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Ultrasonographic Evaluation of the Effect of Positive End-expiratory Pressure on Diaphragmatic Functions in Patients Undergoing Laparoscopic Colorectal Surgery: A Prospective Randomized Comparative Study

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Abstract

Aim: The aim of this study was to evaluate the effects of positive end-expiratory pressure (PEEP) on diaphragmatic functions during pneumoperitoneum and the trendelenburg position in patients undergoing laparoscopic colorectal surgery *via* ultrasonography.

Methods: One hundred and fifty-three patients undergoing laparoscopic colorectal surgery under combined general and epidural anesthesia. Patients were randomly allocated to one of three groups of n=51. Group 1 was mechanically ventilated without PEEP, group 2 received PEEP of 5 cmH_2O, and group 3 received PEEP of 10 cmH_2O. Anesthesia time, pneumoperitoneum duration, vital signs data, diaphragmatic excursion, diaphragmatic thickness, areas of atelectasis, peak inspiratory pressure, and complications.

Results: Excursion of the diaphragm decreased in the three groups and was statistically significantly lower in group 1 compared to groups 2 and 3 after pneumoperitoneum up to 2 h after initiation of the head-down position. Peak inspiratory pressure was statistically significantly higher in group 3 compared to groups 1 and 2. There were no significant differences in diaphragmatic thickness among the three groups. Among all groups and at all time-points measured, atelectasis was only recorded in 3 patients in group 1. No barotrauma was apparent in any of the three groups.

Conclusions: The application of PEEP is helpful for preserving diaphragmatic excursion during laparoscopic colorectal surgery, and it significantly reduces the incidence of atelectasis.

Keywords: Diaphragmatic function; Laparoscopic colorectal surgery; Positive end-expiratory pressure; Ultrasound

Introduction

Following the introduction of laparoscopic procedures, laparoscopic techniques are now the most common procedures in surgery worldwide [1]. Laparoscopic surgery is performed in conjunction with intraabdominal insufflation of CO_2 [2] and this insufflation leads to an increase in intraabdominal pressure [3]. CO_2-pneumoperitoneum may cause several respiratory changes, e.g., decreased functional residual capacity (FRC) and vital capacity [4], formation of atelectasis in the dependent lung regions [5], and reduced respiratory compliance [6].

A laparoscopic approach for colorectal disease is currently considered the gold standard for colonic resection and the optimal approach for rectal surgery. These types of surgeries require prolonged pneumoperitoneum and a head-down position [7]. Pneumoperitoneum and the Trendelenburg position may influence intraoperative respiratory mechanics in anesthetic management [8], and CO_2 inflation and the head-down position can increase abdominal pressure and induce lung atelectasis [9]. The insufflation of CO_2 leads to an increase in intraabdominal pressure and abdominal expansion, and cephalad shift of the diaphragm [10]. The Trendelenburg position reduces lung compliance by altering the position of intestinal contents and the diaphragm [11]. Atelectasis causes postoperative pulmonary complications [12].

Pulmonary gas exchange and respiratory mechanics are impaired during general anesthesia due to atelectasis, which without positive end-expiratory pressure (PEEP), is present in 90% of all anesthetized patients [13,14]. Compression atelectasis is caused by alterations in chest wall mechanics induced by general anesthesia, the head-down position, and the type of surgery (abdominal or laparoscopic), and it is associated with increased intra-abdominal pressure that reduces chest compliance and FRC contributing to further atelectasis and intrapulmonary shunting [15]. PEEP is used to improve respiratory mechanics and oxygenation during pneumoperitoneum [16].

Point-of-care ultrasonography (US) is a sonographic examination that is performed and interpreted by the clinician at the bedside. It can play an important role in evaluating the patient's condition and predicting the expected outcome. Moreover, it can be repeated as required and has no associated hazards. US can be used to evaluate diaphragmatic thickness and movement, and can be particularly useful in critically ill patients [17]. It is non-invasive, readily accessible in operating theatres, and provides high-resolution images depicting diaphragmatic muscle movement, thickness, and echogenicity [18].

The aim of the current study was to evaluate the effects of PEEP on diaphragmatic functions during pneumoperitoneum and the Trendelenburg position in patients undergoing laparoscopic colorectal surgery *via* US.

