Surgical Endoscopy (2019) 33:870–878
https://doi.org/10.1007/s00464-018-6354-2

Comparison of impacts of intraperitoneal saline instillation with and without pulmonary recruitment maneuver on post-laparoscopic shoulder pain prevention: a randomized controlled trial

Kyoung-Ho Ryu[1] · Sung Hyun Lee[1] · Eun-Ah Cho[1] · Ji-A Kim[1] · Go-Eun Lim[1] · Taejong Song[2]

Received: 26 March 2018 / Accepted: 6 July 2018 / Published online: 16 July 2018

Abstract

Background Intraperitoneal isotonic saline instillation (SI) and pulmonary recruitment maneuver (RM) were indicated to alleviate post-laparoscopic shoulder pain (PLSP) effectively. The aim of this study was to compare the effects of the single strategy using SI alone and the combined strategy using SI and RM on PLSP reduction.

Methods Subjects undergoing elective gynecologic laparoscopy were randomly allocated to a control group (no intervention, $n=48$) and two intervention groups (single strategy of SI alone, $n=48$; combined strategy of SI and RM, $n=48$). In the control group, carbon dioxide was removed only via passive evacuation through the port sites at the completion of the laparoscopic procedure. In the saline instillation group, 20-mL/kg of body weight SI was performed. In the combined strategy group, RM using five pulmonary inflations was performed, in addition to SI. The PLSP scores, which were the primary outcome, were recorded using a visual analog scale postoperatively.

Results The PLSP scores 24 and 48 h after surgery were significantly lower in the two intervention groups than in the control group ($P=0.014$ and $P=0.001$, respectively), while no significant differences were observed between the two intervention groups.

Conclusions The single strategy using SI alone is as effective as the combined strategy of SI and RM for removing residual carbon dioxide and consequently preventing PLSP. Therefore, considering the potential risks of pulmonary or hemodynamic complications associated with RM, the single strategy using SI alone might be a better choice than the combined strategy.

Keywords Shoulder pain · Saline instillation · Pulmonary recruitment maneuver · Laparoscopy

In recent surgical practice, laparoscopy is replacing conventional laparotomy owing to its several advantages such as improved postoperative respiratory function, decreased analgesic requirements, shortened hospital stay, lower complication rates, and earlier return to daily activities [1, 2]. Most of these advantages result from the alleviated postoperative pain compared with that in laparotomy [3]. Despite the overall reduction in pain intensity, a substantial number of patients complain of post-laparoscopic shoulder pain (PLSP), which rarely occurs in conventional laparotomy [4].

The precise pathophysiology of PLSP has not been well elucidated. The most accepted mechanism is that residual carbon dioxide (CO_2) after laparoscopy is trapped between the liver and the diaphragm, from which the formation of carbonic acid induces diaphragmatic irritation, leading to PLSP [5, 6]. Therefore, several methods to remove residual CO_2 efficiently have been introduced [7, 8]. Two promising strategies to reduce PLSP by removing residual CO_2 have been widely investigated [9, 10]. The first strategy involves the use of intraperitoneal isotonic saline instillation (SI). By filling the peritoneal cavity with warmed isotonic saline, CO_2 rises and escapes via the laparoscopic port sites, and the carbonic acid present on the peritoneal surfaces of the

Drs. Kyoung-Ho Ryu and Sung Hyun Lee contributed equally to this article.

✉ Taejong Song
taejong.song@gmail.com

[1] Department of Anesthesiology and Pain Medicine, Kangbuk Samsung Hospital, Sungkyunkwan University School of Medicine, 29 Saemunan-ro, Jongno-gu, Seoul 03181, Republic of Korea

[2] Department of Obstetrics and Gynecology, Kangbuk Samsung Hospital, Sungkyunkwan University School of Medicine, Seoul, Republic of Korea

diaphragm is washed out [9–11]. The second strategy, i.e., recruitment maneuver (RM), involves alveolar hyperinflation using positive airway pressure, which increases intrathoracic pressure. As a result, intraperitoneal pressure increases indirectly and facilitates the removal of residual CO_2 from the peritoneal cavity [8–10, 12–14].

A combination of the two strategies described above has been shown to reduce PLSP efficiently [9, 13, 15]. However, as SI and RM act through a similar mechanism of removing residual CO_2 from the peritoneal cavity, it is debatable whether the combined strategy using both interventions is superior to the single strategy using either of them in reducing PLSP. However, there has been no direct comparison between the single strategy using SI alone and combined strategy using SI and RM. Therefore, this study was designed to compare the effectiveness of the single strategy using SI alone with the combined strategy using SI and RM on the reduction of PLSP.

Materials and methods

Subjects and study design

This prospective randomized trial was approved by our institutional ethics committee (Kangbuk Samsung Hospital Institutional Review Board, Seoul, Republic of Korea; approval number: KBSMC 2016-05-048) and was registered at ClinicalTrials.gov (ID: NCT02811081; principal investigator: T. Song; date of registration: June 21, 2016; https://clinicaltrials.gov/ct2/show/NCT02811081) before the first patient's participation; this study also followed the tenets of the Declaration of Helsinki. All eligible women were asked to participate in this study. Written informed consents were obtained from all participating women aged 19–65 years with an American Society of Anesthesiologists physical status classification I–II who were scheduled for benign gynecologic laparoscopic surgery. The exclusion criteria were as follows: inability to understand the pain scale or to express their pain accurately; pregnancy at the time of surgery; history of pulmonary or shoulder surgery; pulmonary diseases, such as pneumothorax or emphysema; chronic shoulder pain; and conversion to laparotomy or incidental upper abdominal procedures owing to injury or adhesion.

