Article

Effects of Sugammadex Versus Neostigmine on Postoperative Oxygenation and Pulmonary Complications in Elderly Patients Undergoing Lower Abdominal Surgery

Ann. Ital. Chir., 2025 96, 10: 1390–1399
https://doi.org/10.62713/aic.4178

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AIM: Neostigmine is a competitive inhibitor of acetylcholinesterase commonly used in neuromuscular blockade (NMB). Sugammadex is a new drug for rapid and reliable reversal of NMB. This study evaluated the effects of sugammadex versus neostigmine on postoperative oxygenation and pulmonary in elderly patients undergoing lower abdominal surgery.

METHODS: A retrospective analysis of 279 patients who underwent lower abdominal surgery in the Quzhou Affiliated Hospital of Wenzhou Medical University from July 2023 to February 2025 was performed. Patients were divided into two groups based on the NMB reversal agents used: the sugammadex group (129 patients) and neostigmine+atropine group (150 patients). The safety and effectiveness of sugammadex in patients undergoing lower abdominal surgery were evaluated in terms of postoperative saturation of peripheral oxygen/fraction of inspired oxygen (SpO_2/FiO_2) ratio, extubation time, post-anesthetic care unit (PACU) stay time, and length of postoperative hospital stay using independent sample t-test, Mann-Whitney U test and χ^2 test.

RESULTS: There was no significant difference in baseline characteristics between the neostigmine+atropine group and the sugammadex group ($p > 0.05$). Compared with the neostigmine+atropine, sugammadex could reverse deep NMB more quickly. The incidence of residual NMB at 10 min (sugammadex: 6.98%, 9/129; neostigmine+atropine: 52.00%, 78/150) and 20 min (sugammadex: 0%, 0/129; neostigmine+atropine: 16.00%, 24/150) was significantly lower in the sugammadex group compared to the neostigmine+atropine group ($p < 0.05$) post-operatively. Sugammadex also significantly improved postoperative oxygenation of patients, reduced the time to achieve Train-of-Four ratio (TOFr) $\geq$0.9, shortened the extubation time ($p < 0.05$), decreased the duration of PACU stay ($p < 0.05$), and lowered the incidence of postoperative pulmonary complications ($p < 0.05$), but has no effect on the length of postoperative hospital stay ($p >$ 0.05).

CONCLUSIONS: By effectively reversing NMB, sugammadex significantly relieves the symptoms of muscle relaxation, accelerates the recovery of respiratory function, shortens the time of TOFr $\geq$0.9, extubation time, PACU duration, and reduces pulmonary complications in elderly patients undergoing lower abdominal surgery.

Keywords: sugammadex; neostigmine; postoperative oxygenation; postoperative pulmonary complications

Introduction

At present, the adoption of neuromuscular blockade (NMB) agents has become more common in major surgeries to facilitate airway intubation and maintain surgical status. Although NMB can be reversed pharmacologically after surgery, residual NMB may still persist [1,2]. Incomplete reversal of NMB after anesthesia recovery can lead to postoperative complications, especially an increase in the incidence of pulmonary complications, including hypoxia, atelectasis, pneumonia and respiratory failure.

Submitted: 23 May 2025 Revised: 25 August 2025 Accepted: 29 August 2025 Published: 10 October 2025

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Neostigmine, as a competitive inhibitor of acetylcholinesterase, prolongs the presence of acetylcholine in neuromuscular junctions to antagonize NMB and restore neuromuscular function [3,4]. However, it is ineffective in reversing deep NMB and may be associated with a high incidence of nicotinic and muscarinic side effect [5]. Sugammadex is a cyclodextrin that selectively binds to rocuronium in plasma to rapidly and completely reverse deep NMB [5–8]. Therefore, postoperative oxygenation may be pronounced in patients receiving sugammadex compared to those receiving neostigmine. A number of studies have confirmed that respiratory failure is associated with postoperative pulmonary complications (PPCs) [9–11]. In addition, compared with neostigmine, reversal with sugammadex is associated with shorter post-anesthesia care unit (PACU) stay, faster extubation time, a lower incidence of PPCs, and improved quality of postoperative recovery [4,12].

