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INCIDENCE, RISK FACTORS, AND ADVERSE OUTCOMES OF RESIDUAL NEUROMUSCULAR BLOCKADE IN OLDER ADULTS UNDERGOING LAPAROSCOPIC ABDOMINAL SURGERY: A PROSPECTIVE OBSERVATIONAL STUDY WITH QUANTITATIVE TRAIN-OF-FOUR MONITORING

INCIDÊNCIA, FATORES DE RISCO E DESFECHOS ADVERSOS DO BLOQUEIO NEUROMUSCULAR RESIDUAL EM IDOSOS SUBMETIDOS A CIRURGIA ABDOMINAL LAPAROSCÓPICA: UM ESTUDO OBSERVACIONAL PROSPECTIVO COM MONITORAMENTO QUANTITATIVO DO MÉTODO TRAIN-OF-FOUR PACIENTES GERIÁTRICOS

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Abstract
Background: Residual neuromuscular blockade (RNMB) may compromise perioperative safety by impairing respiration, delaying recovery, and predisposing to postoperative complications. The cardiopulmonary effects of laparoscopic surgery may further increase susceptibility in elderly patients. Objectives: To determine the incidence of RNMB, identify perioperative risk factors, and evaluate its association with postoperative adverse outcomes in geriatric patients undergoing laparoscopic surgery. Materials and Methods: We conducted a prospective observational study of patients aged ≥65 years who underwent laparoscopic abdominal surgery between May 2023 and June 2024. General anesthesia included non-depolarizing neuromuscular blockade with routine pharmacologic reversal. Train-of-four (TOF) ratios were measured by quantitative acceleromyography (TOF-Watch) immediately after extubation (T1), at 15 minutes (T2), 30 minutes (T3), and 60 minutes (T4), with extended assessments (T5–T6) if clinically indicated. RNMB was defined as TOF <0.9 at

Resumo
Antecedentes: O bloqueio neuromuscular residual (BNMR) pode comprometer a segurança perioperatória ao prejudicar a respiração, retardar a recuperação e predispor a complicações pós-operatórias. Os efeitos cardiopulmonares da cirurgia laparoscópica podem aumentar ainda mais a suscetibilidade em pacientes idosos. Objetivos: Determinar a incidência de RNMB, identificar fatores de risco perioperatórios e avaliar sua associação com resultados adversos pós-operatórios em pacientes geriátricos submetidos à cirurgia laparoscópica. Materiais e Métodos: Realizamos um estudo observacional prospectivo com pacientes com idade ≥65 anos submetidos à cirurgia abdominal laparoscópica entre maio de 2023 e junho de 2024. A anestesia geral incluiu bloqueio neuromuscular não despolarizante com reversão farmacológica de rotina. Os índices de Train-of-four (TOF) foram medidos por aceleromiografia quantitativa (TOF-Watch) imediatamente após a extubação (T1), aos 15 minutos (T2), 30 minutos (T3) e 60 minutos (T4), com avaliações prolongadas (T5–

any time point. Patients with and without RNMB were compared using appropriate independent tests, and paired analyses assessed TOF changes over time. Adverse outcomes—nausea, respiratory failure, and urinary retention—were evaluated between cohorts. Results: RNMB was most frequent at extubation and declined thereafter: 10.8% (T1), 4.4% (T2), 2.0% (T3), and 0% (T4-T6). In the RNMB cohort, median TOF ratios were 0.71 (T1), 0.81 (T2), and 0.79 (T3), with complete recovery by sixty minutes (T4-T6). Higher cumulative rocuronium dose independently increased RNMB risk (OR 1.78 per mg/kg, 95% CI 1.02–3.10; p=0.042). Sugammadex use reduced the odds of RNMB (adjusted OR 0.38, 95% CI 0.15–0.96; p=0.040). Adverse outcomes were numerically more frequent in RNMB patients but did not reach statistical significance. Conclusions: In geriatric patients undergoing laparoscopic surgery, RNMB is frequent at extubation but self-limiting, with complete recovery observed within sixty minutes postoperatively, and no statistically significant differences in adverse outcomes. The cumulative neuromuscular blockade dose is a modifiable risk factor, while the use of sugammadex independently reduces the risk of RNMB.

Keywords: Residual Neuromuscular Blockade. Train-of-Four. Rocuronium. Postoperative Complications.

T6) se clinicamente indicado. A RNMB foi definida como TOF <0,9 em qualquer momento. Pacientes com e sem RNMB foram comparados utilizando testes independentes apropriados, e análises pareadas avaliaram as alterações do TOF ao longo do tempo. Os desfechos adversos — náusea, insuficiência respiratória e retenção urinária — foram avaliados entre as coortes. Resultados: A RNMB foi mais frequente na extubação e diminuiu a partir de então: 10,8% (T1), 4,4% (T2), 2,0% (T3) e 0% (T4-T6). Na coorte com RNMB, as medianas das razões TOF foram 0,71 (T1), 0,81 (T2) e 0,79 (T3), com recuperação completa em sessenta minutos (T4-T6). Uma dose cumulativa mais elevada de rocurônio aumentou independentemente o risco de RNMB (OR 1,78 por mg/kg, IC 95% 1,02–3,10; p=0,042). O uso de sugamadex reduziu as chances de RNMB (OR ajustado 0,38, IC 95% 0,15–0,96; p=0,040). Os desfechos adversos foram numericamente mais frequentes em pacientes com RNMB, mas não alcançaram significância estatística. Conclusões: Em pacientes geriátricos submetidos à cirurgia laparoscópica, o RNMB é frequente na extubação, mas autolimitado, com recuperação completa observada dentro de sessenta minutos no pós-operatório, e sem diferenças estatisticamente significativas nos desfechos adversos. A dose cumulativa de bloqueio neuromuscular é um fator de risco modificável, enquanto o uso de sugamadex reduz independentemente o risco de RNMB.

