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Echocardiography & Focused Cardiac Ultrasound

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Abstract

Objectives—The following review will describe the use of focused cardiac ultrasound performed by non-cardiologists and its role as an acute hemodynamic monitoring tool in pediatric cardiac critical care.

Data Source—MEDLINE, PubMed

Conclusion—The use of focused cardiac ultrasound has grown tremendously over recent years, and is increasingly being performed and interpreted by intensivists, anesthesiologists and emergency medicine physicians. These imaging techniques are useful in establishing etiologies of cardiac dysfunction and should compliment the physical examination and standard hemodynamic monitoring.

Keywords

echocardiography; pediatrics; hemodynamic monitoring; ventricular function; valvar disease; pulmonary hypertension

Introduction

The use of limited diagnostic ultrasound and focused cardiac ultrasound (FoCUS) in pediatric critical care has expanded (1–3). When utilized in cardiac critical care, FoCUS should be performed to answer focused questions and must be interpreted in the clinical context in which it was obtained. The application of critical care ultrasound for cardiovascular assessment should be short in duration, used as an adjunct not in place of the physical examination and should generally be limited to the assessment of: systolic ventricular function, valvar regurgitation and stenosis, pulmonary systolic arterial pressure, the pericardial space, and intravascular volume status.

Training & Imaging techniques

Historically, echocardiography interpreted by a cardiologist has been the first line imaging modality of choice in critical care to delineate cardiac disease not understood with available clinical data. Recently, the use of limited echocardiography or FoCUS by non-cardiology

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trained providers has become commonplace (1–3). Limited transthoracic echocardiograms are increasingly being performed and interpreted by pediatric and adult intensivists, anesthesiologists and emergency medicine physicians. Emergency medicine resident curricula formally include ultrasound education including echocardiograms, a practice that is supported by the American Society of Echocardiography (4). The advent of portable and inexpensive ultrasound platforms that produce high-quality images has contributed to the evolving use of echocardiography as an acute monitoring modality, readily enabling critical care physicians to perform a timely and accurate study in order to establish a diagnosis and to monitor responses to interventions. With this approach, echocardiography plays an integral role in the acute management of critically ill patients.

Studies have shown that with adequate training the accuracy of these studies performed by non-cardiologists is very good (5–7). International guidelines and recommendations have outlined the specifics of a FoCUS exam: a) goal directed, b) problem oriented, c) limited in scope, d) simplified, e) time sensitive and repeatable, f) qualitative or semi-quantitative, g) performed at the point of care, and h) usually performed by clinicians (3). The use of FoCUS is not intended to replace comprehensive echocardiographic examination and clinical questions beyond the scope of FoCUS should be confirmed by complete echocardiographic evaluation and cardiology consultation.

Assessment of Ventricular Function

Myocardial function is a complex entity influenced by a number of rapidly changing dynamics including preload, afterload, heart rate and contractility. The two most common ejection phase indices to assess systolic function are ejection fraction and fractional shortening. Both measures are dependent on loading conditions (i.e., preload and afterload). Increased preload as occurs with atrioventricular or semilunar valve regurgitation will increase the end-diastolic volume and the ejection fraction while increased afterload will decrease the stroke volume and ejection fraction with neither state indicative of an alteration in intrinsic myocardial function (i.e., contractility).

Fractional shortening assesses the change in the left ventricular short axis diameter based on one-dimensional wall motion analysis or M-mode echocardiography. The primary limitation of this technique is that the contraction of the left ventricle cannot be assumed to be entirely uniform or symmetric and M-mode interrogation may not capture regional differences in wall motion and wall thickening. Fractional shortening (FS) is calculated using the end diastolic dimension (EDD) and end systolic dimension (ESD) of the ventricle with the equation: $FS (\%) = (EDD - ESD)/EDD \times 100$.

Two -dimensional (2D) imaging measures left ventricular systolic function by quantifying changes in ventricular volume during the cardiac cycle. The standard 2D echocardiographic view is performed in the apical four or two-chambered view. The ejection fraction (EF) is calculated using the Simpson or modified Simpson method, which divides the left ventricle into cylinders or disks and uses the radius and length of the multiple disks measured to calculate left ventricular volumes $EF (\%) = EDV - ESV/EDV \times 100$, where EDV and ESV are end-diastolic and end-systolic volumes, respectively. Limitations of this method include:

dependence on an elliptical or bullet shaped chamber (limiting its use to an assessment of left ventricular systolic function), optimal delineation of the endocardial-blood interface and potential foreshortening of left ventricular length. Further, in children with high heart rates, the echocardiogram may not capture the true ends of the cardiac cycle. For those with experience reading echocardiograms, there is a very good correlation between visually estimated and measured ejection fractions (8, 9).

