Assessing volume status and fluid responsiveness in the emergency department

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Resuscitation with intravenous fluid can restore intravascular volume and improve stroke volume. However, in unstable patients, approximately 50% of fluid boluses fail to improve cardiac output as intended. Increasing evidence suggests that excess fluid may worsen patient outcomes. Clinical examination and vital signs are unreliable predictors of the response to a fluid challenge. We review the importance of fluid management in the critically ill, methods of evaluating volume status, and tools to predict fluid responsiveness.

Keywords Hemodynamics; Ultrasonography; Shock

Capsule Summary

What is already known
There is increasing evidence that we can tailor the way we use fluids and pressors to optimize cardiac output in a smart way using a variety of tools and techniques.

What is new in the current study
This article will review the various methods and tools for measuring fluid status and predicting the response of the cardiovascular system to a fluid challenge.

INTRODUCTION

Evaluation and management of intravascular volume are a central challenge in caring for the critically ill. Patients with hypotension are commonly resuscitated with intravenous crystalloid fluid, in keeping with recommendations for treatment of many shock states.[1] The therapeutic goal of fluid administration is to increase preload, or the stressed venous volume, leading to an increased stroke volume and cardiac output. However, studies of patients with acute illness or hypotensive patients in the operating room consistently demonstrate that approximately 50% of fluid boluses fail to achieve the intended effect of increasing cardiac output.[2,3] Moreover, there is increasing data to demonstrate that excess fluid administration may be harmful, and is associated with increased mortality.[4,5] Large volume resuscitation promotes endothelial injury, fluid extravasation, and tissue edema. In turn, increasing interstitial fluid and extravascular lung water are associated with progressive organ dysfunction and death.

Giving fluid is a familiar response to hypotension or tachycardia, and the alternatives to crystalloid resuscitation, such as initiating vasopressors, colloids, or blood product transfusion, have attendant risks and resource utilization. The tensions between giving intravenous fluid and using a resource-intensive alternative increase the challenge of using fluid judiciously, and highlight the importance of accurate techniques to predict a patient's response to fluid administration.

THE IMPORTANCE OF VOLUME STATUS AND FLUID MANAGEMENT

Clinicians have traditionally relied on physical examination and physiologic variables such as blood pressure and heart rate to decide whether to provide fluid therapy, but clinical examination alone has consistently proven unreliable in guiding the decision to give intravenous fluid. Over the past two decades, investigators have sought improved techniques and tools to identify which unstable patients are volume-responsive and will respond to intravenous fluid with an increase in cardiac output. Here, we review why careful use of intravenous fluid is important to improving patient outcomes; the methods used to assess volume responsiveness; and the evidence supporting their use and limitations, with particular emphasis on those relevant to emergency physicians.

The Frank-Starling relationship (Fig. 1) illustrates the effect of changes in cardiac preload on stroke volume and cardiac output. Patients whose preload exists on the slope of the curve are said to have preload reserve or dependence and are volume or fluid responsive. In these patients, increasing the stressed venous volume with intravenous fluid will increase venous return, improve overlap of cardiac myofibrils, and augment stroke volume. The Frank-Starling curve may be shifted left or right with changes in ventricular contractility. Most healthy individuals have preload reserve and will be fluid responders. Patients with acute illness or underlying cardiovascular disease may function on the plateau of the curve. Administering more fluid will not improve cardiac out-

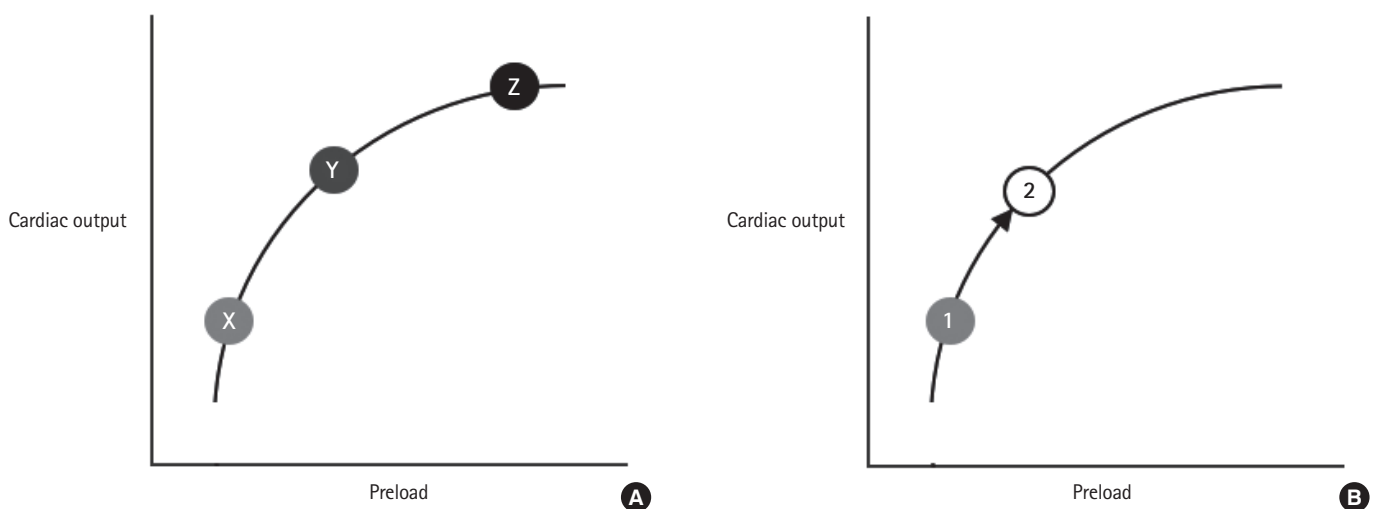**Fig. 1.** (A) Frank-Starling curve. Static measures of preload reflect an individual's cardiac output at a given time point, but cannot inform the clinician if the patient has preload reserve (points X and Y) or is preload independent (Z). (B) Tests of fluid responsiveness should challenge an individual's Frank-Starling relationship, and assess potential to advance along the curve (from 1 to 2).