Palavras-chave: *Bloqueio Neuromuscular Residual. Train-of-Four. Rocurônio. Complicações Pós-Operatórias.*

1 INTRODUCTION

Residual neuromuscular blockade (RNMB), also a TOF ratio of less than 0.9 at the time of tracheal extubation, is an established patient safety concern during the perioperative period [1-3]. For a long time, this condition has been implicated in a variety of adverse events such as attenuated respiratory performance, airway obstruction, aspiration, airway hypoxemia, prolonged recovery time, and longer stay at the post-anesthesia care unit [4-6]. These adverse outcomes indicate the significant challenge posed by RNMB regarding patient safety [3]. Contrary to the existence of quantitative

neuromuscular monitors and improved reversal agents, the phenomenon of RNMB still appears pronounced among varying surgical populations [1,7]. Of specific interest in this analysis are operations performed laparoscopically from the abdomen since the intraperitoneal use of carbon dioxide changes respiratory and hemodynamic parameters and enhances the likelihood of residual neuromuscular block and postoperative pulmonary complications [8].

Surveys conducted across North America and Western Europe established that the incidence of RNMB at the time of tracheal extubation ranges from 20% to upwards of 40% and thus reflects the continued clinical significance of the phenomenon [1,7]. For instance, a multicenter prospective observation conducted across Portugal showed an overall incidence of 5.5% with substantial variations [1], while another demonstrated ranges of 29.9% and up to 49.1% depending on the specific definitional criteria used [8]. Several risk factors were established and include defective neuromuscular monitoring and suboptimal reverse agent dosing, as well as patient-specific factors like advanced age or comorbidities [7]. Clinical research has actually established an increased risk of RNMB among elderly patient populations [8]. Nevertheless, the incidence documented and accompanying factors show wide variability due partly to the context of surgery, anesthetic approach, and structural organization of health systems [7]. Notably, informative data on the incidence of RNMB and accompanying factors from Asia, and particularly from developing nations, are considerably lacking from current literature. The lack of this knowledge restricts context-based prevention and comparison of local practices with global standards.

The present research project was based on the proposition that there are measurable occurrences of RNMB among postextubation adult surgical patients and recognizable causative factors of its occurrence. Therefore, the major aims of this research were as follows: 1) to clarify the incidence and nature of RNMB, 2) to outline risk factors of RNMB, and 3) to identify postoperative complications associated with it.

2 MATERIALS AND METHODS

2.1 Study designs

This investigation was designed as a prospective, observational cohort study. Data were collected from May 2023 to June 2024 at the Department of Anesthesiology and Intensive Care, Cho Ray Hospital, Vietnam. The study protocol was conducted in accordance with the The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines for observational studies and adhered to the principles of the Declaration of Helsinki [9].

2.2 Participants

The study population consisted of older adult patients (≥60 years) who underwent laparoscopic abdominal surgery under general anesthesia with tracheal intubation and neuromuscular blockade Inclusion criteria were: (1) age ≥60 years; (2) American Society of Anesthesiologists (ASA) physical status I–III; (3) laparoscopic abdominal surgery; (4) use of non-depolarizing neuromuscular blocking agents (NMBAs) for intubation, with or without intraoperative maintenance; (5) pharmacological reversal of neuromuscular block with neostigmine or sugammadex at the end of surgery according to departmental protocol; (6) planned tracheal extubation at the conclusion of surgery; and (7) provision of informed consent.

Exclusion criteria were: (1) anticipated or encountered difficult airway due to anatomical reasons; (2) known neuromuscular disorders; (3) renal impairment with estimated glomerular filtration rate ≤30 ml/min; (4) family history of malignant hyperthermia; (5) allergy to anesthetic drugs used in the study; (6) concomitant use of drugs interfering with NMBAs, including aminoglycoside antibiotics, magnesium, or valproate; and (7) occurrence of intraoperative complications precluding study continuation.

2.3 Residual neuromuscular blockade

RNMB was defined as a TOF ratio <0.9 at the adductor pollicis muscle after tracheal extubation. Quantitative neuromuscular monitoring was performed using the TOF Scan acceleromyograph. Before each measurement, the investigator verified the integrity of the device, electrodes, and connecting cables. The monitor was switched on, calibrated according to the manufacturer's instructions, and set to deliver supramaximal stimuli at 50 mA.

Two surface electrodes were placed along the ulnar nerve at the forearm: the distal electrode 2 cm proximal to the wrist crease and the proximal electrode 2–5 cm above the distal electrode, each with a minimum contact area of 2 cm^2. Proper placement was confirmed by the device interface (green signal). The red lead was attached to the distal electrode, and the black lead to the proximal electrode. An acceleration transducer was secured to the distal phalanx of the thumb. TOF stimulation was initiated via the device, which displayed either the TOF ratio (%) if four twitches were detected or the number of visible responses if ≤3 twitches were elicited. Any TOF value >100% prompted recalibration and repeat measurement (**Figure 1**).

If two consecutive TOF measurements yielded a ratio <0.9, stimulation was repeated on the contralateral adductor pollicis using the same protocol. When TOF ratios <0.9 were recorded bilaterally, RNMB was diagnosed, and the first recorded value was retained for analysis. Patients with RNMB continued to undergo TOF monitoring every 5 minutes until recovery was achieved (TOF ≥0.9), and the recovery interval was recorded as part of the dataset.

