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Original Research Article

Effect of PEEP on Lung Compliance and Airway Pressure during Laparoscopic Abdominal Surgery

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Conflict of interest: Nil

Abstract:

Background and Aims: Laparoscopic surgery is a minimally invasive surgery which is getting popularity nowadays for its varied benefits. Pneumoperitoneum being an integral part of laparoscopic surgery, alters the respiratory and cardiovascular mechanics. Positive End Expiratory Pressure (PEEP) after pneumoperitoneum might counteract those adverse physiological changes. The aim of the study was to assess Lung compliance, airway pressures and hemodynamics after pneumoperitoneum induction and after giving PEEP.

Material and Methods: This is a prospective observational study done on 121 patients undergoing laparoscopic abdominal surgery. Parameters observed were Lung Compliance (LC), Peak and Plateau airway pressure, Heart Rate (HR) and Mean Arterial Pressure (MAP) after intubation (int), 5 minutes after pneumoperitoneum induction (pnm) and 5 minutes after giving PEEP of 5 cm H_2O. Statistical analysis plan was done and p-value<0.05 was takes as significant.

Results: Mean value of LC_{pnm} is decreased than LC_{int}(LC_{int}- 35.19 ± 5.423 ml/cmH_2O vsLC_{pnm}- 27.05 ± 5.234 ml/cmH_2O) and incresed significantly after application of PEEP (LC_{pnm}- 27.05 ± 5.234 ml/cmH_2O vs LC_{PEEP}- 30.75 ± 5.514 ml/cmH_2O, p< 0.0001). Mean Peak airway $pressure_{int}$ is 18.18± 2.443 cm H_2O, mean Peak airway $pressure_{pnm}$ is 18.826± 2.654 cm H_2O (Increased) and mean Peak airway $pressure_{PEEP}$ is 21.80± 2.845 cm H_2O (Increased). Likewise mean Plateau airway $pressure_{int}$ is 11.07± 2.549 cm H_2O, mean plateau airway $pressure_{pnm}$ is 11.71± 2.51 cm H_2O (Increased) and mean $plateau_{PEEP}$ is 15.107± 2.738 cm H_2O (Increased).

Conclusions: PEEP applied after pneumoperitoneum improves LC without any adverse effect on airway pressure.

Keywords: Pneumoperitoneum, Laparoscopic Surgery, Positive End Expiratory Pressure, Lung Compliance, Peak airway pressure, Plateau airway pressure.

Background:

Laparoscopic procedures have many advantages over conventional surgeries [1-4]. However, the effect of pneumoperitoneum is deleterious resulting in intraoperative atelectasis causing reduced Lung Compliance [5-11].

Lung protective ventilation using PEEP were studied multiple times to minimize ventilator induced lung injury (VILI) [31-39].

In previous studies, there are controversies regarding PEEP in preventing postoperative atelectasis versus causing intraoperative hemodynamic instability. [12,2,9,14].

This study was done to observe the effect of PEEP on respiratory mechanics in laparoscopic abdominal surgery using GE-Carestation 620 in order to provide evidence for clinical practice and further research. Special emphasis was placed on evaluation of airway pressure and lung compliance. [15-22]

Materials and methods:

This prospective, clinical and observational study was approved by the institutional Ethical Committee. As there was scarcity in similar study in this topic, we have performed a pilot study on 10 patients undergoing laparoscopic abdominal surgery. We have enrolled the patients for pilot study according to study inclusion and exclusion criteria. From the pilot study result, the study sample size i.e. 121 has been calculated from the following formula [23]:

Sample size (N)= $2(Z1-\alpha/2)^2(SD)^2/L^2$

Where, **Z1-α/2**= Standard normal deviate = 1.96 (considering confidence level 95%)

SD= the expected standard deviation of the study variable in target population

Mean difference of lung compliance in the patients in pilot study was calculated and it was found to be 6.71±1.98.

Lc=Lung compliance

L= Precision (we take the precision of our study to be 0.5)