put and exposes the patient to the harms of unnecessary fluid. Thus, a clinician trying to predict volume responsiveness is trying to determine a patient's position on the Frank-Starling curve.

The importance of adequate but not excessive fluid loading is increasingly recognized. Large volume fluid resuscitation may contribute to endothelial injury and lead to interstitial edema and organ dysfunction. Multiple studies have demonstrated the association between progressively positive fluid balance, increased extravascular lung water, and increased mortality.[5-8] In adults with sepsis, Boyd et al.[9] showed greater positive fluid balance and higher central venous pressures (CVPs) at 12 hours and 4 days were predictive of death. Observational data has related large volume resuscitation and elevated filling pressures with acute kidney injury.[10,11] Nor are the concerns regarding excess volume limited to patients with sepsis. A recent meta-analysis of patients with trauma and hypovolemia demonstrated improved survival in patients managed with a fluid-restrictive strategy.[5] The recognition that intravenous fluid can worsen outcomes in trauma has furthered the development of damage control resuscitation, emphasizing blood product replacement and avoidance of coagulopathy.[12]

Despite the growing acknowledgement that excessive fluid administration can be harmful, patients with shock routinely receive large volumes of crystalloid, in keeping with the recommendations of professional organizations.[1] The 2001 trial of early goal directed therapy (EGDT) for septic shock has been the cornerstone of evidence supporting this practice. In this trial, aggressive resuscitation with bundled care in the initial 6 hours of care was associated with a decrease in mortality.[13] Patients in the treatment arm received more fluid in the initial 6 hours of care (5 L vs. 3.9 L) though total volumes of fluid infused at 72 hours were similar (13.6 L vs. 13.4 L). The results of this study prompted changes in emergency department care processes that emphasized early, aggressive fluid loading. Current guidelines for the treatment of septic shock recommend a minimum initial fluid bolus of 30 mL/kg. Guidelines for the care of trauma and postsurgical patients have also emphasized aggressive fluid administration.

The recent ProCESS trial compared the original EGDT protocol to both a modified EGDT and usual care. No difference in mortality was noted between the groups. Fluid administration and vasopressor use between the groups at 6 hours was significantly different and higher in both EGDT arms.[14] It is noteworthy that mortality in the ProCESS EGDT group was markedly lower than the initial EGDT study (21% vs. 44%). While some of this difference is likely attributable to changes in care over the past decade and potentially in the study populations, the ProCESS EGDT group received much less fluid at 72 hours (7.2 L vs. 13.4 L). This raises

the hypothesis that some of the mortality difference might be attributable to differences in fluid resuscitation strategy, as intimated in the Vasopressin and Septic Shock Trial (VASST) of patients with septic shock, where optimal survival was noted with a positive fluid balance of only 3 L at 12 hours.[9]

Data from children also supports the view that excess volume may contribute worsened outcomes. The Fluid Expansion as Supportive Therapy (FEAST) study randomized of 3,141 children with sepsis to either aggressive early fluid administration versus controls with a conservative, no-bolus strategy. Mortality was significantly higher in the patients receiving a bolus; this effect was consistent across all patient subgroups.[15] Interestingly, the primary mechanism of increased mortality in the group receiving fluid boluses was cardiovascular collapse, and not respiratory failure.[16]

Collectively, these data do not imply that all fluid resuscitation is harmful; rather, they highlight that intravenous fluid should be thought of and prescribed as a drug, with associated potential benefits and harms. Moreover, each successive decision to give fluid may have greater implications and a different risk profile. While the challenges of evaluating fluid responsiveness have traditionally fallen to critical care medicine, as our understanding of fluid therapy evolves there may be increasing scrutiny on fluid management decisions in the emergency department (ED). Emergency physicians seeking to provide optimal resuscitation for the critically ill must understand the tools available to help determine whether providing fluid is likely to provide benefit.

