Current Anesthesiology Reports (2018) 8:130–133
https://doi.org/10.1007/s40140-018-0268-3



# Qualitative Neuromuscular Monitoring: Patterns of Stimulation, Site of Monitoring, and Accuracy in Detecting Residual Neuromuscular Blockade

Moumen Asbahi[1] · Roy Soto[1]

Published online: 16 April 2018


**Abstract**

**Purpose of Review** Muscle paralysis is a component of many general anesthetics, and monitoring of neuromuscular function is integral to ensuring complete and safe recovery.

**Recent Findings** Recommendations for qualitative neuromuscular blockade have been well-described in the literature for decades; however practitioners frequently do not follow recommendations, resulting in patient harm from inadequate reversal of paralysis.

**Summary** This review will focus on evidence-based techniques for patterns of stimulation, sites of monitoring, and accuracy in detecting residual neuromuscular blockade; furthermore, the review will also discuss barriers to implementation of best practices.

**Keywords** Paralysis · Neuromuscular blockade · Acetylcholinesterase inhibitor · Neostigmine · Edrophonium · Glycopyrrolate · Atropine · Residual paralysis · Postoperative residual curarization · Sugammadex

## Introduction

The classic components of a general anesthetic include hypnosis, analgesia, and immobility. For nearly a century, immobility was achieved via the relaxant properties of inhaled agents. The agents, however, frequently resulted in hemodynamic depression. Following the introduction of paralytic agents in the mid-twentieth century, the "balanced anesthetic technique" was developed. Analgesics, hypnotics, and paralytics were given in combination in an attempt to reduce the side effects of each medication individually. With the introduction of non-depolarizing neuromuscular blocking agents, new monitoring techniques were also developed, which aided in the titration of these medications during induction, maintenance, and emergence from anesthesia.

This article is part of the Topical Collection on *Neuromuscular Blockade*

✉ Roy Soto
roy.soto@beaumont.edu

1 Department of Anesthesiology, Beaumont Health, 3601 West 13 Mile Road, Royal Oak, MI 48302, USA

## Patterns of Stimulation

Qualitative or subjective monitoring of neuromuscular function requires stimulation of a motor nerve, with observation of the innervated muscle. Patterns of stimulation beyond a single stimulus (or twitch) reveal more detailed information about the degree of paralysis, and other modes of stimulus have been developed to aid with clinical care. Train of four (TOF), double-burst stimulation, post-tetanic count (PTC), and sustained tetanus patterns of stimulation have all been described as ways to detect adequate surgical paralysis and clinical recovery of neuromuscular function [1]. In addition, subjective evaluations of neuromuscular recovery have been used in the clinical setting, including evaluation of head/leg lift, grip strength, bite strength, and respiratory function (specifically tidal volume and vital capacity). Nevertheless, many clinicians do not follow evidence-based recommendations, relying instead on experience, or time-based estimations of paralytic function [2•].

At the start of a surgical procedure, paralytics (both depolarizing and non-depolarizing) are generally dosed at twice to three times the ED95 to achieve rapid onset of clinical effect. Due to the high dose of drug used, onset of paralysis is typically rapid and predictable. Rocuronium, for example, when dosed at 0.6 mg/kg, results in excellent intubating conditions within 90–120 s, rendering neuromuscular monitoring superfluous. As a result, most providers do not monitor for degree of paralysis prior to intubation, trusting instead on the pharmacodynamic properties of the medications given.

During the surgical procedure, however, redosing of paralytic should be based on monitoring of some degree of spontaneous recovery. Using TOF monitoring, 1–2 twitches are generally considered to provide adequate relaxation for surgical procedures, although for some cases, deep blockade may be preferable, and TOF with PTC monitoring may be required [3••]. Many providers choose to forego quantitative or qualitative monitoring, trusting again in pharmacodynamic properties of paralytics, giving an ED50-ED95 dose of paralytic every 20–40 min. Surveys of clinicians in Germany and the UK, for instance, reveal that only 28 and 10%, respectively, use neuromuscular monitors of any kind [4, 5] intraoperatively. Although it follows that these providers probably achieve reasonable clinical results, inter- and intra-patient variability (based on age, comorbidities, and concomitant medications) can make non-monitor-based prediction of degree of paralysis difficult, and potentially dangerous, especially as the conclusion of the surgical procedure nears.

