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Effects of sevoflurane, desflurane or propofolanesthesıa on hıgh dose rocuronıum ın laparoscopıc cholecystectomy operatıons

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Short Report

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Abstract

The aim of this study was to evaluate the effects of sevoflurane, desflurane, and propofol anesthesia on the duration of neuromuscular blockade caused by a high dose of rocuronium in laparoscopic cholecystectomy procedures. Rocuronium, a non-depolarizing neuromuscular blocking agent, is frequently administered at a dose of 1.2 mg/kg to achieve deep neuromuscular block that allows laparoscopic surgery to be performed under lower intra-abdominal pressures without compromising surgical conditions. The first objective of the study was to determine whether the choice of anesthetic maintenance agent altered the duration of rocuronium's effect.

Seventy-five adult patients aged 18 to 65 years, classified as ASA I–III and scheduled for elective laparoscopic cholecystectomy, were enrolled. Patients were randomized into three groups. All patients received rocuronium at 1.2 mg/kg. In Group P, propofol was infused intravenously at 6–12 mg/kg/min. In Group D, desflurane was administered, while in Group S, sevoflurane was given, both inhaled at a minimum alveolar concentration (MAC) of 1–1.5. BIS values were maintained between 40–50. Intraoperative monitoring included train-of-four (TOF) and post-tetanic count (PTC).

No significant differences were observed between the groups regarding demographic and hemodynamic characteristics, rocuronium and sugammadex doses, duration of operation, extubation and recovery times, or postoperative nausea and vomiting. The groups were also similar in terms of surgical satisfaction and time to first defecation. However, a significant difference was identified in the time to TOF=1 and PTC=1, which were longest in the desflurane group compared to sevoflurane and propofol. This indicated that desflurane significantly prolonged the neuromuscular blocking effect of rocuronium.

Keywords: Low pressure, Desflurane, Rocuronium, Sugammadex, Laparoscopic cholecystectomy, neuromuscular blockade

1. Introduction

Background of Laparoscopic Cholecystectomy

Laparoscopic cholecystectomy is today the standard surgical technique for the treatment of gallbladder diseases such as symptomatic cholelithiasis and acute or chronic cholecystitis. Compared with the open surgical technique, laparoscopic cholecystectomy provides several advantages, including faster recovery, shorter hospital stay, reduced postoperative pain, and improved cosmetic outcomes [1]. The introduction of minimally invasive approaches has significantly changed patient outcomes, as the technique allows surgeons to operate under less traumatic conditions with lower risks of wound complications and faster return to daily activities.

A critical component of laparoscopic cholecystectomy is the creation of pneumoperitoneum, typically with carbon dioxide insufflation, to provide surgical exposure [2]. However, pneumoperitoneum increases intra-abdominal pressure (IAP), which in turn alters respiratory and circulatory physiology, sometimes leading to adverse effects such as decreased cardiac output, reduced venous return, increased airway resistance, and impaired renal and splanchnic perfusion. Surgeons have increasingly explored performing operations under lower intra-abdominal pressures to minimize these effects.

Deep neuromuscular blockade (NMB) is essential in such contexts, as it enables surgeons to maintain excellent surgical conditions even at lower pressures [3]. Patients undergoing laparoscopic surgery with deep NMB experience fewer complications and enhanced surgical outcomes compared with those operated under standard block conditions.

Role of Neuromuscular Blockade

Neuromuscular blocking agents play an indispensable role in anesthesia by producing muscle relaxation that facilitates intubation, improves surgical exposure, and enhances patient safety. Rocuronium bromide, a non-depolarizing aminosteroidal muscle relaxant, is especially useful for rapid induction due to its fast onset of action [4]. At high doses, such as 1.2 mg/kg, it produces profound neuromuscular blockade comparable to succinylcholine, traditionally used for rapid sequence induction but with fewer undesirable side effects.

The depth and duration of neuromuscular blockade can directly influence intra-abdominal pressure tolerance during laparoscopic surgery [5]. Deep NMB allows the surgeon to work at pressures as low as 8 mmHg without compromising visualization, thereby reducing postoperative pain and minimizing complications such as shoulder tip pain, nausea, vomiting, and prolonged ileus.

Effects of Anesthetics on Neuromuscular Blockade

The choice of anesthetic maintenance agent significantly influences the pharmacodynamics of neuromuscular blocking agents. Volatile anesthetics such as sevoflurane and desflurane potentiate the effect of non-depolarizing agents, leading to prolonged blockade and delayed recovery [6]. This effect is mediated by increased sensitivity of the neuromuscular junction to the blocking agent. Propofol, on the other hand, an intravenous agent, does not significantly alter the duration of neuromuscular blockade and therefore provides a more predictable recovery profile.

Sevoflurane is widely used for maintenance due to its stable hemodynamic profile, low airway irritability, and smooth recovery. Desflurane, although also offering rapid emergence, is associated with sympathetic stimulation at high concentrations and is known to prolong the effect of rocuronium more than sevoflurane [7]. Propofol remains a preferred intravenous anesthetic for its favorable antiemetic profile, but its influence on neuromuscular blockade is minimal compared with volatile agents.

Aim and Objectives

This study aimed to compare the influence of sevoflurane, desflurane, and propofol anesthesia on the duration of neuromuscular blockade induced by a high dose of rocuronium in laparoscopic cholecystectomy. The primary endpoint was the time to recovery of TOF and PTC values. Secondary endpoints included evaluation of intra-abdominal pressure tolerance, extubation and recovery times, postoperative nausea and vomiting, pain scores, and surgical satisfaction.

2. Literature Review / General Background

2.1 Laparoscopic Cholecystectomy

History

The concept of laparoscopy dates back more than a century, with George Kelling performing the first “celioscopy” in 1901 [8]. Advances in optical technology during the twentieth century, particularly the introduction of video systems, allowed laparoscopy to be incorporated into general surgery. In 1987, Philippe Mouret performed the first laparoscopic cholecystectomy, marking the beginning of a new era in minimally invasive surgery. In Turkey, the first laparoscopic cholecystectomy was performed in 1990 at Istanbul SSK Okmeydanı Hospital [9].

Today, laparoscopic cholecystectomy is considered the gold standard for gallbladder removal, replacing open cholecystectomy due to its numerous benefits in terms of recovery and morbidity.

