Colombian Journal of Anesthesiology

ANESTHESIA · DEORUM ARS · S.C.A.R.E.

ORIGINAL ARTICLE

Incidence of postoperative residual neuromuscular blockade: a prospective observational study

Incidencia del bloqueo neuromuscular residual posoperatorio: un estudio observacional prospectivo

Diego Luis Vélez-Agudelo[a] iD, Santiago Andrés Salazar-Cortés[a], Alex García[a] iD, Fabián David Casas-Arroyave [b] iD

[a] Anesthesiology, University of Antioquia. Medellín, Colombia.
[b] Research Group in Perioperative Medicine, Anesthesia, and Pain (GRIMPA), Universidad de Antioquia. Medellín, Colombia.

Correspondence: Cra. 51D # 62-29, Anesthesiology office, Universidad de Antioquia,. Medellín, Colombia.
E-mail: dluis.velez@udea.edu.co

What is known about this problem?

The use of non-depolarizing neuromuscular blockers (ND-NMB) can lead to residual neuromuscular blockade (RNMB), which has been associated with respiratory adverse events resulting in prolonged hospital stay.
Its incidence varies widely among different reports, with inconsistencies regarding associated risk factors. Furthermore, there is evidence of poor adherence to intraoperative monitoring recommendations for identifying RNMB

How does this study contribute?

Based on the local and current incidence of RNMB, as well as the description of intraoperative characteristics, we can draw a landscape of the adherence to the new international recommendations for monitoring and managing RNMB. Additionally, this study helps identify potential risk factors associated with RNMB in our region.

Abstract

Introduction

The use of non-depolarizing neuromuscular blockers (ND-NMB) is essential in anesthetic management as it improves ventilation conditions, airway management, and surgical conditions. However, the residual neuromuscular blockade (RNMB) in the immediate postoperative period derived from the use of these agents is associated with complications such as desaturation, pneumonia, and unplanned intensive care unit admission. The incidence varies significantly across different studies, and associated risk factors have not been consistent.

Objective

To estimate the incidence of RNMB and to identify characteristics of intraoperative management and potential risk factors for RNMB.

Methods

A prospective observational study was conducted at a university hospital, using convenience sampling. Train-of-four (TOF) measurements were performed in the post-anesthesia care unit. An exploratory multivariate analysis was performed to identify potential risk factors.

Results

A total of 300 patients were included. The incidence of residual neuromuscular blockade (RNMB) was 19% (95% CI: 14.9% - 23.8%). Evidence of relaxation monitoring was observed in 21.3% of the patients. Significant associations with RNMB were found for female gender (OR 1.97, 95% CI 1.02 − 3.81), absence of pharmacological reversal (OR 2.31, 95% CI 1.02 − 5.24), abdominal surgery (OR 2.81, 95% CI 1.37 − 5.72), and multiple intraoperative doses of ND-NMBs (OR 2.77, 95% CI 1.48 − 5.18).

Conclusions

Residual neuromuscular blockade (RNMB) is common in our setting, with a low frequency of intraoperative monitoring. The associated risk factors identified can point to specific scenarios that require special attention.

Keywords

Anesthesia; Neuromuscular blockade; Incidence; Risk factor; Surgery; Neuromuscular blocking agents.

Resumen

Introducción: El uso de bloqueadores neuromusculares no despolarizantes (ND-NMB) es esencial en el manejo anestésico, ya que mejora las condiciones de ventilación, el manejo de la vía aérea y las condiciones quirúrgicas. Sin embargo, el bloqueo neuromuscular residual (RNMB) en el periodo posoperatorio inmediato derivado del uso de estos agentes se asocia con complicaciones como desaturación, neumonía y admisión no planificada en la unidad de cuidados intensivos. La incidencia varía significativamente entre diferentes estudios y los factores de riesgo asociados no han sido consistentes.

Objetivo: Estimar la incidencia e identificar características del manejo intraoperatorio y posibles factores de riesgo para RNMB.

Métodos: Se llevó a cabo un estudio observacional prospectivo en un hospital universitario, utilizando un muestreo por conveniencia. Se realizaron mediciones de Train-of-Four (TOF) en la unidad de cuidados posanestésicos. Se hizo un análisis multivariado exploratorio para identificar posibles factores de riesgo.