Materials and Methods

Patients and setting

The current investigation was a prospective, randomized, comparative, multicenter study. The inclusion criteria were age 30-70 years and American Society of Anesthesiologist (ASA) I or II physical status, and patients undergoing elective laparoscopic colorectal surgery under combined general anesthesia and epidural analgesia were included. The exclusion criteria included lack of consent to participate in the study, body mass index (BMI) above 30, emergency surgery, complicated or recurrent abdominal surgery, peak airway pressure>40 cmH_2O, and conversion to laparotomy. Patients with a history of chronic respiratory disease, diaphragmatic disease, or any contraindication for laparoscopic surgery, the head-down position, or regional anesthesia, or any allergy to the drug used in the study were also excluded.

The current study was conducted at the Beni Suef and Ain Shams University hospitals from April 2017 to June 2018 after obtaining approval from the institutional review board and university ethics committee (approval identifier FM-BSU REC). The trial was registered in the Pan African Clinical Trials Registry (registration number PACTR201704002188293). Written informed consent was obtained from all participants. All patients underwent thorough clinical preoperative evaluation, complete laboratory investigations, and pulmonary function tests.

Study conditions

Upon arrival at the preoperative room, a wide-bore 18 G intravenous cannula was inserted and intravenous infusion of lactate ringer solution was initiated at a rate of 8 mL/kg/h. When the patients arrived at the operating room, standard monitoring was applied including ECG, pulse oximetry, and non-invasive arterial blood pressure. Before the induction of general anesthesia, all patients had a lumbar epidural catheter inserted. In the sitting position, under strict aseptic conditions and after skin infiltration with 2 mL lidocaine (1%) at lumbar interspace 2-3 or 3-4, the lumbar epidural space was identified using the loss of resistance to air technique *via* an 18 G Touhy needle and catheter.

After identifying the epidural space, a test dose of 3 mL lidocaine 1% with 1:200,000 adrenaline was injected and the catheter was fixed after exclusion of intrathecal or intravascular catheter placement. General anesthesia was induced after the administration of 100% oxygen *via* a facemask for 3-5 min, then fentanyl 2 μg/kg, propofol 2 mg/kg, and atracurium 0.5 mg/kg were administered intravenously. The patients were intubated with a suitable sized oral cuffed tube, and mechanically ventilated in volume-controlled mode with tidal volume set at 8 mL/kg predicted body weight, and respiratory frequency set at 12 breaths/min to maintain end tidal CO_2 ($EtCO_2$) between 33 and 36 mmHg. Anesthesia was maintained with sevoflurane 1.5%-2.0% in 100% O_2, and atracurium. Analgesia was maintained *via* infusion of epidural bupivacaine 0.25% at a rate of 6-8 mL/hour and fentanyl IV infusion 1 μg/kg/h. Muscle relaxation was guided by nerve stimulator (Life-Tech EZstimII)

Another wide bore intravenous cannula and central venous catheter were inserted. Intraoperative deficit and maintenance fluids were warmed. CO_2 was insufflated into the peritoneal cavity until the intraabdominal pressure reached 11-15 mmHg.

Patients were randomly allocated to one of three groups of n=51 *via* sealed envelopes. Group 1 was mechanically ventilated without PEEP, group 2 received PEEP of 5 cmH_2O, and group 3 received PEEP of 10 cmH_2O. At the end of the surgery, all anesthetics were discontinued and the patients were extubated after reversal of neuromuscular blockade with intravenous 0.05 mg/kg neostigmine and 0.02 mg/kg atropine, and the patients were shifted to the surgical intensive care unit.

Parameter evaluation

The following parameters were recorded:

1 Demographic data, including age, sex, BMI, and ASA physical status.

2 Anesthesia time (min), pneumoperitoneum duration (min).

3 $EtCO_2$, heart rate, noninvasive mean blood pressure, central venous pressure (CVP), and peripheral capillary oxygen saturation (SPO_2) were continuously monitored, and were recorded every 15 min.

4 Excursion of the diaphragm at the dome was measured in cm using a low-frequency probe (1-3 MHz). Measurements were taken before the induction of anesthesia, after pneumoperitoneum, after adopting the head-down position, every hour thereafter until evacuation of the abdomen, after recovery, and 6 h after the completion of surgery.

5 Peak inspiratory pressures were measured immediately after the initiation of mechanical ventilation, after pneumoperitoneum, after adopting the Trendelenburg position and 2 h thereafter.

6 Other parameters associated with diaphragmatic function including areas of atelectasis and diaphragmatic thickness was recorded.

7 With regard to complications, barotrauma parameters including pneumothorax, surgical emphysema, and reduced air entry were also recorded.

The primary outcome measured was change in diaphragmatic excursion. The secondary outcomes measured were hypoxia and barotrauma parameters (pneumothorax, surgical emphysema, and reduced air entry).

