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ORIGINAL ARTICLE

Positive end-expiratory pressure does not decrease cardiac output during laparoscopic liver surgery

A prospective observational evaluation

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Abstract

Background: Positive end-expiratory pressure (PEEP) has beneficial pulmonary effects but may worsen the hemodynamic repercussions induced by pneumoperitoneum (PNP) in patients undergoing liver laparoscopic liver resection. However, by the increase of intraluminal vena cava (VC) pressures, PEEP may prevent PNP-induced VC collapse. The aim of this original article was to test the validity of this hypothesis.

Methods: After IRB approval and written inform consents, 20 patients were prospectively evaluated. Measurements were performed before and after the application of a 10 cmH_2O PEEP on patient without PNP (Control group) and during a 12 cmH_20 PNP. Results are in means [95%CI]. Comparison used paired-sample *t* test.

Results: PEEP induced a decrease in CI in Control subgroup (2.3 [2.0–2.6] and 2.1 [1.8–2.4] l min^{-1} m^{-2} before and after PEEP. $P < 0.05$). In contrast, PEEP on a pre-established PNP did not significantly modify CI. Transmural pressure on abdominal vena cava decreased with PNP but was partly reversed by the addition of PEEP.

Conclusion: The application of PEEP on a pre-established PNP during laparoscopic liver resection in normovolemic patients did not decrease CI. Analysis of transmural VC pressure variations confirms that the addition of PEEP may prevent the vena cava collapse induced by PNP.

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Introduction

Recent developments have emphasized the feasibility and the safety of laparoscopic approach for major liver surgery[1,2] with excellent short and long-term outcomes.[3] This evolution toward laparoscopic procedures brings up new challenges in intraoperative anesthetic management.

Increase in the abdominal pressure induced by the pneumoperitoneum (PNP) has ventilatory and hemodynamic consequences that have been well characterized.[4] PNP induces a decrease in venous return and cardiac output.[5] In addition, PNP promotes pulmonary atelectasis that may compromise gas exchange and induce postoperative pulmonary complications.[6] It has been shown that the intraoperative application of positive end-expiratory pressure (PEEP) may be able to prevent the occurrence of pulmonary complications induced by PNP.[7,8] However, beneficial effects of PEEP on pulmonary function may be counterbalanced by its detrimental effect on right atrial pressure and cardiac output that may worsen the haemodynamic repercussions due to PNP.[9,10]

Based on previous physiologic studies, an alternative hypothesis about the haemodynamic effects of PEEP on a pre-established PNP can be constructed from hydrodynamic

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pathophysiologic concepts.[11] Blood flow in the vena cava is dependent on pressure gradients between abdominal and thoracic compartments. Due to increased intra-abdominal pressure, inferior vena cava may collapse at the diaphragmatic level, reducing venous return from abdominal compartment.[12,13] This deleterious effect may be worsened if the downstream intrathoracic pressure is low.[11] From this viewpoint, a moderate elevation of intrathoracic pressure, inducing a downstream increase in intrathoracic vena cava pressure, may be able to prevent vessel collapse and to restore the pressure gradient between intrathoracic and intraabdominal compartment as the main determinant of venous return, especially in normovolemic patients.[11] In such conditions, it could be speculated that the application of PEEP during laparoscopic liver resection could have beneficial effects on pulmonary function without detrimental consequences on hemodynamics. The aim of this prospective observational evaluation was to test the validity of this theoretical hypothesis.

Material and methods

This prospective observational study was designed and reported according to the STROBE Guidelines.[14] It received an Ethical Committee Approval (CPP IdF 3 n° 3081). All eligible patients scheduled to undergo major laparoscopic liver resection, requiring hemodynamic monitoring, from June to December 2013 were asked for informed consent. Exclusion criteria were ASA physical status $\geq$3, cardiac and/or pulmonary insufficiency, Child & Pugh score B or C, pregnancy, inability to understand the protocol and refusal to participate.

Anesthesia was conducted according to the usual standard of care at our institution. A single team of anesthesiologists and surgeons was involved in this evaluation. Anesthesia was induced using propofol, sufentanil and atracurium. The trachea was intubated and the lungs were mechanical ventilated with a 7 ml/kg tidal volume and a respiratory rate adjusted to keep end-tidal CO_2 partial pressure between 33 and 37 mmHg. Anesthesia was maintained using desflurane in a mixture of 50% O_2 and 50% N_2O, with continuous infusions of sufentanil and atracurium. Infusion of atracurium was adapted to ensure about optimal muscle relaxation checked by neuromuscular monitoring.

All patients had an internal jugular central venous access and a radial artery catheter. A transesophageal Doppler probe (Cardio Q®, Deltex medical. Chichester, UK) was inserted in order to continuously monitor Stroke volume (SV) and Cardiac index (CI). A 30 cm catheter (Teleflex Medical, Research Triangle Park, NC, USA) was inserted via the jugular vein and the distal extremity positioned under fluoroscopic control in the infradiaphragmatic part of the inferior vena cava. Pressures in the supra diaphragmatic vena cava and in the right atrium were monitored concurrently via the same access. A urinary bladder catheter (Foley catheter) was used to measure variations in intra-abdominal pressures.

Study protocol

Once the monitoring had been correctly placed, and stable haemodynamic conditions obtained, a fluid challenge was performed according to the usual guidelines,[15] in order to optimize the circulatory volume before the study assessments. Briefly, boluses of 200 ml saline solution were infused until SEV, monitored by transesophageal Doppler probe, did not increase by more than 10% of the pre-bolus value.

The study started with the patient in the supine position (Control subgroup), without PEEP nor PNP (Fig. 1). An initial set of measurements was obtained, including Cardiac index (CI), Stroke volume (SV), Heart rate (HR), Mean arterial pressure (MAP), Pressure inside the infradiaphragmatic vena cava (Pivc), Central venous pressure (CVP), and Intraabdominal pressure (Pabd). Transmural pressure was calculated as the difference between Pivc and Pabd. Subsequently, similar measurements were performed after application of a 10 cmH_2O PEEP. All values were obtained after a 5-minutes waiting period to achieve stability. A second set of similar measurements was carried out with the patients positioned 15° head-up (Head-up subgroup). A third and fourth sets of similar measurements was performed after the application of a 12 cmH_20 PNP (PNP subgroup) in supine and 15° head-up position (Fig. 1). A last set of measurements was performed after PEEP discontinuation to ensure about return to Control values.

Statistical analysis

The values before and after the application of PEEP in the 4 sets of experiments were compared using a paired-sample t test, after a normal distribution was confirmed by the Kolmogorov–Smirnov test. Data comparing different subgroups were analyzed using independent-samples t test. The threshold of statistical significance was set at $P < 0.05$. The sample size of 20 patients has been calculated to be able to detect as significant a difference of 0.3 l min^{-1} m^{-2} on CI between pre- and post-PEEP periods with a P value of 5% and a false negative probability of 10%. This value has been chosen because it represents approximately a variation of 10%, which can be considered as a threshold for clinical pertinence. Results are presented as means [95%CI].

Results

Twenty-two consecutive patients were included. Two patients were withdrawn from final analysis because of poor transesophageal Doppler signal. A total of 20 patients were included in the final analysis. Demographic data and surgical procedures are presented in Table 1. All patients received a preoperative fluid infusion during the fluid challenge maneuver (325 ml [250–400]).

The hemodynamic consequences of the application of 10 cmH_2O PEEP are presented in Table 2. In patients lying flat, the addition of a 10 cmH_2O PEEP to a 12 cmH_2O PNP did not

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