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Neuromuscular Monitoring Part 2: A Review and Update

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The first part of Dr Hemmerling's work (*Neuromuscular Monitoring Part 1: A Review and Update*) was the subject of the March issue of *Anesthesiology Rounds*. Please refer to it to view the complete article.

STIMULATION PATTERNS

All of the objective neuromuscular monitoring methods are based on monitoring an evoked response after different patterns of stimulation have been applied to a motor nerve. The most important and widely-used stimulation patterns are single twitch stimulation, train-of-four (TOF) stimulation and, despite a decrease in popularity, post-tetanic facilitation after tetanus stimulation (Figure 1).

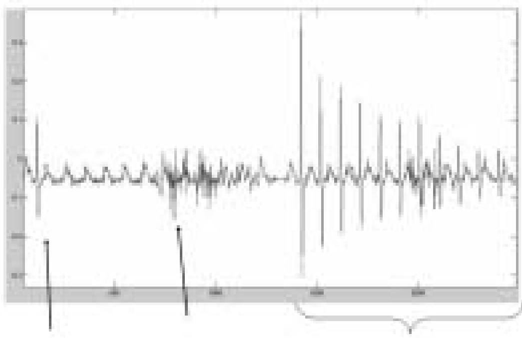
SINGLE TWITCH STIMULATION

Single twitch stimulation consists of a square-wave stimulus of 0.2 ms. The amplitude of the stimulus can be modified using routine nerve stimulators, the most common model is the Innervator® (Fisher & Paykel, NZ). In general, the amplitude can vary incrementally from 0 mA up to 80 mA. Single twitch stimulation can be accurately used in a research situation as long as the amplitude of the measured response returns to its initial control value. Since most clinicians still use tactile or visual evaluations to assess the degree of muscle relaxation, TOF stimulation is the preferred pattern of stimulation. However, single twitch stimulation every 10 seconds is an accurate means to monitor onset of neuromuscular blockade (NMB).

TRAIN-OF-FOUR STIMULATION (TOF)

The generation of square-wave stimuli of 0.2 ms duration at 0.5 Hz has become the most commonly used stimulation mode. Typical fading in the TOF response defines competitive NMB by non-depolarizing neuromuscular blocking agents. TOF stimulation is also used to maintain what is referred to as "surgical" relaxation. It is usually defined by a TOF ratio of 15% to 25% during surgery. During profound relaxation, more than one TOF twitch can be lost and, therefore, no TOF count can be measured. TOF is an important stimulation pattern to evaluate recovery from NMB. A TOF ratio >0.9 has been shown to guarantee sufficient recovery of neuromuscular transmission for extubation after surgery.[1] Although, theoretically, single twitch stimulation could also be used to monitor receding NMB, the need for a pre-registered control response and exact determination of its amplitude has favoured TOF stimulation, since no control stimulation is needed to determine the ratio. It is not surprising that most monitoring methods, whether it is electromyography (EMG), mechanomyography (MMG), acceleromyography (AMG) or phonomyography (PMG), perform reasonably well in evaluating TOF ratios between 0.7 – 0.9.

FIGURE 1: The most common stimulation patterns of a partially relaxed muscle. Just the first twitch response of TOF stimulation is visible; tetanus stimulation is performed, followed by single twitch stimulation to determine the post-tetanic count in profound relaxation.



DOUBLE-BURST STIMULATION

Tactile evaluation of TOF responses at the adductor pollicis muscle is difficult, since distinguishing between TOF values ranging from 0.7 to 0.9 is usually impossible or very difficult. It is for this reason that Viby-Mogensen introduced a new mode of stimulation called "double-burst stimulation" (DBS).[2] The preferred form of DBS consists of 3 stimuli of 0.2 ms duration at 50 Hz (20 ms intervals), followed by 3 equal stimulations (DBS 3, 3). Although initially designed to improve the detection of fade, DBS may give the examiner a false sense of self confidence in its ability to manually detect fade.[3] Consequently, DBS cannot, by any means, be a substitute for an objective method.

POST-TETANIC COUNT

Before recovery of all TOF responses, tetanus stimulation (stimulation at 50 Hz), followed >3 s later by single twitch stimulation every 1 s, can help estimate the profoundness of NMB and the time to recovery. Several charts exist to correlate the recurrence of the first twitch in TOF stimulation with a certain number of single twitches detected during the post-tetanic count. These charts are difficult to obtain for the more modern drugs but, generally, a count >10 is needed before recurrence of the first twitch of TOF stimulation can be assumed.

In general, objective monitoring methods use single twitch stimulation to determine onset of NMB. Then, TOF stimulation every 12 s is used to monitor the maintenance of NMB during surgery.

