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Neonatologist-performed functional echocardiography in the neonatal intensive care unit

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S U M M A R Y

The use of point-of-care functional ultrasound to assess cardiovascular function is gaining interest in the neonatal intensive care unit (NICU). The modality has been in use in adult intensive care units for some time and has often guided management. Clinical signs such as heart rate, blood pressure, and capillary refill time, which physicians traditionally have relied upon, provide limited insight into the adequacy of systemic blood flow and organ perfusion. Enhanced cardiovascular imaging and hemodynamic evaluation offers novel insights regarding the contribution of the ductus arteriosus, myocardial performance and pulmonary hemodynamics to ongoing clinical instability. In addition, it allows more accurate delineation of the nature of the underlying disease process and facilitates the evaluation of response to therapeutic intervention. This review examines the potential clinical role of ultrasound methods in the NICU; specifically, its applications in different disease states, and how the technology may be introduced safely in the NICU.

1. Introduction

Point-of-care ultrasound is increasingly used by neonatologists in the intensive care setting to support clinical decisions. The technology may be applied to evaluation of the neonatal heart, brain, abdomen/pelvis and to facilitate vascular access. This review will focus mostly on neonatologist-performed functional echocardiography. The provision of real-time information on cardiovascular performance and systemic hemodynamics, non-invasive nature of the technique, rapidity of data acquisition and report generation, and ability to perform longitudinal functional assessments have all contributed to the increased use of functional echocardiography by neonatologists in the neonatal intensive care unit (NICU). The lack of a reliable measure of systemic blood flow is one example of a clinical situation which has prompted neonatologists to perform point-of-care echocardiography examinations. Clinical signs such as heart rate, blood pressure, and capillary refill time, which traditionally physicians have relied upon, provide limited insight into the adequacy of systemic blood flow and organ perfusion.[1] Finally, issues of access to echocardiography or a pediatric cardiology service have prompted neonatologists to develop these advanced skills.

This review examines the potential clinical role of ultrasound methods in the NICU; specifically, its applications in different disease states, and how the technology may be introduced safely in the NICU.

2. Evolution of ultrasound in the NICU

The use of point-of-care focused ultrasound for evaluation of the cardiovascular system within the context of clinical decision-making is gaining wide interest. In the acute care setting, non-ultrasound specialists can be trained to provide focused imaging and measurements. This approach does not aim to replace the detailed structural assessments provided by consultative services such as cardiology or radiology. It is designed to support clinical judgment and provide a better understanding of the physiological processes, and monitor the response to treatment; this approach, which combines both clinical examination and bedside echocardiography, has been shown to improve clinical diagnosis and patient management.[2] The point-of-care ultrasound examination is usually directive and focused towards a specific clinical problem. It is usually significantly shorter than a traditional echocardiography evaluation, thereby minimising patient handling. In adult intensive care units, routine use of trans-esophageal echocardiography is common practise. The use of this technique by adequately trained intensivists can change the management of 30% of patients based on the results, and in 10% it may detect severe previously unknown diagnoses.[3]

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The emergence of this modality in the NICU stemmed from the limitations of clinical assessment in cardiovascular monitoring and providing accurate information on systemic blood flow. In addition the complexity and dynamic nature of the transitional circulation, variable responsiveness of the immature myocardium in the early neonatal period, the presence of intracardiac and patent ductus arteriosus (PDA) shunting, makes therapeutic decision-making on clinical evaluation alone challenging. Echocardiography is routinely used in the neonate to assess the structure of the heart. However, obtaining these scans depends on the availability of the cardiologists or access to echocardiography technicians. These scans are usually focused on cardiac anatomy, and only provide a limited snapshot of cardiovascular performance. This approach, however, is inadequate for the assessment of the hemodynamic status and may not meet the ongoing needs of critically ill neonates in the NICU. In addition, evaluating the response to therapeutic interventions requires ongoing assessment by ultrasound.[4] There is increasing evidence that the routine use of functional echocardiography in the neonatal unit does identify cardiovascular compromise, change management,[5] and potentially improve short term outcomes. The introduction of a neonatologist-performed screening program for a hemodynamically significant ductus arteriosus (HSDA) on day 3 of life with targeted intervention was temporally associated with a reduction in the rate of severe intraventricular hemorrhage and duration of ventilation.[6] In addition, Lee et al. showed that portable echocardiography by a neonatologist can provide a quick and accurate method of identifying a PDA with a sensitivity of 87% and a specificity of 71%.[7] Recent studies have also demonstrated that echocardiography in the neonatal unit has a high yield for the diagnosis of structural heart disease and impaired cardiac performance, often resulting in a change of management. Moss et al. reported an 82% complete concordance rate between the scans performed by trained neonatologists and a pediatric cardiologist assessment.[8] Samson et al. reported similar concordance rates in their study.[9] The concerns raised by pediatric cardiologists about the reliability of some hemodynamic measurements are valid. It must be recognized, however, that interpretation of individual hemodynamic measurements in isolation or without careful consideration of their application to the clinical context is likely to lead to erroneous conclusions. Functional echocardiography is likely to have greatest impact when the echocardiography evaluation is of a high quality, comprehensive, and carefully integrated within the clinical scenario.

