Dynamic variables of fluid responsiveness during pneumoperitoneum and laparoscopic surgery

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Background: Few data exist on dynamic variables predicting fluid responsiveness during laparoscopic surgery. The aim of this study was to explore the effects of laparoscopy on four dynamic variables: respiratory variations in pulse pressure (ΔPP), stroke volume variation by Vigileo/FloTrac (SV\textsubscript{Vigileo}), pleth variability index (PVI) and respiratory variations in pulse oximetry waveform amplitude (ΔPOP), and their relation to fluid challenges during laparoscopic surgery.

Methods: ΔPP, SV\textsubscript{Vigileo}, PVI and ΔPOP were studied in 20 adult patients before and during pneumoperitoneum (10–12 mmHg). During ongoing laparoscopic surgery, relations between the dynamic variables and changes in stroke volume oesophageal Doppler (SV\textsubscript{OD}) after fluid challenges (250 ml colloid) were evaluated.

Results: Pneumoperitoneum changed the dynamic variables as follows [mean [95\% confidence interval (CI)]]: ΔPP 0.5 (−1.3, 2.3)\%\textsuperscript{a}, \textsuperscript{a}P = 0.53; SV\textsubscript{Vigileo} 0.6 (−1.3, 2.5)\%\textsuperscript{a}, \textsuperscript{a}P = 0.52; PVI 2.9 (0.4, 5.3)\%\textsuperscript{a}, \textsuperscript{a}P = 0.025. For ΔPOP, median difference (95\% CI) was 2.5 (−0.15, 6.7)\%\textsuperscript{a}, \textsuperscript{a}P = 0.058. During laparoscopic surgery, areas under receiver operating characteristics curves (95\% CI) were ΔPP 0.53 (0.31–0.75), SV\textsubscript{Vigileo} 0.74 (0.51–0.90), PVI 0.61 (0.38–0.81), ΔPOP 0.63 (0.40–0.82). Correlation coefficients (P-values) between changes in dynamic variables and changes in SV\textsubscript{OD} were ΔPP \textsuperscript{b}r = −0.65, \textsuperscript{b}P = 0.009; SV\textsubscript{Vigileo} \textsuperscript{b}r = −0.73, \textsuperscript{b}P = 0.002; PVI \textsuperscript{b}r = −0.22, \textsuperscript{b}P = 0.44; ΔPOP \textsuperscript{b}r = −0.32, \textsuperscript{b}P = 0.24.

Conclusion: ΔPP and SV\textsubscript{Vigileo} did not change as pneumoperitoneum was established, whereas PVI increased and ΔPOP tended to increase. All four dynamic variables predicted fluid responsiveness relatively poor during ongoing laparoscopic surgery. ΔPP and SV\textsubscript{Vigileo} tracked changes in stroke volume induced by fluid challenges during ongoing laparoscopic surgery, whereas ΔPOP and PVI did not.

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An increasing number of complex surgical procedures as liver resections are performed laparoscopically.\textsuperscript{1} As this approach is also recommended in elderly patients with serious comorbidities,\textsuperscript{2} optimal fluid therapy guidance during this procedure is important. Dynamic variables are used to predict and guide fluid therapy during controlled ventilation. These variables arise from heart–lung interactions during positive pressure ventilation, which influence left ventricular stroke volume (SV).\textsuperscript{3} Several dynamic variables are derived from variations in left ventricular SV (SVV), for example pulse pressure variation (ΔPP), variations in pulse oximetry plethysmography waveform amplitude (ΔPOP) and pleth variability index (PVI), which have all been shown to predict fluid responsiveness in different clinical and experimental settings.\textsuperscript{4–7} It is not defined if these variables are influenced by pneumoperitoneum and how they relate to fluid responsiveness during ongoing laparoscopic surgery, aspects that may limit the clinical use of these variables in this setting.\textsuperscript{8}

