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A COMPARATIVE STUDY OF TRAIN-OF-FOUR MONITORING VERSUS CONVENTIONAL CLINICAL METHODS FOR REGULATION AND REVERSAL OF NEUROMUSCULAR BLOCKADE DURING GENERAL ANAESTHESIA

Anaesthesiology

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ABSTRACT

Background: Neuromuscular blocking agents (NMBAs) are routinely used during general anaesthesia to facilitate tracheal intubation and provide optimal surgical conditions. Inadequate monitoring of neuromuscular blockade may result in residual paralysis, delayed recovery, and postoperative respiratory complications. Conventional clinical methods are commonly employed but are subjective and may fail to detect incomplete neuromuscular recovery. Train-of-Four (TOF) monitoring offers an objective and quantitative assessment of neuromuscular transmission. **Aim and Objectives:** To compare Train-of-Four monitoring with conventional clinical methods for regulation and reversal of neuromuscular blockade during general anaesthesia. **Materials and Methods:** This observational comparative study was conducted over 24 months in a tertiary care teaching hospital. Adult patients aged 18–60 years, belonging to ASA physical status I and II, undergoing elective surgeries under general anaesthesia were included. Patients were allocated into two groups: Group 1 (TOF-guided monitoring) and Group 2 (conventional clinical methods). Rocuronium was used for neuromuscular blockade, and neostigmine was used for reversal. Parameters related to dosing, timing of administration, reversal–extubation interval, and postoperative recovery were recorded and analysed. **Results:** TOF monitoring allowed more precise titration of muscle relaxants with reduced cumulative dosing and significantly shorter reversal–extubation time. Time to regain muscle power post-extubation was also significantly shorter in the TOF group. No residual neuromuscular paralysis was observed in either group. **Conclusion:** TOF monitoring is a reliable and effective method for regulating and reversing neuromuscular blockade, offering improved precision and faster recovery compared to conventional clinical methods.

KEYWORDS

INTRODUCTION

Neuromuscular blocking agents (NMBAs) are integral to modern general anaesthesia, facilitating tracheal intubation, optimizing surgical conditions, and preventing patient movement during operative procedures. (1) However, inappropriate dosing or inadequate monitoring of neuromuscular blockade can lead to complications such as residual paralysis, delayed recovery, postoperative respiratory insufficiency, and increased morbidity. Therefore, precise regulation and timely reversal of neuromuscular blockade are critical components of safe anaesthetic practice. (2,3,4)

Traditionally, anaesthesiologists have relied on conventional clinical methods to assess the depth of neuromuscular blockade and recovery, including observation of spontaneous respiration, head-lift tests, limb movement, and tidal volume assessment. Although these methods are simple and widely practiced, they are subjective and often fail to detect subclinical residual neuromuscular blockade, which may persist despite apparent clinical recovery. (5,6)

Train-of-Four (TOF) monitoring provides an objective and quantitative assessment of neuromuscular transmission by delivering a standardized series of electrical stimuli to a peripheral nerve and evaluating the corresponding muscle responses. TOF monitoring enables accurate titration of muscle relaxants and guides appropriate timing of reversal agents, thereby reducing the risk of residual neuromuscular blockade. (7)

Our study aims to compare TOF monitoring with conventional clinical methods in regulating and reversing neuromuscular blockade during general anaesthesia, with the objective of identifying the most reliable approach for optimizing patient safety and improving perioperative outcomes.

MATERIALS AND METHODOLOGY

This observational comparative study was conducted in the Department of Anaesthesiology and Critical Care at Dr. Balasaheb Vikhe Patil Rural Medical College, Pravara Institute of Medical Sciences (Deemed to be University), Loni, Maharashtra. The study period extended over 24 months. After obtaining approval from the Institutional Ethics Committee and written informed consent from participants, adult patients aged 18–60 years of either sex, belonging to American Society of Anesthesiologists (ASA) physical status I and II, and scheduled for elective surgeries under general anaesthesia requiring neuromuscular blockade were included. Patients with neuromuscular disorders, hepatic or renal impairment, electrolyte imbalance, pregnancy, or known allergy to study drugs were excluded.

Eligible patients were randomly allocated into two groups. Group 1 consisted of patients in whom neuromuscular blockade was regulated and reversed using Train-of-Four (TOF) monitoring. Group 2 included patients in whom neuromuscular blockade was managed using conventional clinical methods supplemented by capnography and flow–volume loop analysis. All patients received standardized general anaesthesia with uniform induction agents, maintenance anaesthetic techniques, and ventilatory settings to minimize confounding variables.

In both groups, rocuronium was used as the neuromuscular blocking agent for induction and maintenance. In Group 1, TOF monitoring was performed using a peripheral nerve stimulator, with electrodes placed over appropriate peripheral nerves, and dosing of rocuronium was guided by TOF count and ratio. In Group 2, additional doses of muscle relaxant were administered based on conventional clinical indicators such as changes in end-tidal carbon dioxide, capnographic waveform alterations, flow–volume loop patterns, and clinical signs of diaphragmatic or patient effort. Reversal of neuromuscular blockade in both groups was achieved using neostigmine with appropriate anticholinergic cover.

Hemodynamic parameters, timing of induction and maintenance doses of rocuronium, time interval between the last maintenance dose and administration of reversal agent, reversal–extubation time, recovery of muscle power, and postoperative residual neuromuscular weakness were recorded and compared between the two groups. Data were compiled systematically and subjected to statistical analysis using appropriate descriptive and inferential statistical methods, with results expressed as mean, standard deviation, percentages, and p-values, and a p-value <0.05 was considered statistically significant.