Written informed consent was obtained from all 121 adult patients enrolled in the study. We enrolled 18-60 years old ASA- I and II patients posted for laparoscopic abdominal surgery. Patient with known cardiac or pulmonary disease, obesity [defines as BMI$\geq$ 30 kg m^{-2}] and patient with Unfavourable hemodynamic parameters after pneumoperitoneum are excluded from the study. Patients' current medication reviewed and optimization of the drug therapy was achieved. Upon arriving in Operation Theatre, Patients was positioned supine and monitors were attached as per ASA guideline for checking heart rate, electrocardiogram tracing, non invasive blood pressure, pulse oxymetry and temperature. After checking the preanaesthesia check list, preoxygenation with 100% oxygen was done to the patients for 3 minutes. After administration of Fentanyl(2mcg/kg) and Midazolam(0.05mg/kg), anaesthesia was induced with Propofol (2- 3mg/kg). Following confirmation of adequate mask ventilation, Atracurium(0.5mg/kg) was administered as Muscle relaxant. After 3 minutes, laryngoscopy and endotracheal intubation was performed with appropriate endotracheal tube sizes. During induction and throughout the procedure, oxygen saturation, end tidal CO2 were monitored. Hemodynamic stress response in terms of Heart rate, Systolic blood pressure, Diastolic blood pressure, Mean arterial blood pressure were noted just after intubation. Briefly all patients were set to ventilator support in GE carestation model no-620 with volume controlled mode of ventilation with following parameter- Tidal Volume-(predicted body weight *6-8), Respiratory rate-12/min. Inspiratory:Expiratory-1:2; Tpause-5%, PEEP-0cm H2O. The predicted body weight was calculated as $49.9 + 0.91 \times [\text{height (cm)} - 152.4]$. Sevoflurane was provided in titrated dose along with oxygen and N_2O with an inspiratory oxygen fraction set at 0.4 as needed to maintain the SpO_2 >95%. Standardised fluid management was performed in patients using a crystalloid solution (Lactated Ringer's solution;) at a rate of 20 mL kg^{-1} h^{-1} immediately before the anaesthetic induction and until the patient was placed in Trendelenburg position, followed by 5 kg^{-1} h^{-1} until the end of the surgery. Before the pneumoperitoneum introduction, lung compliance, peak and plateau airway pressure were noted as shown in the GE workstation monitor. 5 minutes after establishing pneumoperitoneum i.e. abdominal carbon di-oxide inflation to obtain intraabdominal pressure of 12 mm of Hg and proper positioning, if the patient is hemodynamically stable(i.e., mean arterial pressure $\geq$ 65 mmHg and heart rate $\geq$ 50 beat), lung compliance, peak and plateau airway pressure were noted along with other variables. PEEP of 5cm of H_2O is added. 5 minutes after adding the PEEP lung compliance, peak and plateau airway pressure and hemodynamic profile were noted(fig-1). At the end of surgery, residual neuromuscular blockade were reversed with neostigmine 0.05mg/kg and glycopyrrolate 0.01mg/kg and extubation were done, when patients were fully awake and breathing spontaneously.