The subjects were randomly allocated to three groups of equal numbers to determine the intervention to reduce PLSP using a random-permuted block randomization algorithm via a web-based response system (http://www.randomization.com). The subjects were randomized at the end of the laparoscopic procedure. Blinding of allocation was performed using serially numbered opaque envelopes, each containing a folded paper stating the assigned group, which was kept and opened by an independent researcher in a laboratory distant from the hospital. The group assignment was not changed after the envelope was opened.

Study protocol

Anesthesia was performed in an identical manner in all groups. Intramuscular glycopyrrolate (0.2 mg) was administered as a premedication. Anesthesia was induced using intravenous propofol (2 mg/kg) and remifentanil (1 μg/kg). After rocuronium (0.6 mg/kg) was administered for neuromuscular block, the trachea was intubated using a cuffed tube. Anesthesia was maintained using sevoflurane at 1.5–2.0 vol% and continuous remifentanil infusion of 0.05–0.1 μg/kg/min to achieve a state entropy of 40–60. During the laparoscopic procedures, a train-of-four count of 1–2 (moderate neuromuscular block) was maintained in all groups.

All laparoscopic procedures were conducted using standard techniques by one surgeon (T. Song) with an experience of performing more than 1000 laparoscopic surgeries. The laparoscopic port (or trocar) placement was determined on the basis of the patients' condition and needs. CO_2 was used as the distension medium for pneumoperitoneum. The flow of insufflation gas did not exceed 2 L/min when creating the pneumoperitoneum. The CO_2 pressure was set at 14 mmHg during the laparoscopic procedure. The intraperitoneal gas pressure and the total gas volume delivered during the laparoscopic procedure were monitored. After a laparoscope was inserted through the laparoscopic port or trocar, the intended surgical procedures, such as ovarian cystectomy, myomectomy, and hysterectomy, were performed. After the laparoscopic procedure was completed by washing the pelvic cavity and absorbing any clots that had formed, a Jackson–Pratt drain was placed in the Douglas pouch only if diffuse oozing was noted from the operative site.

According to a randomization sequence, the subjects were randomly allocated to the control group (no intervention), single strategy group (SI alone), and combined strategy group (combination of SI and RM). In the control group (group C), passive evacuation of CO_2 was performed as the conventional laparoscopic management. At the completion of the laparoscopic procedure and after the subjects were placed in the Trendelenburg position (30°), gentle manual external compression was applied on the abdomen to remove CO_2 from the peritoneal cavity as much as possible (Fig. 1A). In the saline instillation group (group SI), SI was performed as the single intervention, in addition to the passive CO_2 evacuation method conducted in the control group. In the Trendelenburg position at 30°, 20 mL/kg of body weight of warm isotonic saline was instilled in the subdiaphragmatic region, subsequently displacing the residual CO_2 space; thereby, the rising CO_2 escaped through the laparoscopic port sites from the peritoneal cavity (Fig. 1B). In the

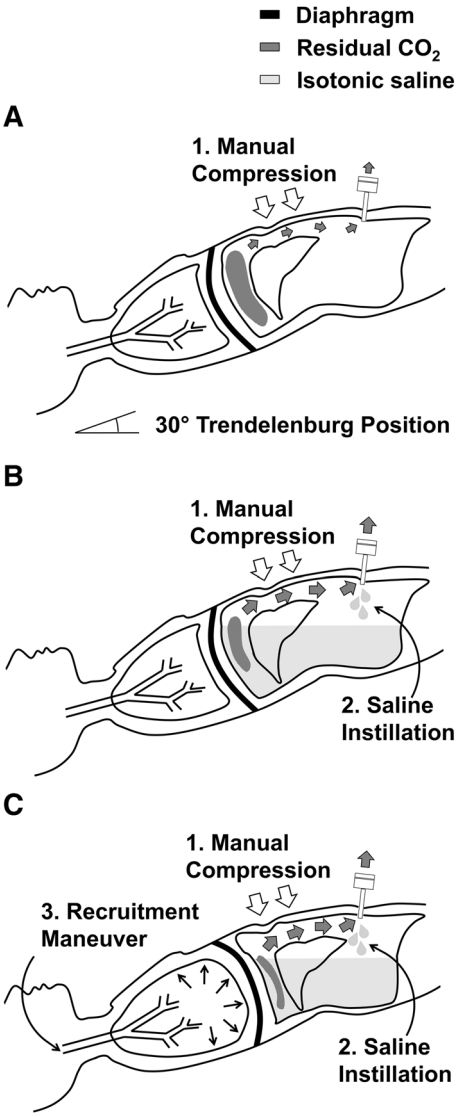

Fig. 1 Illustrations of the interventions by group. **A** Group C, **B** Group SI, and **C** Group CS. *Group C* control group with no intervention, *Group SI* saline instillation group as a single strategy, *Group CS* combined strategy group using the combination of saline instillation and recruitment maneuver, CO_2 carbon dioxide

combined strategy group (group CS), RM was performed, in addition to the maneuvers conducted in the SI group. After SI, five manual pulmonary hyperinflations using positive inspiratory pressure were performed by one anesthesiologist (K.-H. Ryu). Each inflation was maintained at an end-inspiratory plateau pressure of 40 cmH_2O for 5 s, indirectly increasing the intraperitoneal pressure, which consequently facilitated the escape of residual CO_2 from the peritoneal cavity (Fig. 1C). In all subjects, the Trendelenburg position at 30° was maintained with all laparoscopic ports fully opened to exhaust CO_2 from the peritoneal cavity during each intervention period. After completing the assigned intervention, the subjects were placed in a level position; the laparoscopic ports were removed; and the incision sites were then closed.