2.4 Data collection

Baseline characteristics encompassed demographic, nutritional, and laboratory data, along with comorbidities, ASA physical status, and surgical classification. Demographic variables included age, sex, and body mass index, categorized by the WHO Asia-Pacific criteria. Nutritional and biochemical parameters, cardiovascular and non-cardiovascular comorbidities, as well as the type and magnitude of surgery, were systematically documented. Intraoperative data covered surgical duration, anesthetic

technique, neuromuscular blockade management, and reversal strategies. Information on the type and dosage of administered neuromuscular blocking agents, the approach to their delivery, and the choice and cumulative dose of reversal agents was systematically recorded.

Monitored endpoints were: interval from surgery end to extubation, interval from the final non-depolarizing NMBA dose to extubation, and TOF ratios at extubation with serial measurements (T1–T6) repeated every 5 minutes until recovery. Complications were recorded using standardized criteria, including respiratory failure, postoperative nausea/vomiting, urinary retention, and ventilator-associated pneumonia. Neuromuscular recovery was evaluated at predefined postoperative timepoints: T1, immediately after extubation; T2, 15 minutes; T3, 30 minutes; T4, 60 minutes; T5, 120 minutes; and T6, before transfer from the post-anesthesia care unit or at the time of respiratory failure.

2.5 Statistical analysis

All analyses were performed in R (version 4.5.1) within RStudio; R Foundation for Statistical Computing, Vienna, Austria. Descriptive statistics, including means, medians, and standard deviations for continuous variables, and frequencies and percentages for categorical variables, were utilized to characterize the study population and the incidence of RNMB. Chi-square tests were employed for comparing categorical variables, while independent t-test or Mann Whitney U test were used for comparing continuous variables between RNMB and non-RNMB group. For paired comparisons across postoperative timepoints, continuous data used paired t-tests or Wilcoxon signed-rank tests as appropriate; paired binary outcomes used McNemar's test. Multivariable logistic regression analysis was performed to ascertain independent factors associated with RNMB. Variables with statistically significant associations in univariate analyses were entered into the multivariable model; adjusted odds ratios with 95% CIs were reported. Two-sided $p<0.05$ defined statistical significance.

2.6 Ethnic consideration

The study protocol was reviewed and approved by the Institutional Review Board of Hue University of Medicine and Pharmacy (Approval No. H2023/295), as well as the Ethics and Scientific Committees of Cho Ray Hospital, permitting data collection at the Department of Anesthesiology and Intensive Care. The study was conducted in accordance with the Declaration of Helsinki and relevant national guidelines on biomedical research ethics. This was an observational study with no intervention in patient management, and written informed consent was obtained from all participants prior to data collection.

3 RESULTS

3.1 Participants

Patient demographic and baseline clinical characteristics are summarized in Table 1. A total of 250 patients were included in the analysis, of whom 27 (10.8%) were in the residual neuromuscular blockade group. The median age of participants was 69 years (IQR: 65-74), with 50.8% being female. There were no significant differences in most baseline characteristics or underlying comorbidities between the two groups (all p-values > 0.05), with the exception of chronic obstructive pulmonary disease. Regarding ASA physical status classification, the RNMB group had a higher proportion of ASA III patients (20.7% vs. 8.6%) and a lower proportion of ASA II patients (48.3% vs. 70.1%) compared to the non-RNMB group, a difference that was statistically significant (p=0.036).

3.2 Incidences

As illustrated in **Figure 2**, RNMB was 10.8% at T1, 4.4% at T2, 2.0% at T3, and 0% from T4 onward, with significant reductions between early (T1–T2) and later timepoints, while differences among later intervals were not statistically significant.

3.3 Characteristics

Figure 3A shows TOF across T1–T6 with the widest dispersion and multiple values <0.9 at T1, followed by a progressive rise such that by T2–T6 nearly all patients were ≥0.9; **Figure 3B** (cases with TOF <0.9) mirrors this decline in residuals with medians 0.71 at T1, 0.81 at T2, 0.79 at T3, and complete recovery (all ≥0.9) from T4 onward.

3.4 Related factors

Multivariable logistic regression, summarized in **Figure 4**, identified rocuronium dose as an independent predictor of RNMB (adjusted OR per 1 mg/kg: 1.779; 95% CI, 1.020–3.103; p=0.042). Sugammadex reversal was associated with lower odds of RNMB (adjusted OR: 0.377; 95% CI, 0.149–0.956; p=0.040).

3.5 Adverse outcomes

According to **Figure 5**, patients in the RNMB group exhibited higher rates of complications, including nausea (5.4%), renal failure (3.4%), and urinary retention (13.8%), with the exception of peritonitis (3.4%). However, none of these differences reached statistical significance.

4 DISCUSSION

RNMB remains a recognized perioperative safety concern, yet its incidence and clinical course in older adults undergoing laparoscopic abdominal surgery have not been well characterized. We found that RNMB was most frequent immediately after extubation but declined rapidly, with full recovery by sixty minutes. Higher rocuronium exposure significantly increased the risk of RNMB, while sugammadex use reduced it. Although complications such as respiratory events, nausea, and urinary retention were numerically more common in patients with RNMB, no significant associations were observed.

