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Respiration and the Airway

Effect of positive end-expiratory pressure on pulmonary shunt and dynamic compliance during abdominal surgery

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Abstract

Background: General anaesthesia decreases pulmonary compliance and increases pulmonary shunt due to the development of atelectasis. The presence of capnoperitoneum during laparoscopic surgery may further decrease functional residual capacity, promoting an increased amount of atelectasis compared with laparotomy. The aim of this study was to evaluate the effects of different levels of positive end-expiratory pressure (PEEP) in both types of surgery and to investigate whether higher levels of PEEP should be used during laparoscopic surgery.

Methods: This prospective observational study included 52 patients undergoing either laparotomy or laparoscopic surgery. Three levels of PEEP were applied in random order: (1) zero (ZEEP), (2) 5 cmH_2O and (3) 10 cmH_2O. Pulmonary shunt and ventilation/perfusion mismatch were assessed by the automatic lung parameter estimator system.

Results: Pulmonary shunt was similar in both groups. However, in laparotomy, a PEEP of 5 cmH_2O significantly decreased shunt when compared with ZEEP (12 *vs* 6%; P=0.001), with additional PEEP having no further effect. In laparoscopic surgery, a significant reduction in shunt (13 *vs* 6%; P=0.001) was obtained only at a PEEP of 10 cmH_2O. Although laparoscopic surgery was associated with a lower pulmonary compliance, increasing levels of PEEP were able to ameliorate it in both groups.

Conclusion: Both surgeries have similar negative effects on pulmonary shunt, while the presence of capnoperitoneum reduced only the pulmonary compliance. It appears that a more aggressive PEEP level is required to reduce shunt and to maximize compliance in case of laparoscopic surgery.

Key words: end-expiratory pressure, positive; laparoscopic surgery; laparotomy; pulmonary compliance; shunt

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Editor's Key Points

- Atelectasis during laparoscopic surgery may be attenuated by positive end-expiratory pressure (PEEP) but the optimum PEEP is uncertain.
- Using an automated system, this study assessed the effects of different PEEP values on calculated shunt and other respiratory variables.
- Major laparotomy and laparoscopy had similar effects in pulmonary shunt and compliance.
- Shunt during laparoscopy was more resistant to increasing PEEP compared with patients undergoing laparotomy.
- However, the absolute differences were small and more data are required.

General anaesthesia causes impairment in pulmonary gas exchange and respiratory mechanics, even in patients with healthy lungs.[1] Such effects primarily result from the development of atelectasis[2] with subsequent shunting of pulmonary blood flow and impairment of gas exchange.[3] Atelectasis has been described both during laparotomy and laparoscopic surgery.[4] The latter is becoming increasingly prevalent, being associated with a lower incidence of respiratory complication,[5] a reduction in inflammatory and metabolic responses,[5] and a reduction in postoperative pain and analgesic consumption.[5–7] However, laparoscopic surgery is not without potential complications, having been associated with increased intra-abdominal pressure (IAP) due to the presence of capnoperitoneum, which causes further cranial shift of the diaphragm, favouring lung collapse, and decreasing both chest wall compliance and functional residual capacity (FRC).[4] Andersson and colleagues demonstrated that capnoperitoneum results in an increased amount of atelectasis (66%) and a 16% reduction in FRC.[8] The decrease in FRC can lead to ventilation at low lung volume, which in turn can lead to peripheral airway collapse, when the airways closing volume exceeds the end-expiratory lung volume (EELV).[8–10] Positive end-expiratory pressure (PEEP) can counterbalance the decrease in EELV, thereby preventing atelectasis during the intraoperative period,[11–13] improving pulmonary mechanics and decreasing pulmonary shunt.[1] The physiological effects of PEEP may lead the clinician to question whether an increased PEEP level might be beneficial during laparoscopic surgery, providing compensatory alveolar pressure against the collapsing alveolar pressure. To address this question, this study investigated the effects of PEEP on pulmonary mechanics and gas exchange during both laparotomy and laparoscopic surgery. Therefore, the primary endpoint of the present study was to investigate whether different levels of PEEP should be used during major abdominal laparoscopic surgery or laparotomy in order to optimise intraoperative pulmonary shunt, as assessed by the automatic lung parameter estimator (ALPE) system. The secondary endpoints were the variations of both respiratory system compliance ($C_{dyn,rs}$) and low V/Q at different levels of PEEP.

