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Original Article

Evaluation of low tidal volume with positive end-expiratory pressure application effects on arterial blood gases during laparoscopic surgery

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Abstract

Background: Pneumoperitoneum (PNP) and patient positions required for laparoscopy can induce pathophysiological changes that complicate anesthetic management during laparoscopic procedures. This study investigated whether low tidal volume and positive end-expiratory pressure (PEEP) application can improve ventilatory and oxygenation parameters during laparoscopic surgery.
Methods: A total of 60 patients undergoing laparoscopic surgery were randomized to either the conventional group ($n = 30$, tidal volume = 10 mL/kg, rate = 12/minute, PEEP = 0 cm H_2O) or the low tidal group with PEEP group ($n = 30$, tidal volume = 6 mL/kg, rate = 18/minute, PEEP = 5 cm H_2O) at maintenance of anesthesia. Hemodynamic parameters, peak plateau pressure (Pplat) and arterial blood gases results were recorded before and after PNP.
Results: There was a significant increase in the partial pressure of arterial carbon dioxide ($PaCO_2$) values after PNP in the conventional group in the reverse Trendelenburg (41.28 mmHg) and Trendelenburg positions (44.80 mmHg; $p = 0.001$), but there was no difference in the low tidal group at any of the positions (36.46 and 38.56, respectively). We saw that PaO_2 values recorded before PNP were significantly higher than the values recorded 1 hour after PNP in the two groups at all positions. No significant difference was seen in peak inspiratory pressure (Ppeak) at the reverse Trendelenburg position before and after PNP between the groups, but there was a significant increase at the Trendelenburg position in both groups (conventional; 21.67 cm H_2O, $p = 0.041$, low tidal; 23.67 cm H_2O, $p = 0.004$). However, Pplat values did not change before and after PNP in the two groups at all positions.
Conclusion: The application of low tidal volume + PEEP + high respiratory rate during laparoscopic surgeries may be considered to improve good results of arterial blood gases.

Keywords: laparoscopy; pneumoperitoneum; positive end-expiratory pressure

1. Introduction

Laparoscopic procedures often result in multiple post-operative benefits allowing for quicker recovery and shorter hospital stay. These advantages explain the increasing success of laparoscopic surgery, which has been proposed for many surgical procedures. However, pneumoperitoneum (PNP) and the patient positions required for laparoscopy induce pathophysiological

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changes that complicate anesthetic management.[1] PNP is a complex but well-tolerated pathophysiological state characterized by an increase in the intra-abdominal pressure and the partial pressure of carbon dioxide (CO_2); it also significantly affects respiratory mechanics such as intraoperative atelectasis, elevated peak inspiratory pressure (Ppeak) and plateau pressure (Pplat) and decreases dynamic compliance of the respiratory system.[2–5]

Although no one anesthetic technique has been proven to be clinically superior to other techniques, general anesthesia with controlled ventilation seems to be the safest technique for operative laparoscopy.[1]

Lung protective ventilation has evolved over the last several decades and has focused largely on patients suffering from acute respiratory distress syndrome (ARDS) and acute lung injury (ALI). There is clear evidence from animal and human data that mechanical ventilation can induce and exacerbate lung injury, and thus the current standard of care is the use of a lung protective ventilation strategy in patients suffering from ARDS or ALI.[6,7]

Many researchers have conducted several large randomized trials showing that the use of lower tidal volumes is associated with improved outcomes and a reduction in the incidence of ventilatory induced lung injury.[8,9] In addition to the reduction of tidal volume, increasing the level of positive end-expiratory pressure (PEEP) is now considered as an integral part of protective ventilation.[10]

The data for the use of low tidal volume in patients undergoing lower-risk elective operations is less evident. However, evidence also exists that mechanical ventilation can be injurious to the lungs and other organ systems in patients without ALI or ARDS.[10]

In this study, we wanted to compare the effects of low tidal volume with PEEP and conventional ventilation strategy during laparoscopy at the head-up or head-down positions.

