Applications of critical ultrasonography in hemodynamic therapy

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Critical ultrasonography (CUS) is used in almost every branch of critical care medicine because of rapid development of this technology. CUS enables goal-directed, continuous, and dynamic evaluation. The use of CUS in hemodynamic therapy provides a detailed understanding of hemodynamics and optimizes hemodynamic therapy. This article describes the current applications of CUS in hemodynamic therapy from various aspects.

Critical Ultrasonography Can Be Used to Visualize Hemodynamic Theory

The diameter of the vena cava correlates well with central venous pressure.[1] Assessment of the internal diameter and deformation of the vena cava with CUS indicates the volumetric status of patients.[2,3] Moreover, the position of the heart on the Starling curve can be determined on the basis of the increase in the velocity-time integral after fluid infusion. Additionally, the end-diastolic volume increases simultaneously with a change in the ratio of early (E) to late (A) peak diastolic velocity (E/A) in CUS, which represents diastolic function. Therefore, we can “visualize” E/A changing with the velocity-time integral. Furthermore, patients have a larger increase in stroke volume and smaller augmentation in lung water when their heart is functioning on the ascending part of the Starling curve than when their heart is functioning near the top of the curve. On lung ultrasound, the A profile is gradually replaced by the B profile. Therefore, CUS enables visualization of hemodynamic theory.

Critical Ultrasonography Expands Understanding of Hemodynamic Theory

Normal right heart function is the precondition of applying the Starling curve. With an impaired right ventricle, the left heart does not receive a sufficient blood volume, leading to a decrease in cardiac output. Application of the Starling curve is limited by the right heart and its function can be estimated by ultrasound.

Taking into consideration that volume responsiveness is responsiveness to preload of the heart, we suggest that assessment of volume responsiveness should start with cardiac function. Using CUS, patients who require evaluation of volume responsiveness can be rapidly identified. Assessment of right heart function, left ventricular diastolic and systolic function, biventricular systolic dysfunction, and inferior vena cava and arterial tension also helps determine appropriate methods for assessing volume responsiveness in different hemodynamic states. Moreover, during this process, a hemodynamic therapeutic decision can be made, which is more important than the assessment itself.

Critical Ultrasonography Optimizes Hemodynamic Therapy

CUS helps screen for patients with underlying pathophysiological disturbances (*eg*, chronic/congenital heart disease) who are vulnerable to fluid resuscitation because of diastolic dysfunction. This provides clinicians with an “early warning” about high-risk patients and prevents complications. In the case of high-risk patients, use of CUS to evaluate the volume status and filling pressure of the left ventricle (LV) is recommended.

Clinicians have also obtained more information and a better understanding of critical cardiomyopathy with CUS as follows: (1) Dynamic left ventricular outflow tract obstruction (LVOTO) is not uncommon in critically ill patients. Precipitating factors (e.g., hypovolemia, vasoplegia, LV hyperkinesis, and tachycardia) either alone or in combination with an anatomical predisposition (LV hypertrophy) may induce LVOTO. The factors mentioned above are not unusual in the intensive care unit. The use of inotropic drugs or vasodilatation leads to the opposite effect. Therefore, CUS is mandatory for diagnosing LVOTO in some patients with shock. (2) CUS is helpful in identifying and classifying septic cardiomyopathy. Heart dysfunction of septic patients is usually multifactorial and can be divided into four types on the basis of the following CUS findings [Figure 1]. These types include isolated LV diastolic dysfunction, isolated LV

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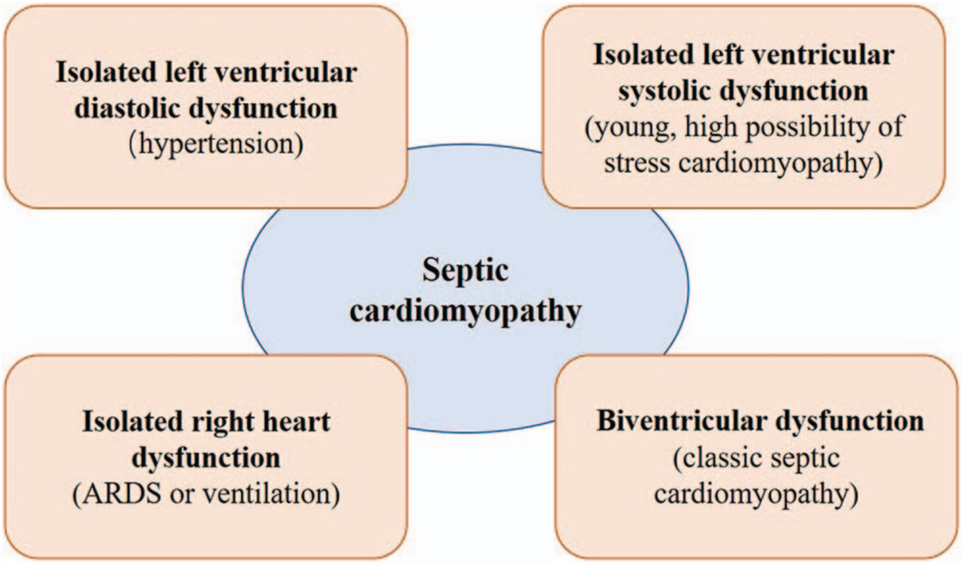

Figure 1: Four types of septic cardiomyopathy as shown by CUS. ARDS: Acute respiratory distress syndrome; CUS: Critical ultrasonography.

systolic dysfunction, isolated right heart dysfunction, and biventricular dysfunction. (3) Takotsubo (stress) cardiomyopathy is characterized by transient systolic and diastolic LV dysfunction with a variety of wall motion abnormalities. Different types of stress cardiomyopathy lead to different complications, and CUS can be used to determine the type of stress cardiomyopathy. Therefore, assessment of the heart by CUS is crucial during hemodynamic therapy for cardiomyopathy.

