Original Article

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Dynamic Indices for the Prediction of Fluid Responsiveness in Laparoscopic Urologic Surgery under General Anaesthesia: An Interventional Study

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Abstract:

Objective: This study aims to evaluate the ability of stroke volume variation (SVV), pulse pressure variation (PPV), and change in PVV and SVV after tidal volume challenge testing (ΔPPV and ΔSVV) aiming to predict fluid responsiveness in patients undergoing laparoscopic urologic surgery.

Material and Methods: A prospective interventional study was performed with 23 patients undergoing urologic surgery while they were placed in Trendelenburg positions. A Vigileo/FloTrac system was used for the analysis. Hemodynamic data such as: arterial pressure (MAP), heart rate (HR), peak airway pressure (PIP), stroke volume (SV), cardiac output (CO), SVV, and PPV were recorded at the tidal volume settings of 8 mL/kg and 12 mL/kg before, and after a fluid challenge (FC). Fluid responsiveness was defined as an increase in SV(ΔSV) ≥15.0%.

Results: After tidal volume challenge tests, there were significant increases in PIP in both groups. PPV increased only in the responders, as opposed to SVV, which increased significantly only in non-responders after tidal volume challenge test. After fluid challenge, PVV and SVV decreased gradually and significantly in both groups. The area under the ROC curves of patients undergoing laparoscopic urologic surgery was 0.872 (95% CI: 0.57-0.96) for ΔPPV, this change was the highest compared to other parameters. The threshold of the ΔPPV of patients undergoing laparoscopic urologic surgery was 4% with a sensitivity at 0.75 and specificity at 0.93.

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Conclusion: Change in PPV after the tidal volume challenge test from 8 mL/kg to 12 mL/kg can be used as an effective indicator to monitor fluid responsiveness in regards to patients undergoing urologic surgery.

Keywords: dynamic indices, predict fluid responsiveness, urologic surgery

Introduction

Individualised hemodynamic monitoring in high-risk patients and in those undergoing surgical procedures under general anaesthesia has been practiced in recent years. Preload monitoring is useful in order to distinguish non-responders from responders via predicting fluid responsiveness. Heart-lung interactions were monitored to assess preload in anaesthetised patients undergoing open abdominal surgery with a tidal volume of over 8 mL/kg.[1] However, pulse pressure variation (PPV) is based on heart-lung interactions, therefore, various factors affecting lung mechanics can influence PPV. For example, several studies reported that chest wall compliance, tidal volume, and intra-abdominal pressure (IAP) can have an affect on PPV values.[2,3] Similarly, the reliability of PPV and stroke volume variation (SVV) is questionable in the condition of pneumoperitoneum, because it can increase IAP, decrease cardiac output, and decrease respiratory compliance[4]; while some positions, for example, the head-down positions, can induce a reversible increase in preload. Among these limitations, the effect of tidal volume (V_T) has been studied in various studies in which PPV values were increased, and its predictability for fluid responsiveness was improved when applying higher V_T ventilation.[5–9] Recent studies indicated that changes in PPV or SVV obtained by briefly increasing V_T to 12 mL/kg (tidal volume challenge test) accurately predicted fluid responsiveness even in anaesthetised patients and critically-ill patients who were in the grey zone of PPV (9.0–13.0%).[7,10] However, to the best of our knowledge, no study has been conducted on patients undergoing laparoscopic surgery. Few studies have demonstrated that PVV and SVV can predict fluid responsiveness in laparoscopic surgery, but they have not addressed the various types of surgeries performed under the umbrella of laparoscopic surgeries[11,12], whereas others showed that PVV and SVV were poor predictors of fluid responsiveness in these surgeries[13,14]; this contradictory results may therefore limit the clinical use of these variables in the aforementioned setting. In our study, we aimed to investigate four dynamic indices i.e., PVV, SVV, ΔPPV (change in PPV by increase or decrease directly from baseline after increasing V_T from 8 mL/kg to 12 mL/kg [tidal volume challenge test]), and ΔSVV (change in SVV after tidal volume challenge test) to predict fluid responsiveness in patients who underwent laparoscopic urologic surgeries in the head-down position.

