EGYPTIAN JOURNAL OF ANAESTHESIA
2024, VOL. 40, NO. 1, 119–126
https://doi.org/10.1080/11101849.2024.2312340

Plethysmography variation index versus pulse pressure variation as an indicator of fluid responsiveness in colorectal surgeries during immediate postoperative period

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ABSTRACT

Background: During major abdominal surgery, goal-directed fluid therapy may lessen postoperative morbidity. It has been demonstrated that the Plethysmography Variability Index (PVI), which is generated from the pulse oximeter waveform, can predict fluid responsiveness in a variety of surgical settings. Pulse pressure variation (PPV), one of the indicators of fluid responsiveness, has received the most research attention and clinical application of all the indicators. Through arterial cannulation, primarily the radial artery, pulse pressure fluctuation is recorded. The cyclic variations in intrathoracic pressure have less of an immediate impact on pulse pressure than they do on systolic pressure. In this study, sedated, intubated, mechanically ventilated patients admitted for postoperative resuscitation in our surgical ICU following colorectal surgeries had their fluid responsiveness assessed using the Plethysmography Variation Index (PVI) and the Pulse Pressure Variation (PPV) to compare their effectiveness and reliability.

ARTICLE HISTORY
Received 31 October 2023
Revised 19 January 2024
Accepted 25 January 2024

KEYWORDS
Plethysmography variation index; pulse pressure variation; cardiac index; goal directed fluid therapy

1. Introduction

At tidal volumes (Vt) > 8 mL/kg, dynamic predictors of fluid responsiveness have performed effectively in mechanically ventilated patients. The utility of dynamic indices based on heart-lung interaction for predicting fluid responsiveness in mechanically ventilated patients is supported by a number of research. Additionally, it has been demonstrated that changes in the amplitude of the plethysmographic pulse wave due to respiration accurately predict fluid responsiveness. To predict fluid responsiveness, the plethysmographic variability index (PVI) (Masimo, Irvine, CA) has been introduced.This index offers the benefit of being automatically calculated and continuously shown on the pulse oximeter screen [1].

PVI was a reliable indicator of fluid reactivity in patients receiving mechanical ventilation while under general anesthesia. PVI can predict fluid responsiveness in critically ill patients, according to a recent study. The dynamic changes in perfusion index (PI) that take place during the respiratory cycle are automatically measured by the plethysmographic variability index [2].

In mechanically ventilated patients who have passively adapted to the ventilator, pulse pressure variation predicts fluid responsiveness. Pulse pressure variation (PPV), one of several functional hemodynamic measures, may rapidly and precisely measure the arterial waveform using an ordinary multiparametric monitor. According to research by Sundaram et al. [3], it has been proven to be an excellent predictor of fluid responsiveness.

2. Aim of the study

The primary objective of this work is to demonstrate the accuracy of the plethysmography variation index in fluid responsiveness prediction. The secondary goal is to demonstrate that PVI is preferable than PPV since it is more accurate in predicting fluid responsiveness.

3. Patients and methods

This cross-sectional study was carried out at the surgical ICU at Ain Shams University Hospital over the course of a year, from April 2021 to April 2022. The patients in this study had been assigned to be mechanically ventilated in surgical ICU. Patients

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who have a history of unsatisfactory cardiac echogenicity, severe valvular heart disease that developed prior to colorectal surgery, known tricuspid insufficiency, an intracardiac shunt, or cardiac arrhythmia, low left ventricular function (ejection fraction 40%), any contraindication to fluid resuscitation, such as congestive heart failure, evidence of fluid overload, or renal dysfunction, lung pathologies (like asthma, COPD), Patients whose temporary removal of the compression stocking due to venous insufficiency (i.e., deep venous thrombosis) were excluded from the trial. These conditions were contraindications for sedation by opioids and midazolam, such as hepatic or renal dysfunction.

Sample size was determined using PASS 11 program, with alpha error set to 5% and power set to 80%. The findings of a prior study indicated that the AUC for diagnostic accuracy for PPV and PVI were 0.939 and 0.78 respectively [4]. This means that 50 respondents and 50 non-responders make up the required sample. Before enrolling in the experiment, each case was advised of the benefits and potential hazards that could arise throughout the study, as well as the medications employed. Prior to being included in the study, every patient provided their consent.