2. Methods

This study was approved by the Afyon Kocatepe University Hospital Ethics Committee, and written informed consent was obtained from each patient. We prospectively enrolled into our study 60 patients with American Society of Anesthesiologists (ASA) physical status I–II, whose ages were between 20 and 75 years and who were undergoing laparoscopic procedures such as cholecystectomy, hysterectomy, cystectomy, and surgery for colon cancer. Pregnant women, patients with cardiorespiratory disease and obesity (body mass index > 40 kg/m^2), previous lung surgery, or home oxygen therapy were excluded from the study.

Patients were randomized to either the conventional group ($n = 30$) or the low tidal group with PEEP group ($n = 30$) using the sealed envelope system.

Upon arrival in the operating room, patients were monitored with standard anesthetic monitors. A standardized anesthetic technique was used in both groups. Patients were premedicated with 0.1 mg/kg midazolam 1 hour before induction of anesthesia. Thereafter, anesthesia was induced with an infusion of remifentanil (0.2 μg/kg/minute for 5 minutes) and a bolus dose of propofol (2–2.5 mg/kg). Intubation was facilitated with 0.6 mg/kg rocuronium. Maintenance of anesthesia was provided by continuous infusion of propofol (3–5 mg/kg/minute) and remifentanil (0.1–0.2 μg/kg/minute). All patients were ventilated with an S15 Avance anesthetic machine (GE Healthcare, Madison, WI, USA). We divided the patients into two groups according to the ventilatory settings (conventional and low tidal group). Then we adjusted them into four subgroups: (1) conventional group in the Trendelenburg position; (2) conventional group in the reverse Trendelenburg position; (3) low tidal group in the Trendelenburg position; and (4) low tidal group in the reverse Trendelenburg position. In all groups, inspiratory to expiratory time ratio was 1:2 and inspired oxygen fraction (FIO_2) was 0.5 (balanced with air). In the conventional group, ventilatory settings included a rate of 12/minute, tidal volume; 10 mL/kg and a PEEP set at 0 cm H_2O. In the low tidal group with PEEP group, the ventilator settings were adjusted to a rate of 18/minute, tidal volume; 6 mL/kg and a PEEP of 5 cm H_2O. The ventilatory rates were increased as end-tidal CO_2 concentration ($ETCO_2$) level was >50 mmHg. The magnitude of Ppeak and Pplat was obtained directly from the ventilator and was recorded 10 minutes before PNP (T1) and 1 hour after PNP (T2). Arterial blood gas was analyzed at T1 and T2. All hemodynamic parameters such as heart rate (HR), mean arterial pressure (MAP), peripheral oxygen saturation (SpO_2), and $ETCO_2$ were also recorded. After surgery was completed, patients were extubated in the operating room.

CO_2 PNP was created with a closed Veress needle technique maintaining a 14 mmHg intra-abdominal pressure. After insufflation, patients were placed in the Trendelenburg or reverse Trendelenburg position according to their type of surgery (cholecystectomy was done at the Trendelenburg position and hysterectomy, cystectomy, and colon cancer were done at the reverse Trendelenburg position) and then laparoscopic procedures were performed by surgeons.

Statistical analyses were performed using the Statistical Package SPSS version 18 (SPSS Inc., Chicago, IL, USA). Data were expressed as mean ± standard deviation (SD) or median. The Mann-Whitney U test was used to compare continuous variables and the Chi-square test was used to compare categorical variables. The Wilcoxon signed rank test was used to compare preoperative and postoperative variables. We used $\alpha = 0.05$ with a power $(1 - \beta)$ of 0.9 with regards to the study conducted by Kim et al[11] and we studied 15 patients per four subgroups. A p value <0.05 was considered to indicate a statistically significant difference.

3. Results

A total of 30 patients were included in each group, and all completed the study. Patient characteristics were similar between the groups ($p > 0.05$, Table 1). There were no statistically significant differences between the hemodynamic parameters (MAP, HR) measured before anesthesia induction (before and after PNP) in each group ($p > 0.05$, Table 2). Operation characteristics of each group are shown in Table 3,

Table 1
Demographic data.

