

Neuromuscular Monitoring Part 1: A Review and Update

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Monitoring the action of neuromuscular blocking drugs is one of the essential components in the practice of anesthesiology. Whether it is used to control the airway or to provide optimal surgical conditions, neuromuscular blockade needs to be carefully induced, maintained, and reversed. Only objective monitoring can assure that all of these aspects are managed safely. This issue of *Anesthesiology Rounds*, as well as the next, will be devoted to reviewing this important topic. Therefore, please keep this issue on hand since it is the first of a two-part article. We wish to thank Dr. Hemmerling, a renowned expert in the field of neuromuscular blockade, who is affiliated with the Centre Hospitalier de l'Université de Montréal (CHUM), for this important and timely article.

No innovation has contributed to decrease the use of neuromuscular blocking drugs more than the laryngeal mask airway (LMA).¹ The insertion of an LMA is easy and necessitates little or no neuromuscular blockade (NMB). Since the stimulus during LMA insertion is less than with tracheal intubation, the requirement for neuromuscular blocking drugs is reduced or absent, unless there is the need to establish NMB for surgical reasons. The requirement for NMB, however, is not decreased when less invasive surgery (eg, laparoscopic surgery) is performed. On the contrary, laparoscopic and thoracoscopic procedures very often demand higher degrees of NMB than the corresponding open forms of surgery. In addition, there are many other cases when insertion of an endotracheal tube is required. In these cases, NMB is generally preferred if not mandatory. Thus, although the tendency in modern anesthesia is towards less invasive airway management, the fact is, NMB is still an essential part of daily practice. A recent editorial emphasized that quantitative neuromuscular monitoring using objective methods should be mandatory when NMB is established during anesthesia.²

WHEN DO ANESTHESIOLOGISTS USE NEUROMUSCULAR BLOCKING DRUGS?

To facilitate good conditions for endotracheal intubation

Some studies have shown that intubation without the aid of neuromuscular blocking drugs is possible.³⁻⁵ It is then performed with the aid of profound anesthesia and still, intubation conditions are not as good as with complete NMB.⁶

To establish and maintain good surgical conditions

Although the definition of optimal surgical conditions, that is, good relaxation of muscles within the surgical field or muscles that have an influence on operating conditions (eg, relaxation of the diaphragm when performing laparoscopic procedures), this definition can be subjective and arbitrary. A recent study has shown that NMB can improve surgical conditions, as exemplified in abdominal surgery.^{7,8} NMB can sometimes be combined with a lighter level of anesthesia; profound NMB can then

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avoid even the slightest patient movement when precision is critical (eg, during neurosurgery or complex eye surgery).

A submaximal degree of NMB facilitates the insertion of an LMA

The insertion of an LMA can frequently be facilitated by establishing a submaximal degree of NMB.⁹ Very often, when an LMA is used with intermittent positive pressure ventilation, a certain degree of NMB will facilitate mechanical ventilation and avoid gas leakage. Thus, NMB drugs play a very important role in daily anesthetic practice and neuromuscular monitoring can be very useful.

The most important time to implement neuromuscular monitoring is probably at the end of surgery and anesthesia, before the patient wakes up. Most anesthesiologists will at least use a nerve stimulator to confirm complete recovery of neuromuscular transmission, with either a tactile or visual evaluation, however limited these methods might be.^{10,11} It is common knowledge that a train-of-four (TOF) ratio of >0.9 at the adductor pollicis muscle is necessary to achieve adequate and sufficient airway protection after anesthesia, in order to avoid post-operative atelectasis or pneumonia.^{12,13}

The absence of the ideal monitoring device has been one of the main reasons why many anesthesiologists do not routinely rely on objective methods for assessing neuromuscular monitoring. This issue reviews the basics of neuromuscular monitoring and stresses the importance of using an objective method to complement sound clinical judgment.

NEUROMUSCULAR MONITORING

Neuromuscular monitoring can be performed subjectively or objectively.

SUBJECTIVE EVALUATION

A subjective evaluation consists of either a clinical evaluation of the degree of relaxation based on the patient's ability to perform certain tasks, or a tactile or visual evaluation after evoked stimulation of motor nerves (eg, the facial or the ulnar nerve).

