Noninvasive pulse wave analysis for monitoring the cardiovascular effects of CO₂ pneumoperitoneum during laparoscopic cholecystectomy

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Abstract

Aims: Peritoneal insufflation results in hemodynamic changes during laparoscopic cholecystectomy. The aim of the present work to test whether non-invasive applanation tonometry is suitable for reflecting these hemodynamic alterations.

Patients and methods: 41 patients undergoing laparoscopic cholecystectomies were monitored using SphygmoCor pulse wave analysing system. Peripheral blood pressures (PBP), central aortic blood pressures (CBP), augmentation index (ALX@HR75) and subendocardial viability ration (SVR) were measured at rest (Phase 1), after anesthetic induction (Phase 2), after peritoneal inflation (Phase 3) and after peritoneal deflation.

Results: Induction of anesthesia resulted in a statistically significant reduction in both the peripheral blood pressure and central aortic pressures, accompanied by a decrease in augmentation pressure and augmentation index. Peripheral blood pressures did not change markedly along with the peritoneal cavity insufflation, except for the moderate increase in systolic blood pressure. In contrast to this, a marked increase could be observed in central aortic pressure values that was accompanied by increased augmentation pressure and augmentation index, indicating a rise in peripheral arterial stiffness.

Conclusions: Sphigmocor pulse wave analysis system can be reliably used for detecting and monitoring cardiovascular changes occurring during laparoscopic cholecystectomy.

Key words: laparoscopic cholecystectomy; hemodynamic changes; applanation tonometry
Laparoscopic cholecystectomy has taken a great flight in recent decades for several reasons, such as less invasivity, shorter postoperative recovery and lower medical costs. In the focus of the concerns at the introducing phase of the method mostly the surgical aspects were discussed. However, along with the advancement of the surgical technique, the surgical intervention itself became safer and more widespread due to its lesser side effects. Therefore, in the recent years, many studies were focusing on the assessment of the non-surgical side effects.

It is proven by previous studies, that inducing a positive pressure within the intraperitoneal cavity results is numerous cardiovascular, neuroendocrine and renal changes [1]. These changes include an increase of systemic and pulmonary vascular resistance and a consequent decrease in cardiac output, that may be attributed to direct mechanical factors due to the intraperitoneal pressure rise, as well as to humoral changes evoked by the procedure [2].

During preoperative anesthesiological consultation, it is a frequent question, whether laparoscopic cholecystectomy can be performed safely in a patients with known cardiovascular risk factors. It is worth mentioning, that in a study of low risk patients undergoing laparoscopic cholecystectomy, 2 out of 16 patients had acute ST changes on the ECG [3]. In view of this, preoperative cardiovascular risk stratification, as well as proper intraoperative monitoring may be of high importance in patients at risk.

Cardiovascular consequences occurring during laparoscopic procedures were assessed so far either during animal experiments [4] or by using invasive intraoperative hemodynamic monitoring of humans [5-9]. However, invasive hemodynamic monitoring techniques may also have side effects and thus are not
indicated in all patients undergoing in an otherwise relatively short and low risk surgical procedure.

Along these lines, we tested the hypothesis that cardiovascular changes caused by CO$_2$-pneumoperitoneum may be accurately assessed intraoperatively by non-invasive applanation tonometry. Our results were compared with data obtained from the literature.

**Patients and Methods**

**Patients**

A total of 41 consecutive patients undergoing elective laparoscopic cholecystectomy for symptomatic cholelithiasis without cholangiography or choledochotomy were enrolled in this prospective case-series. The patients were all in good health, classified as ASA I and II. The patients gave their informed consent to participate in the study, that was approved by the local medical ethics committee. Patients with diabetes mellitus, untreated hypertension, atrial fibrillation, morbid obesity (body mass index [BMI] > 35), infection, psychiatric or neurologic conditions impairing their ability to cooperate were excluded from the study.

