

Comparative Study of Efficacy of Sugammadex versus Neostigmine for Reversal of Neuromuscular Blockade and Its Impact on Perioperative Outcome: A Quasi Experimental Study at Tertiary Care Centre

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Conflict of interest: Nil

Abstract:

Introduction: Neuromuscular blocking agents are widely used during general anaesthesia to facilitate tracheal intubation, provide adequate surgical relaxation, and enable controlled ventilation. However, postoperative residual neuromuscular blockade (RNMB) remains an important perioperative concern and may contribute to airway obstruction, hypoxaemia, impaired protective airway reflexes, aspiration, delayed recovery, and postoperative respiratory complications. A Train-of-Four (TOF) ratio ≥ 0.9 is considered the minimum indicator of adequate neuromuscular recovery. Neostigmine, traditionally used for reversal, has a ceiling effect and its efficacy depends on the depth of blockade. Sugammadex directly encapsulates aminosteroidal neuromuscular blocking agents and provides rapid and predictable reversal.

Aim: To compare the efficacy of Sugammadex with Neostigmine–Glycopyrrolate for reversal of vecuronium-induced neuromuscular blockade and to assess their impact on perioperative outcomes, including neuromuscular recovery, extubation, postoperative respiratory status, haemodynamic stability, and adverse effects.

Methods: This hospital-based prospective quasi-experimental study was conducted in the Department of Anaesthesiology at a tertiary care teaching hospital over 18 months after Institutional Ethics Committee approval. Seventy-six adult patients (ASA I–III) undergoing elective surgery under general anaesthesia with vecuronium-induced neuromuscular blockade were included. Patients were equally allocated into Group S (Sugammadex, n=38), receiving Sugammadex 2 mg/kg IV, and Group N (Neostigmine–Glycopyrrolate, n=38), receiving Neostigmine 0.05 mg/kg with Glycopyrrolate 0.008 mg/kg IV. Neuromuscular recovery was assessed using TOF monitoring. Time to TOF ratio ≥ 0.9 , extubation, eye opening, response to verbal commands, postoperative oxygen saturation, respiratory complications, postoperative nausea and vomiting, and adverse events were recorded.

Results: Sugammadex produced significantly faster neuromuscular recovery than Neostigmine–Glycopyrrolate. The mean time to achieve a TOF ratio ≥ 0.9 was 132.34 seconds in the Sugammadex group compared with 304.21 seconds in the Neostigmine group. Mean extubation time was also markedly shorter with Sugammadex (184.87 seconds versus 374.45 seconds). Patients receiving Sugammadex demonstrated faster eye opening and response to verbal commands, greater haemodynamic stability, and higher postoperative oxygen saturation. Mean postoperative oxygen saturation was 98.34% with Sugammadex compared with 94.11% with Neostigmine–Glycopyrrolate. PONV was uncommon, occurring in one patient (2.6%) in the Neostigmine–Glycopyrrolate group and none in the Sugammadex group.

Conclusion: Sugammadex provided significantly faster and more predictable reversal of vecuronium-induced neuromuscular blockade than Neostigmine–Glycopyrrolate. Its use was associated with earlier achievement of adequate neuromuscular recovery, earlier extubation, improved postoperative oxygenation, and greater haemodynamic stability. These findings support Sugammadex as an effective reversal agent for aminosteroidal neuromuscular blockade in contemporary anaesthetic practice.

Keywords: Sugammadex; Neostigmine; Glycopyrrolate; Vecuronium; Neuromuscular blockade; Train-of-Four; Residual neuromuscular blockade; Reversal; Extubation; Postoperative recovery.

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Introduction

Neuromuscular blocking agents (NMBAs) have become an integral component of modern anaesthetic practice. Since the introduction of curare into clinical anaesthesia by Griffith and Johnson in 1942, neuromuscular blocking drugs have played a crucial role in facilitating tracheal intubation, improving surgical operating conditions, and enabling controlled mechanical ventilation during various surgical procedures. These agents provide optimal skeletal muscle relaxation, enhance surgical exposure, and reduce the requirement for deeper levels of anaesthesia. Consequently, non-depolarizing neuromuscular blocking agents such as rocuronium and vecuronium have become indispensable in contemporary anaesthetic management.[1]

Neuromuscular transmission occurs at the neuromuscular junction, where acetylcholine released from presynaptic motor nerve terminals binds to nicotinic cholinergic receptors on the postsynaptic membrane of skeletal muscle fibres, producing depolarization and muscle contraction. Neuromuscular blocking agents interfere with this process by competitively inhibiting acetylcholine binding, thereby producing reversible skeletal muscle paralysis.[2]

Despite their clinical advantages, NMBAs are associated with postoperative residual neuromuscular blockade (RNMB), characterized by incomplete recovery of neuromuscular function at the conclusion of surgery. Traditionally, recovery was assessed using clinical parameters such as sustained head lift, hand grip strength, tongue protrusion, adequate spontaneous ventilation, and maintenance of oxygen saturation. However, these clinical signs are poor predictors of complete neuromuscular recovery and may fail to identify significant residual paralysis.[3]

Train-of-four (TOF) stimulation is the most widely accepted method for evaluating neuromuscular function during the perioperative period. A TOF ratio of 0.9 or greater is considered the minimum threshold for adequate recovery. Ratios below this level are associated with impaired upper airway muscle function, reduced pharyngeal tone, diminished hypoxic ventilatory response, impaired swallowing, and increased risk of pulmonary complications.[4]

The reported incidence of residual neuromuscular blockade varies from 20% to more than 60%, depending on the neuromuscular blocker, monitoring technique, and reversal strategy used. Even mild residual paralysis can reduce inspiratory force, impair airway patency, and compromise protective airway reflexes, potentially resulting in upper airway obstruction, hypoxaemia, aspiration,

atelectasis, delayed recovery, prolonged recovery-unit stay, and increased postoperative morbidity.[5]