Resultados: Se incluyeron 300 pacientes. La incidencia de bloqueo neuromuscular residual (RNMB) fue del 19 % (IC 95 %: 14,9 %-23,8 %). Se observó monitoreo de la relajación neuromuscular en el 21,3 % de los pacientes. Se encontraron asociaciones significativas con RNMB para el sexo femenino (OR 1,97; IC 95 %: 1,02-3,81), ausencia de reversión farmacológica (OR 2,31; IC 95 %: 1,02-5,24), cirugía abdominal (OR 2,81; IC 95 %: 1,37-5,72) y múltiples dosis intraoperatorias de ND-NMB (OR 2,77; IC 95 %: 1,48-5,18).

Conclusiones: El RNMB es común en el entorno, con una baja frecuencia de monitoreo intraoperatorio. Los factores de riesgo asociados identificados pueden señalar escenarios específicos que requieren atención especial.

Palabras clave: Anestesia; Bloqueo neuromuscular; Incidencia; Factor de riesgo; Cirugía; Agentes bloqueadores neuromusculares.

INTRODUCTION

The use of non-depolarizing neuromuscular blockers (ND-NMB) improves ventilation conditions, and airway management and favors optimal surgical conditions, constituting a cornerstone of anesthetic management [1,2]. Residual neuromuscular blockade (RNMB) is an adverse event associated with the use of ND-NMBs, which has been shown to be associated with an increased risk of desaturation in the post-anesthesia care unit (PACU), pneumonia, the need for intubation, and admission to the intensive care unit [3-5].

The incidence of RNMB has been estimated to range from 0% to 90%, with variability attributed to the different criteria used in its definition, the type of ND-NMB used, and the time between extubation and the measurement of the event [5-16]. The possible risk factors associated with the development of RNMB have also not been consistent in the various studies [5-8,17]. Considering the inconsistency of risk factors and the poor sensitivity of clinical tests, the diagnosis of RNMB is based on the measurement of the Train of Four ratio (TOFr). However, previous studies have reported low frequency of RNMB monitoring by anesthesia personnel [18,19].

International guidelines on the use of ND-NMB recommend ensuring that TOFr values are greater than or equal to 0.9 prior to extubation in all patients who have received any dose of ND-NMB [2,20,21]. We aimed to estimate the incidence, the characteristics of intraoperative monitoring and management, as well as the risk factors associated with RNMB, using a prospective observational study.

METHODS

A cohort study was conducted at a tertiary university hospital in the city of Medellín. The study was approved by the Ethics and Research Committee of Hospital Alma Máter de Antioquia, Medellín, on October 25, 2022, within the framework of the INS15-2022 project. We followed STROBE recommendations for reporting cohort studies.

Participants and eligibility criteria

Patients were recruited prospectively using convenience sampling. Patients were assessed for eligibility in the hospital's surgical preparation room. Patients over 18 years of age undergoing surgery under general anesthesia in which they received any dose of a ND-NMB were included. The exclusion criteria were patients who were transferred directly to the intensive care unit without remaining in the post-anesthesia care unit (PACU); those patients who for some reason did not receive ND-NMB; those for whom TOF measurement was not possible due to monitoring limitations; patients who did not tolerate TOF stimulation and moved their limb during measurement, interfering with precise measurements; or those in whom measurements were not conducted at the specified times. Patients who did not provide a signed informed consent were also excluded.

Measurements

Intraoperative management was at the discretion of the attending anesthesiologist. Anesthesiologists were not informed about patients participation in the study to avoid influencing their usual practice. In this institution, patients are extubated in the operating room. Measurements were conducted in a PACU shared by 14 operating rooms. Within the first 5 minutes of the patient's arrival in the PACU, two TOFr measurements were taken 30 seconds apart, the final result being the average between the two. If the results of these two measurements varied by more than 10%, a third measurement was taken, and the average of the two closest values was considered the final result.

Measurements were performed using a Mindray® NMT module (Nanshan, Shenzhen, China) assigned for the study and calibrated according to the manufacturer's recommendations. The test used four 0.2 ms stimuli, a frequency of 2 Hz, and an intensity between 40 and 55 mA. Electrodes were placed on the ulnar region, 2 to 3 cm apart, and measurements were conducted by the two lead authors and a general physician from the PACU area, after making sure they had performed a minimum of 50 measurements in the past, according to the 2018 consensus on perioperative neuromuscular monitoring (21). We performed non-normalized TOFr to expose patients to fewer stimuli, or to avoid doing it in the operating room, which could create a bias among the institution's anesthesiologists.

If any degree of RNMB was observed in patients, immediate notice was given to the attending anesthesiologist, and pharmacological reversal was suggested. Under no circumstances was this notification omitted. All patients were followed for 72 hours through medical records documented by the treating physicians or until discharge, whichever came first.