Postoperative pain management was performed in an identical manner in all groups according to our institutional protocol. An intravenous patient-controlled analgesia (IV-PCA) device (Ambix Anaplus® AP 1020, E-Wha Fresenius Kabi Inc., Gunpo, Republic of Korea) was connected at the post-anesthesia care unit (PACU) and was maintained for 48 h postoperatively. The regimen comprised 5 μg/mL of fentanyl in a total volume of 100 mL at a basal infusion rate of 2 mL/h and a bolus of 0.5 mL with a lockout interval of 15 min. Intravenous 25 mg meperidine in the PACU and intramuscular 75 mg diclofenac in the wards were administered as rescue analgesics on demand. Non-steroidal anti-inflammatory drugs (200 mg ibuprofen) were administered thrice regularly daily. The subjects were discharged from the hospital after restoration of bowel activity and successful ambulation, when no postoperative fever was observed, and when they no longer needed narcotic analgesics. All subjects were scheduled for follow-up examinations 1 week and 3 months after surgery.

Outcome measures

The primary outcome measure was the severity of PLSP. Twenty-four and forty-eight hours after surgery, the postoperative shoulder and wound pain scores were assessed using a visual analog scale. The scale was presented as a 10-cm line ranging from 0 (no pain) to 10 (the worst pain that the patients can imagine). More severe pain sites (shoulder vs. wound) reported by the subjects were measured simultaneously. Twenty-four hours after surgery, upright posteroanterior and lateral chest radiographs were obtained after assuming an upright position for more than 10 min [16]. The heights of the postoperative pneumoperitoneum were measured using the perpendicular length of the accumulated gas bubble between the right hemi-diaphragm and the liver on chest radiograph [17]. The time to first flatus, number of rescue analgesics, incidence of postoperative nausea and vomiting (PONV), and postoperative pulmonary or operative complications were recorded. The postoperative pulmonary complications, including atelectasis, pleural effusion, and pneumothorax, were evaluated using chest radiographs obtained 24 h after surgery by the radiologist.

Statistical analysis

The sample size was calculated on the basis of the difference in the severity of PLSP 24 h after surgery collected retrospectively from 20 consecutive cases using the combined strategy before this study showing a PLSP score of 2.2 ± 1.7 (authors' unpublished data). We estimated that 48 subjects would be needed per group to provide a type I error of 0.05,

power of 80%, and predicted dropout rate of 5% to detect a 1-point difference, which was considered clinically relevant among the groups.

Statistical analyses were performed using SPSS software (SPSS Statistics for Windows, Version 24.0; IBM Corp., Armonk, New York, USA). All analyses were performed on the basis of the initially allocated group according to the intention-to-treat principle. No interim analysis was planned or performed. Data were presented as numbers (%) for qualitative variables and means ± standard deviations or medians (interquartile ranges) for quantitative variables, as appropriate. The normal distribution for quantitative variables was first evaluated using the Shapiro–Wilk test. The baseline demographic characteristics and study outcomes were compared among the three groups using the chi-squared test or Fisher's exact test for qualitative variables and one-way analysis of variance or Kruskal–Wallis test for quantitative variables, as appropriate. *P* values of <0.05 indicated statistical significance.

Results

One-hundred fifty-three patients were recruited between June 2016 and April 2017; however, seven patients declined participation, and two patients were ineligible in accordance with the exclusion criteria of conversion to open surgery ($n=1$) and need for upper abdominal surgery after diagnosis of ovarian cancer on frozen biopsy ($n=1$). Therefore, 144 subjects were randomly assigned to the three groups (Fig. 2).

The baseline demographic characteristics were comparable in all groups (Table 1). The operative outcomes, including laparoscopic mode, operative time (defined as the time from skin incision to skin closure), operative blood loss (defined as the difference between the total amount of suction and irrigation plus the difference between the total gauze weight before and after surgery), hemoglobin level change (defined as the difference between the preoperative hemoglobin level and the hemoglobin level on postoperative day 1), length of hospital stay (defined as the number of days from the operation until the day of discharge), mean total volume of CO_2 during laparoscopy, time to first flatus, incidence of PONV, and number of rescue analgesics, were not significantly different among the groups (Table 2). Pulmonary complications, including atelectasis and pleural effusion, developed in nine subjects (6.3%), while umbilical wound dehiscence requiring re-suture, which was managed without sequelae, developed in three subjects (2.1%). Pneumothorax was not observed in any group. No significant difference in the pulmonary complications and postoperative complications was observed in all groups.