Elevated intra-abdominal pressure (IAP) has been shown to affect dynamic variables in pigs,\textsuperscript{9–11} and suggested to increase threshold values for fluid responsiveness.\textsuperscript{12} These studies mainly describe elevated IAPs as in an intensive care unit (ICU) setting. However, during laparoscopy, IAP is generally less elevated. In a study comparing obese and lean patients, pneumoperitoneum (15 mmHg) increased respiratory variations in pulse pressure (ΔPP) in lean but not in obese patients.\textsuperscript{13} A non-invasive device was used to calculate ΔPP, and cardiac output

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(CO) was not studied. In a study on morbidly obese patients [body mass index (BMI) 53 ± 9] in the reverse Trendelenburg position, a decrease in SV during laparoscopy (IAP 14–17 mmHg) was found.14 These two studies, focusing on obese patients, are to our knowledge the only clinical studies on dynamic variables during laparoscopy.

The aim of this study was to investigate effects of pneumoperitoneum on four dynamic variables: ∆PP, SVV [measured by the FloTrac/Vigileo system, stroke volume variation by FloTrac/Vigileo (SVVvigileo)], PVI and respiratory variations in pulse oximetry plethysmography waveform amplitude (∆POP). Head-down tilts were performed to induce reversible increases in pre-load. During laparoscopy, relations between dynamic variables and corresponding changes in SV after fluid challenges were studied.

**Methods**

After regional ethics committee approval and written informed consent, patients between March 2010 and January 2011 were included. Patients ≥18 years were eligible when planned to undergo laparoscopic gastrointestinal surgery with arterial and central venous catheterisation and monitoring by oesophageal Doppler (OD). Patients with cardiac arrhythmias were excluded. Twenty-two patients were included. One patient had frequent extrasystoles, and in another, a distinct OD signal could not be obtained, giving 20 patients for final analysis. Patient characteristics are shown in Table 1. Surgery was as follows: liver/gallbladder, 12; ventricle, 2; colon/rectum, 2; adrenal gland, 1. Three patients had diagnostic procedures performed on them.

**Anaesthetic procedure and monitoring**

After overnight fasting, patients were premedicated with oral diazepam 5–10 mg. In nine patients, a thoracic epidural catheter was inserted, and a test dose of local anaesthetic was administered. Anaesthesia was induced with sodium thiopental 5.4 (0.9) mg/kg, fentanyl 2.4 (0.7) μg/kg and cisatracurium 0.15 (0.02) mg/kg, and maintained after endotracheal intubation with desflurane and fentanyl guided by bispectral index and clinical observations. The ventilator (Dräger Primus; Drägerwerk AG & Co. KGaA, Lübeck, Germany) was in volume-controlled mode, inspiratory to expiratory ratio 1 : 2, positive end expiratory pressure 5 cm H₂O. Tidal volumes are shown in Table 1. Patients undergoing intestinal and ventricular surgery received =800 ml fluid with antibiotics before the procedure, but separated from the study protocol. Throughout the study, a continuous infusion of Ringer acetate (2 ml/kg/h) was given. A 20-G catheter was placed in a radial artery and a 7-French catheter in the right internal jugular vein.

The radial catheter was connected to a FloTrac transducer (Edwards Lifesciences, Irvine, CA, USA), with one connection to the clinical monitor (Marquette Solar 8000i; GE Medical Systems, Milwaukee, WI, USA) and the other to a Vigileo monitor, version 03.02 (Edwards Lifesciences). On the same hand as the radial catheter, the probe of a Masimo Radical 7 pulse oximeter, version 7.3.1.1 (Masimo Corp., Irvine, CA, USA) was placed and covered from ambient light. An OD probe (CardioQ; Deltek Medical, Chichester, UK) was positioned to obtain the best signal possible.