Techniques: Advantages, Disadvantages, Indications, Contraindications, and Complications

Laparoscopic cholecystectomy offers many advantages. It allows the operative field to be clearly visualized with magnification, leading to precise dissection. Smaller incisions result in reduced postoperative pain and quicker mobilization. Patients are discharged earlier and resume normal activities faster. The risk of wound-related complications, such as infections and hernias, is significantly lower [10]. Additionally, patients experience better preservation of pulmonary function and lower analgesic requirements.

Despite these benefits, there are disadvantages. The technique requires significant surgical expertise and familiarity with laparoscopic instruments. Depth perception is limited by the two-dimensional camera system. Pneumoperitoneum can result in complications including hypercarbia, pneumothorax, and hemodynamic changes. Intraoperative complications include vascular injury, bile duct injury, and bleeding, while postoperative complications involve bile leakage, wound infection, or incisional hernia [11].

Indications for laparoscopic cholecystectomy include symptomatic cholelithiasis, acute and chronic cholecystitis, gallbladder polyps, gallstone pancreatitis, and biliary dyskinesia. Absolute

contraindications include inability to tolerate general anesthesia, diffuse peritonitis, and uncorrectable coagulopathy. Relative contraindications include severe obesity, advanced pregnancy, and severe jaundice.

Physiological Changes

Pneumoperitoneum causes significant physiological changes. In terms of circulation, intra-abdominal pressure increases systemic vascular resistance and mean arterial pressure while reducing venous return, potentially lowering cardiac output [12]. At pressures above 20 mmHg, these effects become pronounced, causing reduced perfusion to renal and splanchnic circulations. Respiratory physiology is also altered, as diaphragmatic elevation decreases lung compliance and increases airway pressures, sometimes resulting in atelectasis. These changes can be partially corrected with positive end-expiratory pressure (PEEP).

Laparoscopy also influences immune and metabolic function, with evidence suggesting that systemic immune response is better preserved compared with open surgery, though local peritoneal immunity is reduced [13]. Coagulation changes include a trend toward hypercoagulability, increasing the risk of deep vein thrombosis or pulmonary embolism. Gastrointestinal function generally recovers faster in laparoscopic surgery than in open surgery, with earlier return of bowel movements and oral intake.

2.2 Intra-abdominal Pressure

Intra-abdominal pressure is normally between 5 and 7 mmHg. Intra-abdominal hypertension is defined as sustained or repeated elevation above 12 mmHg, classified into four grades, ranging from Grade 1 (12–15 mmHg) to Grade 4 (>25 mmHg). Abdominal compartment syndrome (ACS) is defined as IAP greater than 20 mmHg accompanied by new organ dysfunction.

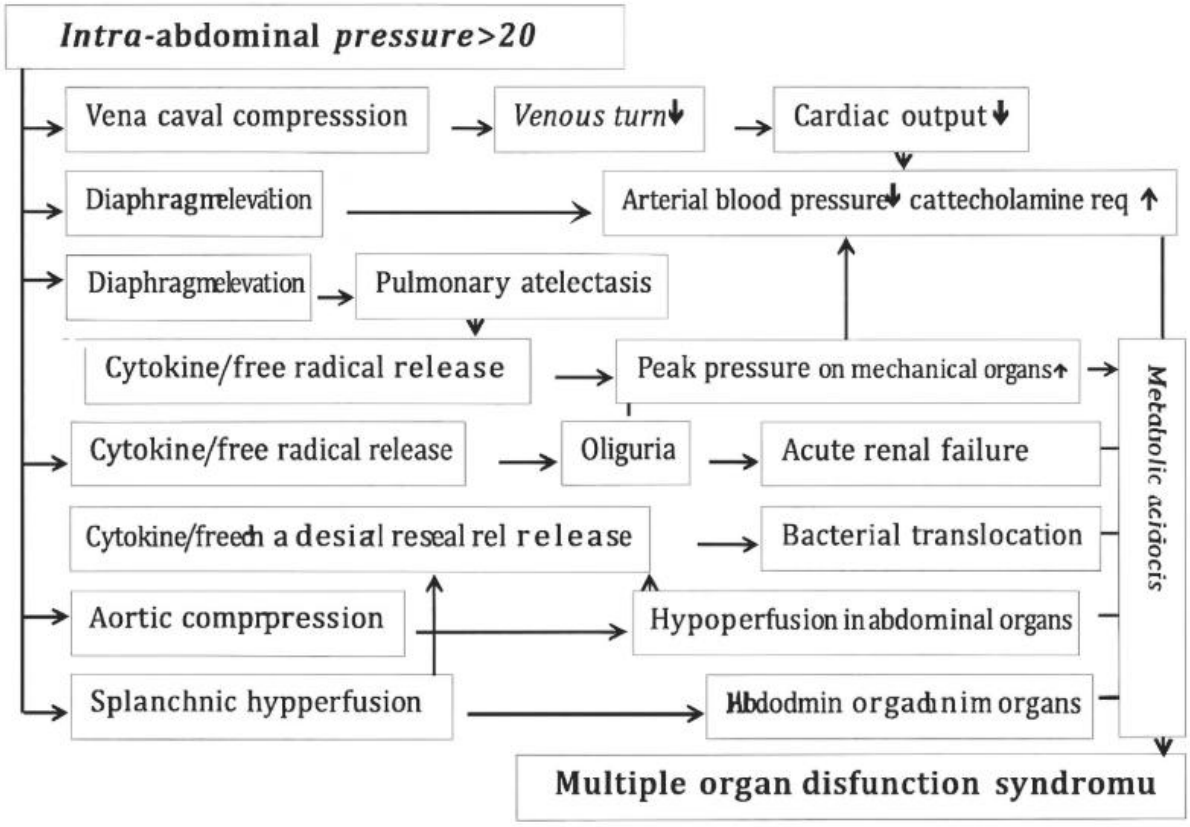


Figure 1. Pathophysiology of Abdominal Compartment Syndrome

IAP can be measured directly through intraperitoneal catheters or indirectly through bladder pressure monitoring, with the latter being the most widely used. Pathophysiologically, rising intra-abdominal pressure causes decreased venous return, reduced cardiac output, impaired renal function, and diminished splanchnic blood flow [14]. Figure 1 from the original article demonstrates the pathophysiology of abdominal compartment syndrome, showing how escalating intra-abdominal volume and pressure create a vicious cycle leading to ischemia, reduced perfusion, and further pressure elevation.