The principal finding, that RNMB incidence peaked at extubation (10.8%) with a rapid resolution to 0% by sixty minutes, aligns with reports indicating that RNMB is most prevalent during emergence from anesthesia and diminishes over time under standardized recovery protocols [1,6]. This trajectory is consistent with findings that, despite its transient nature, RNMB remains a significant concern during the immediate post-extubation period [10,11]. The absolute rates observed herein are lower than those reported in many mixed-age, non-reversed, or neostigmine-only cohorts, where incidence ranges from 17–65% upon arrival to the PACU [3,7]. This lower burden likely reflects (i) the routine administration of reversal agents, predominantly sugammadex [2,12,13]; (ii) systematic, TOF-guided reassessment, which facilitates timely intervention [14]; and (iii) standardized PACU care, including head-up positioning and supplemental oxygen [11]. The conclusion drawn is that among elderly patients undergoing laparoscopic surgery, the risk of RNMB is concentrated within the first thirty minutes post-extubation; with protocolized reversal and monitoring, complete recovery is achievable by sixty minutes. RNMB is often self-limiting, with TOF ratios trending toward ≥0.9 within the first 30–60 minutes post-extubation under standard reversal and monitoring. The trajectory reflects drug redistribution and spontaneous neuromuscular recovery rather than ongoing pathology. Despite this tendency, early postoperative vigilance is mandatory because transient residual weakness can still precipitate airway obstruction, hypoventilation, or aspiration before full recovery occurs.

The key finding that prolonged procedure duration in rocuronium recipients increased the odds of RNMB is consistent with the principle of cumulative neuromuscular blocking agent exposure and context-sensitive recovery [8,15,16]. Higher cumulative doses or prolonged administration of rocuronium can result in a more profound and persistent blockade, thereby elevating the likelihood of residual paralysis if not adequately reversed [16]. While the interval from the final NMBA dose to extubation was associated with RNMB in univariate analysis, it did not emerge as an independent predictor after multivariate adjustment, likely due to confounding by case duration and redosing practices. No association was detected for age strata, sex, or BMI within this elderly, largely non-obese cohort [14], which diverges from some studies encompassing broader age and BMI ranges [4]. This suggests that within an elderly population, other factors may assume greater predictive dominance.

Regarding the role of reversal agents, the extant literature indicates that sugammadex can rapidly and effectively reverse rocuronium-induced neuromuscular blockade, thereby diminishing the incidence of RNMB [11-13]. The mechanism of action involves the encapsulation of rocuronium molecules, which sequesters them from the neuromuscular junction [17-19] and leads to a more rapid and complete reversal compared to traditional agents like neostigmine [20]. This swift, dose-dependent action of sugammadex directly counteracts the effects of rocuronium, mitigating the risk of RNMB.

However, within the specific sample analyzed, the type of reversal agent utilized did not yield a statistically significant difference in RNMB outcomes. This finding stands in contrast to the broader literature, which generally favors sugammadex. It is crucial to acknowledge that the significant imbalance in agent exposure (approximately 78% sugammadex) and the observational study design impose limitations on the inferences that can be drawn from this particular result. The conclusion remains that in elderly patients undergoing laparoscopic surgery, cumulative rocuronium exposure and extended operative times are primary drivers of RNMB [8]. Therefore, randomized trials evaluating dosing and reversal strategies, titrated to objective measures of blockade depth, are warranted to further elucidate the optimal management of neuromuscular blockade in this vulnerable patient population.

The observation that clinical complications were infrequent and did not correlate with RNMB status is of interest; a single transient respiratory failure event occurred, which responded to rescue sugammadex. Postoperative nausea and vomiting and urinary retention were more common non-respiratory events but showed no linkage to RNMB, a finding likely influenced by routine antiemetic prophylaxis and multimodal analgesia. In contrast to prior reports linking RNMB to significant pulmonary complications [3,4,8], these data suggest that aggressive reversal strategies and diligent early monitoring can effectively blunt the clinical expression of RNMB in the immediate postoperative window. Consequently, with high adherence to reversal and PACU protocols, RNMB did not translate into measurable early morbidity in this cohort; alternatively, its self-limiting trajectory—with spontaneous recovery to TOF $\geq$0.9 within 30–60 minutes under monitoring—likely attenuated short-term clinical impact. Future research should extend

surveillance beyond the initial 24-hour period and incorporate objective pulmonary endpoints to detect more subtle effects.

Based on these findings, several practical recommendations can be formulated. Clinicians should employ quantitative TOF monitoring at the adductor pollicis and withhold extubation until a TOF ratio of ≥0.9 is achieved [13,14]. Reassessment at 5-minute intervals within the first 30 minutes post-extubation is also advised. Reversal should be tailored to objectively measured blockade depth; in cases involving prolonged rocuronium administration, sugammadex should be prioritized, and late redosing of NMBAs should be avoided [2,21]. A higher risk of RNMB should be anticipated in longer procedures, prompting planning for earlier NMBA cessation and TOF-guided supplemental doses rather than fixed boluses [22]. Finally, standardized PACU care—including head-up positioning, supplemental oxygen, and continuous oximetry—should be maintained for at least 60 minutes in elderly patients, even after a TOF ratio of ≥0.9 has been confirmed [11].

This study is subject to several limitations. Its single-center design may limit the generalizability of the findings to other healthcare settings. The observational methodology, wherein treatment allocation was at the discretion of clinicians rather than randomized, introduces the potential for selection bias. A pronounced exposure imbalance, with sugammadex being used far more frequently than neostigmine, constrains the ability to draw robust comparisons between reversal agents. Furthermore, the heterogeneous mix of surgical procedures and varying case lengths, coupled with potential measurement variance in TOF timing between the operating room and the PACU, could have influenced the results. Finally, complications were primarily assessed within a 24-hour timeframe, potentially overlooking delayed adverse events. Future research could be enhanced through randomized comparative protocols for reversal and NMBA titration; stratified enrollment by procedure type and duration; standardized extubation criteria linked to both TOF and clinical tests; and an extended follow-up period incorporating endpoints such as pulmonary function and hospital readmission rates.