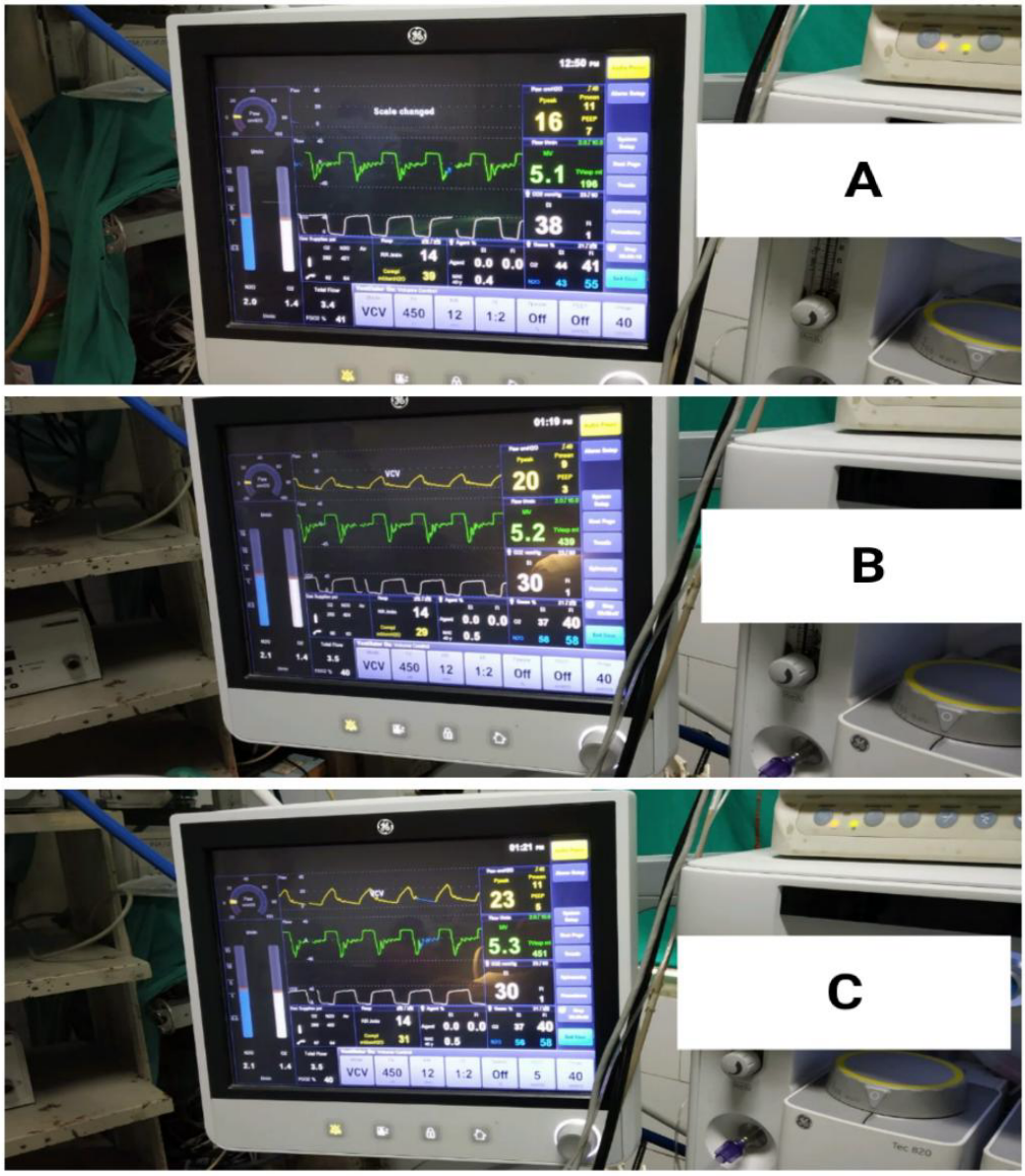

Figure 1: Showing Lung Compliance- 39 ml/cm H_2O and Ppeak- 16 cm H_2O just after intubation; (B) showing Lung Compliance- 29 ml/cm H_2O and Ppeak- 20 cm H_2O after pneumoperitoneum; (C) showing lung compliance- 31 ml/cm H_2O and Ppeak- 23 cm H_2O after applying PEEP

For statistical analysis data were entered into a Microsoft excel spreadsheet and then analyzed by SPSS (version 27.0; SPSS Inc., Chicago, IL, USA) and GraphPad Prism version 5. Data had been summarized as mean and standard deviation for numerical variables and count and percentages for categorical variables. P value <0.05 was considered as statistically significant.

Results

Table 1: Demographic data and ASA distribution

Age(years) Mean±SD		37.75±9.4
BMI Mean±SD		20.52±1.8
Sex(no)	Male	47
	Female	74

It was found that mean difference of Lung compliance after intubation was 35.190 with 95% confidence interval [34.21–36.17, P < 0.0001]; after pneumoperitoneum it was 27.050 with 95%

confidence interval [26.11–27.99, P < 0.0001] and after PEEP was 30.752 with 95% confidence interval [29.76–31.74, P < 0.0001].

Mean difference of Peak airway pressure after intubation was 18.182 [17.74–18.62, P < 0.0001]; after pneumoperitoneum it was 18.826 [18.35–19.30, P < 0.0001] and after PEEP was 21.802 with 95% confidence interval [21.29–22.31, P < 0.0001].

Mean value of Platue pressure after intubation was 11.066 [10.61–11.52, P < 0.0001],; after pneumoperitoneum it was 11.711 [11.26–12.16, P < 0.0001] and after PEEP it was 15.107 with 95% confidence interval [14.61–15.60, P < 0.0001].(Fig-2)