3.1. Study interventions

1- This study included 103 patients who were assigned into two groups: responders and non-responders. All patients' data were gathered at once. Following colorectal surgery, patient's age, sex, and BMI were recoded for all 103 patients upon admission to the ICU. A patient clinical examination was conducted. All patients admitted to the ICU following colorectal surgery had their APACHE II SCOREs completed. The study comprised subjects with an APACHE II score of 18 to 20. Additional hemodynamic measurements included heart rate (bpm), mean arterial pressure (MAP, mmHg), and oxygen saturation. Following colorectal surgery, recording was done every 30 minutes for the first two hours, then every two hours for the following twenty-four hours. All patients were mechanically ventilated. End-tidal carbon dioxide was monitored and kept between 30 and 35 mm Hg by changing respiratory rate. Ventilator settings: Tidal volume = 8 ml/kg of anticipated body weight, inspiratory: expiratory ratio = 1:2. On admission and after fluid challenge, the ABG with lactate was recorded. A midazolam infusion was used to maintain sedation. PPV, CI, and PVI were recorded at the time of ICU admission as well as after volume expansion, which was accomplished by infusing 500 ml of saline over 30 minutes. By using transthoracic echocardiography, CO was calculated. Using data from the left ventricular outflow tract (LVOT), cardiac output was computed. The length between the bases of the aortic valve cusp during systole, as viewed from the long parasternal view, was assumed to equal the diameter of the LVOT. A circular geometry was assumed while calculating the LVOT area. We used the average of three measurements of LVOT diameter to lower variability. The product radius squared was used to determine the LVOT area: LVOT area=[(LVOT diameter average/2)^2]3.14. CO, BW, and height were used to determine the cardiac index (CI). Patients who experienced an increase of ≥ 15% were referred to be "volume responders." Patients who changed < 15% or did not change at all were referred to as "non responders." Considering a rise in cardiac index of 15% or more to be a good sign after which the fluid challenge was discontinued. A Masimo Radical-7® monitor (Masimo Corp., Irvine, CA) was used to capture the PVI. To reduce light interference, a pulse oximeter probe was placed to the finger and covered with a black shield. The Masimo Radical 7 monitor was wired to the probe. Plethysmographic waveform analysis was used to automatically determine the PVI. The PPV was calculated as follows: the maximum (during inspiration) and the minimum (during exhalation) waveforms were identified on the undulating invasive blood pressure pattern. The systolic pressure value for the largest, or maximum inspiratory waveform, then the diastolic pressure was found through minimum expiratory wave. The difference in these two values is the pulse pressure. These steps have given the two pulse pressures. The pulse pressure is the difference between these two numbers. The two pulse pressures were determined by these actions. The formula used to determine the pulse pressure variation was PPV=PPmax-PPmin/(PPmax+PPmin)*2. In patients admitted to the ICU following colorectal surgery, the study compared the efficiency of PVI to PPV in predicting fluid response using cardiac index. If the patients experienced any side effects as a result of our treatments, such as bradycardia (HR fewer than 60 beats/min), hypotension (blood pressure less than 90/60 mmHg), arterial spasm during application of invasive blood pressure, hematoma, or false injection, they were treated as necessary. Atropine (0.01 mg/kg) was administered if the patient had developed bradycardia, and ephedrine (0.1–0.3 mg/kg) was administered if the patient experienced hypotension. Hot fomentations, periarterial xylocaine injections, or stellate ganglion blocks were used to treat arterial spasm. Hematoma was treated with adequate compression and hot fomentations. In the event of a false arterial injection, papaverine was infused intraarterially. Since the patient was hypotensive or hemodynamically unstable and did not

respond to the fluid challenge, he was either given supports like norepinephrine and/or epinephrine or was given treatment in accordance with the cause, which was evaluated.

3.2. Statistical analysis

Using the statistical package for social science (SPSS 15.0.1. for Windows; SPSS Inc, Chicago, IL, 2001), the obtained data were updated, coded, and loaded onto a PC. Quantitative parametric data are described as mean and standard deviation (± SD) and range and they were compared using independent samples t-test. Qualitative data are presented as number and percent and they were compared using the Chi square test. Sensitivity specificity, PPV, NPV were used to test accuracy.