2.3 Rocuronium Bromide

Rocuronium is a non-depolarizing aminosteroidal neuromuscular blocker [15]. Its structure and rapid onset make it ideal for rapid sequence intubation. The typical intubating dose ranges from 0.6 to 0.9 mg/kg, while a dose of 1.2 mg/kg is used for rapid onset comparable to succinylcholine. Rocuronium acts by competitively antagonizing acetylcholine at nicotinic

receptors, preventing depolarization. Its cardiovascular stability is due to lack of histamine release, making it safer in comparison with other agents.

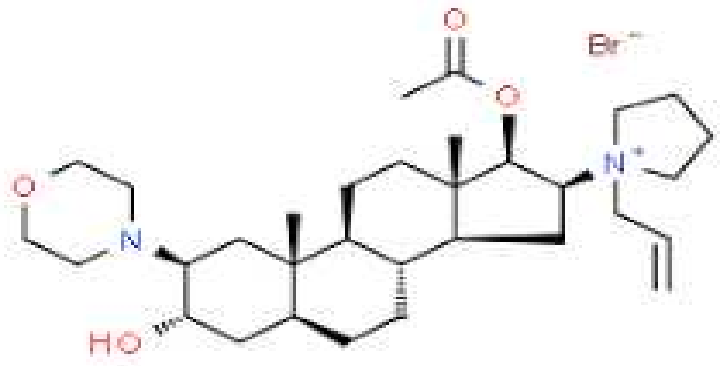


Figure 2. Chemical Structure of Rocuronium

Pharmacokinetically, rocuronium is mainly distributed and eliminated through the liver, with minor renal excretion. Its duration is prolonged in hepatic dysfunction. Figure 2 presents the chemical structure of rocuronium as shown in the original file.

2.4 Sugammadex

Sugammadex is a modified gamma-cyclodextrin specifically developed to encapsulate aminosteroidal neuromuscular blockers such as rocuronium and vecuronium. By forming tight 1:1 complexes, it rapidly reverses deep neuromuscular blockade [16]. The reversal is not mediated through acetylcholinesterase inhibition, unlike neostigmine, thereby avoiding muscarinic side effects and eliminating the need for anticholinergic co-administration.

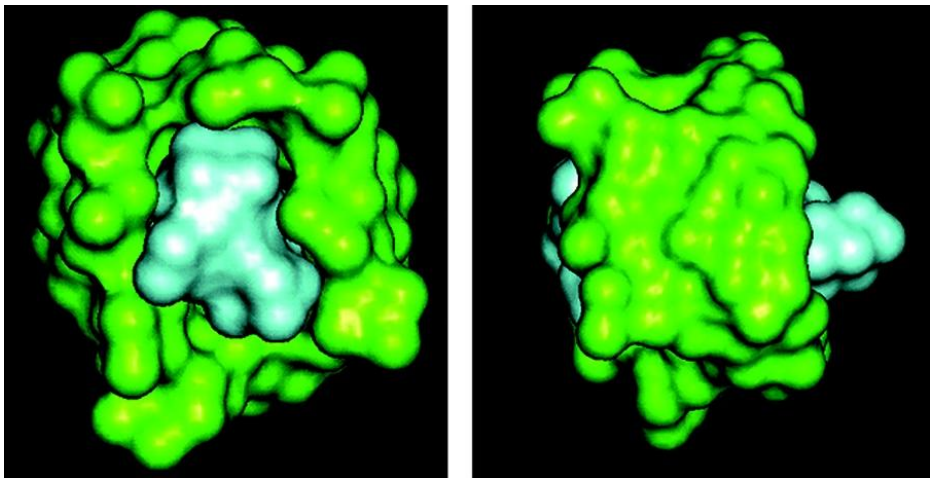


Figure 3. 1:1 Encapsulation of a Rocuronium Molecule (blue) by a Sugammadex Molecule (green)

Pharmacokinetically, sugammadex is excreted unchanged through the kidneys. Its use is therefore limited in severe renal dysfunction. Figure 3 shows the molecular interaction of rocuronium encapsulated by sugammadex.

2.5 Neuromuscular Monitoring

Monitoring neuromuscular function is essential to prevent residual paralysis. Clinical signs such as head lift or swallowing are insufficient. Quantitative monitoring techniques such as train-of-four (TOF), double burst stimulation (DBS), and post-tetanic count (PTC) provide reliable assessment [17]. TOF measures the ratio of the fourth to the first twitch after four supramaximal stimuli at 2 Hz, with ratios below 0.9 indicating residual blockade. DBS is more sensitive for detecting residual paralysis, while PTC is useful during deep blockade when no TOF response is present.

2.6 Propofol

Propofol, chemically 2,6-diisopropylphenol, is an intravenous anesthetic agent used for induction and maintenance. Its rapid onset and short duration of action, combined with favorable hemodynamic profile, make it one of the most commonly used agents.

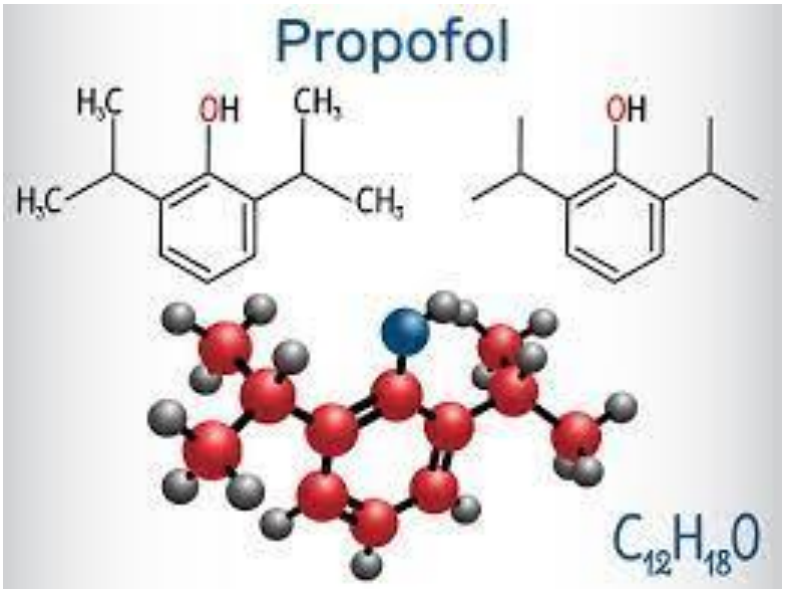


Figure 4. Chemical Structure of Propofol

Figure 4 in the original file shows the molecular structure of propofol. Propofol provides hypnosis by potentiating GABA receptors but has no analgesic effect. It is frequently used in outpatient surgery because of its rapid clearance and low incidence of postoperative nausea and vomiting. Pain on injection is a common side effect.

