Impact of Conventional Versus Biventricular Pacing on Hemodynamics and Tissue Doppler Imaging Indexes of Resynchronization Postoperatively in Children With Congenital Heart Disease

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OBJECTIVES

We sought to evaluate the effects of biventricular (BDOO) pacing compared with conventional (CDOO) atrioventricular (AV) sequential and atrial (AOO) pacing in children and infants in the early postoperative period after open heart surgery for congenital heart disease (CHD).

BACKGROUND

Biventricular pacing using right ventricular (RV) and left ventricular (LV) leads can improve hemodynamics in patients with CHD, but it is unclear whether this occurs in early postoperative children with CHD.

METHODS

Nineteen children (age, 5 days to 5.4 years; median, 5.5 months) with a definitive biventricular repair for CHD underwent AOO, CDOO, and BDOO pacing with temporary epicardial leads for 10 min each. The AV delay was 80% of the PR interval for the CDOO and BDOO modes. Lead placement was two right atrial, two RV, and one LV. Blood samples for cardiac index (arterial and venous) and tissue Doppler (TDI) traces were obtained in each pacing mode with a Vivid 7 BT04 digital ultrasound system (GE/VingMed, Horten, Norway) from an apical four-chamber view and analyzed with EchoPac software.

RESULTS

The QRS duration was significantly shorter for BDOO compared with CDOO, and the cardiac index was higher with BDOO compared with CDOO. Systemic blood pressure was not different between the three modes of pacing (AOO, CDOO, BDOO). The TDI-derived strain rate showed minimal dyssynchrony in AOO as seen by isovolumic tensing (IVT) and peak systolic contraction (PSC) timing differences between RV and LV. The CDOO worsened dyssynchrony with prolonged IVT and PSC. The BDOO showed improved synchrony as seen by IVT and PSC.

CONCLUSIONS

The TDI-derived strain rate showed worsened ventricular dyssynchrony with CDOO and improvement with BDOO. Cardiac index and QRS duration were improved by BDOO compared with CDOO. This suggests that short-term pacing with BDOO may benefit children with CHD needing pacing in the postoperative period. (J Am Coll Cardiol 2005; 46:2284–9) © 2005 by the American College of Cardiology Foundation
Abbreviations and Acronyms
AOO = atrial pacing
BDOO = biventricular pacing
CDOO = conventional dual-chamber pacing
CHD = congenital heart defect
CRT = cardiac resynchronization therapy
IVT = isovolumic tensing
LV = left ventricle/ventricular
PSC = peak systolic contraction
RBBB = right bundle branch block
RV = right ventricle/ventricular
TDI = tissue Doppler imaging

There is limited experience with CRT in children, and little is known about the optimal sites for CRT. Hemodynamic improvement has been shown with various RV pacing sites (12) as well as biventricular pacing (13).

The goals of this study were two-fold. First, we were interested in comparing conventional RV pacing with biventricular pacing in acute postoperative congenital heart disease patients with a two-ventricle repair. The second goal of the study was to evaluate TDI-derived strain rate as an alternative method to the QRS duration for describing mechanical dyssynchrony.

METHODS

This study was performed at Oregon Health and Science University’s Doernbecher Children’s Hospital and was approved by the institutional review board. Informed consent was obtained, and all procedures were conducted in accordance with institutional guidelines.

Patients. Data were obtained from 19 postoperative patients (12 male; 63%), median age, 5.5 months (range, 5 days to 5.4 years); median weight, 6.2 kg (range, 3.2 kg to 19.1 kg); with biventricular anatomy. All patients had a systemic morphologic LV without any residual shunts, and none of the patients were in heart failure or had undergone pacing before the study. Cardiac defects included atrioventricular septal defect (n = 4), ventricular septal defect (VSD) (n = 3), VSD with pulmonary stenosis (n = 1), tetralogy of Fallot (n = 3), atrial septal defect (ASD) with VSD (n = 2), sinus venosus ASD (n = 2), total anomalous pulmonary venous return (n = 1), transposition of the great arteries (n = 1), double-outlet RV (n = 1), and aortic valve disease (n = 1). Four patients consented but were not studied because of complete heart block (n = 1), inadvertent removal of pacing wires and or central intravenous lines before pacing study (n = 2), and a postoperative bleeding complication that required re-operation and refusal on return to the intensive care unit (n = 1). The pacing study was performed in the pediatric intensive care unit at a mean of 22 h (range, 4 to 150 h) after surgery was completed. All patients were deemed stable enough to tolerate the pacing maneuvers by the intensive care physicians. During the pacing study, aspects of care such as ventilator settings and inotrope doses were kept constant. Patients received scheduled sedation if necessary. No crystalloid or colloid boluses were given. A standard 12-lead electrocardiogram was obtained before pacing. Baseline data included a 10-lead rhythm strip at 50 mm/s during right atrial pacing at a rate 10 to 15 beats/min faster than the intrinsic sinus rate to determine the PR interval, which was measured from the pacer spike to the beginning of the QRS.