MONITORING AT DIFFERENT MUSCLE SITES

In the past, the only muscle used for monitoring was the adductor pollicis muscle; however, over the last 15 years, our knowledge about how and why different muscles react to neurostimulation has greatly increased. This knowledge has changed clinical practice in that at least one other muscle site – the corrugator supercilii muscle – is now being used to monitor NMB on a regular basis.

NEUROMUSCULAR MONITORING AT THE LARYNX

MMG, EMG, and PMG have all been applied to the larynx.

Mechanomyography: One form of MMG used at the larynx consists of placing the cuff of the endotracheal tube between the vocal cords and measuring the force of the adducting laryngeal muscles by assessing the degree of pressure changes within the cuff.[4] A recent study has demonstrated the importance of maintaining the resting pressure within the cuff in order to truly reflect the force of adduction throughout NMB.[5]

Electromyography of the larynx consists of using either a specialized endotracheal tube with incorporated wire electrodes[6] or a superficial electrode[7] attached in a circular fashion around the tube and placed between the vocal cords. EMG records the evoked compound action potential of several intrinsic laryngeal muscles, reflecting the neuromuscular action potential of adductor and abductor muscles of the larynx. While it is known that EMG and MMG cannot be used interchangeably for peripheral muscles and the diaphragm, a comparison between laryngeal EMG and the cuff pressure technique has not yet been done.

Phonomyography consists of placing a small microphone in the vestibular fold (lateral to the endotracheal tube) for recording the activity of the adducting laryngeal muscles. This method shows good agreement with the cuff pressure technique and is quite easy to apply.

There are basically 2 sites for transcutaneous stimulation of the recurrent laryngeal nerve. This nerve can be stimulated either medially between the jugular notch and the thyroid cartilage or, particularly if a bipolar stimulation probe is used, just laterally to the sternocleidomastoid muscle, in the tracheo-esophageal notch (Figure 2). Contrary to stimulation of the phrenic nerve, stimulation of the recurrent laryngeal nerve is unlikely to reach the vagal nerve or the brachial plexus.

FIGURE 2: Stimulation of the recurrent laryngeal nerve. Routine AgAgCl electrodes are placed midline along the line between the jugular notch and the thyroid cartilage; a handheld stimulator is placed on the medial side of the sternocleidomastoid muscle.

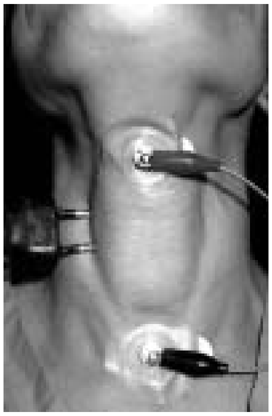


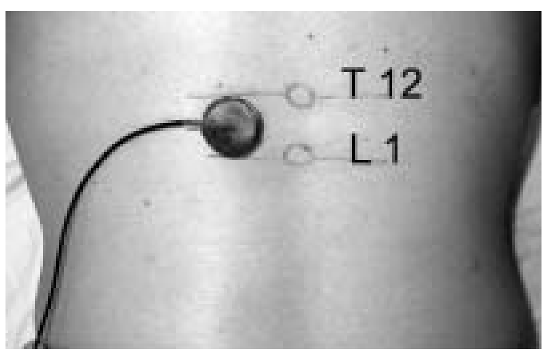
FIGURE 3: Stimulation of the phrenic nerve using a hand-held stimulator. A slight pressure just behind the collarbone needs to be exercised because of the deep localization of the phrenic nerve.

When compared to the adductor pollicis muscle, most studies confirmed that onset and recovery of NMB at the larynx is faster. It appears that when sub-paralyzing doses of neuromuscular blocking agents are used, the peak effect at the larynx is less than at the adductor pollicis muscle. However, for doses that are generally used for endotracheal intubation (>2 ED 95), there is no significant difference between the peak effect at the larynx and at the adductor pollicis muscle. The faster onset of neuromuscular blocking agents at the larynx can probably be attributed to the rapid "central" distribution of these agents. On the other hand, the reason for the faster recovery at the laryngeal site is primarily due to morphological differences between the larynx and the adductor pollicis muscles.

