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ORIGINAL ARTICLE

The effect of lung-recruitment maneuver on postoperative shoulder pain in patients undergoing laparoscopic cholecystectomy: a randomized controlled trial

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Abstract

Purpose Lung-recruitment maneuvers (LRM) have been shown to reduce postoperative pain after laparoscopic surgery. This study aimed to investigate the association of LRM with the incidence of shoulder pain after laparoscopic cholecystectomy.

Methods A randomized controlled study was conducted with 110 patients undergoing elective laparoscopic cholecystectomy from July 2022 to March 2023. Participants were randomized to receive either routine exsufflation or LRM at pneumoperitoneum release. The postoperative shoulder pain and abdominal pain were assessed at 1, 4, 6, 12, and 24 h after surgery using a numeric rating scale. Analgesic consumption and postoperative nausea or vomiting (PONV) were evaluated during the first 24 h after surgery.

Results The incidence of shoulder pain during the first 24 h after surgery was significantly lower in the LRM group compared to the control group (26.9 vs. 59.3%; $P=0.001$). The median [interquartile range] score of worst shoulder pain was significantly lower compared to the control group (3 [2–3] vs 4 [3–5.5]; $P=0.003$). Participants in the LRM group showed reduced abdominal pain at rest at 4 and 24 h after surgery, and experienced significantly lower intensities of abdominal pain during mobilization at all time points over 24 h after surgery. There were no significant differences in opioid consumption or the incidence of PONV between the groups.

Conclusions LRM reduces both the incidence and intensity of shoulder pain during 24 h after laparoscopic cholecystectomy. Additionally, LRM was associated with reduced intensity of abdominal pain during mobilization over the study period.

Keywords Anesthesia · Cholecystectomy · Laparoscopy · Pneumoperitoneum · Postoperative pain · Shoulder pains

Introduction

Laparoscopic cholecystectomy (LC) is the standard treatment for symptomatic cholecystolithiasis and gallbladder disease [1]. Although LC is generally associated with low complication rates and rare mortality, post-laparoscopic shoulder pain frequently occurs in patients undergoing this procedure [2]. Shoulder pain, while often considered a minor and temporary complication, can be problematic as it is less responsive to analgesics compared to abdominal pain and may persist for several days after surgery, potentially decreasing patient satisfaction and impeding functional recovery [2].

The exact mechanism of shoulder pain remains unclear, but the prevailing hypothesis suggests that it is a referred pain originating from the diaphragm due to pneumoperitoneum. Pneumoperitoneum results in irritation by carbon dioxide (CO_2), stretching of the diaphragm and peritoneum, and the formation of a residual CO_2 pocket between the liver and the right diaphragm. A previous study has reported a positive correlation between the amount of pneumoperitoneum and the intensity of shoulder pain [3].

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In light of these theories, various interventions have been investigated to reduce shoulder pain after LC, including low-pressure insufflation of CO_2, preemptive anti-inflammatory medication, intra-abdominal local anesthetic irrigation, and regional anesthesia [4, 5]. However, many of these interventions require additional medical costs or hinder the surgical visual field, resulting in prolonged surgical time. A lung-recruitment maneuver (LRM) has been proposed as a simple method to prevent postoperative shoulder pain [6–10]. Previous research has primarily focused on investigating the effect of LRM on postoperative shoulder pain in gynecologic surgeries [6, 8–10]. However, the applicability of these findings to LC may be limited due to several key differences. One significant difference lies in the surgical positioning and pneumoperitoneum duration between gynecologic surgeries and LC. Additionally, the use of uncontrolled anesthetic and opioid regimens, coupled with the absence of a control group with routine CO_2 evacuation in previous investigations, further complicates the generalizability of the previous results. Particularly in LC, although a few studies have reported the effect of LRM on reducing shoulder pain [11, 12], they did not investigate the differences in pneumoperitoneum volume between groups, which is proposed as the underlying mechanism. Furthermore, methodological issues regarding LRM application indicate that more data are needed to apply LRM in clinical practice.