**Study protocol**

The first part of the study was interventional (Fig. 1). Immediately before surgery, baseline registrations of variables were obtained (Table 2), followed by a head-down tilt to =15°, with maximal attention for optimal OD signal. After 15 s of stabilisation in the head-down position, an average of stroke volume by oesophageal Doppler (SVOD) was obtained over the next 30 s. Patients were then tilted back to the horizontal position, and surgery was commenced. Two to three minutes after inflating the abdomen with CO₂ (10–12 mmHg measured by the insufflator), new sets of measurements were obtained in the horizontal position, immediately followed by a second head-down tilt to =15° with registration of SVOD, averaged over 30 s after 15 s stabilisation. Thus, head-down tilts were performed before and during pneumoperitoneum, and relative changes in SVOD from horizontal position to head-down tilt were calculated.

### Table 1

Patient characteristics (n = 20).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>60 (13)</td>
</tr>
<tr>
<td>Height, cm</td>
<td>173 (9)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>75 (16)</td>
</tr>
<tr>
<td>Female gender, n (%)</td>
<td>7 (35)</td>
</tr>
<tr>
<td>ASA physical status I/I/III, n (%)</td>
<td>1/16/3 (5/80/15)</td>
</tr>
<tr>
<td>Tidal volume/weight, ml/kg</td>
<td>7.8 (7.5–8.5)</td>
</tr>
<tr>
<td>Tidal volume/predicted body weight, ml/kg</td>
<td>8.6 (0.8)</td>
</tr>
</tbody>
</table>

Data are mean (SD) or median (25th–75th percentile). Predicted body weight: males = 50 + 0.91(height in cm-152.4), females = 45.5 + 0.91(height in cm-152.4).

ASA, American Society of Anesthesiologists.
The second part of the study was observational. When the attending anaesthesiologist performed a fluid challenge (250 ml hydroxyethyl starch 60 mg/ml 130/0.4 in saline 0.9% over 2–2.5 min), registrations of dynamic and other haemodynamic variables were obtained before and 5 min after the start of the fluid challenge. During these registrations, patients were tilted head-up or down, left or right depending on surgery, but the position of the patient was not changed. If the position was changed during the fluid challenge, data were discarded. Nineteen of 22 fluid challenges were performed in the reverse Trendelenburg position (reflecting the dominance of liver/ventricular surgery), two in the horizontal position and one in the Trendelenburg position. An increase in $SV_{OD}$ ≥ 15% defined a responder challenge. The study ended when the abdomen was deflated, either due to end of surgery or conversion to open surgery.

**Signal acquisition and analysis**

To calculate $\Delta PP$ and $\Delta POP$, analogue signals of arterial pressure and photoplethysmographic waveforms were downloaded from the Marquette Solar 8000i and Masimo Radial 7, respectively, to an analogue to digital converter (NIADQPad-6015; National Instruments, Austin, TX, USA). Data were sampled at 400 Hz and stored on a computer time synchronised with the thorax impedance from a 5-lead electrocardiogram showing respiration. PVI and perfusion index (PI) from the Masimo Radical 7 were sampled at 0.5 Hz, using the Masimo Trend-Com software (Masimo). Other haemodynamic data, airway pressures and data from the Vigileo monitor were recorded manually. Data from the OD monitor were transferred to a computer by the serial output. $\Delta PP$ and $\Delta POP$ were calculated in a custom-made program in LabVIEW. In this program, each respiratory cycle with corresponding maximal and minimal amplitudes of the arterial pressure and photoplethysmographic waveform were displayed for manual verification before being used for calculation using the formulas: 

$$\Delta PP(\%) = 100 \times \frac{(PP_{\text{max}} - PP_{\text{min}})}{(PP_{\text{max}} + PP_{\text{min}})/2}$$

and 

$$\Delta POP(\%) = 100 \times \frac{(POP_{\text{max}} - POP_{\text{min}})}{(POP_{\text{max}} + POP_{\text{min}})/2}.$$ 

$PP_{\text{max}}$/$POP_{\text{max}}$ is the maximal and $PP_{\text{min}}$/$POP_{\text{min}}$ is the minimal amplitude of the arterial pressure and photoplethysmographic waveform amplitudes, respectively. Respiratory cycles containing extrasystolae were omitted, and data from 10 consecutive respiratory cycles were averaged for analysis. PVI and PI were averaged over 1 min. OD measurements were averaged over 1 min except during head-down tilt, when an average over 30 s was calculated.