Patients undergoing major abdominal surgery face an increased risk of perioperative pulmonary complications due to poor physical condition or multiple comorbidities [5]. This is especially apparent in elderly patients, whose reserve capacity of cardiopulmonary function experiences gradual decline with their age. Pulmonary function is further impaired by anesthesia and pneumoperitoneum during high-intensity abdominal laparoscopic surgery. The incidence of postoperative hypoxemia and atelectasis is also relatively high in elderly patients undergoing laparoscopic surgery. Thus, ensuring safe and effective recovery of patients after surgery is an important consideration for surgeons and anesthesiologists. While there has been evidence supporting the use of sugammadex, studies that determine its role in reducing PPCs after lower abdominal surgery remain relatively scarce. Therefore, this study investigated the impacts of sugammadex versus neostigmine on postoperative oxygenation and PPCs, providing crucial insights for facilitating the selection of safe and effective agents for reversing NMB.

Materials and Methods

Baseline Characteristics

A total 279 elderly patients who underwent lower abdominal surgery in the Quzhou Affiliated Hospital of Wenzhou Medical University from July 2023 to February 2025 were selected as the research subjects. The cohort was divided into two groups according to treatments received: the sugammadex group and the neostigmine+atropine group. There were 129 cases in the sugammadex group, including 68 males and 61 females. The neostigmine+atropine group comprised 150 cases, including 80 males and 70 females. This study was approved by the Medical Ethics Committee of the Quzhou Affiliated Hospital of Wenzhou Medical University (approval number: 2023-056). This study was conducted in compliance with the relevant principles and regulations of the Declaration of Helsinki. All subjects have given the informed consent after being briefed about the study.

The types of lower abdominal surgeries include abdominal wall hernia repair, laparoscopic appendectomy, transabdominal radical rectal cancer surgery, right hemicolectomy, left hemicolectomy, sigmoid colon cancer radical surgery, laparoscopic prostate cancer radical surgery, laparoscopic uterine prolapse suspension surgery, laparoscopic pelvic mass resection surgery, perineal rectal suspension fixation or rectal resection surgery, total uterus and adnexa resection, transurethral bladder tumor electroresection, hysteroscopic uterine cavity lesion resection, adhesion release or intestinal resection anastomosis, partial small intestine resection, ovarian tumor resection, etc.

Inclusion Criteria and Exclusion Criteria

Inclusion criteria: (1) patients aged 60–95 years old; (2) patients who received lower abdominal surgery which was performed with surgical indications; (3) patients with American Society of Anesthesiologists (ASA) classification II–III; (4) patients with normal cardiopulmonary function; and (5) patients and their families who have consented to participating in the study.

Exclusion criteria: (1) patients with primary neuromuscular disease; (2) patients taking drugs that may interfere with neurorelaxants 6 months before admission; (3) patients with a history of alcohol or drug abuse; (4) patients who were allergic to drugs used in this study; (5) patients with communication difficulties; and (6) patients with concurrent mental illness.

Anesthetic Methods

All patients were fasted for 8 hours and deprived of water for 6 hours before surgery. Upon establishing a peripheral venous line, the patient was connected to a monitor, through which the vital signs were continuously monitored. The central venous pressure was measured with a right internal jugular vein puncture catheter. The Train-of-Four (TOF)-watch SX®, calibrated and linked to a portable computer equipped with TOF-Watch SX Monitor Software® (version 1.2, Organon, Dublin, Ireland), was used to monitor the adductor pollicis muscle relaxation. To induce anesthesia, intravenous infusion of etomidate emulsion injection (Chinese Medicine Standard No. H20020511, specification: 10 mL:20 mg, Jiangsu Nhwa Pharmaceutical Co., Ltd., Xuzhou, China) 0.2–0.4 mg/kg, sufentanil citrate injection (Chinese Medicine Standard No. H20054171; specification: 1 mL:50 μg, Yichang Humanwell Pharmaceuticals Co., Ltd., Yichang, China) 0.4 μg/kg, and rocuronium bromide injection (Chinese Medicine Standard No. H20223453; specification: 5 mL:50 mg, Shanghai Haini Pharmaceutical Co., Ltd., Shanghai, China) 0.6 mg/kg were employed. The patient underwent tracheal intubation. Anesthesia was maintained by 1% propofol medium and long-chain fat emulsion injection (Chinese Medicine Approval No. H20213012; specification: 20 mL:0.2 g, Jiangsu Yangtze River Pharmaceutical Group Co., Ltd., Taizhou, China) 2–4 mg/kg/h, 1%–3% sevoflurane for inhalation (Chinese Medicine Approval No. H20070172; specification: 120 mL, Shanghai Hengrui Pharmaceuticals Co., Ltd., Shanghai, China), and 0.2–0.3 μg/kg/min of remifentanil hydrochloride for injection (Chinese Medicine Approval No. H20030197; specification: 1 mg, Yichang Humanwell Pharmaceuticals Co., Ltd., Yichang, China). Based on the results of muscle relaxation monitoring, rocuronium (0.075–0.15 mg/kg) was intermittently administered to maintain muscle relaxation. The depth of anesthesia was adjusted according to the surgical requirements to achieve the appropriate level (bispectral index [BIS] of 40–60). During abdominal closure, the administration of rocuronium was discontinued, the sevoflurane level was adjusted to 1%, and then 5 μg sufentanil citrate was injected intravenously. Sevoflurane inhalation was discontinued at the end of the surgery. After surgery, patients were transferred to the PACU, where Train-of-Four monitoring was performed using a stimulation frequency of 2 Hz and an interval of 15 seconds.

