Inferior Vena Cava Assessment
Correlation with CVP and Plethora in Tamponade

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ABSTRACT

Bedside assessment of intravascular volume status plays an important role in the management of critically ill patients, guiding fluid replacement therapy and the use of vasopressor agents. Despite controversy in the existing evidence, many clinicians advocate the use of inferior vena cava ultrasound (IVC-US) in the assessment of intravascular volume status in critically ill patients. Respirophasic variation in IVC diameter may provide useful information regarding intravascular volume status, particularly in patients with high and low caval indices. However, due to conflicting results of small-scale clinical trials of divergent sample populations, there is insufficient evidence to support routine US assessment of the IVC to determine fluid responsiveness in spontaneous breathing with circulatory compromise. Additional large-scale clinical trials are required to determine the accuracy of IVC-US measurements in diverse populations and to ascertain the effects on IVC dimensions that result from cardiac dysfunction and intra-abdominal hypertension.

Bedside assessment of intravascular volume status plays an important role in the management of critically ill patients, guiding fluid replacement therapy and the use of vasopressor agents. Clinical assessment of volume status using physical examination findings is inaccurate [1], and clinicians have historically relied on information obtained from invasive hemodynamic monitoring, specifically central venous pressure (CVP) and pulmonary capillary wedge pressure (PCWP), to help guide fluid management. Mechanical complications associated with invasive hemodynamic monitoring, as well as a lack of proven efficacy for traditional strategies [2,3] have led to interest in the use of point-of-care ultrasound assessment of the inferior vena cava (IVC-US) as a potentially useful noninvasive, rapid technique to assess intravascular volume status. Whereas studies in the critical care [4], emergency medicine [5], and cardiology [6] literature have supported the use of IVC-US for the assessment of volume status, other studies [7,8] have contradicted these findings. Despite controversy in the existing evidence, many clinicians continue to advocate [9] the use of IVC-US in the assessment of intravascular volume status in critically ill patients.

IS CVP A USEFUL MARKER OF FLUID RESPONSIVENESS?

Traditionally, CVP has been assumed to accurately reflect intravascular volume and has played a central role in guiding fluid management decisions for decades. This concept of CVP as a reliable indicator of volume status has been widely circulated in both medical and surgical disciplines. Internationally endorsed clinical guidelines, including the Surviving Sepsis Campaign Guidelines, specifically target CVP as the endpoint for fluid resuscitation

[10]. Over the last decade, however, the long-held belief that CVP accurately reflects volume status has been challenged. More recent reviews of literature have demonstrated a poor relationship between CVP and blood volume [2,4,11]. A recent meta-analysis calls attention to the lack of evidence in human trials to suggest that CVP is an accurate predictor of volume status and characterizes CVP as a misleading tool for guiding fluid therapy, recommending that it should no longer be routinely measured in critically ill patients [2]. The recent recommendations against the use of CVP for volume assessment are indicative of 2 general trends in the critical care and emergency medicine literature: 1) to focus on identifying fluid responders in addition to identifying patients with low intravascular volumes; and 2) to de-emphasize the use of static physiologic markers in favor of dynamic markers.

FLUID RESPONSIVENESS

Whereas traditional resuscitative strategies have emphasized the importance of determining a patient's intravascular volume, current strategies instead focus on the identification of patients with poor perfusion who are fluid-responsive. Although there is a clear benefit of early aggressive fluid resuscitation in patients with sepsis, overzealous fluid resuscitation leads to extravascular volume overload, prolonged intensive care unit stays, and mortality [12,13]. As a result, current models of resuscitation attempt to identify patients with low intravascular volume whose cardiac function is operating on the steep portion of the Frank-Starling curve, and who will therefore increase their cardiac output in response to a fluid challenge [14]. Patients who are fluid-responsive will exhibit a quantifiable increase in cardiac output (typically 10% to 15% as

measured by invasive or noninvasive cardiac output monitors) in response to a fluid challenge (typically 500 ml of isotonic crystalloid infused over a 10-min period) or effective fluid challenge by means of a passive leg raise. If there is no increase in cardiac output after a fluid challenge, it is highly unlikely that the fluid administered is improving tissue perfusion and may instead be contributing to extravascular volume overload and adverse outcomes.