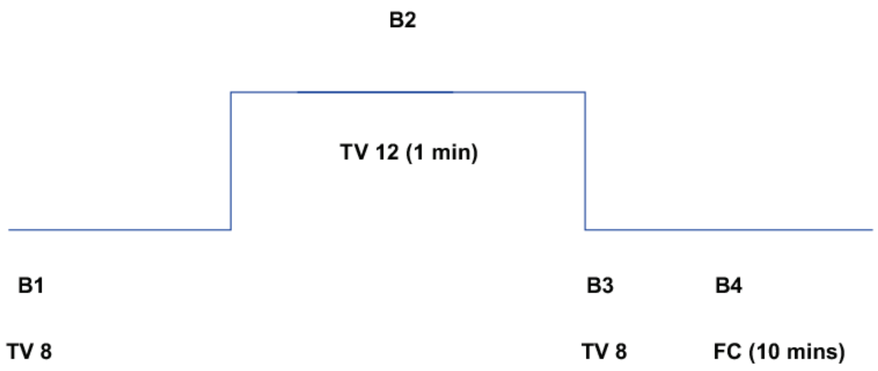
Material and Methods

The regional Ethics Committee of Prince of Songkla University approved this study (REC. 63-356-8-1). The trial was registered in the Thai Clinical Trials Registry (TCTR20220419005). Written informed consent was obtained from the patients. All procedures were conducted in accordance with the tenets of the Declaration of Helsinki (1964). The inclusion criteria were as follows: (i) patients admitted to our institution between April 2021 and March 2022; (ii) patients aged 18–70 years with an American Society of Anesthesiology (ASA) classification score of 1–3; (iii) those that were scheduled to undergo laparoscopic urologic surgery; and (iv) those that were placed in Trendelenburg position with arterial monitoring. Patients who had cardiac arrhythmia, increased intracranial pressure, pregnancy, and body mass index >30 kg/m^2, those that were receiving intraoperative vasopressors or inotropes during the study, and those that had an end-stage renal disease or renal insufficiency were excluded.

All patients underwent standard intraoperative monitoring, namely, electrocardiogram recording, non-invasive blood pressure monitoring, heart rate, and measurement of oxygen saturation with pulse oximeters. The induction of anaesthesia was performed with fentanyl (2–3 mcg/kg), propofol (1–2 mg/kg), and cisatracurium (0.15–0.2 mg/kg), then patients were intubated with an oroendotracheal tube. Next, arterial line monitoring was performed in all patients via a radial artery, and the arterial line was connected to noncalibrated continuous cardiac output monitoring (Vigileo EV1000; Edwards Lifescience™, Irvine, California, United States of America) and the IntelliVue MP70 monitor (Philips Medical Systems, Boblingen, Germany). The EV1000 system continuously analysed arterial waveforms with internal biometric data calibration, then reported stroke volume (SV), cardiac output (CO) and SVV continuously. The IntelliVue MP70 monitor also displayed the automatically calculated PPV in real-time.[11]

The patients were placed on controlled ventilation, with a V_T of 8 mL/kg of predicted body weight and an inspired oxygen concentration of 40.0–60.0%. Respiratory rate and positive end-expiratory pressure (PEEP) were adjusted to keep oxygen saturation ≥96.0% and an end-tidal CO_2 range of 30–40 cmH_2O. During surgery, the depth of anesthesia was maintained with sevoflurane 12.0% or desflurane 6.0-8.0%. Intermittent bolus doses of cisatracurium 2 mg, for adequate muscle relaxation, were injected to maintain a train-of-four count of less than two.