We hypothesized that LRM could potentially reduce the frequency and intensity of shoulder pain during 24 h after laparoscopic cholecystectomy eliminating residual pneumoperitoneum after cholecystectomy. Therefore, this study aimed to investigate the association between LRM and shoulder pain during 24 h after LC. Additionally, we investigated the potential association between LRM and postoperative pain.

Materials and methods

This prospective controlled trial was conducted at a tertiary hospital in Seoul, Republic of Korea, from July 2022 to March 2023. The study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the institutional review board at Samsung Medical Center (SMC 2022-06-011-002) on June 21, 2022. The trial was prospectively registered with the Clinical Research Information Service in the Republic of Korea (https://cris.nih.go.kr/; June 30, 2022). Informed consent was obtained from all participants before enrollment.

Study participants

Patients aged between 18 and 70 years with an American Society of Anesthesiologists physical status classification of I or II who were scheduled for elective laparoscopic cholecystectomy were included. Patients were excluded if they had acute cholecystitis, pancreatitis, cholangitis, or previous endoscopic retrograde biliary drainage. Patients with a history of upper abdominal surgery were also excluded.

Randomization and blinding

Participants were randomly allocated to either the control group or the LRM group using a randomization sheet with a block size of four. Randomization information was securely sealed in opaque envelopes, which were opened only immediately before anesthesia induction.

All participants, surgeons, and outcome assessors were blinded to the allocation. The investigator measuring the patients' pain scores and the amount of pneumoperitoneum by chest radiograph did not know which group the patients were allocated to.

Anesthesia and postoperative analgesia

General anesthesia was induced by an independent attending anesthesiologist using 2 mg/kg of propofol and 0.8 mg/kg of rocuronium. Anesthesia was maintained with sevoflurane. The ventilator (*Dräger Primus* Infinity® Empowered; Dräger Medical GmbH) was set to deliver a tidal volume of 6 ml/kg (ideal body weight) and a positive end-expiratory pressure (PEEP) of 5 cmH_2O using the volume-guaranteed pressure-control mode. The respiratory rate was adjusted to maintain the end-tidal CO_2 level between 38 and 40 mmHg. During surgery, CO_2 insufflation was maintained at a pressure of 12 mmHg and an average flow of 20 L/min for pneumoperitoneum. At the end of the surgery, all patients received intravenous fentanyl (0.5 mcg/kg) for pain control.

Postoperative analgesia followed institutional protocols. In the post-anesthesia care unit, intravenous acetaminophen (500 mg) or ketorolac (30 mg) was administered to patients reporting a breakthrough pain score of ≥ 4 points on a numeric rating scale (NRS) (0–10 points, 0 points = no pain, 10 points = worst imaginable pain). If these analgesics proved ineffective, intravenous pethidine (0.5 mg/kg) was administered. Postoperative nausea and vomiting (PONV) was treated with intravenous ramosetron (0.3 mg).

In the general ward, intravenous ibuprofen (400 mg) was administered for breakthrough pain on the day of surgery. If the patients experienced breakthrough pain despite ibuprofen administration, intravenous pethidine (50 mg) was added. If pethidine proved ineffective for pain control, other types of rescue opioids could be administered at the surgeon's discretion. On the day after surgery, oral Cetamadol (acetaminophen 325 mg with tramadol 37.5 mg) was administered as a regular analgesic.

Intervention

All surgeries were conducted using a 3-port technique, which included inserting a 10-mm umbilical port, a 10-mm xiphoid port, and a 5-mm subcostal port. After retrieving the gallbladder through the umbilical port, participants were positioned in the reverse Trendelenburg position, and all ports were removed under direct vision. The surgeon then closed the two upper trocar sites with gauze and Allis forceps and opened the umbilical trocar site using mosquito forceps. Following this, the surgeon manually compressed the participants' abdomen for CO_2 evacuation for 2 min. In the control group, ventilator settings were maintained. Meanwhile, in the LRM group, an investigator completed the ventilator-piloted LRM, which was performed based on the previous work [6, 8, 13]; specifically, we switched the ventilator to pressure-control mode and increased positive inspiratory pressure (PIP) in stepwise increments as follows: two cycles using 5 cmH_2O of PIP (above PEEP) and 20 cmH_2O of PEEP, two cycles using 10 cmH_2O of PIP and 20 cmH_2O of PEEP, and two cycles using 15 cmH_2O of PIP. Finally, the patients received six breaths for 1 min with 20 cmH_2O of PIP and 20 cmH_2O of PEEP (i.e., total pressure of 40 cmH_2O). Total airflow was 6 L/min during intervention. We monitored hemodynamic variables, including heart rate and blood pressure, immediately before and after LRM. In cases of bradycardia (heart rate < 45 beats/min) or hypotension (a 20% or more reduction from the pre-LRM value), attending anesthesiologists administered treatment at their discretion. Following the intervention, the surgeon proceeded to suture the trocar site, concluding the surgical procedure.