PRINCIPLES OF VOLUME RESPONSIVENESS EVALUATION

Static pressure and volume variables

Static measures of pressure and volume were the first indices developed to assist with predicting volume responsiveness. These include the central venous and pulmonary artery occlusion pressures (PAOP), as well as surrogates obtained through echocardiography. These measurements are obtained at a given condition or time point and are presumed to reflect preload, with lower values implying a point on the slope portion of the Frank-Starling curve, and greater likelihood of a volume responsive state. Static markers of preload (Table 1) have proven unreliable for predicting fluid responsiveness.[17] While a static marker reflects a patient's preload at some point on the Frank-Starling curve, it cannot demonstrate whether there is capacity to advance along the curve and optimize myocardial filament overlap. Moreover, the shape and slope of the Starling curve varies between individuals and in decompensated states, further limiting the ability to define a threshold marker value indicating preload reserve.

Table 1. Static and dynamic hemodynamic parameters

Static parameters	Central venous pressure
	Pulmonary artery occlusion pressure
	Inferior vena cava (IVC) diameter
	IVC collapsibility/distensibility
	End-diastolic volume
	Corrected flow time
Dynamic parameters	Pulse pressure variation
	Stroke volume variation
	Plethysmographic variability index
Modified fluid challenge	Passive leg raise
	Mini fluid bolus (100–200 mL)

Dynamic variables and heart–lung interactions

As the limitations of static measures became evident, investigators suggested changes in preload indices induced by intrathoracic pressure changes during mechanical ventilation as predictors of volume responsiveness (Table 1).[17] Encouraging initial results have been tempered by the need for mechanical ventilation and strict use criteria, but these dynamic variables have some role in predicting fluid responsiveness in selected scenarios.[18]

Volume challenge

More recently, the use of simulated or small volume challenge has emerged as an approach to predicting fluid responsiveness. The passive leg raise (PLR) mobilizes approximately 300 mL from the lower extremities and transiently increases venous return as an "auto-bolus" (Fig. 2). This affords an opportunity to measure a hemodynamic parameter or measure cardiac output. A threshold level of improvement suggests preload reserve. The effect is reversible, and may help avoid an unnecessary fluid bolus. PLR is well validated and importantly, can be used in patients with spontaneously breathing or dysrhythmia.[19-21] The same principle underlies use of a mini-bolus (~100 mL)—the clinician assesses cardiac output pre- and postinfusion to help predict whether a larger volume of crystalloid is likely to be beneficial.[22,23]

TECHNIQUES FOR PREDICTING VOLUME RESPONSIVENESS

Central venous pressure

Measurement of the CVP is a familiar index used to guide fluid management. CVP measurement requires the placement of a central venous catheter, but is relatively easy to measure in the emergency department. Obtaining a CVP is recommended in the care of patients with septic shock, and remains in routine use.[1] However, there is now compelling evidence that CVP measurements fail to predict the cardiac output response to a fluid bolus.[2] A meta-analysis of 23 studies investigating the use of CVP and

Fig. 2. Passive leg raise. To perform a passive leg raise, a patient is placed in a semi-recumbent position at 45°. The patient's legs are then elevated to 45° and the hemodynamic variable of interest evaluated after 30–60 seconds.

ΔCVP to predict fluid responsiveness and blood volume yielded a pooled area under the curve (AUC) of 0.56, indicating poor predictive ability.[24]

Placement of a central venous catheter carries risk of infection and mechanical complications. Although central lines are placed regularly in the ED, they are relatively resource-intensive. While central access may be indicated for vasopressor infusion, measuring CVP is of no use in predicting volume responsiveness.

Pulmonary artery occlusion pressure

Pulmonary artery catheters can measure PAOP as well as cardiac output by thermodilution. Placement of pulmonary artery catheters has decreased markedly due to multiple studies demonstrating that their use does not improve patient outcomes, and catheter placement bears risk of mechanical and infectious complications. Notably, PAOP values have not proven predictive of fluid responsiveness.[25] PAOPs can be estimated non-invasively with lung ultrasound; the absence of diffuse sonographic B-lines suggests an occlusion pressure of less than 18 mmHg.[26] Serial lung ultrasounds during resuscitation may help determine fluid tolerance: if sonographc B-lines are not present, a clinician can infer there is no interstitial edema and proceed with a planned bolus.