According to the European Society of Anaesthesiology and Intensive Care (ESAIC) guidelines [13], the dose of sugammadex depends on the depth. In this study, the reversal block was pre-set to moderate block (TOF count $\geq$2), at which time 2 mg/kg sugammadex (Chinese Medicine Approval No. H20223224; specification 2 mL:200 mg, Jiangsu Cost Pharmaceutical Co., Ltd., Suzhou, China) was given, and the neostigmine+atropine group was given neostigmine (Chinese Medicine Approval No. H41022269; specification: 1 mL:0.5 mg, Henan RunHong Pharmaceutical Co., Ltd., Xinzheng, China) 20 µg/kg and atropine (Chinese Medicine Approval No. H12020382; specification: 1 mL:0.5 mg, Tianjin Jinyao Pharmaceutical Co., Ltd., Tianjin, China) 10 µg/kg at the same time to antagonize its muscarinic side effects. The choice of atropine was based on the conventional drug supply of the hospital at the time of this study. Atropine and neostigmine were injected intravenously through different syringes at the same time. The endotracheal tube was removed once the patient was fully awake and the Train-of-Four ratio (TOFr) $\geq$ 0.9.

Perioperative Optimization Management

All patients received perioperative optimization management, including preoperative nutritional assessment, pulmonary function training, and postoperative multimodal analgesia. For preoperative nutritional assessment, the nutritional risk screening score scale 2002 was used to evaluate the nutritional status of patients. For patients with malnutrition, appropriate oral nutritional supplements were given according to physician's advice. Incentive spirometry training was employed for enhancing pulmonary function, 3 times a day, 15 minutes each time. The visual analogue scale for pain is evaluated every hour within the first 4 hours after the operation. From 4 to 24 hours after the operation, it is evaluated every 4 hours. After 24 hours after the operation, it is evaluated 2 to 3 times a day according to the patient's condition. For patients with a score of >3 points, appropriate analgesic drugs and early activities were prescribed by the physician.

Definition of PPCs

Postoperative pulmonary complications (PPCs) are defined as one or more of the following within 7 days after surgery [14,15]: (1) atelectasis, as defined by computed tomography or chest radiograph; (2) pneumonia, based on the U.S. Centers for Disease Control criteria [16]; (3) acute respiratory distress syndrome, as defined using the Berlin Consensus [17]; and (4) pulmonary aspiration, confirmed by a clear clinical history and radiographic evidence.

Outcome Measures

(1) General and clinical data, including gender, age, height, weight, body mass index, ASA, smoking history, medical history, anesthesia times, intraoperative blood loss, cumulative dose of rocuronium, and interval from the last NMB to antagonism.

(2) The primary outcome was the time required to achieve a TOFr $\geq$0.9 following administration of the NMB reversal agent.

(3) Secondary outcomes included: (i) anesthesia time; (ii) extubation time—the time from the administration of the reversal agent to the extubation of patient; (iii) number of residual NMB 10, 20 and 30 min after application of NMB reversal agents (TOFr <0.9); (iv) PACU duration; (v) saturation of peripheral oxygen/fraction of inspired oxygen (SpO_2/FiO_2): the patient's oxygen inhalation through a double nasal catheter during the patient's transfer to the PACU and during the PACU. SpO_2 and actual oxygen flow (L/min) were recorded when the patient was in a calm state, 10 min after arrival in the PACU. The inhaled oxygen concentration was estimated according to the formula: FiO_2 = 0.21 + (oxygen flow $\times$ 0.04) [18], and then the SpO_2/FiO_2 was calculated for analysis; (vi) postoperative hospital stay time; and (vii) the incidence of PPCs.