US Technique

US examination was performed using a GE Logic P6 pro machine and a MyLabTM50 (Esaote, CA, USA). With a broadband curvilinear array transducer (5-10 MHz), the probe was placed at the right subcostal area midway between the anterior axillary line and mid-clavicular line. Using the liver as an acoustic window, the direction of the probe was moved medially upwards and backwards. The diaphragm is a hypoechoic muscle enclosed by two echogenic lines,

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namely the pleura and peritoneum (Figure 1). Diaphragmatic thickness was measured perpendicular to the muscle, and was conducted at end-expiratory phase (normal diaphragmatic thickness is 0.17 cm-0.20 cm for men and 0.13 cm-0.15 cm for women). The change in thickness (diaphragmatic fraction) was calculated using the following equation:

((end-inspiratory thickness-end-expiratory thickness)/end-expiratory thickness)

The change in thickness is expressed as a percentage, and its lower limit is 20%. Diaphragmatic mobility was evaluated by determining the craniocaudal displacement of the diaphragm using an M-mode US probe positioned in the infra-hepatic region. Its normal upper limits during maximal inspiratory effort are approximately 4.7 cm in men and 3.7 cm in women (higher and lower values have also been reported). The lower limits are 1 cm in men and 0.9 cm in women (Figure 1). Utilizing a subcostal view, basal atelectasis was documented bilaterally and is presented as absence of horizontal A lines, appearance of vertical B lines, or hypoechoic areas with or without air bronchogram (patients with pleural effusion or basal collapse were excluded from the study).

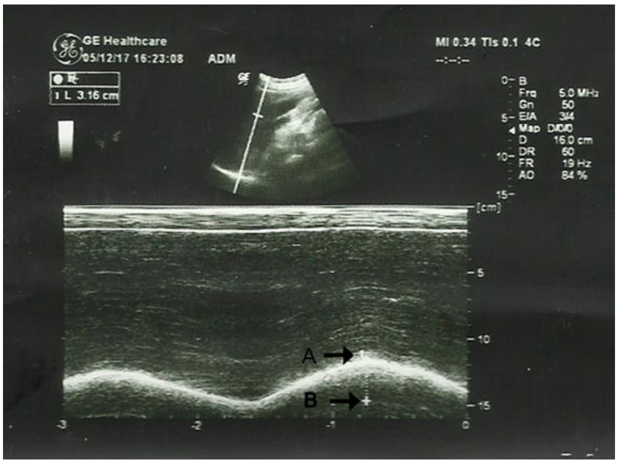

Figure 1: Diaphragmatic excursion. A: Primary position at end expiration; B: Secondary position at end inspiration. A -> B: Caudal displacement of organs due to diaphragmatic excursion.

Sample size determination

Sample size was calculated based on the comparison of diaphragmatic excursion in cm 2 hours after adoption of the Trendelenburg position (the primary outcome of the study) in a pilot study that included 4 patients in each of three groups corresponding to the groups included in the final study. The mean ± SD of diaphragmatic excursion in group 1 was 2.63 ± 0.04 cm, in group 2 it was 2.92 ± 0.08 cm, and in group 3 it was 3.10 ± 0.17 cm. Accordingly, we calculated that the minimum final sample size was 51 patients per group, in order to be able to reject the null hypothesis with 80% power at α=0.05 level using one way analysis of variance (ANOVA). The sample size calculation was done using G*Power software version 3.1.2 for MS Windows (Franz Faul, Kiel University, Germany).

Statistical analysis

Data were statistically described in terms of mean ± SD, median and range, or frequencies (number of cases) and percentages as appropriate. Comparison of continuous variables between the study groups was performed *via* ANOVA with multiple post-hoc two-group comparisons. Within-group comparison of numerical variables was performed *via* repeated measures ANOVA using a general linear model with repeated measures. Multiple post-hoc two-group comparisons tests were performed using the paired t test after adjusting for multiple comparisons. P values<0.05 were considered statistically significant. All statistical calculations were performed using the IBM Statistical Package for the Social Sciences (SPSS) release 22 for Microsoft Windows computer program (IBM Corp, Armonk, NY, USA).

Results

All patients completed the study (Figure 2). There were no statistically significant differences in demographic data, anesthesia time, or pneumoperitoneum duration between the three groups (Table 1). Differences in heart rate between the three groups and pairwise comparisons at the various time-points are shown in (Table 2). Differences in mean blood pressure between the three groups and pairwise comparisons at the various time-points are shown in (Table 3).

