Neuromuscular Monitoring: Keep It Simple!

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The principles of logic … are true, simply because we never allow them to be anything else.
—Sir Alfred Jules Ayer (October 1910–June 1989)

The proposals by Biro et al,[1] which appear in this month's "Open Mind," address the future of perioperative neuromuscular monitoring. In essence, their article is an "opinion piece," which clearly was well received by the peer-review experts of this Journal. However, the authors of this editorial are not ready to accept all of the suggestions by Biro et al.[1] What follows is a contrarian response that we readily admit expresses our own personal biases.

The first half of the article by Biro et al[1] consists of proposed modifications of Naguib et al[2] as to how to define depth of neuromuscular block. What does "deep" or "moderate" block actually mean? The authors' suggestions are not unreasonable, although it is difficult to see how they will be helpful to the clinical anesthesiologist. Intraoperative decisions regarding drug dosage should ultimately be based on the evoked train-of-four ratio or the posttetanic count, not on how we define these levels. The potential benefit of labeling each level is that investigators doing comparative studies between the relationship of depth of block and the adequacy of surgical operating conditions will be more likely to equate similar degrees of depth of relaxation. In the latter setting, we would suggest a further modification (Table) as we believe that train-of-four counts of 1 and 3 should not be grouped together because they represent sufficiently different levels of blockade.

Biro et al[1] argue for the need for deep neuromuscular blockade in different surgical procedures. From our perspective,[3,4] we have no issues regarding the use of deep neuromuscular block when it is indicated, as in, for example, neurosurgical, ophthalmological, airway, and occasionally laparoscopic surgeries. However, we still maintain our views regarding the lack of evidence that supports the routine use of deep block in laparoscopic and robotic-assisted procedures.[5,6] We agree that the use of neostigmine to reverse deep neuromuscular block will not be effective and will not result in adequate recovery, but we question the authors' suggestion that it may result in recurarization in this scenario.[7,8] The majority of reported cases of recurarization after neostigmine are very poorly documented. Most, if not all, represent inadequate antagonism and subsequent fatigue rather than recurrence of block. Recurarization, as a phenomenon, may be seen clinically after using inadequate doses of sugammadex.[9,10]

The more controversial aspect of the article by Biro et al,[1] we think, relates to the mandated features that they suggest should be incorporated into future quantitative (objective) neuromuscular monitors. We cannot agree with the statement that the stimulation patterns such as those available on the TetraGraph (Senzime B.V., Uppsala, Sweden), TwitchView (Blink Device Company, Seattle, WA), or TOFScan (IDMED, Marseille, France) are "still not sufficient." Quantitative monitors need to be able to display the posttetanic count and train-of-four count/ratio in real time. Available units and those on the immediate horizon already do this. The authors argue for much more elaborate capabilities: "Modern neuromuscular monitors should have a built-in trend function that can be reviewed by the clinician contemporaneously, and should have the ability to be annotated by the user. We would welcome equipment with implemented algorithms that [automatically] modify both the stimulation pattern and the interval time according to the result of the last measurement."

One common complaint that we hear from clinicians regarding quantitative neuromuscular monitors is that the user interface is not user friendly. We are unconvinced that adding automatic modes and graphic displays to small handheld devices would represent a step forward. We are strong proponents of the "keep it simple" doctrine. We believe that a monitor with a simple and easy-to-understand interface will ultimately achieve greater acceptance among clinicians than a unit with features that will be used only by a very few. We are concerned that adding multiple bells and whistles to new neuromuscular monitors will make the user interface less friendly and the learning curve steeper. This is exactly what we do not need when many clinicians find using a simple peripheral nerve stimulator too much trouble.[11] We have witnessed on numerous occasions a "new" monitor

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Table. Levels of Neuromuscular Block