Pacing leads. Temporary epicardial pacing leads were placed in the operating room after the cardiac procedure was completed and before chest closure. A pair of temporary pacing electrodes (Ethicon Inc., Somerville, New Jersey) was attached to the right atrium. Two leads were placed in the RV, one at the free wall of the RV near the base and the other at the RV apex. The RV free wall lead was placed in the usual site for placement of temporary and permanent RV pacing leads in our institution. The LV active lead was placed on the LV lateral free wall near the base. All of the clinically necessary hemodynamic monitoring catheters for postoperative management were also placed at this time. All patients had a central venous catheter placed in the internal jugular vein and an arterial line. Some patients received left atrial and/or pulmonary artery lines when deemed necessary for postoperative management by the surgical team.

Pacing protocol. Each patient underwent three methods of pacing for 10 min at a rate 10 to 15 beats/min faster than their intrinsic sinus rhythm with a 10-min rest in between. The leads were attached to a temporary pacemaker (Medtronic model 5388, Medtronic, Minneapolis, Minnesota), and atrial pacing (AOO) was performed using the two right atrial leads. Conventional atrioventricular pacing (CDOO) was done using the right atrium and RV leads. The RV free wall lead was the active lead, and the RV apex lead was the indifferent lead. Biventricular pacing (BDOO) was performed using the right atrial and RV (RV free wall as the active lead and RV apex as the indifferent) plus the LV lead, which was also connected to the active pole (Fig. 1). The atrioventricular delay for the two atrioventricular pacing modes (CDOO, BDOO) was set at 80% of the PR interval during AOO to guarantee ventricular capture (Table 1). An electrocardiogram rhythm strip was obtained at the beginning of each pacing maneuver to confirm appropriate capture (Fig. 2). Data obtained at the end of pacing included right atrial pressure and systemic blood pressure. Mixed venous and systemic arterial blood oxygen saturations were also obtained using a co-oximeter (ABL 720, Radiometer, Copenhagen, Denmark). The cardiac index was calculated using the Fick method with estimated oxygen consumption described by LaFarge and Miettinen (14). The pacing modes were randomized by simple randomization method.

TDI analysis. Tissue Doppler images were obtained using a Vivid 7 BT04 digital ultrasound system (GE/VingMed, Horten, Norway). In each pacing mode, apical scanning was performed with a 5-MHz phase-array transducer to produce an apical four-chamber view. Each image was obtained from the same view for all three pacing modes to maintain...
consistent TDI measurements at the same regions of the myocardium. The digital scan line TDI data were acquired with a Nyquist limit of 10 to 12 cm/s and a frame rate of 150 to 180 frames/s. The TDI sector was adjusted to encompass both RV and LV free walls. The TDI data of the two-dimensional images for 8 to 10 cycles at each pacing mode were stored on compact disc for later off-line analysis. Optimized TDI and strain rate data for the two-dimensional images of each pacing mode were analyzed using EchoPac software (GE/VingMed). This software allows multiple volume sampling (up to eight samples) and display of TDI and strain rate simultaneously in different locations.

Constant-volume sample size zones for strain length (range, 8 to 10 mm) were placed along the RV and LV free wall for measurement of TDI-derived strain rate. An initial positive strain rate deflection termed the isovolumic tensing (IVT) was seen immediately after the beginning of the QRS complex and this in turn was followed by a negative deflection, the peak systolic contraction (PSC). These two mechanical events, IVT and PSC, from the two volume samples at each ventricular free wall were identified for all three pacing methods. Using the echocardiogram’s electrocardiogram trigger, all of the mechanical events were measured from the beginning of the QRS to the peak of the event (Fig. 3). The mechanical timing difference between the two ventricles was noted as ΔIVT and ΔPSC and used as a marker of ventricular dyssynchrony. A larger value of ΔIVT and ΔPSC was taken to represent greater dyssynchrony between RV and LV systolic events. A single observer blinded to the pacing mode setting analyzed all curves.