Patient characteristics were recorded before the initiation of the interventions, including gender, age, weight, height, body mass index (BMI), ASA physical status, duration of operation, amount of fluid, and respiratory parameters, such as V_T, respiratory compliance, driving pressure, and PEEP. After the anaesthetised patients were placed in Trendelenburg positions for 1 hour, the hemodynamic parameters of CO, SV, and the respiratory parameter of peak airway pressure (PIP) were recorded at this time. Next, V_T was increased from 8 mL/kg of predicted body weight to 12 mL/kg of predicted body weight for 1 minute and these parameters were recorded again. Then, V_T was decreased to 8 mL/kg of predicted body weight, and these parameters were recorded again. The fluid challenge was initiated with crystalloids (normal saline, Ringer's lactate solution, or Ringer's acetate solution) at a dose of 6 mL/kg within 10 minutes. The aforementioned parameters were recorded after complete fluid loading (Figure 1).



B1=hemodynamic parameters at tidal volume (V_T) of 8 mL/kg, B2=hemodynamic parameters at V_T of 12 mL/kg, B3=second hemodynamic parameters at V_T of 8 mL/kg, B4=hemodynamic parameters after fluid challenge. FC=fluid challenge, TV8=tidal volume 8 mL/kg, TV12=tidal volume 12 mL/kg

Figure 1 Timeline for the study process

Statistical analysis

The primary outcomes were differences in the values of PPV, SVV, and the tidal volume challenge test between responders and non-responders. Secondary outcomes were the accuracy for the prediction of fluid responsiveness using the parameters of sensitivity, specificity, and the area under the curve. The sample size was calculated using a method from a previous study.[15] Eleven patients were identified as having fluid responsiveness, for whom SVV was 1.5 times that of non-responders. The total sample size was calculated to be n=23 for the null hypothesis (no discrimination between responders and non-responders) with the probability of a type I error of 0.05 and a type II error of 0.2.

All hemodynamic variables were analysed as continuous variables and expressed as the mean±S.D. or as categorical variables expressed as the number of patients (%). Assuming that a 15.0% change in SV was required for clinical significance, patients were separated into responders and non-responders by changes in SV of ≥15.0% and <15.0%, respectively, after fluid therapy.

Patient characteristics were compared between the two groups (responders and non-responders) using an unpaired t-test with unequal variance. A paired t-test for continuous data was used to compare hemodynamic variables between the pre- and post-tidal volume challenge test and the fluid challenge. We assessed the ability of different hemodynamic variables to discriminate between responders and non-responders after fluid therapy using paired t-test. The area under the receiver operating characteristic (AUROC) curves was generated for PPV, SVV, ΔPPV, and ΔSVV.[16] After the AUROC curves were constructed, the optimal cut-off value was defined as the value-based clinical measurement that was closest to the Youden index. For all analyses, p-value<0.05 was considered to be statistically significant. Statistical analyses were performed using R program version 4.1.2

Results

Twenty-eight patients were screened and five patients were excluded due to being older than 70 years. A total of 23 patients were included. Eight patients were defined as responders and 15 patients were non-responders. There was no difference in patient characteristics between responders and non-responders (Table 1).

For respiratory mechanics-related variables, there was a significant increase in PIP after V_T was increased to 12 mL/kg in both responders and non-responders, followed by a return to baseline after V_T was decreased to 8 mL/kg, and there was no change in PIP after fluid loading. In regards to hemodynamic variables, PPV in responders increased significantly after augmentation V_T, while there was no change in PPV for the non-responders. SVV increased gradually at the V_T of 12 mL/kg in non-responders, however, this effect was not observed in responders. After the fluid challenge, PPV and SVV in both groups decreased significantly. Moreover, CO and SV increased after fluid loading but only in responders (Table 2).

The comparison of dynamic indices between responders and non-responders, including PPV, SVV, ΔPPV, and ΔSVV, showed that Δ PPV was significantly higher in responders than in non-responder (5.4% in responders and 0.9% in non-responders), while other indices were not significantly different (Table 3).