Table 3 presents the main outcomes of this study. The shoulder pain scores 24 and 48 h after surgery were significantly different among the three groups ($P=0.014$ and $P=0.001$, respectively); the wound pain scores were not significantly different. In the post hoc analysis, the shoulder pain

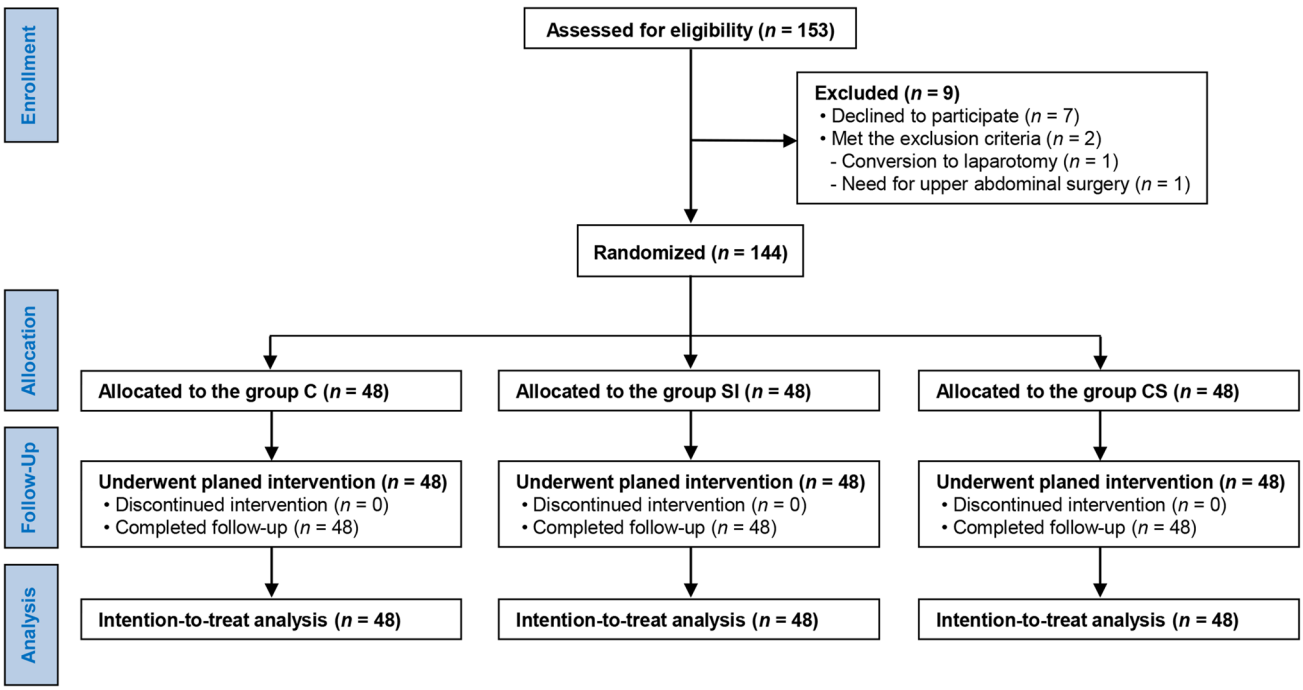

Fig. 2 CONSORT flow diagram. Enrollment, randomization, and allocation of the study subjects

Table 1 Baseline demographic characteristics

	Group C ($n=48$)	Group SI ($n=48$)	Group CS ($n=48$)	P value
Age (years)	40 ± 11	39 ± 13	40 ± 10	0.761
Body mass index (kg/m^2)	22.9 ± 3.4	22.9 ± 3.0	23.5 ± 4.9	0.989
Parity				0.336
Nulliparous	25 (52.1%)	23 (47.9%)	18 (37.5%)	
Parous	23 (47.9%)	25 (52.1%)	30 (62.5%)	
Married	29 (60.4%)	29 (60.4%)	31 (64.6%)	0.889
Menopause	6 (12.5%)	9 (18.8%)	3 (6.3%)	0.180
ASAPS classification				0.904
I	34 (70.8%)	35 (72.9%)	33 (68.8%)	
II	14 (29.2%)	13 (27.1%)	15 (31.3%)	
History of abdominal surgery	19 (39.6%)	17 (35.4%)	20 (41.7%)	0.815
Preoperative hemoglobin level (mg/dL)	12.4 ± 1.5	12.3 ± 1.9	12.5 ± 1.6	0.870
Main indication for surgery				0.915
Adnexal surgery	24 (50.0%)	26 (54.2%)	22 (45.8%)	
Myomectomy	9 (18.8%)	8 (16.7%)	8 (16.7%)	
Hysterectomy	15 (31.3%)	14 (29.2%)	18 (12.5%)	

Data are expressed as means ± standard deviations or numbers (%), as appropriate. *Group C* control group with no intervention, *Group SI* saline instillation group as a single strategy, *Group CS* combined strategy group using the combination of saline instillation and recruitment maneuver, *ASAPS* American Society of Anesthesiologists physical status

scores 24 and 48 h after surgery were significantly lower in group SI and group CS than in group C; however, no significant differences were observed between group SI and group CS (Fig. 3).

The relative pain severity in a specified site (wound pain vs. shoulder pain) 24 and 48 h after surgery was significantly different among the three groups ($P=0.007$ and $P=0.015$, respectively). In the post hoc analysis 24 h after surgery (Fig. 4A), 17 of the 48 subjects (35%) in group C reported that the shoulder pain was more severe than the wound pain; conversely, 12 of the 48 (25%) and 6 of the 48 (13%) subjects in group SI and group CS, respectively, reported the same ($P=0.025$ and $P=0.005$, respectively). However, there was no significant difference between group SI and group CS ($P=0.200$). A similar pattern was observed 48 h after surgery (Fig. 4B).