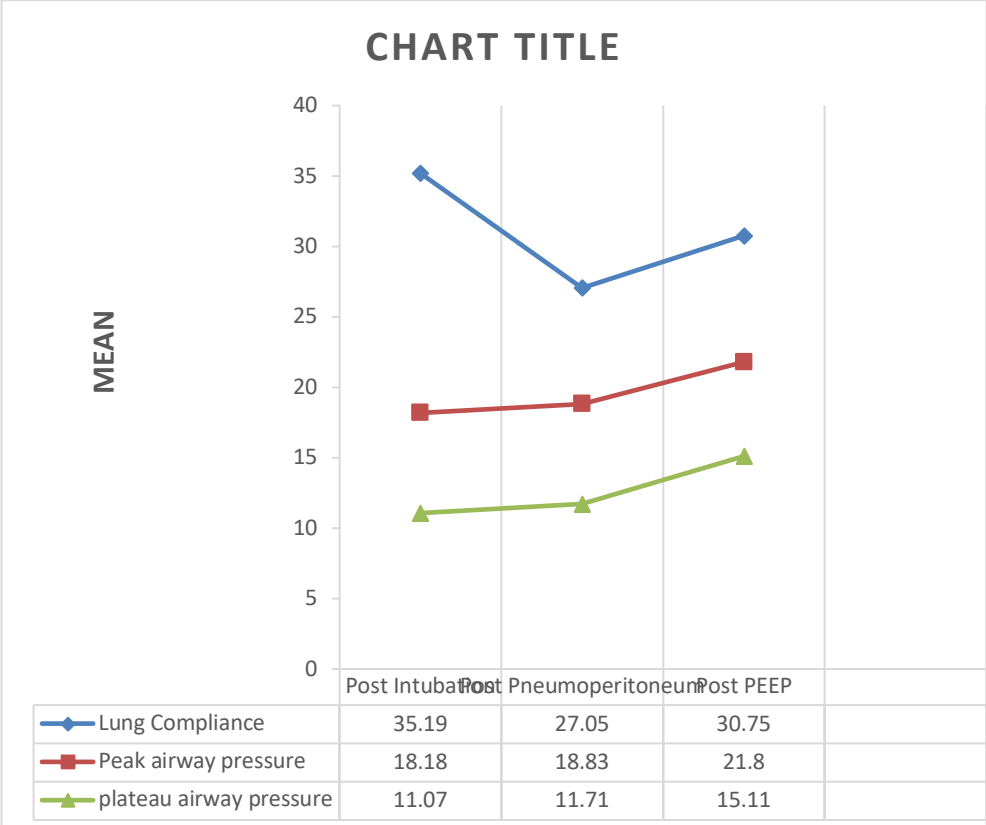

Figure 2: Distribution of mean Lung Compliance, Peak And Plateau Airway pressure after intubation, after pneumoperitoneum and after PEEP

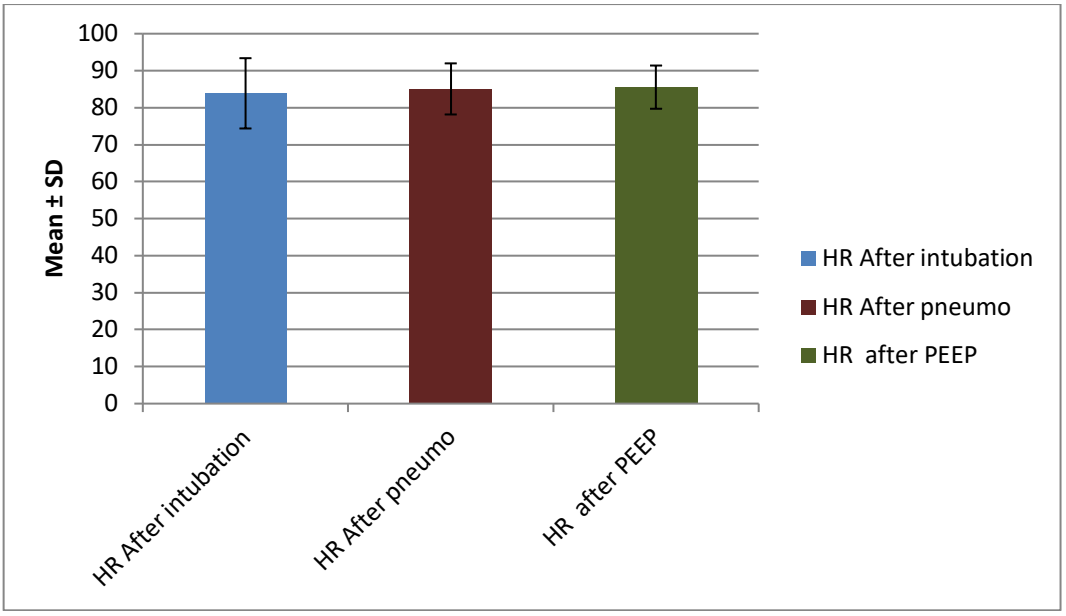

Figure 3: Difference of mean HR After intubation, HR After pneumo and HR after PEEP

It was seen that mean difference of HR after intubation was 83.876 [82.17–85.59], after pneumoperitoneum it was 85.074 [83.83–86.32] and after applying PEEP it was 85.545 with 95% confidence interval [84.49–86.60](Fig-3). Changes in heart rate showed significant difference after pneumoperitoneum and after applying PEEP.