4. Results

One hundred and three patients aged from eighteen to sixty-five years were scheduled for admission to surgical ICU after colorectal surgery for estimation of accuracy between PPV, PVI as indicators for fluid responsiveness.

5. Discussion

Over the course of a year, this observational cross-sectional study was conducted in the surgical ICU. The effectiveness of PVI and PPV to predict fluid responsiveness in mechanically ventilated sedated individuals was compared using data from 103 patients.

In colorectal surgery nowadays, Enhanced Recovery after Surgery (ERAS) pathways direct postoperative treatment. According to numerous randomized clinical trials, ERAS protocols have reduced readmissions, expenses, and lengths of stay (LOS) in hospitals. They have also decreased complications such postoperative ileus and surgical site infections.

Patients undergoing significant colon surgery in the past had excessive fluid administration. A 3 kg weight gain following elective colonic resection was linked to a higher complication rate, a longer hospital stay, and a slower recovery for the gastrointestinal system, according to one randomized, controlled experiment [5].

Early enteral nutrition ought to be made available to patients having colorectal surgery. In the past, patients were maintained NPO during bowel rest in order to guard against an anastomotic leak and to avoid PONV. Early enteral feeding, however, has been demonstrated to be advantageous. Carr et al. discovered that enteral feeding patients did not experience the rise in gut mucosal permeability that was observed in the control group. A RCT conducted by El Nakeeb et al. [6] revealed that early oral feeding was linked to a quicker passage time to flatus and feces in the early feeding group. Additionally, they discovered that the early feeding group's hospital stay was much shorter. Early feeding decreased the incidence of infections of all kinds, according to a comprehensive analysis that included 11 research [7].

Application of the postoperative enhanced recovery pathway (ERP) via goal-directed fluid therapy has been

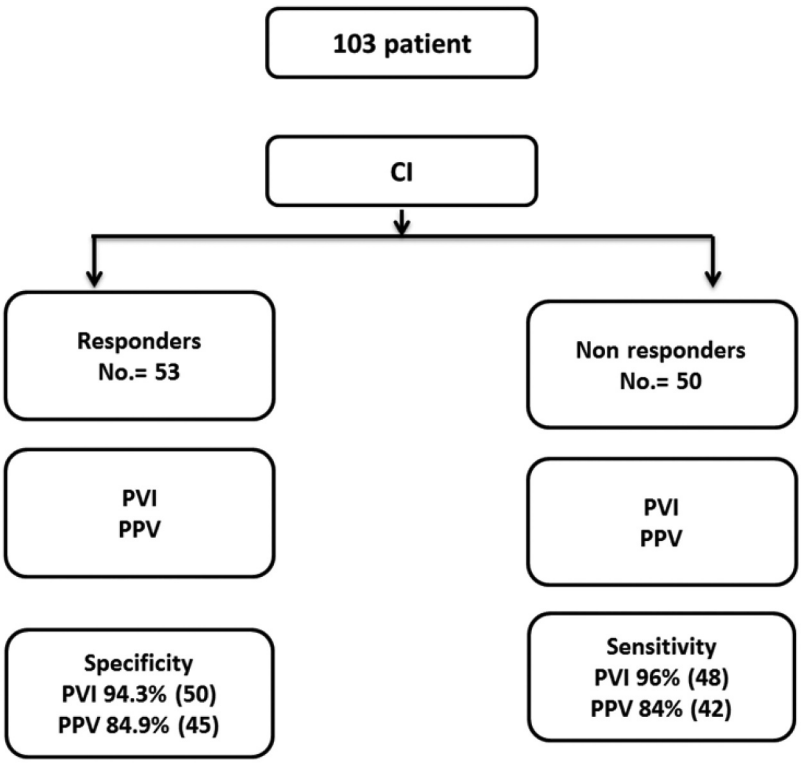

Table 1. Demographic data and APACHE II score.

