Science Letters ISSN 2345-5463 – An International Triannually Journal

THE SCIENCE PUBLISHERS

Research Article
2018 | Volume 6 | Issue 1 | Pages 28-33

ARTICLE INFO

Received
January 19, 2018
Accepted
April 01, 2018
Published
April 25, 2018

***Corresponding Author**
Zi Jun Liu
E-mail
liuzijundoctor@sina.com

Keywords
Electrolyte balance
Fluid balance
Pleth variability index (PVI)
Perfusion index (PI)

How to Cite
Manandhar S, Liu ZJ. Pleth variability index: an insight into its benefits and limitations as a predictor of fluid responsiveness. Sci Lett 2018; 6(1):28-33

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Pleth Variability Index: An Insight into Its Benefits and Limitations as a Predictor of Fluid Responsiveness

Suhreet Manandhar, Zi Jun Liu*

Department of General Surgery, Nanjing First Hospital Affiliated to Nanjing Medical University, Chang Le Road, 68-Nanjing, Jiangsu, China

Abstract

An important step in the management of surgical and critically ill patients is fluid and electrolyte balance as hypovolemia, hypervolemia and electrolyte imbalance can cause poor patient outcomes. The ability to distinguish between fluid responders and non-responders help us to avoid complications of fluid imbalance. Dynamic measures have been considered reliable than static measures to predict the fluid response. However, most dynamic measures are invasive with associated complications. The recent studies have reported that respiratory variations in plethysmographic waveform amplitude (ΔPOP) are strongly linked with pulse pressure variation and hence can be used in predicting fluid response. This has led to pleth variability index (PVI), a dynamic measure developed by Masimo Corporation, which is closely related to ΔPOP and can noninvasively measure the dynamic variations of perfusion index (PI). It has benefited clinicians in distinguishing fluid responders from non-responders in surgical and critically ill patients under mechanical ventilation. Numerous studies have reported PVI as a dependable predictor of fluid responsiveness on par with pulse pressure variation (PPV) and stroke volume variation (SVV). PVI also provides the added benefits of predicting hypotension, especially in patients during anesthesia and also in selecting appropriate positive end expiratory pressure (PEEP) in patients under ventilator support, thus, helping to improve patient clinical outcomes. However, PVI has been reported to be erratic in predicting fluid response in spontaneously breathing patients, patients undergoing laparoscopic and cardiac surgery, and patients with low perfusion index, low tidal volume (<8 ml/kg) and cardiac arrhythmias.

Introduction

Fluid and electrolyte balance is fundamental in managing patients, especially critically ill and surgical patients in maintaining homeostasis. Hypovolemia is associated with impaired tissue perfusion, low cardiac output while fluid overload results in pulmonary oedema, interstitial oedema and other complications. They both may cause worsening of organ dysfunction, resulting in increase in hospital stay duration and affecting the patient's outcome, thus, resulting in high mortality and morbidity [1, 2]. Hence, fluid balance is central in managing patients. One of the key components in fluid resuscitation is the accurate evaluation of cardiac preload. According to the principle of Frank –Starling of the heart, preload is directly related to stroke volume as with increase in preload will result in increase in left ventricular stroke volume until an optimal preload is achieved following which stroke volume remains constant. Hence, there is no point of volume loading in patients once an optimal preload is achieved [2, 3]. Thus, predicting fluid responsiveness is necessary for maintaining fluid balance and preventing unnecessary volume loading.

In clinical practice, static and dynamic indices are used to predict the fluid responsiveness [3]. One of the most commonly used static indices, central venous pressure (CVP) monitoring is an indirect estimate of preload as it only gives a good estimation of pressure of the right atrium and hence, is a relatively poor predictor of fluid response. This was confirmed by a study done by Marik et al. that central venous pressure did not correlate with preload and hence unreliable for guiding fluid therapy [3]. Dynamic indices (pulse pressure variation (PPV), stroke volume variation (SVV) etc.) are considered to be more dependable parameters than static indices in predicting fluid response as they can accurately measure the stroke volume changes in relation to increase or decrease of preload [3, 4]. Pulse pressure variation, the most often used dynamic indices, is considered the best tool in predicting fluid responsiveness [4]. But, these indices are invasive, challenging with associated complications and requires every patient to be in an intensive care unit (ICU).

Recent advances have led to studies focusing on the variations of pulse oximeter plethysmographic waveform amplitude (ΔPOP) during respiration as it is in close relation with pulse pressure variation and could detect changes (increase or decrease) of ventricular preload. Therefore, ΔPOP is considered to be reliable in predicting fluid response [5]. Despite being non-invasive, ΔPOP monitoring was difficult to calculate and could not be extracted from the commonly used pulse oximeter requiring specialized tool and software. Thus, Masimo Corporation developed pleth variability index (PVI) which is visually co-related to ΔPOP, easy to calculate and can continuously calculate variations in the photoplethysmogram during respiration via a pulse oximetry sensor. In this article, we reviewed the benefits and limitations of the PVI as a predictor of fluid responsiveness.