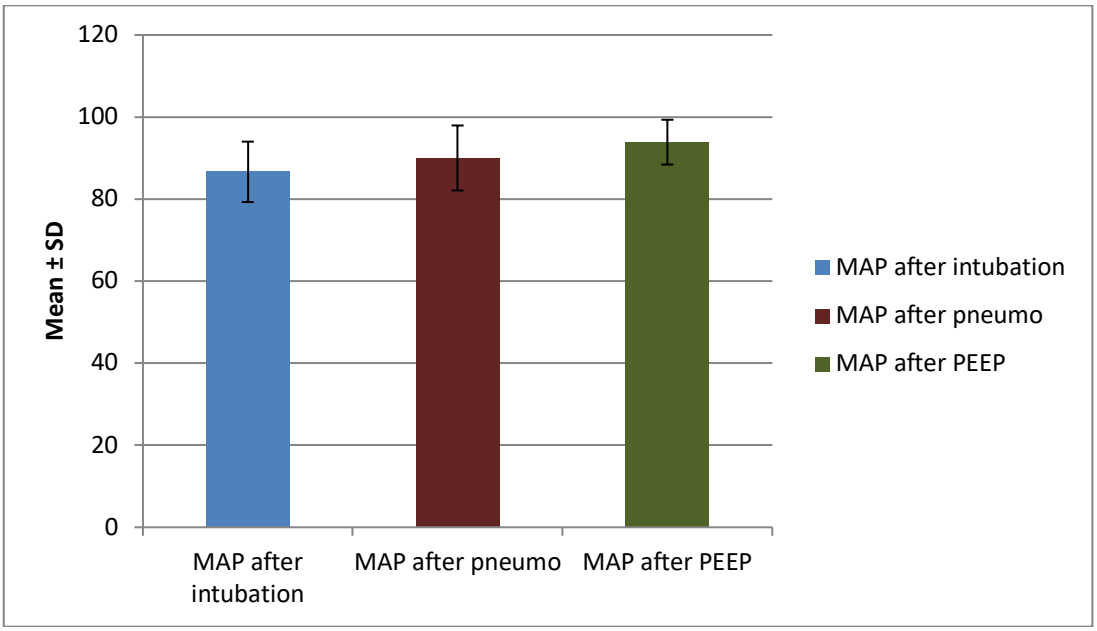

Figure 4: Difference of mean MAP after intubation, after pneumoperitoneum and after PEEP

Likewise, It was documented that mean difference of MAP after intubation was 86.636[85.31–87.96], after pneumoperitoneum it was 90.025[88.60–91.45] and after application of PEEP it was 93.884 with 95% confidence interval [92.90–94.87](Fig-4).

Both pneumoperitoneum and application of PEEP showed significant difference in changes in MAP.

Discussion

Changes on lung physiology after peritoneal insufflation is attributed to splinting of diaphragm and reduced chest wall movement.With combined effect of anaesthesia, it additionally causes disturbances in pulmonary gas exchange, development of atelectasis in basal alveoli, associated with reduction of FRC, due to altered intrathoracic volume, decreased inspiratory muscle tone and increased abdominal pressure[12-18]

Trendelenburg position (Patient positioned supine, 15–30 degree incline with the feet elevated above the head), influences the abdominal pressure through gravity, causes reduction in lung compliance and an elevated airway resistance (RAW), thus may result in additional loss of FRC

and further changes in the respiratory system mechanics [19,20].

Positive pressure controlled ventilation is a major risk for ventilator-induced lung injury(VILI) [21-23].General anaesthesia again makes the patient more vulnerable to VILI, mostly because anaesthetic induction and muscle relaxation decreases the end expiratory lung volume (EELV) by 9–25% in adults [24-28]. Cyclic opening and collapsing of alveoli are being one of the primary mechanisms of VILI during anaesthesia.

Positive end-expiratory pressure (PEEP) can be defined as the application of positive pressure to the airway at the end of expiration. PEEP improves pulmonary oxygen exchange through [9,29,30]:

i. Prevention of the collapse of small bronchiole and alveoli
ii. Redistribution of pulmonary blood flow
iii. Increased Functional Residual Capacity (FRC)
iv. Improves pulmonary compliance
v. Improves ventilation perfusion abnormalities

Work of breathing of the respiratory system is completely depentanton pressure needed to overcome airway resistance, elastic forces and impedance. This way, a betterment of Resistance System Compliance (CRS) indicates lower elastic work pressures and, therefore, a more favorable dynamic pressure/volume curve (P/V curve) [40-42].

Multiple previous studies have suggested high driving pressures (ΔP) i.e. the difference between Plateau pressure and PEEP have been associated with postoperative pulmonary complications [43-46].

In a previous study by Bergesio R et al [47], which was conducted on children undergoing abdominal laparoscopic surgery, it was seen that the changes of respiratory mechanics has been manifested as increased peak airway pressure (P_{aw}) during pneumoperitoneum. Similar changes has also been observed in this study. This finding indicates that pneumoperitoneum in laparoscopic abdominal surgery results in a significant decrease in respiratory compliance and Functional residual capacity which might cause a decrease in arterial oxygenation. Lower arterial oxygenation is detrimental in patients with poor respiratory reserve or prior lung disease.

With this background knowledge we have included patients with healthy lung in our study so that if the result is satisfactory further study can be planned.

A good enough PEEP or optimal PEEP is where oxygenation is maximum and there is minimum end expiratory atelectais.

