Assessment of intravascular volume status and volume responsiveness in critically ill patients

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Accurate assessment of a patient's volume status, as well as whether they will respond to a fluid challenge with an increase in cardiac output, is a critical task in the care of critically ill patients. Despite this, most decisions regarding fluid therapy are made either empirically or with limited and poor data. Given recent data highlighting the negative impact of either inadequate or overaggressive fluid therapy, understanding the tools and techniques available for accurate volume assessment is critical. This review highlights both static and dynamic methods that can be utilized to help in the assessment of volume status.

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Accurate assessment of intravascular volume remains one of the most challenging and important tasks for clinicians. Rivers *et al.*[1] demonstrated that a protocol of early goal-directed therapy, which included aggressive fluid resuscitation targeted to central venous pressure (CVP) and physiological variables, reduced organ failure and improved survival in patients with severe sepsis and septic shock. However, more recent studies in critically ill patients have demonstrated that excessive fluid resuscitation and markedly positive net fluid balance is associated with higher rates of complications and increased mortality.[2,3] In a European multicenter observational study of patients admitted to the intensive care unit (ICU), each 1 liter of positive fluid balance during the first 72 h of ICU stay was associated with a 10% increase in mortality after adjustments for other risk factors.[2] Furthermore, in a landmark study of liberal versus conservative fluid management of patients with acute lung injury in the ICU, a more conservative fluid management strategy improved lung function and shortened the ICU stay, whereas there was no difference in the 60-day mortality between the two groups.[4] Thus, outcomes are clearly influenced by fluid balance with either inadequate or overly aggressive resuscitation associated with excess morbidity and mortality (Figure 1). Despite this, most decisions regarding fluid therapy are still made empirically.

When dosing intravenous fluids, two key clinical questions are asked: (1) what is the current state of the patient's intravascular volume? and (2) if the patient receives continued fluid resuscitation or a fluid bolus, will physiological variables such as blood pressure, tissue perfusion, and urine output improve? Fundamentally, the only reason to give a patient a fluid challenge is to increase the stroke volume (SV; by at least 10–15%) and improve organ perfusion. It is therefore crucial during the resuscitation phase of critically ill patients to determine not only the volume status but also whether the patient is fluid-responsive or not. In clinical practice, physical examination, radiography, laboratory parameters, and in case of the critically ill patients in the ICU, monitoring of central pressures and cardiac output are combined to assess the patient's intravascular volume and determine clinical interventions such as fluid or diuretic administration. As with any diagnostic tests, clinicians utilizing these volume assessment

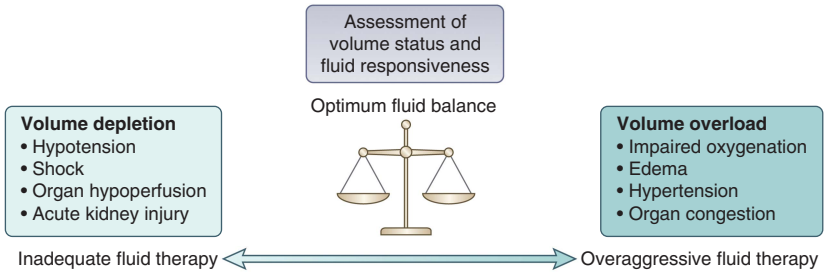

Figure 1 | Volume assessment goals. Proper assessment of patients' volume status and whether they will respond with an increase in cardiac output, following a fluid challenge, are critical to avoid the consequences of either inadequate or overaggressive fluid therapy.

techniques need to understand their limitations and diagnostic accuracy. The intent of this review is to survey the literature and summarize the performance characteristics of tests commonly used for the assessment of both intravascular volume status and volume responsiveness in critically ill patients. It is noteworthy that laboratory assessments such as the mixed venous oxygen saturation, blood lactate, and others are not discussed in this paper.

HISTORY AND PHYSICAL EXAMINATION

The earliest assessment of the patient is the history and physical examination (Table 1). The majority of studies assessing the utility of the history and physical examination in clinical volume assessment are derived from either the assessment of patients with heart failure (HF) or acute blood loss.

Wang *et al.*[5] performed a meta-analysis of 18 studies that evaluated the utility of the history, physical examination, and diagnostic tests in diagnosing HF and volume overload in patients presenting to the emergency department with dyspnea. Among all presenting symptoms, paroxysmal nocturnal dyspnea was most helpful, if present (positive likelihood ratio: 2.6), followed closely by orthopnea and peripheral edema.

In a review on the value of physical examination findings in the diagnosis of hypovolemia, it was shown that physical examination findings are dependent on the type and amount of fluid loss.[6] The most useful physical findings are postural dizziness (preventing measurement of upright vital signs) or a postural pulse increment of 30 beats/min or more. However, these findings had a high sensitivity for hypovolemia caused only by large blood losses (approximately 1 liter) but a poor sensitivity for moderate blood losses (approximately 500 ml). The authors point out that in states of volume depletion produced by non–blood loss states, very few findings have clinical utility, and ancillary lab/diagnostic testing is required.[6] This was confirmed in another study that demonstrated that no single clinical sign was useful in identifying a low circulating blood volume.[7] Furthermore, when clinicians were asked to predict hemodynamic parameters based only on history and physical examination, their performance was poor.[8] In this study, pulmonary artery occlusive (wedge) pressure was correctly predicted only 30% of the time. Cardiac output, systemic vascular resistance, and right atrial pressures were correctly predicted approximately 50% of the time.

Table 1 | Commonly used clinical and laboratory parameters in the assessment of volume status

● Vital signs
○ Blood pressure (mean arterial pressure)
○ Pulse
○ Orthostatic changes in blood pressure and pulse
● Physical examination
○ Mentation
○ Capillary refill
○ Skin turgor/dryness
○ Skin perfusion (color/mottling, temperature)
○ Temperature of extremities
○ Urine output
● Laboratory parameters
○ Fractional excretion of sodium, urea
○ Blood lactate
○ Mixed venous oxygen saturation

CHEST RADIOGRAPHY

The daily chest X-ray (CXR) in the ICU is an established diagnostic tool to complement history and physical examination findings, and is commonly used to assess volume status. In a study of patients with systolic HF awaiting heart transplantation, CXR findings were correlated with measurement of pulmonary capillary wedge pressure (PCWP) as their gold standard for volume overload.[9] Although venous redistribution and interstitial pulmonary edema were seen more commonly among subjects with high PCWP readings, there was a high degree of overlap among groups with different PCWP values. In addition, the absence of radiologic findings typically associated with volume overload did not ensure lower PCWP.[9] Other studies have confirmed that the typical radiologic signs suggesting volume overload are