Statistical Analysis

Data were analyzed using SPSS 27.0 statistical software (IBM Corp., Armonk, NY, USA), and the Kolmogorov–Smirnov test was used to assess normality of data distribution. Normally distributed, continuous data are expressed as mean $\pm$ standard deviation ($\bar{x} \pm$ s), and inter-group comparisons were performed with two independent samples *t*-test. Continuous data that did not meet the normal distribution requirement are expressed as median and interquartile range [M (Q1, Q3)], and inter-group comparisons were performed with the Mann–Whitney U test. Categorical data are expressed as count and percentage, and chi-square test was used for their comparative analysis. The Mann–Whitney U test was used for comparison between groups for the primary outcome (time required to achieve TOFr $\geq$ 0.9). $p <$ 0.05 indicated that the difference was statistically significant.

For the secondary outcome of repeated measures of residual NMB (yes/no), we fitted a population-averaged generalized estimating equation (GEE) model (binomial family, logit link) that included group, time, and their interaction as predictors. Patient ID was used as the clustering variable, and an exchangeable working correlation structure and robust (sandwich) standard errors were employed. If the interaction effect was significant, inter-group comparison was performed at each time point, and the *p*-value was corrected using the Bonferroni method (the corrected significance level was α = 0.05/3 = 0.0167). Since there were six inter-group comparisons of multiple secondary outcomes (SpO_2/FiO_2, anesthesia time, extubation time, PACU duration, length of postoperative hospital stay, and incidence of PPCs), we used Bonferroni correction to control type I error inflation caused by multiplicity. The significance level after correction was set as α = 0.05/6 =0.008333. Therefore, the difference was considered statistically significant only when the $p < 0.00833$. Sensitivity analysis was conducted to assess the potential confounding effect of atropine on the primary outcome.

Results

Baseline Characteristics

A total of 279 patients that met the inclusion criteria were included in the study. Among all the cases that met the criteria, 150 patients received neostigmine+atropine treatment and 129 patients received sugammadex treatment. In the sugammadex group, the median age of the patients was 69 (63, 74) years; regarding the ASA classification, 125 cases were classified as grade II and 4 cases as grade III. In the neostigmine+atropine group, the median age of the patients was 70 (66, 74) years, and 143 cases were classified as ASA grade II and 7 cases as grade III. Table 1 shows the patient's demographic and clinical characteristics. There were no statistically significant differences in gender, age, height, weight, ASA grade, smoking history or medical history among the patients ($p > 0.05$). There were also no statistically significant differences in the body mass index (BMI), types of surgeries, anesthesia times, the intraoperative blood loss, cumulative dose of rocuronium, or duration between the last dose and antagonism between the two groups of patients ($p > 0.05$).

Postoperative Recovery of NMB and Postoperative Oxygenation

Table 2 shows the residual cases of NMB in the two groups after taking medications. The study found that the number of residual cases of NMB in the sugammadex group at different times was less than that in the neostigmine+ atropine group. After 10 minutes of administering medications, the number of residual cases of NMB was 9 in the sugammadex group, and the number of residual cases of NMB was 78 in the neostigmine+atropine group. The difference in the number of residual cases of NMB between the two groups was statistically significant ($p < 0.05$). Twenty minutes after medication, the number of residual cases of NMB was 0 in the sugammadex group, and 24 in the neostigmine+atropine group. This study employed Generalized Estimating Equation model to analyze the effects of sugammadex versus neostigmine+atropine on residual muscle relaxation in elderly patients. The results showed that there was an interaction between the groups and time ($\chi^2_{\text{Group}\times\text{Time}}$ = 112.790, $p < 0.05$, Table 3). Therefore, the individual effect analysis was conducted to further explore the effects of sugammadex versus neostigmine+atropine on residual NMB in elderly patients. After Bonferroni correction, the individual effect analysis of time showed that there were statistically significant differences in residual NMB at different time points within each group ($p < 0.001$, Table 4). The individual effect analysis between groups showed that after 10 min of medication, the residual NMB in the sugammadex group was statistically different from that in the neostigmine+atropine group ($p < 0.05$, Table 5). Thus, sugammadex is more effective than neostigmine in reversing NMB in elderly patients.