2.7 Sevoflurane

Sevoflurane is a halogenated volatile anesthetic with low blood-gas solubility, which allows rapid induction and emergence. It is non-irritating to the airways, making it suitable for inhalational induction [18]. Sevoflurane potentiates the effect of rocuronium and prolongs its duration, although to a lesser extent than desflurane. Its smooth emergence profile and cardiovascular stability contribute to its widespread use in both adult and pediatric populations.

2.8 Desflurane

Desflurane is another halogenated ether with extremely low blood-gas solubility, resulting in very rapid onset and recovery. However, it causes sympathetic stimulation and airway irritability at high concentrations. Among volatile anesthetics, desflurane most strongly potentiates the effect of rocuronium, significantly prolonging neuromuscular blockade and delaying recovery

compared with both sevoflurane and propofol [19]. While it offers advantages in cases requiring quick emergence, its potentiating effect on ne uromuscular blockade requires careful monitoring and dose adjustment of relaxants and reversal agents.

3. Materials and Methods

Study Design and Ethical Approval

This study was designed as a prospective, randomized, observational trial conducted at a tertiary academic hospital. The protocol was reviewed by the institutional ethics committee and approved with decision number and date of 11.04.2022/38, and was registered with the General Directorate of Clinical Research with ID number NCT 06045559. Written informed consent was obtained from all participants. The study was conducted in accordance with the principles of the Declaration of Helsinki and Good Clinical Practice guidelines [20]. Its purpose was to evaluate the effects of different anesthetic maintenance techniques on the neuromuscular blockade induced by a high dose of rocuronium during laparoscopic cholecystectomy procedures.

Patients and Inclusion/Exclusion Criteria

Seventy-five adult patients aged between 18 and 65 years were included. All patients were scheduled for elective laparoscopic cholecystectomy and classified as ASA physical status I to III. Exclusion criteria included the presence of neuromuscular disease, renal or hepatic dysfunction, known allergy to anesthetic agents, pregnancy, morbid obesity, and refusal to participate. Patients with contraindications to laparoscopic surgery such as diffuse peritonitis or severe cardiopulmonary compromise were also excluded.

Randomization and Interventions

Patients were randomly assigned into three groups of twenty-five using a computer-generated randomization table. All patients received intravenous rocuronium at a dose of 1.2 mg/kg during induction, ensuring deep neuromuscular block. Anesthesia induction was standardized across all groups with intravenous propofol and fentanyl, followed by endotracheal intubation.

In Group P, anesthesia was maintained with intravenous propofol at a continuous infusion rate of 6–12 mg/kg/min. In Group S, anesthesia was maintained with sevoflurane inhalation at a MAC of 1–1.5, while in Group D, desflurane was administered at the same MAC range. The depth of anesthesia was guided using bispectral index (BIS) monitoring, and values were maintained between 40 and 50. Ventilation parameters were adjusted to maintain normocapnia.

Monitoring and Measurements

Neuromuscular function was monitored continuously using peripheral nerve stimulation. Train-of-four (TOF) ratios and post-tetanic count (PTC) were recorded intraoperatively. The times to TOF=1 and PTC=1 were noted for each patient. Hemodynamic data including heart rate, mean arterial pressure, and oxygen saturation were recorded at baseline and at regular intraoperative intervals.

Postoperative assessments included evaluation of nausea and vomiting at 4, 12, and 24 hours using a standardized PONV scoring system. Pain was assessed using a visual analog scale at 2 hours, 24 hours, and day 3 postoperatively [21]. The time to first defecation was recorded, along with surgical satisfaction scores given by the operating surgeons, who were blinded to the anesthetic group. Extubation time, recovery time, and total doses of rocuronium and sugammadex used were also documented.

Statistical Analysis

Statistical analysis was performed using SPSS software (version referenced in original thesis). Continuous variables were presented as mean ± standard deviation, while categorical variables were expressed as counts and percentages [22]. Comparisons between groups were conducted using analysis of variance (ANOVA) for normally distributed data and Kruskal–Wallis test for nonparametric variables. Chi-square tests were applied to categorical data. A p-value <0.05 was considered statistically significant.

4. Results

Demographic Characteristics

Table 1. Comparison of Demographic Characteristics Across Groups

Variable	Sevoflurane	Desflurane	Propofol	p-value
Age (years, mean ± SD)	50.5 ± 14.1	50.4 ± 15.1	45.8 ± 15.1	0.444*
BMI (kg/m², mean ± SD)	24.7 ± 3.0	23.2 ± 2.3	24.3 ± 3.2	0.157*
Body weight (kg, mean ± SD)	69.6 ± 12.2	70.6 ± 11.8	68.9 ± 13.0	0.981**
Sex, Male n (%)	13 (32.5)	15 (37.5)	12 (30.0)	0.687***
Sex, Female n (%)	12 (34.3)	10 (28.6)	13 (37.1)	
ASA I n (%)	12 (36.4)	10 (30.3)	11 (33.3)	0.985****
ASA II n (%)	10 (30.4)	12 (36.4)	11 (33.3)	
ASA III n (%)	3 (33.3)	3 (33.3)	3 (33.3)	

*Continuous variables are mean ± SD; categorical variables are n (%). *: ANOVA, **: Kruskal–Wallis, ***: Pearson chi-square, ****: Likelihood Ratio.*

Seventy-five patients completed the study. The three groups were comparable in terms of demographic data including age, sex distribution, body mass index, and ASA classification. No statistically significant differences were observed among the groups. These data are summarized in Table 1 of the original document.