Pleth variability index (PVI)

PVI is derived from the variation in the peripheral perfusion index (PI) during respiration and is an estimate of the dynamic variations of the perfusion index which occur during the respiratory cycle [6]. Perfusion index reflects the amplitude of the pulse oximeter waveform and is described as the amount of light absorbed as a result of arterial pulsation (AC: pulsatile infrared signal) relative to the total amount of light absorbed (DC: non-pulsatile infrared signal), so perfusion index is defined as AC/DC × 100% [6, 7].

PVI is defined as PI_{max} - PI_{min} / PI_{min} × 100%, which are the dynamic variations in perfusion index throughout the respiratory cycle. PVI is displayed as a percentage from 1 to 100%; hence, higher the PVI, more likelihood of patient responding to the fluid therapy [7]. PVI is affected by light so, for PVI calculation, certain measures should be taken to avoid outside light from interfering with the result. PVI being noninvasive, allows continuous monitoring, and has provided clinicians with a different approach to patient's fluid management.

Benefits of pleth variability index

Predicting fluid responsiveness

The recent studies have reported goal directed fluid administration being beneficial for both the patients and the clinicians in reducing the duration of critical care admission and stay, duration of ventilatory support and length of hospital stay, in addition to reducing complications and mortality, especially in critically ill and undergoing surgery patients [8, 9]. Like other dynamic indices, PVI can also predict fluid responsiveness in these groups of patients with the added advantage of being noninvasive.

In surgical patients

Cannesson et al. first time reported the relationship between PVI and ΔPOP and also reported changes of PVI in relation to changes in body position (supine, Tredenlenberg anti-Tredenlenberg) [10]. This research provided the fulcrum for studying the benefits of PVI in clinical practice. Hence, Cannesson et al. again studied the fluid response predicting ability of PVI in twenty five patients undergoing surgery. In their study, PVI of higher than 14% prior to volume loading distinguished fluid responders from the non-responders (sensitivity 81%; specificity of 100%) and thus, reported the fluid predicting capability of PVI [11]. Since then, numerous studies have highlighted PVI's potential in reliably predicting fluid responsiveness in surgical and critically ill patients. Zimmerman et al. in their study of 20 patients undergoing surgery (abdominal surgery) reported PVI [PVI value of 9.5%, area under curve (AUC) 0.973] and stroke volume variation (SVV) [threshold value of 11.1%, area under curve (AUC) 0.993] a reliable predictor of fluid responsiveness and was superior to CVP (area under curve (AUC): 0.553) [12]. Another study involving twenty-nine patients undergoing non cardiac surgery by Siswojo et al. concluded PVI (sensitivity 88% and specificity 67%) reliable in distinguishing fluid responders from non-responders in mechanically ventilated patients in normal sinus rhythm undergoing non cardiac surgery with a threshold PVI value at 10.5% (area under curve (AUC) 0.84, 95% confidence interval (CI) 0.69-0.99) [13].

Table 1 Pleth variability index (PVI) studies with their threshold optimal values.

PVI threshold optimal value (%)	Reference
>14	Cannesson et al. [11]
>9.5	Zimmermann et al. [12]
>13	Forget et al. [16]
>10	Hood et al. [8]
>13	Abdullah et al. [1]
>17	Loupec et al. [21]
>14	Broch et al. [42]
>13	Renner et al. [32] *
>16	Haas et al. [14]
>10.5	Siswojo et al. [13]
>13	Yu et al. [17]

*Pediatrics

A study done by Haas et al. involving eighteen patients who were undergoing cardiac surgery concluded that PVI (PVI value higher than 16%, sensitivity 100%, specificity 88.9%) was accurate as stroke volume variation (SVV) [threshold SVV value greater than or equal to 11.1%, sensitivity 100%, specificity 72.2%] [14]. Another study involving patients undergoing colorectal surgery conducted by Hood and Wilson also concluded PVI reliable in estimating fluid response during surgery [area under curve (AUC) 0.96; 95% CI 0.88-1.00, *P* = 0.011 at steady state and area under curve (AUC) 0.71, 95% CI 0.57–0.85, *P* = 0.006 during intraoperative conditions] [15].

PVI based goal fluid therapy helps to reduce the total amount of fluid administered intraoperatively and to reduce the lactate level postoperatively [16, 17]. Forget et al. in their study involving 82 patients compared goal directed fluid therapy based on PVI with the standard care. They concluded that the PVI group had reduced infusion of intraoperative fluids with reduced lactate levels, thus improving the patient outcome [16]. Their results were similar to a previous study done by Lopes et al. where the goal directed fluid administration was based on pulse pressure variation (PPV) [18]. Hence, all these studies clearly showed the reliability of fluid prediction of PVI in surgical patients (abdominal surgery, cardiac surgery, rectal surgery etc.) [19, 20].