The heights of the postoperative residual pneumoperitoneum were significantly different among the three groups ($P<0.001$). In the post hoc analysis, the heights of the pneumoperitoneum were significantly lower in group SI and group CS than in group C (both $P<0.001$); however, no significant differences were observed between group SI and group CS (Fig. 5; Table 3).

Discussion

As previously mentioned, the purpose of this study was to compare the effectiveness of the single strategy using SI alone with the combined strategy using SI and RM on reducing PLSP. The main finding of this study is that SI alone is as effective as the combination of RM and SI for removing residual CO_2 and consequently preventing PLSP. We also found that there was no significant difference in the clinical outcomes related to SI, such as PONV or time to first flatus. To the best of our knowledge, this is the first study to compare SI alone and a combined strategy. We believe that the SI alone strategy can be easily implemented in daily practice and has a comparable efficacy to the combined strategy for preventing PLSP.

An ideal gas for establishing a laparoscopic pneumoperitoneum should fulfill the following requirements: nontoxic, inexpensive, colorless, non-inflammable, non-explosive, and rapidly excreted from the body [18, 19]. Room air, nitrogen, nitrous oxide, CO_2, helium, and argon have been studied as laparoscopic insufflation gases [19–21]. Among them, CO_2 has been the most frequently selected

Table 2 Operative outcomes

	Group C ($n=48$)	Group SI ($n=48$)	Group CS ($n=48$)	*P* value
Laparoscopic mode				0.237
Single-port	41 (85.4%)	46 (95.8%)	45 (93.8%)	
Multi-port	7 (14.6%)	2 (4.2%)	3 (6.3%)	
Failure of intended laparoscopy				
Insertion to additional trocar	0	0	0	> 0.999
Total CO_2 volume used (L)	115 (74–147)	125 (83–166)	118 (67–185)	0.758
Operative time (min)	59 (49–78)	60 (41–70)	59 (43–73)	0.823
Operative blood loss (mL)	44 (25–85)	45 (29–100)	43 (24–75)	0.830
Hemoglobin level change (mg/dL)	1.8 ± 1.0	1.8 ± 1.0	1.7 ± 0.9	0.945
Transfusion	0	1 (2.1%)	0	> 0.999
Time to first flatus (h)	27.6 ± 7.0	30.4 ± 9.0	29.8 ± 7.9	0.333
Postoperative nausea and vomiting				
At PACU	3 (6.3%)	2 (4.2%)	6 (12.5%)	0.278
At wards	8 (16.7%)	4 (8.3%)	6 (12.5%)	0.467
Number of rescue analgesics requested				
At PACU	21 (43.8%)	18 (37.5%)	14 (29.2%)	0.331
At wards	23 (47.9%)	26 (54.2%)	20 (41.7%)	0.472
Length of hospital stay (days)	2 (2–2)	2 (2–2)	2 (2–2)	0.319
Pulmonary complications[a]				
Atelectasis	1 (2.1%)	1 (2.1%)	1 (2.1%)	> 0.999
Pleural effusion	1 (2.1%)	2 (4.2%)	3 (6.3)	0.593
Pneumothorax	0	0	0	
Operative complications				
Intraoperative complications	0	0	0	
Postoperative complications[b]	1 (2.1%)	1 (2.1%)	1 (2.1%)	> 0.999

Data are expressed as numbers (%), means ± standard deviations, or medians (interquartile ranges), as appropriate. *Group C* control group, *Group SI* saline instillation group, *Group CS* combined strategy group, *CO_2* carbon dioxide, *PACU* post-anesthesia care unit

[a]Postoperative pulmonary complication was evaluated by the radiologist using chest radiographs obtained 24 h after surgery

[b]Three cases of umbilical wound dehiscence were managed with wound debridement and re-suture, which resolved without sequelae

Table 3 Study outcomes

	Group C ($n=48$)	Group SI ($n=48$)	Group CS ($n=48$)	Post hoc analysis	*P* value
24 h after surgery					
Shoulder pain score (VAS)	3.0 (2.0–5.0)	2.0 (0–3.0)	2.0 (0–3.0)	C > SI = CS	0.014
Wound pain score (VAS)	3.0 (3.0–5.0)	3.5 (3.0–5.0)	4.0 (3.0–5.0)	C = SI = CS	0.233
48 h after surgery					
Shoulder pain score (VAS)	3.0 (1.5–5.0)	1.0 (0–3.0)	1.0 (0–3.0)	C > SI = CS	0.001
Wound pain score (VAS)	3.0 (2.0–4.5)	3.0 (2.0–4.0)	3.0 (2.0–4.0)	C = SI = CS	0.850
Height of residual pneumoperitoneum (mm)	11.8 (5.5–24.3)	4.9 (0.0–10.4)	1.3 (0.0–6.3)	C > SI = CS	< 0.001

Data are expressed as medians (interquartile ranges). *Group C* control group with no intervention, *Group SI* saline instillation group as a single strategy, *Group CS* combined strategy group using the combination of saline instillation and recruitment maneuver, *VAS* Visual Analog Scale