**Statistics**

Calculation of sample size was based on data from a previous study. Nineteen patients would detect a change in $\Delta PP$ of 4% with alpha 0.05 and beta 0.2. Data are given as mean (SD) unless otherwise stated. Kolmogorov–Smirnov tests for normality were performed. Comparisons before vs. during pneumoperitoneum, and before vs. after fluid challenges were performed by paired $t$-test or Wilcoxon test. Receiver operating characteristics (ROC) curves for the dynamic variables were based on values before performing fluid challenges, with areas under curves (AUC) illustrating the ability of the variables to separate responders and non-responders. Correlations between changes in dynamic variables and $SV_{OD}$ were corrected for multiple observations as described by Bland and Altman. Median difference with confidence interval (CI) was calculated by the related samples Hodges–Lehman test in IBM SPSS Statistics19.0.0 (IBM, Armonk, NY, USA). Other calculations were performed in MedCalc 11.5.1.0 (MedCalc Software, Mariakerke, Belgium).
<table>
<thead>
<tr>
<th></th>
<th>Before pneumoperitoneum</th>
<th>During pneumoperitoneum</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All, n = 20</td>
<td>NR, n = 16</td>
<td>R, n = 4</td>
</tr>
<tr>
<td>HR, beats/min</td>
<td>59 (54–69)</td>
<td>60 (53–69)</td>
<td>56 (54–74)</td>
</tr>
<tr>
<td>MAP, mmHg</td>
<td>67 (61–70)</td>
<td>67 (58–70)</td>
<td>66 (62–70)</td>
</tr>
<tr>
<td>CVP, mmHg*</td>
<td>11 (7–15)</td>
<td>11 (8–14)</td>
<td>12 (6–18)</td>
</tr>
<tr>
<td>Paw, cm H₂O</td>
<td>18 (15–20)</td>
<td>19 (15–20)</td>
<td>17 (16–20)</td>
</tr>
<tr>
<td>SV̇O₂, ml</td>
<td>80 (65–96)</td>
<td>86 (73–97)</td>
<td>62 (54–65)</td>
</tr>
<tr>
<td>Cl̇O₂, l/min</td>
<td>2.9 (1.9–3.4)</td>
<td>3.0 (2.4–3.4)</td>
<td>1.8 (1.8–2.4)</td>
</tr>
<tr>
<td>Cl̇Vigileo, l/min</td>
<td>2.1 (1.9–2.7)</td>
<td>2.1 (1.9–2.8)</td>
<td>1.9 (1.7–2.2)</td>
</tr>
<tr>
<td>ΔPP, %</td>
<td>8.9 (6.8–11.2)</td>
<td>8.1 (6.5–11)</td>
<td>10.5 (9.4–12.2)</td>
</tr>
<tr>
<td>SVV̇Vigileo, %</td>
<td>9 (8–12)</td>
<td>8.5 (7–12)</td>
<td>13 (9–17)</td>
</tr>
<tr>
<td>PVI, %</td>
<td>7 (6–11)</td>
<td>7 (5–10)</td>
<td>10 (8–24)</td>
</tr>
<tr>
<td>PI, %</td>
<td>8.5 (6.3–14)</td>
<td>8.8 (6.3–15)</td>
<td>8.0 (4.5–11.4)</td>
</tr>
<tr>
<td>ΔPOP, %</td>
<td>8.0 (7.2–10.6)</td>
<td>7.9 (6.9–10)</td>
<td>10.8 (8.0–24.6)</td>
</tr>
<tr>
<td>SV̇O₂ increase by HDT, %</td>
<td>6.5 (2.3–10.8)</td>
<td>6 (1–8)</td>
<td>21 (18–23)</td>
</tr>
</tbody>
</table>