**Anesthesia and CO$_2$ pneumoperitoneum**

General anesthesia was administered to all patients according to the same protocol. During the patient’s stay in the preparation area, 15 ml/kg/BW of Ringer’s acetate solution was infused for a period of 2 hours. As premedication, oral midazolam (0.15 mg/kgBW) were administered 30 minutes before the induction of anaesthesia. Following preoxygenation (2 minutes) by face mask, anesthesia was induced with intravenous propofol (2 mg/kg BW) and fentanyl (3-5 µg/kgBW).
Rocuronium 0.6 mg/kgBW was used to facilitate tracheal intubation and maintain muscle relaxation. After intubation, the lungs were ventilated with a mixture of air/oxygen (50/50%). For maintenance of anesthesia sevoflurane (2 vol%) and intermittent doses of fentanyl were applied. Sevoflurane was titrated in order to keep the bispectral index (BIS) values between 40 and 50. Ventilation was mechanically controlled at a frequency and tidal volume sufficient for maintaining normocapnia. End expiratory CO\textsubscript{2} was used to ensure normoventilation (end-tidal carbon dioxide level was kept between 35 and 38 mmHg). Intraoperative crystalloid infusion was administered at 7 mL/kg per hour. Body temperature was maintained between 36,0 and 36,5 °C during anesthesia by heating blankets.

The surgical technique was similar for all patients. CO\textsubscript{2} insufflation was maintained automatically at a recommended 12-14 mmHg by a CO\textsubscript{2} insufflator at insufflation rate of 1 to 1,5 L/min with the patients placed in the 20° reverse Trendelenburg position (rT). On confirming the appropriate placement of the video laparoscope, each patient’s position was changed to a left lateral tilt (10°-15°). Once the surgery was completed, the abdomen was deflated and each patient was returned to the horizontal position.

Routine intraoperative patient monitoring included continuous five-leads electrocardiography, pulse oximetry, noninvasive blood pressure measurements, peak airway pressures, capnography, as well as BIS monitoring for assessment of depth of anesthesia. Neuromuscular monitoring was performed to control of the neuromuscular block throughout the course of anesthesia by the use of TOF Watch SX acceleromyograph.

*Monitoring cardiovascular function*
We used SphygmoCor pulse wave analysing system for monitoring cardiovascular function that is a non-invasive method based on applanation tonometry [10]. During the present study we measured the systemic and central aortic pressure, augmentation pressure, augmentation index, ejection duration and subendocardial viability ratio.

- **Measurement of central aortic pressure and aortic pressure waveform:** A conventional cuff pressure measurement was used for calibration. After applanation tonometry SphygmoCor derived a complete waveform for the whole cardiac cycle for the aortic pulse. A combination of the two methods makes it possible to analyse the coupling between the ejecting heart and the pressure load.

- **Measurement of augmentation pressure and augmentation index:** Augmentation pressure is based on the principle that there is a reflected pressure from the periphery that appears in the aortic pressure waveform. The amount of augmentation reflects the stiffness of the peripheral arterial tree: it increases along with higher stiffness. In order to make the value of augmentation index independent from the individual changes of pulse rate, the device calculates a corrected augmentation index (ALX@HR75).

- **Subendocardial viability ratio:** This parameter is calculated by the device by dividing the area under systolic and diastolic part of curve. A ration under 100% reflects underperfusion of the subendocardium.

Hemodynamic measurements were repeated in different phases of the procedure: Before induction of anesthesia (resting phase, Time 1); 5 minutes after induction of anesthesia (Time 2); 5 minutes after inflation of the peritoneal space (Time 3).
followed by repeated measurements every 10 minutes and 5 minutes after deflation of the peritoneal cavity (Time 4).

**Statistical analysis:**
Means and standard deviation were calculated for all values. Repeated measure analysis of variance was used for all values to check the time main effect of the laparoscopic procedure, i.e. whether laparoscopic cholecystectomy overall had any significant hemodynamic effect. Pairwise comparisons of all parameters were performed in order to check the effect of inflation and deflation of the peritoneal space by taking the values obtained after induction of anesthesia as reference value. A p<0.05 was considered as statistically significant difference.

**Results:**
A total of 41 patients entered the study. There were 33 females and 8 males with an average age of 52.3±15.4 years.

*The effect of anesthetic induction on hemodynamic parameters:* As it is shown in Table 1, induction of anesthesia resulted in a statistically significant reduction in both the peripheral blood pressure and central aortic pressures, accompanied by a decrease in augmentation pressure and augmentation index.

