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Investigating the effects of pressure support ventilation and positive end-expiratory pressure during extubation on respiratory system complications

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Abstract

Background Postoperative extubation is a critical phase. Various medications and different ventilation modes are employed during extubation to minimize potential issues. This study aimed to observe the early effects of the concurrent use of positive end-expiratory pressure (PEEP) and pressure support ventilation (PSV) modes during the extubation-emerge period on the respiratory system.

Methods After laparoscopic cholecystectomy, patients were administered a remifentanil infusion following the cessation of inhalation agents. PSV and PEEP modes were used on the mechanical ventilator, and the patients were extubated upon awakening. Hemodynamic and respiratory parameters, as well as complications during intraoperative and extubation periods, were recorded.

Results A total of 199 patients were evaluated. Patients with complications were defined as group I ($n = 37$), and those without complications as group 0 ($n = 167$). Post-extubation complications included cough (3 or more, persistent or repetitive coughing) in 12 patients (6.04%), desaturation (SPO2 < 90% for 10 s) in nine patients (4.53%), bronchospasm in eight patients (4.02%), agitation (5 and above on the agitation scale) in three patients (1.5%), need for rescue mask ventilation (SPO2 < 90% lasting longer than 10 s) in three patients (1.5%), and airway obstruction (2 and above according to laryngospasm score) in two patients (1%). Statistically significant differences were observed between the two groups for ASA III ($p = 0.0365$).

Conclusions The use of PSV and PEEP modes during extubation-emergence period in laparoscopic cholecystectomy results in a low rate of respiratory system complications, which are mostly minor. These modes can be safely used during the extubation phase. However, since these complications are seen in patients with high ASA physical scores, further studies are needed for these patients.

Trial registration NCT06356649.

Keywords Extubation, Positive end-expiratory pressure, Postoperative pulmonary complications, Pressure support ventilation

Background

Annually, over 300 million operations are performed globally, and intraoperative ventilator settings can be effective in reducing postoperative complications. However, the optimal ventilator settings remain undetermined

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(Bolther et al. 2022). The tracheal extubation phase following general anesthesia is critical for postoperative complications. Factors such as surgical manipulation, anesthesia duration, and anesthesia position can cause airway edema, creating a less favorable environment than at anesthesia induction (Asai et al. 1998). Furthermore, it has been reported that the positive effects of intraoperative protective ventilation diminish during the extubation process (Jeong et al. 2021).

Various methods have been explored to minimize issues during extubation, including deep extubation, short-acting opioid use, and different mechanical ventilation modes (Juang et al. 2020; Prabhakaran et al. 2023). The most commonly preferred method for extubation is transitioning to intermittent balloon-mask ventilation, allowing the patient to breathe spontaneously and extubating when sufficient respiration is achieved (Juang et al. 2020). However, this method has been associated with postoperative atelectasis (Jeong et al. 2021).

Pressure support ventilation (PSV) is frequently used for extubation in intensive care patients, providing pressure support at a selected level for each breath to enhance their own respiration. In pressure support, driving pressure causes the work of breathing to be reduced by 30% to 40% and the lung expands during inspiration, thus preventing atelectasis (Juang et al. 2020). Positive end-expiratory pressure (PEEP) applies a selected pressure at the end of expiration to prevent alveolar collapse (Pereira et al. 2018). This ventilation mode has been shown to reduce atelectasis following extubation after general anesthesia (Prabhakaran et al. 2023; Pereira et al. 2018).

It has been reported that the concurrent use of PEEP and PSV modes during the termination of general anesthesia and subsequent extubation reduces postoperative atelectasis and the problems arising from this (Jeong et al. 2021). However, the problems encountered in traditional extubation practices are not limited to this. Such as laryngospasm, cough, respiratory depression, and anxiety (Wong et al. 2021). In our study, we aimed to see the effect of PSV + PEEP application under remifentanil infusion and its relationship with intraoperative respiratory parameters to ensure smooth extubation in patients undergoing laparoscopic surgery.

Methods

The study commenced after receiving local ethics committee approval (15.03.2023/36), and it was registered with Clinical Trials (NCT06356649). Verbal and written consent was obtained from patients included in the study.

