Which parameters of ventricular function should be evaluated in the intensive care unit?

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ABSTRACT

Echocardiography is one of the most powerful diagnostic and monitoring tools available to the modern intensivist, providing the means to diagnose cardiac dysfunction, its underlying cause and suggest therapeutic interventions. Although seemingly simple, meaningful and clinically relevant evaluation of ventricular function is challenging, and standard measures frequently unhelpful. Although at present the widespread application of physiological echocardiography and advanced echocardiographic techniques within intensive care remains disappointingly limited, the huge potential for collaborative research between cardiologists and intensivists within this field is evident.

Key words: echocardiographic assessment, cardiac function, intensive care unit

INTRODUCTION

Evaluation of cardiac function was historically performed using a combination of invasive and non-invasive measures, the gold standard being the pulmonary artery catheter. The potential for echocardiography to evaluate cardiac function in the critically ill was first recognised over 25 years ago. However, only recently has it become mainstream in intensive care, due to increasing availability of ultrasound machines, together with concerns regarding the safety of the pulmonary artery catheter. Although one of the most frequent indications for echocardiography in the general intensive care unit is evaluation of left ventricular function, this remains one of the most complex areas of practice. In general, echocardiographic assessment of ventricular function tends to be limited to evaluating substitute measures of contractility which are highly variable depending upon volume status and pharmacological support, as well as the primary pathology of the patient. Further, normal values have not been well-evaluated in the critical care setting. The primary functions of both ventricles (and the heart) include providing adequate antegrade flow whilst maintaining a low venous pressure, thus demanding evaluation of both systolic and diastolic parameters. Standard functional assessment of ventricular function is somewhat artificially divided into systolic and diastolic phases, depending upon period of the cardiac cycle in which they are measured; however, abnormalities in one phase will inevitably be associated with abnormal findings in the other.

LEFT VENTRICULAR FUNCTION ASSESSMENT: FRACTIONAL SHORTENING AND EJECTION FRACTION

The mechanisms of ventricular function in systole and diastole are complex, with differing orientation of fibres at different muscle layers. Contraction comprises changes in minor and long axis dimensions, rotational contraction, as well as differential basal and apical rotational vectors (left ventricle). Despite this, standard techniques to assess ventricular contractility generally depend upon either linear measures of changes in LV internal dimensions (fractional shortening) or differences between systolic and diastolic areas/volumes (ejection fraction) in the minor axis, rather than thickening of the myocardium per se. Normal values of fractional short-ening and ejection fraction are not known for the critically ill patient population, and values remain highly variable depending upon critical care interventions in addition to the inherent contractility of the myocardium (global or regional). The true value of other less widely used techniques (long axis function and total isovolumic time) has not yet been realised in the ICU setting, and that of emerging techniques (strain & strain rate) remain to be evaluated.

Abnormalities of ventricular contractility will be global or regional depending upon the underlying pathology. Fractional shortening and ejection fraction (Teicholz) depend upon two dimensional linear measurements at the base of the left ventricle, and do not take into account function elsewhere in the ventricle. They should not be used in the presence of wall motion abnormalities (whatever the cause), and do not measure contractility per se, but rather changes in cavity size. Despite its limitations, in cardiology the Simpson's biplane summation of discs remains the most commonly used method for 2D echo volume and ejection fraction calculations - and is the recommended method to date. All measures that depend upon changes in LV dimensions/volumes are highly inotrope, activation and load-dependent, and normal values for the critically ill are unknown.

LEFT VENTRICULAR LONG AXIS FUNCTION: SYSTOLIC-DIASTOLIC INTERACTION AND TIMING

The sub-endocardial fibres of the left ventricle run longitudinally, resulting in the characteristic movement of the mitral

annulus towards the apex of the heart in systole, followed by active retraction in diastole. Regional myocardial ischaemia (either due to coronary artery disease or induced by positive inotropic agents) may result in changes in regional wall motion scores associated with a fall in cardiac output at peak stress. Regional dyssynchrony may also develop, demonstrated by broadening of the QRS duration and the appearance/worsening of post-ejection shortening (M-mode), and suppression of early diastolic mitral flow (transmitral Doppler). Thus, there is potential to diagnose subclinical myocardial ischaemia/ Type I/II myocardial infarction using this simple technique, even when standard measures of ventricular function appear normal and two-dimensional views are suboptimal.