Inferior vena cava measurements

Ultrasound measurements of the inferior vena cava (IVC) have been proposed as a tool to help guide fluid management. Well-established correlations exist between respiratory cycle-induced changes in IVC diameter and CVP.[27,28] IVC ultrasound is non-invasive and relatively easy to perform, and has been used extensively in the ED. Beyond providing an estimate of CVP, the caval index, or percentage collapsibility of the IVC (cIVC), has been proposed as a predictor of preload reserve. The cIVC is measured by obtaining a long axis view of the IVC, distal to the entry of the hepatic veins. For mechanically ventilated patients, a distensibility index (dIVC) is measured. Changes in size over the respiratory cycle are identified with the machine in M-mode (Fig. 3).

Early data from mechanically ventilated patients suggested promise for the potential value of IVC ultrasound to predict vol-
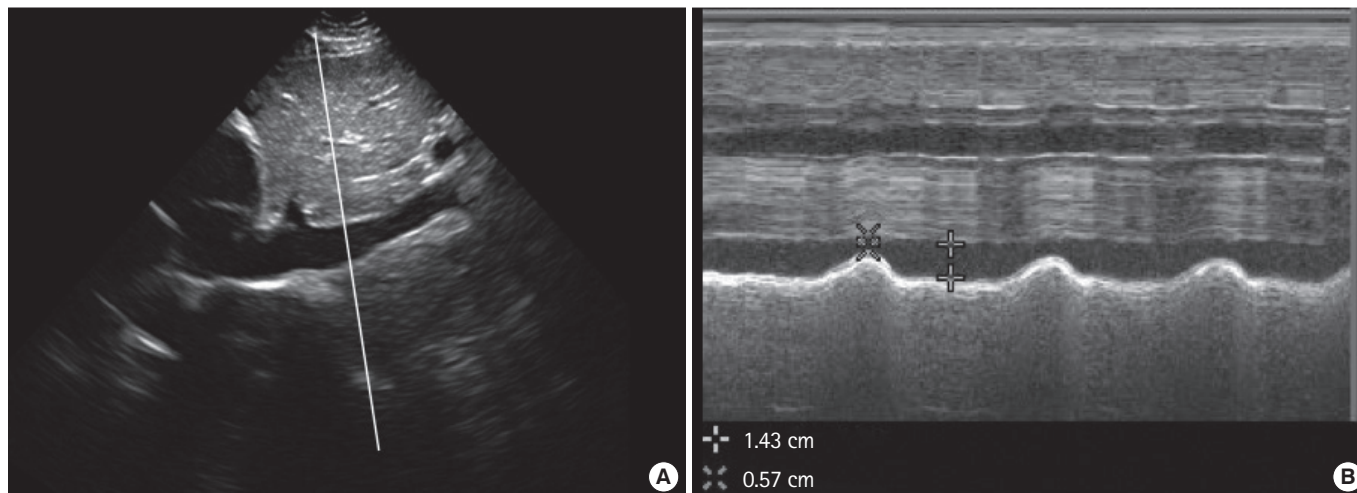
Fig. 3. Measurement of the inferior vena cava (IVC) caval index. (A) Long axis view of the IVC. The diameter is measured with M-mode 2–3 cm distal to the confluence of the hepatic vein and IVC. (B) M-mode tracing of the IVC demonstrating respirophasic changes in diameter.

ume responsiveness. In a group of 39 patients with septic shock, Feissel et al.[29] identified a dIVC of 12% as strongly predictive of fluid responsiveness. All patients in the study were mechanically ventilated at tidal volumes of 8–10 mL/kg. Barbier et al.[30] demonstrated similarly encouraging results in ventilated patients with sepsis, using a dIVC cutoff of 18%.

Subsequent studies, particularly those including spontaneously breathing patients, have failed to show the same predictive ability for changes in IVC diameter. In an ED population with suspected hypovolemia, Corl et al.[31] found cIVC could not predict fluid responsiveness. Muller et al.[32] studied cIVC in an intensive care unit (ICU) setting with mixed causes of circulatory failure. They found the optimal cIVC cutoff for detecting volume responsiveness was 40%, but this still missed multiple fluid responders.