The demographic and perioperative characteristics of the patients were obtained from the anesthesia record, verbal information provided by the attending anesthesiologist during handover to the PACU staff, and electronic medical records completed by the treating physicians.

Outcomes

The primary outcome was the incidence of RNMB in the PACU, defined as a TOFr less than 0.9. Secondary outcomes included describing the perioperative clinical characteristics of patients with RNMB and exploratory identification of potential risk factors associated with RNMB. Additionally, the study aimed to determine the incidence of postoperative intubation, pneumonia, and cardiac arrest within the first 72 hours after discharge from the PACU.

Statistical analysis

A sample size of 300 patients was estimated, assuming an incidence of 25% based on the average reported in the literature (3, 7, 8), with a margin of error of 5% and a confidence level of 95%.

Regarding the primary outcome, the frequency was estimated for the entire study group, with absolute frequency presented as the number of patients with the diagnosis over the total number of patients admitted during the study period. Results are presented as percentages with their respective 95% confidence intervals (CI).

To describe the clinical and perioperative characteristics, a descriptive analysis of patient characteristic variables was conducted using central tendency and dispersion measurements. Absol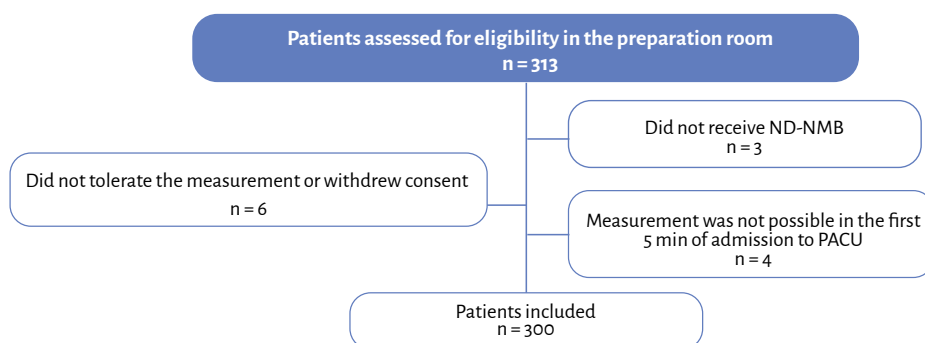ute and relative frequencies are presented for categorical variables. Quantitative variables are described with mean and standard deviation values. Normality assumptions were assessed using the Shapiro-Wilk test. Median and interquartile range were used as measures of central tendency and dispersion, respectively.

A bivariate analysis was conducted to evaluate potential perioperative risk factors associated with the development of RNMB, and the degree of association is presented in terms of odds ratios (OR). Hypothesis testing was performed using the Fisher's exact test, and p-values are reported. After the bivariate analysis, a multivariate analysis was conducted using binary logistic regression to establish adjusted odds ratios (ORs) for variables identified as significant in the bivariate analysis ($p < 0.1$). Assumptions of independence of events, monotonicity of the relationship, and absence of collinearity were considered. CI of 95% were calculated for OR values, along with p-values. A p-value less than 0.05 was considered statistically significant. The SPSS software version 27 was used for the statistical analysis.

RESULTS

Between November 2022 and February 2024, 300 eligible patients were included in the study (Figure 1). In the PACU, 57 patients

Figure 1. Flow diagram.

ND-NMB: non-depolarizing neuromuscular blockers; PACU: post-anesthesia care unit.
Source: Authors.

Table 1. Demographic characteristics.