Effective and reliable reversal of neuromuscular blockade is therefore essential. For several decades, acetylcholinesterase inhibitors, particularly neostigmine, have remained the standard pharmacological agents for reversal of non-depolarizing neuromuscular blockade.[6] Neostigmine inhibits acetylcholinesterase and increases acetylcholine concentration at the neuromuscular junction, allowing acetylcholine to competitively displace non-depolarizing neuromuscular blockers from nicotinic receptors. However, its effectiveness depends on the depth of blockade and it has a ceiling effect, limiting its efficacy in profound neuromuscular blockade.[7]

Neostigmine also produces muscarinic adverse effects, including bradycardia, increased salivation and bronchial secretions, bronchospasm, gastrointestinal hypermotility, nausea, vomiting, and abdominal cramping. Therefore, anticholinergic agents such as glycopyrrolate are routinely co-administered. Glycopyrrolate effectively antagonizes muscarinic effects while producing less tachycardia and fewer central nervous system effects than atropine. Nevertheless, neostigmine-glycopyrrolate therapy may result in incomplete reversal, delayed recovery, and persistent residual blockade, stimulating interest in alternative reversal agents.[8]

The introduction of sugammadex represents a major development in neuromuscular blockade reversal. Unlike neostigmine, which acts indirectly by increasing acetylcholine concentration, sugammadex specifically binds and inactivates amino steroidal neuromuscular blocking agents such as rocuronium and vecuronium. Sugammadex is a modified γ -cyclodextrin that selectively encapsulates these agents. Following intravenous administration, it rapidly binds free rocuronium or vecuronium in plasma, forming stable water-soluble complexes. The resulting reduction in plasma concentration promotes redistribution of the neuromuscular blocker away from the neuromuscular junction, thereby restoring neuromuscular transmission.[9]

Because sugammadex directly removes the causative neuromuscular blocker, recovery is generally faster, more predictable, and less dependent on the depth of blockade than with neostigmine. Studies have demonstrated reversal of moderate and profound blockade within a few minutes, providing important advantages when rapid restoration of muscle strength is required. Sugammadex also lacks the cholinergic adverse effects associated with acetylcholinesterase

inhibitors because it does not increase acetylcholine concentrations; consequently, anticholinergic co-administration is generally unnecessary.[10]

The emphasis on enhanced recovery after surgery (ERAS) has further increased the importance of rapid and reliable neuromuscular recovery. Inadequate reversal may delay recovery and increase immediate postoperative respiratory complications. Even minor residual weakness can impair upper airway patency, ventilatory response to hypoxia, coughing, and airway clearance, making prevention of RNMB an important patient safety objective.[11]

Hence, the present study titled “Comparative Study of Efficacy of Sugammadex versus Neostigmine for Reversal of Neuromuscular Blockade and Its Impact on Perioperative Outcome: A Quasi Experimental Study at Tertiary Care Centre” has been undertaken to compare these reversal strategies with respect to recovery of neuromuscular function, incidence of residual neuromuscular blockade, postoperative respiratory outcomes, recovery-room stay, and overall perioperative outcome.

Material and Methods

The present study was conducted as a hospital-based prospective quasi-experimental by the Department of Anaesthesiology at a tertiary care teaching hospital after obtaining approval from the Institutional Ethics Committee over a period of 18 months. The study was conducted amongst adult patients undergoing elective surgical procedures under general anaesthesia requiring neuromuscular blockade with rocuronium were enrolled in the study.

Sample size calculation was based on the study conducted by Moon TS et al.[12] comparing recovery after reversal of neuromuscular blockade. The probability of achieving a Train-of-Four (TOF) ratio ≥ 0.9 at 15 minutes was 95% in the Sugammadex group and 33% in the Neostigmine group. Total sample size = 76 patients consisting of Group S (Sugammadex): 38 patients and Group N (Neostigmine): 38 patients. Consecutive eligible patients fulfilling the inclusion criteria were recruited until the required sample size was achieved.

Inclusion Criteria- Adult patients aged 18 years and above, patients of either gender. patients scheduled for elective surgery under general anaesthesia requiring neuromuscular blockade, ASA Physical Status I–III and patients willing to provide written informed consent.

Exclusion Criteria - Known neuromuscular disorders, Known hypersensitivity to Sugammadex, Neostigmine, Glycopyrrolate or Rocuronium, severe renal impairment, severe hepatic dysfunction, pregnant patients and patients unwilling to participate in the study.

Pre-Anaesthetic Evaluation: All patients underwent detailed pre-anaesthetic evaluation one day before surgery. Relevant history, physical examination and routine investigations were reviewed. Written informed consent was obtained from all participants.

Anaesthetic Technique: Upon arrival in the operating room, standard ASA monitoring was instituted.

Anaesthesia was induced using: Propofol 2 mg/kg IV • Midazolam 0.03 mg/kg IV • Fentanyl 2 µg/kg IV Neuromuscular blockade was achieved using Vecuronium 0.1 mg/kg IV. Following adequate muscle relaxation, tracheal intubation was performed. Maintenance doses of Vecuronium 0.02–0.03 mg/kg IV were administered as required based on clinical assessment and neuromuscular monitoring. After adequate neuromuscular blockade, tracheal intubation was performed. Anaesthesia was maintained with: Oxygen 60% • Air 40%. • Isoflurane (1 MAC). Additional doses of fentanyl were administered when clinically indicated.

Study Groups: **1.** Group S (Sugammadex Group)- Patients received Sugammadex 2 mg/kg IV for reversal of Vecuronium-induced neuromuscular blockade. **2.** Group N (Neostigmine Group) - Patients received Neostigmine 0.05 mg/kg IV along with Glycopyrrolate 0.008 mg/kg IV for reversal of Vecuronium-induced neuromuscular blockade.