NEUROMUSCULAR MONITORING OF THE DIAPHRAGM

Percutaneous needle or superficial skin electrodes are generally used to record diaphragmatic electromyographic response and measure NMB following phrenic nerve stimulation (Figure 3).[6,8] The conventional site for recording electromyographic signals is the 7th or 8th intercostal space, between the anterior axillary and the mid-clavicular line. A novel site – on the patient's back – has recently been proposed to monitor NMB of the diaphragm and has shown good agreement with intramuscular needle EMG.[9] The posterior site can also be used for PMG (Figure 4). Measurements of evoked transdiaphragmatic pressure as a form of indirect MMG of the diaphragm has also been used to evaluate the level of NMB.[10] To do so, balloons are inserted into the esophagus (to record pleural pressure) and into the stomach (to record intra-abdominal pressure). They are connected with air-filled catheters to identical transducers. The transdiaphragmatic pressure (Pdi) is then obtained by electronic subtraction of gastric (alias intra-abdominal) from esophageal (alias pleural) pressure. This technique, however, is invasive and difficult to apply since data have to be recorded during resting end-expiration and some authors believe that it requires bilateral phrenic nerve stimulation to be accurate. The main disadvantage of this approach, when considering its use from a clinical standpoint, is that it cannot be applied during open abdominal surgery. Its advantage, however, is that it represents a more MMG-like approach since transdiaphragmatic pressure measured in the lower esophagus is a function of the force of the diaphragmatic yet, nonisometric,

FIGURE 4: Posterior monitoring of the diaphragm by PMG. The microphone is attached via self-adhesive tape just lateral of the spinal column.



contraction. Although EMG does not measure the same variable as MMG, studies have found a good correlation between the trans-diaphragmatic pressure method and EMG at the diaphragm.[11,12] Still, it does not necessarily mean that the two methods are interchangeable.

In general, most studies examining the evolution of NMB at both the diaphragm and larynx have shown similar time courses and comparable degrees of NMB.

The greatest difficulty associated with monitoring NMB at the diaphragmatic site pertains to the stimulation of the phrenic nerve. This must be done either with needles or via a handheld stimulator. Since the branches of the diaphragm are profoundly located, the main problem is stabilizing the position of the stimulator when measuring NMB onset and offset.

NEUROMUSCULAR MONITORING OF THE CORRUGATOR SUPERCILII MUSCLE

The corrugator supercilii is a small muscle around the eyebrow, responsible for vertical frowning. Recent studies have used AMG[13,14] and PMG[15,16] to record muscle response. Accelerometry, although well-established for the adductor pollicis muscle, may be problematic at the corrugator supercilii muscle because of the limited capability of the conventional accelerometric probe to detect acceleration created by this small muscle. The original accelerometric probe, used with commercially-available devices such as the TOF-Guard® or TOF-Watch SX,® was originally designed to measure accelerations created by the much larger adductor pollicis muscle. The TOF-Watch SX was designed with a sensitivity set-up that allows increases up to 500 µC (in comparison to 353 µC for the TOF-Guard). A recent comparison of AMG and PMG at the corrugator supercilii muscle raised questions as to whether the TOF-Watch SX is suitable to accurately detect the neuromuscular response at this muscle.[16] Another recent study attempted to evaluate the actual force created by the corrugator supercilii muscle by using an air-filled balloon as a pressure transducer; it found good agreement between PMG and this MMG-like method.[15]

THE CONCEPT OF "SITE-RELATED NEUROMUSCULAR MONITORING"

The role of the anesthesiologist is to achieve optimal surgical conditions. Adequate conditions depend on several factors, namely the proper depth of anesthesia, as well as good muscle relaxation. "Good" muscle relaxation does not always mean extreme NMB, although the success of some surgeries can depend on complete NMB at the surgical site (eg, retinal surgery, spinal procedures, etc.)

Since we know that different muscles react differently to the application of neuromuscular blocking drugs, a very important part of 'optimal' relaxation at a given surgical site is to achieve proper relaxation of the muscles surrounding the site. It would be ideal if we were able to monitor the surgical site itself or be confident that the muscles that we are using for monitoring really reflect the degree of NMB at the surgical site; eg, monitoring the eye or facial muscles on the opposite side during retinovitreal surgery to secure profound site-related NMB. There have not been many studies that have investigated this concept, but we should be aware that monitoring just one muscle is, in fact, primarily just that: the monitoring of NMB at this muscle. NMB at another muscle site might be dramatically different. The surgeon complaining that the muscles within his surgical field are not adequately relaxed might sometimes actually be right.

