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Review

Neonatal echocardiography

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S U M M A R Y

Echocardiography is a technique within neonatal care increasingly used in acute management of patients because of its potential to guide care and hemodynamic management. However, its use continues to provoke controversy, as it was originally within the purview of pediatric cardiologists trained to identify structural as well as functional heart disease. This article examines some of the echocardiographic techniques available to the neonatologist, their applications, and the concerns surrounding their use on neonatal units.

1. Introduction

Until 25 years ago, echocardiography was mainly used to assess the structural normality of the heart, the patency of the ductus arteriosus, and was often the exclusive purview of pediatric cardiologists. However, neonatologists have become more interested in its potential for the assessment of hemodynamic function in infants in an intensive care setting [1–3]. This interest and the increasing availability of echocardiography with smaller, more convenient technology has resulted in more widespread use in neonatal intensive care units (NICUs) around the world [4].

The common concern raised about its use by neonatologists is the possibility of missing or misdiagnosing congenital heart disease (CHD) [5]. NICU patients with hemodynamic instability are at a higher risk for having underlying CHD, and babies with CHD are more than twice as likely to be born prematurely [6,7]. Whereas some of this effect may result from prematurity of infants with trisomy 21, it is clear that the prevalence of CHD in premature babies is twice that found at term [7]. There is also increased mortality among infants born preterm with a cardiovascular malformation [7]. However, this still means that 98% of preterm babies in the NICU will not have CHD. There are few data for term babies receiving intensive care, but four of 93 infants allocated extracorporeal membrane oxygenation (ECMO) in the UK Collaborative ECMO Trial [8] were found to have CHD, which would be more than four times the prevalence in well term babies.

The overall prevalence of CHD in the NICU is likely to be between 2% and 4%, with most babies unaffected. Whereas this must be taken into account when echocardiography is used, it does not seem logical to limit its use for the majority because of the potential harm for a small minority. A greater caution should be that it is a technique which is itself still unproven in terms of important neonatal outcomes. However, there must be a mechanism to ensure certainty about anatomical normality before the technique can be used safely in a number of clinical settings [5].

2. Definitions

The terms functional echocardiography, point-of-care echocardiography, point-of-care ultrasound, targeted neonatal echocardiography, clinician-performed cardiac ultrasound, and neonatologist-performed cardiac ultrasound all describe the use of echocardiography as an adjunct to the clinical assessment of the neonatal hemodynamic status [5,9–12]. This article focuses only upon this use of echocardiography. North American and European guidelines for practice and training have been published [5], although there is a slightly different approach in Australasia [12]. The former are an exceptionally useful starting point, although still predominantly cardiology-biased, but the latter may in time form a basis for worldwide training of neonatologists.

3. Why is neonatal echocardiography potentially so important?

Overall care provided to sick newborn infants has improved significantly in recent decades but the most prematurely born infants remain at high risk for death and disability [13]. In focusing

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on the obvious respiratory problems of premature and newborn babies, the clinician must acknowledge the lungs as merely one component of the cardiorespiratory system. The cardiovascular component, while essential, is often only considered when blood pressure is low or if a patent ductus arteriosus (PDA) is suspected.

Cardiovascular function is not only clearly linked to survival but also to morbidity. Unfortunately, traditional methods of assessing cardiac function are limited. Ideally, cardiovascular dysfunction in the sick preterm neonate should be identified before it becomes irreversible. Capillary refill time is a poor predictor of cardiovascular function in adults [14], children [15], and neonates [16], and cannot be recommended as an important sign in a predominantly endothermic population. Increasing heart rate was thought to be the major mechanism for increasing cardiac output but this is now known to be incorrect in human neonates. Although cardiac output may increase with rising heart rate, tachycardia has low specificity for predicting cardiovascular compromise. Similarly, reduced urine output and spontaneous activity are not individually predictive, especially in the first 24 h of life. Metabolic acidosis is a non-specific indicator of problems in which cardiovascular dysfunction may be involved. Lactate can predict outcome but as yet is not useful in directing any intervention, although improvement in lactate may predict better outcome [17].