Outcomes

The primary outcome of the study was the incidence of shoulder pain during the first 24 h after surgery. Shoulder pain was defined as any pain in either shoulder, with an NRS of 1 or higher.

Secondary outcomes included the scores of worst shoulder pain during 24 h after surgery, and the scores of shoulder pain and abdominal pain at predetermined time points within the same period. Additionally, we collected data on analgesic requirements including opioid consumption and rescue analgesic requirements, sleep quality on the first night after surgery, and satisfaction with analgesia. Furthermore, we investigated the estimated volume of residual pneumoperitoneum and any adverse events during 24 h after surgery.

Baseline characteristics were extracted from the electronic medical records. The intensity of shoulder and abdominal pain was assessed using an NRS at 1, 4, 6, 12, and 24 h after surgery. Additionally, postoperative abdominal pain at rest (resting pain) and during movement (dynamic pain) was also evaluated using the NRS at aforementioned time points. To assess the worst shoulder pain, patients were requested to log their worst shoulder pain using NRS during 24 h after surgery. Opioid doses were converted to intravenous morphine-equivalent dose. The sleep quality on the first night was rated using the NRS (0–10 points, 0 points = the worst night's sleep, 10 points = the best night's sleep) and satisfaction with analgesia was assessed using Likert scale [1–5 point(s), 1 point = very dissatisfied, 5 points = very satisfied]. PONV was assessed using a PONV impact scale [14], and rescue antiemetics administration was recorded.

All participants underwent posteroanterior chest radiography in erect position at 8 h after the surgery. The chest radiographs were reviewed by two blinded investigators to calculate the extent of pneumoperitoneum, upon the study completion. The amount of pneumoperitoneum was calculated based on the height and length of the pneumoperitoneum arc formed in the subdiaphragmatic space on the chest radiograph (Fig. 1) [15].

We observed the occurrence of hemodynamic instability and barotrauma resulting from the intervention. Hemodynamic instability was defined as hypotension, characterized by a reduction of 20% or more from the baseline value or a mean blood pressure of less than 65 mmHg. Barotrauma included pneumothorax, pneumomediastinum, and subcutaneous emphysema, confirmed by ventilation-related variables and postoperative chest radiograph. Additionally, any adverse events occurring within 24 h after surgery were recorded.

Sample size calculation and statistical analysis

Sample size calculation was based on a pilot study (unpublished data) conducted at our institution. In the pilot data, the incidence of shoulder pain was 33.3% in the control group and 9.99% in the LRM group, respectively. With an alpha value of 0.05 and a power of 80%, 48 patients were required for each group. Accounting for an attrition rate of 10%, the study sample size was set at 55 patients per group.

Data are shown as mean ± standard deviation, median (interquartile range), or number of patients (proportion). The normality of distribution was assessed with the Shapiro–Wilk test. Parametric and non-parametric data were analyzed using a two-sample *t* test and the Mann–Whitney *U* test, respectively. Categorical data were analyzed using the Chi-squared test. The relationship between the volume of the residual pneumoperitoneum and postoperative worst pain was analyzed using Spearman correlation analysis. When the interaction was statistically significant, the adjusted *P* value was obtained with Bonferroni correction for multiple comparisons. $P < 0.05$ was considered statistically significant. Statistical analyses were performed using commercially available software (SPSS version 28.0; IBM Corp.).

