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Viewpoint

Echocardiographic Tests of Left Ventricular Function in Pediatric Cardiology: Are We Searching for the Holy Grail?

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In this article the utility of echocardiographic tests of left ventricular (LV) function in pediatric cardiology is reviewed. These indices are derived from the basic concepts of cardiac physiology, namely the Frank-Starling curve, pressure volume loops, and the force frequency relation and, to some extent, are all governed by these general principles. Thus, they are prone to be load-dependent and their utility variable. Methods that use formulas for calculating LV volume are a problem in congenital heart disease in which LV geometry is frequently abnormal. New indices, such as the TEI index, continue to be developed but they are still load-dependent. The utility of more complex LV function tests such as mean velocity of circumferential fibre shortening corrected for heart rate, mean velocity of circumferential fibre shortening corrected for heart rate/wall stress, end-systolic, and arterial elastance also have limitations. Tissue Doppler and its functional derivatives which test myocardial mechanics are being intensively applied to patients with acquired and congenital heart disease. To

RÉSUMÉ

Dans cet article, nous passons en revue l'utilité des évaluations de la fonction du ventricule gauche (VG) par échocardiographie en cardiologie pédiatrique. Ces indices qui sont issus des concepts de base de la physiologie cardiaque, c'est-à-dire la courbe de Frank-Starling, les boucles pression-volume et la relation force-fréquence, sont tous « régis », dans une certaine mesure, par ces principes généraux. Par conséquent, ils ont tendance à être dépendants des conditions de charge, et leur utilité, variable. Les méthodes qui utilisent les formules de calcul du volume du VG posent problème lors de cardiopathie congénitale dont la géométrie du VG est fréquemment anormale. De nouveaux indices, comme l'indice de Tei, continuent d'être développés, mais ils sont encore dépendants des conditions de charge. L'utilité des évaluations plus complexes de la fonction du VG comme la vitesse moyenne de raccourcissement circonférentiel des fibres corrigé en fonction de la fréquence cardiaque, la vitesse moyenne de raccourcissement circonférentiel des fibres corrigé en fonction de la fréquence

This article is based on the 2014 John Keith lecture, which I was greatly honoured to deliver.

Dr Keith's legacy is remarkable. He was an unassuming man for someone who had achieved so much. He created the Division of Cardiology at the Hospital for Sick Children in Toronto, laid the foundations for one of the best clinical and research pediatric cardiac units, made major contributions to pediatric and adult cardiology in Canada, and his textbook was the "go to" reference book for many years. Many of the most prominent pediatric cardiologists in the world were trained in his unit.

This article reflects a personal view and is intended to stimulate discussion. It is my perception that echocardiographers believe that there is one test of ventricular function that describes everything, if only we could find or develop it.

This is somewhat like the myth of the Holy Grail. As with so many tests of left ventricular (LV) function, the latest and greatest comes and, after a while, is shown to have limitations. There are multiple, complex factors that affect cardiac performance and myocardial mechanics. The purpose of this article is to briefly review the physiologic basis of LV function and to present a personal view of some of the echocardiographic measures of LV function, how they may or may not be helpful, and how our experience with semisupine cycle ergometry (SSCE) has been used to enhance clinical care. It is not intended to be a comprehensive or exhaustive review of this topic.

The physiologic concepts upon which our understanding of LV systolic function is based are: (1) Frank-Starling pressure-volume curves; (2) preload and afterload; (3) pressure-volume loops, end-systolic elastance (Ees); and (4) the force-frequency relationship.

Frank-Starling Curves

Cardiologists often refer to the Frank-Starling pressure-volume curves, which demonstrated that, within limits, progressive stretching of the relaxed isolated myocardium or the diastolic volume in the isolated heart preparation

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See page 6 for disclosure information.

apply these tests appropriately, knowledge of the strengths, limitations, and variability of each of these tests is required. Resting echocardiograms may mask limited myocardial reserve. Our experience with semisupine cycle ergometry has unmasked limited myocardial reserve and helped in clinical decision-making. Thus, there is no single echocardiographic test that is perfect for all clinical questions. Clinicians must use the appropriate combination of tests to answer the question relevant to individual patients.

produced progressive enhancement of the force of contraction.^{1,2} In clinical practice, resting myocardial length cannot be measured and estimates of end-diastolic pressure or the diastolic LV dimension are used as surrogates of preload. This ignores the effect of myocardial stiffness or transmural forces such as the pericardium or transpulmonary pressure.