In addition, the study also found that the postoperative oxygenation, measured by the SpO_2/FiO_2, in patients of the sugammadex group was significantly higher than those of the neostigmine group (median: 334.48 vs. 332.48, $p < 0.001$); however, following adjustment with Bonferroni correction, postoperative oxygenation became significantly higher in the sugammadex group ($p < 0.05$, Table 6).

Early Recovery and Pulmonary Complications

According to Table 7, compared with the neostigmine+atropine, sugammadex was able to significantly shorten the time for achieving TOFr $\geq$0.9 ($p < 0.05$). We found that patients of the sugammadex group exhibited significantly shorter duration of PACU stay and extubation time compared with those of the neostigmine+atropine group. The length of postoperative hospital stay and anesthesia duration for the sugammadex group were shorter than those for the neostigmine group, but there was no statistical significance between the two groups ($p > 0.05$). In addition, the study also found that sugammadex significantly reduced the incidence of pulmonary complications such as pneumonia (0.78%, 1/129) and atelectasis (1.55%, 2/129) compared to the neostigmine+atropine group ($p < 0.05$). After Bonferroni correction, the PACU stay time ($p < 0.001$), the anesthesia time ($p = 0.002$) and incidence of PPCs ($p = 0.008$) showed significant differences between the two groups. The differences in PACU duration, extubation time and incidence of PPCs between the two groups remained statistically significant following Bonferroni correction, but the differences in anesthesia time and length of postoperative hospital stay were no longer significant.

Sensitivity Analysis

In standard clinical practice, neostigmine is typically combined with atropine, an anticholinergic drug, to prevent the muscarinic side effects caused by neostigmine. For this reason, sensitivity analysis was utilized to verify that the difference in the main outcome (time for achieving TOFr $\geq$0.9) is exclusively attributed to the NMB reversal agent itself, rather than the potential impact of atropine. In the multivariate analysis of covariance model, after adjusting for BMI, SpO_2/FiO_2, anesthesia time, cumulative dose of rocuronium, and the interval from the last NMB to antagonism, the NMB reseveral agent group remained the independent predictor of TOFr recovery time (95% CI: 0.275–9.071, $p < 0.05$, Table 8). This suggests that the observed

Table 1. Comparison of baseline and clinical characteristics of the two groups of patients.

	Sugammadex (n = 129)	Neostigmine+atropine (n = 150)	t/Z/χ^2	p
Gender (n, %)			0.011	0.918
Male	68 (52.71)	80 (53.33)		
Female	61 (47.29)	70 (46.67)		
Age [years, M (Q1, Q3)]	69 (63, 74)	70 (66, 74)	1.342	0.180
Height [cm, M (Q1, Q3]	160 (153, 166)	160 (153, 166)	1.053	0.292
Weight (kg, $\bar{x} \pm$ s)	60.22 $\pm$ 9.15	59.63 $\pm$ 9.55	0.525	0.600
BMI (n, %)				0.421
$<$18 kg/m^2	2 (1.55)	6 (4.00)		
18 $\leq$ BMI $<$ 24 kg/m^2	65 (50.39)	83 (55.33)		
24 $\leq$ BMI$<$ 30 kg/m^2	54 (41.86)	55 (36.67)		
$\geq$30 kg/m^2	8 (6.20)	6 (4.00)		
ASA (n, %)				0.554
II	125 (96.90)	143 (95.33)		
III	4 (3.10)	7 (4.67)		
Smoking status (n, %)			0.011	0.918
Never smokers	61 (47.29)	70 (46.67)		
Current smokers	68 (52.71)	80 (53.33)		
Medical history (n, %)				0.311
Inguinal hernia	37 (28.68)	35 (23.33)		
Appendicitis	14 (10.85)	19 (12.67)		
Rectal neoplasms	14 (10.85)	24 (16.00)		
Colon tumor	15 (11.63)	10 (6.67)		
Prostate tumor	11 (8.53)	21 (14.00)		
Uterine prolapse	13 (10.08)	16 (10.67)		
Pelvic mass	10 (7.75)	15 (10.00)		
Others	15 (11.63)	10 (6.67)		
Types of surgery (n, %)				0.613
Abdominal wall hernia repair	37 (28.68)	35 (23.33)		
Laparoscopic appendectomy	14 (10.85)	19 (12.67)		
Transabdominal radical rectal cancer surgery	14 (10.85)	24 (16.00)		
Right hemicolectomy	4 (3.10)	5 (3.33)		
Left hemicolectomy	6 (4.65)	3 (2.00)		
Sigmoid colon cancer radical surgery	5 (3.88)	2 (1.33)		
Laparoscopic prostate cancer radical surgery	11 (8.53)	21 (14.00)		
Laparoscopic uterine prolapse suspension surgery	13 (10.08)	16 (10.67)		
Total uterus and adnexa resection	10 (7.75)	15 (10.00)		
Adhesion release	3 (2.33)	2 (1.33)		
Intestinal resection anastomosis	4 (3.10)	2 (1.33)		
Partial small intestine resection	5 (3.88)	3 (2.00)		
Ovarian tumor resection	3 (2.33)	3 (2.00)		
Anesthesia times (n, %)			1.062	0.303
1	124 (96.12)	140 (93.33)		
$\geq$2	5 (3.88)	10 (6.67)		
Intraoperative blood loss (n, %)			0.399	0.528
$<$300 mL	115 (89.15)	130 (86.67)		
$\geq$300 mL	14 (10.85)	20 (13.33)		
Cumulative dose of rocuronium [mg, M (Q1, Q3)]	123.77 (92.70, 188.60)	145.60 (89.39, 195.81)	0.733	0.464
Interval from the last NMB to antagonism [min, M (Q1, Q3)]	36 (30, 41)	37 (33, 41)	1.563	0.118

