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Integrating lung ultrasound in the hemodynamic evaluation of acute circulatory failure (the fluid administration limited by lung sonography protocol) ☆

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Abstract In circulatory failure, fluid administration limited by lung sonography protocol uses lung ultrasound artifacts and makes sequential diagnosis of obstructive, cardiogenic, hypovolemic, and septic shock. Lung ultrasound is used along with simple cardiac and vena cava analysis. Whenever echocardiography cannot be performed, fluid administration limited by lung sonography protocol is favored because of its simplicity and could prove contributive. It is based on the presence (B profile) or the absence (A profile) of interstitial pulmonary edema. However, the latter does not represent actual alveolar edema, and transthoracic echocardiography is still used by intensivists as a pivotal hemodynamic measure. Tissue Doppler imaging facilitates the estimation of left ventricular filling pressures, whereas assessing right ventricular function is of prognostic value in states of shock due to massive pulmonary embolism and acute respiratory distress syndrome. In mechanically ventilated patients, poor acoustic windows are evident and performing transesophageal echocardiography may be necessary. Whenever noninvasive hemodynamic measures are inconclusive, in a deteriorating patient, a pulmonary artery catheter may be placed. Ultrasound is not a therapy but a guide for treatment, and physicians should aim to treat underlying pathologies. Despite its limitations, general chest ultrasound (lung and cardiac ultrasound) is a powerful diagnostic and monitoring tool reflecting an era of genuine "visual" medicine.

Abbreviations: ICU, Intensive Care Unit; LU, Lung Ultrasound; TTE, Transthoracic Echocardiography; TEE, Transesophageal Echocardiography; TDI, Tissue Doppler Imaging; LV, Left Ventricle; RV, Right Ventricle; LVEDP, Left Ventricular End-Diastolic Pressure; IVC, Inferior Vena Cava; PAC, Pulmonary Artery Catheter; PAOP, Pulmonary Artery Occlusion Pressure; PE, Pulmonary Edema; SIRS, Systemic Inflammatory response Syndrome; FALLS, Fluid Administration Limited by Lung Sonography; FEEL, Focused Echo Evaluation in Life Support; FATE, Focused Assessed Transthoracic Echocardiography; FAST, Focused Assessed Sonography in Trauma.

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1. Introduction

Assessing hemodynamic function in acute circulatory failure is the routine work of the intensivist. The trend moves from pulmonary artery catheterization [1], now in decreasing use [2-14], to transthoracic echocardiography (TTE) [15-23]. Many tools are also used: analysis of inferior vena cava (IVC), continuous cardiac output devices, esophageal Doppler, pulse pressure variation, oxygen transport assessment, analysis of tissue oxygenation, gastric tonometry, laser Doppler flowmetry, and near-infrared spectroscopy [24-27]. This substantial number allows thinking that the criterion standard method is currently missing. Lung ultrasound (LU) was introduced in the critical care practice since 1989, due to the pioneering work performed in Francois Jardin's Intensive Care Unit (ICU) [28,29]. The former facilitated the prompt diagnosis of pneumonia, pulmonary edema (PE), pulmonary embolism, pneumothorax, severe asthma, and exacerbation of chronic obstructive pulmonary disease [28-30]. There is no consensus for the use of LU as measure of the hemodynamic status in the critically ill. Hence, we analyze the role of LU in the evaluation of acute circulatory failure by illustrating the end points of the fluid administration limited by lung sonography (FALLS) protocol; moreover, we discuss the advantages and disadvantages of LU compared with the hemodynamic assessment of shock states by TTE.