5 CONCLUSION

RNMB is common immediately after extubation but typically resolves within the early postoperative period. Higher cumulative rocuronium exposure increases RNMB risk, while sugammadex use independently lowers it. Despite transient residual weakness, early adverse outcomes were not clearly increased, emphisizes the value of judicious NMBA dosing, quantitative monitoring, and protocolized reversal to optimize recovery.

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ETHICAL STATEMENT

The authors are accountable for all aspects of the work and ensure that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This retrospective study did not influence the patients' diagnosis, treatment, or follow-up. The Ethics Council in Biomedical Research of University Medical Center Ho Chi Minh City granted ethical approval for the study (H2023/295)**.**

DISCLOSURE

All authors report no conflicts of interest in this work

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DATA AVAILABILITY STATEMENT

The datasets used in this study can be obtained from the corresponding author upon a reasonable request.

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ATTACHMENT

Tables

Table 1

Baseline demorgraphics characteristics and comorbidities stratified of patients surgery.

Variables	General (n=250)	RNMB (n=29)	Non-RNMB (n=221)	p-value
Characteristics				
Age, years	69 (65–74)	71 (68–74)	69 (65–74)	0.107
Female, n (%)	127 (50.8)	17 (58.6)	110 (49.8)	0.485
BMI, kg/m²	21.6 ± 3.3	21.6 ± 3.2	21.6 ± 3.4	0.938
Comorbidities				
ASA classification, n (%)				0.036
– I	56 (22.4)	9 (31)	47 (21.3)	
– II	169 (67.6)	14 (48.3)	155 (70.1)	
– III	25 (10)	6 (20.7)	19 (8.6)	
Hypertension, n (%)	88 (35.2)	13 (44.8)	75 (33.9)	0.343
Cardiovascular disease, n (%)	16 (6.4)	1 (3.4)	15 (6.8)	0.702
Atrial fibrillation, n (%)	4 (1.6)	0 (0)	4 (1.8)	1.000
Heart failure, n (%)	4 (1.6)	0 (0)	4 (1.8)	1.000
Aortic disease, n (%)	3 (1.2)	0 (0)	3 (1.4)	1.000
Tuberculosis, n (%)	7 (2.8)	0 (0)	7 (3.2)	1.000
COPD, n (%)	3 (1.2)	2 (6.9)	1 (0.5)	0.036
Diabetes mellitus, n (%)	50 (20)	7 (24.1)	43 (19.5)	0.730
Thyroid disease, n (%)	9 (3.6)	0 (0)	9 (4.1)	0.604
Cancer, n (%)	12 (4.8)	1 (3.4)	11 (5)	1.000
Laboratory findings				
Albumin, g/dL	4.1 ± 0.5	4.1 ± 0.4	4.1 ± 0.5	0.870
Hematocrit, %	37.2 ± 4.7	38 ± 3.4	37.1 ± 4.9	0.365
Sodium, mmol/L	137 (135–139)	137 (135–139)	137 (135–139)	0.910
Potassium, mmol/L	3.8 ± 0.4	3.8 ± 0.5	3.8 ± 0.4	0.730
Calcium, mmol/L	2.3 (2.2–2.4)	2.3 (2.2–2.4)	2.3 (2.2–2.4)	0.923
Glucose, mg/dL	106 (94–128)	110 (91–133)	105 (94–128)	0.973
ALT, U/L	20 (14–32)	16 (11–23)	20 (15–33)	0.031
AST, U/L	24 (18–32.8)	21 (18–28)	25 (18–34)	0.159
Ejection fraction, %	65.6 ± 7.8	64.4 ± 7.2	65.8 ± 7.9	0.550

Abbreviations: *ALT, alanine aminotransferase; ASA, American Society of Anesthesiologists; AST, aspartate aminotransferase; BMI, body mass index; COPD, chronic obstructive pulmonary disease; RNMB, residual neuromuscular blockade*.

Table 2

Intraoperative characteristics of patient surgery.