Characteristics	Conventional ($n = 30$)	Low-tidal with positive end-expiratory pressure ($n = 30$)	p
Age (y)	50.27 ± 13.99	54.50 ± 15.40	0.234[a]
Sex, n (M/F)	3/27	8/22	0.095[b]
Weight (kg)	70.40 ± 8.04	72.33 ± 10.19	0.520[a]
Height (cm)	162.47 ± 5.84	163.07 ± 7.63	0.840[a]
Operation time (min)	124.83 ± 29.31	129.0 ± 24.29	0.298[a]
Smoking status, n	3	5	0.448[b]
Diabetes mellitus, n	1	4	0.061[b]
Hypertension, n	6	11	0.152[b]

Data are presented as the mean ± standard deviation where indicated.
$p < 0.05$ was accepted to be statistically significant.
[a] Mann-Whitney U test.
[b] Chi-square test.

and there were no significant differences between both groups ($p = 0.665$).

No significant differences were seen in Ppeak between the groups at the reverse Trendelenburg position before and after PNP between the groups, but there was a significant increase at the Trendelenburg position in both groups (conventional; $p = 0.041$, low tidal; $p = 0.004$, Table 4). However, Pplat values were not changed before and after PNP in two groups at all positions (Table 4).

A significant decrease was seen in pH values sampled from arterial blood gases in both positions in the conventional group ($p = 0.01$, Table 4). However, in the low tidal group with PEEP, group pH values were stable in the reverse Trendelenburg position at T1 and T2, and a significant decrease was seen in the Trendelenburg position in the low tidal group with PEEP group ($p = 0.007$, Table 4).

There was a significant increase in $PaCO_2$ values after PNP in the conventional group at the reverse Trendelenburg and Trendelenburg positions ($p = 0.001$ and $p = 0.001$, Table 4), but no difference was found in the low tidal group with PEEP group at any positions ($p = 0.426$ and $p = 0.589$, respectively, Table 4).

Table 2
Hemodynamic parameters.

		T0	T1	T2
Mean arterial pressure (mm/Hg)	Conventional	93.87 ± 20.31	90.50 ± 18.71	88.83 ± 12.69
	Low-tidal with positive end-expiratory pressure	105.40 ± 23.17	96.73 ± 20.43	95.80 ± 17.58
	p	0.550	0.206	0.070
Heart rate (beat/min)	Conventional	80.73 ± 10.88	81.47 ± 12.81	76.43 ± 11.51
	Low-tidal with positive end-expiratory pressure	84.47 ± 19.40	81.87 ± 13.93	79.13 ± 18.46
	p	0.678	0.906	0.982

Data are presented as the mean ± standard deviation where indicated.
T0 = before anesthesia induction; T1 = 10 minutes before pneumoperitoneum; T2 = 1 hour after pneumoperitoneum.
A value of $p < 0.05$ was accepted to be statistically significant, and was evaluated with the Mann-Whitney U test.

Table 3
Operation characteristics.

	Conventional ($n = 30$)	Low-tidal with positive end-expiratory pressure ($n = 30$)	p
Hysterectomy, n	6	7	0.665
Cholecystectomy, n	15	15	
Colon cancer, n	3	5	
Cystectomy, n	6	3	

A value of $p < 0.05$ was accepted to be statistically significant, and was evaluated using the Chi-square test.

When we looked at PaO_2 values, we saw that PaO_2 values recorded before PNP (T1) were significantly higher than the values recorded 1 hour after PNP (T2) in two groups at all positions (Table 4).

4. Discussion

The main finding in our study was that low tidal volume with PEEP application showed positive effects on $PaCO_2$ and pH of patients undergoing laparoscopic surgeries.