Statistics. All of the data are expressed as mean values ± SD. Two-way analysis of variance was used to compare the means for cardiac index, QRS duration, blood pressure, and mechanical ventricular timing between the three pacing modes. The results are expressed as p values. A p value ≤0.05 was considered statistically significant. All statistical analysis was performed using SPSS for Windows version 13 (SPSS Inc., Chicago, Illinois).

| Table 1. PR Interval for AOO Mode With Shortened PR Interval With CDOO and BDOO Mode, Pacing Order for Each Patient |
|---|---|---|---|
| Patient No. | AOO PR Interval (ms) | CDOO and BDOO PR Interval (ms) | Pacing Order |
| 1 | 120 | 80 | BDOO AOO CDOO |
| 2 | 140 | 110 | AOO CDOO BDOO |
| 3 | 120 | 90 | BDOO AOO CDOO |
| 4 | 130 | 100 | BDOO AOO CDOO |
| 5 | 120 | 90 | BDOO CDOO AOO |
| 6 | 250 | 140 | BDOO CDOO AOO |
| 7 | 130 | 100 | AOO CDOO BDOO |
| 8 | 140 | 100 | CDOO BDOO AOO |
| 9 | 120 | 80 | CDOO BDOO AOO |
| 10 | 120 | 60 | BDOO CDOO AOO |
| 11 | 130 | 80 | CDOO AOO BDOO |
| 12 | 140 | 110 | BDOO AOO CDOO |
| 13 | 240 | 130 | BDOO CDOO AOO |
| 14 | 150 | 110 | CDOO AOO BDOO |
| 15 | 130 | 100 | CDOO BDOO AOO |
| 16 | 120 | 120 | AOO CDOO BDOO |
| 17 | 170 | 120 | CDOO AOO BDOO |
| 18 | 140 | 110 | BDOO CDOO AOO |
| 19 | 140 | 110 | BDOO AOO CDOO |

AOO = atrial pacing; BDOO = biventricular pacing; CDOO = conventional dual-chamber pacing.
RESULTS

QRS complex. During pacing, all patients had appropriate atrial and ventricular capture during the three pacing modes. The mean QRS duration with AOO (baseline) pacing was 96 ± 18 ms (range, 60 to 120 ms). Compared with AOO pacing, there was a prolongation of QRS duration with CDOO (105 ± 15 ms, p = 0.025) but not BDOO (94 ± 13 ms, p = NS). When CDOO pacing was compared with BDOO pacing, the QRS duration significantly decreased with BDOO (p = 0.025) (Table 2).

Systolic blood pressure. There were no significant changes in blood pressure among the three pacing modes. The systolic blood pressure for AOO was 84 ± 18 mm Hg, and for CDOO and BDOO were 82 ± 14 mm Hg (p = NS) and 83 ± 12 mm Hg (p = NS), respectively (Table 2).

CARDIAC INDEX. The mean cardiac index for AOO was 3.5 ± 1.2 l/min/m². The cardiac output with BDOO (4.7 ± 2.8 l/min/m²) was increased compared with CDOO (3.7 ± 1.4 l/min/m², p = 0.0032) (Table 2).

TDI. Tissue Doppler data were available for 18 patients (Table 3). The IVT of the RV and LV in AOO occurred at 56 ± 17 ms and 60 ± 16 ms, respectively, with a ΔIVT (4 ± 8 ms) suggesting synchronous contraction of the two ventricles during AOO. In CDOO, there was a significant increase in ΔIVT (31 ± 26 ms), suggesting loss of synchrony compared with BDOO (12 ± 16 ms, p = 0.0005). Likewise, the ΔPSC during AOO was short (4 ± 24 ms). With CDOO, the ΔPSC (53 ± 36 ms) was significantly longer compared with BDOO (7 ± 18 ms, p < 0.0001).

DISCUSSION

As in previous studies (2,13), our data showed improvement in cardiac index with biventricular pacing, and unlike some other studies (2,3,12), we were unable to show any benefit with conventional atrioventricular pacing. We found that TDI, a new modality for assessing CRT, can help assess the degree of interventricular synchrony in children with a congenital heart defect (CHD). Whether the degree of dyssynchrony seen in these patients is clinically significant is less certain.

To date there have been two studies of CRT in children with CHD and a biventricular heart in the acute postoperative period (2,3). Janousek et al. (2) first reported acute CRT in 20 children. They showed that BDOO decreased QRS duration and improved blood pressure in patients with left bundle branch block, whereas CDOO (using different lead placements than ours) decreased QRS duration and increased blood pressure in those with isolated right bundle branch block (RBBB). Contrary to this report, our data do not show improvement in blood pressure with CDOO or BDOO. However, similar to this study, we found there was a shorter QRS duration with BDOO. The main difference was that our patients’ initial QRS duration was shorter and the patients who received BDOO pacing did not have left bundle branch block as seen in the study by Janousek et al. (2).