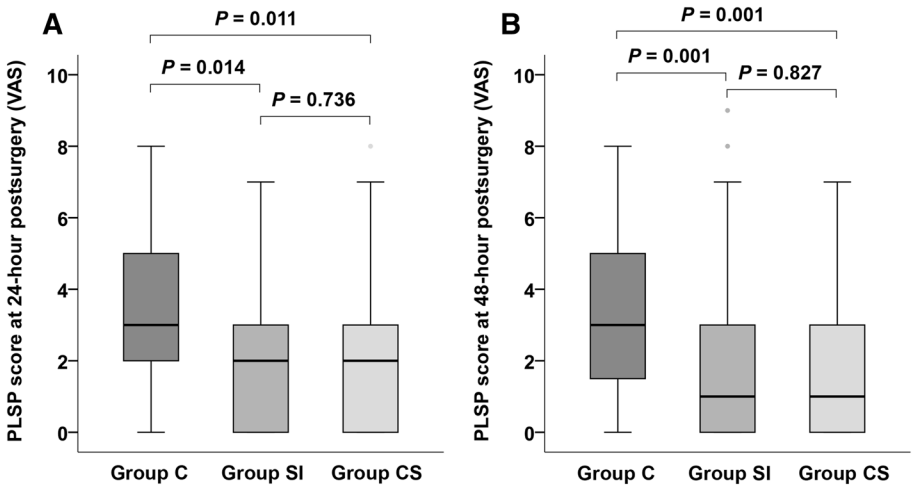

Fig. 3 Comparison of the PLSP scores among the three groups **A** 24 h and **B** 48 h after surgery. Boxplots indicate the 25th and 75th percentiles with the median depicted as the bold black line within each box; whiskers indicate non-outlier maximum and minimum; outliers are plotted individually by solid dots. *Group C* control group, *Group SI* saline instillation group, *Group CS* combined strategy group, *PLSP* postlaparoscopic shoulder pain, *VAS* visual analog scale

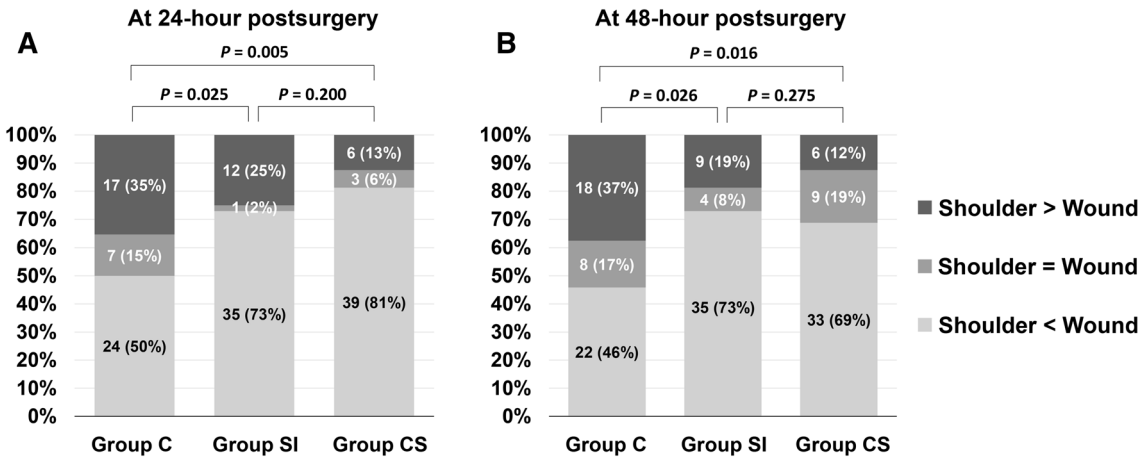

Fig. 4 Pain severity in specified sites (wound pain versus shoulder pain) **A** 24 h and **B** 48 h after surgery. *Group C* control group, *Group SI* saline instillation group, *Group CS* combined strategy group

gas for the past few decades, as it meets most of the requirements for a therapeutic pneumoperitoneum. Nevertheless, a pneumoperitoneum induced using CO_2 is associated with PLSP [22]. The most accepted hypothesis for the pathophysiology of PLSP is that intraperitoneal carbonic acid derived from CO_2 insufflation induces phrenic nerve irritation, subsequently causing referred pain to the corresponding dermatome (C3-5) [5, 6, 11, 23]. This hypothesis is supported by the findings of our previous study in which the intensity of PLSP was positively correlated with the volume of residual CO_2 [24]. This is consistent with the result of this study. Herein, the PLSP scores in the two intervention groups (group SI and group CS) were significantly lower than that in the no intervention group (group C), and similar patterns were also observed in the comparison of the residual pneumoperitoneum heights.

In the current study, the PLSP scores between group SI and group CS were not significantly different. The reason for this result is unclear; however, it may be because of the overwhelming effect of SI over RM on the reduction of PLSP. There are several possible explanations. First, SI and RM have a similar mechanical process in removing residual CO_2 from the peritoneal cavity [9]. However, SI removes the residual pneumoperitoneum via a 'direct' mechanism in which isotonic saline replaces the remaining CO_2 pockets, while RM is based on an 'indirect' mechanism that raises intrathoracic pressure and subsequently intraperitoneal pressure to facilitate the removal of CO_2 [9, 14]. Second, SI is not only a mechanical method but also a physiologic method, while RM is only a mechanical method. The instilled saline acts as a physiologic buffer to dissolve CO_2 and allow dissipation of CO_2 from the peritoneal cavity [10, 15]. Third, SI may yield longer-lasting reductions of PLSP than RM. Tsai et al. reported that the effect of RM lasted until 24 h postoperatively but disappeared after 48 h, while that of SI still lasted after 48 h [10]. Taken together, these explanations

