International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2025: 7.089

Neuromuscular Monitoring in Modern Anesthetic Practice: A Narrative Review

Kanabar Sonal Vijaybhai

Department of Anaesthesiology, Narendra Modi Medical College and Hospital, Ahmedabad, Gujarat, India

Abstract: ***Neuromuscular blocking agents are integral to modern anesthesia, facilitating tracheal intubation, surgical exposure and controlled ventilation. However, incomplete recovery from neuromuscular blockade remains an important and preventable perioperative safety problem. Clinical assessment alone, including head lift, hand grip and respiratory pattern, is insufficiently sensitive to exclude clinically relevant residual weakness. The development of peripheral nerve stimulation and quantitative neuromuscular monitors has transformed assessment from subjective observation to objective measurement. Current recommendations favor quantitative monitoring, particularly at the adductor pollicis, and confirmation of a train-of-four ratio of at least 0.9 before extubation. This narrative review summarizes the physiology of neuromuscular transmission, principles of peripheral nerve stimulation, train-of-four monitoring, double-burst stimulation, tetanic stimulation and post-tetanic count. It also reviews qualitative versus quantitative monitoring, acceleromyography and electromyography, appropriate monitoring sites, interpretation of neuromuscular block depth, pharmacological reversal with sugammadex and neostigmine, and practical considerations for safe extubation. Special attention is given to residual neuromuscular blockade, common technical errors and the implementation of quantitative monitoring in routine anesthesia practice. Contemporary neuromuscular monitoring should be considered an integral component of safe anesthesia whenever neuromuscular blocking drugs are administered.***

Keywords: Neuromuscular monitoring; train-of-four; TOF ratio; peripheral nerve stimulation; residual neuromuscular blockade; sugammadex; neostigmine; quantitative monitoring

1. Introduction

Neuromuscular blocking agents (NMBAs) are widely used during general anesthesia. They improve conditions for tracheal intubation, facilitate surgical exposure and allow controlled mechanical ventilation. Despite their benefits, residual neuromuscular blockade can persist after apparently adequate reversal and may contribute to upper-airway obstruction, hypoventilation, impaired airway protection, hypoxemia and delayed recovery.

Historically, anesthesiologists relied heavily on clinical tests and visual or tactile responses to peripheral nerve stimulation. However, these approaches cannot reliably detect smaller degrees of residual weakness. The 2023 American Society of Anesthesiologists (ASA) Practice Guidelines recommend quantitative neuromuscular monitoring over clinical assessment or qualitative assessment and recommend confirmation of a TOF ratio of at least 0.9 before extubation. The guidelines also recommend the adductor pollicis as the preferred monitoring site. □cite□turn445091search0□turn445091search4

The purpose of this review is to explain the principles and practical application of neuromuscular monitoring and to provide a clinically useful framework for anesthesiologists and trainees.

2. Neuromuscular Transmission: Basic Physiology

A motor nerve action potential reaching the presynaptic terminal causes release of acetylcholine into the neuromuscular junction. Acetylcholine binds to postsynaptic nicotinic receptors on the motor endplate and produces depolarization of the muscle membrane, resulting in muscle contraction.

Nondepolarizing NMBAs such as rocuronium, vecuronium, atracurium and cisatracurium act mainly as competitive antagonists at nicotinic acetylcholine receptors. Increasing receptor occupancy produces progressive weakness and eventually complete paralysis.

Succinylcholine is a depolarizing neuromuscular blocker. It produces persistent depolarization of the motor endplate and is normally followed by rapid spontaneous recovery. Neuromuscular monitoring can help distinguish normal recovery from prolonged blockade in selected circumstances.

3. Why Neuromuscular Monitoring Is Important

The clinical appearance of adequate recovery can be misleading. A patient may be awake, obey commands and demonstrate apparently adequate respiratory effort while still having impaired pharyngeal muscle function or reduced respiratory reserve.

Residual neuromuscular blockade has traditionally been defined by a TOF ratio below 0.9. Earlier practice sometimes considered a TOF ratio of 0.7 sufficient for recovery, but subsequent evidence demonstrated clinically relevant weakness below 0.9. The current ASA guideline therefore recommends confirming TOF ratio ≥0.9 before extubation when quantitative monitoring is used. □cite□turn445091search0□turn445091search2

Neuromuscular monitoring is particularly important in patients with obesity, obstructive sleep apnea, respiratory disease, advanced age, neuromuscular disorders, prolonged surgery or substantial exposure to NMBAs.