In critically ill patients under ventilator support

PVI is beneficial in predicting fluid response in critically ill patients under ventilator support similar to surgical patients. Loupec et al. in a study involving 40 patients with circulatory insufficiency under ventilator support concluded that PVI at a threshold value of 17% could discriminate fluid responders from the non-responders (sensitivity of 95%, 95% CI 74-100%, specificity of 91%, 95% CI 70 to 99%) [21]. A meta-analysis by Chu et al. also reported that PVI was reliable in predicting fluid response in patients under ventilator support who had normal sinus rhythm [22]. In critically ill patients under ventilator support, positive end expiratory pressure (PEEP) level should be ideal to improve ventilation and maintain pulmonary compliance so as to attain an ideal tidal volume to minimize the risk of lung injury due to ventilator [23]. A study done by Desebbe et al. concluded that PVI was useful in monitoring the hemodynamic effects of PEEP when the tidal volume (VT) was greater than 8 ml per kilogram in patients under ventilator support following cardiac surgery [23]. Similarly, another study by Zhou and Han involving 22 patients under mechanical ventilation determined that PVI and respiratory system compliance (RSC) were useful in predicting the hemodynamic effects of PEEP, thus, reducing complications to improve patient outcomes [24]. All these studies suggest PVI benefits clinicians in selecting appropriate PEEP noninvasively for better patient outcome [25].

Predicting hypotension in patients during anesthesia

Hypotension is a life threatening complication and can cause severe organ damage. Hypotension is common during anesthesia induction and spinal anesthesia [26]. PVI is able to foresee the patients at risk prevent complications and improve outcomes [27, 28]. Tsuchiya et al. conducted a study involving 76 patients and concluded that PVI was capable to predict hypotension during induction of anesthesia [29]. Another study involving fifty patients undergoing cesarean delivery under spinal anesthesia done by Kuwata et al. came to a conclusion of PVI being a fine predictor of spinal anesthesia induced hypotension (PVI threshold value 18%, sensitivity 78.1%, specificity 83.3%) [30]. These studies suggest PVI may be able to predict hypotension in patients during anesthesia. Although the optimal PVI values for different studies have been different (Table 1), the ultimate conclusion of these studies is that PVI is a reliable in distinguishing fluid responders from non-responders in patients undergoing surgery and critically unstable patients under ventilator support. PVI has also been useful in pediatric patients (neonates, infants) and has also found to be beneficial in predicting fluid responsiveness in these patient groups [31-33].

Limitations of pleth variability index

Researchers still have doubts about the fluid predicting ability of PVI. A study by Brandon et al. involving 47 postoperative patients following cardiac surgery with pulmonary artery catheter reported PVI [area under curve (AUC) 0.63, P = 0.16] being unreliable in predicting fluid response (measured by pulmonary artery catheter thermodilution) between intubated patients and spontaneously breathing patients [area under curve (AUC) 0.41, P = 0.75] [34]. Another study by Kayhan et al. concluded PVI as a weak indicator than SVV in predicting fluid responsiveness in 25 patients undergoing orthotopic liver transplantation. In this study, area under curve (AUC) for PVI at dissection phase was 0.56 (sensitivity 35% specificity 90%, P=0.58) and at anhepatic phase was 0.55 (sensitivity 55%, specificity 60%, P = 0.58) [35]. In patients undergoing laparoscopic surgery, PVI is not recommended as it was found to be erratic in predicting fluid response [36].

Further, PVI is considered to be unreliable in predicting fluid response in patients receiving vasoactive drugs [37, 38]. A study done by Monnet et al. involving 42 critically ill patients receiving norepinephrine compared PVI to PPV in predicting fluid response and concluded that PVI [threshold value higher than or equal to 16%, sensitivity 47%, specificity 90%, area under curve (AUC) 0.68 (0.06)] was less reliable than PPV [area under curve (AUC) 0.93 (0.06)] and stroke volume variation (SVV) [Area under curve (AUC) 0.89 (0.07)] [39]. Similarly, this study also stated PVI unreliable in spontaneously breathing patients, patients with low tidal volume and patients with cardiac arrhythmia.

PVI is directly related to perfusion index and perfusion index is correlated to the vasomotor tone and cardiopulmonary interactions under stable clinical conditions. However, in spontaneously breathing patients, these are no longer consistent and hence, PVI will poorly predict fluid responsiveness. Only limited studies involving spontaneously breathing patients are available. A study involving 25 spontaneously breathing patients done by Keller et al. reported PVI unreliable in predicting fluid response (threshold PVI value 19%, area under curve (AUC) 0.734, sensitivity 82%, specificity 57%) [14]. Also, a low perfusion index value affects the PVI making it unreliable. Similarly, in patients with low ejection fraction (EF < 40%) and cardiac arrhythmia, the vasomotor tone and cardiopulmonary interactions are inconsistent. Also, the impaired right ventricular function is seen in patients with low ejection fraction. Hence, PVI is not reliable in predicting fluid response in these groups of patients [40]. In short, PVI is unreliable in patients undergoing open cardiac surgery, laparoscopic surgery, spontaneously breathing patients, patient with low ejection fraction, cardiac arrhythmia, low tidal volume and low ejection fraction.

Conclusions

Pleth variability index is a valuable tool for clinicians as it provides noninvasive, continuous monitoring for predicting the fluid response in surgical patients and critically ill patients under ventilator support, however, PVI still has certain restrictions and further studies is warranted.

Conflict of Interest

The authors have no conflict of interest.

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