		Non responders No. = 50	Responders No. = 53	Test value	P-value
Age (years)	Mean ± SD	47.28 ± 14.95	50.06 ± 15.96	−0.910•	0.365
	Range	19 – 90	20 – 83		
Sex	Female	23 (46.0%)	25 (47.2%)	0.014*	0.905
	Male	27 (54.0%)	28 (52.8%)		
Height (cm)	Mean ± SD	171.02 ± 8.40	170.60 ± 7.73	0.262•	0.794
	Range	151 – 188	152 – 188		
Weight (kg)	Mean ± SD	80.24 ± 9.24	81.21 ± 8.61	−0.550•	0.583
	Range	59 – 102	66 – 102		
BMI (kg/m^2)	Mean ± SD	27.52 ± 3.46	27.92 ± 2.63	−0.667•	0.507
	Range	21.16 – 37.28	24.15 – 37.53		
Body surface area (m^2)	Mean ± SD	1.92 ± 0.14	1.93 ± 0.13	−0.277•	0.783
	Range	1.66 – 2.24	1.65 – 2.25		
APACHE II	Mean ± SD	18.92 ± 0.85	19.00 ± 0.83	−0.482•	0.631
	Range	18–20	18–20		

• Chi Sqaure Test.

Table 2. Effect of fluid challenge on HR, MAP, lactate, CI, PVI & PPV in non-responders' group.

		Non responders			
		Before	After	Test value	P-value
HR (beat/min)	Mean ± SD	91.40 ± 6.31	90.44 ± 6.04	1.691•	0.097
	Range	81 – 105	80 – 104		
MAP (mmhg)	Mean ± SD	70.38 ± 5.28	73.56 ± 5.01	−4.340•	0.000**
	Range	60 – 79	63 – 82		
Lactate (mmol/L)	Mean ± SD	2.69 ± 0.52	2.63 ± 0.45	3.136•	0.003**
	Range	1.5 – 3.6	1.5 – 3.5		
CI (L/min/m^2)	Mean ± SD	3.20 ± 0.20	3.53 ± 0.20	−28.689•	0.000**
	Range	2.82 – 3.52	3.11 – 3.85		
PVI (%)	Mean ± SD	11.32 ± 1.93	7.98 ± 1.95	27.857•	0.000**
	Range	8 – 15	4 – 12		
PPV (%)	Mean ± SD	11.18 ± 2.27	9.70 ± 1.34	5.002•	0.000**
	Range	8–16	7–12		

• Chi Sqaure Test.

Table 3. Effect of fluid challenge on HR, MAP, lactate, CI, PVI & PPV in responders' group.

		Responders			
		Before	After	Test value	P-value
HR (beat/min)	Mean ± SD	95.19 ± 7.13	92.23 ± 6.70	18.337•	0.000**
	Range	80 – 112	78 – 106		
MAP (mmHg)	Mean ± SD	62.87 ± 5.15	68.70 ± 4.83	−28.989•	0.000**
	Range	54 – 74	59 – 78		
Lactate (mmol/L)	Mean ± SD	2.56 ± 0.46	2.43 ± 0.39	5.417•	0.000**
	Range	1.7–3.5	1.7–3.2		
CI (L/min/m^2)	Mean ± SD	2.78 ± 0.19	3.24 ± 0.25	−41.101•	0.000**
	Range	2.39–3.05	2.76–3.65		
PVI (%)	Mean ± SD	17.72 ± 2.37	11.06 ± 1.95	54.026•	0.000**
	Range	13–22	8–15		
PPV (%)	Mean ± SD	16.62 ± 2.70	10.74 ± 1.61	22.227•	0.000**
	Range	11–22	7–14		

• Chi Sqaure Test.

Table 4. Comparison between responders and non-responders regarding the difference in HR, MAP, lactate, CI, PVI &PPV after fluid challenge.

Difference	Non responders No. (50) Mean ± SD	Responders No. (53) Mean ± SD	Test value	P-value
HR)	−0.96 ± 4.02	−2.96 ± 1.18	3.477	0.001**
MAP(mmHg)	1.02 ± 3.05	5.83 ± 1.46	10.300	<0.001**
Lactate (mmol/L)	−0.05 ± 0.15	−0.13 ± 0.17	−2.527	0.013*
CI (L/min/m^2)	0.02 ± 0.11	0.46 ± 0.08	23.312	<0.001**
PVI (%)	−0.22 ± 1.49	−6.66 ± 0.90	−26.724	<0.001**
PPV (%)	−0.42 ± 1.83	−5.89 ± 1.93	−14.741	<0.001**

Independent t-test.