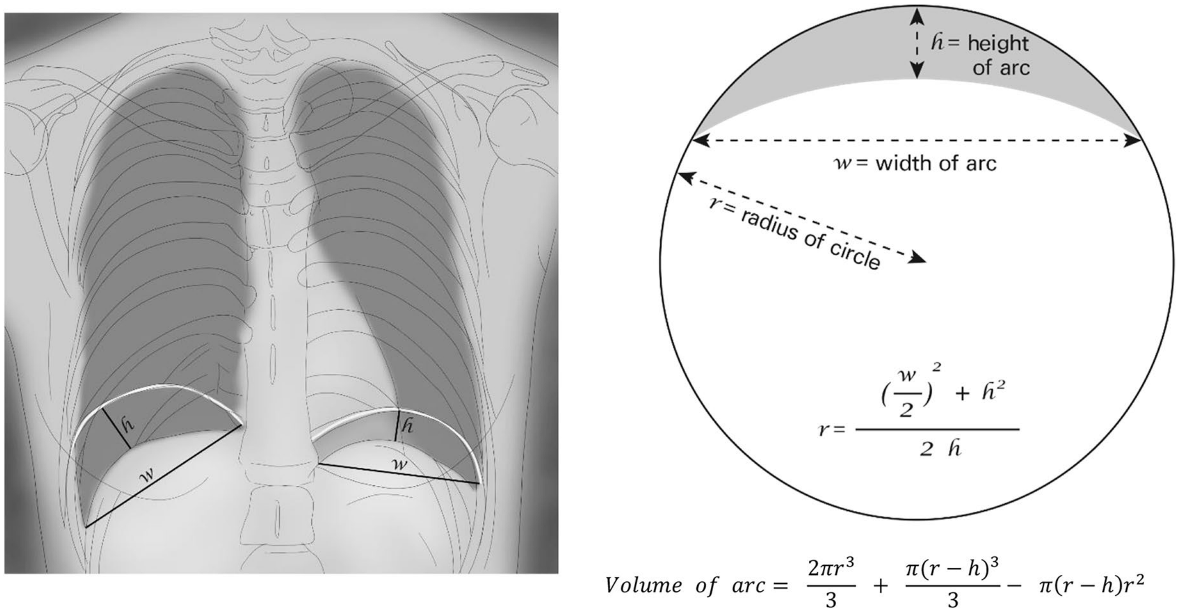

Fig. 1 Pneumoperitoneum estimation on chest radiograph. The amount of pneumoperitoneum was estimated by the volume of the arc on the chest radiograph using the following formula