Depth of Block	Objective Measurement at Adductor Pollicis Muscle	Subjective Measurement at Adductor Pollicis Muscle
Complete block	Posttetanic count = 0	Posttetanic count = 0
Profound block	Posttetanic count = 1–3	Posttetanic count = 1–3
Deep block	Posttetanic count ≥4, train-of-four count = 0	Posttetanic count ≥4, train-of-four count = 0
Moderate block	Train-of-four count = 1–2	Train-of-four count = 1–2
Modest block	Train-of-four count = 3–4	Train-of-four count = 3–4
Shallow block	Train-of-four ratio <0.40	Train-of-four count = 4, fade
Minimal block	Train-of-four ratio = 0.40–0.90	Train-of-four count = 4, no fade
Acceptable recovery	Train-of-four ratio ≥0.90	Cannot be determined

languishing in the bottom drawer of the anesthesia machine, forgotten within 3 months of its purchase. While Biro et al[1] focus on the minute details of display trending and customizing stimulus intervals, they ignore a core issue: data reliability. Should acceleromyography devices continue to be developed despite their inherent weaknesses (eg, control train-of-four ratios >1.00)?[12] A word about the potential advantages of electromyographic monitoring would seem appropriate in any discussion of the future of neuromuscular monitoring.

Focusing on hardware ignores a more fundamental problem. Misconceptions, lack of knowledge, and failure to follow well-established guidelines regarding the clinical use of neuromuscular blocking drugs are commonplace.[13] What we need most within the realm of neuromuscular monitoring is not more complicated monitors, but rather the application of well-established lessons. The basic principles (the dos and don'ts) of neuromuscular blockade and reversal are well known and have been the subject of countless editorials, review articles, and scientific papers. Unless strong educational efforts regarding neuromuscular protocols are made at the departmental level, merely acquiring the latest and most expensive quantitative monitor is not likely to solve the problem of undetected postoperative residual neuromuscular block.[14]

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Proposal for a Revised Classification of the Depth of Neuromuscular Block and Suggestions for Further Development in Neuromuscular Monitoring

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See Editorial, p 1063

Anesthesiologists are experiencing new demands for the induction and maintenance of deep neuromuscular block for certain surgical interventions and simultaneously witnessing technical advances in neuromuscular monitoring equipment. The authors view this article as an educational proposal in a process that has gained new momentum and that addresses both clinicians and the manufacturers of medical devices.

The discussion whether a deep or even total neuromuscular block might be justified for surgeries such as robot-assisted endoscopic, ophthalmological, or airway operations is still ongoing. Some authors state that maintaining a deep neuromuscular block between 1 and 3 post-tetanic counts during pneumoperitoneum or operations in the posterior chamber of the eye is mandatory.[1,2] The authors support their claim with the well-accepted patient safety argument that inadvertent movements of insufficiently paralyzed patients can cause significant morbidity. It is self-explanatory that this cannot be proven in prospective, randomized studies. Fernando et al[3] have demonstrated that even at the very low post-tetanic count value of 1, the diaphragm still can inadvertently contract. If this happens, endoscopic instruments can injure the intra-abdominal organs, large vessels, or other delicate structures. Another argument favoring deep block is the improved access to the operation field in the abdominal cavity by the surgeons, if the abdominal wall is completely relaxed.[4,5] The application of lower insufflation pressures of carbon dioxide into the abdominal cavity during a very deep block may cause less postoperative pain associated with residual carbon dioxide below the diaphragm.[6,7] Even if these findings remain controversial, we believe there is a need to redefine the nomenclature for the spectrum of neuromuscular block. With a clearer differentiation of deep block levels, we might facilitate future discussions.

Naguib et al[8] have proposed the following stratification of the neuromuscular block spectrum (Table 1), which is widely accepted. We consider the designated area for "deep block" in Naguib list, which ranges from a train-of-four count = 0 to a post-tetanic count ≥1 to be too broad. Although this classification may be sufficient for the majority of surgical purposes, for those who prefer to work with the very deep and narrow segment of post-tetanic counts values ranging from 1 to 3, this area should be specifically identified. For this particular range, we propose the term "profound block." Thus, our slightly modified scale divides the original deep block as shown in Table 2.