Hemodynamic Data

Hemodynamic parameters remained stable throughout the procedures. Heart rate, mean arterial pressure, and oxygen saturation did not differ significantly among the three groups at any measured time point. The choice of anesthetic agent did not influence intraoperative hemodynamic stability.

Table 3. Intra-abdominal Pressure Over Time

Time point	Sevoflurane	Desflurane	Propofol	p-value
IAP 5 min	8.0 ± 0.0 [8.0 (8.0–8.0)]	8.0 ± 0.0 [8.0 (8.0–8.0)]	8.0 ± 0.0 [8.0 (8.0–8.0)]	1.00
IAP 10 min	8.0 ± 0.0 [8.0 (8.0–8.0)]	8.0 ± 0.0 [8.0 (8.0–8.0)]	8.0 ± 0.0 [8.0 (8.0–8.0)]	1.00
IAP 15 min	8.0 ± 0.0 [8.0 (8.0–8.0)]	8.0 ± 0.0 [8.0 (8.0–8.0)]	8.0 ± 0.0 [8.0 (8.0–8.0)]	1.00
IAP 20 min	7.7 ± 1.4 [8.0 (8.0–8.0)]	8.0 ± 0.0 [8.0 (8.0–8.0)]	8.6 ± 1.6 [8.0 (8.0–8.0)]	0.015
IAP 25 min	8.1 ± 0.4 [8.0 (8.0–8.0)]	8.1 ± 0.4 [8.0 (8.0–8.0)]	8.3 ± 0.6 [8.0 (8.0–8.0)]	0.246
IAP 30 min	8.4 ± 1.0 [8.0 (8.0–8.0)]	8.1 ± 0.7 [8.0 (8.0–8.0)]	8.3 ± 0.6 [8.0 (8.0–8.5)]	0.252
IAP 35 min	8.5 ± 0.8 [8.0 (8.0–9.0)]	8.2 ± 0.8 [8.0 (8.0–8.0)]	8.6 ± 0.8 [8.0 (8.0–9.0)]	0.196
IAP 40 min	8.5 ± 0.8 [8.0 (8.0–9.0)]	8.2 ± 0.8 [8.0 (8.0–8.0)]	9.4 ± 1.1 [9.0 (9.0–10.0)]	0.016
IAP 45 min	9.0 ± 2.0 [8.0 (8.0–10.0)]	8.3 ± 0.9 [8.0 (8.0–8.0)]	12.0 [12.0 (12.0–12.0)]	–

Values shown as mean ± SD and median (25th–75th percentile). Kruskal–Wallis test. "–" = not calculable.

Table 5. Vital Signs — SpO_2, HR, SBP, MAP, DBP

For readability, retain as a composite table (matching the thesis "Tablo 5" and continuation).

Variable	Sevoflurane Mean ± SD	Desflurane Mean ± SD	Propofol Mean ± SD	p-value
SpO_2 Preop (%)	96.6 ± 2.0	95.8 ± 2.7	96.2 ± 1.9	0.466**
SpO_2 Post-intubation	96.4 ± 2.1	96.0 ± 2.0	96.1 ± 1.7	0.563**
SpO_2 5 min	97.1 ± 2.0	96.2 ± 2.2	96.7 ± 3.1	0.246**
SpO_2 10 min	96.8 ± 1.9	96.2 ± 1.8	97.0 ± 2.2	0.310*
SpO_2 15 min	96.8 ± 1.8	96.3 ± 1.7	97.0 ± 1.9	0.280**
SpO_2 20 min	96.8 ± 1.8	96.6 ± 1.8	97.3 ± 2.0	0.340**
SpO_2 PO 5 min	97.1 ± 2.0	96.3 ± 2.2	97.0 ± 3.1	0.155**
SpO_2 PO 15 min	96.8 ± 1.9	96.2 ± 1.8	97.0 ± 2.1	0.251*
SpO_2 PO 30 min	96.9 ± 1.6	96.3 ± 1.7	97.3 ± 2.0	0.111**
HR Preop (bpm)	73.3 ± 12.4	76.4 ± 13.3	77.7 ± 9.7	0.415*
HR Post-intubation	70.5 ± 11.8	76.4 ± 13.3	77.3 ± 9.9	0.089*
HR 5 min	70.8 ± 11.6	76.4 ± 13.3	75.5 ± 10.0	0.201*
HR 10 min	63.2 ± 9.9	64.5 ± 10.9	68.2 ± 7.7	0.176*
HR 15 min	67.2 ± 13.7	66.1 ± 11.9	69.8 ± 8.6	0.507*
HR 20 min	68.0 ± 13.2	65.5 ± 11.5	71.2 ± 8.1	0.201*
HR PO 5 min	69.6 ± 12.3	76.9 ± 13.3	69.1 ± 10.4	0.043*
HR PO 15 min	64.3 ± 10.4	65.6 ± 11.2	71.0 ± 13.1	0.099*
HR PO 30 min	74.5 ± 14.2	71.6 ± 14.1	72.9 ± 7.2	0.847**
SBP Preop (mmHg)	119.7 ± 9.7	117.8 ± 9.1	120.7 ± 7.7	0.508*
SBP Post-intubation	120.0 ± 7.2	116.6 ± 7.9	120.1 ± 7.6	0.072**
SBP 5 min	122.9 ± 11.6	116.3 ± 14.3	120.6 ± 8.5	0.396**