The dose of reversal agent used at the end of the procedure is also highly variable between clinicians. Neostigmine, the most-commonly used anticholinesterase, provides an example of this variability. While 0.07 mg/kg is described in the literature as a maximum dose, neostigmine can result in muscle weakness when given in the absence of remaining paralysis [6]. In other words, the degree of spontaneous recovery (hence, the degree of remaining paralytic) should determine the dose of neostigmine used. Some providers give 0.07 mg/kg to every patient, some choose a lower dose of 0.02 to 0.05 mg/kg, and some skip reversal altogether without objective data to support the practice (Table 1). An evidence-based approach would include the following recommendations [7–9]:

Sugammadex, a relatively new rocuronium-/vecuronium-binding agent, provides reversal of all depths of paralysis when dosed appropriately, but again, the degree of spontaneous recovery and timing of reversal administration determine complete recovery.

Again, despite evidence-based recommendations to the contrary, many providers do not monitor for degree of spontaneous recovery at the conclusion of a case, resulting in guess-work at the time of reversal administration. A survey of American and European anesthesia providers revealed that 9.4 and 19.3% (respectively) of respondents never use neuromuscular monitors at the time of reversal [10], although they did express an understanding of the importance of complete recovery.

**Table 1** Recommended dosing of neostigmine based on degree of spontaneous recovery

| Twitches on TOF monitoring | Recommended dose of neostigmine |
|---|---|
| 1 or 2 | 0.07 mg/kg |
| 3 or 4 (with fade) | 0.05–0.07 mg/kg |
| 4 without detectable fade (tactile or visual) | 0.025 mg/kg |

## Site of Monitoring

For each time point (beginning, middle, and end) during a surgical procedure, it is clear that appropriate monitoring of neuromuscular function can lead to better titration of paralytic or reversal agents. Clinical/subjective signs of recovery (head lift, grip strength, etc.) are insufficient in determining whether full recovery of neuromuscular function has occurred and in addition require patient participation…something that can be difficult to achieve in patients that are still partially sedated [5, 11]. Qualitative or quantitative monitoring, therefore, should be used for reasons previously described.

Various devices for monitoring neuromuscular function exist in the operating room, including quantitative and qualitative monitors. Qualitative monitors are ubiquitous, inexpensive, and simple to use. Quantitative monitors, in contrast, are expensive, and comparatively complex. Accelerometers represent the “gold standard” of quantitative monitoring in the clinical setting and provide specific objective data about onset and recovery of neuromuscular blockade. Movement sensors are also available (the kinemyography GE NMT product, which detects deformation of a piezoelectric sensor placed between the thumb and first finger), and both provide improved accuracy with detection of residual paralysis [12–14].

The site of monitoring can also impact the degree of neuromuscular recovery, and appropriate interpretation of twitch response at one anatomic site may not necessarily correlate with that at another. Most published (and nearly all textbook) data on paralytic onset and recovery are based on thumb movement after stimulation of the ulnar nerve. The arm may not be readily available at times due to surgical conditions or positioning, necessitating monitoring at an alternate site, including the face (facial nerve) or foot (medial plantar nerve).

During facial nerve monitoring, direct muscle stimulation can occur if leads are placed incorrectly, and while facial nerve recovery more closely approximates that of the diaphragm, monitoring on the face less accurately predicts complete recovery of pharyngeal muscles which maintain airway patency and aspiration protection. In effect, a patient being monitored at the face might receive more paralytic during the case to produce complete paralysis, and may be inadequately reversed at case completion. Indeed, it has been shown that patients monitored at the facial nerve are five times more likely to experience incomplete recovery compared to those monitored at the adductor pollicis (hand) [15]. Lower extremity monitoring has not been well-described in the literature, and care must be taken when extrapolating any leg/foot twitch information to dosing and reversal decision-making. Clearly, the adductor pollicis (hand) should be monitored when access to the hand is available, and data derived from other sites should be interpreted carefully and conservatively.