Zimmerman et al. (3) studied a similar group of patients with RBBB. Their version of CDOO using a different set of lead positions resulted in decreased QRS duration and improved cardiac index. This is different from our study, in which CDOO worsened ventricular dyssynchrony and failed to improve cardiac index. The presence of RBBB in their patients may explain this difference.

Previous studies in adults with congestive heart failure have shown that QRS duration is not a good predictor of the absence of synchrony and that TDI techniques have
greater sensitivity to the demonstration of synchrony or its absence. We found the TDI-derived strain rate to be a simple yet sensitive technique for showing dyssynchrony. Furthermore, the data from this study showed that dyssynchrony observed by TDI with CDOO is associated with a worse cardiac index, as seen by the comparison with BDOO.

Yet another intriguing recent study, from Vanagt et al. (15), suggests that LV apex pacing can produce improved cardiac performance as measured by LV dp/dt, whereas RV apex pacing worsens LV dp/dt. This again needs further corroboration because this could be a simpler approach to achieving resynchronization with fewer leads.

**Study limitations.** Our study is limited not only by the small number of patients but also by the heterogeneity of their congenital cardiac defects and associated surgical repair. Our study also only evaluated the CRT pacing for a very short period of time (10 min). A longer pacing period could possibly reveal further objective benefits such as decreased lactic acid production or remodeling, as have been described in adults. To our knowledge, this is the first study to use TDI in the assessment of dyssynchrony and CRT in children with congenital heart disease. Because this is the first study reporting the use of this technique in patients with a CHD, it should be corroborated by other observers.

**Clinical implications.** There is evidence to show that biventricular pacing can augment cardiac performance in patients after repair of CHD. In patients with normal interventricular conduction, conventional RV pacing leads to worsening of the cardiac index compared with biventricu-

![Figure 3. Still images of an apical four-chamber two-dimensional view and tissue Doppler-derived strain rate color map (left).](Figure3)

The graph shows a typical longitudinal strain rate with the mechanical events of the left (LV) and right ventricle (RV) during conventional dual-chamber pacing. HR = heart rate; IVT = isovolumic tensing; PSC = peak systolic contraction; SR = strain rate; SRI = strain rate index; V = ventricle.

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**Table 2.** QRS Duration, Systolic Blood Pressure, and Cardiac Index (Calculated by Assumed Oxygen Consumption) for the Three Different Pacing Modes

<table>
<thead>
<tr>
<th>Pacing Mode</th>
<th>QRS (ms)</th>
<th>p Value Compared With CDOO</th>
<th>Systolic Blood Pressure (mm Hg)</th>
<th>p Value Compared With CDOO</th>
<th>Cardiac Index (l/min/m²)</th>
<th>p Value Compared With CDOO</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOO</td>
<td>96 ± 18</td>
<td>0.025</td>
<td>84 ± 18</td>
<td>NS</td>
<td>3.5 ± 1.2</td>
<td>NS</td>
</tr>
<tr>
<td>CDOO</td>
<td>105 ± 15</td>
<td>NS</td>
<td>82 ± 14</td>
<td>NS</td>
<td>3.7 ± 1.4</td>
<td>NS</td>
</tr>
<tr>
<td>BDOO</td>
<td>94 ± 13</td>
<td>0.025</td>
<td>83 ± 12</td>
<td>NS</td>
<td>4.7 ± 2.8</td>
<td>0.0032</td>
</tr>
</tbody>
</table>

Data presented as mean values ± SD. No statistical difference among the three pacing modes. Abbreviations as in Table 1.
lar pacing. However, further studies are needed before recommending routine CRT in the postoperative period.

Also, there are a number of unanswered questions about this new approach to pacing. The question of whether RV pacing alone will be sufficient in patients with RBBB remains to be proven. Also, the optimal site for RV pacing is unknown. Many studies in adults have shown non-responders. Why some patients do not respond to CRT remains to be elucidated. The role of intraoperative tissue Doppler echocardiography to identify the best site for pacing leads requires evaluation.

CONCLUSIONS

Our study suggests that in patients needing pacing in the postoperative period, biventricular pacing is better than conventional pacing. The TDI-derived strain rate could be used to assess the presence of dysynchrony and to verify the effectiveness of resynchronization after CRT.

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