Reliability was measured using AUROC. AUROC of ΔPPV was 0.82 (95% confidence interval (CI): 0.57–0.96), which was the highest when compared with other dynamic indices (AUROC of PPV was 0.48 [95% CI: 0.27–0.74], AUROC of SVV was 0.5 [95% CI: 0.38–0.74], and AUROC of ΔSVV was 0.55 [95% CI: 0.23–0.80]), as shown in Figure 2. The optimal threshold of ΔPPV was 4 with a sensitivity of 0.75, specificity of 0.93, negative predictive value of 0.88, and a positive predictive value of 0.38 (Figure 3). Complications including pulmonary oedema and pneumothorax were not found in our study.

Table 1 Patient characteristics

Variables	Overall (N=23)	Responders (N=8)	Non-responders (N=15)	p-value
Age (in years), mean (S.D.)	59.43 (9.10)	54.90 (11.80)	61.86 (6.50)	0.15
Men, n (%)	21 (91.30)	7 (87.50)	14 (93.33)	1.00
Weight (in kg), mean (S.D.)	67.13 (10.07)	62.00 (9.20)	69.86 (9.69)	0.07
Height (in cm), mean (S.D.)	165.43 (8.09)	165.40 (8.32)	165.5 (8.26)	0.98
BMI (in kg/m^2), mean (S.D.)	24.23 (2.87)	22.50 (2.77)	25.10 (2.56)	0.98
ASA physical status I/II/II, n (%)	1/19/3 (4.4/82.6/13)	1/6/1 (12.5/75/12.5)	0/13/2 (0/86.7/13.3)	0.37
Operation duration (in minutes), mean (S.D.)	296.96 (78.43)	282.50 (83.00)	304.67 (77.70)	0.54
Fluids (in mL), mean (S.D.)	615.22 (324.19)	581.25 (205.11)	633.33 (378.00)	0.67
Tidal volume (in mL), mean (S.D.)	469.13 (47.76)	455.00 (37.40)	476.67 (52.10)	0.27
Respiratory compliance (in mL/cmH_2O), mean (S.D.)	29.78 (11.41)	25.88 (4.05)	31.86 (13.50)	0.13
Driving pressure (in cmH_2O), mean (S.D.)	17.13 (4.14)	17.75 (3.24)	16.80 (4.62)	0.58
Respiratory rate (times/minute), mean (S.D.)	13.48 (2.19)	14.0 (2.83)	13.2 (1.82)	0.49
PEEP (in cmH_2O), mean (S.D.)	5 (0)	5 (0)	5 (0)	1
Urologic laparoscopic surgery type, n (%)				
Intra-abdomen	6 (26.2)	3 (37.5)	3 (20)	0.68
Prostate	17 (73.8)	5 (62.5)	12 (80)	
Degree of Trendelenburg position, mean (S.D.)	33.43 (13.25)	26.75 (13.60)	37.00 (12.00)	0.10

BMI=body mass index, ASA=American Society of Anesthesiology, PEEP=positive end-expiratory pressure
Values are expressed as mean±S.D. or number (%)

Table 2 Comparison of hemodynamic variables between fluid responders and non-responders for different tidal volumes and for before and after the fluid loading