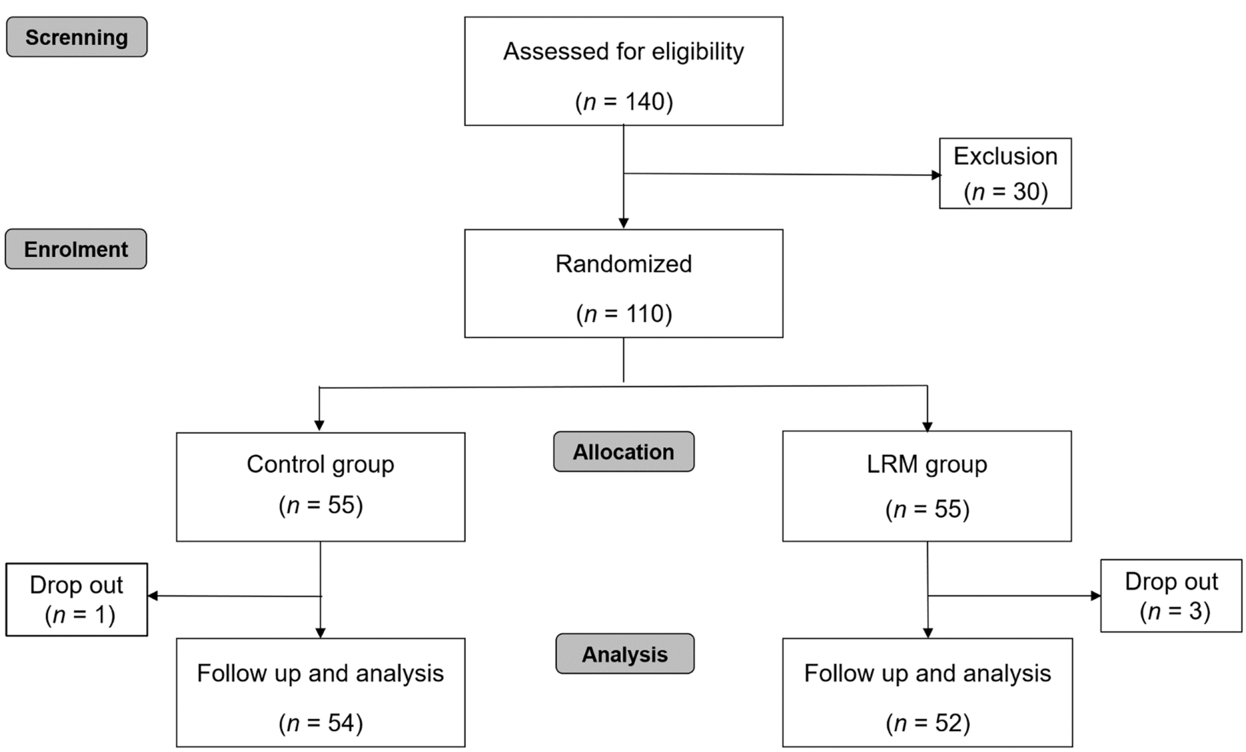

Fig. 2 Consolidated standards of reporting trials flow diagram of the study

Results

Between July 2022 and March 2023, a total of 140 patients who underwent laparoscopic cholecystectomy were assessed for eligibility. Of these, 110 participants were enrolled, with 106 completing the study (Fig. 2). Four patients dropped out after randomization: one due to conversion to open surgery in the control group, one due to colicky pain before surgery in the LRM group, and two due to schedule alterations in the LRM group. Baseline characteristics and intraoperative variables showed no significant differences between the groups (Table 1). Pain profiles and the postoperative variables recorded within the first 24 h after surgery are presented in Table 2.

Pain profiles after surgery

Approximately 43.4% of patients reported shoulder pain within the first 24 h post-surgery. The incidence of shoulder pain was significantly lower in the LRM group during the first 24 h after surgery, compared to the control group. (26.9% vs. 59.3%; $P = 0.001$). The median worst shoulder pain score was also lower in the LRM group compared to the control group (0 vs. 3 points; difference, 1 [95% Confidence Interval (CI), 0–3]; $P = 0.002$). Resting pain scores were lower in the LRM group at both 4 and 24 h after surgery compared to the control group (Table 2). Dynamic pain scores showed a consistent reduction in the LRM group throughout the study period. However, opioid consumption and the number of rescue analgesic administrations did not significantly differ between the two groups. Although sleep quality on the first night after surgery was similar between the groups, overall satisfaction with analgesia was higher in the LRM group compared to the control group.

Pneumoperitoneum estimation

Analysis of chest radiograph revealed a larger volume of pneumoperitoneum in the control group compared to the LRM group (17.12 vs. 2.73 mL; difference, 8.24 [95% CI, 1.33–22.45]; $P = 0.003$). Interestingly, there was a positive

Table 1 Patient characteristics and intraoperative variables

Baseline characteristics	Control group ($N = 54$)	LRM group ($N = 52$)	Standardized difference
Age, years	47 ± 13	49 ± 11	−0.188
BMI, kg/m^2	25 ± 4	25 ± 4	−0.069
ASA physical status (I; II)	30 (55.6); 23 (44.2)	24 (44.4); 29 (55.8)	n.a
Male; female	27 (50); 27 (50)	21 (40.4); 31 (59.6)	n. a
Comorbidity			n.a
Hypertension	9 (16.7)	4 (7.7)	
Diabetes mellitus	2 (3.7)	4 (7.7)	
Liver dysfunction	3 (5.6)	2 (3.8)	
Indication for surgery			n.a
Asymptomatic gallstone	37 (68.5)	33 (63.4)	
Gall bladder adenomyomatosis	1 (1.9)	3 (5.8)	
Gall bladder polyp	10 (18.5)	13 (25)	
Multiple cause	6 (11.1)	3 (5.8)	
Intraoperative variables			
Anesthetic time, min	62 [57–69]	64 [57–71]	0.007
Crystalloid, mL/h	200 [200–300]	200 [150–250]	0.256
Estimated blood loss, mL	30 [20–50]	30 [20–50]	0.294
Heart rate before LRM	78 [70–88]	75 [67–81]	0.200
Heart rate after LRM	77 [72–88]	78 [68–87]	0.048
Mean blood pressure before LRM	94 [85–107]	92 [81–103]	0.158
Mean blood pressure after LRM	97 [88–106]	86 [69–99]	0.662
Adverse event in OR[a]	0 (0.0)	2 (3.8)	n.a