Clinical evaluation relying on tasks performed by the patient obviously cannot be used during general anesthesia. It can only be used to ascertain return of normal neuromuscular transmission after the patient has awakened. Although some of the tests recommended can be quite reliable with a cooperative patient, – such as a sustained head-lift, leg-lift, or hand-grip for more than 5 sec,¹⁴ – in general, they are difficult to perform. These tests depend on a degree of awareness and cooperation that is sometimes diffi-

cult to obtain from a patient emerging from general anesthesia. There are, therefore, many situations in which a clinical evaluation will be unreliable. Nonetheless, when cooperative patients cannot perform adequately during these tests, clinicians should suspect that residual NMB is present and initiate more objective testing.

Tactile or visual evaluation of an evoked muscle response is still the most widely used method of neuromuscular monitoring. It is used mainly at the hand to evaluate the response of the adductor pollicis muscle, but also at the eyebrow to record the response of the corrugator supercillii muscle. Whether there is good agreement between these subjective tests and more objective methods such as accelerometry depends on the experience of the observer.¹⁵⁻¹⁷ Even if tactile or visual evaluations are adequate methods to count the absolute number of responses following TOF stimulation, distinguishing between a TOF ratio of 0.7, 0.8, or 0.9 is very difficult, if not impossible. Although double-burst stimulation (see below) might improve the tactile or visual evaluation, it should be understood that this method of neuromuscular monitoring cannot be substituted for objective methods and does not allow the exact titration of NMB drugs.

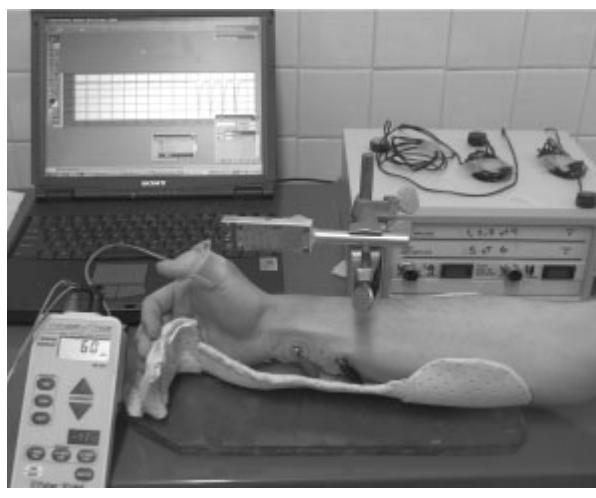
OBJECTIVE MONITORING METHODS

Electromyography

Electromyography (EMG) is the oldest method of neuromuscular monitoring¹⁸ and is based on recording the compound action potential after the evoked stimulation of a motor nerve. Whether integrated or peak-to-peak amplitude is used to determine the power of the potential, this method is useful for routine monitoring.¹⁹ In general, it can be and has been used on most muscle sites of interest for the purpose of research or during regular clinical procedures. Muscle sites, including the larynx,²⁰⁻²³ diaphragm,²³⁻²⁵ adductor pollicis^{26,27} and, with restrictions, the eye muscles (orbicularis oculi or the corrugator supercillii muscle),²⁸ are all described in the literature. However, EMG of smaller muscles is difficult because of the small action potentials observed. Agreement between EMG and mechanomyography (MMG) is controversial and several studies have demonstrated that these techniques should not be used interchangeably.²⁹⁻³³ Technical problems that may arise with EMG include: drift over time (the EMG potential does not return to control levels), failure to disappear completely even in entirely relaxed muscles, and interference with other electric or electronic devices. In most research centres, EMG is reserved for monitoring diaphragmatic activity. Good correlation

FIGURE 1: Setup for mechanomyographic monitoring.

The arm should be placed in a pre-molded cast, the thumb attached to a force-transducer with an adequate preload; signals are recorded on a portable computer using Polyview software. (Amplifier model: 15 LT, Grass)



was found between external EMG monitoring and a method that monitors NMB at the diaphragm by manometrically measuring pressure induced within the esophagus^{34,35} (which is obviously cumbersome and invasive). Refinements in this monitoring technique have included posterior monitoring of the diaphragm.²⁴ Although there are commercially available EMG-based monitoring devices, like the Datex Relaxograph[®] or the monitor integrated into the Datex Ohmeda anesthesia machine (Datex Ohmeda, Finland), their failure to give reliable results that can be used interchangeably with mechanomyography have limited their use as routine monitoring devices.