Variable	No RNMB (n=243)	RNMB (n=58)	p-value
Age (years), Median (IQR)	54 (38.5-67)	63 (44-73)	0.019*
Gender, n (%)			
Female	116 (47.7%)	37 (64.9%)	0.020*
Male	127 (52.3%)	20 (35.1%)	
Weight (kg), Median (IQR)	66 (59-77)	67 (55-75)	0.796
Height (m), Median (IQR)	1.65 (1.57-1.70)	1.60 (1.56-1.70)	0.148
ASA Classification			**0.007***
ASA I	38 (15.7%)	6 (10.9%)	0.439
ASA II	112 (46.1%)	16 (28.1%)	0.019*
ASA III	89 (36.6%)	35 (61.4%)	0.001*
ASA IV	4 (1.6%)	0	1.0
BMI > 35, n (%)	13 (5.3%)	6 (10.5%)	0.105
Comorbidities, n (%)			
Hypertension	92 (37.9%)	22 (38.6%)	0.918
Diabetes mellitus	37 (15.2%)	14 (24.6%)	0.091
Heart failure	20 (8.2%)	2 (3.5%)	0.218
Coronary artery disease	6 (2.5%)	2 (3.5%)	0.661
Solid organ cancer	29 (11.9%)	12 (21.1%)	0.071
Hematologic cancer	2 (0.8%)	0	0.492
Metastatic disease	5 (2.1%)	4 (7.0%)	0.048*
Chronic lung disease	12 (4.9%)	4 (7.0%)	0.529
Chronic renal failure	21 (8.6%)	6 (10.5%)	0.655
Hypothyroidism	17 (7.0%)	5 (8.8%)	0.643
Obstructive sleep apnea syndrome	3 (1.2%)	2 (3.5%)	0.227
Polyneuropathy or neuromuscular junction disease	4 (1.6%)	3 (5.3%)	0.104
Acute or chronic liver failure	2 (0.8%)	0	0.492
Acute kidney injury	6 (2.5%)	5 (8.8%)	0.023*
Neurodegenerative disease	3 (1.2%)	0	0.399
Aminoglycoside administration	2 (0.8%)	0	0.492

*p-values less than 0.05 are considered statistically significant.

BMI: Body mass index, IQR: Interquartile range; RNMB: residual neuromuscular block.

Source: Authors.

were found to have some degree of RNMB, corresponding to an incidence of 19% (95% CI: 14.9% - 23.8%). Among these patients, 48 had a TOF ratio between 0.9 and 0.7 (84.2%), and 9 had a TOF ratio between < 0.7 and 0.4 (15.8%). No patient had a TOF ratio less than 0.4.

The main demographic characteristics of the patients are summarized in Table 1.

Most patients with residual blockade were female (p = 0.020), with ASA III classification, whereas those without the event were predominantly younger male patients with ASA I and II classifications. The main comorbidities in both groups included hypertension, diabetes mellitus, and chronic renal insufficiency.

The most common surgical procedure was abdominal surgery. The main ND-NMB

used was rocuronium in 92% of cases, with an average dose of 0.55 mg·kg⁻¹ in patients without RNB compared to 0.57 mg·kg⁻¹ in those with RNB, with no statistical differences (P = 0.324). Intraoperative monitoring of RNMB was performed in only 21.3% of cases, and pharmacological reversal measures were not used in 48.7% of cases. The other intraoperative

Table 2. Intraoperative management characteristics.

Variable	No RNMB (n=243)	RNMB (n=57)	p-value
Type of surgery, n (%)			
Abdominal	82 (33.7%)	31 (54.4%)	0.004*
Head and neck	28 (11.5%)	5 (8.8%)	0.550
Orthopedic	27 (11.1%)	4 (7.0%)	0.360
Thoracic	23 (9.5%)	6 (10.5%)	0.807
Urological	21 (8.6%)	3 (5.3%)	0.397
Neurological	18 (7.4%)	3 (5.3%)	0.568
Plastic	13 (5.3%)	1 (1.8%)	0.247
Maxillofacial	12 (4.9%)	1 (1.8%)	0.289
Vascular	11 (4.5%)	1 (1.8%)	0.336
Gynecological	5 (2.1%)	2 (3.5%)	0.883
Soft tissue	3 (1.2%)	0	0.399
Perioperative use of magnesium sulfate, n (%)	11 (4.5%)	4 (7.0%)	0.437
ND-NMB n (%)			
Rocuronium	226 (93.0%)	50 (87.7%)	0.186
Cisatracurium	17 (7.0%)	7 (12.3%)	
Rocuronium dose, mg (SD)	36.4 (13.8)	38.3 (15.2)	0.765
Cisatracurium dose, mg (SD)	8.23 (4.1)	11.5 (7.3)	0.005*
More than one dose of ND-NMB, n (%)	46 (18.9%)	22 (38.6%)	<0.001*
Intraoperative monitoring of muscle relaxation, n (%)	56 (23.0%)	8 (14.0%)	0.135
Neuromuscular reversal agent, n (%)			
None	112 (46.1%)	34 (59.6%)	0.065
Neostigmine	68 (28%)	15 (26.3%)	0.800
Sugammadex	63 (25.9%)	8 (14.0%)	0.057
Neostigmine dose, mg (SD)	1.82 (0.49)	1.93 (0.48)	0.245
Time between administration of the relaxant and extubation less than 120 minutes, n (%)	118 (48.6%)	34 (59.6%)	0.132

*SD: Standard deviation; ND-NMB: non-depolarizing neuromuscular blocker.
Source: Authors.

characteristics of the patients are shown in Table 2.