Neuromuscular Monitoring: Neuromuscular function was monitored using Train-of-Four (TOF) stimulation. The following parameters were recorded: TOF count at time of reversal • Time from reversal agent administration to TOF ratio ≥ 0.9 • Time to extubation • Time to eye opening • Time to head lift • Time to obey verbal commands

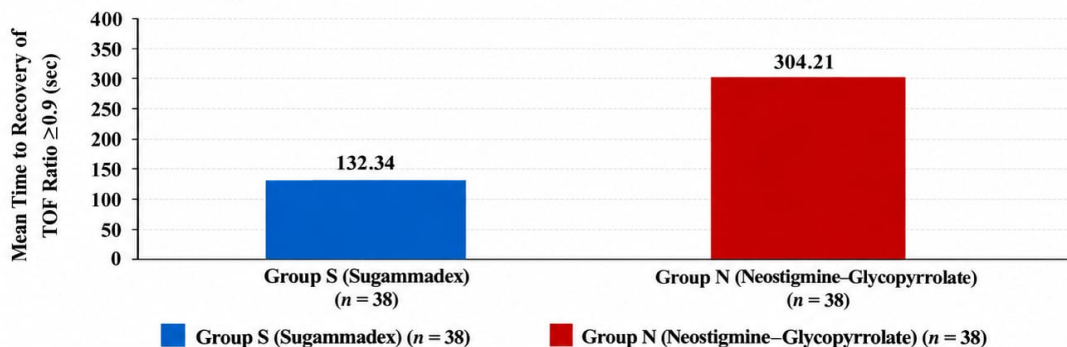
Postoperative Assessment: Following extubation, patients were transferred to the Post Anaesthesia Care Unit (PACU).

The following were recorded: Residual neuromuscular blockade • Oxygen saturation • Respiratory complications • Postoperative nausea and vomiting • Requirement of supplemental oxygen • Adverse events.

Results

Graph No. 1

Comparison of mean time to recovery of TOF ratio ≥ 0.9 between Group S (Sugammadex) and Group N (Neostigmine–Glycopyrrolate).

**Table No. 1**

Comparison of Time to Recovery of TOF Ratio ≥ 0.9 Between the Study Groups

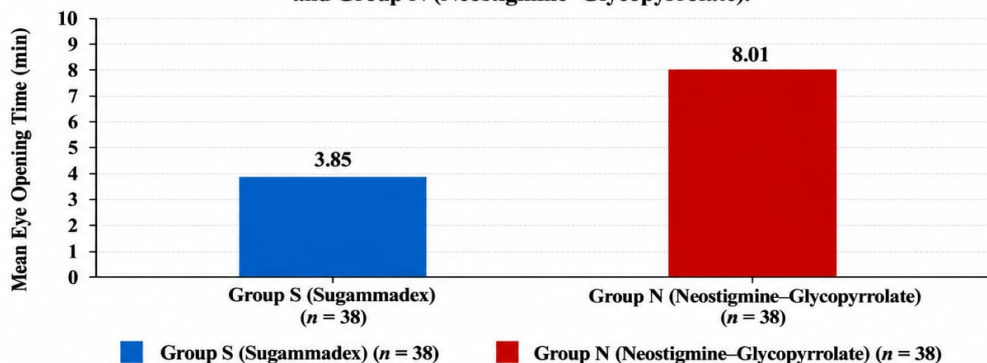
Variable	Group S (Sugammadex) (Mean $\pm$ SD) (n = 38)	Group N (Neostigmine–Glycopyrrolate) (Mean $\pm$ SD) (n = 38)	p-value (Independent Student's <i>t</i> -test)
Time to Recovery of TOF Ratio ≥ 0.9 (sec)	132.34 $\pm$ 28.15	304.21 $\pm$ 57.48	<0.001

Statistical test used: Independent Student's *t*-test

Table No. 1 compares the mean time to recovery of TOF ratio ≥ 0.9 between the two study groups. The mean time in the Sugammadex group (Group S) was 132.34 $\pm$ 28.15 seconds, whereas in the Neostigmine–Glycopyrrolate group (Group N) it was 304.21 $\pm$ 57.48 seconds. Statistical analysis using Independent Student's *t*-test showed that the difference between the groups was statistically significant ($p < 0.001$), indicating that Sugammadex provides significantly faster recovery to TOF ratio ≥ 0.9 compared to Neostigmine–Glycopyrrolate.

Graph No. 2

Comparison of mean eye opening time between Group S (Sugammadex) and Group N (Neostigmine–Glycopyrrolate).

**Table No. 2**

Comparison of Mean Eye Opening Time Between the Study Groups

Variable	Group S (Sugammadex) (Mean $\pm$ SD) (n = 38)	Group N (Neostigmine–Glycopyrrolate) (Mean $\pm$ SD) (n = 38)	p-value (Independent Student's <i>t</i> -test)
Eye Opening Time (min)	3.85 $\pm$ 0.87	8.01 $\pm$ 1.21	$p < 0.001$

Statistical test used: Independent Student's *t*-test

Table No. 2 compares the mean eye opening time between the two study groups. The mean eye opening time in the Sugammadex group (Group S) was 3.85 $\pm$ 0.87 minutes, whereas in the Neostigmine–Glycopyrrolate group (Group N) it was 8.01 $\pm$ 1.21 minutes. Statistical analysis using Independent Student's *t*-test showed that the difference between the groups was statistically significant ($p < 0.001$), indicating that Sugammadex provides significantly faster eye opening compared to Neostigmine–Glycopyrrolate.