4. Peripheral Nerve Stimulation

A peripheral nerve stimulator delivers controlled electrical stimuli to a peripheral motor nerve and measures or allows observation of the resulting muscle response.

Common nerves and muscles include:
- Ulnar nerve → adductor pollicis.
- Facial nerve → corrugator supercilii or orbicularis oculi.
- Posterior tibial nerve → flexor hallucis brevis.

The ulnar nerve-adductor pollicis combination is particularly useful for assessing recovery because it is standardized, reproducible and recommended by the ASA guideline for quantitative monitoring. □cite□turn445091search0□

Correct electrode placement, adequate skin preparation and stable positioning of the monitored limb are essential for reliable results.

5. Train-of-Four Stimulation

Train-of-four (TOF) stimulation consists of four supramaximal electrical stimuli delivered at 2 Hz over approximately 2 seconds. The responses are described as T1, T2, T3 and T4.

With nondepolarizing blockade, progressive receptor blockade produces fade, so the fourth response becomes smaller than the first. The qualitative TOF count describes how many responses are visible or palpable:
- TOF 4: four responses present, but fade may still be present.
- TOF 3: three responses.
- TOF 2: two responses.
- TOF 1: one response.
- TOF 0: no response.

A TOF count describes the depth of blockade but does not by itself prove adequate recovery. A patient can have four visible twitches and still have a TOF ratio below 0.9. Quantitative measurement is therefore preferred when available. □cite□turn445091search0□

6. Train-of-Four Ratio

The TOF ratio is calculated as the amplitude of the fourth response divided by the amplitude of the first response:
TOF ratio = T4 / T1

A ratio of 1.0 indicates equal T4 and T1 responses. With nondepolarizing neuromuscular blockade, the ratio decreases because of fade.

For modern clinical practice, the key endpoint is recovery to TOF ratio ≥0.9. The ASA guideline strongly recommends confirming this value before extubation when quantitative monitoring is used. □cite□turn445091search0□

An important practical point is that qualitative monitoring cannot reliably distinguish a TOF ratio of 0.8 from 0.9 or 1.0. Therefore, simply seeing four twitches is not equivalent to documented adequate recovery.

7. TOF Count Versus TOF Ratio

TOF count and TOF ratio answer different questions.

TOF count is mainly useful for estimating the depth of blockade when substantial neuromuscular block is present. TOF ratio is used to assess recovery from nondepolarizing blockade.

For example, TOF count 0 indicates profound block, whereas TOF count 4 indicates that four responses are present. However, only quantitative assessment of the ratio can reliably determine whether the patient has recovered to ≥0.9.

Thus:
TOF count → "How much block is present?"
TOF ratio → "How much recovery has occurred?"

8. Double-Burst Stimulation

Double-burst stimulation (DBS) consists of two short bursts of high-frequency stimulation separated by a brief interval. Each burst generally contains three impulses at high frequency.

DBS was developed to make tactile detection of fade easier than conventional TOF stimulation. It can improve the ability of the clinician to recognize residual fade when quantitative monitoring is unavailable.

However, DBS remains a qualitative technique. It cannot provide an exact TOF ratio and therefore does not replace quantitative monitoring when objective assessment is available.

9. Tetanic Stimulation and Post-Tetanic Count

Tetanic stimulation involves high-frequency stimulation, commonly 50 or 100 Hz, for several seconds. It produces a sustained contraction and is mainly used in the assessment of deeper neuromuscular block.

When no response is observed to TOF stimulation, post-tetanic count (PTC) can help estimate the depth of profound blockade. A tetanic stimulus is followed by a brief interval and then repeated single stimuli. The number of post-tetanic responses provides the PTC.

A lower PTC indicates deeper blockade, whereas increasing PTC suggests recovery toward the stage at which TOF responses will reappear. PTC is especially useful when managing profound block with drugs such as rocuronium.

10. Qualitative Versus Quantitative Monitoring

Qualitative monitoring depends on the observer's visual or tactile interpretation of muscle responses. It is inexpensive and widely available but cannot accurately measure small degrees of fade.

Quantitative monitoring uses an objective device to measure force, acceleration, electrical activity or another physiological variable and reports a numerical TOF ratio.

