MONITORING NEUROMUSCULAR BLOCKADE USING PERIPHERAL NERVE STIMULATOR (PNS) – A review

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Summary

Peripheral nerve stimulators are extensively used for monitoring neuro-muscular blockade after administration of muscle relaxant in the operation theatre as well as in ICU. Different stimulation modalities were introduced into practice to take advantage of the characteristic features of non-depolarizing neuromuscular blockade such as fade, post-tetanic facilitation. Increase in awareness of the problems of postoperative residual neuromuscular blockade in recent years has increased its use.

Keywords

Supramaximal stimulus, Train of four, Double burst stimulation.

Introduction

In 1958, Christie and Churchill-Davidson described how nerve stimulators could be used to assess neuromuscular function objectively during anaesthesia. In 1970, H.H.Ali and collegues deviced the technique of delivering four supramaximal impulses delivered at 2 Hz, or a "Train of four" as method of quantifying the degree of residual neuromuscular blockade. For many years, however the degree of neuromuscular block during and after anaesthesia was evaluated with clinical criteria alone. Increase in awareness of the problems of post-operative residual neuromuscular blockade in recent years has increased its use.

In awake patients muscle power can be evaluated through tests of voluntary muscle strength, but during anaesthesia and recovery from anaesthesia this is not possible. Though the clinical tests such as muscle tone, feel of anaesthesia bag etc can be used to assess muscle power directly and neuromuscular function indirectly, these are influenced by factors other than the degree of neuromuscular blockade.

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Therefore, whenever more precise information regarding the status of neuromuscular functioning is desired, the response of muscle to nerve stimulation should be assessed.
Monitoring neuromuscular blockade helps the anaesthesiologist
1) To use optimal (individually tailored) doses of muscle relaxant and reversal drugs which in turn avoid drug over dosage and direct cost saving.
2) To administer these drugs at the right time e.g. timing of administration of reversal, top up doses of muscle relaxant etc.
3) To identify the type of drug in effect. (Depolarizing or non-depolarizing) This is particularly useful if there is any residual block effect or dual block.

The ideal nerve stimulator

A nerve stimulator should meet the following basic requirements for clinical use[1]

- The stimulus should produce a monophasic and rectangular waveform.
- Length of the pulse should not exceed 0.2 to 0.3 msec
- Stimulation at a constant current is preferable.
- For safety reasons, it should be battery operated, include a battery check and be able to generate 60 to 70 mA, but not more than 80mA.
- Should have a built-in warning system or a current level display.
- The polarity of the electrodes should be indicated.

The ideal nerve stimulator should have other features as well.
Apparatus should be capable of delivering the following modes of stimulation.

- TOF (as both a single train and in a repetitive mode, TOF stimulation being given every 10 – 20 seconds).
- Single-twitch stimulations at 0.1Hz and 1Hz.
- Tetanic stimulation at 50Hz.
- Post-tetanic count – tetanic stimulus should last 5 seconds and be followed 3 seconds later by the first post-tetanic stimulus.
- DBS – At least one DBS mode should be available, preferably **DBS_{33}.**

Principles

Neuromuscular function is monitored by evaluating the response of muscle to supramaximal electrical stimulation of a peripheral motor nerve.

The response of the whole muscle to a stimulus depends on the number of muscle fibres activated. After administration of neuromuscular blocking drug, the response of the muscle decreases in parallel with the number of fibres blocked. The reduction in response during constant stimulation reflects the degree of neuromuscular blockade. The electrical stimulus should be supramaximal throughout the period of monitoring, usually at least 20 to 25% above that necessary for a maximal response.

The stimulating electrodes

Electrical impulses are transmitted from stimulator to nerve by means of surface or needle electrodes, the former being most commonly used.

Two basic types of surface electrodes exist : Rubber electrodes and disposable pre-gelled silver or silver chloride electrodes.

When a supramaximal response cannot be obtained by using surface electrodes, needle electrodes should be used. The needles should be placed subcutaneously but never in a nerve.

Sites of nerve stimulation

In general, any superficially located peripheral motor nerve may be stimulated. In clinical anaesthesia, the ulnar nerve is the most popular site. The median, posterior tibial, common peroneal and facial nerves are also sometimes used.

Different muscle groups have different sensitivities to neuromuscular blocking agents; results obtained for one muscle cannot be extrapolated automatically to other muscles. The diaphragm is among the most resistant of all muscles, requires 1.4 to 2 times as much muscle relaxant as the adductor pollicis, for an identical degree of blockade.

In assessing neuromuscular function, the use of relatively sensitive muscle such as adductor pollicis of hand has following advantages.

a. The chances of overdosing the patient decreases.

b. During recovery, when the adductor pollicis has recovered sufficiently, it can be assumed that no residual neuromuscular blockade exists in the diaphragm.