The study included patients over 18 years of age undergoing laparoscopic cholecystectomy, classified as having American Society of Anesthesiologists (ASA) functional status 1–3. Postoperative complications are frequently encountered due to the pneumoperitoneum applied in laparoscopic surgery. Patients with advanced chronic lung disease (Global Initiative for Chronic Obstructive Pulmonary Disease (COPD) [GOLD]−3 and GOLD-4), neuromuscular disease, advanced heart disease (New York Heart Association [NYHA] stage 3 and stage 4), or difficult airways were excluded. Patients were also excluded if they required conversion from laparoscopic to open surgery, if the surgery exceeded 120 min, if intraoperative bleeding was > 500 ml, or if they withdrew consent during the study.

Anesthesia and monitoring

Patients were routinely monitored (electrocardiogram, non-invasive blood pressure [NIBP], pulse oximetry (SPO2), end-tidal CO2 [ETCO2], bispectral index [BIS], and neuromuscular monitoring). After preoxygenation with 100% oxygen for 2 min, anesthesia was induced with 1 mg/kg lidocaine, 2–3 mg/kg propofol, 0.5–1 mcg/kg remifentanil, and 0.8 mg/kg rocuronium. Patients were intubated when the train of four (TOF) value reached 0. After intubation, patients were connected to a mechanical ventilator (Drager Perseus A-500, Germany) in pressure-controlled ventilation mode with initial settings of tidal volume 5–8 ml/kg, respiratory rate to maintain ETCO2 at 30–40 mmHg, PEEP 7 cmH2O, and I/E ratio 1/2. PEEP was adjusted to maintain a driving pressure < 14 cmH2O based on plateau pressure, and the I/E ratio was adjusted according to ETCO2 levels. After the mechanical ventilator circuit was saturated with an inhalation anesthetic agent, the fresh gas flow in the anesthesia machine was reduced to 1 l/min. Mechanical ventilator alarms were set for peak pressure ≤ 30 cmH2O and inspiratory O2 concentration ≥ 35% for safety.

Anesthesia was maintained with desflurane to keep BIS in the range of 40–60 and remifentanil 0.05–3 mcg/kg/h. Pneumoperitoneum was created with CO2, maintaining intra-abdominal pressure at 12–15 mmHg. The same surgical technique was used in all patients.

Hydration was maintained with an infusion of isotonic or Ringer's lactate solution at a rate of 3 mL/kg to 5 mL/kg during surgery. Intraoperative hypotension was treated with 0.1 mg/kg of ephedrine, and bradycardia with 0.01 mg/kg of atropine. For postoperative analgesia, 10 mg/kg of paracetamol and 1 mg/kg of tramadol were administered 20 min before the end of surgery. To prevent postoperative nausea and vomiting, 4 mg of dexamethasone was given after induction and 4 mg of ondansetron at the end of surgery. Recruitment maneuvers were performed with 40 cmH2O pressure after deflation of the abdomen. Patients were antagonized with sugammadex 2–4 mg/kg based on the TOF value before extubation.

Extubation and study protocol

Following surgery, desflurane was discontinued, and remifentanil infusion continued at 0.025–0.05 mcg/kg/min during the emergence-extubation phase. Mechanical ventilation was set to PSV mode (Psupport 10 cmH2O, flow trigger 4 L/min), PEEP 5 cmH2O, fiO2 70%, and fresh gas flow 10 L/min. Patients were extubated upon responding to verbal commands or audible stimuli, swallowing or coughing, eyes centered and conjugate, BIS > 80, regular breathing, and TOF > 90%.

Hemodynamic parameters (heart rate [HR], SPO2, NIBP, and BIS) and respiratory parameters (respiratory rate, tidal volume, ETCO2, Ppeak, Pplateau, and PEEP) were recorded before induction, intraoperatively, and during emergence-extubation. End of surgery-to-awakening time and awakening-to-extubation time were also documented. The time from the end of surgery until leaving the operating room was defined as the emergence period, and respiratory complications that developed during this period were recorded. The patients were then transferred to the post-anesthesia care unit. Postoperative hemodynamic data were recorded until discharge from the post-anesthesia care unit. Anesthesia was performed by the same experienced team in all patients.