Methods

After obtaining approval from the ethics committee of our institution (Arcispedale Sant′Anna, Ferrara, Italy), informed consents were obtained from each patient. The study was performed in consecutive patients undergoing elective abdominal surgery from June 2014 to January 2015. We enrolled patients >18 yr of age, with an American Society of Anesthesiologists Physical Status Classification score of 1–3, scheduled for either laparoscopic surgery or laparotomy.

Patients with haemodynamic instability, severe chronic respiratory failure, non-elective surgery, or preoperative anaemia (haemoglobin <10 g 100 ml^{-1}) were excluded from the study.

All patients were breathing a fraction of inspired oxygen (F_{IO_2}) of 1.0 during the induction of general anaesthesia. The latter was induced with propofol (1.5–2 mg kg^{-1}) and fentanyl (3 μg kg^{-1}). Muscle paralysis was obtained with rocuronium (0.6 mg kg^{-1}) to facilitate tracheal intubation. Patients were intubated via an endotracheal low-pressure cuffed tube with an internal diameter ranging between 7.5 and 8.0 mm (Rushelit Rush AG Lab, Waiblingen, Germany). Anaesthesia was maintained with an infusion of propofol (150–200 μg kg^{-1} min^{-1}), remifentanil (0.1–0.2 μg kg^{-1} min^{-1}), and cisatracurium (1.5 μg kg^{-1} min^{-1}). The lungs were ventilated through a Dräger Primus ventilator (Drägerwerk AG & Co. KGaA, Lübeck, Germany) with a square flow waveform with a tidal volume (TV) of 6–8 ml kg^{-1} ideal body weight, inspiratory time of 33%, and an inspiratory pause of 20%. The respiratory rate was varied to ensure eucapnia [end-tidal carbon dioxide partial pressure ($EtCO_2$) 3.9–5.3 kPa]. Patients were ventilated using oxygen and air with an F_{IO_2} set at ≥40%, to maintain the peripheral oxygen saturation (SpO_2) at ≥95%. At the start of the study, PEEP was set to zero. Patients were given 8 ml kg^{-1} of Ringer's lactate intravenously before the induction of anaesthesia and were then maintained with 5 ml kg^{-1} h^{-1} Ringer's lactate. During laparoscopic procedures, capnoperitoneum was established with CO_2 insufflation and the intra-abdominal pressure was maintained automatically at 12–13 mmHg.

Patients were monitored by ECG, pulse oximetry, $EtCO_2$, and invasive arterial pressure using a Datex Ohmeda S/5 monitor (Datex-Ohmeda Division, Instrumentarium Corp., Helsinki, Finland). The radial artery was cannulated before induction of anaesthesia, in line with the standard practice of our institution, for invasive blood pressure and blood gas monitoring. Analysis of arterial blood gases was performed within 3 min from sampling using an ABL 330 blood gas analyser (Radiometer, Copenhagen, Denmark). The depth of anaesthesia was monitored through bispectral index monitoring (Aspect A-2000; Aspect Medical System, Newton, MA, USA).

Study protocol

To analyse the effects of PEEP, patients in each group were subjected to different values of PEEP: (1) 0 cmH_2O (ZEEP), (2) 5 cmH_2O, and (3) 10 cmH_2O. About 15 min after incision (for laparotomy) or capnoperitoneum (for laparoscopy), if the patients were haemodynamically stable, that is, mean blood pressure ≥80 mmHg and heart rate ≥60 beats min^{-1}, the protocol started.

Although patients were not randomized to laparoscopic surgery or laparotomy, the level of PEEP applied was randomized by using a computer-generated number. After the onset of the protocol study at PEEP 0 cmH_2O, each patient was ventilated with PEEP levels of 0, 5, or 10 cmH_2O in random order. Once haemodynamic stability was achieved, the level of PEEP was maintained for a period of 15 min. A 15 min period was chosen to allow the effects of PEEP to reach equilibrium. Apart from the variations in PEEP described here, basal ventilator settings were maintained for each patient throughout the experiment.

At each PEEP level, and following the 15 min period, pulmonary shunt and V/Q mismatch were assessed by the ALPE system (ALPE Integrated, Mermaid Care A/S, Nr. Sundby, Denmark). The ALPE system includes pulse oximetry, capnography, and indirect calorimetry and mathematical models, which describe the