Assessment of right ventricular systolic function by echocardiography has a number of limitations. The right ventricle lacks uniform geometry that prevents quantitative 2D echocardiographic assessments of stroke volume. However, ultrasound remains an important tool to assess qualitative right ventricular systolic function as well the etiologies of right ventricular pathology and pulmonary hypertension.

Assessment of Valvar Stenosis and Regurgitation

Echocardiography is a useful diagnostic tool for assessing valvar regurgitation or stenosis. Pulse wave Doppler interrogation and color flow assessment of semilunar and atrioventricular valves can provide important data to assist clinical management.

The assessment of semilunar and atrioventricular valves for regurgitation should include Doppler analysis and color flow assessment of the regurgitant jet. A semi-quantitative estimate of regurgitation severity can be determined by color flow assessment; however, if the flow is asymmetric caution should be taken not to underestimate the degree of regurgitation. In addition to evaluating the degree of regurgitation, FoCUS should include analysis of the mechanism of the regurgitation (e.g., non-coaptation, annular dilatation, intrinsic valvar anomalies).

Evaluation of valvar stenosis includes 2-dimension evaluation, color flow evaluation and Doppler assessment of pressure gradients (10, 11). Two-dimension evaluation of stenosis should focus on the level of stenosis – valvar, subvalvar or supra-valvar - and the morphology of the valve. Doppler interrogation allows one to determine the pressure gradient across the valve and can be followed sequentially over time. The degree of stenosis is estimated by the modified Bernoulli equation from the peak instantaneous Doppler velocity (pressure gradient = $4v^2$, where v is the velocity of blood as it accelerates across a narrowed orifice), which correlates well with invasive measures. Accurate assessment requires proper alignment of the ultrasound probe with the flow jet. Additionally, the degree of stenosis will be underestimated in patients with decreased myocardial function and stroke volume.

Right Ventricular Pressure/Pulmonary Systolic Arterial Pressure

The pulmonary artery systolic pressure can be estimated by measuring the tricuspid valve regurgitant jet velocity and applying the modified Bernoulli equation. This measurement added to the central venous pressure correlates well with the right ventricular systolic pressure and in the absence of obstruction to right ventricular outflow also estimates the pulmonary arterial systolic pressure. Another method for estimating the pulmonary arterial systolic pressure is to evaluate the position and orientation of the interventricular septum during ventricular systole. The transeptal pressure gradient determines the position and

orientation of the septum throughout the cardiac cycle. Under normal conditions, left ventricular pressures exceed right ventricular. As a result, the interventricular septum bows into the right ventricle throughout the cardiac cycle. Studies have shown that with systolic flattening of the interventricular septum right ventricular systolic pressure is at least the half systemic pressure (12).

Evaluation of Intravascular Volume Status

Management of intravascular fluid shifts is common in critically ill children. The assessment of surrogates for ventricular preload and intravascular volume status including right atrial/central venous pressure and pulse wave variation are poorly correlated or inaccurately assessed by clinicians (13). Many of these surrogates for ventricular preload are invasive. Multiple adult studies studying ultrasound examination of the inferior vena cava as a noninvasive measure of preload have shown conflicting results (14–16).

Assessment of the Pericardium

The FoCUS examination is the imaging study of choice for diagnosing a pericardial effusion and for determining if tamponade physiology is present. The rate at which the pericardial fluid accumulates is an important determinant of its clinical significance. The pericardium is predominantly fibrous and has a limited degree of elasticity. However if the rate of fluid accumulation is gradual, the operative distensibility of the pericardium or its compliance increases. In any case, as intrapericardial fluid accumulates and pericardial pressure rises, and the transmural pressure for the right atrium and right ventricle becomes negative, the respective chamber collapses, indicating the presence of tamponade physiology. Because the right atrium is more compliant than the right ventricle, right atrial collapse is a more sensitive indicator of tamponade physiology than right ventricular collapse.

Other Uses

An estimate of chamber sizes and ventricular wall thickness can be made. Echocardiography can be used to delineate causes of hypoxemia. A contrast echocardiogram using agitated saline or Doppler may be used to detect right to left intracardiac shunting; the use of bubble contrast echocardiography may also be used to demonstrate the presence of a pulmonary arteriovenous malformation or systemic veno-venous collateral between the Glenn circuit and the common atrium or pulmonary veins (17, 18), for example.

Conclusion

FoCUS and limited, goal-directed echocardiography training should be integrated into pediatric critical care training programs and advanced fellowships such as cardiac critical care. The utility of the examinations depends on the quality of the imaging and the ability to correctly interpret the study. While no standards exist for training, ideally all FoCUS exams and limited echocardiograms should be supported by full cardiology service and echocardiographic capabilities to confirm and elaborate on findings. Training in pediatric FoCUS must include facets of ultrasound basics, cardiac anatomy and modalities to assess left and right ventricular function. While multiple authors have reported their successful

institutional experiences with the development of specific pediatric critical care cardiac ultrasound curricula, standardization and consensus training recommendations for pediatric critical care medicine are lacking. Standardized training guidelines for FoCUS and limited echocardiography must be developed to ensure safe, cost-effective and uniform care.