The primary outcome was respiratory complication, defined as any of the following events; persistant cough (0 = no incidence of coughing, 1 = only one cough, 2 = two coughs to slight coughing, 3 = persistant or repetitive coughing), desaturation (SPO2 < 90% for 10 s), laryngospasm (0 = no symptoms, 1 = stridor, 2 = total occlusion of the cords (respiratory efforts with no air movement), 3 = cyanosis with evidence for airway obstruction at the level of vocal cords) (Safavi et al. 2016), agitation (1—represents no or minimal response to noxious stimuli; 2—represents arousal to physical stimuli but does not communicate; 3—represents difficulty in arousal but awakens to verbal stimuli or gentle shaking; 4—represents calm and follows commands; 5—represents physically agitated or anxious and calms to verbal instructions; 6:represents requiring restraint and frequent verbal reminding of limits; and 7—represents pulling at tracheal tube, trying to remove catheters, or striking at staff. Five and above accepted) (Lee et al. 2020), desaturation (SPO2 < 90% for 10 s), need for rescue mask ventilation (SPO2 < 90% lasting longer than 10 s), bronchospasm, bronchospasm requiring post-operative intubation.

Statistical analysis

When calculating the a priori sample size in the study, it was planned to reach 199 patients upon making calculations based on a type 1 error of 0.05, a power level of 80%, and an effect size of 0.10. Continuous data were presented as mean ± standard deviation values, and categorical data as percentages. The Shapiro–Wilk test was used to assess normality. The independent-samples t-test was conducted to compare two groups in the presence of a normal distribution, and the Mann–Whitney U test otherwise. Pearson chi-square and exact chi-square tests were employed to analyze cross-tabulated data. Analyses were conducted using IBM SPSS Statistics version 21.0, with statistical significance set at $p < 0.05$.

Results

A total of 204 patients were included in the study. Two patients withdrew from the study and 3 patients were excluded because they were converted to open surgery. 199 patients were evaluated, consisting of 137 females (68.84%) and 62 males (31.16%). Respiratory complications were observed in 37 patients (18.59%). Patients with complications were defined as group I ($n = 37$), while those without complications were defined as group 0 ($n = 162$). Group 0 included 112 females (69.1%) and 50 males (30.9%), whereas group I included 25 females (67.6%) and 12 males (32.4%) ($p = 1$). The mean age was 52.45 ± 14.70 years in group 0 and 57.24 ± 13.22 years in group I ($p = 0.122$). The body mass index (BMI) was 26.76 in group 0 and 27.92 in group I ($p = 0.202$). There were no statistically significant differences concerning these demographic parameters.

Regarding ASA scores, group 0 had 34 patients (21.0%) with ASA 1, 107 patients (66.0%) with ASA 2, and 21 patients (13.0%) with ASA 3. In group I, there were two patients (5.4%) with ASA 1, 26 patients (70.3%) with ASA 2, and nine patients (24.3%) with ASA 3. Statistically significant differences were observed between the two groups for ASA I and ASA III ($p = 0.016$ and $p = 0.0365$, respectively). Overall, patients with ASA II were more prevalent compared to other ASA groups ($p < 0.05$) (Table 1).

The duration from the start to the end of anesthesia was 75.59 ± 19.15 min in group 0 and 83.84 ± 18.34 min in group 1, with this difference being statistically significant ($p = 0.0148$). The duration from the end of surgery to awakening was 6.537 ± 1.581 min in group 1 and 7.838 ± 3.492 min in group 0, while the awakening-to-extubation time was 1.217 ± 0.975 min in group 1 and 3.216 ± 2.907 min in group 0. Although the time from the end of surgery to awakening did not significantly differ between the groups, the awakening-to-extubation time was significantly longer in group 1 ($p < 0.001$) (Table 1).