Thus, while IVC size may serve as a surrogate for CVP, it has not proven reliable as a stand-alone marker of fluid responsiveness. Patient factors contributing to this finding include variable tidal volumes and changes in intrathoracic pressure. Technical factors contributing to the inconsistency and limitations of IVC ultrasound include the effect of respiration and attendant IVC movement on sampling location, as cIVC is affected by the position at which it is measured; the effect of increased intra-abdominal pressure; and patient factors such as obesity.[33]

Flow time

Flow time is the time required for systole in the cardiac cycle. The time is corrected for heart rate (FTc) and is calculated as FTc = systole time/the square root of cardiac cycle time. In the 1990s, Singer et al.[34] developed the concept of measuring aortic flow time with an esophageal Doppler monitor. Initially encouraging results culmi-

nated in the publication of a trial demonstrating improved patient-oriented outcomes in patients undergoing hip surgery with intraoperative fluid management guided by FTc.[35] Subsequent efforts to validate the use of FTc as a predictor of preload reserve have not been consistently successful.[36-38]

Aortic flow time measurement is typically obtained with an esophageal Doppler monitor. Patients who are not intubated tolerate esophageal Doppler monitors poorly, and acquisition of accurate measurements can be operator dependent. Coupled with the inconsistent performance of FTc, the constrained indications render aortic flow time highly impractical for any ED applications.

Blehar et al.[39] recently described the use of carotid FTc in an ED population with hypovolemia and demonstrated significant increases in FTc that correlated with crystalloid resuscitation. As it is relatively easy to image with ultrasound, carotid FTc is likely feasible for many emergency physicians. However, as a static marker of preload, isolated FTc measures are unlikely to identify volume responders. Limited data suggest that the ability of FTc to predict preload reserve might be improved by using a passive leg raise and determining a ΔFTc, but at present there is insufficient evidence to support this approach.[40]

Pulse pressure variation

Pulse pressure variation (PPV) is the difference between maximum and minimum pressure over a respiratory cycle, divided by their mean. It is a dynamic variable derived from intrathoracic pressure changes during mechanical ventilation. Positive pressure decreases right ventricular preload and increases right ventricular afterload, decreasing right heart stroke volume to a minimum during inspiration. In turn, preload to the left ventricle is decreased, and

after a short delay, left heart stroke volume decreases. Changes in left-sided stroke volume are exaggerated on the steep portion of the Frank-Starling curve, and thus PPV can be used to predict volume responsiveness. PPV is typically determined by a commercial hemodynamic monitor. Most require, at minimum, placement of an arterial catheter. Several manufacturers market systems that allow for PPV calculation (Table 2).

With the recognition that static predictors of fluid responsiveness were unreliable, the advent of dynamic variables such as PPV offered a new approach to determining fluid responsiveness. A 2009 meta-analysis demonstrated that PPV was strongly predictive of fluid responsiveness; a PPV of 13% discriminated volume responders accurately.[3] While potentially helpful, enthusiasm for the use of PPV has been tempered by the need for strict conditions to ensure accuracy. Numerous studies have confirmed that using PPV for the prediction of volume responsiveness requires patients be mechanically ventilated with no spontaneous respirations or dysrhythmia.[41-43] PPV is also contingent on the use of tidal volumes >8 mL/kg; such relatively large tidal volumes are increasingly uncommon in an era of lung-protective ventilation.[18] These strict limits, coupled with the need for a invasive and proprietary monitors, render PPV essentially irrelevant to patients in the ED. Indeed, even in large studies of patients in the operating room or intensive care unit, the conditions for using PPV are rarely met.[44]

Stroke volume variation

The principle of stroke volume variation (SVV) is similar to PPV, and rests on identifying changes in stroke volume during the respiratory cycle. An arterial catheter and commercial monitoring system (Tables 2, 3) analyzes the shape of the pulse pressure contour to calculate stroke volume. SVV thresholds of 12% suggest fluid responsiveness.[3,37] SVV is also determined by pulse contour analysis and requires a commercial device to measure (Table 2). A meta-analysis of dynamic variables found SVV less predictive than PPV.[3] SVV is subject to similar limitations as PPV, requiring mechanical ventilation with no spontaneous breathing and con-

Table 2. Techniques and monitors for evaluating fluid responsiveness

Parameter	Monitor
Passive leg raise	Echocardiography, CardioQ (esophageal Doppler), NICOM, PiCCO, Vigileo FloTrac
Pulse pressure variation	LiDCO, Clearsight (Nexfin), PRAM
Stroke volume variation	LiDCO, PiCCO, Pulsioflex, PRAM, Vigileo FloTrac, VolumeView
Pleth variability index	Masimo Radical7