Abbreviations: ASA, American Society of Anesthesiologists; BMI, body mass index; NMB, neuromuscular blockade.

Table 2. Comparison of postoperative muscle relaxation recovery between the two groups.

	Sugammadex (n = 129)	Neostigmine+atropine (n = 150)
10 min after administration (n, %)		
Without	120 (93.02)	72 (48.00)
With	9 (6.98)	78 (52.00)
20 min after administration (n, %)		
Without	129 (100.00)	126 (84.00)
With	0 (0.00)	24 (16.00)
30 min after administration (n, %)		
Without	129 (100.00)	147 (98.00)
With	0 (0.00)	3 (2.00)

Table 3. Analysis of the Group × Time interaction effect of residual NMB.

	Wald chi-square	df	p
Group	2.232	1	0.135
Time	1070.180	2	<0.001
Group × Time	112.790	2	<0.001

Abbreviation: NMB, neuromuscular blockade.

Table 4. Analysis of individual effects of sugammadex and neostigmine+atropine over time.

	β (SE)	p	OR (95% CI)
Group = sugammadex			
Intercept	1.225 (0.014)	<0.001	3.404 (3.314~3.495)
Time-10 min	–0.216 (0.004)	<0.001	0.806 (0.800~0.813)
Time-20 min	–0.116 (0.004)	<0.001	0.891 (0.884~0.898)
Time-30 min	0		
Scale	0.023		
Group = neostigmine+atropine			
Intercept	1.271 (0.017)	<0.001	3.563 (3.446~3.685)
Time-10 min	–0.421 (0.019)	<0.001	0.657 (0.632~0.682)
Time-20 min	–0.150 (0.012)	<0.001	0.861 (0.841~0.881)
Time-30 min	0		
Scale	0.066		

Abbreviation: OR, odds ratio.

Table 5. Analysis of the individual effects within groups (Group × Time).

	β (SE)	p	OR (95% CI)
Intercept	0.850 (0.024)	<0.001	2.340 (2.232~2.452)
Time-30 min	0.421 (0.019)	<0.001	1.523 (1.466~1.582)
Time-20 min	0.271 (0.018)	<0.001	1.311 (1.266~1.357)
Time-10 min	0		
Sugammadex ×30 min	–0.046 (0.022)	0.036	0.955 (0.915~0.997)
Neostigmine+atropine ×30 min	0		
Sugammadex ×20 min	–0.011 (0.025)	0.647	0.989 (0.942~1.038)
Neostigmine+atropine ×20 min	0		
Sugammadex ×10 min	0.159 (0.027)	<0.001	1.173 (1.111~1.237)
Neostigmine+atropine ×10 min	0		
Scale	0.046		

outcome differences are mainly driven by the NMB reversal agent itself rather than atropine.

Discussion

In conjunction with population aging globally, there has been a growing number of elderly patients undergoing

Table 6. Comparison of postoperative oxygenation between the two groups of patients.

