Novel Method of Predicting the Optimal Atrioventricular Delay in Patients With Complete AV Block, Normal Left Ventricular Function and an Implanted DDD Pacemaker

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Background: The optimal atrioventricular (AV) delay setting is important for achieving optimal AV synchrony in patients with an implanted DDD pacemaker. Using pulsed Doppler echocardiography is the most common method of predicting the optimal AV delay, but it is a complicated and time-consuming method. Therefore, an automatic optimizing function of the AV delay at different atrial rates is desirable for achieving a favorable hemodynamic state. This study aimed to predict the optimal AV delay using phonocardiography.

Methods and Results: The amplitude of the first heart sound (S1) recorded on the phonocardiogram was measured with different AV delays in 6 patients with complete AV block, normal left ventricular function and an implanted DDD pacemaker. The correlation between the amplitude of S1 and the length of the AV delay was a cubic curve \( y=974.15x^3-23.084x^2-8.0074x+0.7495 \), with \( R^2=0.9511 \). The length of the AV delay at the inflection point of the curve showed a significant positive correlation with the optimal AV delay determined by pulsed Doppler echocardiography (\( R=0.9254, P<0.01 \)).

Conclusions: This study demonstrated a novel simple method of predicting the optimal AV delay using phonocardiography. (Circ J 2009; 73: 654–657)

Key Words: Atrioventricular delay; Echocardiography; Pacemaker; Phonocardiography
the S1 amplitude could be measured easily without using a sound room.

Analysis of S1 Characteristics
The S1 amplitude and the LVOT TVI at each AV delay were determined by averaging 3 cardiac cycles and are expressed as relative values to the peak values. The average S1 amplitude for each AV delay vs AV delay was plotted, and the relationship between S1 amplitude and the optimal AV delay predicted by our method using pulsed Doppler echocardiography was analyzed. Measured variables were expressed as mean±SD.

Statistical Analysis
Statistical analyses were performed by paired Student’s t-test and Pearson’s correlation coefficient analysis. Values of P<0.05 were considered to be statistically significant.

Results
One representative case (patient no. 3) is shown in Figure 1. The patient’s characteristics and results are sum-

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**Table. Patients’ Characteristics and Results**

<table>
<thead>
<tr>
<th>Patient no.</th>
<th>Gender</th>
<th>Age (years)</th>
<th>Ejection fraction (%)</th>
<th>CTR (%)</th>
<th>Optimal AV delay by UCG (ms)</th>
<th>AV delay at inflection point (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>68</td>
<td>60.0</td>
<td>59.6</td>
<td>150</td>
<td>168.5</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>75</td>
<td>56.8</td>
<td>50.3</td>
<td>130</td>
<td>150.5</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>80</td>
<td>69.9</td>
<td>43.7</td>
<td>140</td>
<td>140.8</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>64</td>
<td>58.8</td>
<td>43.9</td>
<td>140</td>
<td>154.8</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>75</td>
<td>60.0</td>
<td>49.6</td>
<td>120</td>
<td>111</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>74</td>
<td>62.1</td>
<td>50.9</td>
<td>150</td>
<td>166.7</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>72.7</td>
<td>61.3</td>
<td>49.7</td>
<td>138.3</td>
<td>148.7</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>5.7</td>
<td>4.6</td>
<td>5.8</td>
<td>11.7</td>
<td>21.1</td>
</tr>
</tbody>
</table>

CTR, cardiac resynchronization therapy; AV, atrioventricular; UCG, ultrasonic cardiography.
The amplitude of S1 changed according to the change in AV delay. When the AV delay was shortened, the amplitude of S1 gradually increased and reached a plateau. The correlation between the amplitude of S1 and the length of AV delay showed a cubic curve (Figure 2) \(y=974.15x^3-23.084x^2-8.0074x+0.7495, R^2=0.9511\). The length of the AV delay at the inflection point of this cubic curve (AVDI) showed a significant positive correlation with the optimal AV delay determined by echocardiography (OAVDE) (R=0.925, P<0.005) (Figure 3). The average AVDI was 148.7±21.1 ms, and the average OAVDE was 138.3±11.7 ms (average AVDI slightly longer than the average OAVDE). The peak of TVI at the LVOT was not determined because TVI was unchanged at different AV delays ranging from 50 to 250 ms.

**Discussion**

Previously we reported that the optimal AV delay could be predicted as the AV delay at which the QT interval was maximal\(^1\)\(^\text{14–17}\). In the present study, we observed that the correlation between the amplitude of S1 and the length of the AV delay was represented as a cubic curve. Furthermore, the AV delay at the inflection point of this cubic curve showed a significant positive correlation with the optimal AV delay determined by echocardiography (R=0.925, P<0.005). The reason why the correlation between the amplitude of S1 and the AV delay is a cubic curve is unclear. When the atrial pressure decreases gradually after atrial contraction, the AV pressure gradient is reversed in the end-diastolic phase. The reversed AV pressure gradient may be important for mitral valve closure, but it is not sufficient to bring about complete closure of the mitral valve without ventricular contraction\(^\text{18,19}\), which is required for complete closure of the mitral valve. With the setting of a long AV delay, mitral valve closure is incomplete, because ventricular contraction has not yet started. Complete closure of the mitral valve is achieved by ventricular contraction with the half-open mitral valve and the amplitude of S1 is decreased with the setting of a long AV delay. When the AV delay is shortened, the amplitude of S1 increases gradually. When the AV delay is set extremely short, complete closure of the mitral valve is achieved in a burst without a stop against the atrial kick, and atrial contraction is interrupted. The amplitude of S1 will decrease with an extremely short AV delay setting. In this study, all patients had normal LV function and the length of the AV delay had an insignificant effect on TVI at the LVOT. In patients with complete AV block and an implanted DDD pacemaker, Ritter et al reported a highly significant difference between the optimal AV delay obtained by echocardiography and that obtained by the peak endocardial accel-

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**Figure 2.** Correlation between the first heart sound (S1) and the atrioventricular (AV) delay is a cubic curve \(y=974.15x^3-23.084x^2-8.0074x+0.7495, R^2=0.9511\).  
**Figure 3.** Atrioventricular (AV) delay at the inflection point of the cubic curve shows a significant positive correlation with the optimal AV delay determined by echocardiography (R=0.925, P<0.005).
eration (PEA) method, which corresponds to the ‘knee’ of the PEA curve vs the AV delay.\textsuperscript{20,21} PEA is detected by a ventricular lead equipped with a micro-accelerometer. Various reports have shown that PEA is synchronous with S1. If a pacemaker equipped with an acoustic wave sensor could be developed, automatic AV delay optimization using PCG at different atrial rates might be achieved. An activity sensor is a type of vibration sensor, and might be used for this purpose, obviating the need for a specially designed lead such as with the PEA method.

Additionally, AV delay optimization is important in patients with severely impaired cardiac function, especially in cardiac resynchronization therapy (CRT). Further examination of whether this PCG method of predicting the optimal AV delay is also useful in patients undergoing CRT will be required.

Conclusions

The present study demonstrated a novel simple method of predicting optimal AV delay using phonocardiography.

References