Several ventilatory strategies have been proposed to prevent intraoperative atelectasis and improve arterial oxygenation in laparoscopic surgeries.[11−14] To the best of our knowledge, there is no study comparing the effectiveness of low tidal volume with PEEP against the conventional method for laparoscopy in the literature. Current guidelines recommend a tidal volume of 6 mL/kg for the management of patients with ALI or ARDS.[15] Application of low tidal volume in patients undergoing lower-risk elective operations is less evident. A study of 39 low-risk patients undergoing elective surgery, randomized patients to 15 mL/kg of tidal volume with zero PEEP, 6 mL/kg of tidal volume with zero PEEP or 6 mL/kg tidal volume with a PEEP of 10 cm H_2O.The authors were unable to find any difference in inflammatory biomarkers in any of the groups.[16] In addition to the reduction of tidal volume, increasing the level of PEEP is now considered as an integral part of protective ventilation. Lower tidal volume may cause atelectasis, especially if PEEP is low or not used at all. Sufficient PEEP must be used to minimize atelectasis and maintain oxygenation. Satoh et al[17] found that PEEP showed positive effects on functional residual capacity, compliance, and PaO_2/FIO_2 ratio in patients undergoing upper abdominal surgery. They used a low tidal volume with 7 mL/kg and the respiratory rate was adjusted to $ETCO_2$ levels, and they suggested that PEEP 10 cm H_2O is necessary to maintain lung function.[17] However, Pelosi et al[18] reported that PEEP 10 cm H_2O did not improve respiratory function in anesthetized postoperative patients, and their tidal volume was 8−12 mL/kg. Determann et al[19] described a randomized, controlled preventive trial comparing mechanical ventilation with tidal volume of 10 versus 6 mL/kg in critically ill patients without ALI at the onset of mechanical ventilation. Mechanical presentation with 10 mL/kg is associated with sustained cytokine production in plasma. Those results suggest that mechanical ventilation with conventional tidal volumes contributed to the development of lung injury in patients

Table 4
Lung inspiratory pressures according to the positions and values of arterial blood gases.

		Conventional		Low-tidal with positive end-expiratory pressure	
		Reverse Trendelenburg	Trendelenburg	Reverse Trendelenburg	Trendelenburg
P peak (cm H_2O)	T1	18.87 ± 3.96	19.33 ± 6.34	20.27 ± 3.51	19.80 ± 4.84
	T2	22.00 ± 5.02	21.67 ± 5.96	19.73 ± 3.99	23.67 ± 5.75
	p	0.086	0.041	0.721	0.004
P plateau (cm H_2O)	T1	13.93 ± 4.20	12.53 ± 3.22	15.47 ± 3.37	12.33 ± 3.45
	T2	14.13 ± 3.44	12.13 ± 3.81	15.20 ± 4.24	14.07 ± 6.06
	p	0.813	0.717	0.574	0.151
$PaCO_2$ (mmHg)	T1	34.23 ± 5.13	36.39 ± 4.46	36.04 ± 4.08	35.62 ± 5.90
	T2	41.28 ± 4.89	44.80 ± 488	36.46 ± 5.46	38.56 ± 6.12
	p	0.01	0.01	0.426	0.589
PaO_2 (mmHg)	T1	218.73 ± 50.06	200.46 ± 69.86	204.74 ± 26.32	182.06 ± 35.45
	T2	167.55 ± 42.82	173.72 ± 54.69	177.14 ± 46.71	177.56 ± 39.01
	p	0.005	0.047	0.015	0.047
pH	T1	7.40 ± 0.05	7.38 ± 0.03	7.41 ± 0.04	7.40 ± 0.06
	T2	7.34 ± 0.06	7.32 ± 0.04	7.38 ± 0.04	7.36 ± 0.05
	p	0.01	0.001	0.023	0.007

Data are presented as the mean ± standard deviation where indicated.
T1 = 10 minutes before pneumoperitoneum; T2 = 1 hour after pneumoperitoneum.
A value of $p < 0.05$ was accepted to be statistically significant, and was evaluated with the Wilcoxon test.
$PaCO_2$, PaO_2 and pH are the results of arterial blood gases.

