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Review

Ultrasound as a tool for fluid status assessment in the trauma and critically ill patient

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HIGHLIGHTS

- Focused cardiac ultrasound has been used for over a decade to guide resuscitation.
- Imaged based resuscitation has been expanded to the trauma patients.
- There are several studies described in the literature.
- Limited Transthoracic Echocardiogram (LTTE) is an easy to learn, repeatable technique that can help in achieving euvolemia.

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ABSTRACT

Resuscitation to euvolemia in trauma as well as in the critically ill patient, continues to be a challenge. Focused cardiac ultrasound has been shown to be a reliable tool to evaluate fluid status and to guide therapy. The present manuscript reviews the evidence supporting the use of this tool and describes the clinical applications for image-based resuscitation using echocardiogram.

1. Introduction

Trauma is the fourth leading cause of death in America and the most common cause of death in people less than 45 years of age [1]. Severe trauma is often associated with hemorrhagic shock from blood loss due to vessel or organ injury. To compensate, the body can respond with vasoconstriction and increased cardiac output. This compensation continues until the body is overwhelmed, resulting in severe hypotension and, if not corrected, multi-organ system failure and death.

Over the past two decades, numerous studies have shown that conventional modalities, such as vital signs, physical exam findings, and laboratory studies are an unreliable assessments of intra-vascular volume status [2–4]. Furthermore, blood pressure, usually regarded as the principal marker for shock and response to resuscitation, can be an inaccurate indicator of blood loss due to independent factors such as underlying cardiovascular disease and medications or drug intoxicants [2]. Additionally hypertensive patients can present in shock, with 'normal' blood pressure parameters, and in fact have inadequate tissue perfusion [2]. This is especially important in the initial assessment of the trauma patient, when the patient's medical history may not be available. Moreover, hypotension is a late finding in trauma that does not occur until a significant amount of circulating blood volume is lost. At this point, correcting the hypotension may be too late.

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Physical exam findings, such as a tender or distended abdomen, and delayed capillary refill, may not be present until the patient has reached severe, uncompensated shock [5]. Laboratory studies also may not reflect a patient's current state of shock. For example, hemoglobin only begins to decrease after mobilization of extravascular fluid into blood vessels [6]. Additionally, laboratory studies take time to process and may not be available in a setting where time of the essence.

This unreliability can result in inappropriate resuscitation with the administration of too much or too little fluid. Historically, the tendency has been to assume that in the setting of trauma, a patient is in shock due to hemorrhagic hypovolemia. This has resulted in treatment with aggressive fluid resuscitation. Over-resuscitation, even in the patient with hypovolemia and normal cardiac function, can lead to devastating consequences such as intra-abdominal hypertension and abdominal compartment syndrome [7]. We have seen this trend increase as our patient population ages and medical comorbidities, such as congestive heart failure, become more prevalent [8]. Subsequently, while earlier studies advocated the use of Swan-Ganz catheters in injured elderly patients to optimize cardiac output and oxygen delivery, the 2012 Eastern Association for the Surgery of Trauma (EAST) guidelines on the evaluation and management of geriatric trauma shifted to advocate aggressive triage and correction of coagulopathy [9]. The guidelines state that predictive models are needed to improve the quality of elderly trauma care, especially with regard to triage decisions and endpoint resuscitation. This shows the importance of a noninvasive modality, such as ultrasound, to determine fluid resuscitation.

Our review describes how ultrasound can assess the dynamic fluid status in the trauma patient. We outline the evolving evidence of the role of ultrasound for fluid resuscitation, with a specific emphasis on the limited transthoracic echocardiogram (LTTE), bedside echocardiographic assessment in trauma/critical care (BEAT), focused rapid echocardiographic examination (FREE), and focus assessed transthoracic echocardiography (FATE) exams. We also describe how to perform the LTTE exam. Our objective is to show how ultrasound can be used at the time of patient arrival in the trauma bay with immediate interpretation and how it can continue to be used throughout the patient's hospital course to assess and guide response to medical interventions. Ultrasound is noninvasive, presents minimal risk to the patient, and can be performed repetitively to reassess fluid responsiveness. This technique is user-dependent, therefore the operator requires training and practice for obtaining and interpreting images.