After adjusting for potential confounders, the exploratory analysis found, among the risk factors for the development of RNMB, that female gender, use of multiple doses of ND-NMB, abdominal surgery, and lack of pharmacological reversal were associated with a higher risk of RNMB in the postoperative period (Table 3).

Within the first 72 hours, no patients required ventilatory support or orotracheal intubation. There were no reports of respiratory arrest or death. Only one patient in the RNMB group (1.8%) was diagnosed with pneumonia, compared to none in the non-RNMB group.

DISCUSSION

This study found a high number of patients with RNMB, with an estimated incidence of 19% in the PACU. This value is lower than the findings reported in prospective observational studies such as RECITE and RECITE US, which reported incidences of 44% and 64%, respectively (7,8), and it is higher than the recently published INSPIRE-2 study, which reported an incidence of only 5% in the PACU (10).

Table 3. Risk factors associated with the development of residual neuromuscular blockade.

Variable	OR (IC 95 %)	p-value	Adjusted OR (CI 95%)	p-value
Age older than 63 years	1.82 (1.02-3.26)	0.043	1.47 (0.71-3.07)	0.295
Female gender	2.02 (1.11-3.69)	0.021	1.97 (1.02-3.81)	0.045*
ASA classification III	2.75 (1.52-4.98)	<0.001	1.89 (0.86-4.11)	0.112
Non-use of pharmacological reversal	4.01 (1.53-10.78)	0.005	2.31 (1.02-5.24)	0.046*
BMI > 35	2.08 (0.16-5.74)	0.156	1.58 (0.49-5.14)	0.445
Acute kidney injury	3.80 (1.11-12.9)	0.033	2.84 (0.73-10.99)	0.131
Diabetes mellitus	1.81 (0.90-3.64)	0.095	1.44 (0.62-3.30)	0.387
Solid tumors	1.97 (0.93-4.14)	0.075	1.47 (0.56-3.91)	0.434
Metastatic disease	3.59 (0.93-13.83)	0.063	1.21 (0.24-6.13)	0.818
Neuromuscular junction disease	3.31 (0.72-15.26)	0.123	5.12 (0.92-28.4)	0.062
Abdominal surgery	2.34 (1.30-4.20)	0.004	2.81 (1.37-5.72)	0.005*
More than one dose of NDNMB intraoperatively	3.62 (1.73-7.57)	<0.001	2.77 (1.48-5.18)	0.001*
No monitoring of neuromuscular relaxation	1.83 (0.82-4.10)	0.140	1.71 (0.69-4.29)	0.249
Time between ND-NMB administration and extubation < 120 min	1.56 (0.87-2.81)	0.134	1.91 (0.95-3.82)	0.066

* p-values less than 0.05 are considered statistically significant.
BMI: Body mass index, ND-NMB: non-depolarizing neuromuscular blocker.
Source: Authors.

The higher incidence in RECITE and RECITE US can be explained by differences in the study population, as both studies included only patients undergoing abdominal surgery, which has been described as a risk factor for RNMB (16). Consistent with this, we found an association between abdominal surgery and increased risk of RNMB with an OR of 2.81 (95% CI 1.37 - 5.72). This increased risk in abdominal surgery may be attributed to the need for repeated doses of ND-NMB to facilitate optimal surgical conditions. In our analysis, these additional doses were associated with a higher risk of RNMB, with an OR of 2.77 (95% CI 1.48 - 5.18), creating the need for greater caution in this type of patients.

In INSPIRE-2, 96% of patients received pharmacological reversal, 92% with sugammadex. In our study, only 51% of patients received pharmacological reversal, predominantly with neostigmine (53%), which may explain the higher incidence we reported compared to INSPIRE-2. We found an association between the absence of pharmacological reversal and the risk of RNMB, with an odds ratio (OR) of 2.31 (95% CI 1.02 - 5.24). However, we did not observe a statistically significant difference between the use of neostigmine or sugammadex and the frequency of RNMB, as described in two previous studies (22, 23).

In our population, only 21% of patients had evidence of intraoperative monitoring, a value lower than previously reported in other regions (24,25) and below what is recommended by recent international guidelines and consensus statements (2, 20, 21). This low frequency of monitoring may be related to the limited availability of monitors in operating rooms and to a lack of awareness among professionals about the RNMB.