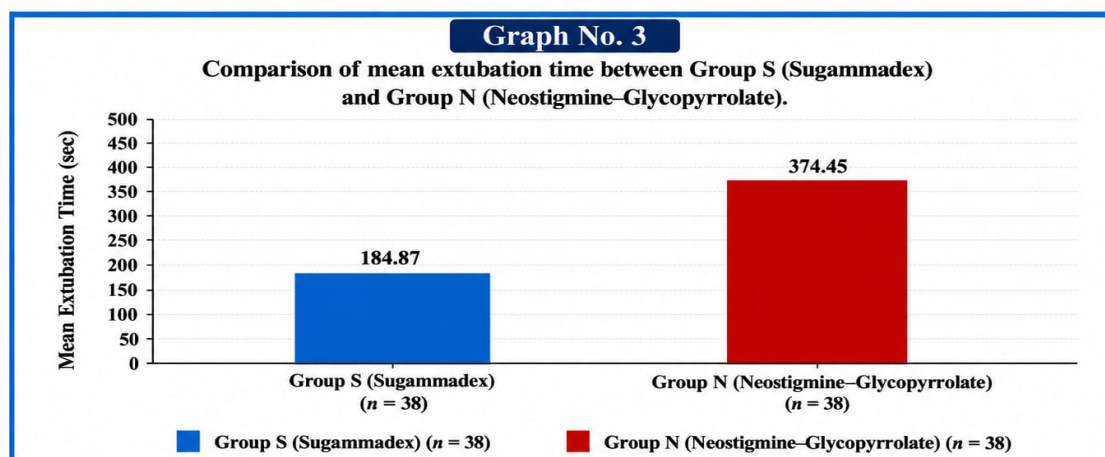


Table No. 3

Comparison of Mean Extubation Time Between the Study Groups

Variable	Group S (Sugammadex) (Mean $\pm$ SD) (n = 38)	Group N (Neostigmine–Glycopyrrolate) (Mean $\pm$ SD) (n = 38)	p-value (Independent Student's t-test)
Extubation Time (sec)	184.87 $\pm$ 14.65	374.45 $\pm$ 30.62	$p < 0.001$

Statistical test used: Independent Student's t-test

Table No. 3 compares the mean extubation time between the two study groups. The mean extubation time in the Sugammadex group (Group S) was 184.87 $\pm$ 14.65 seconds, whereas in the Neostigmine–Glycopyrrolate group (Group N) it was 374.45 $\pm$ 30.62 seconds. Statistical analysis using Independent Student's t-test showed that the difference between the groups was statistically significant ($p < 0.001$), indicating that Sugammadex provides significantly shorter extubation time compared to Neostigmine–Glycopyrrolate.

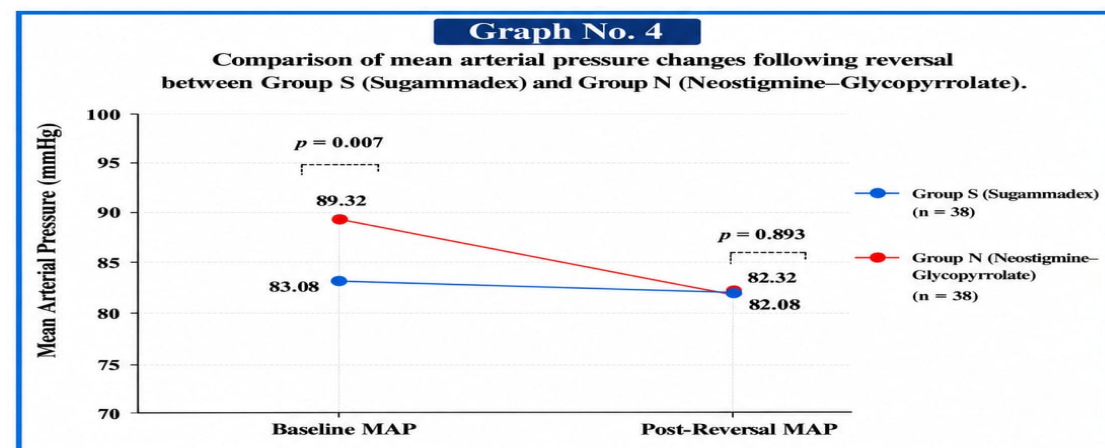


Table No. 4

Comparison of Mean Arterial Pressure Changes Following Reversal Between the Study Groups

Parameter	Group S (Sugammadex) Mean $\pm$ SD (mmHg) (n = 38)	Group N (Neostigmine–Glycopyrrolate) Mean $\pm$ SD (mmHg) (n = 38)	p-value (Independent Student's t-test)
Baseline MAP (mmHg)	83.08 $\pm$ 8.97	89.32 $\pm$ 9.48	$p = 0.007$
Post-Reversal MAP (mmHg)	82.08 $\pm$ 8.65	82.32 $\pm$ 8.72	$p = 0.893$

Statistical test used: Independent Student's t-test

Table No. 4 compares the mean arterial pressure (MAP) changes following reversal between the two study groups. At baseline, the mean MAP in Group S (Sugammadex) was 83.08 $\pm$ 8.97 mmHg, whereas in Group N (Neostigmine–Glycopyrrolate) it was 89.32 $\pm$ 9.48 mmHg. This difference was statistically significant ($p = 0.007$). Following reversal, the mean MAP in Group S was 82.08 $\pm$ 8.65 mmHg and in Group N it was 82.32 $\pm$ 8.72 mmHg. The difference between the groups after reversal was not statistically significant ($p = 0.893$), indicating that MAP values were comparable between the two groups after reversal.

Figure 5: Comparison of distribution of Residual Neuromuscular Blockade between Group S (Sugammadex) and Group N (Neostigmine–Glycopyrrolate).