Values are median (25th–75th percentiles). Responders (R) and non-responders (NR) are separated, but statistical comparisons with P-values are between ‘All’. Comparisons by paired t-test or Wilcoxon test. Responders defined as an increase in SV̇O₂ ≥ 15% by HDT. *n = 19; †Wilcoxon test; NR, non-responder; R, responder; HR, heart rate; MAP, mean arterial pressure; CVP, central venous pressure; Paw, peak airway pressure; SV̇O₂, stroke volume by oesophageal Doppler; Cl̇O₂, cardiac index by oesophageal Doppler; Cl̇Vigileo, cardiac index by FloTrac/Vigileo; ΔPP, respiratory variations in pulse pressure; SVV̇Vigileo, stroke volume variation by FloTrac/Vigileo; PVI, pleth variability index; PI, perfusion index; ΔPOP, respiratory variations in pulse oximetry plethysmography waveform amplitude; HDT, head-down tilt.
Results

Heart rate (HR), mean arterial pressure (MAP), central venous pressure (CVP) and peak airway pressure increased with pneumoperitoneum (HR only of borderline statistical significance, Table 2). SV_{OD}, cardiac index by oesophageal Doppler (CI_{OD}) and PI decreased, whereas the cardiac index by FloTrac/Vigileo (CI_{Vigileo}) increased. Dynamic variables derived from the arterial pressure waveform were not significantly altered. Mean changes (95% CI) were ΔPP: 0.5 (−1.3, 2.3)%, P = 0.53; SVV_{Vigileo}: 0.6 (−1.3, 2.5)%, P = 0.52. Changes in photoplethysmographic variables were PVI: 2.9 (0.4, 5.3)%, P = 0.025. Changes in ΔPOP were not normally distributed, and changes in medians were 2.5 (−0.15, 6.7)%, P = 0.058.

We found no statistically significant correlations between dynamic variables before head-down tilts and the increases in SV_{OD} with head-down tilts either before or during pneumoperitoneum (data not shown). However, there was a significant correlation between SV_{OD} increases before vs. during pneumoperitoneum (r = 0.70, P < 0.001, Fig. 2). There was no significant difference in SV_{OD} increases induced by head-down tilts before vs. during pneumoperitoneum (Table 2).

Twenty-five fluid challenges were performed during pneumoperitoneum in 15 patients. Three fluid challenges were discarded as patient position was changed during the challenge. The laparoscopic procedure lasted 3.0 (1.6) h. Haemodynamic measurements before and after fluid challenges are presented in Table 3. MAP, CVP, SV_{OD}, CI_{OD} and CI_{Vigileo} increased with fluid challenge, whereas ΔPP, SVV_{Vigileo} and ΔPOP decreased. We found no significant change in PVI. Correlations between changes in dynamic variables vs. changes in SV_{OD} from before to after fluid challenge were as follows: ΔPP r = −0.65, P = 0.009; SVV_{Vigileo} r = −0.73, P = 0.002; PVI r = −0.22, P = 0.44; ΔPOP r = −0.32, P = 0.24 (Fig. 3). Areas under ROC curves (95% CI) calculated from values before fluid challenges were as follows: ΔPP 0.53 (0.31–0.75), SVV_{Vigileo} 0.74 (0.51–0.90), PVI 0.61 (0.38–0.81), ΔPOP 0.63 (0.40–0.82) (Fig. 4). When defining a responder by an increase in CI of ≥ 15% as measured by the FloTrac/Vigileo system, the following AUC values (95% CI) were calculated: ΔPP 0.62 (0.39–0.82), SVV_{Vigileo} 0.73 (0.49–0.89), PVI 0.71 (0.48–0.88), ΔPOP 0.73 (0.50–0.90).

Discussion

The main findings in the present study are that pneumoperitoneum did not alter dynamic variables derived from the arterial pressure waveform (ΔPP and SVV_{Vigileo}), whereas the photoplethysmographic variables PVI increased and ΔPOP tended to increase (P = 0.058). Correspondingly, during laparoscopic surgery, ΔPP and SVV_{Vigileo} tracked changes in SV_{OD} induced by fluid challenges, whereas PVI and ΔPOP did not. During ongoing laparoscopic surgery, all four dynamic variables predicted fluid responsiveness relatively poor.

