Non Invasive Life Savers

Role of Echocardiography in the critically ill child

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Introduction
Monitoring of physiologic variables is an essential part of providing critical care. It is important not only for assessing the condition of the patient on a continuous and real time basis, but also provides vital clues that may help in diagnosis and treatment. Although, the importance of the clinical monitor, i.e. the critical care physician cannot be replaced and will always be the cornerstone of modern day intensive care, it is not without its share of inaccuracies. Therefore, utility of simple bedside invasive and non-invasive monitoring devices to add to the clinical judgement is increasingly being recognized as important. Important among these are tools for monitoring oxygenation such as pulse oximetry (now regarded as the fifth vital sign), arterial blood gases; devices for monitoring ventilation such as capnometry, transcutaneous CO₂; tools for monitoring perfusion such as transcutaneous oxygen monitoring (PtcO₂/PaO₂), gastric intramucosal pH, mixed venous/central venous oxygen saturation (continuous/ intermittent) etc.¹,². Some of the procedures for monitoring perfusion and/or tissue oxygenation are invasive and may end up with complications which may become more cumbersome than the primary illness itself. The concept of noninvasive hemodynamic monitoring is therefore gaining acceptance and popularity worldwide. Non-invasive hemodynamic monitoring helps in early recognition of low flow states thus allowing for early therapeutic intervention. It is easier, quicker, less expensive, and safer than invasive monitoring. Two methods of noninvasive hemodynamic monitoring widely used and popular are bedside ultrasound (BUS) and echocardiography.³,⁴.

These are the evolving tools for pediatric intensivists, not only useful for noninvasive hemodynamic monitoring such as assessment of volume status and cardiac function in the patient with shock, but also have wide applicability such as in evaluation of several disease processes, assist in procedural interventions, assess the complications related to those procedures etc. In this review we would be limiting our discussion to the use of echocardiography in the critically ill child ⁵.

Echocardiography-principles
Echocardiography is an essential monitoring tool in critical care. It provides vital information regarding the hemodynamics of a critically ill child and should be performed in a timely manner in order to intervene early. Echocardiography allows assessment of baseline cardiac structure and function and quickly excludes early, treatable cause of shock such as tamponade. It also helps establish if the shock is of cardiogenic nature due to a structural heart disease ⁶.

Additional hemodynamic information such as cardiac output (CO), end-diastolic volume, global and regional ventricular function, and valvular abnormalities can also be obtained ⁶,⁷,⁸. The systolic function can be assessed by the shortening fraction and the ejection fraction measured with the use of M-mode or cross-sectional two-dimensional images. Measurements from Doppler-derived aortic velocity curves have been used to assess
systolic function, including peak velocity, acceleration time, ejection time, isovolemic contraction time, and the velocity-time integral. Indices derived from these measures include peak rate of acceleration and mean acceleration, which correlate with systolic performance. The ratios of acceleration time to ejection time and of isovolemic contraction time to acceleration time also maybe used as indices of ventricular function. The diastolic function is assessed by standard measures of ventricular relaxation or Adenosine Triphosphate dependent part of ventricular diastole that include-E wave, A wave, E/A ratio, E', A' and myocardial performance index (MPI) or Tei index by Doppler Echocardiography. Of all these parameters, early diastolic mitral annular velocity (E'), as measured by tissue Doppler imaging (TDI), reflects left ventricular (LV) relaxation and is independent of both preload and heart rate (HR). Therefore, it is often the preferred parameter for assessing diastolic function in patients with shock. For assessing global dysfunction MPI is often preferred as it combines features of both systolic and diastolic function. It is calculated by dividing the total isovolemic time (IVCT + IVRT) by the Ejection Time (ET).

Several new techniques have been developed, including tissue Doppler imaging and color kinesis imaging, to evaluate ventricular function objectively. The correlation with myocardial indices in children however, has not been well established. Other improvements and innovations in echocardiography include three-dimensional echocardiography with volumetric data. This technology enables the delineation of mass-volume relationships and function, especially of the right side of the heart, which are difficult to calculate with two dimensional techniques.

**Uses of diagnostic echocardiography**

a. In the pediatric emergency department (PED)

Echocardiography in the PED can be used for two main purposes. First, it can be used to help differentiate the causes of shock. It can provide information on cardiac wall motion, chamber size, and pericardial fluid. Enlarged ventricular chambers and hypokinesis may be evidence of ventricular failure, whereas small heart chambers and hyperkinesis may suggest hypovolemic shock. Echocardiography performed by emergency physicians has been shown to be able to detect even small quantities of pericardial fluid easily. The rapid exclusion of pericardial effusion as the cause of shock can allow the physician to entertain other causes more quickly, whereas ultrasound can be used to help guide pericardiocentesis.