Variable	Group 1 (n=51)	Group 2 (n=51)	Group 3 (n=51)	P value
Age (years)	53.49 ± 12.00	53.63 ± 11.39	53.04 ± 11.90	0.967
BMI[a] (kg/m^2)	29.57 ± 0.92	29.47 ± 0.95	29.45 ± 0.94	0.791
Sex (F/M)	13/38	15/36	16/35	0.601
ASA[b] (I/II)	15/36	18/33	14/37	0.815
Anesthesia time (min)	242.57 ± 32.32	239.80 ± 29.01	240.14 ± 26.80	0.913
Pneumoperitoneum duration (min)	125.10 ± 8.92	130.00 ± 9.38	139.12 ± 10.27	0.81

Table 1: Demographic data. Data are presented as mean ± SD or numbers. [a]Body mass index; [b]American Society of Anesthesiologist. Group 1=mechanically ventilated without positive end-expiratory pressure; Group 2=positive end-expiratory pressure of 5 cmH_2O; Group 3=positive end-expiratory pressure of 10 cmH_2O.

CVP, SPO_2, and $EtCO_2$ were all comparable in the three groups. CVP was 5.70 ± 1.199 to 8.36 ± 1.481 cmH_2O in group 1, 5.36 ± 1.102 to 8.98 ± 1.237 cmH_2O in group 2, and 5.29 ± 1.021 to 8.94 ± 1.278 cmH_2O in group 3. SPO_2 was 99 ± 0.05% in group 1, 99 ± 0.04 % in group 2, and 99 ± 0.01% in group 3. $EtCO_2$ was 33.12 ± 0.34 mmHg in group 1, 32.2 ± 0.14 mmHg in group 2, and 32.00 ± 0.24 mmHg in group 3.

Before the induction of anesthesia, there was no significant difference in diaphragmatic excursion between the three groups. After pneumoperitoneum, diaphragmatic excursion was significantly lower in group 1 than in groups 2 and 3 as determined *via* pairwise comparison, and it was lower in group 2 than it was in group 3, but this difference was not statistically significant (Table 4). Two hours after

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adoption of the head-down position, diaphragmatic excursion was significantly lower in group 1 than it was in groups 2 and 3, and it was non significantly lower in group 2 than it was in group 3 (Table 4). Again, in pairwise comparisons, after recovery and at 6 h after the completion of surgery, excursion of the diaphragm was non significantly lower in group 1 than it was in group 2 and group 3, and it was non significantly lower in group 2 than it was in group 3 but neither of these differences were statistically significant (Table 4). In within group comparisons, diaphragmatic excursion was statistically significantly lower in all three groups after pneumoperitoneum until recovery compared to the preoperative value (Table 4, Figure 3).

	Group 1 (n=51)	Group 2 (n=51)	Group 3 (n=51)	P value
Before induction	78.78 ± 6.40[§]	75.73 ± 6.37	77.18 ± 5.92	0.05
15 min	76.94 ± 4.6	74.39 ± 4.14	75.73 ± 4.36	0.015
30 min	76.43 ± 5.78[§‡]	72.98 ± 4.58	71.29 ± 10.46	0.002
45 min	76.37 ± 7.58[§‡]	71.51 ± 10.23	70.35 ± 10.45	0.004
60 min	76.45 ± 6.51[§‡]	70.67 ± 10.06	71.27 ± 5.71	<0.001
75 min	73.98 ± 4.76	70.41 ± 10.09	72.00 ± 6.21	0.054
90 min	74.20 ± 5.77	73.08 ± 5.43	72.35 ± 3.86	0.192
105 min	74.59 ± 6.11	71.84 ± 11.55	71.96 ± 5.00	0.16
120 min	75.88 ± 6.14	73.33 ± 5.65	72.71 ± 5.96	0.019
135 min	74.94 ± 7.06	72.96 ± 4.97	73.10 ± 5.01	0.16
150 min	72.78 ± 5.76	72.47 ± 5.40	72.94 ± 4.19	0.899
165 min	76.22 ± 6.37[§‡]	72.29 ± 5.03	72.84 ± 4.72	0.001
180 min	75.65 ± 6.91	72.00 ± 5.27	73.04 ± 4.57	0.005
195 min	75.75 ± 6.36	71.80 ± 5.41	72.45 ± 5.33	0.001
210 min	79.67 ± 7.11	78.06 ± 7.66	74.92 ± 0.41	0.002
225 min	77.96 ± 6.35	76.47 ± 7.22	73.57 ± 4.52	0.002

Table 2: Heart rate (beats per minute). Data are presented as mean ± SD. [§]Statistically significant difference compared to group 2; [‡]Statistically significant difference compared to group 3. Group 1=mechanically ventilated without positive end-expiratory pressure; Group 2=positive end-expiratory pressure of 5 cmH_2O. Group 3=positive end-expiratory pressure of 10 cmH_2O.