without ALI at the onset of mechanical ventilation. Cinnella et al[20] investigated the effects of recruitment maneuver and PEEP on respiratory mechanics and transpulmonary pressure during gynecologic laparoscopic surgery. They found that a recruitment maneuver followed by the application of PEEP led to significant alveolar recruitment and improved chest wall and lung elastance in all patients. Kim et al[21] demonstrated that pressure controlled ventilation with PEEP of 5 cm H_2O significantly improves PaO_2/FIO_2 without hemodynamic changes during laparoscopic cholecystectomy. Although the optimal level of PEEP is still controversial, the use of zero PEEP has been associated with worse outcomes, including increased hypoxemia, ventilator-associated pneumonia, and hospital mortality.[22] We used a tidal volume of 10 versus 6 mL and 5 cm H_2O PEEP, and positive benefits were seen in $PaCO_2$ and pH values of arterial blood gases in our study. However, PaO_2 values decreased after PNP in both groups; in order to prevent this, the recruitment maneuver could be done after PNP.

During uneventful CO_2 PNP, the $PaCO_2$ progressively increases after the beginning of CO_2 insufflation in patients under controlled ventilation during gynecologic laparoscopy in the Trendelenburg position, or during laparoscopic cholecystectomy in the head-up position. Due to the reduction in tidal volume and subsequent minute ventilation, CO_2 levels are often elevated in these patients.[23] To avoid severe respiratory acidosis (pH < 7.20), the respiratory rate needs to be increased often up to 30 breaths/minute. In our study, a respiratory rate of 18 breaths/minute was used at the beginning of the operation with low tidal volume to avoid respiratory acidosis. Also in the conventional group, we prevented $ETCO_2$ levels from exceeding 50 mmHg by increasing the inspiratory rates. Although there was a significant increase of $PaCO_2$ after PNP in the conventional group at the reverse Trendelenburg position and the Trendelenburg position, no difference was found in the low tidal group with PEEP group at any positions. Due to adjusting the inspiratory rates according to the $ETCO_2$ values, we thought that low tidal volume and PEEP were responsible for the positive results of $PaCO_2$ and pH values. However, we could not distinguish whether the causative reason was low tidal volume or PEEP, and this was the limitation of our study. Consequently, this effect of low tidal volume and PEEP should be separately studied. In a recent study, Russo et al[24] investigated the effects of PEEP on the respiratory system and cardiac function by using transthoracic echocardiography. They showed that PaO_2 values were improved in the PEEP groups, and both $PaCO_2$ and $ETCO_2$ increased after gas insufflation in the control group. Although both were decreased with 10 cm H_2O of PEEP, using 5 cm H_2O of PEEP only improved the $ETCO_2$ values.

PNP decreases thoracopulmonary compliance by 30–50% in healthy and obese patients.[25,26] A reduction can be expected in the functional residual capacity and development of atelectasis, due to elevation of the diaphragm and changes in the distribution of pulmonary ventilation and perfusion from increased airway pressure.[27] In our study, no difference was seen in Pplat in each group at either the Trendelenburg or reverse Trendelenburg positions, but a significant increase was obtained at the Trendelenburg position in each group.

It is well-known that general anesthesia and mechanical ventilation facilitate atelectasis development in the gravity-dependent regions of the lungs.[27] Furthermore, PNP, high inspired oxygen concentration, and general anesthetics also predispose patients to atelectasis formation during laparoscopic procedures.[28,29] It has already been demonstrated that inhalatory anesthetics such as enflurane and nitrous oxide decrease the ciliary motion of the respiratory epithelium, reduce the surfactant stability, and enhance the production of mucus.[30] A recent study made by Kwak et al[31] showed that application of PEEP with 10 cm H_2O during CO_2 PNP could preserve cerebral oxygen saturation and hemodynamic stability in patients undergoing laparoscopic cholecystectomy under propofol anesthesia.[31] In our study, FIO_2 0.5 and total intravenous anesthesia were used to reduce the interference of high inspired oxygen concentration and inhalational agents on the respiratory mechanics.