This normal response to increasing inotropy is shortening of the QRS duration with an associated shortening of the t-IVT (measured using Doppler) – a measure of global LV electromechanical dyssynchrony. This is relevant in the critical care arena in two potential scenarios. First, as t-IVT is a major determinant of maximal cardiac output during pharmacological stress, it may be possible to titrate on an individual patient basis the response to positive inotropic agents, in order to minimise electromechanical dyssynchrony and avoid it limiting cardiac output. Second, other factors associated with an increase in tIVT include conduction system disturbances and loading conditions. Although there is little in the literature regarding resynchronisation therapy (A-V and/ or V-V) in the intensive care unit the effects of dyssynchrony are well-recognised (including reduced LV contractility (dP/ dT), pulse pressure, ejection fraction and cardiac output, diastolic filling time, and increased duration of mitral regurgitation and t-IVT). Even simple manipulations of heart rate and AV delay can result in significant improvement in cardiac filling. Global left ventricular electromechanical dyssynchrony measured by t-IVT is common (22% patients in cardiothoracic intensive care), and associated with increased mortality. Emerging case series suggest that resynchronisation therapy may be of use in selected critically ill patients, however, case selection remains key.

LEFT VENTRICULAR FUNCTION: STRAIN AND STRAIN RATE IMAGING

These techniques have been proposed to improve the ability to detect ischaemia and ventricular dysfunction not demonstrable by more conventional echocardiographic techniques. They are measures of myocardial deformation that are basic descriptors of both the nature and function of cardiac tissue. Strain/strain rate can be measured using Doppler or 2D (speckle tracking) echocardiography. Strain rate is measured by obtaining a series of velocity curves (from tissue Doppler imaging (TDI) comprising isovolumic contraction, systolic, diastolic and atrial components) to demonstrate a velocity gradient along a length of ventricular wall. A regression calculation between adjacent tissue velocity data points along this length is used to generate strain rate, which is integrated to calculate strain. Thus strain-rate reflects dP/dT of adjacent areas of the myocardium ($SR = (V1 - V2) / L$), and is thought to be less load-dependent than strain. Strain (ε) is a unitless measure of lengthening and shortening only (defined as the change in distance between two points divided by the initial distance between those two points, $\varepsilon = (L1 - L0) / L0$)), assumes non-compressiblility of tissues, and can be calculated for three axes of myocardial motion, resulting in longitudinal, circumferential and radial strain. The techniques have been well-validated with cardiac magnetic resonance scanning and animal models using sonomicrometry. As data are derived from Doppler imaging (TDI), certain caveats regarding their use exist; in particular sensitivity to signal noise and alignment. By contrast, speckle tracking uses 2D echocardiography to identify areas of correlation within signature blocks of backscattered echocardiographic tissue, and tracks tissue motion accordingly, allowing simultaneous longitudinal, radial, circumferential and also torsion analysis. It avoids the angle-dependency of Doppler, and allows interrogation of multiple vectors of movement simultaneously.

Currently strain rate imaging is regarded as a tool for understanding myocardial mechanics. It is highly sensitive in detecting changes in wall motion, and clinical applications include potential identification of myocardial viability and detection of subclinical ventricular dysfunction. There is little in the ICM literature regard-

ing strain rate imaging, however, emerging studies have suggested the potential use of speckle tracking to detect ventricular dysfunction in septic shock, not appreciated by conventional echocardiography. Here, despite no demonstrable difference in fractional shortening and ejection fraction between controls and children with sepsis being demonstrated, significant abnormalities in circumferential and longitudinal strain, strain rate, radial displacement and rotational velocity and displacement existed. If the emerging paediatric ICM literature is supported by similar findings in the adult ICU, the potential for these techniques to help with early identification and evaluation of myocardial dysfunction in critical care is huge.