Our findings are consistent with a study on rabbits in which pneumoperitoneum (10 mmHg) did not induce significant changes in ΔPP.17 In that study, the systolic pressure variation increased due to increased Δup-component. An increase in systolic pressure variation due to increased Δup-component was also found in a study on pigs with pneumoperitoneum (12 mmHg).18 We did not explore systolic pressure variation, as ΔPP is considered superior for evaluation of fluid responsiveness.19

In a study comparing obese and lean patients, pneumoperitoneum (15 mmHg) increased ΔPP in lean but not in obese patients.13 This was explained by different ‘abdominal vascular zones’,20 with lean persons having more zone II conditions. A non-invasive device (arterial applanation
tonometry) was used to calculate \( \Delta PP \). Pre-load responsiveness/CO was not studied. We found no increases in \( \Delta PP \) when pneumoperitoneum was established. Our patients had BMI 25 (5.8), comparable to their lean group, with BMI 23 (3). We have no obvious explanation for this discrepancy, except the slightly higher IAP (15 vs. 10–12 mmHg) in their study.

Unaltered \( \Delta PP \) and \( SVV_{\text{Vigileo}} \) when establishing pneumoperitoneum do not necessarily imply that relations between the variables and fluid responsiveness were also unchanged, for example, threshold values.\(^{12}\) We, therefore, performed a head-down tilt before and after pneumoperitoneum to evaluate the effects of transient increases in pre-load. This allowed the patients to act as their own controls as the increased pre-load is reversed when returning to the horizontal position.\(^{21}\) We found no correlation between any of the dynamic variables and the relative increases in \( SVV_{\text{OD}} \) during the head-down tilts. That most values of \( \Delta PP \) were in the ‘grey zone’, where responders and non-responders are not well separated,\(^{22}\) may explain the lack of correlation. Relative increases in \( SVV_{\text{OD}} \) during the head-down tilts were unchanged by pneumoperitoneum. Thus, assuming that the head-down tilt test is unaffected by pneumoperitoneum, \( \Delta PP \) and \( SVV_{\text{Vigileo}} \) and the response to increased pre-load were unaltered by pneumoperitoneum at the levels of IAP studied.

PVI increased and \( \Delta POP \) tended to increase when pneumoperitoneum was established. This may be caused by sympathetic activity\(^{23}\) induced by surgery or possibly release of norepinephrine induced by pneumoperitoneum \( \text{per se} \).\(^{24}\) The finger photoplethysmographic waveform is affected by vasoconstriction induced by cold pressor test, stimulating sympathetic stimulation.\(^{25}\) Both inflation of \( CO_2 \) and surgical stimulation may contribute to the changes observed in the photoplethysmographic variables. The same mechanisms probably explain the reduction in PI. These findings are supported by a study on PVI and PI during skin incision, in which PVI increases and PI decreases with incision.\(^{26}\)

### Table 3

<table>
<thead>
<tr>
<th>Variable</th>
<th>Before fluid challenge</th>
<th>After fluid challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All, ( n = 22 )</td>
<td>NR, ( n = 15 )</td>
</tr>
<tr>
<td>HR, beats/min</td>
<td>73 (66–87)</td>
<td>74 (61–86)</td>
</tr>
<tr>
<td>MAP, mmHg</td>
<td>71 (63–77)</td>
<td>67 (62–72)</td>
</tr>
<tr>
<td>CVP, mmHg*</td>
<td>4 (0–10)</td>
<td>5 (1–10)</td>
</tr>
<tr>
<td>Paw, cm H(_2)O</td>
<td>23 (20–26)</td>
<td>24 (20–26)</td>
</tr>
<tr>
<td>( SV_{\text{OD}}, ) ml</td>
<td>69 (57–76)</td>
<td>73 (63–78)</td>
</tr>
<tr>
<td>( CI_{\text{OD}}, ) l/min</td>
<td>2.6 (2.1–3.3)</td>
<td>2.8 (2.2–3.3)</td>
</tr>
<tr>
<td>( CI_{\text{Vigileo}}, ) l/min</td>
<td>2.4 (2.1–2.9)</td>
<td>2.4 (2.1–3.4)</td>
</tr>
<tr>
<td>( \Delta PP, ) %</td>
<td>10.9 (8.9–18.2)</td>
<td>10.7 (9.0–17.1)</td>
</tr>
<tr>
<td>( SVV_{\text{Vigileo}}, ) %</td>
<td>13 (11–17)</td>
<td>12 (11–15)</td>
</tr>
<tr>
<td>PVI, %</td>
<td>10.5 (7–20)</td>
<td>10 (7–17)</td>
</tr>
<tr>
<td>PI, %</td>
<td>6.2 (3.5–10)</td>
<td>6.5 (5.1–9.8)</td>
</tr>
<tr>
<td>( \Delta POP, ) %</td>
<td>14.1 (8.3–21.1)</td>
<td>13.8 (7.4–20.2)</td>
</tr>
</tbody>
</table>

