Echocardiographic tools for pacemaker optimization of ventricular function in an infant following surgical repair for double outlet right ventricle

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A case of an infant, following surgical repair for double outlet right ventricle, who developed low cardiac output syndrome and complete heart block that required insertion of a pacemaker is presented. The infant underwent optimization of his ventricular function to determine whether pacing the right ventricle or left ventricle or both would improve cardiac function. Using standard two-dimensional echocardiography and Doppler imaging, tissue synchronization imaging, and two-dimensional speckle-tracking strain analysis, improvement in cardiac output and function was demonstrated. The present case highlights the usefulness of newer echocardiographic techniques in pacemaker optimization in the acute postoperative setting.

Key Words: Congenital heart disease; Tissue and strain Doppler echocardiography

CASE PRESENTATION

A case of cardiac resynchronization therapy (CRT) that was optimized using echocardiography in a male infant who underwent surgery for complex congenital heart disease is described. A four-month-old male infant with VACTERL (Vertebral anomalies, Anal atresia, Cardiovascular anomalies, Tracheoesophageal fistula, Esophageal atresia, Renal (kidney) and/or radial anomalies, and Limb defects) association, including double outlet right ventricle (tetralogy of Fallot type), underwent ventricular septal defect closure, resection of infundibular muscle and narrowing of the atrial septal defect. Before leaving the operating room, temporary pacing wires were placed on the epicardial surface of the right atrium, right ventricle and the most lateral portion of the left ventricular free wall. The immediate postoperative course was complicated by severe low cardiac output, with subsequent placement on venoarterial extracorporeal membrane oxygenation (ECMO) for five days. Following decannulation from the ECMO circuit, the patient could not be weaned from mechanical ventilation and his electrocardiogram revealed complete heart block requiring epicardial pacing with a temporary dual-chamber pacemaker.

Optimization of ventricular function was attempted by performing quantitative assessments with conventional two-dimensional (2D) echocardiography and Doppler imaging, tissue synchronization imaging (TSI) and 2D speckle-tracking strain analysis. Each method was used to evaluate his ventricular wall motion during atrioventricular (AV) sequential pacing under the following conditions: right ventricle (RV)-only paced, left ventricle (LV)-only paced and biventricularly paced. No changes to inotropes, mechanical ventilation or volume status were made during pacing. The AV delay was set to ensure adequate filling time based on mitral E and A wave velocities, and was

Les outils échocardiographiques pour optimiser la fonction ventriculaire à l'aide d'un stimulateur cardiaque chez un nourrisson après la réparation chirurgicale d'un ventricule droit à double issue

Est exposé le cas d'un nourrisson qui, après la réparation chirurgicale d'un ventricule droit à double issue, a présenté un syndrome de bas débit cardiaque et un blocage cardiaque complet. Le nourrisson a subi une optimisation de sa fonction ventriculaire pour déterminer si le rythme du ventricule droit, du ventricule gauche ou des deux ventricules améliorerait la fonction cardiaque. Au moyen de l'échocardiographie bidimensionnelle standard et de l'imagerie de Doppler, de l'imagerie de la synchronisation des tissus et de l'analyse bidimensionnelle des déformations par chatoiment (*speckle-tracking strain analysis*), on a démontré une amélioration du débit et de la fonction cardiaques. Le présent cas démontre l'utilité des nouvelles techniques échocardiographique pour optimiser un stimulateur cardiaque en soins aigus postopératoires.

TABLE 1
Tissue synchronization imaging calculated indexes in all pacer settings

	Pacer setting		
	LV only	RC only	Biventricular
Septal lateral delay	37	27	0
Septal postdelay	9	30	25
Basal maximum delay	37	41	60
Basal SD	14	17	22
All seg maximum delay	40	147	74
All seg SD	12	58	25

Times are presented in ms. LV Left ventricle; RV Right ventricle; seg Segment

kept constant throughout all three pacing strategies. RV-only pacing, then biventricular pacing, followed by LV-only pacing occurred for approximately 15 min each before measuring the echocardiographic parameters. The cardiac index was repeatedly measured to ensure that improvements in function were not transient. There were subtle differences in the cardiac index between RV-only and biventricular pacing, but the most improved cardiac index was noted with LV-only pacing. The global strain values were similar to RV-only and biventricular pacing but, again, the best global strain values were noted with LV-only pacing. The TSI calculated indexes were poorest with RV-only pacing, better with biventricular pacing and best with LV-only pacing (Table 1). Therefore, LV-only pacing produced the optimal cardiac index with quantitatively improved ventricular function as measured by TSI indexes and global strain values (function was also improved

