TRAIN-OF-FOUR MONITORING AND THE PERSISTENT PROBLEM OF RESIDUAL NEUROMUSCULAR BLOCKADE

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Residual neuromuscular blockade (RNMB) continues to be a pervasive and underestimated perioperative risk. Recent observational studies report RNMB incidence ranging from approximately 33% in patients without objective monitoring to 5–16% when quantitative monitoring and appropriate reversal were used, highlighting both the prevalence and preventability of this complication (1).

Physiology and Value of Train-of-Four (TOF) Monitoring

Train-of-Four stimulation (four supramaximal stimuli at 2Hz) produces a measurable twitch-fade response. A TOF ratio of ≥ 0.9, ideally measured via acceleromyograph, electromyography, is necessary for the safe return of upper airway tone, pharyngeal coordination and ventilatory drive (2). Subjective assessment is grossly insensitive, and clinicians typically cannot detect fading at TOF ratios above 0.4, meaning patients may appear to breathe adequately yet still be at significant risk of postoperative airway compromise.

Clinical Consequences of RNMB

Objective evidence demonstrates that TOF ratios < 0.9 correlate with increased symptoms of muscle weakness in the PACU. Patients with residual blockade report more weakness signs and have more severe symptoms compared to those with TOF ≥ 0.9 (3). In a randomized trial, extubating guided by ensuring a TOF ratio ≥ 0.9 significantly reduced critical respiratory events - such as hypoxia, upper airway obstruction and airway manipulation - compared to clinical judgment alone (4).

Incidence of RNMB: The Impact of Monitoring

A 2025 prospective observational study found RNMB (TOF ≤ 0.9) in about 5% of the patients, some of whom required supplemental oxygen postoperatively - that is, RNMB remains relevant even when the best practices are used (5). A meta-analysis of 12,664 patients across over 50 studies revealed that without neuromuscular monitoring**,** the average RNMB incidence is approximately 33% (6). Even with sugammadex, arguably the most effective reversal agent,

residual blockade can still be detected in around 5% of the cases when monitoring is not used (7).

“Post-anesthesia pulmonary complications after the use of muscle relaxants” (POPULAR) is a large prospective observational cohort study across 211 hospitals in 28 European countries. 22,803 patients undergoing general anesthesia (excluding cardiac surgery) were analyzed to assess the impact of neuromuscular blocking agents (NMBAs) on postoperative pulmonary complications. The use of NMBAs was associated with a significantly increased risk of PPCs (adjusted OR 1.86), with no protective effect observed from neuromuscular monitoring, reversal agents or the use of sugammadex compared to neostigmine. These findings suggest that while NMBAs may be useful for surgical conditions, their usage carries a measurable increase in pulmonary risk that anesthesiologists must carefully weigh against potential intraoperative benefits (8).

In 2023, the European Society of Anesthesiology and Intensive Care published its first comprehensive, evidence-based guidelines on the peri-operative management of neuromuscular block. These guidelines provide key recommendations on the use of muscle relaxants for intubation, optimization of surgical conditions, monitoring to prevent residual paralysis, and safe strategies for pharmacological reversal. Together, they aim to standardize practice, enhance patients’ safety, and reduce postoperative complications related to neuromuscular blockade. Inappropriate management of neuromuscular block remains common, with residual paralysis and related postoperative complications despite the availability of reliable monitoring and reversal agents. Using structured literature review (88 relevant studies from 24,000 screened), GRADE methodology, and a Delphi consensus, recommendations were formulated on key clinical questions regarding intubation, depth of blockade during abdominal surgery, and strategies for diagnosing and treating residual paralysis. Strong recommendations include the use of muscle relaxants for tracheal intubation, pharyngeal/ laryngeal protection, and rapid sequence induction; deepening blockade when required to optimize surgical conditions; quantitative neuromuscular monitoring; and sugammadex for reversal of amino-steroidal agents (9).

Pharmacologic Reversal: Neostigmine vs. Sugammadex

Sugammadex offers rapid, predictable reversal of amino-steroidal NMBAs. A Cochrane review confirms its superiority over neostigmine in terms of reducing residual paralysis, bradycardia, nausea and vomiting - and targeted use with quantitative monitoring, can effectively eliminate RNMB. Nevertheless, even sugammadex fails in a small percentage of cases when used empirically without monitoring (7-9). While neostigmine can facilitate TOF recovery to ≥ 0.9, its efficacy is dose- and timing-dependent; suboptimal use may paradoxically worsen neuromuscular function (10).

Barriers to Implementation of Quantitative Monitoring

Despite compelling data, implementation remains uneven. Surveys and studies reflect ongoing reliance on subjective assessment or time-based dosing (11). Guidelines from major bodies - such as the Association of Anesthetists of Great Britain and Ireland and the Australian and New Zealand College of Anesthetists - call for mandatory use of quantitative monitoring (with TOF ratio $\geq$ 0.9) to confirm neuromuscular recovery before extubating. Yet, adoption in routine practice is patchy, due to cost, logistic, educational and cultural barriers. Residual neuromuscular blockade (RNMB) remains a persistent and clinically significant problem, even in the era of modern anesthesia. Despite advances in pharmacology and monitoring technology, patients continue to face the risks associated with incomplete recovery from neuromuscular blocking agents. Quantitative train-of-four (TOF) monitoring and evidence-based reversal should no longer be regarded as optional or discretionary; they represent the standard of care that every anesthesiologist must embrace (12). Professional societies worldwide have already issued strong recommendations in favor of quantitative monitoring, yet practice often lags policy. The next step is clear: integration. Monitoring must be woven into institutional protocols, embedded in training curricula, and made a mandatory element of perioperative safety checklists. Only through systematic adoption we can ensure consistent protection for every patient. Each time quantitative monitoring is neglected, patients are exposed to avoidable risks - hypoxemia, airway obstruction, reintubation and other serious postoperative complications (13). Such outcomes are not inevitable; they are the result of a preventable gap between evidence and practice. The time for half-measures has passed. Patients' safety demands nothing less than full commitment to monitoring, reversal and vigilance in every anesthetic practice.

Conclusion

Residual neuromuscular blockade persists as a significant hazard in modern anesthesia, despite decades of evidence and the availability of effective solutions. Subjective assessment is inadequate; pharmacologic reversal is not foolproof; and patients' safety is compromised when TOF monitoring is neglected. Routine quantitative TOF monitoring, integrated into clinical pathways and supported by appropriate reversal strategies, should be regarded as a minimum standard of perioperative care. Adoption will require education, institutional support and a cultural shift in anesthetic practice. The cost of inaction - avoidable pulmonary complications, delayed recovery and patient's harm - is too high.

Ensuring full neuromuscular recovery before extubating is not a technical nicety; it is a fundamental responsibility. The time has come for anesthesia practice worldwide to make residual neuromuscular blockade a problem of the past.

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