Table 5. The diagnostic power of the indices for diagnosis of fluid responsiveness.

Variables	Cut off point	AUC	Sensitivity	Specificity	+PV	-PV	P-value
PVI	≤14	0.990 (0.979 to 1.000)	96.00 (86.3–99.5)	94.34 (84.3–98.8)	94.1 (83.6–98.8)	96.2 (86.8–99.5)	**0.003**
PPV	≤13	0.930 (0.886–0.974)	84.00 (70.9–92.8)	84.91 (72.4–93.3)	84.0 (70.7–92.9)	84.9 (72.4–93.3)	

This table shows that PVI has better sensitivity and specificity than PPV in the responding group with a highly significant p-value.
() : values are stated with their confidence interval (C.I).
+ PV: (Positive predictive value).
-PV: (Negative predictive value).

linked to better results in colorectal procedures, according to multicenter observational studies.

The most sensitive methods to assess a patient's reaction to a fluid bolus are cardiac output and CI improvement [8]. The best and most accurate way to measure CO is with TTE, according to Desai and Garry [9].

As a result, we relied on the cardiac index as a reliable measure to identify preload response. Numerous studies have shown that it is effective whether or not the patient is mechanically ventilated, according to a comprehensive review and meta-analysis by Monnet et al. [10].

For rapid CO estimation in critically ill patients, non-invasive cardiac output monitoring might be applied [11]. In order to identify fluid responsiveness and prevent the negative effects of volume overload, dynamic approaches are more accurate and sensitive than static ones [4,12].

The best way to reduce the hazards to critically ill patients is to use a dynamic approach that is least invasive and can give a continuous means to detect fluid response [13]. PVI has several benefits since it is simple, noninvasive, and it measures changes in the amplitude of the pulse oximeter wave in mechanically ventilated patients between inspiration and expiration [14].

Numerous factors, such as vasoactive medications and hypothermia, which reduce peripheral perfusion, can influence the accuracy of PVI readings [10]. The PVI readings can also be influenced by the anatomical site; in individuals with perfusion issues, earlobe readings were shown to be more accurate than fingertip readings [15].

In order to distinguish between responders and nonresponders, this study used CI measured through TTE to compare PVI and PPV as predictors of fluid responsiveness following intravenous bolus of 500 ml crystalloid in 103 mechanically ventilated patients following major abdominal surgery.

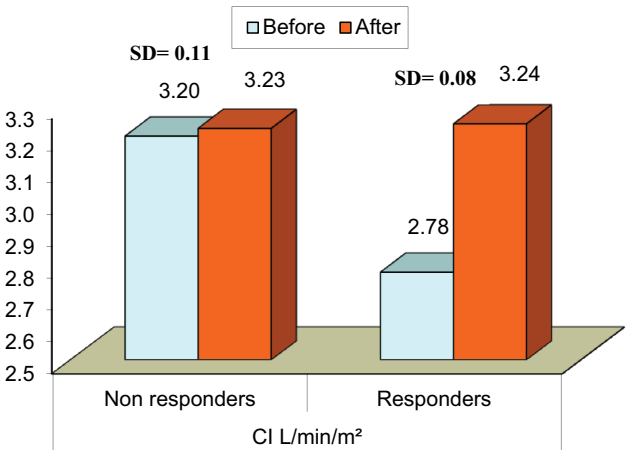

Figure 1. Cardiac index before and after fluid challenge in responders and non-responders.

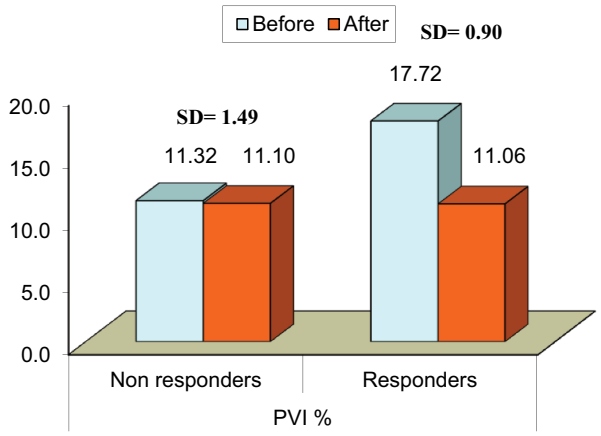

Figure 2. PVI before and after fluid challenge in responders and non- responders.