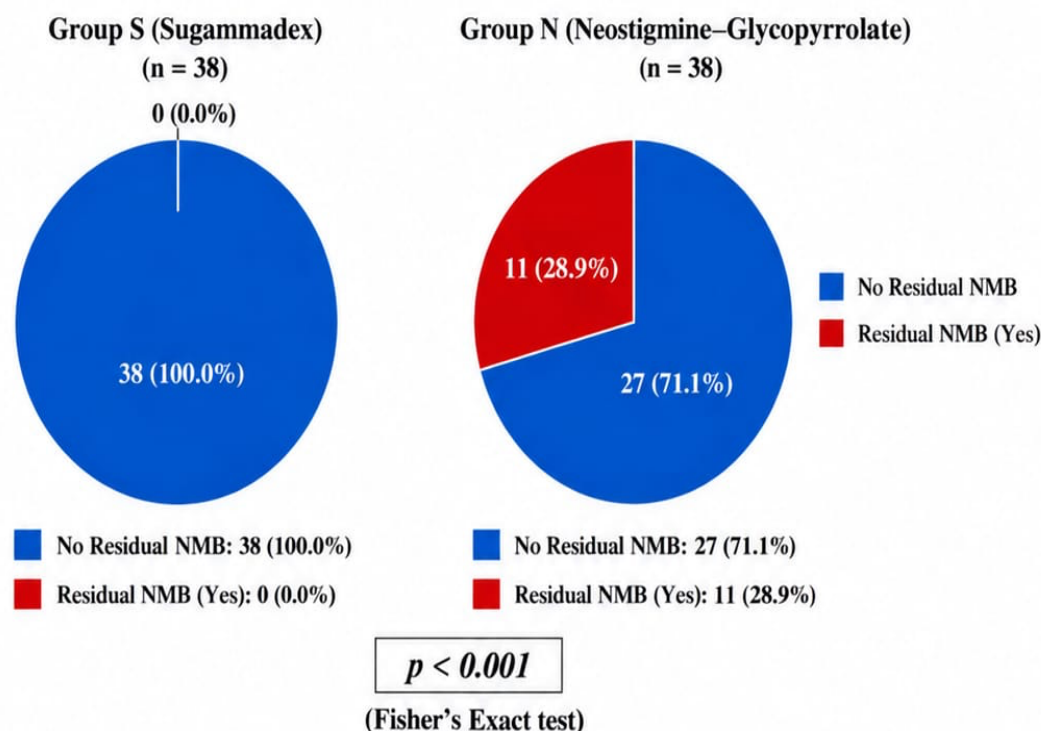


Table 5: Comparison of Residual Neuromuscular Blockade Between the Study Groups

Variable	Group S (Sugammadex) n (%) (n = 38)	Group N (Neostigmine–Glycopyrrolate) n (%) (n = 38)	p-value (Chi-square test/ Fisher's Exact test)
Residual Neuromuscular Blockade (Yes)	0 (0.0%)	11 (28.9%)	$p < 0.001$

Statistical test used: Fisher's Exact test

Table 5 describes the incidence of residual neuromuscular blockade in the two study groups. In the Sugammadex group (Group S), no patient (0.0%) had residual neuromuscular blockade, whereas in the Neostigmine–Glycopyrrolate group (Group N), 11 patients (28.9%) exhibited residual neuromuscular blockade. Statistical analysis using Fisher's Exact test showed that the difference between the groups was statistically significant ($p < 0.001$), indicating that Sugammadex was associated with a significantly lower incidence of residual neuromuscular blockade compared to Neostigmine–Glycopyrrolate.

Figure 6: Comparison of incidence of postoperative nausea and vomiting (PONV) between Group S (Sugammadex) and Group N (Neostigmine–Glycopyrrolate).

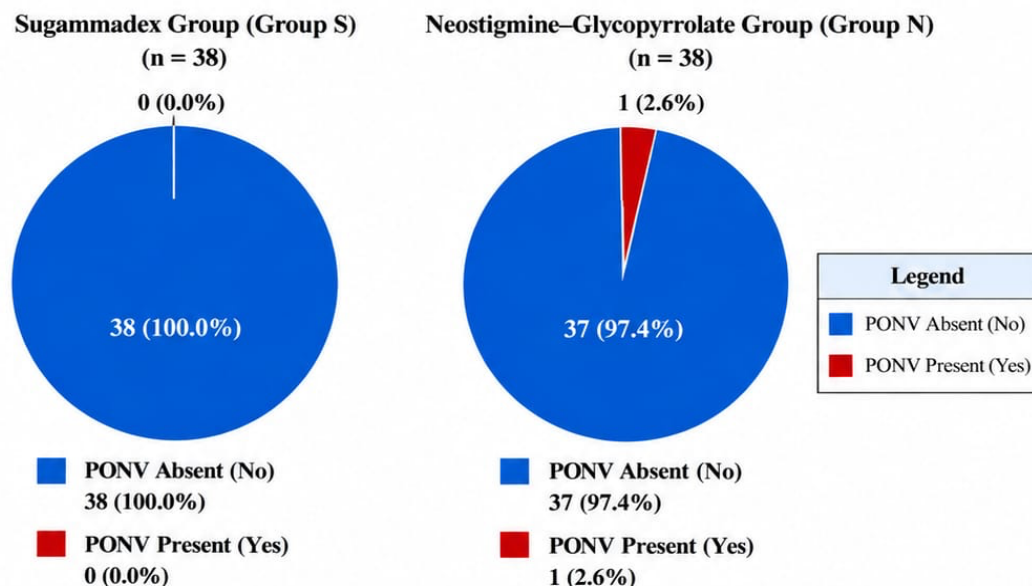


Table 6: Comparison of Incidence of Postoperative Nausea and Vomiting (PONV) Between the Study Groups

Variable	Sugammadex Group (Group S) n (%) (n = 38)	Neostigmine–Glycopyrrolate Group (Group N) n (%) (n = 38)	p-value (Fisher's Exact test)
PONV Present (Yes)	0 (0.0%)	1 (2.6%)	p = 1.000

Statistical test used: Fisher's Exact test

Table 6 describes the incidence of postoperative nausea and vomiting (PONV) in the two study groups. In the Sugammadex group (Group S), no patient (0.0%) experienced PONV, whereas in the Neostigmine–Glycopyrrolate group (Group N), 1 patient (2.6%) had PONV. Statistical analysis using Fisher's Exact test showed that the difference between the groups was not statistically significant ($p = 1.000$), indicating that the incidence of PONV was comparable between the two study groups.