Interestingly, we did not find an association between the absence of intraoperative monitoring and the risk of RNMB. However, the proportion of monitored patients was higher in the group without RNMB.

The low dose of ND-NMB used in the patients in this study is striking.

One explanation could be that this intraoperative approach aims to avoid cases of RNMB, given the low frequency of monitoring and pharmacological reversal that we observed. Female sex has consistently been identified as a risk factor associated with RNMB (10,17,26,27). Consistent with these findings, our study showed an association of female sex with an increased risk of RNMB, with an OR of 1.97 (95% CI 1.02 - 3.81). This has been attributed to differences in the proportion of adipose tissue and lean mass in women, which could explain the shorter onset and longer duration of effect observed with rocuronium (28,29).

Although previous studies have described risk factors associated with RNMB such as age, time less than 120 minutes since the last dose ND-NMBD, renal disease, oncologic disease, hypothyroidism, or hepatic failure, this study did not find a statistically significant association (6,16,17,30). This inconsistency in risk factors highlights the need for universal monitoring.

This study provides current data on RNMB in a tertiary university hospital in Colombia. These data differ from previous estimates that reported the use of vecuronium and pancuronium, which are associated with a higher risk of RNMB and are currently not commonly used in anesthesia practice in our setting (11,12). Despite this change in the ND-NMB administered and international recommendations for monitoring and management in all patients who have received one of these drugs, the findings of this research should encourage efforts to improve intraoperative monitoring and management practices for RNMB, as a marker of good anesthesia practice.

Strengths

To the authors' knowledge, the prospective analysis of a large number of patients in this study represents the largest cohort in our country. We successfully identified

risk factors associated with residual neuromuscular blockade RNMB that were statistically significant after adjusting for confounding factors. These risk factors may suggest which patient populations or surgical models require heightened vigilance. Additionally, it is noteworthy that the anesthesiologists managing intraoperative care were unaware of the patients' participation in the study, thereby reducing the Hawthorne effect and potential biases.

Limitations

This study employed convenience sampling rather than randomization. Data collection took place at a tertiary university hospital, which may differ from the monitoring and pharmacological reversal practices of other hospitals and limit its external validation. The time between extubation and arrival at the post-anesthesia care unit (PACU) was not quantified, potentially underestimating the incidence of the event. Additionally, non-normalized TOFr was measured, which may underestimate the incidence of the event. Furthermore, the study design did not allow for the evaluation of potential complications associated with RNMB, as immediate pharmacological reversal after diagnosis of RNMB was recommended in all cases due to ethical considerations.

Future research could focus on identifying the factors that determine the low frequency of intraoperative monitoring of RNMB by anesthesiologists in our region. Additionally, studies on the cost-effectiveness of pharmacological reversal agents and universal TOFr monitoring are needed, as well as studies that include pediatric populations.

CONCLUSION

RNMB in our setting is a common condition, characterized by a low frequency of intraoperative monitoring. Female gender, abdominal surgery, absence of pharmacological reversal, and repeated doses of

ND-NMB were identified as risk factors associated with RNMB, suggesting scenarios requiring heightened vigilance.

ETHICAL DISCLOSURES

Ethics committee approval

This study was approved by the institutional Research Ethics Committee of Hospital Alma Máter de Antioquia, in a meeting held on October 25, 2022, within the framework of the INS15-2022 project.

Protection of human and animal subjects

The authors declare that no experiments were performed on humans or animals for this study. The authors declare that the procedures followed were in accordance with the regulations of the relevant clinical research ethics committee and with those of the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Data confidentiality

The authors declare that they have followed the protocols of their work center on the publication of patient data.

Right to privacy and informed consent

The authors declare that no patient data appear in this article.

The authors have obtained the written informed consent of the patients or subjects mentioned in the article. This document is kept by the corresponding author.

ACKNOWLEDGEMENTS

Authors' contributions

Assistance for the study

None declared.

Financial support and sponsorship

None declared.

Conflicts of Interest

No author declares any conflicts of interest. There were no sources of funding other than personal resources.

Presentations

None declared.