Mechanomyography (MMG)

If neuromuscular monitoring should reflect the degree of relaxation of a given muscle, then measuring the actual force of this muscle should be the best method to monitor NMB. Of all the monitoring methods, MMG requires the most stringent preparations and precautions. Ideally, the muscle should be fixed in a specially molded cast to prevent changes in positioning. Moreover, the application of a constant preload is recommended. A given preload will be dependent on muscle site and size (Figure 1). The best-known commercially available device for clinical routine MMG is the Myograph 2000[®] (Biometer International, Denmark) for measurement of the adductor pollicis muscle. However, MMG is not problem-free:

- drift can be a problem
- the response does not always return to the control amplitude

- slight detachments of the hand from the monitoring device can change the amplitude of the evoked signal
- the devices are bulky and cumbersome to set up
- meticulous control of the correct positioning is required
- only the response at the adductor pollicis muscle can be measured.

There are methods that could be called “MMG-like,” such as the balloon pressure method for monitoring of either the larynx³⁶ or the corrugator supercilii muscle.³⁷ These methods measure, indirectly, the force generated by the contraction of these muscles, (ie, the change of pressure exerted onto a balloon compressed by movement of the thumb or contraction of the corrugator supercilii muscle). Again, these methods are not easy to apply and are mostly reserved for research purposes as a gold standard or as a reference against which other methods are tested.

Accelerometry or acceleromyography (AMG)

Accelerometry measures the acceleration of a given end-organ (eg, the thumb) when moved by its attached muscle (eg, the adductor pollicis muscle). It correlates with the actual force using this formula: $\text{force} = \text{mass} \times \text{acceleration}$. Commercially available devices performing AMG are the TOF-watch[®] and TOF-watch SX[®] (distributed by the Philips Company, USA). They are easy to use, can be connected to data-processing devices, and are not overly expensive. Their agreement with MMG has been tested and the results are usually good when the devices are carefully set up.^{38,39} However, use of AMG at muscles other than the adductor pollicis is limited, and it cannot be used at the larynx and the diaphragm. Moreover, it can be used only with difficulty at muscle sites that do not create distinct movement, like the movement of the thumb after contraction of the adductor pollicis muscle. Recently, it was demonstrated that its use at the eye muscles (eg, the corrugator supercilii muscle) is also limited, especially in detecting the maximum degree of NMB.⁴⁰ In general, the accuracy of AMG is low when only low-amplitude movement (or acceleration) occurs at a given end-organ. The accuracy of the movement measured at the eyebrow (orbicularis oculi or the corrugator supercilii muscle) may also be influenced by the mass of the accelerator probe itself. Thus far, there have been no studies testing the influence of the mass of the accelerometer probe on monitoring results, but the potential for any probe to influence the degree of acceleration that occurs at the monitoring site seems obvious. Despite these pitfalls, AMG is the most accurate and reliable

FIGURE 2: NMT-mechanosensor: a flexible plastic device is applied to the thumb to mimic a MMG-like preload. Recording displays columns and percentages of control amplitude.



monitoring device on the market to objectively measure NMB during routine clinical procedures.

Kinemyography

Recently, a new monitoring device integrated into the Datex Ohmeda anesthesia machine entered the market. Its goal is to evaluate NMB by measuring movement of the thumb (Figure 2). It is based on a piezo-electric transducer and consists of a molded plastic device that fits the hand. It can be used only to monitor the response of the adductor pollicis muscle. It is interesting to note that the method this device is based on has not been well-documented. In addition, no substantial studies were published before it was commercialized. Initially, only a small study was available on the company website that described the device and its use in a handful of patients. More recently, studies with classical designs from several centres have demonstrated that results with this device agree reasonably well with MMG regarding TOF ratios. On the other hand, other pharmacodynamic indices do not correlate satisfactorily with MMG.⁴¹ Although the NMT Mechanosensor device appears to be handy, its accuracy is not superior to any of the AMG devices available, and careful hand positioning is necessary to avoid artifacts and information that could be misleading, especially during the recovery period.⁴²