1.1. The FALLS protocol

The concept of *clinical volemia* indicates that we are interested in early demonstration of fluid overload at the main vital organ, supposedly fluid-free, rather than following indirect parameters such as changes in left ventricular (LV) or IVC size. Lung ultrasound can accurately demonstrate interstitial edema [31] with steep learning curve [32] at an early stage [33]. Interstitial syndrome is described from a particular comet-tail artifact called the B line. Multiple B lines are called lung rockets (Fig. 1). Disseminated lung rockets in the critically ill indicate PE, schematically [30,34]. The B profile, that is, lung rockets associated with lung sliding, indicates hemodynamic PE [30]. The normal lung surface shows horizontal artifacts called A lines (Fig. 1). We apply the probe on 2 standardized Bedside Lung Ultrasound in Emergency (BLUE) points at the anterior chest wall, enabling fast protocols [35]. The predominance of A lines showed a 93% specificity and a 97% positive predictive value when diagnosing pulmonary artery occlusion pressure (PAOP) 18 mm Hg or greater [36]. We have previously documented a limited investigation for analyzing a simple model of heart, associated with lung and veins in acute circulatory failure [29]. In connection with any other available tool (history, physical examination, monitoring of IVC dimensions, comprehensive echocardiography, etc), the intensivist will sequentially rule out the usual causes of circulatory failure. Other causes (anaphylaxis, spinal shock, etc) occurring in evident setting are not in our scope. Fig. 2 shows the outline of the FALLS protocol used in the differential diagnosis of shock states: (1) obstructive shock: this limited investigation protocol first rules out pericardial tamponade, a rare but easy-to-diagnose life-threatening condition. We are applying simple 2-dimensional echocardiography to perform cardiac function analysis (ie, hypocontractility, rapid accumulation of pericardial fluid, etc) by using transthoracic and/or subxiphoid pericardial windows. Then, we rule out pulmonary embolism, unlikely when a nondilated right ventricle (RV) is seen in patients with acute circulatory failure. If the cardiac window is not available, the well-known BLUE protocol can be used instead, that is, lung and venous analysis with 81% sensitivity and 99%

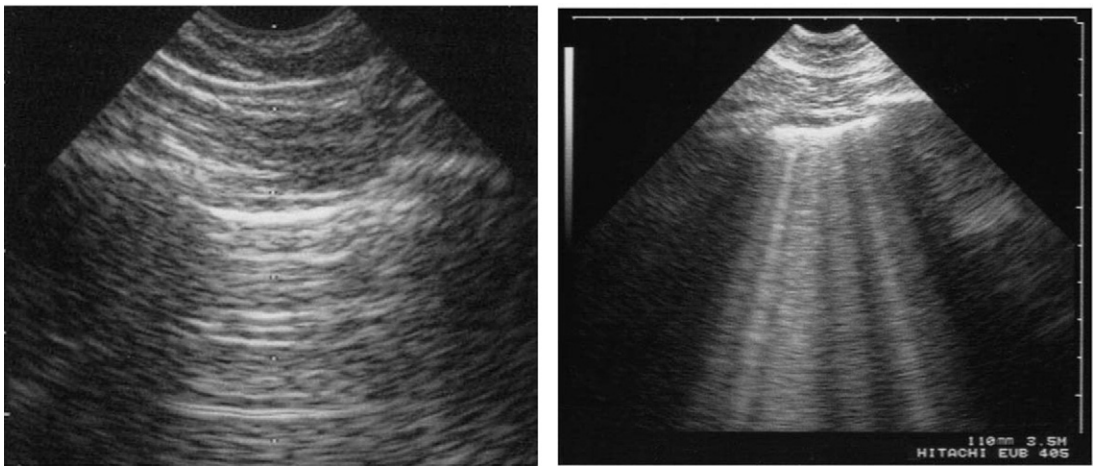

Fig. 1 A lines (left) and B lines (right). The horizontal repetitions of the pleural line are called A lines. The normal lung surface associates A lines and lung sliding. Please observe 6 of the 7 characteristics of the B lines: comet-tail artifacts, arising from the pleural line; long, expanding to the edge of the screen without fading; well-defined; laser ray-like; echoic (like the pleural line); erasing the A lines; and moving in concert with lung sliding (not visible in this image). Three or more B lines visible at the same intercostal space are called lung rockets and indicate interstitial syndrome.