Preload and Afterload

It is interesting to see the different way that preload and afterload are illustrated in the isolated myocardium experiment in the basic textbooks. The illustration (Fig. 1) that I prefer is from Milnor, a vascular cardiologist.³ I think that a combination of Figure 1B and D represent in vivo physiology and clinical practice more accurately. What is important is the introduction of the concept of viscous elements, which is additional to afterload. This explains why the force developed by “isotonic” contraction is flat in Figure 1C, and increases in the model in Figure 1D and why ejection is never “isotonic” in vivo. Without the additional loading of viscous elements, the afterload would simply be the intraventricular pressure that is needed to open the aortic valve and no further increase in force would be necessary to eject the blood from the ventricle. Instead there is impedance within the vascular system, which necessitates continued LV force generation during ejection. Thus, afterload (ie, systolic blood pressure) can be thought of as the sum of pulse pressure, representing the viscous elements, plus diastolic blood pressure, representing the afterload weight in Figure 1D of the papillary muscle model.

Pressure and Volume Loops

The work by Sagawa⁴ and others bridged the gap between the studies of isolated myocardium and the whole ventricle. Using pressure-volume loops, it was shown that, for a given inotropic state, the end-systolic pressure volume plots for different loading conditions formed a quasistraight line, which described intrinsic myocardial contractility and which they called Ees. Despite the limitations of this model, it does what any good scientific theory should do, that is, to predict cardiac performance. This model explains why afterload reduction is successful in increasing stroke volume and predicts the effects of increasing or decreasing inotropy on stroke volume.

cardiaque et de la tension pariétale, l'élastance téléstolique et l'élastance artérielle montre également des limites. Le Doppler tissulaire et ses dérivés fonctionnels qui sont utilisés pour évaluer la mécanique myocardique sont appliqués intensivement aux patients atteints d'une cardiopathie acquise ou congénitale. Pour appliquer convenablement ces examens, il est nécessaire de connaître les forces, les limites et la variabilité de chacun d'eux. Les échocardiogrammes au repos masqueraient la réduction de la réserve myocardique. Notre expérience à l'aide du vélo ergométrique en position semi-allongée a démasqué la réduction de la réserve myocardique et facilité la prise de décision clinique. Par conséquent, il n'existe pas d'évaluation unique par échocardiographie qui soit parfaite pour répondre à toutes les questions cliniques. Les cliniciens doivent utiliser la bonne combinaison d'évaluations pour répondre à la question par rapport à chacun des patients.

Force-Frequency Relationship

The force-frequency relationship, which was first described by Bowditch⁵ and summarized by Ross et al.,⁶ stated that increasing the heart rate increased myocardial contractility. Unfortunately, this response is limited in patients with myocardial failure.

Goals of LV Function Testing

The ultimate goal of any test of ventricular function should be to measure intrinsic myocardial contractility. However, most measure preload- and/or afterload-dependent ventricular performance. The value of the measurement of performance should not be minimized because it is practical to achieve and provides valuable information for the clinical assessment and monitoring of patients.

Echocardiographic Tests of LV Function

The ability to use echocardiography to noninvasively diagnose cardiac lesions and monitor cardiac function was a revolutionary improvement in patient care. Echocardiographic methods were developed to derive the established indices of LV function such as stroke volume, ejection fraction, mean velocity of circumferential fibre shortening corrected for heart rate (MVCFC), wall stress, intraventricular contraction time, intraventricular relaxation time, pre-ejection period, ejection time, and mean systolic ejection rate. However, these indices are preload- and/or afterload-dependent with limitations to their usefulness. Kass et al. noted that changes in preload or afterload can have a large effect on the predictive value of some indices and the index may not have a very high relative inotropic sensitivity.⁷ New indices continue to appear and Carabello⁸ graded the load dependence, independence, and utility of the major indices and, not surprisingly, found that the best tests were the most difficult to perform.

Several echocardiographic indices rely on formulas that assume a normal LV shape. These are problematic in the diseased heart in general and especially true for pediatric cardiology where abnormal LV shape or geometry is common. As a consequence, biplane and 3-dimensional area-derived LV ejection fraction has reappeared as the “preferred test” of LV function. Although the ventricular volumes obtained using this method are more accurate than volumes derived from a

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