STATIC VERSUS DYNAMIC PHYSIOLOGIC MARKERS OF INTRAVASCULAR VOLUME

Common static measures of intravascular volume include CVP and pulmonary capillary wedge pressure. Despite the widespread use of CVP [15], multiple studies have demonstrated that both CVP and pulmonary capillary wedge pressure are unreliable markers of intravascular volume in critically ill patients and consistently fail to identify fluid responders [2,16]. In contrast, dynamic measures of intravascular volume are far more accurate predictors of intravascular volume and fluid responsiveness and are dependent on changes in intrathoracic pressure during the respiratory cycle. These include pulse pressure variation, stroke volume variation, vena cava collapsibility/distensibility indices, and bioimpedance/bioreactance technology.

STATIC VERSUS DYNAMIC MEASUREMENTS OF THE IVC

The IVC can be assessed with static measures (diameter) or with dynamic measures (respirophasic variation). The physiologic mechanism resulting in respirophasic variation warrants review. In a spontaneously breathing patient, negative intrathoracic pressure generated during inspiration draws blood from the IVC into the right atrium, resulting in varying degrees of IVC collapse. Measurements of IVC collapse are commonly reported as the "collapsibility index," which is calculated as (maximum IVC diameter on expiration − minimum IVC diameter on inspiration/maximum IVC diameter on expiration). In contrast, during mechanical ventilation, the force of inspiration is generated by positive pressure and the IVC distends rather than collapses. Studies of IVC respirophasic variation in mechanically ventilated patients (IVC distensibility) are typically performed with fixed tidal volume in adequately sedated patients with controlled ventilation. In mechanically ventilated patients, the "distensibility index" is calculated as (maximum IVC diameter on inspiration − minimum IVC diameter on expiration/minimum IVC diameter on expiration). The term "caval index" (CI) has been used to refer to respirophasic changes in IVC diameter irrespective of whether the patient is spontaneously breathing or receiving mechanical ventilation.

DO IVC MEASUREMENTS CORRELATE WITH CVP?

Early interest in the role of IVC-US in the determination of intravascular volume status focused on correlating IVC diameter (size) with measured CVP. The results of these

initial studies suggested that mean IVC diameter correlated with CVP [17,18]. More recent work, however, has demonstrated a more modest correlation of IVC diameter with CVP [19]. Predictably, with the increased emphasis on dynamic markers of intravascular volume, subsequent studies have compared CVP with US assessments of IVC respirophasicity, rather than IVC diameter alone. Overall, the results of these studies suggest that, at extremes, the CI does have an inverse relationship to CVP. In a small group of emergency department patients with suspected sepsis, Nagdev et al. [5] reported that CI >50% was strongly associated with a CVP <8 mm Hg. Kircher et al, [6] came to a similar conclusion, reporting that CI >50% was indicative of right atrial (RA) pressures <10 mm Hg, whereas CI <50% indicated RA pressures >10 mm Hg. In a study of patients undergoing right heart catheterization, IVC-US measurements within 1 h of the procedure demonstrated that CI <20% during passive respiration and CI <40% during forceful inhalation were both predictive of RA pressures >10 mm Hg. Another study of surgical intensive care unit patients demonstrated that CI appeared to correlate best with CVP in the setting of low (<20%) and high (>60%) values and suggested that the closer the CI is to 0% or 100%, the more likely the patient is volume-overloaded or volume-depleted, respectively [20]. Whereas none of the available evidence clearly supports a linear relationship between CI and CVP, there does appear to be an inverse relationship when CI values are very high or low. Perhaps more importantly, the ability to accurately predict CVP values is of unproven clinical benefit, given the poor performance of CVP as a marker of intravascular volume and fluid responsiveness. It is likely, however, that a very high CI (often associated with a very low CVP) may serve as a reasonable indication that it is safe to give more fluid without risking volume overload. As the CI decreases with fluid administration, it becomes increasingly less reliable as a surrogate for intravascular volume.