Values are presented as mean ± SD, median [IQR], or frequency (%)

ASA American Society of Anesthesiologists, *IQR* interquartile range, *LRM* lung-recruitment maneuver, *OR* operating room, *SD* standard deviation

[a]Adverse events included one patient experiencing laryngospasm after extubation, and another patient experiencing severe hypotension requiring treatment

Table 2 Pain profiles and postoperative variables

Parameter	Control group (*N* = 54)	LRM group (*N* = 52)	Difference of medians (95% CI)	*P* value*
Incidence of shoulder pain	32 (59.3)	14 (26.9)	n.a	0.001[c]
Shoulder pain, NRS (0–10)[a]				
Worst shoulder pain	3 [0–5]	0 [0–1]	1 (0–3)	0.002
1 h	0 [0–0]	0 [0–0]	0 (0 to 0)	0.090[d]
4 h	0 [0–2]	0 [0–0]	0 (0 to 0)	0.150[d]
6 h	0 [0–2]	0 [0–0]	0 (0 to 0)	0.005[d]
12 h	0 [0–2]	0 [0–0]	0 (0 to 0)	0.170[d]
24 h	0 [0–3]	0 [0–0]	0 (0 to 0)	< 0.001[d]
Among the patients with shoulder pain, NRS (0–10)	*n* = 32	*n* = 14		
Worst shoulder pain	4 [3–6]	3 [2–3]	2 (1 to 3)	0.003[d]
1 h	0 [0–1]	0 [0–0]	0 (0 to 0)	0.168[d]
4 h	0.5 [0–3]	0.5 [0–3]	0 (0 to 1)	0.590[d]
6 h	2 [0–4]	0 [0–2]	1 (0 to 3)	0.035[d]
12 h	2 [0–3]	2 [1–3]	0 (-1 to 1)	0.959[d]
24 h	2 [0–4]	0 [0–1]	2 (0 to 3)	0.012[d]
Abdominal pain at rest, NRS (0–10)[a]				
1 h	5 [4–7]	4 [3–6]	1 (0 to 1)	0.120[d]
4 h	4 [3–5]	3 [2–4]	1 (0 to 1)	0.010[d]
6 h	3 [2–4]	3 [2–3]	0 (0 to 1)	0.405[d]
12 h	3 [2–4]	3 [2–3]	1 (0 to 1)	0.300[d]
24 h	3 [2–3]	2 [1–2]	1 (0 to 1)	0.025[d]
Abdominal pain during mobilization, NRS (0–10)[a]				
1 h	7 [6–8]	6 [5–7]	1 (0 to 2)	0.020[d]
4 h	6 [5–7]	5 [3–6]	1 (1 to 2)	< 0.001[d]
6 h	5 [4–7]	4 [3–5.5]	1 (0 to 2)	0.015[d]
12 h	5 [4–7]	5 [3–5]	1 (0 to 2)	0.020[d]
24 h	5 [3–5]	3 [3–4]	1 (0 to 2)	0.005[d]
Opioid consumption, mg	8 [4–13]	5 [3–12]	1 (0 to 4)	0.195[d]
Rescue analgesics administration	5 [4–5]	4 [3–5]	1 (0 to 1)	0.072[c]
First night's sleep quality	6 [5–8]	7 [5–9]	−1 (−2 to 0)	0.070[d]
Satisfaction for analgesia	4 [3–4]	5 [4–5]	−1 (−1 to−1)	< 0.001[d]
PONV	33 (61.1)	32 (61.5)	n.a	0.880[c]
PONV impact scale	2 [1–3]	2 [1–2]	0 (0 to 1)	0.243[d]
Rescue antiemetics administration	20 (37.0)	22 (42.3)	n.a	0.579[c]
Amount of pneumoperitoneum, mL	17 [2–87]	3 [0–16]	8 (1 to 23)	0.001[c]
Adverse event during 24 h after surgery[b]	0 (0.0)	3 (5.8)	n.a	0.115[e]