	Group 1 (n=51)	Group 2 (n=51)	Group 3 (n=51)	P value
Before induction	74.53 ± 7.15	74.63 ± 7.02	73.63 ± 7.53	0.752
15 min	72.96 ± 7.47	72.82 ± 8.09	72.27 ± 8.96	0.626
30 min	70.35 ± 6.10	71.80 ± 6.91	70.69 ± 6.35	0.498
45 min	73.90 ± 8.15	72.29 ± 7.74	71.35 ± 8.60	<0.001
60 min	71.76 ± 7.70	72.27 ± 7.37	71.82 ± 7.80	0.934
75 min	72.13 ± 6.86[‡]	70.98 ± 0.27[‡]	68.80 ± 6.92	<0.001
90 min	72.90 ± 8.15[‡]	71.45 ± 8.24[‡]	69.69 ± 8.21	<0.001
105 min	74.33 ± 7.46[§‡]	72.29 ± 7.74[‡]	70.69 ± 8.21	<0.001
120 min	75.65 ± 7.36[§‡]	72.27 ± 7.37	71.82 ± 7.80	<0.001
135 min	76.90 ± 8.15[‡]	73.98 ± 8.27[‡]	68.80 ± 6.92	<0.001
150 min	74.35 ± 7.37	72.45 ± 8.24	71.69 ± 8.21	0.022
165 min	72.84 ± 7.30[‡]	72.43 ± 7.60[‡]	68.24 ± 7.55	<0.001
180 min	73.84 ± 7.30	72.65 ± 7.36	71.23 ± 7.24	<0.001
195 min	73.00 ± 0.33	72.90 ± 8.15	70.27 ± 8.67	0.004
210 min	74.06 ± 7.98[§‡]	70.35 ± 7.37	70.35 ± 7.47	0.212
225 min	74.92 ± 8.52	72.84 ± 7.30	72.04 ± 7.48	0.001

Table 3: Mean arterial blood pressure (mmHg). Data are presented as mean ± SD. [§]Statistically significant difference compared to group 2; [‡]Statistically significant difference compared to group 3. Group 1=mechanically ventilated without positive end-expiratory pressure; Group 2=positive end-expiratory pressure of 5 cmH_2O; Group 3=positive end-expiratory pressure of 10 cmH_2O.

	Group 1 (n=51)	Group 2 (n=51)	Group 3 (n=51)	P value
Before induction of anesthesia	3.74 ± 0.26	3.76 ± 0. 29	3.77 ± 0.32	0.844
After pneumoperitoneum	3.04 ± 0.17[§‡@]	3.39 ± 0.31[@]	3.40 ± 0.29[@]	0.844
After Trendelenburg	2.78 ± 0.08[§‡@]	3.24 ± 0.30[@]	3.27 ± 0.30[@]	0.000
2 h after Trendelenburg	2.70 ± 0.07[§‡@]	3.14 ± 0.30[@]	3.21 ± 0.31[@]	0.000
After recovery	3.32 ± 0.38[@]	3.40 ± 0.35[@]	3.41 ± 0.36[@]	0.000
6 h after completion of surgery	3.66 ± 0.38	3.74 ± 0.29	3.75 ± 0.31	0.000
				0.232

Table 4: Excursion of the diaphragm. Data are presented as mean ± SD. [§]Statistically significant difference compared to group 2; [‡]Statistically significant difference compared to group 3; [@]Statistically significant difference compared to the value before the induction of anesthesia. Group 1=mechanically ventilated without positive end-expiratory pressure; Group 2=positive end-expiratory pressure of 5 cmH_2O; Group 3=positive end-expiratory pressure of 10 cmH_2O.