	Sugammadex (n = 129)	Neostigmine+atropine (n = 150)	Z	p
SpO_2/FiO_2* [M (Q1, Q3)]	334.48 (334.48, 337.93)	332.48 (331.03, 334.48)	3.126	<0.001

*$p < 0.05$ compared with the neostigmine+atropine group. FiO_2, fraction of inspired oxygen; SpO_2, saturation of peripheral oxygen.

Table 7. Comparison of early recovery and pulmonary complications between the two groups of patients.

	Sugammadex (n = 129)	Neostigmine+atropine (n = 150)	Z/χ^2	p
Time of TOFr ≥0.9* [min, M (Q1, Q3)]	10 (2, 15)	12 (2, 30)	2.047	0.041
Anesthesia time [min, M (Q1, Q3)]	140 (95, 220)	156 (102, 249)	1.630	0.103
Extubation time* [min, M (Q1, Q3)]	15 (2, 20)	15 (5, 39)	3.142	0.002
Duration of PACU stay* [min, M (Q1, Q3)]	45 (30, 55)	50 (40, 74)	3.750	<0.001
Length of postoperative hospital stay [days, M (Q1, Q3)]	5 (3, 10)	6 (4, 11)	1.581	0.114
Pulmonary complications* (n, %)				0.008
None	126 (97.67)	132 (88.00)		
Pneumonia	1 (0.78)	6 (4.00)		
Atelectasis	2 (1.55)	12 (8.00)		
Pulmonary aspiration	0 (0.00)	0 (0.00)		
Acute respiratory distress syndrome	0 (0.00)	0 (0.00)		

Note: *$p < 0.05$ compared with the neostigmine+atropine group.

Abbreviations: PACU, post-anesthetic care unit; TOFr, Train-of-Four ratio.

Table 8. Multivariate analysis of covariance of the effect of atropine on the primary outcome.

Parameter	β	S.E.	t	p	95% CI
Intercept	47.650	17.810	2.675	0.008	12.587–82.714
BMI	–0.478	0.391	–1.223	0.222	–1.247–0.291
SpO_2/FiO_2	–0.057	0.041	–1.398	0.163	–0.138–0.060
Anesthesia time	0.016	0.022	0.728	0.467	–0.028–0.060
Cumulative dose of rocuronium	–0.003	0.026	–0.108	0.914	–0.053–0.048
Interval from the last NMB to antagonism	–0.173	0.149	–1.161	0.247	–0.467–0.120
Group = neostigmine+atropine	4.673	2.234	2.092	0.037	0.275–9.071
Group = sugammadex	0				

lower abdominal surgery. Most of the elderly patients undergo such surgery due to acute diseases and tend to experience more severe postoperative pain. Pain stimulation can cause stress response in the body, increase the risk of complications, and then affect postoperative recovery, accompanied by lengthened hospital stay and increased medical costs. The mortality rate among the elderly patients following lower abdominal surgery is higher compared to the young individuals. By deepening our understanding of the physiological conditions and pathological mechanisms of the elderly demographic, we can contribute to lowering the mortality rate in these patients. Through this retrospective study, we found that sugammadex, an NMB reversal agent, improves postoperative oxygenation and reduces the incidence of PPCs. However, it has no significant impact on the length of postoperative hospital stay.

The elderly patients included in this study had normal cardiopulmonary function and a uniform baseline health status, which are the potentially primary reasons for the relatively low incidence of postoperative complications following lower abdominal surgery in the elderly patients. Additionally, the perioperative optimization management performed on elderly patients undergoing lower abdominal surgery at the center where this study was conducted may contribute to the reduced incidence of postoperative complications among the elderly patients.

Due to the intermittent nature of arterial partial pressure of oxygen (PaO_2) measurements, the SPO_2/FiO_2 ratio—rather than the conventional PaO_2/FiO_2 ratio—was chosen for analysis. As a noninvasive alternative to the PaO_2/FiO_2 ratio, the SpO_2/FiO_2 ratio features good discriminative capability [19] and encapsulates essential information about patients such as respiratory distress and the risk for mortality [20–22]. Our retrospective analysis showed that, despite the improvement of postoperative oxygenation by sugammadex, the increase was negligible and held no clinical significance.