Appreciation

REFERENCES

1. Lundstrøm LH, Duez CH, Nørskov AK, Rosenstock CV, Thomsen JL, Møller AM, et al. Avoidance versus use of neuromuscular blocking agents for improving conditions during tracheal intubation or direct laryngoscopy in adults and adolescents. Cochrane Database Syst Rev. 2017;5(5):CD009237. http://www.doi.org/10.1002/14651858.CD009237

2. Fuchs-Buder T, Romero CS, Lewald H, Lamperti M, Afshari A, Hristovska AM, et al. Peri-operative management of neuromuscular blockade: A guideline from the European Society of Anaesthesiology and Intensive Care. Eur J Anaesthesiol. 2023;40(2):82-94. http://www.doi.org/10.1097/EJA.0000000000001769

3. Kirmeier E, Eriksson LI, Lewald H, Jonsson Fagerlund M, Hoeft A, Hollmann M, Meistelman C, Hunter JM, Ulm K, Blobner M; POPULAR Contributors. Post-anaesthesia pulmonary complications after use of muscle relaxants (POPULAR): a multicentre, prospective observational study. Lancet Respir Med. 2019;7(2):129-40. http://www.doi.org/10.1016/S2213-2600(18)30294-7

4. Grabitz SD, Rajaratnam N, Chhagani K, Thevathasan T, Teja BJ, Deng H, et al. The Effects of Postoperative Residual Neuromuscular Blockade on Hospital Costs and Intensive Care Unit Admission: A Population-Based Cohort Study. Anesth Analg. 2019;128(6):1129-36. http://www.doi.org/10.1213/ANE.0000000000004028

5. Murphy GS, Szokol JW, Avram MJ, Greenberg SB, Shear TD, Vender JS, et al. Residual Neuromuscular Block in the Elderly: Incidence and Clinical Implications. Anesthesiology. 2015;123(6):1322-36. http://www.doi.org/10.1097/ALN.0000000000000865

6. Raval AD, Uyei J, Karabis A, Bash LD, Brull SJ. Incidence of residual neuromuscular blockade and use of neuromuscular blocking agents with or without antagonists: A systematic review and meta-analysis of randomized controlled trials. J Clin Anesth. 2020;64:109818. http://www.doi.org/10.1016/j.jclinane.2020.109818

7. Saager L. Incidence, risk factors, and consequences of residual neuromuscular block in the United States: The prospective, observational, multicenter RECITE-US study. J Clin Anesth. 2019;55:33-41. http://www.doi.org/10.1016/j.jclinane.2018.12.042

8. Fortier LP, McKeen D, Turner K, de Médicis É, Warriner B, Jones PM, et al. The RECITE Study: A Canadian Prospective, Multicenter Study of the Incidence and Severity of Residual Neuromuscular Blockade. Anesth Analg. 2015;121(2):366-72. http://www.doi.org/10.1213/ANE.0000000000000757

9. Yu B, Ouyang B. Incidence of postoperative residual neuromuscular blockade after general anesthesia: a prospective, multicenter, anesthetist-blind, observational study. Curr Med Res Opin. 2016;32(1):1-9. http://www.doi.org/10.1185/03007995.2015.1103213

10. Esteves S. Incidence of postoperative residual neuromuscular blockade - A multicenter, observational study in Portugal (INSPIRE 2), 2023;8(4):e225. http://www.doi.org/10.1097/j.pbj.0000000000000225.

11. González-Cárdenas VH, Salazar-Ramírez KJ, Coral-Sánchez GT. Postoperative residual paralysis in patients aged over 65 years old at the Post-Anesthesia Care Unit. Colombian Journal of Anestesiology. 2016;44(3):211–7. http://www.doi.org/10.1016/j.rca.2016.04.006

12. Ariza F, Dorado F, Enríquez LE, González V, Gómez JM, Chaparro-Mendoza K, et al. Postoperative residual paralysis in patients aged over 65 years old at the Post-Anesthesia Care Unit. Colombian Journal of Anestesiology. 2017;45(1):15–21. http://www.doi.org/10.1016/j.rca.2016.08.002

13. Barajas R, Camarena J, Castellanos A, et al. Determinación de la incidencia de la parálisis residual postanestésica con el uso de agentes bloqueadores neuromusculares en México. Rev Mex Anest. 2011;34(3):181-188.

14. Zapata D, Ángeles-de la Torre R, Aguirre-Ibarra C, et al. Bloqueo residual neuromuscular en pacientes hospitalizados versus ambulatorios en la Unidad de Cuidados Postanestésicos. Rev Mex Anest. 2016;39(2):97-105.