DOES IVC-US PREDICT FLUID RESPONSIVENESS?

A more clinically relevant question is whether IVC-US can predict fluid responsiveness. In mechanically ventilated patients, high CI values appear to accurately identify fluid responders. Barbier et al. [4] demonstrated that using a threshold CI of 18%, mechanically ventilated septic responders and nonresponders could be discriminated with 90% sensitivity and specificity. Similarly, Feissel et al. [21] reported a threshold CI of 12% could discriminate mechanically ventilated septic responders and nonresponders with positive and negative predictive values of 93% and 92%, respectively. In contrast, studies of spontaneously breathing patients have had markedly discordant results. Lanspa et al. [22] reported that a CI >15% predicted volume responsiveness in spontaneously breathing patients with positive and negative predictive values of 62% and 100%, respectively. Of note, however, this included a sample of 14 patients, only 5 of whom were volume

responders. Corl et al. [7] and Weekes et al. [23] both failed to demonstrate a correlation between CI and fluid responsiveness. Recently, in another study of spontaneously breathing patients, a CI >40% correlated well with fluid responsiveness, whereas a CI <40% was unable to discriminate responders from nonresponders [8]. Overall, the poor performance of the CI in spontaneously breathing patients as compared to that of those receiving mechanical ventilation is somewhat predictable; respirophasic changes in intrathoracic pressure are difficult to quantify when the inspiratory force itself cannot be measured or standardized in a single patient or among different patients.

WHAT IS THE BEST WAY TO ASSESS THE IVC?

To date, the most reliable way to evaluate IVC-US has not been fully determined. The most common protocols require that the IVC is imaged longitudinally in the sub-xiphoid area, near the junction of the IVC and right atrium. The location at which measurements are obtained varies greatly in the literature, however, and there is no evidence to suggest superiority of a given location. Measurements have historically been recorded at locations ranging from the junction of the IVC and right atrium to the junction of the IVC and left renal vein. Wallace et al. [24] reported that the lowest IVC CI was found at the junction of the IVC and RA (presumably because of the IVC's attachment to the diaphragm), and found good correlation between CI obtained 2 cm caudal from the middle hepatic vein's junction with the IVC, and at the junction of the left renal vein and IVC. Other studies [25] assert that the area most responsive to respiratory changes is located 2 cm distal to the junction of the IVC with the right atrium, just caudal to the middle hepatic vein.

The majority of studies measure the IVC diameter and CI in the longitudinal plane, caudal to the junction of the middle hepatic vein, approximately 2 to 4 cm from the IVC/RA junction. In spontaneously breathing patients, IVC measurements are typically measured during quiet passive respiration, yet some studies [19] have reported improved accuracy when measurements are performed while the patient forcefully inhales by performing a "sniff" maneuver. Of note, Fields et al. [26] found that emergency physicians' US measurement of IVC diameter had a high degree of inter-rater reliability, but visual assessment and caliper measurement of CI was less reliable. Because threshold values of CI can be as low as 12% to 18%, small variations in these measurements could have significant impact in the determination of the CI and are not insignificant.