*The effect of peritoneal insufflation on hemodynamic parameters:* Table 2 summarizes the parameters that were obtained before and after peritoneal cavity insufflation. Peripheral blood pressures did not change markedly along with the peritoneal cavity insufflation, except for the moderate increase in systolic blood
pressure. In contrast to this, a marked increase could be observed in central aortic pressure values that was accompanied by increased augmentation pressure and augmentation index, indicating a rise in peripheral arterial stiffness. Despite changes in the central aortic blood pressure, subendocardial viability ratio remained relatively stable during and after peritoneal cavity insufflation.

After deflation of the abdominal cavity both peripheral and aortic pressure values returned to the levels that were observed after induction of anesthesia. Although augmentation pressures were still higher than before inflation, augmentation index (the main indicator of peripheral arterial stiffness) also returned to the pre-insufflation value. Figure 1 depicts and summarizes the changes of all parameters during the entire course of the study.

Discussion

In this cohort study we used a new noninvasive technique for assessing the cardiovascular changes that occur during laparoscopic cholecystectomy, the Sphigmocor pulse wave analysis. The method has already been tested in different clinical conditions such as arterial hypertension, diabetes mellitus, systolic heart failure and preeclampsia [11-13]. In anesthesiological practice, this is the first report on the use of the technique.

Similar to previous reports we were able to detect a significant decline of the systemic blood pressure after anesthetic induction that is accompanied by a decrease in the augmentation index reflecting the stiffness of the peripheral vessels [3,5,9,14,15]. This initial reduction in blood pressure and peripheral resistance may be ascribed to the direct myocardial depressant and vasodilatory effects of the
anesthetics together with the loss of sympathetic tone [2]. During the next phase of the procedure, after inflating the abdomen and tilting the patient to a reverse Trendelenburg position, the most important observations were increases in central aortic pressures accompanied by a gradual increase of the augmentation index. This is in line with the previous observations reporting on a moderate increase in mean arterial pressure and the peripheral resistance [1,2,5,9,14] after peritoneal insufflation. To transform this results to our observation, we have to mention that systolic central aortic pressure increased by 10.6%, whereas augmentation index referring to peripheral resistance increased by 66% in average after peritoneal insufflation.

In a previous review Wahba an co-workers [2] summarized the hemodynamic effects and suggested that direct mechanical, neurohumoral processes play a role, slightly modified by the effect of the resorbed CO₂ during pneumoperitoneum. Mechanical effects of pneumoperitoneum may decrease renal flow and therewith activate renin-angiotensine-aldosteron system, may result in compression of the abdominal veins and the aorta. It has also been proven that inducing pneumoperitoneum results in an increased production of vasopressin, adrenalin, noradrenalin, renin and cortisol that is in correlation with the changes of mean arterial pressure and systemic resistance [15]. According to previous reports, this is the phase of laparoscopic cholecystectomy where patients of different ASA severity (ASA I-II vs. ASA III-IV) may react differently to pneumoperitoneum. In more severe patients (ASA III-IV) pressure rise in the abdomen resulted in more pronounced increase in mean arterial pressure and decreased oxygen delivery [16]. Consequently, left ventricular stroke work index increases that causes higher oxygen demand of the myocardium [7]. In our series we included ASA I and II patients and
subendocardial viability ratio reflecting the potential underperfusion of the subendocardium could not be detected after and during the course of abdominal inflation.

The principal basis of the pulse wave analysis system is that the peripheral arterial pressure waveform may be used for reconstruction of the central (aortic) pressure. The method behind is applanation tonometry that ensures the sensitive detection of the radial artery pulse waveform. It is accepted, that the characteristics of the peripheral pulse reflects the changes in arterial diameters, wall elasticity, wall thickness and the condition of the peripheral vascular beds. The main attribute of SphygmoCor is its ability to derive the central aortic pressure waveform noninvasively from the pressure pulse recorded at a peripheral site, usually at the upper arm (radial artery) [10]. The intraoperative use of the device is limited by the position of the radial artery, i.e. in some surgical scenarios it may disturb the surgical team that makes monitoring impossible. Another limitation to be mentioned is operator-dependency: for reliable monitoring it is necessary to have previous experience with the technique.