RIGHT VENTRICULAR FUNCTION

The right ventricle is exquisitely sensitive to increases in afterload and reduction in coronary perfusion, and fails due to either or both of these, being readily evaluated using echocardiography. In the intensive care unit right ventricular dysfunction is most commonly secondary to increased afterload due to pulmonary disease, ventilation and/or left ventricular dysfunction. A range of conventional echocardiographic techniques are used to assess right ventricular systolic function, however measurement of right ventricular geometry and volumes is complex, and here 3D echocardiography has great potential, although currently limited by image quality in intensive care. A physiological approach to the right ventricle when using echocardiography can provide information with potential to modulate interventions aimed to improve right ventricular performance and/or monitor and modify interventions in order to minimise the adverse effects of therapies commonly used on the intensive care.

DURATION OF TRICUSPID REGURGITATION

The tricuspid regurgitation signal (CW Doppler) is routinely interrogated in order to estimate the severity of any pulmonary hypertension, calculated by the simplified Bernoulli equation (Chapter x), but can be additionally evaluated for its duration. Here, where the regurgitation is prolonged (either due to prolonged systole related to

pulmonary hypertension, or to conduction system disorder) it may temporally limit cardiac filling on both the right and occasionally also the left side of the heart, thereby limiting cardiac output. As with mitral regurgitation of prolonged duration, the cause should be sought, and if possible corrected. In addition, echocardiographic heart rate optimisation should be performed in order to maximise the time available for diastole, but this must be balanced against the often concomitant requirement for an adequate heart rate in the presence of a fixed stroke volume.

RIGHT VENTRICULAR RESTRICTION

The diagnosis of right ventricular restrictive physiology is made using PW Doppler of the proximal pulmonary artery, demonstrating forward flow in late diastole. This occurs when the right ventricular end diastolic pressure exceeds that of the pulmonary arterial diastolic pressure, the proposed mechanism being that the stiff right ventricle is unfillable. In the presence of positive pressure ventilation, may increase the tricuspid E/A ratio, and abolish the pulmonary arterial diastolic wave, making the diagnosis more challenging. Literature relating to the adult population is scarce, in particular with respect to intensive care, however the features may be seen in 43-50% patients. Confounding factors include the presence of left ventricular restriction, elevation of pulmonary arterial diastolic pressures, tachycardia and requirement for high ventilatory pressures. The relative contribution of the restrictive antegrade a wave to pulmonary flow (and hence right-sided output) changes as a result of positive pressure ventilation (inspiration 7+8% vs expiration 22+10%), and thus when diagnosed, ventilation should be modified to minimise this adverse effect where possible.

CONCLUSION

Echocardiography is one of the most powerful diagnostic and monitoring tools available to the modern intensivist, providing the means to diagnose cardiac dysfunction, its underlying cause and suggest therapeutic interventions. Although seemingly simple, meaningful and clinically relevant evaluation of ventricular function is challenging, and standard measures frequently unhelpful. Although at present the widespread application of physiological echocardiography and advanced echocardiographic techniques within intensive care remains disappointingly limited, the huge potential for collaborative research between cardiologists and intensivists within this field is evident.

Table 1. Evaluation of ventricular function in the intensive care unit

Technique	Routine ICU Use Recommended?	Comments
Focused cardiac ultrasound	Yes	Easy, binary decision-making to exclude/diagnose treatable causes of peri-arrest and arrest states Qualitative assessment of ventricular function demands experience
Ejection fraction	No	Normal values unknown in ICU Too many dynamic variables Does not measure contractility
Long axis function	Yes	Easy to acquire (even with suboptimal views) Reproducible Sensitive to ischaemia
Physiological Doppler	Yes	Assessment of standard echodynamics Evaluation of t-IVT
Strain/strain rate	Not yet	Research tool Not validated in critically ill adults Image resolution an issue (TTE)
3D/4D echo	Not yet	Assessment of ejection fraction Right ventricular function/dyssynchrony (research) Image resolution an issue (TTE)

ICU; intensive care unit, tIVT; total isovolumic time, TTE; transthoracic echocardiography, 3D; three dimensional, 4D; four dimensional

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