In conclusion, application of low tidal volume with PEEP and high respiratory rate during laparoscopic surgeries may be considered to improve good results of arterial blood gases.

References

1. Jean LJ. Anesthesia for laparoscopic surgery. In: Miller RD, editor. *Miller's anesthesia*. 7th ed. Philadelphia: Churchill Livingstone; 2010. pp. 2185−202.
2. Klopfenstein CE, Schiffer E, Pastor CM, Beaussier M, Francis K, Soravia C, et al. Laparoscopic colon surgery: unreliability of end-tidal CO_2 monitoring. *Acta Anaesthesiol Scand* 2008;**52**:700−7.
3. Nguyen NT, Anderson JT, Budd M, Fleming NW, Ho HS, Jahr J, et al. Effects of pneumoperitoneum on intraoperative pulmonary mechanics and gas exchange during laparoscopic gastric bypass. *Surg Endosc* 2004;**18**:64−71.
4. Oikkonen M, Tallgren M. Changes in respiratory compliance at laparoscopy: measurements using side stream spirometry. *Can J Anaesth* 1995; **42**:495−7.
5. Hong JY, Chung KH, Lee YJ. The changes of ventilatory parameters in laparoscopic colecystectomy. *Yonsei Med* 1999;**40**:307−12.
6. Webb HH, Tierney DF. Experimental pulmonary edema due to intermittent positive pressure ventilation with high inflation pressures. Protection by positive end expiratory pressure. *Am Rev Respir Dis* 1974;**110**:556−65.
7. Slutsky AS. Basic science in ventilator-induced lung injury: implications for the bedside. *Am J Respir Crit Care Med* 2001;**163**:599−600.
8. Esteban A, Anzueto A, Frutos F, Alía I, Brochard L, Stewart TE, et al. Characteristics and outcomes in adult patients receiving mechanical ventilation: a 28-day international study. *J Am Med Assoc* 2002;**287**:345−55.
9. Wongsurakiat P, Pierson DJ, Rubenfeld GD. Changing pattern of ventilator settings in patients without acute lung injury: changes over 11 years in a single institution. *Chest* 2004;**126**:1281−91.
10. Lipes J, Bojmehrani A, Lellouche F. Low tidal volume ventilation in patients without acute respiratory distress syndrome: a paradigm shift in mechanical ventilation. *Crit Care Res Pract* 2012;**10**:1155−67.
11. Kim JY, Shin CS, Kim HS, Jung WS, Jeong H. Positive end-expiratory pressure in pressure-controlled ventilation improves ventilatory and oxygenation parameters during laparoscopic cholecystectomy. *Surg Endosc* 2010;**24**:1099−103.
12. Meininger D, Byhahn C, Mierdl S, Westphal K, Zwissler B. Positive end-expiratory pressure improves arterial oxygenation during prolonged pneumoperitoneum. *Acta Anaesthesiol Scand* 2005;**49**:778−83.
13. Maracajà-Neto LF, Verosai N, Erosa A, Roncally AC, Giannella A, Bozza A, et al. Beneficial effects of high positive end-expiratory pressure in lung respiratory mechanics during laparoscopic surgery. *Acta Anaesthesiol Scand* 2009;**53**:210−7.
14. Talab HF, Zabani IA, Abdelrahman HS, Bukhari WL, Mamoun I, Ashour MA, et al. Intraoperative ventilatory strategies for prevention of pulmonary atelectasis in obese patients undergoing laparoscopic bariatric surgery. *Anesth Analg* 2009;**109**:1511−6.
15. Perilli V, Sollazzi L, Modesti C, Annetta MG, Sacco T, Bocci MG, et al. Comparison of positive end-expiratory pressure with reverse Trendelenburg position in morbidly obese patients undergoing bariatric surgery: effects on hemodynamics and pulmonary gas exchange. *Obes Surg* 2003;**13**:605−9.