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TABLE 2
Strain values for all segments in all pacer settings

Pacer setting	Average global strain	APLAX strain	4-chamber strain	2-chamber strain
LV only	-19.96	-17.5	-24.2	-18.2
RV only	-11.8	-14.5	-12.3	-8.7
Biventricular	-13.4	-10.1	-19.7	-10.6

Data presented as %. APLAX Apical long axis; LV Left ventricular; RV Right ventricular

Figure 1 Tissue synchronization imaging measuring time to peak velocity of the 17-segment left ventricular (LV) bull's eye during LV-only pacing

Figure 2 Tissue synchronization imaging measuring time to peak velocity of the 17-segment left ventricular (LV) bull's eye during right ventricle (RV)-only pacing

qualitatively by visual assessment – see Videos 1 and 2). In adults, the normal global speckle-tracking strain values for the longitudinal fibres in the apical views (apical long axis, apical four-chamber and apical two-chamber views) range from -16% to -19% (1). In our patient, the longitudinal speckle-tracking strain values were best when pacing the LV only (peak value at -24%), and were reduced when pacing the RV only (-11%) and when pacing biventricularly (-13%) (Table 2). Of note, the strain analysis was performed in the apical views only observing longitudinal fibres: parasternal windows were not adequate because of ECMO cannulae and an open sternum, and strain values for the radial or circumferential fibres could not be assessed.

The TSI time-to-peak '17-segment bull's eye' emphasizes that the all-segment SD, or Yu index, was improved when the patient underwent LV-only pacing (normal less than 32 ms) (2), implying synchronous movement of the myocardium (Figures 1 and 2). Doppler measurements of cardiac output also showed an increase in the cardiac

Figure 3 Echocardiographic determination of cardiac index using left ventricular outflow tract (LVOT) velocity-time integral (VTI) during LV-only pacing. CI Cardiac index; Dopp Doppler; Env.Ti Envelope time; HR Heart rate; LVCI LV cardiac index; LVCO LV cardiac output; LVSI LV stroke index; LVSV LV end-systolic volume; max Maximum; PG Pressure gradient; V Velocity

Figure 4 Echocardiographic determination of cardiac index using left ventricular outflow tract (LVOT) velocity-time integral (VTI) during right ventricle-only pacing. CI Cardiac index; Dopp Doppler; Env.Ti Envelope time; HR Heart rate; LVCI Left ventricular cardiac index; LVCO Left ventricular cardiac output; LVOT Left ventricular outflow tract; LVSI Left ventricular stroke index; LVSV Left ventricular end-systolic volume; max Maximum; PG Pressure gradient; RV Right ventricular; V Velocity

index when the patient was LV-only paced versus RV-only paced (Figures 3 and 4), with the lowest cardiac index measured during biventricular pacing. A permanent dual-chamber, epicardial pacemaker set to dual-chamber pacing with a low rate of 100 beats/min and AV sequential pacing of the LV only, was implanted after 10 days. The patient improved postoperatively, and was extubated and transferred out of the intensive care unit shortly thereafter.

DISCUSSION

Biventricular pacing has been well described as an adjunctive therapy for adults with New York Heart Association class III or IV heart failure (3). Little is known about the effects of CRT in the pediatric population. To date, there are very few prospective studies describing pediatric patients and CRT. Janousek and Gebauer (4) reviewed the current pediatric CRT studies that have been published. These studies showed improvement in either hemodynamic parameters or echocardiographic evidence of dyssynchrony with multisite pacing in both temporary and permanent pacing protocols.

Speckle-tracking strain analysis is a relatively new technique in echocardiography, using grey-scale 2D images, which permits the assessment of myocardial deformation from the parasternal long axis and apical views. Myocardial deformation can be differentiated by radial strain, circumferential strain and longitudinal strain, which represent the myocardial thickening and shortening in the different anatomical planes. Adult studies have shown the utility of speckle tracking to assess ventricular dyssynchrony for the evaluation of patients for CRT (5). We are not aware of any pediatric study that has incorporated speckle tracking in the optimization for CRT. As well, the norms of speckle-tracking strain values for children have not been established, and it is unclear whether these would differ from the adult population.

The present case highlights the potential clinical advantages of standard echocardiographic techniques, such as 2D echocardiography and Doppler imaging, and incorporating the newer modalities of TSI and 2D strain imaging as additional tools for the quantitative assessment of ventricular function and synchrony. These methods enabled us to optimize the location for pacemaker lead insertion in an infant following cardiac surgery, and improved his hemodynamics and ventricular function.

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