Table 2 presents the HR, systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), SPO2, and BIS values measured at different times. No significant statistical differences were found between the groups in terms of HR, DBP, MAP, or BIS

Table 1 Demographic data

	Group 0 (N = 162)	Group I (N = 37)	P	Total (N = 199)
Gender				
Female	112 (69.1%)	25 (67.6%)	1	137 (68.8%)
Male	50 (30.9%)	12 (32.4%)		62 (31.2%)
Age	52.45 ± 14.70	57.24 ± 13.22	0.122	53.34 ± 14.53
BMI	26.76 ± 4.474	27.92 ± 4.924	0.202	26.98 ± 4.570
ASA class				
I	34 (21.0%)	2 (5.4%)	0.016*	36 (18.1%)
II	107 (66%)	26 (70.3%)	0.154	133 (66.8%)**
III	21 (13%)	9 (24.3%)	0.0365*	30 (15.1%)
Anesthesia duration (min)	75.59 ± 19.15	83.84 ± 18.34	0.0148*	77.12 ± 19.23
End of surgery-to-awakening time (min)	6.537 ± 1.581	7.838 ± 3.492	0.0736	6.779 ± 2.123
Awakening-to-extubation time (min)	1.217 ± 0.975	3.216 ± 2.907	< 0.001*	1.588 ± 1.708

BMI body mass index, *ASA* American Society of Anesthesiologists

Data presented as mean ± standard deviation and percentages

* Statistically significant at $p < 0.05$ for intergroup comparisons

** Between ASA I and II in all patients

Table 2 Hemodynamic data of patients

	HR	SBP	DBP	MAP	SPO_2	BIS
Preoperative						
- Group 0	73.20 ± 14.93	141.9 ±19.75	82.88 ±10.35	102.9 ±11.68	97.04 ± 2.13	95.97 ±2.14
- Group I	76.30 ± 14.02	145.8 ±21.42	81.89 ±13.98	102.8 ±12.85	95.92 ± 2.36	95.86 ±3.53
- *p*	0.276	0.197	0.371	0.933	**0.00902***	0.355
Insufflation period						
- Group 0	67.86 ± 11.84	109.5 ± 14.68	10.91	82.57 ± 11.15	98.11 ± 1.67	42.09 ± 6.08
- Group I	70.05 ± 11.78	115.9 ± 21.00	71.35 ± 9.17	86.66 ± 11.65	98.03 ± 1.69	42.32 ± 6.24
- *p*	0.293	0.182	0.095	0.063	0.073	0.89
Emergence period						
- Group 0	75.72 ± 15.99	124.2 ± 16.20	76.76 ± 11.88	93.07 ± 12.34	98.85 ± 1.59	83.19 ± 6.98
- Group I	78.97 ± 17.46	131.3 ± 20.43	79.51 ± 15.55	96.85 ± 15.57	98.54 ± 1.60	84.46 ± 5.04
- *p*	0.349	**0.0391***	0.387	0.184	0.14	0.25
PACU						
- Group 0	83.21 ± 11.74	145.5 ± 17.96	11.99	106.5 ± 12.57	94.56 ± 2.38	-
- Group I	84.56 ± 10.56	150.3 ± 23.07	83.92 ± 12.65	109.5 ± 16.24	92.86 ± 4.436	-
- *p*	0.289	0.259	0.847	0.342	0.079	-

HR Heart rate, *SBP* Systolic blood pressure, *DBP* Diastolic blood pressure, *SPO2* Oxygen saturation, *BIS* Bispectral index, *PACU* Post-anesthesia care unit

Data are presented as mean ± standard deviation (*p < 0.05)

values. Preoperative SPO2 values were higher in group 0 compared to group I at a statistically significant level (97.04 ± 2.13 vs. 95.92 ± 2.36, p = 0.00902). During the emergence period, the SBP value was lower in group 0 compared to group I, which was also statistically significant (124.2 ± 16.20 vs. 131.3 ± 20.43, p = 0.0391). Other values did not show significant differences (p > 0.05).