3. Ultrasound techniques

3.1. Imaging the newborn

Echocardiography evaluation of the newborn is complicated by issues related to patient size and transthoracic acoustic windows. The interpretation of hemodynamic data is totally dependent on the quality of the images, hence the competence of the operator is important. Serial scans of the same patient should ideally be performed by one examiner to limit interobserver variability, and to maximize patient benefit. Functional echocardiography includes evaluation of the heart using two-dimensional (2D) pulsed wave Doppler (PWD), continuous wave Doppler (CWD) and m-mode methods. There are many challenges facing the ultrasonographer, particularly in the setting of preterm infants. As highlighted above, high quality imaging is essential, particularly when Doppler interrogation of vessels is being performed to evaluate blood flow. In preterm infants, image quality may be compromised in the presence of hyperinflated lungs. Imaging neonates with bronchopulmonary dyplasia often poses a particular challenge as the hyperinflated lung fields or areas of air trapping may obstruct the heart, limiting adequate image acquisition. In addition, preterm infants may decompensate with excessive handling or chest compression from overzealous probe positioning to acquire images. All efforts should be directed to limiting the duration of these studies, aiming to gather all the information needed while considering patient stability.

3.1.1. Two-dimensional methods

Two-dimensional imaging is the most common modality and is typically used to illustrate the structural anatomy of the heart. The ultrasound probe sends a sweeping beam from side to side along a particular plane of the heart to generate the 2D image. The frame rate of the probe is the number of sweeps per second. In order to generate seamless images of the moving myocardium, the frame rate needs to be faster than the heart rate of the infant. The most commonly used probe in echocardiography is the curvilinear scanner. This provides a wide field of vision both close to the probe and at depth. The frequency of the ultrasound waves dictates image quality and resolution. Higher frequencies provide enhanced image resolution, but the lower power admissible in infants limits the depth of the image. Conversely, lower frequencies can reach deeper into tissue, but with poorer image resolution. In term and preterm infants a probe frequency range of 7.5–10 MHz provides excellent resolution with adequate tissue penetration (Fig. 1).

3.1.2. m-Mode methods

m-Mode scanning interrogates moving tissue along a single line with respect to time. The time base is displayed in a sideways fashion perpendicular to the line of interrogation. The display screen represents each reflected echo along a line. Stationary echoes are represented as a straight flat line along the screen and moving echoes are represented as curvy lines reflecting movement in relation to time. The clinical applications of m-mode echocardiography include the evaluation of chamber size, wall thickness, valvular motion and quantification of myocardial contractility (Fig. 2).

3.1.3. Doppler imaging

The Doppler effect is the term given to the change in frequency of a wave experienced by an object when there is relative movement between the object and the wave transmitter. In echocardiography, the transmitter (ultrasound probe) is always stationary relative to moving blood cells. Traditionally, Doppler-based echocardiography has been used in clinical practise to evaluate blood flow. The stationary ultrasound probe emits waves which are reflected by moving blood and received by the probe again. The frequency of the emitted waves is different from those reflected back to the receiver within the probe. Each moving cell generates its own Doppler signal which is scattered in all directions. Signals are reflected back to the ultrasound probe by millions of blood cells. The difference in frequencies is then expressed as both an audible pitch and velocity on the screen. The clinical applications of Doppler include PW, CW and colour flow Doppler methods.

3.1.4. Continuous wave Doppler

This is the older and more basic of the two techniques. The transducer generates CWs with simultaneous wave reception. The main advantage of this modality is the ability to accurately measure blood flow at high velocities. This is of particular importance in assessing infants with a restrictive ductus arteriosus, pulmonary hypertension and tricuspid regurgitation, valvular abnormalities or septal wall defects. These lesions usually have velocities of >2 m/s, and therefore CW is ideal for the examination of the full abnormal flow pattern (Fig. 3). Knowing the peak velocity of blood flow between two chambers facilitates the assessment of the pressure