Variables	V_T 8 mL/kg	V_T 12 mL/kg	p-value	Before fluid loading	After fluid loading	p-value
SBP (in mmHg)						
Responders	114.75 (17.95)	113.50 (18.24)	0.50	110.50 (18.23)	112.50 (13.41)	0.64
Non-responders	123.80 (16.55)	122.93 (16.36)	0.42	120.73 (16.38)	122.07 (19.78)	0.71
DBP (in mmHg)						
Responders	68.88 (6.90)	68.00 (8.59)	0.40	66.63 (8.37)	67.38 (6.00)	0.71
Non-responders	71.33 (10.31)	70.67 (11.86)	0.44	68.80 (9.40)	69.53 (10.78)	0.68
MAP (in mmHg)						
Responders	85.75 (11.85)	84.38 (13.26)	0.39	82.00 (12.92)	83.88 (9.50)	0.50
Non-responders	89.13 (13.16)	89.00 (12.76)	0.91	86.93 (10.90)	87.47 (13.64)	0.80
HR (beats/min)						
Responders	67.75 (9.22)	68.13 (9.88)	0.62	67.13 (10.03)	67.13 (10.87)	1.00
Non-responders	62.40 (12.57)	59.80 (11.03)	0.10	60.40 (11.87)	63.73 (13.49)	0.33
PIP (in cmH_2O)						
Responders	22.75 (2.38)	27.5 (2.78)	<0.05*	22.00 (1.93)	23.0 (1.51)	0.07
Non-responders	23.93 (2.91)	30.4 (4.07)	<0.05*	24.00 (3.21)	24.6 (2.80)	0.08
PPV (%)						
Responders	10.13 (4.82)	15.50 (7.50)	<0.05*	12.65 (6.80)	8.25 (3.01)	0.03*
Non-responders	10.66 (4.73)	11.57 (5.26)	0.26	10.40 (4.52)	8.20 (3.69)	<0.05*
SVV (%)						
Responders	14.75 (5.90)	17.63 (8.37)	0.14	16.75 (8.19)	12.0 (5.55)	0.04*
Non-responders	15.00 (5.69)	17.87 (5.67)	<0.05*	14.67 (5.67)	12.6 (5.29)	0.02*

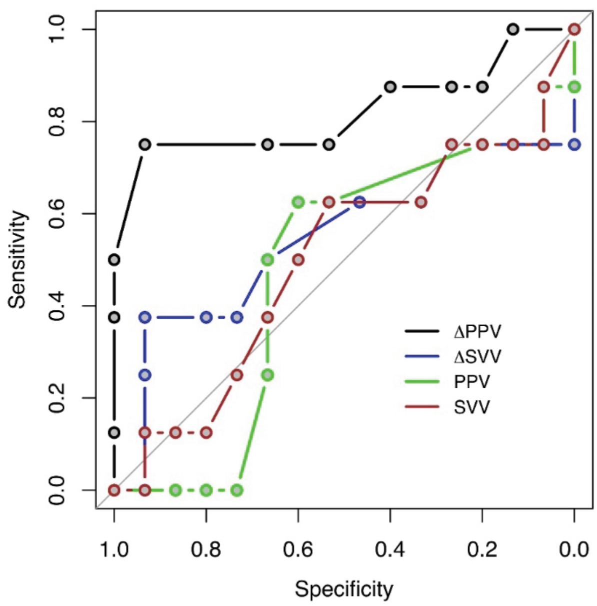
Table 2 (continued)

Variables	V_T 8 mL/kg	V_T 12 mL/kg	p-value	Before fluid loading	After fluid loading	p-value
CO (L/min)						
Responder	4.41 (1.40)	4.25 (1.29)	0.08	4.15 (1.29)	4.75 (1.13)	<0.05*
Non-responder	4.21 (1.10)	4.07 (1.15)	0.38	4.11 (0.92)	4.33 (1.42)	0.07
SV (in mL)						
Responder	57.13 (14.59)	57.13 (14.04)	1.00	56.38 (13.75)	65.63 (16.31)	<0.05*
Non-responder	68.87 (20.58)	69.13 (22.75)	0.91	67.60 (20.38)	70.00 (22.93)	0.10

SBP=systolic blood pressure, DBP=diastolic blood pressure, MAP=mean arterial pressure, HR=heart rate, PIP=peak inspiratory pressure, PPV=pulse pressure variation, SVV=stroke volume variation, CO=cardiac output, SV=stroke volume

Data are expressed as mean±S.D.

*Values of p-value<0.05 are considered as statistically significant.