Table 3. Hemodynamic monitoring systems

Technology	Device	Invasiveness	Principle	Advantage	Disadvantage
Bioreactance	NICOM	Non-invasive	Bioreactance	Non-invasive. Continuous CO measurements.	Fewer validation studies. Accuracy may be decreased in critical illness.
Plethymosgraphic wave form analysis	Radical7	Non-invasive	Plethysmograph wave form analysis	Continuous CO measurements. Easy to use. Non-invasive.	Decreased accuracy with poor perfusion. Requires calibration. Validated in ventilated patients with TV >8 mL/kg in SR.
Pulmonary artery catheter	Vigilance	Central arterial catheter	Thermodilution	Measurement of multiple hemodynamic parameters. CO measurement gold standard.	Highly invasive. Intermittent CO measurements. Poor predictor of fluid responsiveness.
Pulse contour analysis	FloTrac	Arterial catheter	Pulse wave analysis	Continuous CO measurements. No calibration requirement. Easy use.	Inconsistent CO tracking. Decreased accuracy with decreased vascular resistance. Validated in ventilated patients with TV >8 mL/kg in SR.
	LiDCO	Arterial catheter	Lithium dilution	Continuous CO measurements. Performs well in broad range of patient conditions.	Requires frequent calibration. Validated in ventilated patients with TV >8 mL/kg in SR.
	PiCCO	Central arterial & venous catheters	Thermodilution	Continuous CO measurements. Performs well in broad range of patient conditions.	Invasive. Requires calibration. Validated in ventilated patients with TV >8 mL/kg in SR.
	PRAM	Arterial catheter	Pulse wave analysis	No calibration. Continuous CO measurements.	Few studies validating use.
	Clearsight/ Nexfin	Non-invasive	Pulse wave analysis	Non-invasive. Continuous CO measurements.	Decreased accuracy in critical illness. Few validation studies.
	Volume view	Central arterial & venous catheters	Thermodilution	Continuous CO measurements.	Invasive. Requires calibration. Validated in ventilated patients with TV >8 mL/kg in SR.
Ultrasound	Cardio Q	Esophageal probe	Doppler ultrasound	Well validated. Continuous CO measurements.	Operator dependent. Most patients require intubation.
	USCOM	Non-invasive	Doppler ultrasound	Non-invasive	Operator dependent. Intermittent CO measurement.

CO, cardiac output; TV, tidal volume; SR, sinus rhythm.

trolled tidal volumes (>8 mL/kg) and the absence of dysrhythmia. The resources required and limitations of use make SVV impractical for the ED.

Plethysmographic variability index

The plethysmographic variation index (PVI) uses a modified pulse oximeter to measure respiratory cycle-induced variation in the plethysmograph waveform. The PVI is measured by a commercial device (Table 3), and has the advantage of being non-invasive. PVI measurements appear to be subject to similar limitations as PPV and SVV—that is, they have adequate ability to predict volume responsiveness in patients who are intubated with no spontaneous respiratory effort, and tidal volumes >8 mL/kg.[45,46] While these prerequisites constrain applicability in the ED setting, it is notable that PVI has been used successfully in ED patients.[47] The study population consisted of septic patients with hemodynamic instability who had already received a 20 mL/kg crystalloid bolus. All were mechanically ventilated and sedated. Mean PVI was significantly higher in fluid responders (30% vs. 8%), and a threshold PVI of 19% was 94% sensitive and 86% specific. In patients who meet the narrow applicability criteria, PVI may be a useful technique.

Echocardiography
Static echocardiographic parameters

Several echocardiographic pressure and volume measurements have been proposed to predict fluid responsiveness, including estimations of CVP and PAOP and end-diastolic area of left or right ventricles. Echocardiography has the advantage of allowing an accurate non-invasive estimation of CVP by IVC size, and PAOP by Doppler mitral flow (E/A ratio) or tissue Doppler (E/Ea ratio). However, Doppler evaluation is beyond the scope of many point-of-care ultrasound users. More importantly, echo-derived estimates of these variables are subject to the same limitations as those obtained directly from a central venous catheter or pulmonary artery catheter. Studies of echocardiographic estimates of CVP and PAOP confirm that they fail to predict volume responsiveness.[25]

End diastolic ventricular area has also been studied as a marker of volume responsiveness. Multiple studies have demonstrated that end-diastolic area does not reliably predict the response to volume expansion.[48,49] One exception may be patients with extremely small, hyperdynamic left ventricles, which can be noted in the early phases of resuscitation. A global, qualitative assessment of ventricular size and function may aid decision-making in fluid resuscitation, but should not be used in isolation to predict the response to a fluid bolus.