Values are median (25th–75th percentiles). Responders (R) and non-responders (NR) are separated, but statistical comparisons with \( P \)-values are between `All`. Comparisons by paired t-test or Wilcoxon test. Responders defined as an increase in \( SVV_{\text{OD}} \) > 15% by fluid challenge. \( * n = 21; \dagger \text{Wilcoxon test; HR, heart rate; MAP, mean arterial pressure; CVP, central venous pressure; Paw, peak airway pressure, SV}_{\text{OD}}, \) stroke volume by oesophageal Doppler; \( CI_{\text{OD}}, \) cardiac index by oesophageal Doppler; \( CI_{\text{Vigileo}}, \) cardiac index by FloTrac/Vigileo; \( \Delta PP \), respiratory variations in pulse pressure; \( SVV_{\text{Vigileo}}, \) stroke volume variation by FloTrac/Vigileo; PVI, pleth variability index; PI, perfusion index; \( \Delta POP \), respiratory variations in pulse oximetry plethysmographic waveform amplitude.
An apparent discrepancy is that when pneumoperitoneum was established, CI_{OD} decreased, whereas CI_{Vigileo} increased. When IAP is increased, blood flow may be redistributed from the descending aorta to vessels leaving the aortic arch. This may contribute to falsely reduced CI as OD measures blood flow in the descending aorta. Additionally, the trending ability of pulse contour devices during changes in peripheral resistance, as may occur with establishment of pneumoperitoneum, has been questioned. Future studies must take this discrepancy in consideration. Most commonly, CO is reduced when pneumoperitoneum is initiated. However, a biphasic response with an initial increase in CO with increasing IAP up to 7.5 mmHg with return to baseline at 15 mmHg is reported in pigs.

The poor prediction of fluid responsiveness for the dynamic variables as shown in the ROC plots in
Fig. 4 contrasts numerous studies performed in the ICU or before surgery. These studies generally show excellent predicting values of the dynamic variables. However, our results are consistent with other studies performed during open abdominal surgery, underscoring the need to interpret dynamic variables cautiously during ongoing abdominal surgery. It is not clear what causes these discrepancies, but we have earlier demonstrated a large variability of the dynamic variables during ongoing surgery, which can contribute to the finding of lower predictive values.

Abdominal surgery could potentially influence dynamic variables by direct mechanical effects and through the autonomic nervous system, which could confound effects of fluid challenges. Changes in ΔPP and SVV_Vigileo were, however, significantly correlated to changes in SV_OD (Fig. 3), showing the ability of these variables to track changes in SV_OD induced by fluid challenges during laparoscopic surgery. As SV is often not measured during routine surgery, an important clinical implication of these findings is that SV can be presumed to increase when SVV or ΔPP is reduced by fluid challenges. In contrast to PVI and ΔPOP, these variables were unaffected by pneumoperitoneum, and thus seem more robust in this setting.