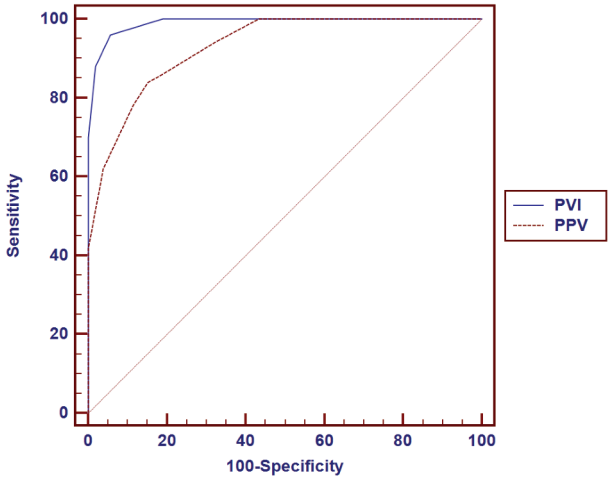

Figure 3. ROC curve comparing sensitivity and specificity between PVI and PPV before fluid administration in non-responding cases.

According to our research, PVI, a noninvasive method, has a greater sensitivity and specificity for predicting fluid responsiveness than PPV when used with an IV 500 ml crystalloid bolus in patients on mechanical ventilation in the surgical intensive care unit. In comparison to PPV, which had an 84% sensitivity and an 84.91% specificity with a threshold value of greater than 13%, PVI was shown to have a 96% sensitivity and 94.34% specificity.

Hoiseth et al. separately guided fluid management using TEE SV measures, in line with our work, although they concentrated on comparing PVI to PPV for predictive ability. An 86% sensitivity, p value < 0.001, and an AUC of 0.92% were obtained with a PVI threshold of 11.4%. This outcome demonstrated how well PVI could predict fluid responsiveness [16].

However, Liu et al., reported that PVI had better bedside dependability (79% sensitivity and 88% specificity) than PPV in ICU patients. In patients under anesthesia, it demonstrated minimal ability. Higher sensitivity of fluid responsiveness in the OR compared to the ICU was demonstrated by Chu et al.'s 2016 meta-analysis [17,18].

According to Desgranges et al.'s [19] systematic review and meta-analysis, digital PVI is a good indicator of fluid responsiveness in children on mechanical ventilation during surgery. However, compared to earlier reports in the adult surgical population, the diagnostic performance of digital PVI for differentiating between responders and non-responders to a fluid challenge was not as high [20].

Karadayi et al. found that while a number of research showed that PVI was sensitive, accurate, and had a high application value in predicting fluid responsiveness, their small sample sizes made them less convincing [21].

Regarding PPV, Cannesson et al., and colleagues showed that although PPV has a good predictive value, it may be imprecise and inconclusive in predicting fluid responsiveness in 25% of patients undergoing general anesthesia [22].

However, when Ji et al. evaluated PPV and PVI in pediatric children under 2 years old in the prone position, they found no discernible difference between the two groups before to or following the patients' change in position [23].

When PPV and PVI were compared during the intraoperative phase of low- to moderate-risk abdominal surgery, Coeckelenbergh et al. examined the impact on the duration of hospital stay and found no discernible differences between the two groups [24].

In critically ill septic patients, Karadayi et al. compared the pleth variability index and pulse pressure variation in the semi-recumbent and Trendelenburg positions. They found that there is a moderate correlation between the PPV and the PVI, and that this correlation is not affected by position [21].

When Do-hyeong Kim et al. compared PPV and PVI in the supine and prone positions, they found that both models could predict fluid responsiveness, and that there was no discernible difference in either model's predictive power between the two groups when the models were used in the prone position [25].

In conclusion, this study showed that PVI and PPV can be used in assessment of fluid responsiveness of the intubated ventilated sedated patients with sinus rhythm in ICU, and both methods can be performed at the bedside, but PVI has advantage of being continuous, operator independent, and more reliable than PPV.