References

1. Lambert RL, Boker JR, Maffei FA. National survey of bedside ultrasound use in pediatric critical care. *Pediatr Crit Care Med*. 2011; 12(6):655–659. [PubMed: 21725274]
2. Klugman D, Berger JT. Echocardiography as a hemodynamic monitor in critically ill children. *Pediatr Crit Care Med*. 2011; 12(4 Suppl):S50–54. [PubMed: 22129550]
3. Via G, Hussain A, Wells M, et al. International evidence-based recommendations for focused cardiac ultrasound. *J Am Soc Echocardiogr*. 2014; 27(7):683e1–683e19. [PubMed: 24951446]
4. Labovitz AJ, Noble VE, Bierig M, et al. Focused cardiac ultrasound in the emergent setting: a consensus statement of the American Society of Echocardiography and American College of Emergency Physicians. *J Am Soc Echocardiogr*. 2010; 23:1225–1230. [PubMed: 21111923]
5. Manasia AR, Nagaraj HM, Kodali RB, et al. Feasibility and potential clinical utility of goal-directed transthoracic echocardiography performed by noncardiologist intensivists using a small hand-carried device (Sonoheart) in critically ill patients. *J Cardiothorac Vasc Anesth*. 2005; 19:155–159. [PubMed: 15868520]
6. Kobal SL, Trento L, Baharami S, et al. Comparison of effectiveness of hand-carried ultrasound to bedside cardiovascular physical examination. *Am J Cardiol*. 2005; 96:1002–1006. [PubMed: 16188532]
7. Spurney CF, Sable CA, Berger JT, et al. Use of a hand-carried ultrasound device by critical care physicians for the diagnosis of pericardial effusions, decreased cardiac function, and left ventricular enlargement in pediatric patients. *J Am Soc Echocardiogr*. 2005; 18:313–319. [PubMed: 15846157]
8. Rich S, Sheikh A, Gallastegui J, et al. Determination of left ventricular ejection fraction by visual estimation during real-time two-dimensional echocardiography. *Am Heart J*. 1982; 104:603–606. [PubMed: 7113901]
9. Hope MD, de la Pena E, Yang PC, et al. A visual approach for the accurate determination of echocardiographic left ventricular ejection fraction by medical students. *J Am Soc Echocardiogr*. 2003; 16:824–831. [PubMed: 12878991]
10. Pearlman AS, Scoblionko DP, Saal AK. Assessment of valvular heart disease by Doppler echocardiography. *Clin Cardiol*. 1983; 6(12):573–587. [PubMed: 6362941]
11. Richards KL. Assessment of aortic and pulmonic stenosis by echocardiography. *Circulation*. 1991; 84(3 Suppl):I182–187. [PubMed: 1884484]
12. King ME, Braun H, Goldblatt A, et al. Interventricular septal configuration as a predictor of right ventricular systolic hypertension in children: A cross-sectional echocardiographic study. *Circulation*. 1983; 68:68–75. [PubMed: 6851056]
13. Iregui MG, Prentice D, Sherman G, et al. Physicians' estimates of cardiac index and intravascular volume based on clinical assessment versus transesophageal Doppler measurements obtained by critical care nurses. *Am J Crit Care*. 2003; 12(4):336–342. [PubMed: 12882064]
14. Stawicki SP, Adkins EJ, Eiferman DS, et al. Prospective evaluation of intravascular volume status in critically ill patients: does inferior vena cava collapsibility correlate with central venous pressure? *J Trauma Acute Care Surg*. 2014; 76(4):956–963. discussion 963–954. [PubMed: 24662857]
15. Stawicki SP, Braslow BM, Panebianco NL, et al. Intensivist use of hand-carried ultrasonography to measure IVC collapsibility in estimating intravascular volume status: correlations with CVP. *J Am Coll Surg*. 2009; 209(1):55–61. [PubMed: 19651063]
16. De Lorenzo RA, Morris MJ, Williams JB, et al. Does a simple bedside sonographic measurement of the inferior vena cava correlate to central venous pressure? *J Emerg Med*. 2012; 42(4):429–436. [PubMed: 22197199]

17. Chang R-K, Alejos JC, Atkinson D, et al. Bubble contrast echocardiography in detecting pulmonary arteriovenous shunting in children with univentricular heart after cavopulmonary anastomosis. *J Am Coll Cardiol.* 1999; 33:2052–2058. [PubMed: 10362213]
18. Magee AG, McCrindle BW, Mawson J, et al. Systemic venous collateral development after the bidirectional cavopulmonary anastomosis. *J Am Coll Cardiol.* 1998; 32:502–508. [PubMed: 9708483]

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