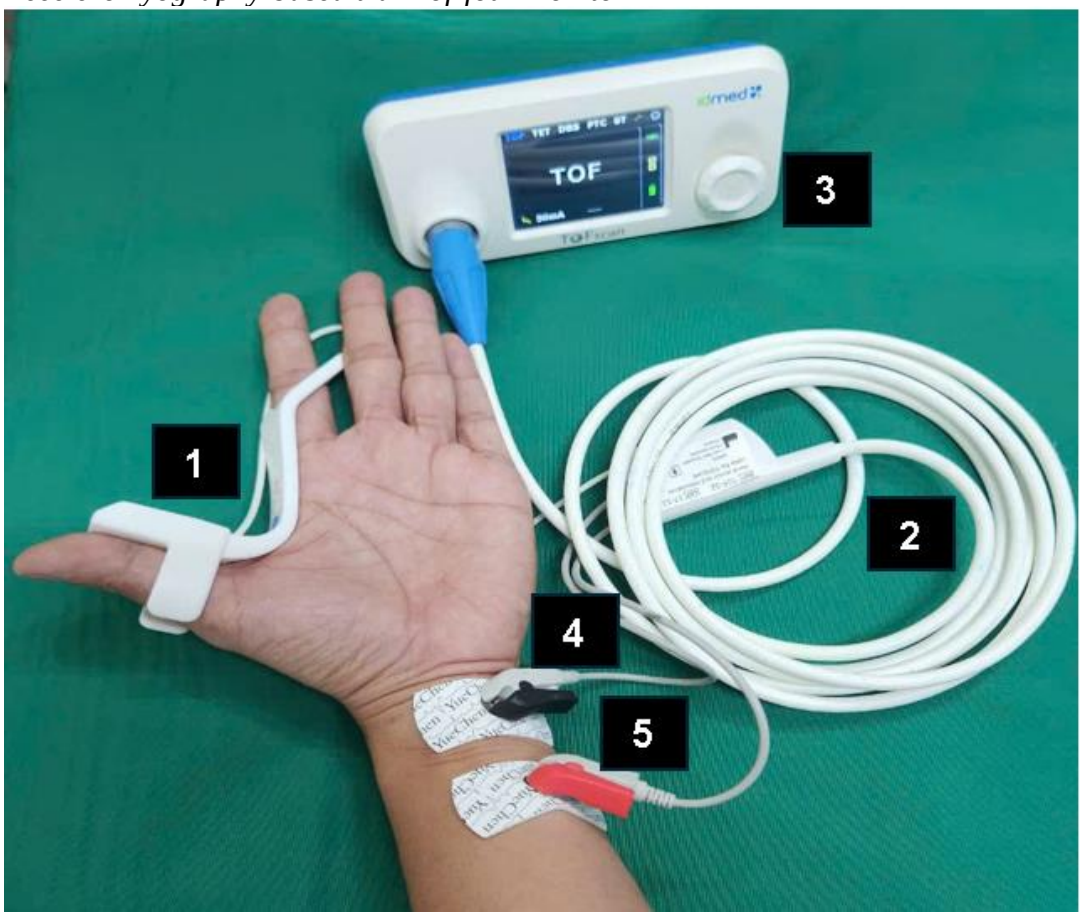
Variables	General (n=250)	RNMB (n=29)	Non-RNMB (n=221)	p-value
Duration of surgery, min	160.8 ± 74.2	205.9 ± 72.4	154.9 ± 72.5	<0.001
Rocuronium use, n (%)	232 (92.8)	28 (96.6)	204 (92.3)	0.703
Atracurium use, n (%)	18 (7.2)	1 (3.4)	17 (7.7)	0.703
Rocuronium dose, mg	60 (50–100)	100 (70–100)	50 (50–90)	<0.001
Volatile anesthetics, n (%),				0.219
- Sevoflurane use, n (%)	248 (99.2)	28 (96.6)	220 (99.5)	
- Desflurane use, n (%)	2 (0.8)	1 (3.4)	1 (0.5)	
Use of reversal agent, n (%)				0.283
- Sugammadex	196 (78.4)	20 (69)	176	
- Neostigmine	54 (21.6)	9 (31)	45 (20.4)	

Abbreviations: *NMBA, neuromuscular blocking agent*

Figures

Figure 1

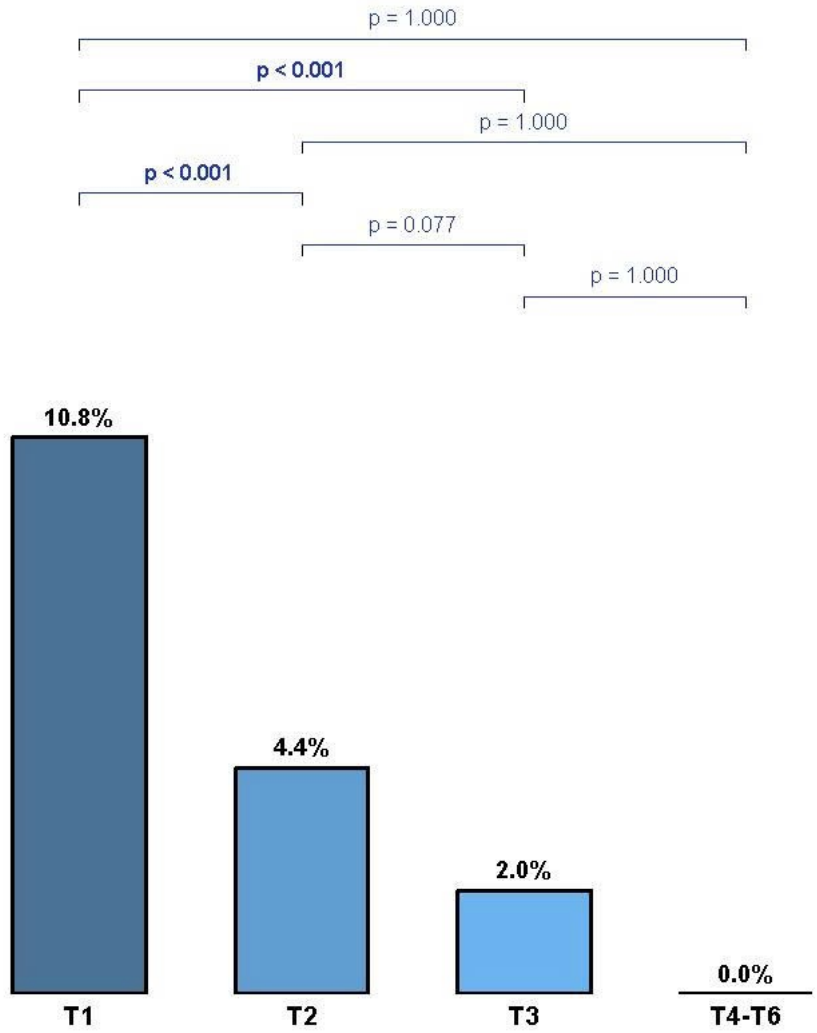
Acceleromyography-based train-of-four monitor



Abbreviations: 1, acceleromyography sensor; 2, connecting cable; 3, control knob; 4, proximal electrode; 5, distal electrode.