The main limitation of our study is that using TTE as a cardiac output measuring technique may be affected with the obesity, patient position or intrathoracic pressure of the patient which may affect the result of our study. Also, further studies needed to detect the efficacy of PVI and PPV in OR.

6. Conclusion

Both PVI and PPV have the advantage of being continuous, easy to use, operator independent, and more dependable than PPV concerning evaluation of fluid responsiveness in intubated, ventilated, sedated patients in the intensive care unit. Both techniques can be performed as bedside dynamic predictors for fluid responsiveness.

List of abbreviations

ABG	Arterial blood gases
BMI	Body mass index
C.I	Cardiac index
C.O	Cardiac output
COPD	Chronic obstructive pulmonary disease
CVP	Central venous pressure
F.R	Fluid responsiveness
H.R	Heart rate
ICU	Intensive care unit
L.V.	Left ventricle
LVOT	Left ventricular outflow tract
MAP	Mean arterial blood pressure
NPO	Nothing by mouth/nil per os
PLR	Passive leg raising
PONV	Postoperative nausea and vomiting
PPV	Pulse pressure variation
PVI	Plethysmography variation index
RV	Right ventricle
SVV	Stroke volume variation
TTE	Trans thoracic echo

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

There was no specific funding from any funding facility.

Acceptance of participation and ethical clearance

The research ethical committee at the medical school at Ain Shams University gave its approval to this study. (FMASU MD 259a/2018/2019/2020/2021) with Pan African Clinical Trial Registry, identifier PACTR202309486066044

Availability of data and material

All the data are available upon reasonable request from the main author.

References

[1] Bastani A, Galens S, Rocchini A, et al. ED identification of patients with severe sepsis/septic shock decreases mortality in a community hospital. Am J Emerg Med. 2012;30(8):1561–6. doi: 10.1016/j.ajem.2011.09.029

[2] Miller TE, Roche AM, Mythen MG. Fluid management and goal-directed therapy as an adjunct to enhanced recovery after surgery (ERAS). Can J Anaesth. 2016;62 (2):158–168. doi: 10.1007/s12630-014-0266-y

[3] Sundaram SC, Salins SR, Kumar AN, et al. Intra-operative fluid management in adult neurosurgical patients undergoing intracranial tumour surgery: randomised control trial comparing pulse pressure variance (PPV) and central venous pressure (CVP). J Clin Diagn Res. 2016;10(5):1–5. doi: 10.7860/JCDR/2016/18377.7850

[4] Theerawit P, Morasert T, Sutherasan Y. Inferior vena cava diameter variation compared with pulse pressure variation as predictors of fluid responsiveness in patients with sepsis. J Crit Care. 2016;36:246–51. doi: 10.1016/j.jcrc.2016.07.023

[5] Koller SE, Bauer KW, Egleston BL, et al. Comparative effectiveness and risks of bowel preparation before elective colorectal surgery. Ann Surg. 2018;267 (4):734–42. doi: 10.1097/SLA.0000000000002159

[6] El Nakeeb A, Fikry A, El Metwally T, et al. Early oral feeding in patients undergoing elective colonic anastomosis. Int J Surg. 2009;7(3):206–9. doi: 10.1016/j.ijsu.2009.03.003

[7] Aga Z, Machina M, McCluskey SA. Greater intravenous fluid volumes are associated with prolonged recovery after colorectal surgery: a retrospective cohort study. Br J Anaesth. 2016;116(6):804–10. doi: 10.1093/bja/aew125

[8] Pierrakos C, Velissaris D, Scolletta S, et al. Can changes in arterial pressure be used to detect changes in cardiac index during fluid challenge in patients with septic shock? Intensive care Med. 2012;38(3):422–428. doi: 10.1007/s00134-011-2457-0

[9] Desai N, Garry D. Assessing dynamic fluid-responsiveness using trans-thoracic echocardiography in intensive care. Bja Education; 2018.