A second application of echocardiography in the ED is in cases of pulseless electrical activity (PEA). Echocardiography showing visible cardiac activity in the patient with PEA should prompt an aggressive search for a reversible cause (ie, tension pneumothorax, hypovolemia, and cardiac tamponade). Conversely, absence of cardiac activity is a poor prognostic sign and may prompt early cessation of resuscitative efforts. There have also been anecdotal reports of emergent echocardiography performed in the ED contributing to the diagnosis of and survival from myocardial rupture as a result of blunt cardiac trauma, penetrating trauma, or myocardial infarction.

b. In the pediatric intensive care unit (PICU)

Bedside echocardiography performed by intensivists is gaining increasing popularity as a way of determining sepsis induced myocardial dysfunction or SIMD and volume status early in the course of illness. Estimating myocardial performance and intravascular volume status from clinical examination may be difficult in patients with septic shock who have not responded to 40-60 ml/kg fluid and are also on inotrope and/or vasopressor
combination. Under these circumstances, echocardiographic assessment may be useful in delineating the heterogeneous cardiovascular profiles. However, experience with the use of this technique is limited in pediatric septic shock. The limited evidence available shows favourable outcomes in terms of mortality in patients intervened. In a prospective observational study of patients with unresolved septic shock after infusion of 40ml/kg fluid in the first hour by Ranjit S et al, the authors made the following observations. Fifty-six percent were found to be in warm shock and 44% in cold shock. The most common echocardiography findings were impaired left ventricular function with or without right ventricular function in 40% of the patients and hypovolemia in 33%. Echocardiography, along with invasive arterial pressure monitoring, allowed fluid, inotropy, and vasopressors to be titrated more precisely in 87.5% of patients. Shock resolved in 46 of 48 patients (96%) and 44 patients (91.6%) survived to discharge. The authors thus concluded that echocardiography was a simple noninvasive tool to determine the cause of low cardiac output and the physiological basis for adjustment of therapy in patients who remained in shock despite 40mL/kg fluid (9). The prevalence of SIMD in their study was 39.6% involving both ventricles. In another study on prevalence and outcome of diastolic dysfunction in children with fluid refractory septic shock (shock despite 60ml/kg fluid boluses) by our team, we observed that the prevalence of diastolic dysfunction was 41.1% (95%CI: 27.8 to 54.4) and the mortality rate 43% in those with diastolic dysfunction. We also observed that those with diastolic dysfunction tended to have higher mean CVP (p<0.0001). Although limited, these observations reiterate the importance of bedside echocardiography early in the course of illness of children with septic shock so that further inotropes/vasopressors and fluids could be titrated optimally to achieve the desired resuscitation endpoints.

The myocardial dysfunction seen in sepsis is different physiologically from that due to acute fulminant myocarditis or myocarditis due to other causes. Most patients with SIMD are under filled at initial presentation, as compared to those with acute myocarditis due to other causes. Assessment of simultaneous volume status therefore is of utmost importance for improving outcomes. Assessment of respiratory variation in inferior vena cava diameter or VTI in the aorta or left ventricular outflow tract, as well as qualitative assessment of left ventricle size and motion is commonly used to identify preload-dependence. With more advanced training, the intensivist can use respiratory variation of SV(stroke volume) determined by Doppler echocardiography and changes in SV after the passive leg maneuver to identify volume responsiveness. In a non-randomized experimental study of 40 patients with circulatory failure, the authors assessed the hemodynamic parameters such as stroke volume and cardiac index at baseline, after passive leg raising, at second baseline, and after volume expansion (10ml/kg normal saline infusion over 15 mins) using Doppler echocardiography. The hemodynamic changes induced by passive leg raising were monitored. Nearly 50% of patients had a cardiac index increase of >10% after volume expansion. There was significant relation between changes in cardiac index to predict fluid responsiveness. An increase in cardiac index by ≥ 10% induced by passive leg raising predicted preload-dependent status with a specificity of 85%.

Apart from the above indications, echocardiography in the ICU, has been used for procedures such as confirming cannula position during pediatric extracorporeal membrane oxygenation and even for assessing clinically significant abnormal hemidiaphragm motion. In a study of 100 pediatric patients requiring ECMO, in nearly 12% patients with cannula position confirmed on chest X-ray, echocardiography identified abnormal cannula position prompting repositioning. In the other study on comparison of fluoroscopy with 2-D echocardiography for assessing abnormal hemidiaphragm motion in 36 pediatric cardiothoracic patients, the authors found a sensitivity and specificity of 100% and 81% respectively for echocardiography as compared to 100 and 74% for fluoroscopy. Their study results therefore supported the use of echocardiography in the assessment of diaphragm function and the authors also suggested that when the diaphragm is clearly visualized by echo, the addition of a fluoroscopic study would not add much to the clinical value.
Conclusion

To conclude, owing to its non-invasive, portable and widespread applicability in noninvasive hemodynamic monitoring in the PICU, echocardiography is quickly becoming a necessity rather than an optional one. For the pediatrician caring for the acutely ill child it would greatly add to the clinical judgement if performed in a timely and correct manner. Estimation of volume status, cardiac output, and function in patients with circulatory failure, especially in children with fluid refractory septic shock may be considered definitive indications. While its use for confirmation of cannula placement during ECMO and assessment of hemidiaphragm motion abnormalities may be considered relative indications.

Finally, transthoracic echocardiography is a skill that can be achieved up to a certain standard by most intensivists. However, we need to remember that, intensivists should not perform echocardiograms independently unless they are comprehensively trained and accredited. There is no such thing as a “basic echo” in children. An inexperienced operator can obtain suboptimal images and misinterpret optimal ones. The clinical consequences of these mistakes can be profound. Therefore, proper training and expertise are essential for carrying out this useful procedure at the bedside.

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References