When extubating a patient's trachea, the difference between "minimal" and "shallow" block is important. We believe that a distinction between a deep and profound block is also justified, considering their significance for specific surgeries. We must emphasize that the proposal for introducing the profound block level into this list of definitions is not meant to encourage clinicians to achieve deeper block levels than they otherwise would. However, for some surgical procedures, such as intraocular, where even minor patient movements may be disastrous, and when diaphragmatic contractions must be prevented to avoid increases in intracranial pressure associated with tracheal suctioning, profound levels of block are recommended.[3,9] Ultimately, these are decisions that each clinician must make based on individual clinical need. Our proposal merely fine-tunes the set of definitions of the various depths of neuromuscular block in an attempt to standardize the terminology. In addition, although profound block may be necessary in certain settings to prevent injury, the clinician cannot and must not assume that this technique is devoid of significant side effects. First, many clinicians do not have unrestricted access to sugammadex, while neuromuscular antagonism from profound degrees of block is ineffective with neostigmine. Second, the very surgeries that may require profound block (laparoscopic, robotic, eye, and airway surgery) have

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Table 1. Original Neuromuscular Block Levels by Naguib et al[8]

Level of Block	Depth of Block	Objective Measurement at the Adductor Pollicis	Subjective Measurement at the Adductor Pollicis
Level 5	Complete block	Post-tetanic count = 0	Post-tetanic count = 0
Level 4	Deep block	Post-tetanic count ≥1, train-of-four count = 0	Post-tetanic count ≥1, train-of-four count = 0
Level 3	Moderate block	Train-of-four count = 1–3	Train-of-four count = 1–3
Level 2b	Shallow block	Train-of-four ratio <0.4	Train-of-four count = 4; train of four fade present
Level 2a	Minimal block	Train-of-four ratio = 0.4–0.9	Train-of-four count = 4; train of four fade is not detectable
Level 1	Acceptable recovery	Train-of-four ratio ≥0.9	Cannot be determined

Levels of neuromuscular block. Subjective evaluation of neuromuscular block is not recommended, but it is included as an interim transition from current practice to the preferred, objective monitoring-based practice.

Table 2. Modified Neuromuscular Block Levels

Level of Block	Depth of Block	Objective Measurement at the Adductor Pollicis	Subjective Measurement at the Adductor Pollicis
Level 7	Complete block	Post-tetanic count = 0	Post-tetanic count =0
Level 6	Profound block	Post-tetanic count = 1–3	Post-tetanic count = 1–3
Level 5	Deep block	Post-tetanic count ≥4, train-of-four count = 0	Post-tetanic count ≥4, train-of-four count = 0
Level 4	Moderate block	Train-of-four count = 1–3	Train-of-four count = 1–3
Level 3	Shallow block	Train-of-four ratio <0.4	Train-of-four count = 4; train of four fade present
Level 2	Minimal block	Train-of-four ratio = 0.4–0.9	Train-of-four count = 4; train of four fade is not detectable
Level 1	Acceptable recovery	Train-of-four ratio ≥0.9	Cannot be determined

Adapted from Naguib et al[8] with renamed levels of block and split former deep block level and integer level numbering.

surgical closure times that are much shorter than traditional open abdominal procedures. Therefore, the depth of block at the time of neostigmine reversal may be deeper than of other surgeries, rendering patients at increased risk of residual neuromuscular block or recurrence of block ("recurarization").

A second topic we believe needs to be addressed is the display of neuromuscular monitoring data over time. Older technology, such as the TOF-Watch (Organon, Ireland), allowed the user to download the intraoperative data onto an interfaced computer and display them in a trend format; these data included train-of-four ratio, baseline twitch height, train-of-four count, skin temperature, etc. Modern neuromuscular monitors should have a built-in trend function that can be reviewed by the clinician contemporaneously and should have the ability to be annotated by the user. We would welcome equipment with implemented algorithms that modify both the stimulation pattern and the interval time according to the result of the last measurement. Newer neuromuscular monitoring equipment such as the TOFscan (IdMed, Marseille, France), TetraGraph (Senzime BV, Uppsala, Sweden), and TOFcuff (RGB Medical, Madrid, Spain) display time and dosing-related courses of neuromuscular block with the main stimulation patterns of train-of-four ratio, train-of-four count, and post-tetanic counts. In some of these devices, a semiautomatic or even a fully automatic mode is already implemented.