In conclusion: in the present study we have shown that Sphigmocor pulse wave analysis system can be reliably used for detecting and monitoring cardiovascular changes occurring during laparoscopic cholecystectomy. Further studies are needed to prove whether the method is helpful in delineating critical situations in patients with limited cardiovascular reserve (ASA III-IV patients) and to help in guiding abdominal insufflation and tilting during the procedure as suggested in previous reports [17].
Table 1. The effect of anesthetic induction on peripheral and central (aortic) blood pressures and pressure augmentation. Means and standard deviations are shown.

<table>
<thead>
<tr>
<th></th>
<th>Before induction</th>
<th>After induction</th>
<th>p-value</th>
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<tr>
<td><strong>Peripheral blood pressure</strong></td>
<td></td>
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<tr>
<td>Systolic</td>
<td>132,47±18,87</td>
<td>116,80±18,61</td>
<td>P&lt;0.001</td>
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<tr>
<td>Diastolic</td>
<td>78,60±10,40</td>
<td>72,71±13,54</td>
<td>P&lt;0.05</td>
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<td>Pulse pressure</td>
<td>52,12±16,12</td>
<td>43,65±11,96</td>
<td>P&lt;0.01</td>
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<tr>
<td><strong>Central (aortic) blood pressure</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Systolic</td>
<td>120,80±19,10</td>
<td>106,77±18,78</td>
<td>P&lt;0.001</td>
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<tr>
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<td>80,00±10,38</td>
<td>73,88±13,79</td>
<td>P&lt;0.01</td>
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<tr>
<td>Pulse pressure</td>
<td>41,05±14,70</td>
<td>33,11±11,08</td>
<td>P&lt;0.001</td>
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<td><strong>Pressure augmentation</strong></td>
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<tr>
<td>Augmentation pressure</td>
<td>10,52±8,52</td>
<td>7,31±5,59</td>
<td>P&lt;0.01</td>
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<tr>
<td>Augmentation index</td>
<td>23,62±10,58</td>
<td>18,97±10,80</td>
<td>P&lt;0.01</td>
</tr>
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<td>Subendocardial viability ratio (%)</td>
<td>121,85±22,7</td>
<td>142,5±38,2</td>
<td>P&lt;0.01</td>
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</table>
Table 2. The effect of peritoneal cavity insufflation on peripheral and central (aortic) blood pressures and pressure augmentation. Means and standard deviations are shown.

<table>
<thead>
<tr>
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<th>Before insufflation</th>
<th>After insufflation</th>
<th>p-value</th>
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<tr>
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<td>116,80±18,61</td>
<td>125,17±20,21</td>
<td>P&lt;0.05</td>
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<tr>
<td>Diastolic</td>
<td>72,71±13,54</td>
<td>78,92±16,94</td>
<td>NS</td>
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<tr>
<td>Pulse pressure</td>
<td>43,65±11,96</td>
<td>44,64±13,23</td>
<td>NS</td>
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<tr>
<td><strong>Central (aortic) blood pressure</strong></td>
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<td></td>
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<tr>
<td>Systolic</td>
<td>106,77±18,78</td>
<td>118,05±19,85</td>
<td>P&lt;0.01</td>
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<td>Diastolic</td>
<td>73,88±13,79</td>
<td>81,82±12,28</td>
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<td>Pulse pressure</td>
<td>33,11±11,08</td>
<td>36,41±12,60</td>
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<td><strong>Pressure augmentation</strong></td>
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<tr>
<td>Augmentation pressure</td>
<td>7,31±5,59</td>
<td>12,61±7,56</td>
<td>P&lt;0.001</td>
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<tr>
<td>Augmentation index</td>
<td>18,97±10,80</td>
<td>31,55±12,01</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>Subendocardial viability ratio (%)</td>
<td>142,5±38,2</td>
<td>137,11±26,3</td>
<td>P=0,48</td>
</tr>
</tbody>
</table>
References


Figure 1. Hemodynamic changes during the different phases of laparoscopic cholecystectomy. Means and standard deviations are shown. SBP = systolic blood pressure; DBP = diastolic blood pressure; PP = pulse pressure; ALX HR75 = augmentation index.