CUS is used to rule out different types of shock and make a rapid diagnosis of the etiology of shock, helping to provide an early warning, diagnosis, and treatment. The guidelines for sepsis recommend that the hemodynamic status be evaluated by CUS.[4] In patients with nontraumatic hypotension, immediate ultrasound decreases the misdiagnosis rate from 50% to 5% compared with delayed ultrasound.[5] Moreover, after initial assessment and treatment of shock by CUS, it serves as a tool for repeated dynamic observations and evaluations. In patients with shock, CUS is recommended as the preferred modality for initial evaluation of hemodynamics.

For patients with acute respiratory distress syndrome (ARDS), CUS moves beyond the stethoscope, which is fully confirmed during the pandemic of coronavirus disease 2019. Lung ultrasound has excellent consistency with lung computed tomography (CT) for assessing lung aeration. Pathological changes in the lungs are heterogeneous, which means that normal lungs, edematous lungs, and consolidated lungs exist simultaneously. Therefore, lung ultrasound can discover ARDS early, promoting understanding of the pathophysiology. Furthermore, lung ultrasound can be used to evaluate the efficacy of prone positioning and recruitment maneuvers, enable dynamic monitoring, and guide application of these two procedures. A variety of causes can lead to right ventricular dysfunction during ARDS. Therefore, surveillance of right ventricular function during treatment is necessary, and comparing the changes on ultrasound before and after interventions to titrate the treatment is beneficial.

CUS optimizes management of organ hemodynamics. In the kidney, CUS helps optimize the circulation necessary to maintain volume and pressure, screen prerenal and postrenal causes, and evaluate treatment effects. Adequate renal perfusion can be titrated by evaluating renal blood flow with CUS, and the renal resistive index is the most widely used index.[6] Moreover, contrast-enhanced ultrasound provides additional information about renal perfusion. In the brain, the optic nerve sheath diameter (ONSD) is thought to be related to intracranial pressure. A dilated ONSD decreases as intracranial pressure decreases,[7] indicating that ONSD may be a non-invasive tool for dynamically evaluating intracranial pressure. Moreover, transcranial Doppler and transcranial color Doppler are used to track cerebral blood flow, helping to evaluate cerebral vasospasm, congestion, and ischemia, and providing information about cerebral perfusion. In the abdomen, CUS can be used to detect gastroenteric function, such as dynamic changes in wall thickness, cavity size, contents, and movement of the digestive tract. CUS can also be used as an adjuvant in intra-abdominal management of hypertension. Furthermore, evaluation of vasal blood flow (*eg,* in the superior mesenteric artery, celiac trunk, and portal vein) may provide reliable information about gastroenteric perfusion.

CUS assists management of extracorporeal membrane oxygenation (ECMO) in the following situations:[8] (1) At pre-ECMO assessment, CUS can be used to preclude an urgent situation, choose an ECMO mode, and exclude some pathologies and contraindications. (2) For cannulation, CUS enables assessment of potential barriers to cannulation, choosing a cannula size, determining the distal perfusion cannula, and guiding insertion of the cannula. (3) For monitoring during ECMO, a daily CUS examination should be performed while the patient is on ECMO because other methods for assessing cardiac output may be unreliable.

CUS should be used to monitor the size and function of the heart, follow up any pre-existing pathologies, and evaluate intracavitary thrombus, aortic thrombus, the cannula position, opening of the aortic valve, pericardial effusion, inferior vena cava size, and collapsibility. (4) Weaning from ECMO is considered when there are signs of cardiac recovery, although weaning strategies are highly dependent on the center, and there are no well-defined standard operating procedures. (5) In the post-ECMO phase, CUS allows discovery of the presence of a thrombus or obstruction *in situ* after decannulation. A CUS-trained physician should be part of the team caring for patients on ECMO.

Critical Care Transesophageal Echocardiography (TEECC) in Hemodynamic Therapy

TEECC provides a consistently higher image quality and lower dependence of the operator than transthoracic echocardiography (TTE). This is because TEECC is not hampered by the numerous limitations of surface ultrasonography (*eg,* obesity, emphysema, high positive end-expiratory pressure levels, fluid overload, dressings, and drains). Therefore, TEECC is more accurate than TTE in obtaining a diagnosis and allows for reproducible and sequential hemodynamic assessments.[9] A previous study reported that among 60% of changes in strategy in critically ill patients, 48% were due to TEECC alone.[10] The indications for TEECC include an inadequate view in TTE when assessing hemodynamic failure, unexplained hypotension in post-cardiac surgery patients, unexplained hypoxemia, and identification of preload sensitivity.[11] The recently developed miniaturized transesophageal echocardiography probes can remain inserted into the esophagus for a prolonged period without relevant side effects,[12] which could be a future direction for TEECC.

However, there are some limitations of CUS as follows: (1) performance of CUS strongly depends on the operator, with inappropriate operation leading to incorrect data; and (2) in terms of "visualized" data, more research is required on assessment of the microcirculation. Therefore, CUS needs improvement and standardization, which can promote development of critical care medicine. In summary, CUS combines structural assessment with functional monitoring, achieving qualitative and quantitative evaluation, and making the examination much more purposeful. Implementation of a standard CUS procedure in hemodynamics which is called echodynamics is beneficial.

Conflicts of interest

None.

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