Brueckmann *et al*. [23] reported that postoperative administration of sugammadex can effectively reverse residual NMB during PACU recovery after abdominal surgery. Similarly, a previous systematic review and meta-analysis comparing postoperative discharge times of patients receiving sugammadex versus neostigmine after general anesthesia reported a shorter interval from the PACU to the surgical ward for patients receiving glucose reversal therapy [24]. These results may be attributed to faster recovery from deep NMB after administration of sugammadex.

Residual NMB can lead to a delayed recovery of pulmonary muscle function in patients, increasing the risk of upper airway obstruction. It can also cause a reduction of postoperative tidal volume, cough and expectoration, thereby inducing adverse respiratory events [25]. In this study, we found that the use of sugammadex reduced the incidence of PPC. Sugammadex neither participates in cholinergic mechanisms nor produces cholinergic side effects [26]. However, the effect of NMB reversal on PPC remains a subject of investigation [25]. Consistent with this study, a previous retrospective matched cohort analysis showed that in non-cardiac surgery, administration of sugammadex significantly reduced the incidence of PPCs, including pneumonia and respiratory failure [12]. In addition, Moon *et al*. [27] showed that in one-lung ventilation surgery, administration of sugammadex reversed moderate NMB more rapidly than neostigmine and was linked to reduced incidence of postoperative hypoxia. In contrast, a multicenter, prospective, observational study conducted by Kirmeier *et al*. [25] found no difference in the incidence of PPC between neostigmine and sugammadex administration. Another observational cohort study found that administration of sugammadex and neostigmine was not associated with the occurrence of postoperative PPC [28]. These inconsistent results may be caused at least in part by nuances in surgical conditions and patient characteristics. Numerous existing studies focus on upper abdominal surgery in the elderly. For example, He *et al*. [29] observed that the incidence of PPC in elderly patients undergoing upper abdominal surgery was 8.7%, and Boden *et al*. [30] pointed out that the probability of PPCs in adults over 18 years old after upper abdominal surgery was 27%. Elderly patients constituted the primary study cohort in the present investigation, with a mean age of 69.24 years in the sugammadex group and 70.13 years in the neostigmine+atropine group; therefore, it is not surprising that a relatively high incidence of PPCs was detected herein, since elderly patients suffer from low lung compliance and lung function [31]. Currently, there are few reports of pulmonary complications after lower abdominal surgery in elderly patients. Our research pointed out that the incidence of PCCs in elderly patients after lower abdominal surgery in the sugammadex group (2.33%, 3/129) was lower than that in the neostigmine+atropine group (12.00%, 18/150). Therefore, sugammadex is a potential alternative that is conducive to controlling PPC in elderly patients undergoing lower abdominal surgery.

Due to its retrospective study design, this study has certain limitations. Because this study was conducted with a relatively small sample size, it is not fully representative of the entire population. Therefore, future multicenter prospective studies with large sample sizes are needed. Secondly, this study focused exclusively on lower abdominal surgery, where postoperative intestinal motility significantly influences recovery quality. However, key indicators for intestinal motility, such as first exhaust time and defecation time, were not included in the analysis. Furthermore, the effects of glucagon and neostigmine on reversing NMB could not be fully analyzed in this study. Lastly, the use of atropine was completely collinear with the treatment grouping, as dictated by standard clinical practice. However, due to the unclarified pharmacological mechanism by which atropine reverses NMB, and based on our sensitivity analysis showing no correlation between its dosage and outcomes, we believe that atropine is unlikely to be the main contributor to the observed inter-group differences.

Conclusions

This study suggests that sugammadex may shorten the time to achieve a TOFr $\geq$0.9, which is associated with a reduced incidence of PPCs, as well as shorter extubation time and PACU stay. However, further multicenter randomized controlled trials are needed to verify the impact of sugammadex on postoperative oxygenation and PPCs in elderly patients undergoing lower abdominal surgery.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

QC and CZX had the original conception of the work. LS, LH and GMY collected the clinical data. LH and XYF performed the research. QC drafted the manuscript. All authors contributed to the important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study was approved by the Medical Ethics Committee of the Quzhou Affiliated Hospital of Wenzhou Medical University (approval number: 2023-056). This study was conducted in compliance with the relevant principles and regulations of the Declaration of Helsinki. All subjects have given informed consent after being briefed about the study.

Acknowledgment

The authors would like to acknowledge the support and assistance of the Quzhou Affiliated Hospital of Wenzhou Medical University.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

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