*p-value of less than 0.05 is considered statistically significant

Values are presented as median [IQR], or number (%). Opioid consumption is converted to intravenous morphine-equivalent dose

CI confidence interval, *IQR* interquartile range, *LRM* lung-recruitment maneuver, *OR* operation room, *PONV* postoperative nausea and vomiting, *SD* standard deviation

[a]Individual *P* values were adjusted using Bonferroni correction for repeated measures of pain scores. *P* value is set to 0.05

[b]Adverse events observed during 24 h after surgery included one patient experiencing chest pain and two patients exhibiting desaturation events ($SpO_2 < 92\%$), necessitating transient oxygen supplementation

[c]Chi-squared test

[d]Mann–Whitney *U* test

[e]Fisher's exact test

correlation between pneumoperitoneum volume at 8 h after surgery and the scores of worst shoulder pain during the first 24 h after surgery ($r = 0.452$, $P < 0.05$), suggesting a potential contributing factor to postoperative shoulder pain. However, no significant correlation was found between pneumoperitoneum volume and postoperative resting pain or dynamic pain (Supplement 1).

The incidence of PONV was comparable between the groups. Among patients experiencing PONV, the severity and the number of rescue antiemetic administrations did not exhibit significant differences between the groups.

During and before/after LRM, hemodynamic changes were not significant in either group, except for one patient in LRM group (Table 1 and Supplement 2). The patient received medication due to severe hypotension (mean blood pressure 44 mmHg) after LRM and recovered with a systolic blood pressure above 90 mmHg. Within 24 h after surgery, one patient experienced chest pain and two patients in the LRM group experienced desaturation with $SpO_2 < 92\%$, requiring O_2 supplementation. There were no complications associated with barotrauma resulting from the intervention.

Discussion

In this study, we found that the incidence and intensity of shoulder pain during the first 24 h after surgery were significantly reduced in the LRM group compared to the control group. Interestingly, the intensity of abdominal pain in the LRM group was also lower than that in the control group, particularly evident in pain at rest at 4 and 24 h after surgery, and during mobilization across the entire study period.

The findings of the current research indicate that the implementation of LRM is effective in reducing shoulder pain, consistent with the previous studies [6–8, 11–13]. While the exact mechanism of shoulder pain has not been clearly identified, the previous studies have suggested that CO_2 gas plays a significant role in the development of shoulder pain. Currently, shoulder pain is considered to be referred pain originating from the diaphragm, with irritation and stretching of the diaphragm and peritoneum due to CO_2 and intraabdominal acidosis being considered possible mechanisms. We attribute the reason for reduced shoulder pain to the reduction in CO_2 gas in the peritoneal cavity by LRM. As high PEEP is applied during LRM, the diaphragm moves downward, and intra-abdominal pressure also increases, facilitating CO_2 evacuation from the trocar site. We believe that this manipulation may provide pain relief by reducing residual pneumoperitoneum in the abdominal cavity and thereby reducing irritation of the diaphragm and peritoneum caused by CO_2. The analysis of chest radiograph in this study demonstrates that the LRM technique effectively eliminates CO_2 gas from the peritoneal cavity. The positive correlation between the volume of postoperative pneumoperitoneum and shoulder pain supports our hypothesis, distinguishing our findings from previous studies.