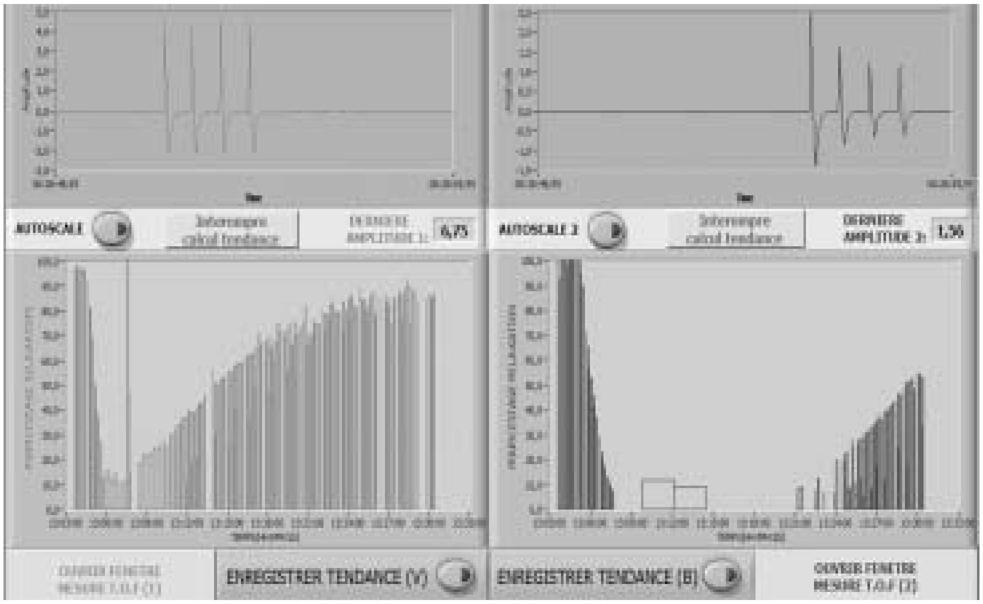
CONCLUSION

• ***Subjective evaluation of NMB*** via tactile or visual examination is not sufficient to titrate NMB during modern forms of general anesthesia in light of increasing knowledge that a profound block is not necessary for most surgeries. Tactile or visual evaluation cannot be used if the goal is to provide precise surgical NMB with a TOF of 0.25. It is also unsuitable to precisely evaluate TOF ratio values between 0.7 and 0.9. Still, such information may be crucial when deciding if NMB needs to be reversed.

Although evaluating the clinical signs associated with recovery from NMB can be helpful, this information may be difficult to interpret since it is dependent on the patient's cooperation; it should not be used as a substitute for objective neuromuscular monitoring.

• ***Monitoring the corrugator supercilii muscle*** should be used for determining the earliest possible time for intubation, since it reflects laryngeal relaxation better than the adductor pollicis muscle does. Single twitch stimulation at 1 Hz is then recommended. It should be noted

FIGURE 5: Model of an interface using PMG with 2 microphones. Left: corrugator supercilii muscle, right: adductor pollicis muscle, including graphical tendencies of NMB; interface developed by the Neuromuscular Research Group (NRG)



that a TOF ratio of 1 at the corrugator supercilii muscle does not necessarily mean complete recovery at the adductor pollicis muscle!

Complete recovery of neuromuscular transmission is best monitored at the adductor pollicis since, in general, it is the last muscle to recover from NMB. TOF stimulation every 12 s is the best way to ascertain complete recovery or estimate when complete recovery can be achieved following reversal of the NMB drugs.

• ***If surgery or the type of anesthesia necessitates NMB to a certain degree,*** (eg, TOF 0.25), monitoring a muscle that best reflects the degree of NMB at the surgical site should be used. In general, when surgery is performed on the extremities (eg, on an arm or a leg), monitoring the adductor pollicis muscle or any other hand muscle is preferred. For surgery within the great cavities, where relaxation of the diaphragm is necessary, the corrugator supercilii muscle should be used. More studies are needed to investigate which monitoring site best reflects a given surgical site.

• ***There is no substitute for objective neuromuscular monitoring***. At present, the most versatile device and method to ascertain NMB is AMG since it can be applied at different muscle sites. PMG is a promising technique and could establish itself as a viable alternative during routine clinical procedures.

• Regarding ***pharmacodynamic studies*** – anesthetists should be aware of the great interpatient variability with regard to onset, duration, and recovery following administration of NMB drugs. Extensive clinical experience is not a substitute for objective neuromuscular monitoring.

• ***The ideal monitoring device*** should be easy to apply and based on a method that produces results in good agreement with MMG. It should be possible to use it at several different muscle sites, even simultaneously. It should be noninvasive and not too expensive. We have recently designed an interface based on PMG that incorporates the possibility of monitoring two muscles (Figure 5); eg,the corrugator supercilii muscle and the adductor pollicis muscle, at the same time, thus providing more information with regard to NMB through the whole body. The prototype uses two small microphones glued to the skin overlying the monitored muscles and a microprocessor whose graphical interface displays the evoked responses of both muscles side-by-side, including TOF ratios and trends during any given time. This might be an interesting step towards a more sophisticated, albeit simple monitoring device, for everyday use.

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