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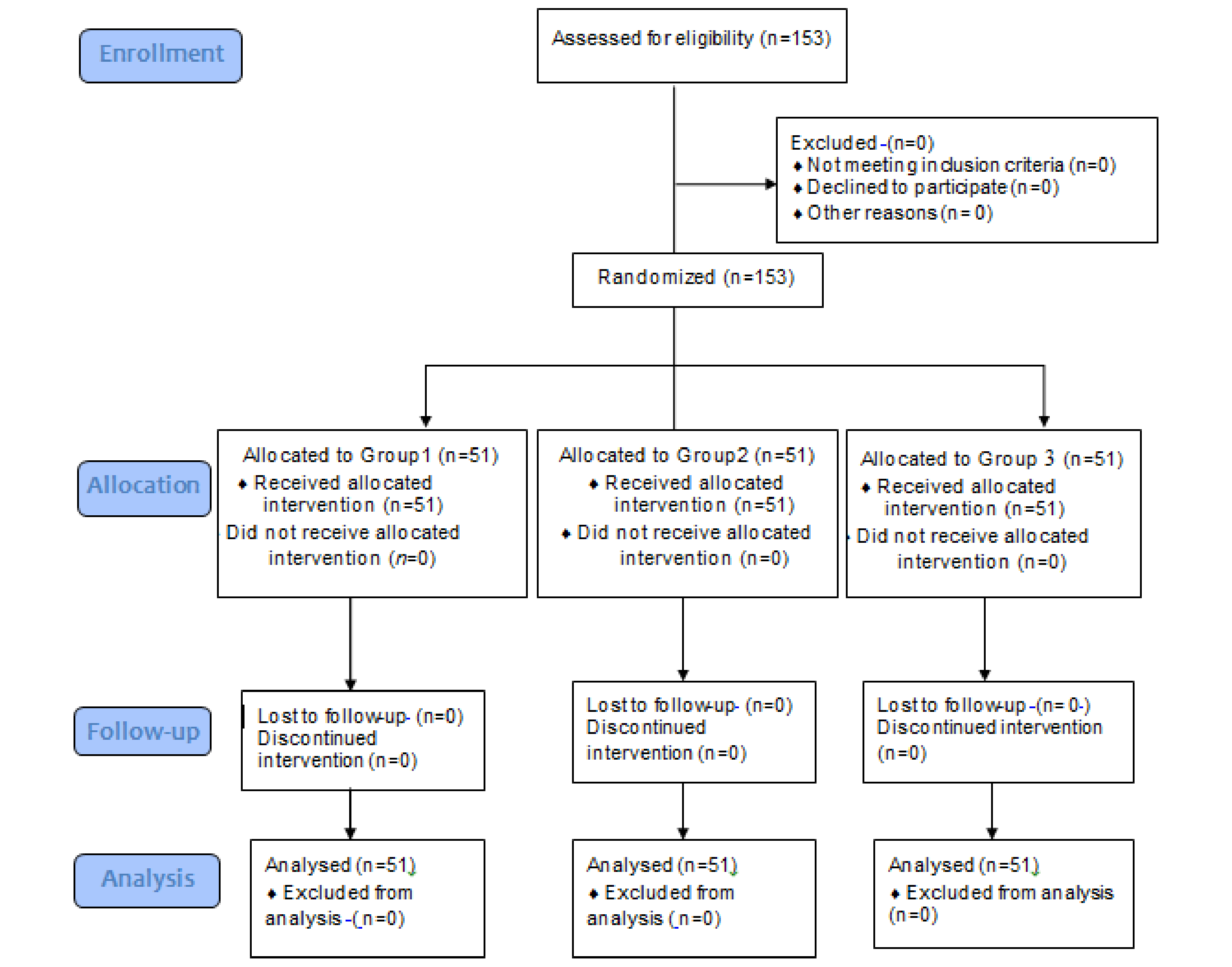

Figure 2: Consort participant flow diagram.

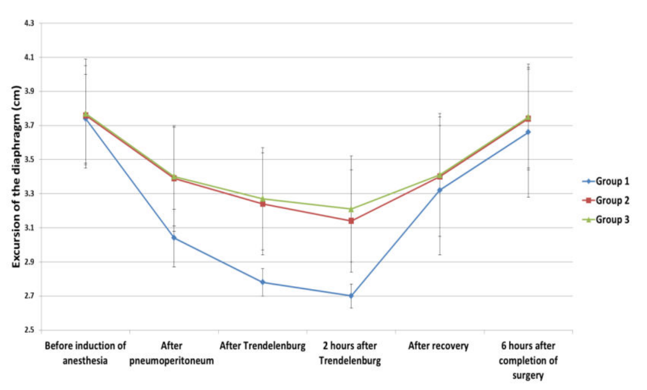

Figure 3: Mean Excursion of the diaphragm (cm) in the study groups over the study period.

