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Review

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The Utility of Echocardiography in Estimating Fluid Responsiveness

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Abstract

Assessing the volume status in critically ill patients is the key to maintain the stability of the hemodynamics; however, it can be challenging to view the complexity of cases and the diversity of shock etiology. Multiple noninvasive means have been used to study the effectiveness of volume resuscitation, but none of them have been used as gold standard. We aim to illustrate the most used techniques: left ventricular outflow tract velocity time integral versus inferior vena cava compressibility index, and highlight their limitations and strengths. These tools are both operator-dependent and might be affected by several factors including ventilator settings.

Keywords: Fluid responsiveness; Echocardiography; Stroke volume; Cardiac output; Inferior vena cava; Left ventricular outflow tract

Introduction

Establishing hemodynamic stability in critically ill patients optimizes their clinical outcome. Intravenous fluid therapy is a common treatment modality in critical care medicine and is essential in maintaining hemodynamic stability [1]. However, in the critical care setting, the etiology of hemodynamic instability is often multifactorial. Critically ill patients require accurate monitoring and estimation as to when fluid therapy is warranted. This is often difficult as clinical parameters such as blood pressure, urine output and heart rate may not detect early signs of hypovolemia [2]. Furthermore, fluid therapy in a patient that is not fluid responsive has shown to increase morbidity and mortality [3]. Fluid responsiveness is classically defined as an increase in stroke volume (SV) by greater than 10% after rapid volume infusion as well as a change in cardiac output (CO) [4, 5].

Body

Standard of care in determining fluid responsiveness in patients

Traditionally, central venous pressure (CVP) monitoring and mean arterial pressure (MAP) were used to assess when invasive fluid therapy was indicated in critically ill patients. However, multiple studies have shown that they are not accurate in predicting fluid responsiveness among these patients [6]. Marik et al conducted a meta-analysis which enforced that CVP should not be used to guide fluid therapy. Methods like pulse-pressure change by radial arterial line, fluid challenge, left ventricular outflow tract (LVOT) velocity time integral (VTI) on echocardiogram, carotid doppler flow on transesophageal echocardiogram (TEE), inferior vena cava (IVC) collapsibility index (IVCCI) have been proposed as alternate modes of determining fluid management [7]. Additionally, a prospective observational study suggested that the right subclavian vein variation during a respiratory cycle matches up with IVCCI and can be used to speculate fluid responsiveness [8].

Noninvasive cardiac imaging and most common techniques

Several techniques for assessing fluid responsiveness and CO have been validated. Although it is beyond the scope of this paper, we would like to list some of these described tools.

CVP or right atrial pressure is used to be considered one of the parameters that we used to judge whether fluids should be administered or not. A large number of studies have shown that the positive predictive value of CVP for fluid responsiveness is low [9]. Similar findings were reported in regards of using pulmonary artery occlusion pressure (PAOP) as an accurate predictor of preload even in healthy subjects. Like CVP, PAOP should not be used to decide on fluid administration [9]. Passive leg raise (PLR) has been used as a trial of reversible fluid challenge. It is applicable in spontaneous breathing, low tidal volumes (TVs), and is not affected by

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irregular cardiac rhythms. The test starts in semi recumbent position, then the head is lowered, and the legs are raised. The effect is expected in 1 to 5 min. Several studies, even in ventilated patients, have shown that PLR successfully predicts a response to volume administration. However, this technique might be limited in increased intra-abdominal pressure, musculoskeletal problems and may require a special hospital bed [10]. Pulse pressure variation (PPV) is also another famous technique, reported in one of the most influential studies to be effective in predicting fluid responsiveness. However, its use is limited in ventilated patients with TV < 8 mL/kg, irregular rhythm, right ventricular dysfunction or those who are spontaneously breathing [11].

Echocardiography has become the most common method of estimating fluid responsiveness in the intensive care unit by monitoring CO [12]. The LVOT VTI has been the most studied technique [13]. McGregor et al conducted a study with LVOT VTI as the standard and compared the technique to other methods of noninvasive CO monitoring which include common carotid artery blood flow monitoring and plethysmography using the vascular unloading technique. Although IVCCI does not estimate CO, this method was also included in the analysis [13]. This analysis showed variability in the ability of noninvasive cardiac imaging evaluating SV and CO when compared with LVOT VTI in estimating fluid responsiveness [13].

LVOT effectiveness

Left ventricular systolic function is monitored using LVOT. An increase in LVOT VTI can be extrapolated to an increase in SV which subsequently means an increase in CO [14]. Using the echocardiogram, the VTI is measured before and after fluid challenge or a PLR which is equivalent to 250 - 500 mL fluid bolus. A greater than 10% change in VTI after the fluid challenge is an indicator of fluid responsiveness. Wang et al looked at the effect of LVOT VTI variation rate in assessing fluid responsiveness in ventilated patients with septic shock. They utilized the variation in hemodynamic parameters like SV, cardiac index, and pulse pressure after volume expansion test, comparing it to the LVOT VTI variation. They found that there was a positive relation between the change in these parameters and the LVOT VTI after the volume expansion test. LVOT VTI was found to have extremely high sensitivity and specificity in predicting fluid responsiveness. However, this study only included sedated and ventilated septic patients [3].

Similarly, Asta et al performed a study looking at LVOT VTI in spontaneous breathing patients after major abdominal surgery and found that LVOT VTI variation of more than 10% during the respiratory cycle correlated with fluid responsiveness. There are limitations when using dynamic parameters in spontaneous breathing patients such as TV, variation in intrathoracic pressure as well as abdominal wall contraction [15]. However, these limitations did not pose any significant difference. In this study, the variation in abdominal wall contraction was limited as these patients were in the early postoperative period [15].