Note: PONV – Postoperative Nausea and Vomiting

Discussion:

The primary objective of the present study was to compare the time required to achieve recovery of Train-of-Four (TOF) ratio ≥ 0.9 following administration of Sugammadex and Neostigmine–Glycopyrrolate. Secondary objectives included comparison of extubation time, eye-opening time, response to verbal commands, postoperative oxygen saturation, hemodynamic parameters, incidence of residual neuromuscular blockade, and postoperative adverse effects.

A total of 76 patients were enrolled in the study and were equally allocated into two groups, with 38 patients receiving Sugammadex and 38 patients receiving Neostigmine–Glycopyrrolate. No patient was excluded from the final analysis, ensuring complete data collection and strengthening the validity of the study findings.

Demographic Characteristics: The mean age of patients in the Sugammadex group was 51.03 years, while the mean age in the Neostigmine–Glycopyrrolate group was 52.03 years. Age is an important determinant of anaesthetic drug

pharmacokinetics and pharmacodynamics. Elderly patients often exhibit prolonged neuromuscular blockade due to age-related reductions in hepatic and renal function, altered drug distribution, and decreased physiological reserve. Miller et al. and Naguib and Lien have described the influence of age on the pharmacokinetic and pharmacodynamic behaviour of neuromuscular blocking agents and their reversal drugs, emphasizing the importance of age-matched study populations while evaluating recovery characteristics. [1,2]

The duration of surgery was comparable between groups, suggesting that exposure to anaesthetic agents and cumulative doses of vecuronium were likely similar. Surgical duration is a clinically relevant factor because prolonged procedures may require repeated dosing of neuromuscular blocking agents, potentially affecting the depth of blockade and subsequent recovery characteristics. The absence of a significant difference in operative duration reduced the likelihood of bias arising from unequal neuromuscular blocker exposure. Therefore, the observed differences in recovery parameters can be more confidently attributed to the reversal agents rather than differences in surgical or anaesthetic duration. [8]

Jones et al. [13] conducted a multicentre randomized controlled trial comparing Sugammadex with Neostigmine for reversal of amino steroidal neuromuscular blockade and reported no significant differences in age, gender distribution, body weight, or perioperative characteristics between the treatment groups. The authors emphasized that demographic comparability was essential for accurate evaluation of recovery outcomes and concluded that the observed differences in neuromuscular recovery were attributable to the reversal agent rather than baseline patient characteristics.

Blobner et al. [14] similarly evaluated the efficacy of Sugammadex compared with Neostigmine and demonstrated comparable demographic and operative characteristics between study groups. Their study highlighted the importance of minimizing demographic bias when assessing recovery parameters and showed that balanced baseline characteristics strengthen the validity of comparative clinical studies.

Recovery of Neuromuscular Function: The most significant finding of the present study was the markedly faster recovery observed in patients receiving Sugammadex. The mean time required to achieve a TOF ratio of ≥ 0.9 was 132.34 seconds in the Sugammadex group compared with 304.21 seconds in the Neostigmine–Glycopyrrolate group. Statistical analysis demonstrated a highly significant difference between the groups, indicating the

superior efficacy of Sugammadex in reversing vecuronium-induced neuromuscular blockade.

This difference can be explained by the fundamentally different mechanisms of action of the two reversal agents. Neostigmine is an acetylcholinesterase inhibitor that indirectly antagonizes neuromuscular blockade by increasing the concentration of acetylcholine at the neuromuscular junction. The increased availability of acetylcholine competes with the neuromuscular blocking agent for binding at nicotinic receptors, thereby facilitating recovery. However, the effectiveness of Neostigmine depends on the depth of blockade present at the time of administration. If significant receptor occupancy persists, complete reversal may be delayed or incomplete. Furthermore, Neostigmine exhibits a ceiling effect, beyond which additional doses do not produce greater reversal. [15]

In contrast, Sugammadex acts through a completely different and highly specific mechanism. It is a modified γ -cyclodextrin molecule specifically designed to encapsulate aminosteroidal neuromuscular blocking agents such as vecuronium and rocuronium. Upon administration, Sugammadex forms a stable complex with free vecuronium molecules in the plasma, reducing their concentration and creating a concentration gradient between plasma and the neuromuscular junction. Consequently, vecuronium molecules dissociate from nicotinic receptors and diffuse into the circulation, where they are rapidly bound by Sugammadex. This process results in prompt and predictable restoration of neuromuscular transmission independent of acetylcholine activity. [9]

The rapid recovery observed in the present study is therefore consistent with the pharmacological properties of Sugammadex and confirms its ability to provide effective reversal of vecuronium-induced blockade. The significantly shorter recovery time observed with Sugammadex has important clinical implications, as delayed recovery from neuromuscular blockade is a major contributor to postoperative respiratory complications and prolonged recovery room stay. [3]

Jones et al. [13] conducted one of the landmark multicentre randomized controlled trials comparing Sugammadex with Neostigmine for reversal of amino steroidal neuromuscular blockade. In their study, recovery to a TOF ratio of 0.9 occurred substantially faster with Sugammadex than with Neostigmine. The authors concluded that Sugammadex provided more rapid and predictable recovery and significantly reduced variability in recovery times. They also observed that Sugammadex consistently achieved complete neuromuscular recovery irrespective of the depth of

blockade at the time of administration. The findings of the present study are in close agreement with their observations. Carron et al. [16] also reported favourable recovery profiles associated with Sugammadex. Their study demonstrated earlier restoration of neuromuscular function, shorter recovery room stay, and improved postoperative recovery parameters in patients reversed with Sugammadex. The authors suggested that rapid recovery of muscle strength contributes to enhanced patient comfort and may reduce postoperative complications associated with residual neuromuscular blockade. These findings are consistent with the observations of the present study. Brull and Murphy [3] extensively reviewed the clinical consequences of residual neuromuscular blockade and emphasized that incomplete recovery remains a significant problem despite the routine use of Neostigmine. They reported that residual blockade is associated with impaired upper airway muscle function, decreased hypoxic ventilatory response, increased risk of airway obstruction, aspiration, hypoxemia, and postoperative pulmonary complications. Their observations provide important context for the findings of the present study and underscore the clinical relevance of achieving rapid and complete neuromuscular recovery.