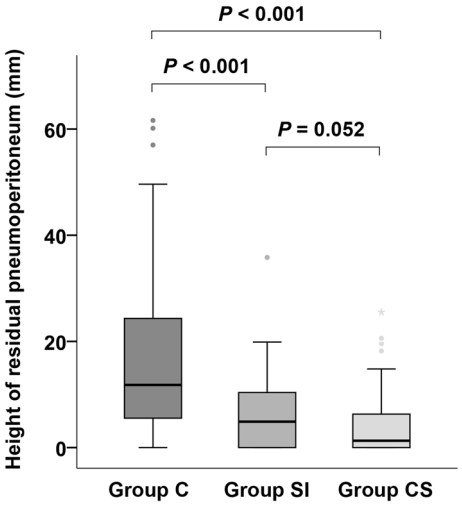

Fig. 5 Height of the residual pneumoperitoneum 24 h after surgery among the three groups. Boxplots indicate the 25th and 75th percentiles with the median depicted as the bold black line within each box; whiskers indicate non-outlier maximum and minimum; outliers are plotted individually by solid dots. *Group C* control group, *Group SI* saline instillation group, *Group CS* combined strategy group

suggest that the single strategy using SI alone may be as effective as the combined strategy using SI and RM in terms of PLSP reduction.

RM using a high airway pressure is associated with potential risks for pulmonary or cardiovascular complications. Hyperinflation of the lungs increases intrapulmonary pressure, which subsequently increases pulmonary vascular resistance and reduces venous return, resulting in cardiac output reduction, and pulmonary barotrauma/volutrauma or hemodynamic instability [25, 26]. In most previous studies, RM was conducted using maximum inspiratory pressures of either 40 or 60 cmH_2O. Our previous study comparing between 40 and 60 cmH_2O reported that RM with 40 cmH_2O was efficacious and safe for the reduction of PLSP [13]. However, this study was performed on healthy subjects with an American Society of Anesthesiologists physical status classification I or II. In patients with critical lung conditions or reduced cardiovascular reserve, there may be potential risks of life-threatening complications, even with RM using inspiratory pressures of the physiological range near ~40 cmH_2O [27–30]. Considering the potential risks of RM and the similar PLSP scores between group SI and group CS in this study, it is suggested that the single strategy using SI alone might be safe and efficient for the reduction of PLSP.

This study has some limitations. First, the fact that there was no single strategy group using RM alone is a major limitation of this study. If a 2 × 2 factorial study design had been used, it would have provided important information to assess the effects of RM and to determine whether there is an interaction between SI and RM. Second, the point difference in the pain score is modest, although it is statistically significant. This might have been because of the universal use of IV-PCA in this study. Owing to the characteristics of the Korean national health insurance system (diagnosis-related group payment system), it was inevitable to apply IV-PCA in all subjects. In addition, because most South Korean patients covered comprehensive national health insurance and their hospital costs were generally very low, the length of hospital stay was longer than in other countries and postoperative management is also different from that of many institutions. These might have reduced the overall postoperative pain including PLSP in all groups, and result in this modest point difference in the pain score among the groups. Further clinical investigation using IV-PCA without a baseline continuous infusion may be helpful to validate our results. Third, most of the procedures were performed *via* a single-port laparoscopy, and the frequency of insertion of pelvic drains was very low. Finally, the minor limitations of this study include the inclusion of only female subjects and the elective nature of the procedures. Therefore, some caution is warranted in interpreting our results.

In conclusion, the combined strategy using SI and RM was not superior to the single strategy using SI alone in terms of PLSP reduction. Furthermore, the single strategy using SI alone is simple and safe; thus, it can be employed to avoid the potential risks of pulmonary or hemodynamic complications associated with RM. Our results will potentially benefit all laparoscopists interested in performing minimally invasive surgeries. However, large multi-center randomized studies are required to confirm our findings.

Compliance with ethical standards

Disclosures Drs. Kyoung-Ho Ryu, Sung Hyun Lee, Eun-Ah Cho, Ji-A Kim, Go-Eun Lim, and Taejong Song have no conflicts of interest or financial ties to disclose.

References

1. Kluivers KB, Johnson NP, Chien P, Vierhout ME, Bongers M, Mol BW (2008) Comparison of laparoscopic and abdominal hysterectomy in terms of quality of life: a systematic review. Eur J Obstet Gynecol Reprod Biol 136:3–8
2. Grace PA, Quereshi A, Coleman J, Keane R, McEntee G, Broe P, Osborne H, Bouchier-Hayes D (1991) Reduced postoperative hospitalization after laparoscopic cholecystectomy. Br J Surg 78:160–162
3. Mouton WG, Bessell JR, Otten KT, Maddern GJ (1999) Pain after laparoscopy. Surg Endosc 13:445–448
4. Lee DH, Song T, Kim KH, Lee KW (2018) Incidence, natural course, and characteristics of postlaparoscopic shoulder pain. Surg Endosc 32:160–165
5. Fredman B, Jedeikin R, Olsfanger D, Flor P, Gruzman A (1994) Residual pneumoperitoneum: a cause of postoperative pain after laparoscopic cholecystectomy. Anesth Analg 79:152–154