### Accuracy in Detecting Residual Neuromuscular Blockade

For reasons already given, many providers either do not use twitch monitors, place the monitors in inappropriate locations, interpret twitch data incorrectly, or give incorrect doses of reversal agents. Complete recovery occurs when a patient has recovered to a TOF ratio > 0.9, defined using quantitative monitoring. Many studies have shown that in routine clinical practice, patients receiving non-depolarizing paralytics are likely to have residual paralysis (defined as a TOF ratio < 0.9 at time of PACU admission) 30–50% of the time. Routine use of monitoring reduces that risk, especially when quantitative monitors are used [16].

Incomplete recovery has been shown to be associated with adverse postoperative outcome [17]. Providers generally do not monitor for paralysis in the postoperative period, so many paralysis-related events, including, importantly, pulmonary complications, may be missed. Subjectively, patients with residual paralysis are more likely to complain of weakness and reduced satisfaction with perioperative care [18]. Again, when degree of paralysis is not measured, it is hard to attribute complaints to incomplete recovery. Finally, lack of reversal of paralysis has been found to be an independent risk factor for coma and mortality, increasing the risk by 90% within 24 h or surgery [19].

While we do not recommend routine monitoring of muscle weakness in awake and alert postoperative patients using high stimulating currents, it is important to remember that incomplete recovery may be an important contributing factor to patients that are experiencing adverse events after surgery. Appropriate intraoperative management will ensure the safest recovery for our patients, especially when quantitative monitors are used, and data are interpreted correctly.

## Conclusion

Monitoring and reversal of neuromuscular blockade is an essential component of safe anesthesia care. When inappropriate monitoring is used, or when monitoring is avoided altogether, patient safety is impacted. Monitoring at the hand provides more accurate data about neuromuscular recovery, and appropriate dosing of reversal agents is key to providing adequate recovery. Although the incidence of residual block is high, most patients recover without adverse sequelae. This lends support to commonly practiced clinical techniques [2•, 5]. It must be pointed out, however, that not all patients are created equally, and obese/elderly/pediatric/frail patients are at a uniquely increased risks of weakness-associated adverse events, and many adverse events that have no clear causation can retrospectively be attributed to residual paralysis [20, 21]. The Association of Anaesthetists of Great Britain, Ireland, and other countries around the world has mandated that a peripheral nerve stimulator be used whenever NMB drugs are given [12], and while the American Society has not followed suit, evidence-based practice should be followed whenever possible to provide the best quality care to our patients.

### Compliance with Ethical Standards

**Conflict of Interest** Moumen Asbahi and Roy Soto declare they have no conflict of interest.

**Human and Animal Rights and Informed Consent** This article does not contain any studies with human or animal subjects performed by any of the authors.

## References

Papers of particular interest have been highlighted as:
• Of importance,
•• Of outstanding importance

1. Bevan DR, Donati F, Kopman AF. Reversal of neuromuscular blockade. Anesthesiology. 1992;77:785–805. https://doi.org/10.1097/00000542-199210000-00025.
2.• Todd MM, Hindman BJ, King BJ. The implementation of quantitative electromyographic neuromuscular monitoring in an academic anesthesia department. Anesth Analg. 2014;119:323–31. **Implementation of quantitative neuromuscular blockade monitoring resulted in a significant reduction in the incidence of incompletely reversed patients in the PACU.** https://doi.org/10.1213/ANE.0000000000000261.
3.•• McLean DJ, Diaz-Gil D, Farhan HN, Ladha KS, Kurth T, Eikermann M. Dose-dependent association between intermediate-acting Neuromuscular-blocking agents and postoperative respiratory complications. Anesthesiology. 2015;122(6):1201–13. **A study which shows a neuromuscular-blocking agent dose-dependent association with increased risk of respiratory complications in the postoperative period, and also suggesting that the proper use of neostigmine guided by neuromuscular transmission monitoring results can help eliminate postoperative respiratory complications associated with neuromuscular-blocking agents.**
4. Madsen MV, Staehr-Rye AK, Gatke MR, Claudis C. Neuromuscular blockade for optimising surgical conditions during abdominal and gynaecological surgery: a systematic review. Acta Anaesthesiol Scand. 2015;59:1–16. https://doi.org/10.1111/aas.12419.
5. Fuchs-Buder T, Hofmockel R, Geldner G, Diefenbach C, Ulm K, Blobner M. The use of neuromuscular monitoring in Germany. Anaethesitst. 2003,52–55-6.