The markedly shorter recovery time observed in the Sugammadex group has significant implications for perioperative patient management. Faster restoration of neuromuscular function facilitates earlier extubation, improved respiratory function, reduced postoperative monitoring requirements, and more efficient utilization of operating room resources. In high-risk populations such as elderly patients, obese patients, individuals with pre-existing respiratory disease, and patients undergoing major surgery, these advantages may translate into substantial improvements in patient safety and clinical outcomes. [17]

Furthermore, rapid achievement of a TOF ratio ≥ 0.9 minimizes the risk of residual neuromuscular blockade, which remains one of the most important causes of preventable postoperative respiratory morbidity. The ability of Sugammadex to provide complete and reliable reversal irrespective of blockade depth offers a distinct advantage over Neostigmine, whose effectiveness may be limited under certain clinical conditions. [18]

Therefore, the findings of the present study clearly demonstrate that Sugammadex provides significantly faster and more predictable recovery of neuromuscular function compared with Neostigmine–Glycopyrrolate following vecuronium-induced neuromuscular blockade. These results are consistent with previously published literature and further support the growing role of Sugammadex as a preferred reversal agent for

amino steroidal neuromuscular blocking drugs in contemporary anesthetic practice. [6]

Extubation Time: In the present study, extubation time was significantly shorter in patients who received Sugammadex compared with those who received Neostigmine–Glycopyrrolate. The mean extubation time was 184.87 seconds in the Sugammadex group, whereas it was 374.45 seconds in the Neostigmine group. This difference was statistically significant and indicates a faster recovery profile with Sugammadex.

The shorter extubation time observed in the Sugammadex group can be explained by its rapid and predictable reversal of vecuronium-induced neuromuscular blockade. By directly encapsulating free vecuronium molecules in the circulation, Sugammadex rapidly decreases the concentration of active drug at the neuromuscular junction, resulting in early restoration of muscle strength. Recovery of diaphragmatic function, upper airway muscle tone, and protective airway reflexes occurs more rapidly, allowing earlier and safer removal of the endotracheal tube. [10]

In contrast, reversal with Neostigmine depends on indirect enhancement of acetylcholine activity at the neuromuscular junction. Although effective in many patients, the recovery process is generally slower and less predictable. The degree of recovery achieved with Neostigmine may vary depending on the depth of neuromuscular blockade at the time of administration. Consequently, patients may require a longer period before fulfilling extubation criteria. [19]

Blobner et al. [14] similarly demonstrated that patients reversed with Sugammadex achieved faster recovery of neuromuscular function and earlier extubation than those receiving conventional reversal agents. The authors concluded that rapid restoration of muscle strength contributed to improved perioperative workflow and enhanced patient safety. Their findings closely parallel the observations of the present study. Murphy et al. [5] also reported shorter extubation times and improved recovery profiles in patients receiving Sugammadex. In their studies, earlier recovery of airway and respiratory muscle function was associated with a lower incidence of residual neuromuscular weakness during the immediate postoperative period. The authors emphasized that complete recovery prior to extubation is essential for preventing postoperative respiratory complications. These observations support the findings of the present study. Wachtendorf et al. [20] demonstrated that Sugammadex was associated with improved perioperative efficiency and favourable recovery outcomes. Their findings suggest that even modest reductions in recovery and extubation times can

have meaningful implications in high-volume surgical centers.

Eye Opening Time and Response to Verbal Commands

In the present study, postoperative recovery was assessed by measuring the time to spontaneous eye opening and the time required to respond appropriately to verbal commands following administration of the reversal agent. Patients in the Sugammadex group demonstrated significantly faster recovery for both parameters when compared with patients in the Neostigmine–Glycopyrrolate group. The findings of the present study suggest that Sugammadex provides a smoother and more predictable recovery profile than Neostigmine–Glycopyrrolate. The shorter eye opening and response times observed with Sugammadex indicate not only faster neuromuscular recovery but also improved overall readiness for postoperative care.

Jones et al. [13] in their multicentre randomized trial reported significantly shorter recovery times with Sugammadex. The study demonstrated that rapid reversal of aminosteroidal neuromuscular blockade was associated with earlier return of normal physiological function and reduced variability in recovery patterns. The consistency of recovery observed with Sugammadex was considered one of its major clinical advantages. The present study demonstrated similar benefits in terms of earlier eye opening and response to verbal commands. Cho et al. [21] compared postoperative recovery profiles following Sugammadex and Neostigmine reversal and observed that patients receiving Sugammadex achieved recovery milestones significantly earlier. Their findings indicated faster emergence, improved responsiveness, and earlier readiness for postoperative assessment, supporting the results of the present study.

Hemodynamic Changes: In the present study, heart rate and mean arterial pressure were monitored before and after administration of the reversal agents and during the recovery period. Comparison of these parameters between the two groups demonstrated that patients receiving Sugammadex maintained greater hemodynamic stability than those receiving Neostigmine–Glycopyrrolate.