Dynamic echocardiographic parameters

Changes in stroke volume measured with echocardiography are an excellent method for predicting preload reserve. Stroke volume can be measured by determining the velocity-time integral (VTI) of aortic blood flow with transthoracic echocardiography (Fig. 4). The product of VTI and aortic area equals the stroke volume; assuming that the aortic diameter is constant, multiplying the result by heart rate yields cardiac output. Changes in stroke volume
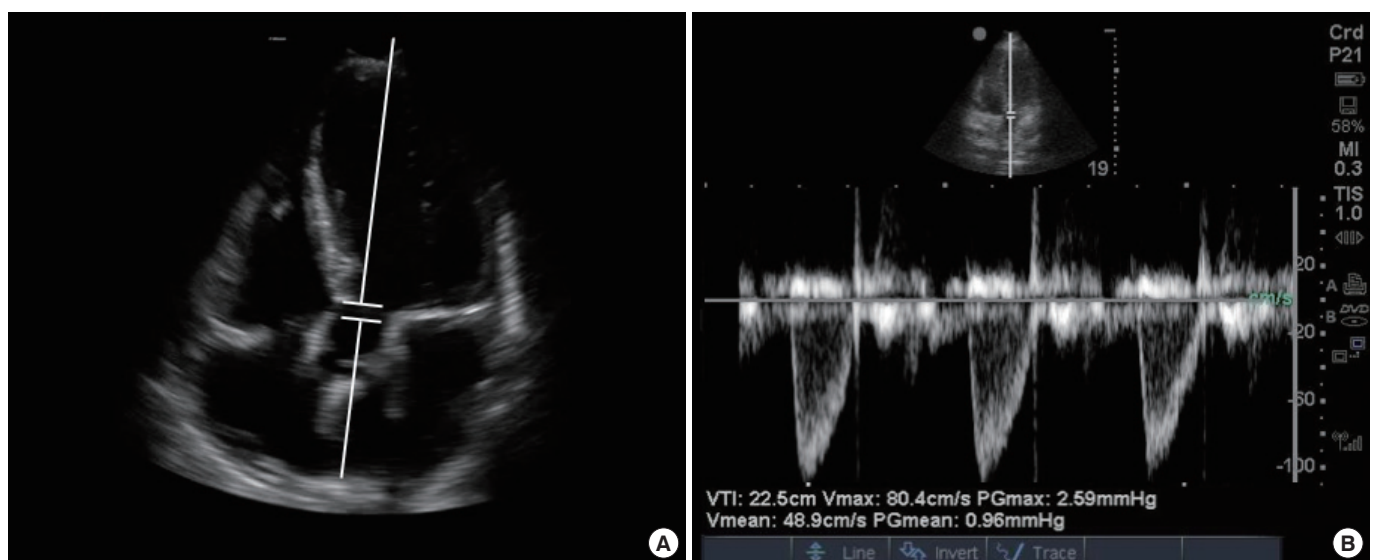

Fig. 4. Measurement of aortic velocity-time integral (VTI). (A) Apical 5-chamber view of the heart, demonstrating position for Doppler measurement of aortic blood flow. (B) Spectral Doppler tracing of aortic blood flow. The area under the curve is the VTI.

induced by a passive leg raise have shown excellent ability to identify patients who are volume responsive. Lamia et al.[50] identified a 12.5% change in VTI as 77% sensitive and 100% specific for detection of a >15% in cardiac output following volume expansion. Their study included ICU patients with shock; the population included spontaneously breathing patients with and without mechanical ventilation. The associated area under the curve (AUC) of the receiver operating characteristic was 0.96, indicating excellent performance. Maizel et al.[51] conducted a similar study in a patient group with circulatory failure and spontaneous respiration. They identified a 12% increase in stroke volume after passive leg raise as 69% sensitive and 89% specific for response to 500 mL of crystalloid administration. The corresponding AUC was 0.9.

The consistency between these two studies is impressive, and supports the concept of passive leg raise-induced ΔVTI as a noninvasive predictor of volume responsiveness. Measuring VTI requires acquisition of a transthoracic apical 5-chamber view (or a transesophageal approach), the ability to use and interpret Doppler, and thus above basic competence with point-of-care echocardiography. A recent study of emergency physicians demonstrated that VTI could reliably be obtained after a focused training period.[52] While this study is encouraging, we pragmatically acknowledge that acquiring this view in a patient with critical illness or unfavorable habitus may be challenging.

The USCOM monitor calculates cardiac output using VTI and an internal algorithm to estimate aortic size based on patient factors. While this theoretically facilitates VTI measurement, in comparison to transthoracic echocardiography and other cardiac output measurement devices, the USCOM has performed inconsistently, and has not reliably predicted cardiac output or preload reserve.[53,54] This may relate to difficulty in obtaining an adequate Doppler tracing; alignment of the Doppler beam with the outflow tract depends on patient positioning and operator technique. Estimation of the aortic area likely also contributes to inaccuracy in comparison to other output devices.

Building on the potential use of aortic VTI, a recent report described the use of carotid blood flow (CBF) measurement in the carotid artery to predict fluid responsiveness. This approach measures the diameter of the carotid and carotid VTI. A ΔCBF of 20% after passive leg raising predicted an increase in cardiac output with 94% sensitivity and 86% specificity, using bioreactance as a gold standard for cardiac output.[55] Given the technical challenges of measuring aortic VTI, carotid CBF may be well suited to use in the emergency department, but needs further study and validation.