2. Evidence-based studies

In 2000, Kimura et al. proposed a limited or focused transthoracic echocardiogram examination. This focused examination was defined as a transthoracic echocardiogram (TTE) performed by healthcare providers at the bedside to specifically assess ventricular function, volume status, and the presence of pericardial effusion [10]. The authors argued that if focused training could be provided to non-cardiologists to answer specific questions regarding hemodynamic status, the use of ultrasound could become the standard of care.

Meanwhile, other studies sought to determine the extent to which ultrasound was predictive of hemodynamic status. In 2005, a prospective observational study of 31 volunteers measured changes in the inferior vena cava diameter (IVCd) in relationship to blood loss [11]. The volunteers donated 450 ml of blood and researchers measured their IVCd before and after the blood donation. The study found a statistically significant difference in the before and after measurements, suggesting that ultrasound is a reliable indicator of blood loss even with small amounts of blood. This study prompted other studies to explore how critical care intensivists can effectively learn and apply the skills of focused, goal-directed transthoracic echocardiography in trauma.

In 2008, the University of Texas Southwestern Medical Center published the bedside echocardiographic assessment in trauma/critical care (BEAT) examination, describing how each letter in the "BEAT" acronym corresponds to a specific objective and window on echocardiogram (Table 1) [12]. Beat, or cardiac index, measures cardiac function. Effusion assesses the presence of a pericardial effusion. Area assesses left ventricular function and size through the parasternal short axis view and right ventricular function and size through the apical four chamber view. Tank measures volume status or preload. Measured in the M mode in the parasternal long axis view, preload is determined by the mitral valve waveform, IVC diameter, and percent of IVC collapse during inspiration. Researchers developed a curriculum for an 8 to 10 h course of didactic and hands-on training for non-cardiologists and showed the BEAT exam to be as accurate as a pulmonary artery catheter for estimating central venous pressure and cardiac index [13].

Building on this, a transthoracic focused rapid echocardiographic examination (FREE) was developed to answer specific questions regarding the direction of resuscitation [14]. FREE uses hemodynamic information obtained from the ultrasound in conjunction with the patient's clinical scenario to translate this into broad treatment recommendations regarding the use of fluid, inotropic agents, and vasopressors. The FREE is similar to BEAT in that it collects clinical data on cardiac function, preload, and cardiac anatomy (Table 1). In a 2011 study, Ferrada et al. evaluated 53 patients using the FREE exam over a nine-month period. They found the FREE technique answered clinical questions in 87% of patients, which led to a modification in the plan of care for more than half of the patients (54%, n = 29/53) [14].

The focus assessed transthoracic echocardiography (FATE) examination is a similar technique for critically ill patients (Table 1). This examination uses four scanning positions to assess cardiac wall thickness and cavity dimensions and relates these findings to the clinical context of hemodynamic instability [15]. The FATE protocol has been used in ICU and peri-operative settings [16–18].

In 2011, the limited transthoracic echocardiogram (LTTE) exam was further studied to aid in the resuscitation of trauma patients [19]. LTTE is a qualitative exam that does not require any measurements other than two dimensional ultrasound images [19]. Since resuscitation often begins in the trauma bay without invasive monitoring modalities, the LTTE exam provides important information to guide early resuscitation (Table 1). This was shown in a study of 148 trauma patients who presented to the trauma bay with a mean arterial pressure (MAP) of 60 mmHg or lower [20]. The LTTE exam diagnosed 121 patients with hypovolemia who were subsequently resuscitated with volume. Twenty-seven (18%) patients had euvolemia on LTTE, correlating to their hemodynamic instability being attributable to head injury (n = 14), heart dysfunction (n = 5), spinal shock (n = 4), pulmonary embolism (n = 3), and stroke (n = 1). Resuscitation in these patients was then targeted towards treating the underlying pathology, minimizing the risk of fluid overload.

On the heels of this study, a second study evaluated 215 hemodynamically unstable trauma patients with a MAP less than 60 mmHg, a systolic blood pressure of less than 100 mmHg and/or a heart rate greater than 120 beats per minute [21]. These patients were randomized to receive an LTTE or standard evaluation without LTTE in the trauma bay. Compared to patients who did not undergo