RESULTS

Table 1. Demographic and Baseline Characteristics of Study Participants

Parameter	Group 1 (TOF Monitoring)	Group 2 (Conventional Methods)	p-value
Number of patients (n)	25	25	—
Mean age (years)	Comparable	Comparable	>0.05
Gender (M/F)	Comparable	Comparable	>0.05

ASA Grade (I/II)	Comparable	Comparable	>0.05
Mean body weight (kg)	Comparable	Comparable	>0.05

Both groups were comparable with respect to age, gender distribution, ASA physical status, and body weight, indicating adequate baseline homogeneity.

Table 2. Comparison of Timing of Rocuronium Administration Between Groups

Parameter (minutes)	Group 1 (TOF) Mean ± SD	Group 2 (Conventional) Mean ± SD	p-value
Induction dose to first maintenance dose	77.47 ± 6.11	81.94 ± 8.17	<0.05
Maintenance dose to last dose	50.34 ± 5.38	46.56 ± 6.55	<0.05
Total maintenance dose (mg/kg)	Lower	Higher	<0.05

TOF-guided monitoring allowed more precise timing and reduced cumulative dosing of rocuronium compared to conventional methods.

Table 3. Comparison of Reversal and Extubation Parameters

Parameter	Group 1 (TOF) Mean ± SD	Group 2 (Conventional) Mean ± SD	p-value
Time from last rocuronium dose to reversal (min)	Shorter	Longer	<0.05
Reversal–extubation time (min)	3.09 ± 0.91	3.59 ± 0.83	<0.05
Neostigmine dose (mg/kg)	Comparable	Comparable	>0.05

Patients monitored with TOF demonstrated significantly faster reversal and extubation times, indicating more efficient neuromuscular recovery.

Table 4. Post-extubation Recovery and Complications

Parameter	Group 1 (TOF)	Group 2 (Conventional)	p-value
Time to regain muscle power (min)	31.39 ± 4.49	33.36 ± 4.13	<0.05
Residual neuromuscular paralysis	0	0	—
Head-lift test (within 10 min)	Successful in all	Successful in all	—
Leg-lift test (within 10 min)	Successful in all	Successful in all	—
Post-operative nausea & vomiting	Comparable	Comparable	>0.05

DISCUSSION

The present study was conducted to compare Train-of-Four (TOF) monitoring with conventional clinical methods for the regulation and reversal of neuromuscular blockade during general anaesthesia. Neuromuscular blocking agents are indispensable in modern anaesthetic practice; however, inadequate monitoring may lead to residual neuromuscular blockade, delayed recovery, and postoperative respiratory complications. (8,9) The findings of this study highlight the advantages of objective neuromuscular monitoring using TOF over conventional clinical assessment methods.

In the present study, both groups were comparable with respect to demographic variables such as age, gender distribution, body weight, and ASA physical status, thereby eliminating baseline confounding factors. This ensured that the observed differences in neuromuscular management and recovery parameters could be attributed primarily to the monitoring technique used rather than patient-related variables. Similar demographic comparability has been reported in previous studies evaluating neuromuscular monitoring techniques. (10)

A key finding of this study was the significant difference in the timing and dosing of rocuronium between the two groups. Patients monitored using TOF required maintenance doses at longer intervals and demonstrated a reduced cumulative requirement of neuromuscular blocking agents. This finding reflects the precision offered by TOF monitoring, which allows titration of muscle relaxants based on objective neuromuscular transmission data rather than indirect clinical indicators. In contrast, reliance on conventional methods, including capnography and flow–volume loop assessment, may lead to relatively earlier or additional dosing due to subjective interpretation of respiratory patterns or diaphragmatic movement. (11,12)

The reversal and extubation parameters further emphasized the superiority of TOF-guided management. The reversal–extubation time was significantly shorter in the TOF group compared to the conventional group, indicating faster and more predictable recovery of neuromuscular function. Although both groups received comparable doses of neostigmine, the timing of reversal in the TOF group was more appropriately guided by the degree of neuromuscular recovery, as reflected by TOF count and ratio. This supports existing literature suggesting that anticholinesterase reversal is most effective when administered at an optimal level of neuromuscular recovery rather than empirically.

Post-extubation recovery outcomes revealed that both groups achieved successful head-lift and leg-lift tests within 10 minutes, and no patient demonstrated clinically evident residual neuromuscular paralysis. However, the time required to regain full muscle power was significantly shorter in the TOF group. This difference, although modest, is clinically relevant, as even subtle residual weakness can predispose patients to airway compromise, hypoventilation, and delayed discharge from post-anaesthesia care units. The absence of residual paralysis in both groups may be attributed to vigilant intraoperative monitoring and timely administration of reversal agents, yet the faster recovery observed with TOF monitoring underscores its role in enhancing patient safety.

Postoperative complications such as nausea and vomiting were comparable between the two groups, suggesting that neuromuscular monitoring modality did not significantly influence these outcomes. However, the primary strength of TOF monitoring lies in its ability to minimize residual neuromuscular blockade, a factor strongly associated with postoperative respiratory morbidity.

CONCLUSION

In conclusion, the findings of this study demonstrate that TOF monitoring provides a more accurate, objective, and reliable method for regulating and reversing neuromuscular blockade compared to conventional clinical methods. Its routine use can optimize neuromuscular blocker dosing, facilitate timely reversal, and promote faster recovery, thereby improving overall perioperative outcomes and patient safety during general anaesthesia.

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