Figure 2

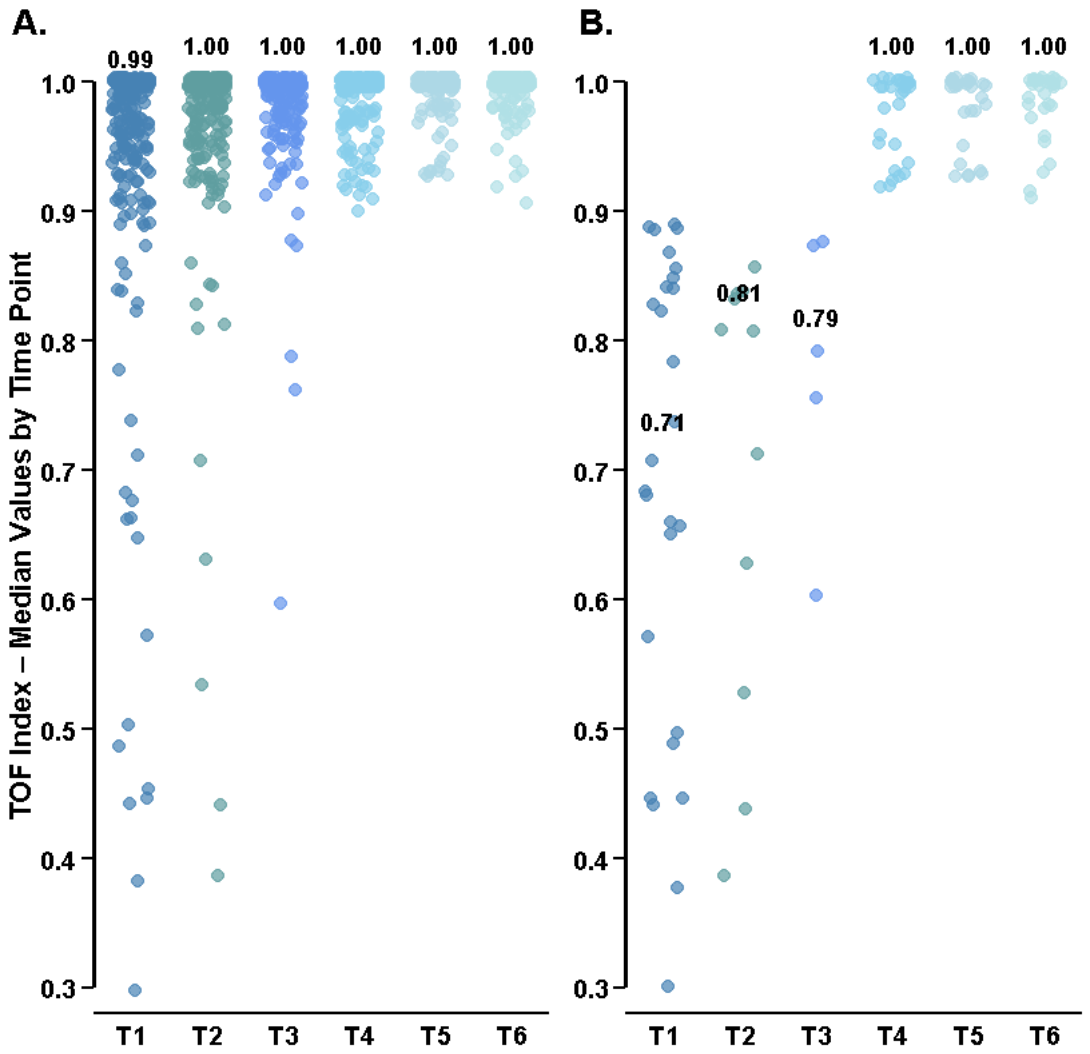
Incidence of residual neuromuscular blockade at different postoperative assessment timepoints.



Annotation: Neuromuscular recovery was assessed at four predefined time points: T1, immediately after tracheal extubation; T2, 15 minutes after extubation; T3, 30 minutes after extubation; T4, 60 minutes after extubation; T5, 120 minutes; and T6, before transfer from the post-anesthesia care unit or at the time of respiratory failure. These intervals were selected to capture the early postoperative period when residual neuromuscular blockade is most prevalent and to document the trajectory of recovery over the first hour.