Variable	Sevoflurane Mean ± SD	Desflurane Mean ± SD	Propofol Mean ± SD	p-value
SBP 10 min	120.6 ± 8.5	112.4 ± 13.3	120.0 ± 7.7	0.009*
SBP 15 min	120.1 ± 6.6	114.6 ± 13.2	120.7 ± 8.7	0.324**
SBP 20 min	120.4 ± 6.7	113.9 ± 14.1	120.1 ± 10.2	0.362**
SBP PO 5 min	113.3 ± 13.5	120.9 ± 10.7	124.3 ± 10.4	0.005*
SBP PO 15 min	113.9 ± 12.5	121.0 ± 7.1	121.3 ± 7.5	0.009*
SBP PO 30 min	112.9 ± 14.4	123.2 ± 10.0	119.7 ± 7.6	0.024**
MAP Preop (mmHg)	89.2 ± 9.6	87.3 ± 9.8	90.0 ± 7.5	0.553*
MAP Post-intubation	89.2 ± 6.7	87.0 ± 6.7	89.5 ± 6.6	0.366*
MAP 5 min	91.3 ± 11.7	88.4 ± 12.1	91.9 ± 8.9	0.493*
MAP 10 min	89.5 ± 8.9	84.7 ± 10.8	90.4 ± 7.9	0.075*
MAP 15 min	89.0 ± 6.8	86.4 ± 9.9	91.6 ± 8.6	0.103*
MAP 20 min	88.9 ± 6.3	86.1 ± 9.6	91.4 ± 7.5	0.068*
MAP PO 5 min	83.7 ± 10.7	91.2 ± 9.6	94.0 ± 10.8	0.001**
MAP PO 15 min	85.8 ± 8.9	90.5 ± 6.7	91.5 ± 7.9	0.029*
MAP PO 30 min	85.2 ± 10.0	91.1 ± 10.1	90.4 ± 7.3	0.055*
DBP Preop (mmHg)	74.0 ± 9.8	72.0 ± 10.7	74.6 ± 7.8	0.601*
DBP Post-intubation	73.8 ± 6.9	72.3 ± 7.0	74.2 ± 7.0	0.588*
DBP 5 min	75.5 ± 12.2	74.4 ± 11.5	77.6 ± 9.4	0.603*
DBP 10 min	74.0 ± 9.6	70.9 ± 10.2	75.6 ± 8.9	0.215*
DBP 15 min	73.4 ± 7.5	72.3 ± 9.1	77.2 ± 8.9	0.115*

Variable	Sevoflurane Mean ± SD	Desflurane Mean ± SD	Propofol Mean ± SD	p-value
DBP 20 min	73.2 ± 7.0	72.2 ± 8.1	77.2 ± 7.5	0.057*
DBP PO 5 min	68.9 ± 9.8	76.4 ± 9.4	78.9 ± 11.4	0.003*
DBP PO 15 min	71.7 ± 7.9	75.2 ± 7.0	76.6 ± 8.5	0.088*
DBP PO 30 min	71.4 ± 8.5	75.1 ± 10.6	75.8 ± 8.1	0.202*

*Test types per row match the thesis: * ANOVA, ** Kruskal–Wallis.*

Table 6. Multiple Comparisons at Selected Time Points

Dependent Variable	Pairwise Comparison	p-value
HR PO 5 min	Sevoflurane vs Desflurane	0.035
	Sevoflurane vs Propofol	0.889
	Desflurane vs Propofol	0.025
SBP 10 min	Sevoflurane vs Desflurane	0.006
	Sevoflurane vs Propofol	0.857
	Desflurane vs Propofol	0.010
SBP PO 15 min	Sevoflurane vs Desflurane	0.009
	Sevoflurane vs Propofol	0.007
	Desflurane vs Propofol	0.928
MAP PO 15 min	Sevoflurane vs Desflurane	0.039
	Sevoflurane vs Propofol	0.013
	Desflurane vs Propofol	0.655
DBP PO 5 min	Sevoflurane vs Desflurane	0.011
	Sevoflurane vs Propofol	<0.001

Dependent Variable	Pairwise Comparison	p-value
	Desflurane vs Propofol	0.394

Rocuronium Effect Durations

Table 2. Distribution of Operative and Neuromuscular Variables by Group

Variable	Sevoflurane	Desflurane	Propofol	p-value
Rocuronium dose (mg, by weight)	84.7 ± 14.5	84.9 ± 14.1	82.7 ± 15.6	0.946**
Sugammadex dose (mg)	148.9 ± 22.8	140.1 ± 16.8	144.4 ± 22.1	0.434**
Operation duration (min)	33.6 ± 9.1	36.4 ± 7.6	37.8 ± 9.5	0.235*
Extubation time (s)	183.6 ± 58.7	179.2 ± 39.6	198.0 ± 58.3	0.426*
Time to TOF = 0 (s)	129.8 ± 32.8	128.1 ± 26.9	124.3 ± 32.1	0.780**
Time to PTC = 0 (s)	129.8 ± 32.8	128.1 ± 26.9	124.3 ± 32.1	0.780**
Total rocuronium dose (mg)	85.2 ± 14.8	84.9 ± 14.1	83.7 ± 15.5	0.972**

*Kısaltmalar: sn = seconds; dk = minutes. *: ANOVA, **: Kruskal–Wallis.*

The primary outcome measure, the time to TOF=1 and PTC=1, demonstrated significant differences between groups. The desflurane group exhibited the longest duration of rocuronium effect, with times to recovery significantly higher than those observed in the sevoflurane and propofol groups. In contrast, the propofol group showed the shortest recovery times, consistent with its lack of potentiation of neuromuscular blockade. These findings are illustrated in Table 2 and Figure 2 of the original file.

Postoperative Outcomes

Postoperative nausea and vomiting were assessed at 4, 12, and 24 hours, with no statistically significant differences between the groups. Similarly, pain scores at 2 hours, 24 hours, and day 3 were comparable [23]. The time to first defecation did not differ significantly. Extubation and

recovery times were also similar among the groups, and surgical satisfaction scores remained high in all three arms. Overall, while desflurane prolonged neuromuscular blockade, this did not translate into differences in postoperative recovery or patient comfort.

Table 4. Surgical Recovery and Surgeon Satisfaction

Outcome	**Sevoflurane**	**Desflurane**	**Propofol**	**p-value**
Recovery score “1”, n (%)	12 (48.0)	14 (56.0)	12 (48.0)	–
Recovery score “2”, n (%)	13 (52.0)	11 (44.0)	11 (44.0)	–
Recovery score “3”, n (%)	0 (0.0)	0 (0.0)	2 (8.0)	–
Surgeon satisfaction at case end: Optimal n (%)	18 (72.0)	23 (92.0)	16 (64.0)	0.119*
Surgeon satisfaction: Good n (%)	6 (24.0)	2 (8.0)	7 (28.0)	
Surgeon satisfaction: Acceptable n (%)	1 (4.0)	0 (0.0)	2 (8.0)	
Surgeon satisfaction: Poor n (%)	0 (0.0)	0 (0.0)	0 (0.0)	

*Categorical variables are n (%). *: Likelihood Ratio. Interim time-point CM distributions (5–45 min) are consistent with the above pattern.*

5. Discussion

Comparison with Literature

The findings of this study are consistent with existing literature reporting that volatile anesthetics prolong the duration of non-depolarizing neuromuscular blockers, with desflurane exerting the most pronounced effect [24]. Prior investigations demonstrated that desflurane increases the sensitivity of the neuromuscular junction, leading to longer blockade durations compared with sevoflurane and propofol. This study’s observation that desflurane significantly delayed TOF and PTC recovery aligns with earlier research, reinforcing its role as the most potent potentiator of rocuronium.