M-MODE VERSUS B-MODE

Many studies of IVC diameter and CI were performed with measurements obtained using M-mode [4,7,8,21] (motion mode), as images of the IVC can be obtained that incorporate the full respiratory cycle. However, it is important to note that these measurements may be inaccurate. Mechanical displacement of the diaphragm during respiration frequently results in measurement of the IVC at 2 different locations during inspiration and expiration, and the IVC exhibits different degrees of collapsibility at different locations along its course [23]. In addition, respiratory displacement of the IVC often precludes placing an M-mode cursor perpendicular to the vessel, contributing to inaccurate measurements [27]. Blehar et al. [28] investigated the degree of IVC displacement during quiet respiration and found that the mean caudal movement of the IVC in relation to the transducer averaged 21.7 mm, whereas average lateral movement was significantly less at 3.9 mm. In contrast, Moreno et al. [29] found no statistically significant difference between measurements obtained using M-mode and B-mode, and found no statistical difference when measuring CI in the longitudinal or transverse plane.

IS IVC APPEARANCE HELPFUL IN DIAGNOSING CARDIAC TAMPONADE?

In contrast to the uncertain role of IVC-US in the assessment of intravascular volume and the identification of fluid responders, the value of IVC-US in the evaluation of patients with suspected cardiac tamponade is less controversial. As pericardial pressures increase, so does venous return to the right atrium. As a result, the normal respirophasic collapse of the IVC diminishes. As right atrial and subsequently IVC pressures increase, the IVC will eventually cease to collapse and will remain plethoric throughout the respiratory cycle. In cardiac tamponade, IVC plethora (defined as a decrease in the proximal venal caval diameter by <50% during deep inspiration) is often the first echocardiographic sign to appear and the last to resolve after pericardial drainage [30]. When compared with RA collapse and right ventricular diastolic collapse, IVC plethora has been described as the most sensitive (97%) although least specific (40%) echocardiographic sign of cardiac tamponade [29]. IVC plethora can also result from right ventricular failure (secondary to left ventricular dysfunction, right ventricular infarction, pulmonary hypertension, or severe tricuspid regurgitation). Interestingly, however, in patients with known pulmonary hypertension, IVC plethora still had the highest predictive accuracy of cardiac tamponade when compared with other echocardiographic signs [24].

ADDITIONAL LIMITATIONS OF IVC-US

There are a number of technical and pathophysiologic factors that limit the utility and accuracy of IVC-US. First, the subcostal window may not afford adequate visualization of the IVC, particularly in patients with obesity, abdominal pain, gastric insufflation, large amounts of bowel gas, or post-surgical wounds and/or pneumoperitoneum. As some studies have excluded patients from enrollment [5] or failed to report the degree to which IVC visualization was technically limited [31], the exact percentage of patients in whom adequate views cannot be obtained is unknown, but even in the hands of experienced

echocardiographers, the percentage commonly exceeds 10% [4,7,18] and has been reported as high as 18% [19]. Whereas there has been speculation that excessive transducer pressure during technically challenging IVC-US may compress the IVC and lead to alterations in measurements, no study has specifically investigated the extent to which this phenomenon plays a role. Additionally, IVC diameter and CI are significantly influenced by pulmonary hypertension, tricuspid regurgitation, tachycardia [32] and variations in tidal volumes and patterns of respiration in spontaneously breathing patients. In addition, high intra-abdominal pressures, such as those associated with the abdominal compartment syndrome, have been shown to affect IVC diameter [33] and, though not specifically investigated, are likely to affect respirophasic variation of the IVC as well.

SUMMARY

In patients with pericardial effusions, the absence of IVC plethora provides strong evidence against the diagnosis of cardiac tamponade.

Respirophasic variation in IVC diameter may provide useful information regarding intravascular volume status, particularly in patients with high and low CI. However, due to conflicting results of small-scale clinical trials of divergent sample populations, there is insufficient evidence to support routine US assessment of the IVC to determine fluid responsiveness in spontaneously breathing patients with circulatory compromise.

Whereas high CI may identify mechanically ventilated patients who will respond to a fluid challenge, further large-scale clinical trials are required to determine the accuracy of these measurements in diverse populations, and to ascertain the effects on IVC dimensions that result from cardiac dysfunction and intra-abdominal hypertension.

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