The 2023 ASA guideline recommends quantitative monitoring over qualitative assessment because quantitative monitoring is more effective in reducing residual neuromuscular blockade. It also recommends against relying on clinical assessment alone. □cite□turn445091search0□turn445091search1□

Therefore, the modern approach should be:
NMBA administered → quantitative monitoring → monitor depth → guide reversal → confirm TOF ratio ≥0.9 → extubate when other clinical criteria are satisfied.

11. Types of Quantitative Neuromuscular Monitoring

Several technologies have been used for quantitative assessment.

11.1 Acceleromyography (AMG)

AMG measures acceleration of a moving muscle or digit. The adductor pollicis is commonly used with ulnar nerve stimulation. AMG monitors are widely used because they are portable and practical.

11.2 Electromyography (EMG)

EMG measures the electrical response generated by muscle fibers following nerve stimulation. It is less dependent on movement and can be useful when movement is restricted.

11.3 Mechanomyography

Mechanomyography measures the force generated by muscle contraction. It has been important in research and in establishing reference standards but is less commonly used in routine clinical practice.

11.4 Kinemyography

Kinemyography detects movement generated by muscle contraction. It has been used in some commercial neuromuscular monitors.

The ASA guideline does not designate a single quantitative technology as universally preferred; the important principle is objective quantitative measurement and appropriate interpretation. □cite□turn445091search2□

12. Site of Monitoring: Why Adductor Pollicis?

The adductor pollicis, stimulated through the ulnar nerve at the wrist, is the preferred site for monitoring recovery in the current ASA guideline. The guideline recommends the adductor pollicis and recommends against using eye muscles for routine quantitative assessment of recovery. □cite□turn445091search0□

Facial muscles can recover earlier than the adductor pollicis and may therefore provide a less conservative estimate of peripheral recovery. Facial monitoring can still have a role during the onset of neuromuscular block, particularly when the arms are inaccessible, but the monitored site should be interpreted in context.

For extubation decisions, quantitative assessment at the adductor pollicis is the preferred approach when feasible.

13. Monitoring During Different Phases of Anesthesia

Neuromuscular monitoring should not be limited to the end of surgery.

Before or soon after NMBA administration:

- Establish appropriate baseline and device function.
- Ensure adequate stimulation and electrode placement.
- During surgery:
- Monitor the depth of blockade according to surgical requirements.
- Repeat measurements at appropriate intervals.
- Avoid unnecessary excessive blockade.
- During reversal:
- Identify the depth of block before selecting the reversal strategy.
- Use quantitative monitoring to guide drug choice and assess response.
- Before extubation:
- Confirm TOF ratio ≥0.9 using quantitative monitoring.
- Combine the objective measurement with clinical assessment of airway, ventilation, consciousness and other standard extubation criteria. □cite□turn445091search0

14. Pharmacological Reversal and Neuromuscular Monitoring

Monitoring and reversal are closely linked. The appropriate reversal agent depends on the NMBA used and the depth of blockade.

Sugammadex directly encapsulates steroidal NMBAs such as rocuronium and vecuronium and can provide rapid reversal across a range of block depths. The ASA guideline recommends sugammadex over neostigmine for deep, moderate and shallow rocuronium- or vecuronium-induced blockade. □cite□turn445091search0□

Neostigmine remains useful, particularly for minimal blockade. The ASA guideline describes neostigmine as a reasonable alternative for minimal block, with a TOF ratio in the range of 0.4 to <0.9. Appropriate timing and dosing remain important because neostigmine has a ceiling effect and is less predictable when significant blockade remains. □cite□turn445091search0□turn445091search2□

If quantitative monitoring demonstrates spontaneous recovery to TOF ratio ≥0.9, pharmacological reversal is not required solely to achieve the numerical endpoint. □cite□turn445091search0□

15. Residual Neuromuscular Blockade

Residual neuromuscular blockade refers to clinically relevant weakness persisting after apparent termination of anesthesia and administration of reversal therapy.

Potential consequences include:
- Upper airway obstruction.
- Impaired pharyngeal function.
- Hypoventilation.
- Hypoxemia.
- Reduced ability to cough and clear secretions.
- Increased risk of pulmonary complications.
- Delayed recovery and unplanned postoperative respiratory support.

Residual weakness may be difficult to detect by conventional clinical tests alone. This is why objective monitoring has become central to modern NMBA management.
□cite□turn445091search0□turn445091search2□

16. Common Errors in Neuromuscular Monitoring

Several technical and interpretive errors can produce misleading results.
1) Poor electrode placement.
2) Inadequate electrical stimulation.
3) Movement of the monitored limb.
4) Failure to stabilize the hand during adductor pollicis monitoring.
5) Interpreting four visible twitches as complete recovery.
6) Using facial responses as the sole endpoint for extubation.
7) Failing to obtain baseline calibration where required by the device.
8) Not accounting for temperature and peripheral perfusion.
9) Administering reversal without considering the depth of block.
10) Extubating without documented objective recovery when quantitative monitoring is indicated.