On the other hand, propofol, despite its widespread use, did not significantly extend the duration of neuromuscular blockade, consistent with multiple studies demonstrating its neutral interaction with rocuronium [25]. Sevoflurane's effect was intermediate, producing longer blockade compared with propofol but shorter than desflurane.

Explanations for Differences between Anesthetic Agents

The pharmacological mechanisms explain these differences. Desflurane and sevoflurane alter muscle contractility and enhance the action of neuromuscular blocking drugs at the receptor level, thereby prolonging recovery [26]. Desflurane, with its unique pharmacodynamic properties, leads to the greatest prolongation. Propofol, acting via potentiation of GABA receptors without significant interference at the neuromuscular junction, does not influence rocuronium's pharmacokinetics or pharmacodynamics, accounting for its minimal effect.

Implications for Surgical Practice

From a surgical perspective, prolonged blockade with desflurane provide superior surgical conditions, particularly in operations performed under low intra-abdominal pressures [27]. The extended effect of rocuronium allows surgeons to operate in a stable and relaxed field. However, this advantage must be weighed against the potential for delayed recovery, which not be desirable in outpatient settings or short-duration surgeries. The use of sugammadex mitigates these concerns by enabling rapid reversal, but availability and cost considerations remain.

The similarity in postoperative comfort and recovery across groups suggests that while anesthetic choice influences neuromuscular blockade duration, it does not significantly alter overall patient outcomes in terms of pain, nausea, or satisfaction [28]. This indicates that anesthesiologists select maintenance agents based on other priorities such as hemodynamic stability, recovery profile, or institutional protocols.

Limitations

This study has several limitations. The sample size, while adequate to detect differences in neuromuscular recovery times, not have been sufficient to identify smaller differences in

postoperative outcomes. The study was conducted in a single center, potentially limiting generalizability [29]. Furthermore, while BIS monitoring ensured standardized anesthetic depth, individual variability in pharmacodynamics still influence results. Finally, long-term outcomes such as overall recovery quality or cost-effectiveness were not evaluated.

6. Conclusion

In conclusion, this study demonstrated that desflurane significantly prolongs the neuromuscular blockade induced by high-dose rocuronium compared with sevoflurane and propofol. While this effect extended recovery times in terms of TOF and PTC, it did not lead to significant differences in postoperative comfort, nausea, pain, or surgical satisfaction. Sevoflurane produced an intermediate effect, and propofol had no measurable influence on blockade duration.

The choice of anesthetic maintenance agent should therefore be tailored to the clinical context. Desflurane is advantageous in surgeries requiring prolonged deep relaxation, whereas propofol is preferred when rapid recovery is essential. Regardless of the anesthetic agent, the availability of sugammadex ensures that prolonged blockade can be reversed efficiently, maintaining patient safety. Future research should investigate larger populations, cost implications, and long-term outcomes to refine anesthetic strategies in laparoscopic cholecystectomy.

It was declared by the authors of this study that all three authors in this study are the main authors.

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Appendixes

Table 7. SBP PO 5 min — Pairwise Differences

Pair	p-value
Sevoflurane – Propofol	0.007
Sevoflurane – Desflurane	0.097
Propofol – Desflurane	0.595

Table 8. SBP PO 30 min — Pairwise Differences

Pair	p-value
Sevoflurane – Desflurane	0.019
Sevoflurane – Propofol	0.421
Propofol – Desflurane	0.634

Table 9. MAP PO 5 min — Pairwise Differences

Pair	p-value
Sevoflurane – Desflurane	0.043
Sevoflurane – Propofol	0.001
Desflurane – Propofol	0.735

Table 10. Time to First Defecation

Group	Mean (days)	SD	p-value

Group	Mean (days)	SD	p-value
Sevoflurane	1.4	0.5	
Desflurane	1.6	0.5	0.622
Propofol	1.4	0.5	

Table 11. Apfel Scores (PONV Risk)

Score	Sevoflurane n (%)	Desflurane n (%)	Propofol n (%)	p-value
0	3 (12.0)	1 (4.0)	1 (4.0)	0.564
1	5 (20.0)	11 (44.0)	9 (36.0)	
2	13 (52.0)	9 (36.0)	12 (48.0)	
3	4 (16.0)	4 (16.0)	3 (12.0)	

Likelihood Ratio; variables are n (%).

Table 12. PONV Incidence and Severity

Window	Outcome	Sevoflurane n (%)	Desflurane n (%)	Propofol n (%)	p-value
0–4 h	PONV present	6 (24.0)	4 (16.0)	4 (16.0)	0.711*
	PONV absent	19 (76.0)	21 (84.0)	21 (84.0)	
4–12 h	PONV present	6 (24.0)	6 (24.0)	4 (16.0)	0.728**
	PONV absent	19 (76.0)	19 (76.0)	21 (84.0)	
12–24 h	PONV present	2 (8.0)	3 (12.0)	3 (12.0)	0.864*
	PONV absent	23 (92.0)	22 (88.0)	22 (88.0)	

Severity (0–4 h): none 19 (76.0), 21 (84.0), 21 (84.0); mild 1 (4.0), 0 (0.0), 1 (4.0); moderate 3 (12.0), 3 (12.0), 1 (4.0); frequent vomiting 2 (8.0), 1 (4.0), 2 (8.0).

Severity (4–12 h): none 19 (76.0), 19 (76.0), 21 (84.0); mild 1 (4.0), 0 (0.0), 1 (4.0); moderate 3 (12.0), 6 (24.0), 0 (0.0); frequent vomiting 2 (8.0), 0 (0.0), 3 (12.0). **Severity (12–24 h)**: none 23 (92.0), 21 (84.0), 22 (88.0); mild 0 (0.0), 0 (0.0), 1 (4.0); moderate 0 (0.0), 3 (12.0), 1 (4.0); frequent vomiting 2 (8.0), 1 (4.0), 1 (4.0).