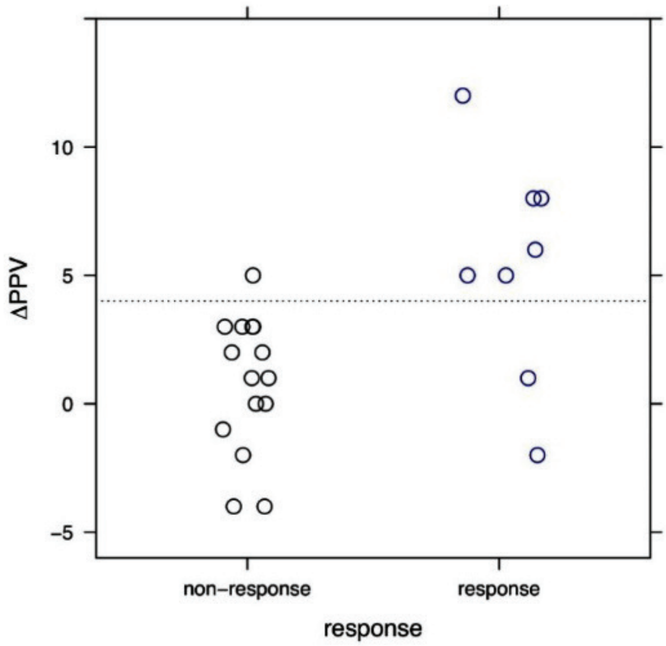
PPV=pulse pressure variation, SVV=stroke volume variation, ΔPPV=difference of PPV between tidal volumes of 12 mL/kg and 8 mL/kg, ΔSVV=difference of SVV between tidal volumes of 12 mL/kg and 8 mL/kg.

Figure 2 Receiver operating characteristics curves were plotted showing areas under the curves for PPV, SVV, ΔPPV, and ΔSVV

Table 3 Comparison of PPV, SVV, ΔPPV, and ΔSVV between responders and non-responders

Dynamics indices	Responders (N=8)	Non-responders (N=15)	p-value
PPV, %	10.13 (4.82)	10.66 (4.73)	0.80
SVV, %	14.75 (5.90)	15.00 (5.69)	0.92
ΔPPV, %	5.37 (4.34)	0.80 (2.65)	0.02*
ΔSVV, %	2.88 (4.94)	2.86 (3.27)	0.99

PPV=pulse pressure variation, SVV=stroke volume variation, ΔPPV=difference of PPV between tidal volumes of 12 mL/kg and 8 mL/kg, ΔSVV=difference of SVV between tidal volumes of 12 mL/kg and 8 mL/kg, V_T=tidal volume. All values are expressed as mean±S.D.
*Values of p-value<0.05 are considered as statistically significant.



ΔPPV=difference of PPV between tidal volumes of 12 mL/kg and 8 mL/kg

Figure 3 Individual values of ΔPPV after tidal volume challenge test in responders and non-responders (dotted line represent cut-off value to discriminate between responder and non-responders

Discussion

Our study evaluating patients undergoing laparoscopic urologic surgery at the Trendelenburg position found that ΔPPV was higher in responders than in non-responders when V_T was increased from 8 mL/kg to 12 mL/kg. Other indices did not demonstrate a statistically significant change. Moreover, we found that ΔPPV can predict fluid responsiveness with good reliability. The optimal threshold of ΔPPV was 4.0% with a sensitivity of 0.75, a specificity of 0.93, a negative predictive value of 0.88, and a positive predictive value of 0.38. No previous study identified the optimal threshold of ΔPPV in patients undergoing laparoscopic urologic surgery under general anaesthesia in Trendelenburg position.