[10] Monnet X, Marik P, Teboul JL. Passive leg raising for predicting fluid responsiveness: a systematic review and meta-analysis. Intensive care Med. 2016;42 (12):1935–1947. doi: 10.1007/s00134-015-4134-1

[11] Jalil BA, Cavallazzi R. Predicting fluid responsiveness: a review of literature and a guide for the clinician. Am J Emerg Med. 2018;36(11):2093–102. doi: 10.1016/j.ajem.2018.08.037

[12] Sakr Y, Birri PN, Kotfis K, et al. Higher fluid balance increases the risk of death from sepsis: results from a large international audit. Crit Care Med. 2017;45 (3):386–94. doi: 10.1097/CCM.0000000000002189

[13] Scheer BV, Perel A, Pfeiffer UJ. Clinical review: complications and risk factors of peripheral arterial catheters used for haemodynamic monitoring in anaesthesia and intensive care medicine. Crit Care. 2002;6(3):199. doi: 10.1186/cc1489

[14] Schoonjans A, Forget P, Labriola L, et al. Pleth variability index combined with passive leg raising-induced pulse pressure variation to detect hypovolemia in spontaneously breathing patients. Acta Anaesthesiologica Belgica. 2010;61(3):147–150.

[15] Desgranges FP, Desebbe O, Ghazouani A, et al. Influence of the site of measurement on the ability of plethysmographic variability index to predict fluid responsiveness. Br J Anaesth. 2011;107(3):329–35. doi: 10.1093/bja/aer165

[16] Høiseth LØ, Hoff IE, Myre K, et al. Dynamic variables of fluid responsiveness during pneumoperitoneum and laparoscopic surgery. Acta Anaesthesiol Scand. 2012;56 (6):777–786. doi: 10.1111/j.1399-6576.2011.02641.x

[17] Chu H, Wang Y, Sun Y, et al. Accuracy of pleth variability index to predict fluid responsiveness in mechanically ventilated patients: a systematic review and meta-analysis. J Clin Monit Comput. 2016;30 (3):265–274. doi: 10.1007/s10877-015-9742-3

[18] Liu T, Xu C, Wang M, et al. Reliability of pleth variability index in predicting preload responsiveness of mechanically ventilated patients under various conditions: a systematic review and meta-analysis. BMC Anesthesiol. 2019;19(1):1–7. doi: 10.1186/s12871-019-0744-4

[19] Desgranges FP, Bouvet L, Pereira de Souza Neto, et al. Non-invasive measurement of digital plethysmographic variability index to predict fluid responsiveness in mechanically ventilated children: a systematic review and meta-analysis of diagnostic test accuracy studies. Anaesth Crit Care Pain Med. 2023;42 (3):101194. doi: 10.1016/j.accpm.2023.101194

[20] Myles PS, Andrews S, Nicholson J, et al. Contemporary approaches to perioperative IV fluid therapy. World J Surg. 2017;41(10):2457–2463. doi: 10.1007/s00268-017-4055-y

[21] Karadayı S, Karamanlıoglu B, Memı D, et al. Comparing pulse pressure variation and pleth variability index in the semi-recumbent and trendelenburg position in critically ill septic patients. Signa Vitae. 2017;13(2):91–96.

[22] Cannesson M, Gan TJ. PRO: perioperative goal-directed fluid therapy is an essential element of an enhanced recovery protocol. Anesthesia &

Analgesia. 2016;122(5):1258–60. doi: 10.1213/ANE.0000000000001144

[23] Ji SH, Song IK, Jang YE, et al. Comparison of pulse pressure variation and pleth variability index in the prone position in pediatric patients under 2 years old. Korean J Anesthesiol. 2019;72(5):466–471. doi: 10.4097/kja.19128

[24] Coeckelenbergh S, Delaporte A, Ghoundiwal D, et al. Pleth variability index versus pulse pressure variation for intraoperative goal-directed fluid therapy in patients undergoing low-to-moderate risk abdominal surgery: a randomized controlled trial. BMC Anesthesiol. 2019 Dec;19(1):1–7. doi: 10.1186/s12871-019-0707-9

[25] Kim DH, Shin S, Kim JY, et al. Pulse pressure variation and pleth variability index as predictors of fluid responsiveness in patients undergoing spinal surgery in the prone position. TCRM. 2018;Volume 14:1175–1183. doi: 10.2147/TCRM.S170395