There were no significant differences in diaphragm thickness between the three groups. Peak inspiratory pressure was statistically significantly increased in group 3 compared to group 1 and group 2 until 2 h after adoption of the head-down position. Peak inspiratory pressure was increased in group 2 compared to group 1 but not significantly, and it was statistically significantly higher in all three groups compared to the pre-initiation of PEEP value (Table 5, Figure 4).

Throughout the entire study, only 3 patients in group 1 exhibited atelectasis. It did not occur in groups 2 or 3, and this was statistically significant ($p<0.05$). No barotrauma was apparent in any of the three groups.

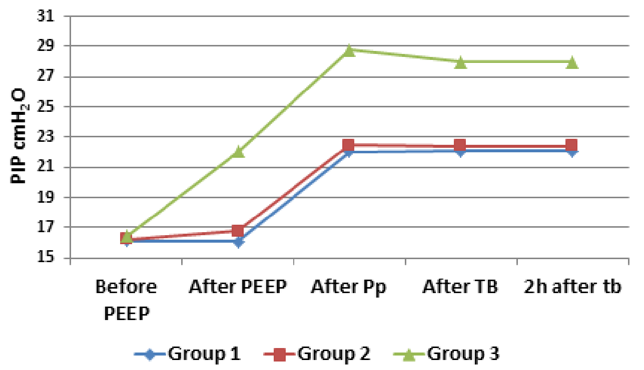

Figure 4: Mean peak inspiratory pressure (cmH_2O) in the study groups over the study period. PIP=peak Inspiratory Pressure; Pp=pneumoperitoneum; TB=Trendelenburg; PEEP=positive end-expiratory pressure.

Groups	Group 1 (n=51)	Group 2 (n=51)	Group 3 (n=51)	P value
Before initiation of PEEP	16.12 ± 0.90	16.20 ± 1.05	16.43 ± 0.96	0.246
After initiation of PEEP	16.06 ± 0.90‡	16.75 ± 2.73‡	22.02 ± 1.50	<0.001
After pneumoperitoneum	22.02 ± 1.24‡@	22.45 ± 1.39‡@	28.78 ± 2.50@	<0.001
After head-down position	22.06 ± 1.20‡@	27.98 ± 2.28@	22.41 ± 1.417‡@	<0.001
2 hours after head-down position	22.06 ± 1.27‡@	22.41 ± 1.41‡@	27.96 ± 2.28@	<0.001

Table 5: Peak inspiratory pressure (cmH_2O). Data are presented as mean ± SD. ‡Statistically significant difference compared to group 3; @Statistically significant difference compared to the value before the induction of anesthesia. Group 1=mechanically ventilated without positive end-expiratory pressure; Group 2=positive end-expiratory pressure of 5 cmH_2O; Group 3=positive end-expiratory pressure of 10 cmH_2O. PEEP=positive end-expiratory pressure.

Discussion

In the current study, US were used to evaluate the effects of PEEP on diaphragmatic functions during pneumoperitoneum and the Trendelenburg position in patients undergoing laparoscopic colorectal surgery. Excursion of the diaphragm decreased in all three groups investigated, and was statistically significantly lower in group 1 compared to groups 2 and 3 up to 2 h after adoption of the head-down position. There was no significant difference in diaphragmatic thickness between the study groups, and no barotrauma apparent in any of the three groups.

Laparoscopic surgery requires pneumoperitoneum and the lithotomy-Trendelenburg position [19]. The increase in abdominal pressure during laparoscopic surgery impairs respiratory function, inducing atelectasis in the dependent lung region [20]. The steep head-down position results in atelectasis and hypoxemia due to decreased functional residual capacity [21]. The application of PEEP increases functional residual capacity [22], the corresponding increase in lung volumes lowers the diaphragmatic dome [23], and this can result in reduced diaphragmatic excursion that is not related to diaphragmatic dysfunction but to caudal displacement of the diaphragmatic dome at the end of expiration [24].

During pneumoperitoneum, diaphragmatic excursion is limited because the abdomen is distended by CO_2, resulting in raised intra-thoracic pressure, reduced pulmonary compliance, and reduced functional residual capacity, which in turn leads to pulmonary atelectasis [25].