6. Sasaki N1, Meyer MJ, Malviya SA, Stanislaus AB, MacDonald T, Doran ME, et al. Effects of neostigmine reversal of nondepolarizing neuromuscular blocking agents on postoperative respiratory outcomes: a prospective study. Anesthesiology. 2014;121:959–68.
7. Fuchs-Buder T, Meitelman C, Alla F, Grandjean A, Wuthrich Y, Donati F. Antagonism of low degrees of atracurium-induced neuromuscular blockade. Dose-effect relationships for neostigmine. Anesthesiology. 2010;112:34–40. https://doi.org/10.1097/ALN.0b013e3181c53863.
8. Fuchs-Buder T, Baumann C, De Guis J, Guerci P, Meistelman C. Low-dose neostigmine to antagonize shallow atracurium neuromuscular block during inhalational anaesthesia. A randomized controlled trial. Eur J Anaesth. 2013;30:594–8. https://doi.org/10.1097/EJA.0b013e3283631652.
9. Naguib M, Kopman AF, Lien CA, Hunter JM, Lopez A, Brull SJ. A survey of current management of neuromuscular block in the United States and Europe. Anesth Analg. 2010;111:110–9. https://doi.org/10.1213/ANE.0b013e3181c07428.
10. Grayling M, Sweeney BP. Recovery of neuromuscular blockade: a survey of practice. Anaesthesia. 2007;62:806–9. https://doi.org/10.1111/j.1365-2044.2007.05101.x.
11. Checketts MR, Alladi R, Ferguson K, et al. Recommendations for standards of monitoring during anaesthesia and recovery 2015: Association of Anaesthestists of Great Britain and Ireland. Anaesthesia. 2015;
12. Lien CA, Kopman AF. Current recommendations for monitoring depth of neuromuscular blockade. Curr Opin Anesthesiol. 2014;27:616–22.
13. Brull S, Kopman A. Current status of neuromuscular reversal and monitoring: challenges and opportunities. Anesthesiology. 2017;126:173–90. https://doi.org/10.1097/ALN.0000000000001409.
14. Ortega R, Brull SJ, Prielipp R, Gutierrez A, De La Cruz R, Conley C. Monitoring neuromuscular function. N Engl J Med. 2018;378:e6. https://doi.org/10.1056/NEJMvcm1603741.
15. Thilen SR, Hansen BE, Ramaiah R, Kent CD, Treggiari MM, Bhananker SM. Intraoperative neuromuscular monitoring site and residual paralysis. Anesthesiology. 2012;117:964–72. https://doi.org/10.1097/ALN.0b013e31826f8fdd.
16. Kopman AF, Eikermann M. Antagonism of non-depolarising neuromuscular block: current practice. Anaesthesia. 2009;64(Suppl 1):22–30.
17. Murphy GS, Szokol JW, Marymont JH, Greenberg SB, Avram MJ, Vender JS, et al. Intraoperative acceleromyographic monitoring reduces the risk of residual neuromuscular blockade and adverse respiratory events in the postanesthesia care unit. Anesthesiology. 2008;109:389–98. https://doi.org/10.1097/ALN.0b013e318182af3b.
18. Murphy GS, Szokol JW, Marymont JH, Greenberg SB, Avram MJ, Vender JS. Residual neuromuscular blockade and critical respiratory events in the postanesthesia care unit. Anesth Analg. 2008;107:130–7. https://doi.org/10.1213/ane.0b013e31816d1268.
19. Debaene B, Plaud B, Dilly M-P, Donati F. Residual paralysis in the PACU after a single intubating dose of nondepolorazing muscle relaxant with an intermediate duration of action. Anesthesiology. 2003;98:1042–8. https://doi.org/10.1097/00000542-200305000-00004.
20. Arbous MS, Meursing AE, van Kleef JW, de Lange JJ, Spoormans HH, Touw P, et al. Impact of anesthesia management characteristics on severe morbidity and mortality. Anesthesiology. 2005;102:257–68. https://doi.org/10.1097/00000542-200502000-00005.
21. Asbahi M, Soto R. Dosing, monitoring, and reversal of neuromuscular blockade: are anesthesiologists following evidence-based practices? Curr Anesthesiol Rep. 2016;6:160–3. https://doi.org/10.1007/s40140-016-0161-x.