Above figure shows 2 different methods of electrode placement to obtain contraction of adductor pollicis muscle. The device fixed to the thumb is an accelerometer.

Patterns of nerve stimulation

Traditionally, three patterns of electrical stimulation have been used for evaluation of neuromuscular function.

- Single twitch
- Train of four (TOF)
- Tetanic nerve stimulation.

Newer modes available are

- Post tetanic count (PTC)
- Double burst stimulation (DBS)

Single twitch stimulation

Here single supramaximal electrical stimulus is applied to a peripheral motor nerve at frequencies ranging from 0.1Hz to 1.0Hz. The response to single twitch stimulation depends on the frequency with which the individual stimuli are applied. A frequency of 0.1Hz is generally used. 1Hz stimulation is sometimes

employed during induction of anaesthesia to determine supramaximal stimulation, as it shortens the time necessary to determine supramaximal stimulation.

Train of four stimulation (TOF)

Nerve stimulation in clinical anaesthesia is usually synonymous with train of four stimulation. Here four supramaximal stimuli are given every 0.5 seconds (2Hz). When used continuously, each set (train) of stimuli normally is repeated every 10^{th} to 20^{th} second. Each stimulus in the train causes the muscle to contract, and "fade" in the response provides the basis for evaluation. That is, dividing the amplitude of fourth response by the amplitude of first response provides the TOF ratio. In the control response, all responses are ideally the same, the TOF ratio is 1.0. During non-depolarizing block the ratio decreases ("fades") and is inversely proportional to the degree of blockade. During depolarising block no fade occurs in the TOF response. Fade in the TOF response after injection of Succinylcholine signifies the development of a phase II block.

Advantages

1.During non-depolarising blockade, the degree of block can be read directly from the TOF response, even though a pre operative value is lacking.
2.When compared to tetanic stimulation, it is less painful and generally does not affect the degree of neuromuscular blockade.
3.During clinical anaesthesia, TOF response to nerve stimulation is used to evaluate the degree of neuromuscular blockade.
During non-depolarizing neuromuscular blockade TOF recording demonstrates 3 phases or levels of neuromuscular blockade.

- Intense blockade
- Moderate or surgical blockade and
- Recovery

Pattern of electrical stimulation and evoked muscle responses to TOF nerve stimulation

Intense neuromuscular blockade

Occurs within 3 to 6 minutes of injection of an intubating dose of a non depolarizing muscle relaxant. This phase is also called "period of no response" because no response to TOF or single twitch stimulation occurs. Although during this phase, it is not possible to determine exactly how long intense neuromuscular blockade will last, correlation does exists between PTC and time to reappearance of first response to TOF stimulation.

Moderate or surgical blockade

It begins when the first response to TOF stimulation appears. This phase is characterised by a gradual return of the fourth response to TOF stimulation. Good correlation exists between the degree of neuromuscular blockade and the number of

responses to TOF stimulation. When only one response is detectable the degree of neuromuscular blockade (depression of twitch tension) is 90 to 95 percent. When the fourth response reappears, neuromuscular blockade is usually 60-85%.

The presence of one or two responses in the TOF pattern normally indicates sufficient relaxation for most of the procedures.

Antagonism of neuromuscular blockade should not be initiated before at least two or preferably three responses in the TOF are observed.

Recovery

The return of the fourth response in the TOF heralds the recovery phase.

During neuromuscular recovery, a reasonably good correlation exists between the actual TOF ratio and clinical observations, but the relationship between TOF ratio and signs and symptoms of residual blockade varies greatly among patients[1]

TOF ratio	Clinical Signs/ Symptoms
< 0.4	Patient unable to lift the head or arm, tidal volume may be normal. Vital capacity decreased. Inspiratory force decreased.
0.6	Able to lift head for 3 seconds. Open eyes widely. Can protrude the tongue but vital capacity / inspiratory force still reduced.
0.7 – 0.75	Can normally cough sufficiently, lift head for at least 5 seconds, grip strength may be as low as about 60% of control.
≥ 0.8	Vital capacity and inspiratory force are normal.

In clinical anaesthesia, a TOF ratio of 0.70 to 0.75 has been thought to reflect adequate recovery of neuromuscular function. However, recent studies have shown that TOF ratio, must exceed 0.80 or even 0.90 to exclude clinically important residual neuromuscular blockade[2]

Tetanic stimulation

It consists of very rapid delivery of electrical stimuli. The most commonly used pattern in clinical practice is 50Hz stimulation given for 5 seconds.

During normal neuromuscular transmission and a pure depolarising block, the muscle response to 50Hz tetanic stimulation for 5 seconds is sustained. During non-depolarising block and a phase II block the response will not be sustained (i.e., fade occurs).