Systemic blood pressure is relatively easy to measure and is widely used as an indicator of cardiac function. The association of a mean arterial blood pressure <30 mmHg with both cranial ultrasound abnormalities and poor outcome [18] and evidence that cerebral autoregulation fails below this level has reinforced this as a point for intervention [19]. However, there is equally compelling evidence that cerebral blood flow depends more on left ventricular output than blood pressure and that mean blood pressures <25 mmHg are neither rare nor associated with adverse outcome in extremely low gestational age babies [20]. Blood pressure is a poor predictor of systemic flow [21] and there is no dependable evidence from which to define a blood pressure threshold for intervention or that such intervention improves outcome [22]. Worryingly, simply increasing blood pressure may actually reduce tissue perfusion in some instances and may cause adverse events [23]. Therefore, before treatment is considered, more information regarding the hemodynamic status of the baby should be obtained. In older critically ill subjects, measurement of cardiac output by thermodilution, continuous Doppler techniques, and derivations from blood pressure waveforms is possible. Continuous Doppler assessment [24] and electrical impedance [25] have been evaluated in neonates but were compared to neonatal Doppler echocardiography as the gold standard.

4. Neonatal echocardiography

Neonatal echocardiography offers a direct view of the cardiac structure including the ductus arteriosus but also offers increasing amounts of functional information, and it is possible to derive estimates of a wide range of hemodynamic parameters. Although the effects of therapeutic interventions have been reported [23,26], it remains to be seen whether it alters neonatal outcomes. However, it offers the possibility of delineating clinical situations to test commonly used treatments in randomized controlled trials. Increasingly, neonatologists perform serial echocardiographic studies [27,28], which would not be possible if relying upon cardiologists.

Although ultrasound measurements have an intrinsic error ranging from about 10% for intra-observer variability up to 15–20% for inter-observer variability, this is similar to other non-invasive measurements [29].

5. Two-dimensional echocardiography

Two-dimensional (2D) echocardiography is used to assess anatomy, to allow accurate positioning of an M-mode cursor, continuous or pulsed wave Doppler cursor, and to obtain a subjective impression of ventricular function. A good understanding of normal cardiac anatomy is essential, and, whereas there are educational resources available [1,2,30,31], the value of mentored clinical experience cannot be underestimated.

Two-dimensional neonatal echocardiography may also demonstrate rare cardiac complications such as intracardiac thrombus and pericardial effusion [32]. In the latter case, early diagnosis can be life-saving.

The standard views in diagrammatic form are the long axis parasternal view (Fig. 1), the short axis parasternal pulmonary view (Fig. 2), the four chamber apical view (Fig. 3), the suprasternal view, and the subcostal view. These, with minor modifications, are used to assess ventricular measurements and function, ventricular output, preload or volume loading, pulmonary pressure, superior vena cava (SVC) flow, and intra-atrial flow, as well as assessing the size and flow through the PDA.

6. Doppler ultrasound

The Doppler principle can be applied to ultrasound because frequency changes when sound is reflected from moving objects. The frequency shift is directly proportional to the velocity of the moving object if the angle of insonation is within 20° of the axis of movement. The various types of Doppler allow estimation of both the direction and velocity of blood flow, allowing calculation of the pressure gradient using a modified Bernoulli equation (pressure gradient $= 4 \times \text{velocity}^2$). By measuring the diameter of a vessel as well as the flow velocity, blood flow can be estimated.

Three types of Doppler are commonly used in neonatal units: pulsed wave, continuous wave, and color Doppler. Pulsed wave permits the operator to focus the velocity assessment to a certain "range gate" shown on the 2D image. However, pulsed wave Doppler cannot assess higher velocities (>2 m/s). Continuous wave Doppler can assess higher velocities but is less focused, assessing the whole path of transmission. These assessments are displayed as a directional velocity–time plot.

Colour Doppler is a derivative of pulsed wave Doppler, where flow direction and velocity are displayed as colors mapped on to a 2D image. Flow away from the probe is usually blue and flow towards is red.

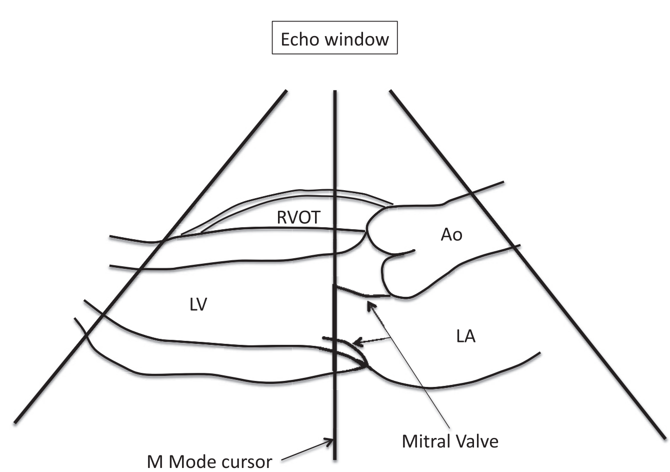

Fig. 1. Long-axis parasternal view. LV, left ventricle; LA, left atrium; RVOT, right ventricular outflow tract; Ao, aorta.