One notable benefit of LRM in laparoscopic surgery is the lower intensity of postoperative abdominal pain. Postoperative pain arises from the surgical site (somatic pain) and the viscera (visceral pain) [16, 17]. The reduced pneumoperitoneum results in less peritoneal irritation, leading to lower postoperative abdominal pain intensity by alleviating visceral pain. However, there was no direct correlation between the volume of pneumoperitoneum and the intensity of abdominal pain. This lack of correlation can be attributed to various surgical traumas contributing to abdominal pain (somatic pain) beyond just pneumoperitoneum. However, several studies in gynecologic surgery reported that LRM did not reduce postoperative abdominal pain, which is not congruent with our findings [18, 19]. This discrepancy may be attributed to differences in the procedural site (upper abdomen vs. pelvic cavity), operation time (shorter vs. longer), and patient position during surgery (reverse Trendelenburg vs. Trendelenburg). The Trendelenburg positioning and longer pneumoperitoneum duration in gynecologic surgeries contribute to more significant intraoperative atelectasis [20, 21], potentially interfering with the re-expansion of atelectatic lungs and the downward movement of the diaphragm. There is a possibility that insufficient CO_2 evacuation due to intense atelectasis results in ineffectiveness in pain relief for gynecologic surgeries.

Another potential benefit of LRM, in contrast with various interventions to decrease intraperitoneal CO_2 gas, is its usefulness in addressing pulmonary atelectasis, which commonly occurs during laparoscopic surgery [22, 23]. While other interventions require additional cost, time, and specialized equipment, timely implementation of LRM can reduce postoperative shoulder pain and re-expand collapsed alveoli after laparoscopic surgery, providing a dual benefit without requiring additional medical resources. However, it is important to note that in our study, there was no significant difference in the frequency of postoperative pulmonary complications between the groups.

Applying LRM to the general population undergoing laparoscopic surgery requires careful screening of appropriate candidates. In this study, the incidence of shoulder pain decreased by approximately 45%, and for those experiencing shoulder pain, LRM reduced pain scores by about 2 points. However, these benefits may not outweigh the possible risks of LRM, such as hemodynamic instability and lung injury in vulnerable patients. LRM could potentially raise the risk of lung injury in patients with preexisting pulmonary conditions, such as emphysema [24]. Although we did not observe any pulmonary complications related to LRM during the study period, it should be noted that the scope of this study was limited to patients with

ASA classifications I and II, and patients with lung disease were excluded. Furthermore, LRM may induce unintended hemodynamic changes [25, 26]. Although recent meta-analyses have reported that the transient application of LRM does not increase the risk of cardiopulmonary complications [6], we observed a case of severe hypotension (systolic blood pressure of 56 mmHg) induced by LRM, which was rapidly corrected with pharmacological intervention. This underscores the importance of carefully evaluating the risk–benefit ratio when considering LRM, especially in patients with potential vulnerabilities. Intensive medical attention from anesthesiologists is crucial both before and after LRM to ensure patient safety.

This study has several limitations. First, as mentioned above, the study included only patients classified as ASA-PS I or II, who are generally considered healthy. Therefore, the findings may not be generalizable to the other types of laparoscopic surgeries that involve different patient positions, operation times, and patient characteristics. Second, we applied the relatively high PIP and PEEP to all patients. However, a previous study based on CT imaging suggested that a recruited pressure of 40 cm H_2O was effective in reversing pulmonary atelectasis [27]. Furthermore, the PIP and PEEP used in this study adhere to the same settings as those in the previous literature [6, 8, 13]. Additionally, to prevent possible adverse events, we cautiously increased PIP stepwise in a ventilator-piloted manner. It is important to note that vulnerable patients were pre-excluded based on chest radiograph and pulmonary function tests. Future studies could explore individualized PIP and PEEP titration, taking into account the individual's lung compliance. Third, the mechanism of pain relief is not fully elaborated. While our results suggested that LRM might be associated with pain relief in abdominal pain, we cannot provide conclusive evidence. Finally, while LRM effectively alleviated both shoulder pain and abdominal pain, and increased patient satisfaction with pain relief, it did not result in reduced opioid consumption. This suggests that the clinical relevance of these findings may be potentially diminished. It is probable that laparoscopic cholecystectomy, being considered a minor surgery with originally low levels of pain, was not associated with a reduction in opioid consumption.

In conclusion, our study demonstrates that LRM significantly reduces the incidence of shoulder pain in patients undergoing laparoscopic cholecystectomy. Additionally, LRM was associated with a reduction in the intensity of worst shoulder pain and abdominal pain without any evident adverse events.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00540-024-03403-8.

Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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