*P-value tests: * Likelihood Ratio, ** Pearson chi-square; "–" not estimable.*

Table 13. Pain Assessments (Abdominal, Incisional, Shoulder)

Part A

Measure	Sevo (Mean ± SD / Median [P25–P75])	Des (Mean ± SD / Median [P25–P75])	Prop (Mean ± SD / Median [P25–P75])	p
Abdominal pain, rest, 2 h	32.8 ± 11 / 30 [30–40]	34.0 ± 13.2 / 30 [30–40]	29.2 ± 12.9 / 30 [20–30]	.189
Abdominal pain, rest, 24 h	27.6 ± 7.8 / 30 [20–30]	29.6 ± 7.3 / 30 [20–30]	24.8 ± 8.2 / 20 [20–30]	.052
Abdominal pain, rest, day 3	16.8 ± 9.0 / 20 [10–20]	14.0 ± 5.8 / 10 [10–20]	10.0 ± 8.2 / 10 [0–20]	.024
Abdominal pain, movement, 2 h	33.2 ± 10.3 / 30 [30–40]	35.6 ± 13.9 / 30 [30–40]	30.0 ± 12.2 / 30 [20–30]	.159
Abdominal pain, movement, 24 h	26.8 ± 7.5 / 30 [20–30]	31.6 ± 6.9 / 30 [30–40]	27.6 ± 8.8 / 30 [20–30]	.039
Abdominal pain, movement, day 3	16.8 ± 9.0 / 20 [10–20]	14.0 ± 7.1 / 10 [10–20]	10.4 ± 8.4 / 10 [0–20]	.042
Incisional pain, rest, 2 h	27.2 ± 7.4 / 30 [20–30]	34.8 ± 14.2 / 30 [30–40]	30.0 ± 11.5 / 30 [20–30]	.074
Incisional pain, rest, 24 h	26.0 ± 6.5 / 30 [20–30]	33.6 ± 14.7 / 30 [20–40]	27.6 ± 7.8 / 30 [20–30]	.130

Measure	Sevo (Mean ± SD / Median [P25–P75])	Des (Mean ± SD / Median [P25–P75])	Prop (Mean ± SD / Median [P25–P75])	p
Incisional pain, rest, day 3	19.2 ± 9.1 / 20 [10–20]	15.6 ± 6.5 / 20 [10–20]	12.4 ± 8.3 / 10 [10–20]	.042
Incisional pain, movement, 2 h	30.4 ± 9.3 / 30 [20–30]	37.2 ± 14.0 / 40 [30–40]	35.2 ± 11.6 / 30 [30–40]	.113
Incisional pain, movement, 24 h	28.0 ± 7.1 / 30 [20–30]	36.4 ± 14.4 / 30 [30–40]	30.4 ± 9.3 / 30 [20–40]	.067

Part B (Continuation)

Measure	Sevo (Mean ± SD / Median [P25–P75])	Des (Mean ± SD / Median [P25–P75])	Prop (Mean ± SD / Median [P25–P75])	p
Incisional pain, movement, day 3	22.8 ± 12.4 / 20 [20–30]	17.6 ± 5.2 / 20 [10–20]	17.6 ± 9.3 / 20 [10–20]	.135
Shoulder pain, rest, 2 h	7.2 ± 8.4 / 0 [0–10]	5.2 ± 7.1 / 0 [0–10]	7.2 ± 11.0 / 0 [0–10]	.715
Shoulder pain, rest, 24 h	6.8 ± 8.0 / 0 [0–10]	4.4 ± 7.1 / 0 [0–10]	6.0 ± 11.2 / 0 [0–10]	.476
Shoulder pain, rest, day 3	4.8 ± 7.1 / 0 [0–10]	4.0 ± 7.1 / 0 [0–10]	4.4 ± 6.5 / 0 [0–10]	.857
Shoulder pain, movement, 2 h	8.8 ± 7.8 / 10 [0–10]	5.6 ± 7.1 / 0 [0–10]	7.6 ± 12.7 / 0 [0–10]	.268
Shoulder pain, movement, 24 h	6.8 ± 8.0 / 0 [0–10]	4.4 ± 7.1 / 0 [0–10]	6.0 ± 11.2 / 0 [0–10]	.476
Shoulder pain, movement, day 3	6.8 ± 8.0 / 0 [0–10]	4.4 ± 7.1 / 0 [0–10]	3.2 ± 5.6 / 0 [0–10]	.225

All tested by Kruskal–Wallis; where $p < .05$, post-hoc provided below.

Table 14. Post-hoc Pairwise Comparisons for Pain

Measure	Pair	p-value
Abdominal pain, rest, day 3	Propofol – Sevoflurane	0.020
	Propofol – Desflurane	0.302
	Desflurane – Sevoflurane	0.860
Abdominal pain, movement, 24 h	Propofol – Sevoflurane	1.000
	Propofol – Desflurane	0.079
	Sevoflurane – Desflurane	0.084
Abdominal pain, movement, day 3	Propofol – Sevoflurane	0.039
	Propofol – Desflurane	0.336
	Desflurane – Sevoflurane	1.000
Incisional pain, rest, day 3	Propofol – Sevoflurane	0.036
	Propofol – Desflurane	0.758
	Desflurane – Sevoflurane	0.514

Table 15. TOF1 and PTC1 Times by Group

Variable	Sevoflurane Mean ± SD (min)	Desflurane Mean ± SD (min)	Propofol Mean ± SD (min)	p-value
TOF1 time	37.240 ± 9.275	45.000 ± 10.874	35.760 ± 9.9133	**0.009**
PTC1 time	34.960 ± 9.058	42.880 ± 11.285	33.520 ± 9.5965	**0.008**

Kruskal–Wallis test.

Table 16. Pairwise Post-hoc for TOF1

Pair	p-value
Propofol – Sevoflurane	0.550
Propofol – Desflurane	0.010
Sevoflurane – Desflurane	0.060

Table 17. Pairwise Post-hoc for PTC1

Pair	p-value
Propofol – Sevoflurane	0.556
Propofol – Desflurane	0.003
Sevoflurane – Desflurane	0.018

Supplementary Files

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- tezim.xls