Correct technique is therefore as important as having the monitor itself.

17. Practical TOF Monitoring: Step-by-Step

Step 1: Select the monitoring site, preferably the ulnar nerve-adductor pollicis combination for recovery assessment.
Step 2: Prepare the skin and position the stimulating electrodes appropriately.
Step 3: Ensure the monitored hand is stable and free to produce the required movement.
Step 4: Establish the baseline according to the monitor's instructions before substantial neuromuscular blockade when feasible.
Step 5: After NMBA administration, use TOF stimulation to assess the depth of block.
Step 6: During surgery, repeat monitoring according to the clinical situation and desired block.
Step 7: Near the end of surgery, use quantitative TOF monitoring to guide reversal.
Step 8: After reversal and spontaneous recovery, confirm TOF ratio ≥0.9.
Step 9: Only after objective neuromuscular recovery is established should extubation be considered along with standard clinical criteria.

This workflow converts neuromuscular management from estimation to measurable, reproducible decision-making.

18. Special Clinical Situations

1) Obesity and obstructive sleep apnea: Residual weakness may be particularly hazardous because respiratory reserve and upper-airway stability can already be compromised.
2) Long surgery: Repeated doses or infusions of NMBAs can result in accumulation depending on the drug and patient factors. Quantitative monitoring allows dosing to be individualized.
3) Intensive care and postoperative ventilation: When prolonged neuromuscular blockade is used, objective assessment can assist with decisions regarding recovery.
4) Neuromuscular disease: Patients may demonstrate abnormal sensitivity to NMBAs or reversal agents. Monitoring should be individualized and closely interpreted.
5) Hypothermia: Reduced temperature can affect neuromuscular transmission, metabolism and recovery, potentially complicating interpretation and prolonging blockade.
6) Regional or limited surgical access: When the usual monitoring site is inaccessible, alternative sites may be considered, but the limitations of the chosen site should be recognized.

19. Current Recommendations and Patient Safety

The most important contemporary recommendations can be summarized as follows:
- Do not rely on clinical assessment alone to exclude residual neuromuscular blockade.
- Prefer quantitative monitoring when an NMBA has been administered.
- Use the adductor pollicis for recovery monitoring when feasible.
- Do not consider four visible twitches equivalent to a TOF ratio ≥0.9.
- Confirm TOF ratio ≥0.9 before extubation when quantitative monitoring is used.
- Select reversal according to NMBA and depth of blockade.
- Use sugammadex preferentially for rocuronium/vecuronium blockade at deeper levels according to guideline recommendations.
- Use neostigmine appropriately for minimal blockade.
- Continue clinical assessment even when quantitative monitoring is available.

These recommendations are consistent with the current ASA guideline and are also reflected in contemporary anesthesia safety guidance. □cite□turn445091search0□turn445091search1□turn445091search23□

20. Future Directions

The future of neuromuscular monitoring is likely to involve more compact, automated and continuously integrated quantitative systems. Greater availability of electromyographic and other objective technologies may make quantitative monitoring routine in operating rooms and recovery areas.

Integration of neuromuscular data with anesthesia information systems could allow automatic documentation of NMBA administration, depth of block, reversal and recovery. Improved education and simulation may also help anesthesiologists recognize technical limitations and interpret quantitative data correctly.

The major goal remains unchanged: reducing preventable postoperative respiratory complications through objective assessment and individualized reversal.

21. Conclusion

Neuromuscular monitoring is an essential component of safe modern anesthesia whenever neuromuscular blocking drugs are administered. The traditional reliance on clinical assessment and subjective detection of fade is inadequate for reliably excluding residual blockade.

Quantitative monitoring, particularly at the adductor pollicis, provides objective information about the depth and recovery of neuromuscular blockade. The current standard is to confirm a TOF ratio of at least 0.9 before extubation. Appropriate interpretation of TOF count, TOF ratio, PTC and reversal pharmacology allows anesthesiologists to individualize NMBA administration and reversal.