Methodological considerations
Sample size in this study is limited (20 patients for analysis) and was calculated to demonstrate a presumed clinical relevant change in ΔPP with pneumoperitoneum. ΔPP was chosen for power analysis, as this variable is most extensively studied so far. However, CI for AUC values are wide, and predictive values of the dynamic variables during ongoing laparoscopic surgery need to be further elucidated.

Both OD and FloTrac/Vigileo (version 3.02) were used in this study to estimate SV/CO. We chose OD as our reference method to measure effects of preload changes, as the trending ability of OD is well established. Further, the concordance of these two devices is low during changes in vasomotor tone, as may occur during surgery. Preload responsiveness when exploring the effects of pneumoperitoneum per se was assessed by head-down tilts, approximating a transient volume expansion, enabling us to compare the response before and during pneumoperitoneum with patients as their own controls. Pneumoperitoneum may, however, possibly affect the volume mobilised by head-down tilts. Passive leg raise has been shown not to predict fluid responsiveness in patients with IAP > 16 mmHg. In this study IAP was lower. Furthermore, we found a good correlation between relative changes in SV before and during pneumoperitoneum.

Five patients had an ongoing infusion of norepinephrine when pneumoperitoneum was established. Due to patient safety, the dose had to be changed from before to during pneumoperitoneum in three patients (two decreased/stopped and one increased). These patients did not constitute outliers. A continuous infusion of norepinephrine (six patients, mean dose 0.035 μg/kg/min) or phenylephrine (one patient, 0.1 μg/kg/min) was given during seven fluid challenges. Norepinephrine infusions have been shown to affect dynamic variables in dogs, presumably by converting venous unstressed volume to stressed volume. The vasoressor dose was kept unchanged during the challenges and registrations, and the circulatory effects should thus also be unchanged. One fluid challenge was performed during continuous epidural analgesia, which started well before and was not changed during the fluid challenge. In the other patients who had an epidural catheter, only a test dose of local anaesthetic was given in the study period well
before the fluid challenges. Thus, it is unlikely that sympatholytic effects of epidural analgesia affected our results.

During surgery, fluid challenges were performed at the discretion of the attending anaesthesiologist. As this part of the study was observational, we did not have pre-specified triggers for fluid challenges. The haemodynamic status preceding the fluid challenges is given in Table 3. For measurement of SV, we used the OD. This is an operator-dependent technique. All measurements were performed by the same experienced operator. A possible influence of pneumoperitoneum on the distribution of blood flow to the descending aorta has been discussed. However, during ongoing surgery, we believe that the trending ability of OD is not affected by pneumoperitoneum once established. The AUC values calculated using the FloTrac/Vigileo to define responders were comparable to the values calculated based on the OD measurements. This supports our findings, making it less likely that measurement errors with the OD caused the low AUC values.

Although efforts were made to synchronise measurements from the different devices, different registration periods made perfect synchronisation difficult. For APP and ΔPOP, we averaged 10 respiratory cycles. SV_{Vigileo} is averaged over 20 s, whereas our PVI software is averaged over minutes in a proprietary manner. SV_{OD}-measurements were averaged over 1 min. It might, thus, be that variability within registration periods affected our results. For the calculations of ΔPP and ΔPOP in the LabVIEW program, each respiratory cycle was manually delimited and visually inspected. It is, thus, unlikely that measurements on, for example, a paper strip, would give different results.

In conclusion, pneumoperitoneum did not change ΔPP or SVV_{Vigileo} whereas the photoplethysmographic variables PVI increased and ΔPOP tended to increase. Correspondingly, ΔPP and SVV_{Vigileo} tracked changes in SV induced by fluid challenges, whereas ΔPOP and PVI did not. Predictive values of fluid responsiveness during ongoing laparoscopic surgery were relatively poor for all four variables studied. Awaiting further studies, dynamic variables should be used and interpreted with caution during ongoing laparoscopic surgery.

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Conflict of interest: Masimo Radical 7 pulse oximeter provided by Masimo Corp. Masimo Corp had no influence on any part of the study. Otherwise, the authors have no conflicts of interest to declare.

References