Bioreactance

Bioreactance detects phase shifts in an oscillating electrical cur-

rent crossing the thorax to measure stroke volume. A non-invasive device (NICOM) (Table 3) is used to obtain a measurement of the stroke volume, and thus cardiac output; readings are obtained by applying electrodes to the patient's chest, which are attached to a generator. NICOM measurements of cardiac output have correlated with those obtained via pulmonary artery catheter.[56]

Studies of postoperative patients have shown fluid responsiveness can be predicted by changes in NICOM-derived stroke volume after a passive leg raise. In a population of patients with sepsis, Marik et al.[55] demonstrated that a 10% increase in stroke volume index with passive leg raise was 94% sensitive and 100% specific for a positive response in stroke volume with fluid challenge. The study population included a mixed population, with and without mechanical ventilation or vasopressor infusion, and is relevant to an ED population.

As it is non-invasive, bioreactance may be well suited to predicting preload reserve and volume status in ED patients. Multiple reports of NICOM use in the ED have described uses to estimate cardiac output and total body fluid in trauma and dyspnea.[57,58] Further studies validating the use of bioreactance would help establish a potential role in the ED and initial phases of resuscitation.

PRACTICAL APPROACHES TO VOLUME RESPONSIVENESS IN THE ED

The number of techniques to predict volume status reflects that each has inherent challenges and limitations. Methods that require mechanical ventilation or commercial monitors are necessarily less applicable to patients in the ED. Moreover, some of the dynamic techniques, such as PPV and PVI, require such specific conditions that they are impractical for use even in the operating room or ICU.

An ideal predictor of volume responsiveness would be non-invasive, continuous, accurate, and inexpensive. Point-of-care ultrasound meets most core criteria for predicting hemodynamic responses to volume loading. Ultrasound is familiar to most emergency physicians, and an array of applications is already part of the core content of training in the specialty. Coupled with ultrasound, passive leg raising maneuvers currently have the best test performance characteristics for determining preload reserve, and have fully reversible effects. In addition, the methods of predicting volume responsiveness with the best evidence and broadest inclusion criteria use ultrasound.

For emergency physicians with confidence in their ability to acquire an apical 5-chamber view of the heart and to use Doppler applications, measurement of the aortic VTI is currently the best evidence-based method to predict the effect of a fluid chal-

lenge. Identifying a ΔVTI greater than 12% after passive leg raise is strongly predictive of an increase in cardiac output with crystalloid infusion. Carotid VTI with PLR is an interesting alternative, as it is technically easier, but requires further study to support its use.

In the absence of advanced point-of-care ultrasound skill, mechanical ventilation, or invasive monitoring equipment, the best alternative to evaluating the response to volume loading is likely a serial ultrasound evaluation of the heart, lungs, and IVC. Multiple protocols have been suggested.[59,60] An initial ultrasound of an unstable patient can help define a likely etiology for shock or dyspnea; a growing body of evidence supports the value of ultrasound for this purpose. Ultrasound findings of normal or hyperdynamic cardiac function, a small IVC diameter with high cIVC, and the absence of an interstitial syndrome (lack of sonographic B lines) suggest a fluid-tolerant state. Fluid boluses in 500–1,000 mL increments can be given, with serial clinical and ultrasound reassessment. Decrease in the cIVC and the appearance of sonographic B-lines, suggesting subclinical interstitial edema, can prompt a reasoned transition to alternative therapies such as vasopressors or inotropes.[59]

This approach of using an integrated ultrasound assessment to guide fluid therapy needs further study, but initial reports of this strategy suggest promise. A recent study of fluid point-of-care ultrasound to guide fluid management showed improved outcomes in the group with ultrasound-driven management. While limited by a case-control design, the ultrasound group had lower 28-day mortality, reduced fluid administration, and a reduced need for renal replacement therapy.[11] A study by Haydar et al.[61] of unstable patients in the ED with suspected sepsis showed integrated ultrasound improved physician decision-making and changed therapeutic plan, including fluid management, in over 50% of the study population. Caltabeloti et al.[62] recently demonstrated the ability of lung ultrasound to define a fluid-tolerant state. In their study of patients with shock and ARDS, fluid loading produced only a transient improvement in hemodynamics and oxygenation but worsened interstitial edema, as demonstrated by lung ultrasound.

CONCLUSIONS

Careful management of volume status and fluid administration is an important determinant of outcomes of the critically ill. Fluid responsiveness cannot be predicted on the basis of clinical examination. The best tools to predict volume responsiveness in ED patients use a passive leg raise maneuver to detect a change in a hemodynamic variable; the aortic blood flow, as determined by echocardiographic velocity-time integral, is most applicable to the emergency physicians. For practitioners with basic competence in point-of-care ultrasound, serial ultrasound of the heart, lungs, and IVC is the best tool to help guide fluid resuscitation and to direct transition away from fluid administration to other therapies.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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