Blancas et al did not find a definite association between LVOT VTI and SV. They suggest the use of this method in correlation with other tools of hemodynamic monitoring [16]. Another study that looked at LVOT VTI using TEE, found a weak correlation between using LVOT VTI measured by TEE and SV index calculated using a pulmonary artery catheterization. This study was only done in patients undergoing cardiac surgery [17]. Factors that influence the accuracy of LVOT VTI are usually in cases with LVOT obstruction [16]. Low preload states as well as dynamic obstruction can influence these readings. It is also important to note that it does not consider right ventricular dysfunction [3].

IVC diameter

The IVC diameter dilates during inspiration and contracts during expiration. The IVC distensibility index takes into account the percentage variation of the IVC during the respiratory cycle [18]. Orso et al conducted a meta-analysis on the accuracy of using variation in IVC diameter as a predictor of fluid responsiveness [18]. Multiple studies varied in analyzing the possible correlation between the IVC and fluid responsiveness [19, 20]. Some studies were able to show that the IVCCI was a strong predictor of fluid responsiveness and other studies were not [19, 21]. However, these variations were seen across different patient populations. There was variation in the accuracy of the IVCCI in patients examined in the emergency department and the operating rooms versus in the intensive care unit [18].

Orso et al conducted a meta-analysis and found that in septic patients the distensibility index was more reliable in predicting fluid responsiveness as compared to surgical patients given the component of increased abdominal pressure affecting the reliability of the IVCCI [18].

Multiple studies looked at the flatness of IVC on computed tomography (CT) scan and compared it to lactate level and predictability of shock. Some studies found a relationship between flat IVC and indication for massive transfusion [22], while others did not show any correlation with IVC flatness and fluid responsiveness. However, CT scans are static and ultrasound technique is dynamic which allows better assessment of the variation [23].

During passive ventilation, the IVC diameter increases during inspiration as the pressure in the right atria increases and decreases during expiration. In mechanically ventilated patients, IVCCI has been shown to be an accurate measure of fluid responsiveness [15, 24, 25] and both inspiratory and expiratory IVC correlated significantly with CVP [24]. However, Si et al found that it was an accurate measure of fluid responsiveness in ventilated patients when the TV was ≥ 8 mL/kg and positive end expiratory pressure (PEEP) was ≤ 5 cm water (cm H_2O). When these parameters were not accounted for, they found that the IVCCI was a poor predictor of fluid responsiveness [26]. Similarly, He et al demonstrated that IVC distensibility index is affected by TV and is most accurate at TV of 9 mL/kg [27]. On the other hand, an observational study on 79 critically ill patients who were on mechanical ventilation showed that LVOT VTI variations can be taken into account when predicting fluid responsiveness at PEEP level ranging between 0 and 10 cm H_2O [28].

Given the variation with spontaneous breathing, there has been heterogeneity in the studies involving this patient population. In spontaneous breathing patients, the variation in the IVCCI greater than 40% has been shown to be a strong indicator for fluid responsiveness [15]. However, a variability of less than 40% does not strongly indicate that a patient would not be considered fluid responsive and leaves room for clinical assessment [29]. Some studies have shown fluid responsiveness with IVC variability of > 27% and even as low as 20% variation. In other words, fluid responsiveness should not be excluded in cases with small variation in IVC [15].

Limitations

Noninvasive cardiac imaging has limitations in the sense that it is mostly dependent on the sonographic skill, and the breathing motion can affect the ability to obtain accurate visualization of the LVOT VTI as well as the IVC. The use of LVOT VTI is limited in patients with aortic regurgitation, dilated left ventricle, and atrial fibrillation. Thus, the use of noninvasive cardiac imaging and the interpretation of the results in patients with structural heart disease should be done cautiously.

Another limitation of the LVOT VTI would be chest wall abnormalities which is commonly seen in our practice. Concave shaped chest wall, or anterior chest wall deformity such as pectus excavatum can affect echocardiographic measurements such as SV. Therefore, LVOT VTI should be put in relation to body surface area and chest wall confirmation [30].

LVOT VTI seems to be less affected by mechanical ventilation parameters (TV and PEEP) as compared to IVCCI which seems to be more reliable in cases of structural heart disease. IVCCI technique has more limitations when it comes to mechanical ventilation, respiratory cycle, and abdominal wall surgeries.

Lastly, these methods are of importance in evaluating volume status in hypovolemic or septic state. Whereas in cardiogenic, anaphylactic, mixed or undifferentiated shock, these modalities are not effective in estimating volume status.

Conclusion

In this review, we described the effectiveness and limitations of LVOT VTI and IVCCI in predicting fluid responsiveness. The use LVOT VTI appears to be a superior technique in estimating fluid responsiveness especially when it comes to intubated patients as compared to IVCCI which showed more variations. In conclusion, the use of the noninvasive cardiac imaging techniques in conjunction with other tools of hemodynamic monitoring and clinical judgment are recommended to improve the accuracy of fluid responsiveness estimation.

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Conflict of Interest

The authors declare that there is no conflict of interest.

Author Contributions

All authors have participated in writing this manuscript. Doctor El Hage and Doctor Assaad are responsible for concept and editing. Doctor Assaad is responsible for supervision and writing. Doctor Asogwa, Ling and Wahbah Makhoul did the literature review and the writing.

Data Availability

The authors declare that data supporting the findings of this study are available within the article.

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