Figure 3

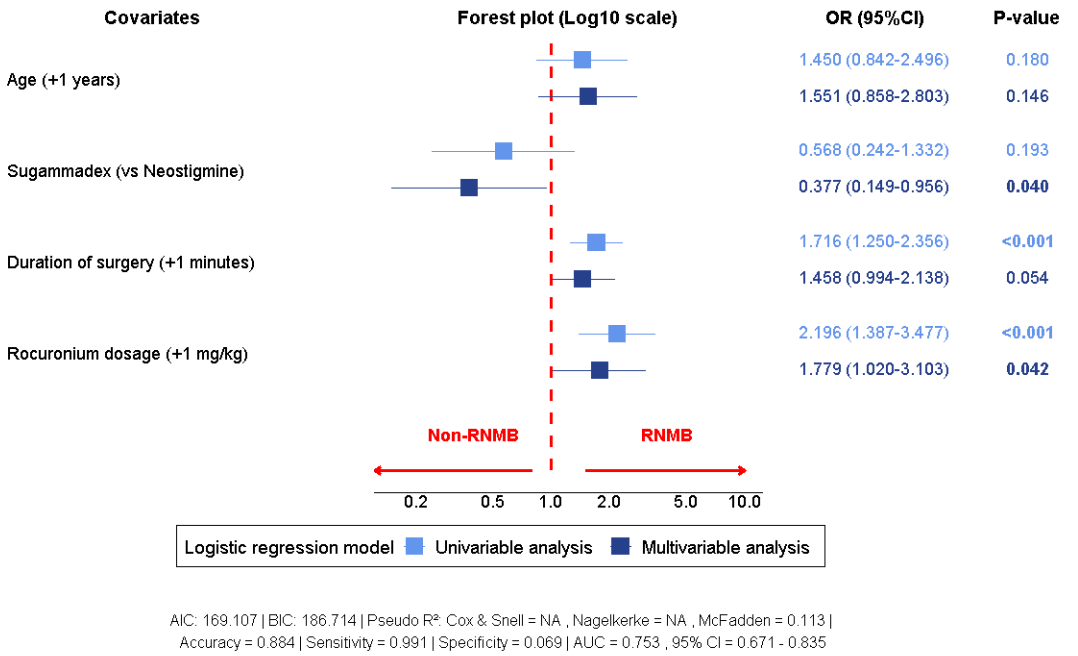
Train-of-four ratio values at postoperative assessment timepoints: (A) entire study population; (B) patients with residual neuromuscular blockade. Abbreviations: TOF, train-of-four.



Annotation: *Neuromuscular recovery was assessed at four predefined time points: Train-of-four ratio values at postoperative assessment timepoints: T1, immediately after extubation; T2, 15 minutes; T3, 30 minutes; T4, 60 minutes; T5, 120 minutes; and T6, before transfer from the post-anesthesia care unit or at the time of respiratory failure.*

Figure 4

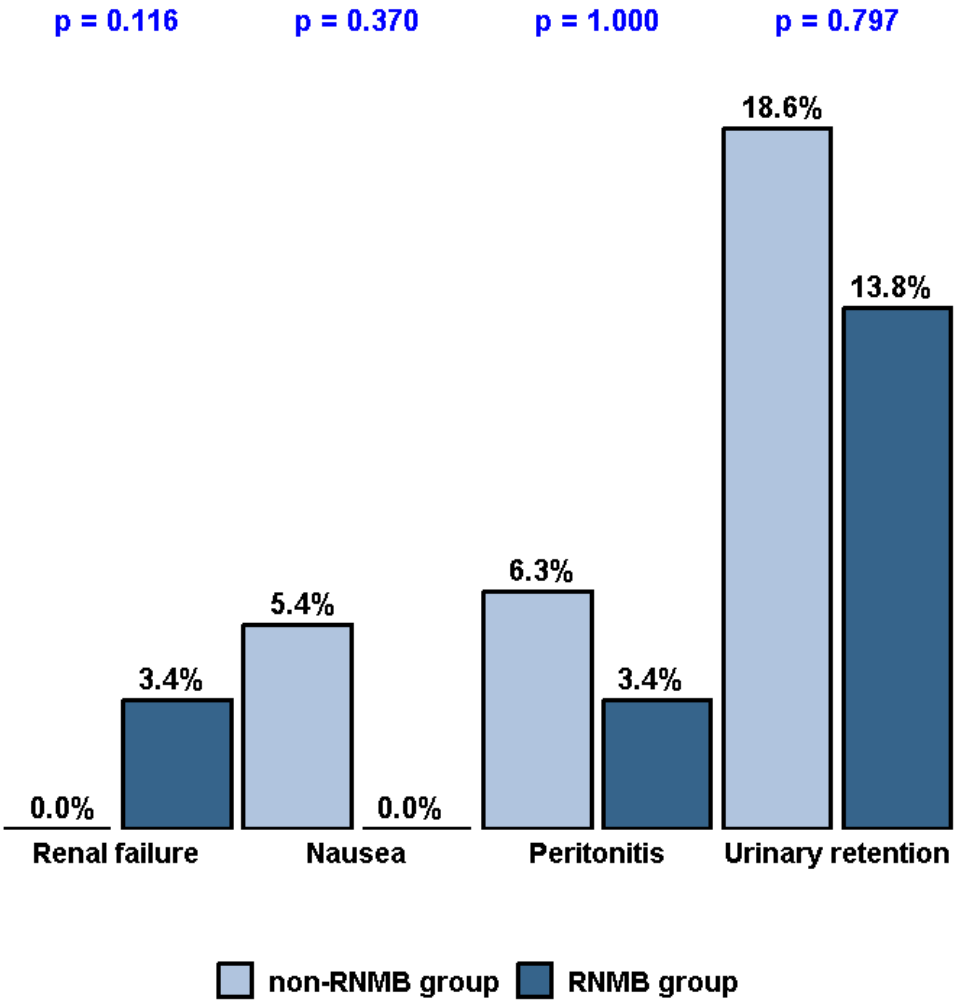
Factors associated with residual neuromuscular blockade using logistic regression model.



Abbreviation: OR, odd ratio; RNMB, residual neuromuscular blockade.

Figure 5

Postoperative complications in patients with and without residual neuromuscular blockade.



Abbreviations: NMBA, neuromuscular blocking agent