A study by Ostberg E et al [48] in 2015 showed that an isolated PEEP without any recruitment maneuver resulted in significant reduction in atelectasis as seen in intraoperative and postoperative computed tomography. As guided by this finding, we have obsereved if there is any improvement in lung mechanics while using PEEP during laparoscopic surgery. It has been seen in previous literature PEEP of less than 10 cm H2O is seldom associated with hemodynamic instability in absence of intravascular volume depletion. So, we have used PEEP of 5 cm of H_2O to observe any effect on lung mechanics.

This study was conducted for a period of January, 2020 to January, 2021.

Mean BMI of the study population in this study was 20.52± 1.803.

In a study conducted by Tomescu DR et al [49] on 50 patients undergoing Robot Assisted surgery, it had been proved that obesity with BMI of more that 30 kg/m^2 causes significant decrease in lung compliance after induction of anaesthesia.This was the reason we excluded patients with BMI of more than 30 kg/m^2 as that would cause a confounding effect in the result of the study.

It was found that, mean value of HR, SBP, DBP and MAP all increased after pneumoperitoneum and after applying PEEP [$P < 0.0001$], even though those are not beyond 20 percentile of baseline vital parameters.

From the collected data, it was deducted that the mean Lung compliance after intubation was 35.19± 5.423, after pneumoperitoneumwas 27.05± 5.234 and after applying PEEP increased to30.75± 5.514. So, the lung compliance measured by GE Carestation 620 shows an increment while applying PEEP as it was seen in a study by Spaeth J et al [50] in their study in 2016.

The mean Peak airway pressure after intubation was 18.18± 2.443. Pneumoperitoneum increased it to18.83± 2.654. Also the further application of PEEP increased the value to 21.80± 2.845.

Mean level of Plateue airway pressure after intubation was 11.07± 2.549. After pneumoperitoneumthe Plateau pressure was 11.71± 2.511. The application of PEEP increases the mean Plateaue pressure to 15.11± 2.738.

So in this study, we found that pneumoperitoneum worsens lung compliance and increases airway pressure and applying PEEP can restore the lung compliance in a value nearing baseline value. But applying PEEP also worsens airway pressure which is not found to be detrimental to patient as the airway pressure never exceeds 30 cm H_2O and it never

causes unstable hemodynamic profile. This data can be used in future study in geriatric patients or in patients with preoperative lung pathology to reduce intraoperative lung stress and postoperative lung injury.

Conclusion

PEEP applied after pneumoperitoneum would rightfully reverse the changes in Respiratory mechanics happened during laparoscopic abdominal surgery which can be reflected by improved lung compliance. Airway pressures may increase, but is not seen to be detrimental for the patient.