Mechanical restriction of diaphragmatic excursion also induces an imbalance in the ventilation/perfusion ratio, causing hypoventilation in ventilator-dependent areas of the lung [26]. In a study by Normando et al. [27] the amplitude of diaphragmatic excursion was restricted during abdominal insufflation pneumoperitoneum in pigs, Meininger et al. [28] reported a study involving 20 patients undergoing totally endoscopic robot-assisted radical prostatectomy allocated to one of two groups; a PEEP group wherein a constant PEEP of 5 cmH_2O was used, or a ZPEEP group in which no PEEP was used. In that study, the application of a constant positive airway pressure of 5 cmH_2O preserved arterial oxygenation during prolonged pneumoperitoneum. A study by Andersson et al. [29] involving 7 patients scheduled to undergo laparoscopic cholecystectomy showed that induction of pneumoperitoneum increased the mean atelectasis volume in the dependent lung regions by 66% (range 11%-170%). The overall lung volume and gas as well as tissue volume significantly decreased, and they concluded that pneumoperitoneum at an intraabdominal pressure of 11-13 mmHg increased the volume of atelectasis.

Futier et al. [30] conducted a study involving 60 adult patients (30 obese, 30 healthy weight) undergoing laparoscopy in reverse Trendelenburg position with zero end-expiratory pressure, with PEEP alone, or with PEEP+“recruitment maneuvers” (RMs). They concluded that RMs combined with 10 cmH_2O of PEEP improved respiratory mechanics and oxygenation during pneumoperitoneum whereas PEEP alone did not. In a study by Cinnella et al. [31] involving 29 consecutive patients, a RM followed by PEEP 5 cmH_2O maintained until the end of surgery was applied after pneumoperitoneum induction. They concluded that an open lung strategy applied after pneumoperitoneum induction increased transpulmonary pressure and led to alveolar recruitment and improvement of gas exchange.

The optimization of PEEP may be an important factor during the perioperative period. Weingarten et al. [32] reported that optimization of PEEP improved oxygenation in patients aged over 65 years undergoing abdominal laparoscopic surgery compared to those who received conventional ventilation. Monastesse et al. [33] conducted a pilot study involving 30 patients scheduled for laparoscopic surgery, and concluded that lung US in the perioperative period before the induction of general anesthesia, after the induction of general anesthesia, after pneumoperitoneum insufflation, on arrival in the recovery room, and before recovery room discharge is feasible, allows tracking of perioperative atelectasis, and facilitates the diagnosis of respiratory complications.

US are a non-ionizing radiation imaging tool that can be used for evaluation of the diaphragm. It can assess diaphragmatic structure by measuring diaphragmatic thickness and diaphragmatic function by measuring diaphragmatic excursion. Being a bedside test conducted *via* a portable machine, it is considered the modality of choice for evaluation of diaphragmatic functions intraoperatively and in critically ill mechanically ventilated patients [34]. It is a promising technique for the evaluation of the structure and dynamic function of the diaphragm. It is accurate, reproducible, and relatively easy to learn [35]. Many clinical groups have reported that US was the modality of choice for evaluation of diaphragm paralysis, especially in neonatal, pediatric, and critically ill patients [36].

Notably however, one of the major limitations of US is the lack of reference values for diaphragm parameters in some patients, especially those with pulmonary or neuromuscular disease, because they have different ranges of lung volumes for quiet breathing, deep breathing, and/or sniff maneuvers [37]. Those types of patients were excluded from the current study from the outset. This limitation can be overcome *via* follow-up and comparison between consecutive values derived from the same patient, and relating the change to the clinical situation of the patient as was done in the current study.

The measurement of excursion depends on maximal voluntary inspiratory effort, and this limits the interpretation and generalization of cut-off values of excursion amplitudes in heterogeneous populations [35-37]. Another limitation apparent in diaphragm US is the inability to obtain suitable scans of the left diaphragmatic copula due to lack of an acoustic window in some patients [38]. This limitation did not have a significant effect in the current study, because we utilized the right subcostal area for scanning using the liver as an acoustic window.

Change in the speed of sound through muscle can produce an error in the thickness measured at peak inspiration. However, this effect has been shown to be negligible [39].

Another well-known limitation pertaining to US in general is that it is an operator-dependent tool, which we tried to overcome by assigning one radiologist with expertise of 10 years in US to perform all the scanning throughout the study.

Conclusion

The application of PEEP is helpful for preserving diaphragmatic excursion during laparoscopic colorectal surgery. It also significantly reduces the incidence of atelectasis. These changes can be evaluated very accurately *via* diaphragmatic US. In the present study, PEEP 10 cmH_2O improved diaphragmatic excursion more than PEEP 5 cmH_2O, although the improvement was not statistically significant, and significantly increased peak inspiratory pressure more than PEEP 5 cmH_2O. Thus, we recommend the use of PEEP 5 cmH_2O.

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