16. Dellinger RP, Levy MM, Carlet JM, Bion J, Parker MM, Jaeschke R, et al. Surviving sepsis campaign: international guidelines for management of severe sepsis and septic shock. *Crit Care Med* 2008;**36**:296−327.
17. Wrigge H, Zinserling J, Stüber F, von Spiegel T, Hering R, Wetegrove S, et al. Effects of mechanical ventilation on release of cytokines into systemic circulation in patients with normal pulmonary function. *Anesthesiology* 2000;**93**:1413−7.
18. Satoh D, Kurosawa S, Kirino W, Wagatsuma T, Ejima Y, Yoshida A, et al. Impact of changes of positive end-expiratory pressure on functional residual capacity at low tidal volume ventilation during general anesthesia. *J Anesth* 2012;**26**:664−9.
19. Pelosi P, Ravagnan I, Giurati G, Panigada M, Bottino N, Tredici S, et al. Positive end-expiratory pressure improves respiratory function in obese but not in normal subjects during anesthesia and paralysis. *Anesthesiology* 1999;**91**:1221−31.
20. Determann RM, Royakkers A, Wolthuis EK, Vlaar AP, Choi G, Paulus F, et al. Ventilation with lower tidal volumes as compared to conventional tidal volumes for patients without acute lung injury: a preventive randomized controlled trial. *Crit Care* 2010;**14**:R1.
21. Cinnella G, Grasso S, Spadaro S, Rauseo M, Mirabella L, Salatto P, et al. Effects of recruitment maneuver and positive end-expiratory pressure on respiratory mechanics and transpulmonary pressure during laparoscopic surgery. *Anesthesiology* 2013;**118**:114−22.
22. Manzano F, Fernández-Mondéjar E, Colmenero M, Poyatos ME, Rivera R, Machado J, et al. Positive-end expiratory pressure reduces incidence of ventilator-associated pneumonia in nonhypoxemic patients. *Crit Care Med* 2008;**36**:2225−31.
23. O'Croinin D, Ni Chonghaile M, Higgins B, Laffey JG. Bench-to-bedside review: permissive hypercapnia. *Crit Care* 2005;**9**:51−9.
24. Russo A, Di Stasio E, Scaglisui A, Bevilacqua F, Antonietta M, Marana R, et al. Positive end-expiratory pressure during laparoscopy: cardiac and respiratory effects. *J Clin Anesth* 2013;**25**:314−20.
25. Fahy BG, Barnas GM, Nagle SE, Flowers JL, Njoku MJ, Agarwal M. Changes in lung and chest wall properties with abdominal insufflation of carbon dioxide are immediately reversible. *Anesth Analg* 1996;**82**:501−5.
26. Dumont L, Mattys M, Mardirosoff C, Vervloesem N, Allé JL, Massaut J. Changes in pulmonary mechanics during laparoscopic gastroplasty in morbidly obese patients. *Acta Anesthesiol Scand* 1997;**41**:408−13.
27. Andersson LE, Bååth M, Thörne A, Aspelin P, Odeberg-Wernerman S. Effect of carbon dioxide pneumoperitoneum on development of atelectasis during anesthesia, examined by spiral computed tomography. *Anesthesiology* 2005;**102**:293−9.
28. Nguyen NT, Wolfe BM. The physiologic effects of pneumoperitoneum in the morbidly obese. *Ann Surg* 2005;**241**:219−26.
29. Vassiliou MP, Rizzoti L, Laopodis V, Amygdalou A, Psarakis C, Leontaridi C, et al. Non-linear evaluation of respiratory mechanics during laparoscopic cholecystectomy. *Hepatogastroenterology* 2003;**50**:934−8.
30. Wahba RW, Tessler MJ, Kleiman SJ. Acute ventilatory complications during laparoscopic upper abdominal surgery. *Can J Anaesth* 1996;**43**: 77−83.
31. Kwak HJ, Park SK, Lee KC, Lee DC, Kim JY. High positive end-expiratory pressure preserves cerebral oxygen saturation during laparoscopic cholecystectomy under propofol anesthesia. *Surg Endosc* 2013;**27**:415−20.