During the intraoperative insufflation period, respiratory parameters were as follows: ETCO2, 35.29 ± 6.20 in group 0 and 35.29 ± 6.20 in group I (p = 0.047); plateau pressure 19.12 ± 2.61 in group 0 and 20.51 ± 2.19 in group I (p = 0.003); peak pressure, 19.60 ± 2.58 in group 0 and 21.05 ± 2.08 in group I (p = 0.002); respiratory rate, 12.65 ± 3.24 in group 0 and 12.89 ± 2.76 in group I (p = 0.675); tidal volume, 435.43 ± 6.87 in group 0 and 440.02 ± 4.72 in group I (p = 0.125); and PEEP, 7.42 ± 3.37 in group 0 and 7.94 ± 2.53 in group I (p = 0.224). Differences were significant for ETCO2, plateau pressure, and

Table 3 Respiratory parameters of patients

Insufflation period	Group 0	Group I	p
RR	12.65 ± 3.24	12.89 ± 2.76	0.675
TV	435.43 ± 6.87	440.02 ± 4.72	0.125
PEEP	7.42 ± 3.37	7.94 ± 2.53	0.224
$ETCO_2$	35.29 ± 6.20	36.38 ± 2.77	0.047*
$P_{plateau}$	19.12 ± 2.61	20.51 ± 2.19	0.003*
P_{peak}	19.60 ± 2.58	21.05 ± 2.08	0.002*
Emergence period			
RR	14.09 ± 2.33	13.51 ± 2.76	0.211
$ETCO_2$	34.09 ± 4.56	35.54 ± 3.13	0.018*
$P_{plateau}$	18.70 ± 4.55	20.32 ± 4.21	0.007*
P_{peak}	19.23 ± 5.49	21.70 ± 4.27	0.006*

RR respiratory rate, *TV* tidal volume, *ETCO2* end-tidal carbon dioxide, *Pplateau* plateau pressure, *Ppeak* peak pressure

*Data are presented as mean ± standard deviation (*p < 0.05)*

Table 4 Encountered complications

	Group I $n = 37$	All patients $n = 199$
Persistent cough	12 (33%)	6.04%
Desaturation	9 (24%)	4.53%
Bronchospasm	8 (22%)	4.02%
Agitation	3 (8%)	1.5%
Need for rescue mask ventilation	3 (8%)	1.5%
Airway obstruction	2 (5%)	1%

peak pressure ($p < 0.05$), but not for respiratory rate, tidal volume, or PEEP values (Table 3).

During the emergence period, respiratory parameters were as follows: ETCO2, 34.09 ± 4.56 in group 0 and 35.54 ± 3.13 in group I ($p = 0.0184$); plateau pressure, 18.70 ± 4.55 in group 0 and 20.32 ± 4.21 in group I ($p = 0.007$); peak pressure, 19.23 ± 5.49 in group 0 and 21.70 ± 4.27 in group I ($p = 0.006$); and respiratory rate, 14.09 ± 2.33 in group 0 and 13.51 ± 2.76 in group I ($p = 0.211$). Significant statistical differences were found for ETCO2, plateau pressure, and peak pressure values ($p < 0.05$) (Table 3).

The incidence of complications following extubation with PSV and PEEP was 18.59%. Complications included persistent cough in 12 patients (6.04%), desaturation in nine patients (4.53%), bronchospasm in eight patients (4.02%), agitation in three patients (1.5%), need for rescue mask ventilation in three patients (1.5%), and airway obstruction in two patients (1%) (Table 4). None of the patients required intensive care unit admission or had prolonged hospital stays.

Discussion

This study aimed to examine the effects of extubation using PSV and PEEP and showed that 18.59% of patients experienced at least one respiratory complication, with persistent cough being the most common.

The concept of uneventful extubation following general anesthesia is defined as the absence of any adverse physiological responses that could arise from extubation, such as airway irritation, hemodynamic disturbances, airway/oropharyngeal injuries, respiratory depression, aspiration, and pulmonary edema. These complications are particularly common during awake extubation (Wong et al. 2021).

To eliminate atelectasis, one of the problems encountered following extubation, PSV used for weaning in intensive care units has begun to be utilized for extubation. Jeong et al. compared the use of pressure support during extubation to spontaneous ventilation in patients undergoing laparoscopic colectomy and robot-assisted laparoscopic prostatectomy. They found a lower incidence of atelectasis with PSV. This outcome was achieved in patients who underwent deep extubation. Furthermore, the authors reported that PSV reduced the risk of atelectasis, hypoxia, and extubation failure regardless of patient age, BMI, cardiovascular disease, ASA physical status, or anesthesia duration (Jeong et al. 2021). Unlike that study, we applied PSV and 5 cmH2O PEEP to all patients at the end of surgery and focused on early complications. We observed that patients with higher ASA physical status and lower preoperative SPO2 levels. During the intraoperative insufflation period, ETCO2, Pplato, and Ppeak levels were higher than in the group without complications. During the emergence period (when PSV and PEEP were applied), ETCO2, Pplato, and Ppeak levels were found to be higher than in the group without complications. These findings indicate that patients who developed complications were at higher risk preoperatively, intraoperatively, and during the emergence period.