Reference

1. Buia A, Stockhausen F, Hanisch E. Laparoscopic surgery: A qualified systematic review. World Journal of Methodology. 2015;5 (4):238.
2. Matovic E, Hasukic S, Ljuca F, Halilovic H. Quality of Life in Patient, s After Laparoscopic and Open Cholecystectomy. Medical Archives. 2012 Mar 1;66(2):97.
3. Johansson M, Thune A, Nelvin L. Randomized clinical trial of open versus laparoscopic cholecystectomy in the treatment of acute cholecystitis. Br J Surg 2005;92:44–9.
4. Joris J, Cigarini I, Legrand M, Jacquet N, De Groote D, Franchimont P, Lamy M. Metabolic and respiratory changes after cholecystectomy performed via laparotomy or laparoscopy. BJA: British Journal of Anaesthesia. 1992 Oct 1;69(4):341-5.
5. Valenza F, Vagginelli F, Tiby A, Francesconi S, Ronzoni G, Guglielmi M, et al. Effects of the beach chair position, positive end-expiratory pressure, and pneumoperitoneum on respiratory function in morbidly obese patients during anesthesia and paralysis. Anesthesiology. 2007;107:725–732.
6. Pelosi P, Foti G, Cereda M, Vicardi P, Gattinoli L. Effects of carbon dioxide insufflation for laparoscopic cholecystectomy on the respiratory system. Anaesthesia. 1996;51(8):744-749.
7. Sprung J, Whalley D, Falcone T, Warner D, Hubmayr R, Hammel J. The Impact of Morbid Obesity, Pneumoperitoneum, and Posture on Respiratory System Mechanics and Oxygenation During Laparoscopy. Anesthesia & Analgesia. 2002;94(5):1345-1350.
8. Andersson L, 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(2):293-299.
9. Duggan M, Kavanagh BP. Pulmonary atelectasis: a pathogenic perioperative entity. Anesthesiology 2005;102:838–54.
10. Hedenstierna G, Rothen HU. Atelectasis formation during anesthesia: causes and measures to prevent it. J ClinMonitComput 20 00;16:329–35.
11. Wang M, Geng N, Gao Y, Zhang Y, Wang Y, Shen X etal.Comparison of the effects of different positive end-expiratory pressure levels on respiratory mechanics and oxygenation in laparoscopic surgery: A protocol for systematic review and network meta-analyses. Medicine. 2018 Nov;97(48).
12. Feldman JM. Optimal ventilation of the anesthetized pediatric patient. AnesthAnalg. 2015; 120:165–75.
13. Wanderer JP, Ehrenfeld JM, Epstein RH, Kor DJ, Bartz RR, Fernandez-Bustamante A, et al. Temporal trends and current practice patterns for intraoperative ventilation at U.S. academic medical centers: a retrospective study. BMC Anesthesiol. 2015;15:40.
14. Vargas M, Sutherasan Y, Gregoretti C, Pelosi P. PEEP role in ICU and operating room: from pathophysiology to clinical practice. ScientificWorldJournal. 2014;2014:852356.
15. Futier E, Constantin JM, Paugam-Burtz C, Pascal J, Eurin M, Neuschwander A, et al. IMPROVE study group. A trial of intraoperative low-tidal-volume ventilation in abdominal surgery. N Engl J Med. 2013;369: 428–37.
16. Wolthuis EK, Choi G, Dessing MC, Bresser P, Lutter R, Dzoljic M, et al. Mechanical ventilation with lower tidal volumes and positive end-expiratory pressure prevents pulmonary inflammation in patients without preexisting lung injury. Anesthesiology. 2008;108:46–54
17. Barbosa FT, Castro AA. de Sousa-Rodrigues CF. positive end-expiratory pressure (PEEP) during anaesthesia for prevention of mortality and postoperative pulmonary complications. Cochrane Database Syst Rev. 2014;6:CD007 922.
18. Severgnini P, Selmo G, Lanza C, Chiesa A, Frigerio A, Bacuzzi A, et al. Protective mechanical ventilation during general anesthesia for open abdominal surgery improves postoperative pulmonary function. Anesthesiology. 2013;118:1307–21. https://doi.org/10.1097/ ALN.0b013e31829102de
19. Kneyber MC. Intraoperative mechanical ventilation for the pediatric patient. Best Pract Res ClinAnaesthesiol. 2015;29:371–9.
20. Futier E, Marret E, Javer S. Perioperative positive pressure ventilation: an integrated approach to improve pulmonary care. Anaesthesiology. 2015;123:400-408.
21. Hedenstierna G, Rothen HU. Atelectasis formation during anesthesia: causes and