Phonomyography (PMG)

This method has been developed in the author's department at the University of Montreal

FIGURE 3: A small piezoelectric microphone is attached with self-adhesive tape onto the skin overlying the corrugator supercillii muscle. Nerve stimulation is performed in routine fashion using AgCl-electrodes.



and is based on the fact that when muscles contract, they evoke low-frequency sounds that can be detected using special microphones. Initially, air-coupled, bulky microphones were used and one study showed very good agreement with MMG.⁴³ Another study, however, could not find an agreement good enough for research purposes.⁴⁴ Since these studies, extensive testing has been done in our laboratory. We found that the limited ability of the air-coupled microphones – especially the failure to detect frequencies of 2 Hz – might be the reason for these contradictory results. We have shown that the peak frequency of a typical signal is at 4-5 Hz and the maximum power occurs in a spectrum of frequency up to 50 Hz. We have used piezoelectric microphones that are able to detect frequencies down to 2 Hz, which can be easily applied by using a simple tape (Figure 3). Good to very good agreement with MMG or MMG-like methods have been shown for the adducting laryngeal muscles,⁴⁵ corrugator supercillii muscle,³⁷ and the adductor pollicis muscle.⁴⁶ In fact, at the corrugator supercillii muscle, the PMG was better than AMG in detecting the peak effect.⁴⁰ With PMG, vulnerability to artifact influence is not that different from MMG (influence of electrocautery), nor is its tendency to drift over time. The advantages of PMG are that it can be used at every muscle site of interest and is an easy to apply, noninvasive method. One problem is the difficulty to securely tape the microphone. Care is required so it does not detach during times

of measurement, since changes in contact surface or pressure between the microphone and skin or muscle are likely to influence the signal amplitude (important for single twitch stimulation). In a typical set-up, the hand is simply taped to an armboard, while the microphone is taped to the thenar region (for monitoring of the adductor pollicis muscle) or the back of the hand for monitoring of the first dorsal interosseus muscle. We are currently developing a prototype based on this method and experimenting with self-adhesive microphones to improve user-friendliness and increase stability.

In the next issue (Part 2), we will review the various stimulation patterns and monitoring sites.

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Abstract of Interest

Comparison of phonomyography with balloon pressure mechanomyography to measure contractile force at the corrugator supercilii muscle.

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PURPOSE: Phonomyography is based on the creation of low frequency sounds during muscle contraction, which can be recorded and used for neuromuscular monitoring. In this study, balloon pressure mechanomyography, a novel method to measure the force of contraction via pressure changes in an air-filled balloon, was compared with phonomyography to determine neuromuscular blockade at the corrugator supercilii muscle.

METHOD: After approval of the Ethics Committee and informed consent, 15 patients were studied. A small condenser microphone

was taped to the area just above the eyebrow for phonomyography; an air-filled balloon was taped to the area just above the opposite eyebrow. After induction of anesthesia using remifentanyl and propofol, a laryngeal mask airway was inserted without the aid of neuromuscular blocking agents. The facial nerve was stimulated supramaximally with single-twitch stimulation (0.1 Hz) using superficial electrodes placed on both temporal areas for onset and train-of-four stimulation every 12 sec during offset of neuromuscular blockade produced by mivacurium 0.1 mg.kg(-1). Onset and recovery measured by the two methods were compared using the t test and agreement between phonomyography and balloon pressure mechanomyography was examined using the Bland-Altman method.

RESULTS: Onset, peak effect, and time to reach 25%, 75%, and 90% of control twitch response for phonomyography vs balloon pressure method were 83 +/- 16 sec vs 81 +/- 15 sec, 80 +/- 15% vs 82 +/- 17%, 7.7 +/- 2.3 min vs 7.5 +/- 2.4 min, 9.9 +/- 4.1 min vs 10.5 +/- 4 min, and 12.6 +/- 4.3 min vs 13.1 +/- 4.5 min respectively without being significantly different. Mean bias was 1% with limits of agreement of -9 and +9% of twitch height (T1).

CONCLUSION: We applied a balloon pressure method to measure the force at the corrugator supercilii. Phonomyography at the corrugator supercilii shows good agreement with this modified version of mechanomyography.

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