6. Nyerges A (1994) Pain mechanisms in laparoscopic surgery. Semin Laparosc Surg 1:215–218
7. Donatsky AM, Bjerrum F, Gogenur I (2013) Surgical techniques to minimize shoulder pain after laparoscopic cholecystectomy. A systematic review. Surg Endosc 27:2275–2282
8. Pergialiotis V, Vlachos DE, Kontzoglou K, Perrea D, Vlachos GD (2015) Pulmonary recruitment maneuver to reduce pain after laparoscopy: a meta-analysis of randomized controlled trials. Surg Endosc 29:2101–2108
9. van Dijk JEW, Dedden SJ, Geomini P, Meijer P, van Hanegem N, Bongers MY (2017) POstLAparoscopic reduction of pain by combining intraperitoneal normal salinE and the pulmonary recruitment maneuver (POLAR BEAR trial). RCT to estimate reduction in pain after laparoscopic surgery when using a combination therapy of intraperitoneal normal saline and the pulmonary recruitment maneuver. BMC Womens Health 17:42
10. Tsai HW, Chen YJ, Ho CM, Hseu SS, Chao KC, Tsai SK, Wang PH (2011) Maneuvers to decrease laparoscopy-induced shoulder and upper abdominal pain: a randomized controlled study. Arch Surg 146:1360–1366
11. Donatsky AM, Bjerrum F, Gogenur I (2013) Intraperitoneal instillation of saline and local anesthesia for prevention of shoulder pain after laparoscopic cholecystectomy: a systematic review. Surg Endosc 27:2283–2292
12. Phelps P, Cakmakkaya OS, Apfel CC, Radke OC (2008) A simple clinical maneuver to reduce laparoscopy-induced shoulder pain: a randomized controlled trial. Obstet Gynecol 111:1155–1160
13. Ryu K, Choi W, Shim J, Song T (2017) The impact of a pulmonary recruitment maneuver to reduce post-laparoscopic shoulder pain: a randomized controlled trial. Eur J Obstet Gynecol Reprod Biol 208:55–60
14. Sharami SH, Sharami MB, Abdollahzadeh M, Keyvan A (2010) Randomised clinical trial of the influence of pulmonary recruitment manoeuvre on reducing shoulder pain after laparoscopy. J Obstet Gynaecol 30:505–510
15. Tsai HW, Wang PH, Yen MS, Chao KC, Hsu TF, Chen YJ (2013) Prevention of postlaparoscopic shoulder and upper abdominal pain: a randomized controlled trial. Obstet Gynecol 121:526–531
16. Woodring JH, Heiser MJ (1995) Detection of pneumoperitoneum on chest radiographs: comparison of upright lateral and posteroanterior projections. AJR Am J Roentgenol 165:45–47
17. Millitz K, Moote DJ, Sparrow RK, Girotti MJ, Holliday RL, McLarty TD (1994) Pneumoperitoneum after laparoscopic cholecystectomy: frequency and duration as seen on upright chest radiographs. AJR Am J Roentgenol 163:837–839
18. Neuhaus SJ, Gupta A, Watson DI (2001) Helium and other alternative insufflation gases for laparoscopy. Surg Endosc 15:553–560
19. Yu T, Cheng Y, Wang X, Tu B, Cheng N, Gong J, Bai L (2017) Gases for establishing pneumoperitoneum during laparoscopic abdominal surgery. Cochrane Database Syst Rev 6:Cd009569
20. Junghans T, Bohm B, Grundel K, Schwenk W (1997) Effects of pneumoperitoneum with carbon dioxide, argon, or helium on hemodynamic and respiratory function. Arch Surg 132:272–278
21. Menes T, Spivak H (2000) Laparoscopy: searching for the proper insufflation gas. Surg Endosc 14:1050–1056
22. Alexander JI (1997) Pain after laparoscopy. Br J Anaesth 79:369–378
23. Kandil TS, El Hefnawy E (2010) Shoulder pain following laparoscopic cholecystectomy: factors affecting the incidence and severity. J Laparoendosc Adv Surg Tech A 20:677–682
24. Song T, Kim KH, Lee KW (2017) The intensity of postlaparoscopic shoulder pain is positively correlated with the amount of residual pneumoperitoneum. J Minim Invasive Gynecol 24:984–989.e981
25. Slutsky AS (1993) Barotrauma and alveolar recruitment. Intensive Care Med 19:369–371
26. Lovas A, Szakmany T (2015) Haemodynamic effects of lung recruitment manoeuvres. Biomed Res Int 2015:478970
27. Westermann EJ, Jans M, Gaytant MA, Bach JR, Kampelmacher MJ (2013) Pneumothorax as a complication of lung volume recruitment. J Bras Pneumol 39:382–386
28. Anzueto A, Frutos-Vivar F, Esteban A, Alia I, Brochard L, Stewart T, Benito S, Tobin MJ, Elizalde J, Palizas F, David CM, Pimentel J, Gonzalez M, Soto L, D'Empaire G, Pelosi P (2004) Incidence, risk factors and outcome of barotrauma in mechanically ventilated patients. Intensive Care Med 30:612–619
29. Bautin AE, Mazurok VA, Osovskikh VV, Afanas'eva K (2014) Hemodynamic effects of the alveolar recruitment maneuver in cardiosurgical patients with left ventricular systolic dysfunction. Anesteziol Reanimatol 59:43–48
30. Lim SC, Adams AB, Simonson DA, Dries DJ, Broccard AF, Hotchkiss JR, Marini JJ (2004) Transient hemodynamic effects of recruitment maneuvers in three experimental models of acute lung injury. Crit Care Med 32:2378–2384