During partial non-depolarising blockade, tetanic nerve stimulation is followed by a post-tetanic increase in twitch tension (ie. Post tetanic facilitation of transmission [PTF]).

Tetanic stimulation has several disadvantages.It is very painful and therefore not acceptable to the unanaesthetized patient. In the late phase of neuromuscular

recovery tetanic stimulation may produce a lasting antagonism of neuromuscular blockade in the stimulated muscle such that the response of the tested site may no longer be representative of other muscle groups.

Traditionally, tetanic stimulation has been used to evaluate residual neuromuscular blockade.

Post tetanic count stimulation

It is used to quantify the intense neuromuscular blockade of the peripheral muscles by applying tetanic stimulation (50Hz for 5 sec) and observing the post tetanic response to single-twitch stimulation given at 1Hz starting 3 seconds after the end of tetanic stimulation.

During very intense blockade, there is no response to either tetanic or post-tetanic stimulation. However, when the very intense neuromuscular blockade dissipates and before the first response to TOF stimulation reappears, the first response to post-tetanic twitch stimulation occurs. As the intense block dissipates, more and more responses to post-tetanic twitch stimulation appear. For a given neuromuscular blocking drug, the time until the return of the first response to TOF stimulation is related to the number of post tetanic twitch responses present at a given time (the post-tetanic count).

Approximate time in minutes until recovery of detectable twitch response[3]

No. of Post Tetanic Count	Atracurium or Vecuronium (min.)	Pancuronium (min.)
	> 9	37
1	9	37
2	7	30
4	4	20
6	2	10
8	0 – 2	5

The main application of the PTC method is in evaluating the degree of neuromuscular blockade when there is no reaction to single twitch or TOF nerve stimulation, as may be the case after injection of a large dose of a nondepolarizing neuromuscular blocking agent.

PTC can also be used, whenever sudden movements must be eliminated (e.g., during ophthalmic surgery).

Double-burst stimulation (DBS)

Double-burst stimulation was developed with the specific aim of allowing manual (tactile) detection of small amounts of residual blockade under clinical conditions.

DBS consists of two short bursts of 50-Hz tetanic stimulation separated by 750 ms. The duration of each square wave impulse in the burst is 0.2ms. The

number of impulses in each burst can vary. Initial studies indicated that DBS with three impulses in each of the two tetanic bursts (DBS_{33}) is suitable for clinical use.

In nonparalysed muscle, the response to DBS_{33} is two short muscle contractions of equal strength. In the partly paralysed muscle, the second response is weaker than the first (i.e., the response fades).

During recovery and immediately after surgery, tactile evaluation of the response to DBS_{33} is superior to tactile evaluation of the response to TOF stimulation[4].

Recording of evoked responses

The choice of recording method is a practical decision. Five methods are available.

1. Measurement of evoked mechanical response of the muscle – **Mechanomyography (MMG).**
2. Measurement of evoked electrical response of the muscle– **Electromyography(EMG)**
3. Measurement of acceleration of the muscle response – **Acceleromyography(AMG)**
4. Special microphones sensitive to frequencies below the threshold of human ear –**Phonomyography(PMG)**
5. Measurement of evoked electrical response in a piezoelectric film sensor attached to the muscle-**Piezo electromyography(PZEMG)**

Use of nerve stimulators without recording equipment

Although the interest in recording the evoked responses to nerve stimulation during clinical anaesthesia is growing, muscle response is usually still evaluated by eye or by feel. Therefore anaesthesiologist must know how to use a nerve stimulator when recording equipment is unavailable and must be aware of the possible pitfalls of this method. Every effort should be taken to prevent central cooling as well as cooling of the extremity being evaluated. When possible, the response to nerve stimulation should be evaluated by feel and not by eye, and the response of the thumb (rather than that of the fifth finger) should be evaluated. The different sensitivities of various muscle groups to neuromuscular blocking agents should always be kept in mind.

Visual or tactile evaluation of the evoked thumb twitch for TOF stimulation is a simple, convenient and reliable mode for evaluation of moderate degrees of nondepolarizing blockade. However, during recovery it is difficult to estimate the TOF ratio with sufficient certainty to exclude residual curarization. Greater sensitivity can be achieved with double burst-stimulation (DBS_{33}), but even absence of manual fade for the DBS_{33} response does not exclude clinically significant residual blockade. Therefore, manual evaluation of responses to nerve stimulation should always be considered in relation to clinical signs and symptoms of residual neuromuscular blockade, such as the ability of the patient to lift the head for 5 seconds, to open the eyes, to stick out the tongue, and to cough sufficiently.

Use of peripheral nerve stimulator during various peri operative times[1]

The following figure shows, which modes of nerve stimulation can be used at various perioperative times.

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