15. Vela-Vásquez R, Hurtado M. Postoperative residual paralysis after general anesthesia without objective neuromuscular monitoring: An observational study at the Regional Cajamarca Hospital, Perú. Acta Med Peru. 2019;36(4):274-80. https://doi.org/10.35663/amp.2019.364.901

16. Stewart P, Fanzca M. The Impact of Residual Neuromuscular Blockade, Oversedation, and Hypothermia on Adverse Respiratory Events in a Postanesthetic Care Unit: A Prospective Study of Prevalence, Predictors, and Outcomes. Anesthesia & Analgesia. 2016;123(4):859-68. https://doi.org/10.1213/ANE.0000000000001513

17. Rudolph MI, Ng PY, Deng H, Scheffenbichler FT, Grabitz SD, Wanderer JP, et al. Comparison of a novel clinical score to estimate the risk of REsidual neuromuscular block Prediction Score and the last train-of-four count documented in the electronic anaesthesia record: A retrospective cohort study of electronic data on file. Eur J Anaesthesiol. 2018;35(11):883-92. http://www.doi.org/10.1097/EJA.0000000000000861

18. 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(1):110-9. http://www.doi.org/10.1213/ANE.0b013e3181c07428

19. Söderström CM, Eskildsen KZ, Gätke MR, Staehr-Rye AK. Objective neuromuscular monitoring of neuromuscular blockade in Denmark: an online-based survey of current practice. Acta Anaesthesiol Scand. 2017;61(6):619-26. http://www.doi.org/10.1111/aas.12907

20. Thilen SR, Weigel WA, Todd MM, Dutton RP, Lien CA, Grant SA, et al. 2023 American Society of Anesthesiologists Practice Guidelines for Monitoring and Antagonism of Neuromuscular Blockade: A Report by the American Society of Anesthesiologists Task Force on Neuromuscular Blockade. Anesthesiology. 2023;138(1):13-41. http://www.doi.org/10.1097/ALN.0000000000004379

21. Naguib M, Brull SJ, Kopman AF, Hunter JM, Fülesdi B, Arkes HR, et al. Consensus Statement on Perioperative Use of Neuromuscular Monitoring. Anesth Analg. 2018;127(1):71-80. http://www.doi.org/10.1213/ANE.0000000000002670

22. Domenech G, Kampel M, García M. Usefulness of intra-operative neuromuscular blockade monitoring and reversal agents for postoperative residual neuromuscular blockade: a retrospective observational study. BMC Anesthesiology. 2019;19:143. https://doi.org/10.1186/s12871-019-0817-4

23. Lee YJ, Oh AY, Koo BW, Han JW, Park JH, Hong JP, et al. Postoperative residual neuromuscular blockade after reversal based on a qualitative peripheral nerve stimulator response: A randomised controlled trial. Eur J Anaesthesiol. 2020;37(3):196-202. http://www.doi.org/10.1097/EJA.0000000000001157

24. 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(1):110-9. http://www.doi.org/10.1213/ANE.0b013e3181c07428

25. Söderström CM, Eskildsen KZ, Gätke MR, Staehr-Rye AK. Objective neuromuscular monitoring of neuromuscular blockade in Denmark: an online-based survey of current practice. Acta Anaesthesiol Scand. 2017;61(6):619-626. http://www.doi.org/10.1111/aas.12907

26. Tawuye HY, Yimer A, Getnet H. Incidence and associated factors of residual neuromuscular block among patients underwent general anaesthesia at University of Gondar Hospital, a cross-sectional study. J Anesth Crit Care. 2017;7(6):00284. http://www.doi.org/10.15406/jaccoa.2017.07.00284

27. Aytac I, Postaci A, Aytac B, Sacan O, Alay GH, Celik B, et al. Survey of postoperative residual curarization, acute respiratory events and approach of anesthesiologists. Braz J Anesthesiol. 2016;66(1):55-62. http://www.doi.org/10.1016/j.bjane.2012.06.011

28. Adamus M, Koutna J, Gabrhelik T, Hubackova M, Janaskova E. Influence of gender on the onset and duration of rocuronium-induced neuromuscular block. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub. 2007;151(2):301-5. http://www.doi.org/10.5507/bp.2007.051

29. Xue FS, Liao X, Tong SY, Liu JH, An G, Luo LK. Dose-response and time-course of the effect of rocuronium bromide during sevoflurane anaesthesia. Anaesthesia. 1998;53(1):25-30. http://www.doi.org/10.1111/j.1365-2044.1998.00278.x

30. Pietraszewski P, Gaszyński T. Residual neuromuscular block in elderly patients after surgical procedures under general anaesthesia with rocuronium. Anaesthesiol Intensive Ther. 2013;45(2):77-81. http://www.doi.org/10.5603/AIT.2013.0017