcium Channel Blockers , Corticosteroids , Diuretics (furosemide and thiazides) and Carbamazepine .
2. Anesthetic drugs like Enflurane and Isoflurane (inhalants).
3. Antibiotics (Amikacin , Clindamycin, Gentamycin, Kanamycin, Neomycin , Piperacillin, A, B and E, Streptomycin , Tetracycline and Tobramycin).
4. Anti-arrhythmic medications (Bretyllium , Lidocaine , Propranolol , Quinidine)
5. Electrolyte and thermal disorders (Hypokalemia , Hypocalcemia , Hypomagnesaemia, Hyponatremia , Hypothermia and Acidosis) .
6. Organ Failure (renal and hepatic) .
7. Neuromuscular diseases (Myasthenia Gravis , Bell's Palsy) **(16).**

No Conflict of interest.

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