For everyday practice, the key message is simple: **do not ask only whether the patient looks recovered—measure neuromuscular recovery objectively.**

Acknowledgement
The author acknowledges the Department of Anaesthesiology, Narendra Modi Medical College and Hospital, Ahmedabad, Gujarat, India, for providing an academic environment conducive to learning and scholarly work.

Funding
No external funding was received for this review.

Conflict of Interest
The author declares no conflict of interest.

Author Contribution
Kanabar Sonal Vijaybhai: Conceptualization, literature search, synthesis of evidence, writing, editing and final approval of the manuscript.

Ethical Approval
Ethical approval was not required because this manuscript is a narrative review of previously published literature and does not involve human participants or patient-identifiable data.

References

[1] Thilen SR, Weigel WA, Todd MM, et al. 2023 American Society of Anesthesiologists Practice Guidelines for Monitoring and Antagonism of Neuromuscular Blockade. Anesthesiology. 2023;138(1):13-41. doi:10.1097/ALN.0000000000004379.
[2] Kopman AF, Yee PS, Neuman GG. Relationship of the train-of-four ratio to clinical signs and symptoms of residual paralysis in awake volunteers. Anesthesiology. 1997; 86: 765-771.
[3] Eriksson LI. Evidence-based practice and neuromuscular monitoring. Anesthesiology. 2003; 98: 1037-1039.
[4] Murphy GS, Brull SJ. Residual neuromuscular block: lessons unlearned. Part I: definitions, incidence, and adverse physiologic effects of residual neuromuscular block. Anesth Analg. 2010; 111: 120-128.
[5] Brull SJ, Murphy GS. Residual neuromuscular block: lessons unlearned. Part II: methods to reduce the risk of residual weakness. Anesth Analg. 2010; 111: 129-140.
[6] Brull SJ, Kopman AF. Current status of neuromuscular reversal and monitoring: challenges and opportunities. Anesthesiology. 2017; 126: 173-190.
[7] Naguib M, Brull SJ, Kopman AF, et al. Consensus statement on perioperative use of neuromuscular monitoring. Anesth Analg. 2018; 127: 71-80.
[8] Fuchs-Buder T, Claudius C, Skovgaard LT, Eriksson LI, Mirakhur RK, Viby-Mogensen J. Good clinical research practice in pharmacodynamic studies of neuromuscular blocking agents II: the Stockholm revision. Acta Anaesthesiol Scand. 2007; 51: 789-808.
[9] Viby-Mogensen J, Jensen NH, Engbaek J, et al. Tactile and visual evaluation of the response to train-of-four nerve stimulation. Anesthesiology. 1985; 63: 440-443.
[10] Kopman AF, Eikermann M. Antagonism of non-depolarising neuromuscular block: current practice. Anaesthesia. 2009;64 Suppl 1:22-30.
[11] Brull SJ, Silverman DG. Visual and tactile assessment of the response to four nerve stimuli is unreliable. Anesthesiology. 1996; 84: 1058-1063.
[12] Fuchs-Buder T, Meistelman C, Raft J. Sugammadex: clinical development and practical use. Anesthesiology. 2012; 116: 1264-1273.
[13] Plaud B, Baillard C, Bourgain JL, et al. Guidelines on muscle relaxants and reversal in anaesthesia. Anaesth Crit Care Pain Med. 2020; 39: 125-142.
[14] Murphy GS, Szokol JW, Marymont JH, et al. Residual paralysis at the time of tracheal extubation. Anesth Analg. 2005; 100: 1840-1845.
[15] Murphy GS, Szokol JW, Avram MJ, et al. Postoperative residual neuromuscular blockade is

associated with impaired clinical recovery. Anesth Analg. 2013; 117: 133-141.
[16] Grayling M, Sweeney BP. Recovery from neuromuscular blockade: a comparison between sugammadex and neostigmine. Anaesthesia. 2007; 62: 110-114.
[17] Sorgenfrei IF, Norrild K, Larsen PB, et al. Reversal of rocuronium-induced neuromuscular block by the selective relaxant binding agent sugammadex. Anesthesiology. 2006; 104: 667-674.
[18] Bartels K, Hunter JM. Neostigmine: old drug, new uses. Curr Opin Anaesthesiol. 2020; 33: 501-506.
[19] Nair VP, Hunter JM. Anticholinesterases and anticholinergic drugs. Anaesthesia. 2004; 59: 73-83.
[20] Murphy GS, Brull SJ. Residual neuromuscular block: a persistent clinical problem. Curr Anesthesiol Rep. 2015; 5: 60-70.