The difference observed between the two groups can be explained by their distinct mechanisms of action. Sugammadex acts through selective encapsulation of vecuronium molecules and does not interact with cholinergic receptors. Consequently, it produces minimal direct cardiovascular effects. This pharmacological property contributes to the stable hemodynamic profile observed following its administration. [9]

The preservation of blood pressure in the Sugammadex group further supports its favourable

safety profile. Because Sugammadex does not possess cholinergic or anticholinergic activity, it is less likely to produce significant alterations in vascular tone or autonomic function. As a result, recovery from neuromuscular blockade occurs without substantial cardiovascular disturbance. [22]

Jones et al. [13] evaluated the efficacy and safety of Sugammadex and reported minimal cardiovascular effects following its administration. The authors observed stable heart rate and blood pressure measurements in patients receiving Sugammadex and concluded that the drug possessed a favourable hemodynamic profile. Their findings support the observations of the present study. Blobner et al. [14] reported that Sugammadex produced rapid reversal of neuromuscular blockade without causing clinically significant cardiovascular changes. Their study demonstrated that hemodynamic variables remained stable during the recovery period, supporting the safety of Sugammadex in routine anesthetic practice. Similar findings were observed in the present study.

Another important consideration is the increasing number of surgical procedures being performed in patients with multiple comorbidities. As perioperative care continues to evolve toward enhanced recovery pathways, the importance of smooth and predictable recovery becomes increasingly relevant. A reversal agent that provides rapid neuromuscular recovery without causing significant cardiovascular disturbances is therefore highly desirable. [17] Wachtendorf et al. [20] demonstrated that Sugammadex was associated with improved perioperative efficiency and favourable recovery outcomes without increasing cardiovascular complications. Their findings support the use of Sugammadex in modern perioperative practice, particularly in patients requiring rapid and predictable recovery.

Postoperative Oxygen Saturation: In the present study, postoperative oxygen saturation was assessed following reversal of neuromuscular blockade and during the immediate recovery period. Patients who received Sugammadex demonstrated significantly higher postoperative oxygen saturation compared with those who received Neostigmine–Glycopyrrolate. The mean postoperative oxygen saturation was 98.34% in the Sugammadex group, whereas it was 94.11% in the Neostigmine group.

Sugammadex provides rapid restoration of neuromuscular transmission by directly encapsulating free vecuronium molecules and removing them from circulation. This mechanism allows prompt recovery of respiratory muscle strength and upper airway function. As a result, patients are better able to maintain airway patency, generate adequate tidal volumes, and sustain

effective spontaneous ventilation, leading to improved postoperative oxygenation. [23]

The relationship between residual neuromuscular blockade and postoperative respiratory impairment has been well documented in the literature.

Murphy et al. [24] reported that incomplete recovery of neuromuscular function was associated with impaired respiratory performance and a higher incidence of postoperative hypoxemia. Their studies demonstrated that patients achieving complete neuromuscular recovery experienced fewer respiratory complications and maintained better oxygenation during recovery. The authors emphasized that prevention of residual neuromuscular blockade is essential for improving postoperative respiratory outcomes. Murphy and Brull [3] further emphasized that residual neuromuscular blockade remains a major cause of preventable postoperative respiratory morbidity. They reported that even small degrees of residual weakness can adversely affect upper airway function and ventilatory control. The authors highlighted the importance of achieving a TOF ratio of at least 0.9 before extubation in order to minimize the risk of postoperative respiratory compromise.

The advantages observed with Sugammadex may be particularly relevant in high-risk patient populations. Elderly patients, obese individuals, patients with obstructive sleep apnoea, chronic obstructive pulmonary disease, restrictive lung disease, or other respiratory disorders are especially susceptible to the adverse effects of residual neuromuscular blockade. In these patients, complete recovery of respiratory muscle function is essential to prevent postoperative respiratory complications. [24]

Overall, the results of the present study demonstrate that patients receiving Sugammadex achieved significantly higher postoperative oxygen saturation compared with those receiving Neostigmine–Glycopyrrolate. This finding reflects more effective restoration of respiratory muscle function, improved airway patency, and more complete neuromuscular recovery. The results are consistent with previously published literature and highlight the important role of Sugammadex in enhancing postoperative respiratory safety. [6]

Postoperative Nausea and Vomiting: In the present study, the incidence of postoperative nausea and vomiting was low in both groups. Only one patient (2.6%) in the Neostigmine–Glycopyrrolate group experienced PONV, whereas no patient in the Sugammadex group developed postoperative nausea or vomiting. Although the overall incidence was low and the difference between the groups was not statistically significant, the findings suggest a trend toward a lower occurrence of PONV in patients receiving Sugammadex.

The lower incidence of PONV observed in the Sugammadex group may be explained by differences in the pharmacological mechanisms of the reversal agents. Sugammadex acts through selective encapsulation of vecuronium molecules and does not affect cholinergic receptors. As a result, it does not produce the muscarinic side effects commonly associated with anticholinesterase agents. [23]

Neostigmine, in contrast, increases acetylcholine concentrations not only at nicotinic receptors but also at muscarinic receptors throughout the body. Increased muscarinic activity can stimulate gastrointestinal motility and secretions, which may contribute to the development of nausea and vomiting. Although glycopyrrolate is administered concurrently to counteract these effects, complete elimination of muscarinic activity may not always be achieved. Consequently, patients receiving Neostigmine may remain susceptible to cholinergic adverse effects during the recovery period. [19]

Several studies have evaluated the relationship between reversal agents and postoperative nausea and vomiting.

Murphy et al. [5] reported a lower incidence of adverse cholinergic effects in patients receiving Sugammadex compared with conventional anticholinesterase-based reversal. The authors suggested that the absence of muscarinic receptor stimulation contributes to the improved postoperative recovery profile observed with Sugammadex. Their findings support the favourable tolerability profile observed in the present study. Blobner et al. [14] noted that Sugammadex was generally well tolerated and was associated with a low incidence of adverse effects, including postoperative nausea and vomiting. Their findings support the favourable safety profile of Sugammadex demonstrated in the present study.

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