However, this is still not sufficient. In an ideal system, during anesthesia and neuromuscular block induction, the device would measure TOF in short intervals (eg, every 20 seconds) as long as a train-of-four count is present. As soon as train-of-four count becomes 0 (which might be confirmed by a second measurement), the device should assess the post-tetanic counts. This would indicate that the neuromuscular block level has reached a deep block, where TOF stimulation does not yield positive values. Because of the more pronounced release of synaptic acetylcholine induced by the tetanic stimulation, the time interval after a post-tetanic count sequence should then automatically switch to a longer period (eg, 3 or 4 minutes) and avoid measurements during post-tetanic potentiation.[10] In addition, before each post-tetanic count measurement, a TOF count of zero (train-of-four count = 0) should ensure that a tetanic stimulation is only delivered during deep or profound block. This sequence of train-of-four count = 0 followed by a post-tetanic count sequence should be repeated every 3 minutes until train-of-four count becomes positive (>0), in which case the sequence should automatically revert to train-of-four count every 20 seconds until train-of-four ratio >0.9. Users could set threshold limits for a desired neuromuscular block level, which would deliver a warning when a measurement is outside of the desired range.

Concerning the monitor screen, we suggest using intuitive symbols on a large screen, which enables an overview of a longer period, preferably with a variable time scale resolution. In the Figure, the consecutive display of the entire spectrum of neuromuscular block values is illustrated, as implemented to various degrees in the TetraGraph and in an experimental version of the TOFcuff software (Figure). In addition to these clear and self-explanatory symbols, we would like to include the option for the user to set a mark that indicates the moment when a repeated dose of neuromuscular block agent has been administered. This could be, for example, a small triangle at the upper screen margin, as depicted in the image. By viewing the neuromuscular blocking pattern and the times of drug dosing, the individual kinetics of a patient can be better understood, thus leading to better individualized neuromuscular blocking agent dosing.

A better delineation of the levels of intraoperative neuromuscular block, an improved trend display of the varying depths of intraoperative block with appropriate symbols to indicate important events, and the appearance on the

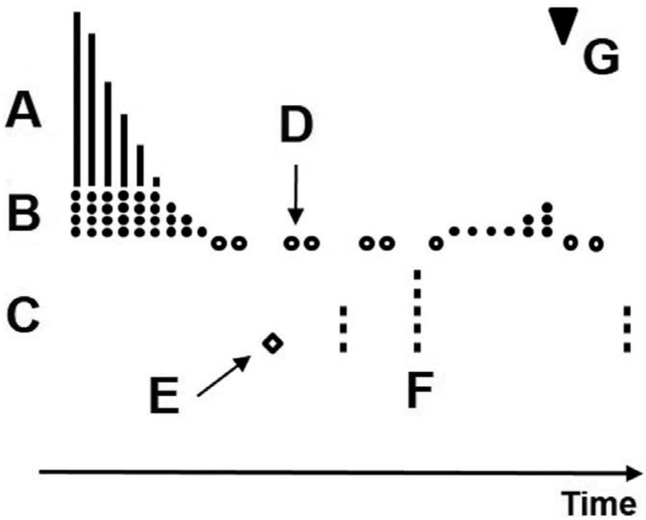

Figure. Symbols indicating the responses to various stimulation patterns displayed over time. The image shows an example of the succession of values that may occur after an initial bolus dose of a nondepolarizing neuromuscular blocker and after 1 repetition dose. A, Fading train-of-four ratio (TOFR) after induction. B, Number of prevailing and receding train-of-four count (TOFC). C, Region for dots representing post-tetanic count (PTC) values. D, Symbol for TOFC = 0. E, Symbol for PTC = 0. F, A PTC value of 5. The triangle on the top right corner (G) is user set and indicates the time when a repetitive dose of neuromuscular blocking agent has been administered. The different time intervals between the measurements are not displayed proportionally in this image.

market of new quantitative monitors are all significant events that should improve patient care.

Summarizing our proposals, we would modify Naguib scale by dividing the original deep block into profound block (post-tetanic counts = 1–3) and deep block (post-tetanic count ≥4 and train-of-four count = 0). We also suggest renumbering the levels with integers. New neuromuscular monitoring equipment may implement an automatic mode that adapts to the stimulation pattern and the time intervals to the measured values. Finally, a larger portion of the neuromuscular block course would be visible if displayed on a screen in a landscape orientation or as a module on the monitoring display, thus illustrating the timely context of dose and effect in a clear and intuitive fashion.

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