measures to prevent it. J ClinMonitComput 2000;16:329–35.
22. Hedenstierna G, Tokics L, Strandberg Å, Lundquist H, Brismar B. Correlation of gas exchange impairment to development of atelectasis during anaesthesia and muscle paralysis. Acta Anaesthesiologica Scandinavica. 1986 Feb;30(2):183-91.
23. Charan J, Biswas T. How to calculate sample size for different study designs in medical research. Indian J Psychol Med. 2013;35(2): 121-126.
24. Meininger D, Byhahn C, Mierdl S, Westphal K, Zwissler B. Positive end-expiratory pressure improves arterial oxygenation during prolonged pneumoperitoneum. Acta Anaesthesiologica Scandinavica. 2005 Jul; 49(6):778-83.
25. Lundquist H, Hedenstierna G, Strandberg Å, Tokics L, Brismar B. CT-assessment of dependent lung densities in man during general anaesthesia. ActaRadiologica. 1995 Jul;36(4-6):626-32.
26. Neumann P, Rothen HU, Berglund JE, Valtysson J, Magnusson A, Hedenstierna G. Positive end-expiratory pressure prevents atelectasisduring general anaesthesia even in the presence of a high inspired oxygen concentration. Acta Anaesthesiologica Scandinavica. 1999 Mar;43(3):295-301.
27. Tokics L, Hedenstierna G, Strandberg Å, Brismar BO, Lundquist H. Lung collapse and gas exchange during general anesthesia: effects of spontaneous breathing, muscle paralysis, and positive end-expiratory pressure. The Journal of the American Society of Anesthesiologists. 1987 Feb 1;66(2):157-67.
28. Brismar B, Hedenstierna G, Lundquist H, Strandberg A, Svensson L, Tokics L. Pulmonary densities during anesthesia with muscular relaxation--a proposal of atelectasis. Anesthesiology. 1985 Apr 1;62(4):422-8.
29. Lumb AB, Nunn JF. Respiratory function and ribcage contribution to ventilation in body position commonly used during anesthesia. AnesthAnalg 1991;73:422–6.
30. 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. Surgical Endoscopy And Other Interventional Techniques. 2004 Jan;18(1):64-71.
31. Slutsky AS, Ranieri VM. Ventilator-induced lung injury. N Engl J Med. 2013;369:2126–36.
32. Donoso A, Cruces P. Dañopulmonarinduci doporventilaciónmecánica y estrategiaventilatoriaconvencionalprotectora. Rev ChilPediatr. 2007;78:241–52.
33. Cruces P, González-Dambrauskas S, Cristiani F, Martínez J, Henderson R, Erranz B, Díaz F. Positive end-expiratory pressure improves elastic working pressure in anesthetized children. BMC anesthesiology. 2018 Dec;18(1):1-7. https://doi.org/10.1186/s12871-018-0611-8
34. Wahba RW. Perioperative functional residual capacity. Can J Anaesth. 1991;38:384–400.
35. Fletcher ME, Stack C, Ewart M, Davies CJ, Ridley S, Hatch DJ, et al. Respiratory compliance during sedation, anesthesia, and paralysis in infants and young children. J Appl Physiol. 1985;70:1977–82.
36. Dobbinson TL, Nisbet HI, Pelton DA, Levison H. Functional residual capacity (FRC) and compliance in anaesthetized paralysed children. II. Clinical results. Can Anaesth Soc J. 1973;20:322–33
37. Serafini G, Cornara G, Cavalloro F, Mori A, Dore R, Marraro G, et al. Pulmonary atelectasis during paediatricanaesthesia: CT scan evaluation and effect of positive end-expiratory pressure (PEEP). PaediatrAnaesth. 1999;9:225–8.
38. Trachsel D, Svendsen J, Erb TO. vonUngern-Sternberg BS. Effects of anaesthesia on paediatric lung function. Br J Anaesth. 2016; 117 :151–63.
39. Pelosi P, Ravagnan I, Giurati G, Panigada M, Bottino N, Tredici S, Eccher G, Gattinoni L. Positive end-expiratory pressure improves respiratory function in obese but not in normal subjects during anesthesia and paralysis. The Journal of the American Society of Anesthesiologists. 1999 Nov 1;91(5):1221.
40. Cinnella G, Grasso S, Spadaro S, Rauseo M, Mirabella L, Salatto P, Capraris AD, Nappi L, Greco P, Dambrosio M. Effects of recruitment maneuver and positive end-expiratory pressure on respiratory mechanics and transpulmonary pressure during laparoscopic surgery. The Journal of the American Society of Anesthesiologists. 2013 Jan 1;118(1):114-22.
41. Erranz B, Díaz F, Donoso A, Salomón T, Carvajal C, Torres MF, et al. Decreased lung compliance increases preload dynamic tests in a pediatric acute lung injury model. Rev ChilPediatr. 2015;86:404–9.
42. Díaz F, Erranz B, Donoso A, Carvajal C, Salomón T, Torres M, et al. Surfactant deactivation in a pediatric model induces hypovolemia and fluid shift to the extravascular lung compartment. PaediatrAnaesth. 2013;23:250–7.
43. Feldman JM. Optimal ventilation of the anesthetized pediatric patient. AnesthAnalg. 2015; 120:165–75.
44. Neto AS, Hemmes SN, Barbas CS, Beiderlinden M, Fernandez-Bustamante A,

Futier E et al. PROVE Network Investigators: Association between driving pressure and development of postoperative pulmonary complications in patients undergoing mechanical ventilation for general anaesthesia: A meta-analysis of individual patient data. Lancet Respir Med 2016; 4: 272–80.
45. Ladha K, Vidal Melo MF, McLean DJ, Wanderer JP, Grabitz SD, Kurth T et al: Intraoperative protective mechanical ventilation and risk of postoperative respiratory complications: Hospital based registry study. BMJ 2015;351:h3646.
46. Pereira SM, Tucci MR, Morais CC, Simões CM, Tonelotto BF, Pompeo MS et al. Individual positive end-expiratory pressure settings optimize intraoperative mechanical ventilation and reduce postoperative atelectasis. Anesthesiology. 2018 Dec;129(6):1070-81.
47. Bergesio R, Habre W, Lanteri C, Sly P. Changes in respiratory mechanics duringabdominal laparoscopic surgery in children. Anaesth Intensive Care. 1999;27(3): 245-248.
48. Östberg E, Thorisson A, Enlund M, Zetterström H, Hedenstierna G, Edmark L. Positive End-expiratory Pressure Alone Minimizes Atelectasis Formation in Nonabdominal Surgery: A Randomized Controlled Trial. Anesthesiology. 2018; 128(6): 1117-1124.
49. Tomescu DR, Popescu M, Dima SO, Bacalbasa N, Bubnek- Turconi S. Obesity is associated with decreased lung compliance and hypercapnia during robotic assisted surgery. J ClinMonitComput. 2017;31(1):85–92.
50. Spaeth J, Daume K, Goebel U, Wirth S, Schumann S. Increasing positive end-expiratory pressure (re-)improves intraoperative respiratory mechanics and lung ventilation after prone positioning. Br J Anaesth. 2016;116 (6):838-846.