For optimal haemodynamic monitoring in high-risk surgical patients, the evaluation of preload is important. A wide range of studies suggest that PPV and SVV are useful predictors of fluid responsiveness in patients receiving mechanical ventilation, but data were inconsistent in patients undergoing laparoscopic surgeries while in a head-down position owing to increased IAP and decreased lung compliance. Nonetheless, a head-down position can affect heart-lung interaction because the position increases cardiac preload from the major vessels in the lower extremities, decrease the compliance of the respiratory system, and reduce functional residual capacity as the diaphragm is forced toward the heart.[15,17]

A study by Hoiseth et el. demonstrated that in the condition of pneumoperitoneum, PPV and SVV poorly predicted fluid responsiveness.[13] However, the reliability of PPV and SVV in discriminating responders from non-responders in our study was different from that of Liu et al.[15]; they concluded that patients who received mechanical ventilation while undergoing laparoscopy-assisted gastrointestinal surgery and had a maintained IAP of 12 mmHg, demonstrated a PPV threshold of >10.5% and an SVV threshold of >7.5%, which could predict fluid responsiveness at the Trendelenburg position. Our study included both patients undergoing laparoscopic lower intrabdominal surgery and prostatectomy with variant degrees of the Trendelenburg position, which were steeper than those of the previous study.[15] This may affect a decrease in the PPV and SVV owing to an increased cardiac preload.[18] Moreover, we did not maintain the IAP constantly over a period of time, and this may have influenced the reliability of PPV and SVV, as even passive leg raising has been demonstrated to be unable to predict fluid responsiveness in patients with an IAP of more than 16 mmHg.[19] In addition, an experimental animal study demonstrated that the threshold value for PPV dramatically increased from 11.5% to 20.5% after elevating IAP to 25 mmHg.[20]

One-third of our sample size underwent robot-assisted surgery, and this was similar to Chin et al.[11], who demonstrated that in patients with pneumoperitoneum that underwent robot-assisted surgery in steep Trendelenburg position (35 degree), PPV and SVV could predict fluid responsiveness with a PPV cut-point of ≥9.5% and an SVV cut-point of ≥7.5%; however, a quarter of patients in the study[11], both responders and non-responders, showed values of PPV and SVV in a reverse direction to that of the cut-off value. Furthermore, we used Vigileo/FloTrac to evaluate stroke volume in our study, as opposed to other studies that used transoesophageal echocardiography[11,21]; this may have possibly been influenced by the condition of pneumoperitoneum affecting the distribution of blood flow to the descending aorta.[22]

In our study, we demonstrated that PPV and SVV were poor predictors of fluid responsiveness, but that ΔPPV calculated by a tidal volume challenge test (V_T 8 mL/kg to V_T 12 mL/kg) for 1 minute could predict fluid responsiveness with good reliability for the various types of major laparoscopic urologic surgeries. No complications were observed. This technique is useful in a resource-limited setting, where continuous monitoring of cardiac output is not required.

There are many limitations in the present study. First of all, as our study was conducted in an operating room setting, with a controlled V_T of 8 mL/kg in patients without any cardiovascular or respiratory problems, the applications of our findings may not be applicable to those patients that need a protective lung strategy such as patients with acute respiratory distress syndrome. Moreover, while we employed a short-duration V_T increase, the possible clinical consequences of a temporary increase in V_T are uncertain. A briefly high V_T could potentially be disadvantageous due to alveolar stretch or decreased venous return, especially in patients with severe cardiopulmonary disease, or may reduce intraoperative atelectasis.[23] Therefore, our strategy for PPV augmentation should be applied carefully with due consideration in regard to its risks and benefits. However, at V_T 12 mL per kg of body weight, the maximum PIP in our study was 32 mmHg, which is less likely to result in pneumothorax[20], and no patient developed this complication in our study. Another point is that, we did not assess the dynamic indices for the prediction of fluid responsiveness at the kidney position, which was used in some urologic surgeries. Finally, the effect of the level of the Trendelenburg position combined with the intensity of IAP could affect the accuracy of dynamic indices, especially, PPV and SVV. Further studies are needed to evaluate the effect of both factors.

Conclusion

The ΔPPV after the tidal volume challenge test (V_T from 8 mL/kg to 12 mL/kg) can be used as an effective indicator to monitor fluid responsiveness in patients who are undergoing laparoscopic urologic surgeries at the Trendelenburg position.

Conflict of interest

The authors declare that there is no conflict of interest in regard to the publication of this paper.

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