In group I, the proportion of patients with high ASA physical status was higher. Among these patients, we observed that the proportion of patients with asthma and COPD was particularly high. In previous studies, asthma, ASA > II and SPO2 < 95% were stated as risk factors for postoperative pulmonary complications (Gupta et al. 2020; Kumar et al.2023). In addition, advanced age and increased BMI are also risk factors for postoperative pulmonary complications (Qaseem et al. 2006). However, in our study, no difference was found between the groups in terms of patient age and BMI values.

Another method used to manage extubation issues is pharmacological agent-assisted extubation (intravenous lidocaine, dexmedetomidine, and remifentanil) (Wong et al. 2021). It has been reported that coughing affects 40–76% of patients during emergence from general anesthesia (Tung et al. 2020). Remifentanil, due to its short duration of action, suppresses reflex responses to the tracheal tube and acts on the medulla to prevent emergency coughing. Aouad et al. compared patients who received remifentanil infusion with a control group, finding a reduction in the frequency and severity of emergency coughing without prolonging the awakening time (40% vs. 80%) (Aouad et al. 2009). In our study, the most common complication was coughing ($n = 12$, 6.04%). However, our rate was considerably lower than that reported by Aouad et al. This could be attributed not only to remifentanil but also to the reduced airway irritation due to PSV, which decreases respiratory workload while promoting spontaneous breathing.

In our study, patients who experienced desaturation and bronchospasm were those with COPD GOLD 1–2 and/or smokers. The prevalence of emergence agitation, characterized by uncontrolled limb movements that can harm both the patient and healthcare workers, varies from 0.25 to 90.5% depending on the type and duration of surgery (Lee et al. 2020). Remifentanil has been reported to reduce the frequency of emergence agitation (Li et al. 2024). We consider that the low incidence of awakening agitation in our study is due to the use of remifentanil during extubation, along with the high gas flow washing of desflurane.

This study has several limitations. First, it had a single-center, randomized, controlled, prospective design without a control group, with all patients being included in the intervention group. Second, our evaluation was made only during the emergence period. Complications such as atelectasis, which are expected to occur later, were excluded from the evaluation.

In this study, the incidence of respiratory system complications was lower during extubation with PSV and PEEP in patients receiving remifentanil infusion compared to the literature (Popat et al. 2012; Baijal et al. 2015). Patients who developed complications had higher ASA scores and higher $ETCO_2$, Pplateau, and Ppeak values during intraoperative and extubation-emergence periods compared to those without complications. Nonetheless, the complications we encountered were minor and did not prolong postoperative hospital stays.

In conclusion, our findings indicate that the application of PSV and PEEP during extubation in patients undergoing laparoscopic cholecystectomy results in a lower incidence of respiratory complications during the emergence period. The complications observed were minor and did not prolong postoperative hospital stays. Therefore, PSV and PEEP can be used safely during the extubation phase in this type of surgery, however, since these complications are seen in patients with high ASA physical scores, further studies are needed for these patients.

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Authors' contributions
Study conception, design, validation: A.R.A. and D.C; data acquisition: A.R.A. and D.C; analysis: A.R.A, D.C. and F.Y; data interpretation: A.R.A. and D.C; drafting of the manuscript: A.R.A, D.C. and F.Y; review of the manuscript: A.R.A, D.C. and F.Y. All authors read and approved the submission and publication of this manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
Ethics Committee of Eskisehir Osmangazi University (15.03.2023/36). Verbal and written consent was obtained from patients included in the study.

Consent for publication
A consent form was filled out by all participants.

Competing interests
The authors declare no competing interests.

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