A Simple Method for Programmer-Based Individualized AV-Delay Optimization

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Summary

Optimal AV delay (AVD) in DDD pacemaker patients is mainly determined by individually differing interatrial conduction times. The latter can be measured by synchronous recordings of the telemetric right atrial electrogram or marker, and a noninvasive left atrial esophageal lead. From a hemodynamic point of view, the AVD is optimal when the end of the left atrial contraction and the beginning of the left ventricular contraction coincide. Synchronous recordings of the surface ECG, left atrial electrogram, and pulsed-wave Doppler mitral inflow have shown that a mean interval LA-S_V between the left atrial deflection, LA, and the ventricular stimulus, S_V, of 71.8 ± 17.5 ms achieves this synchronicity during both DDD and VDD operation. Using 70 ms as a representative mean optimal LA-S_V interval provides sufficient accuracy. The optimal AVD can then be approximated as being the sum of the measured interatrial conduction interval during DDD or VDD modes, respectively, and 70 ms. The procedure was performed with programmers by different manufacturers. Either an external hardware filter or internal software support was used to display and record the filtered left atrial electrogram from the esophageal lead on the surface ECG channel. The recording was synchronous with the telemetric right atrial electrogram or a sense-event marker. Two programmers that showed a relevant telemetric marker delay were excluded from the study. With the internal left atrial electrogram software, programmer-based individual AVD optimization was routinely done in approximately 10 min and without any additional devices.

Key Words

AV delay, interatrial conduction time, left atrial esophageal lead, programmer software

Introduction

Applying various methods for AV-delay (AVD) optimization to DDD pacing is hampered by time demands and the need for special devices. It is well known that the hemodynamically optimal AVD [1] in DDD pacemaker patients with AV block is mainly determined by interatrial conduction times [2-5], which differ by a large margin among patients. In pacing systems that provide telemetry, the interatrial conduction time can be measured non-invasively by simultaneous recording the telemetric right atrial electrogram or marker channel and the left atrial electrogram [6] via an esophageal lead. Binkley [7] reported that atrial deflection in the esophageal lead closely corresponds to the dorsal mid-left atrial depolarization in intracardiac leads in both normal and enlarged atria.

From a hemodynamic point of view, the AVD is optimal when the end of the left atrial contraction and the beginning of the left ventricular contraction coincide. From synchronous recordings of the surface ECG, left atrial electrogram, and pulsed-wave Doppler mitral inflow, a mean interval (LA-S_V) between the left atrial deflection (LA) and the ventricular stimulus (S_V) of 71.8 ± 17.5 ms was found to achieve this synchronicity during both DDD and VDD operation [8,9]. Therefore, noninvasive left atrial esophageal electrography was proposed to measure interatrial conduction times for a simplified individual AVD optimization. Using 70 ms as a sufficiently accurate representative mean for an optimal LA-S_V interval, an

Programmer	LAE	Screen-freeze and calipers	Simultaneous ECG printout	Printout of caliper measurements
BIOTRONIK EPR1000	ISF	yes	yes	yes
CPI 2901	EHF	yes	yes	no
ELAmedical CPR 1C	EHF	yes	marker delay !	no
Intermedics RX5000	EHF	yes	yes	no
Medtronic 9790	EHF	yes	yes	no
Sorin PMP1000	EHF	yes	yes	no
St. Jude APS II	EHF	no	yes	no
Vitatron 9790	EHF	no	marker delay !	no

Table 1. Programmers by different manufacturers used to simplify AVD optimization by left atrial electrography. Left atrial electrogram (LAE) recording was implemented in some devices using an external hardware filter (EHF) connected to lead I of the ECG input cable. An internal software filter (ISF) was applied in the EPR 1000 (BIOTRONIK). Interatrial conduction intervals were measured from simultaneous recordings of sense-event marker and left atrial electrogram either using calipers on the frozen screen or manually in the printed ECG strips.

optimal AVD can be approximated as being the sum of the interatrial conduction interval and 70 ms. By implementing this method in programmers, the time and device expenditure for individual routine AVD programming could be reduced significantly.

Materials and Methods

The following programmers were tested for measuring the interatrial conduction intervals by simultaneous recordings of the telemetric right atrial electrogram or the marker channel, M_A, and the filtered left atrial electrogram from the bipolar esophageal lead: CPI 2901 (CPI), CPR I (ELAmedical), RX 5000 (Intermedics), Medtronic 9790 (Medtronic), PMP 1000 (Sorin), APS II (St. Jude), Vitatron 9790 (Vitatron), and EPR 1000 (BIOTRONIK). Depending on the vendor, either an external hardware or internal software filter was used to implement the left atrial electrogram in place of the programmer's surface ECG channel (Table 1).

The definition of interatrial time relations differs between atrial pacing and sensing. During DDD operation, interatrial conduction time is defined by the interval S_A-LA between the atrial stimulus, S_A, at the location of the right atrial electrode and the onset of the left atrial deflection, LA, in the esophageal lead. Because the mean value of the hemodynamically optimal interval LA-S_V between LA and right ventricular stimulus, S_V, is about 70 ms, the optimal AVD during DDD operation can be approximated as being the sum of the measured S_A-LA and 70 ms:

$$AVD_{STIM} = S_A\text{-}LA + 70\ \text{ms}.$$

During VDD operation, excitation is induced by the sinus node. Due to the different locations of the sinus node and the atrial electrode, excitation propagates simultaneously from the sinus node towards both the right atrial electrode and the dorsal mid-left atrium. In systems providing real-time telemetry, the right atrial electrogram, RA, or the sense-event marker, M_A, appear immediately after detection by the electrode. Thus, interatrial time relations during VDD operation are represented by the intervals RA-LA or M_A-LA between the onset of telemetric right atrial electrogram or the sense-event marker, M_A, respectively, and the onset of left atrial deflection, LA, in the esophageal lead. As before, the optimal AVD can be approximated as being the sum of the interatrial intervals RA-LA or M_A-LA and 70 ms:

$$AVD_{SENS} = RA\text{-}LA + 70\ \text{ms} \quad \text{or}$$
$$AVD_{SENS} = M_A\text{-}LA + 70\ \text{ms}\ .$$

In systems with real-time telemetry, differences of RA-LA and M_A-LA were reported to be negligible [10]. As sense-event markers are widely supported in

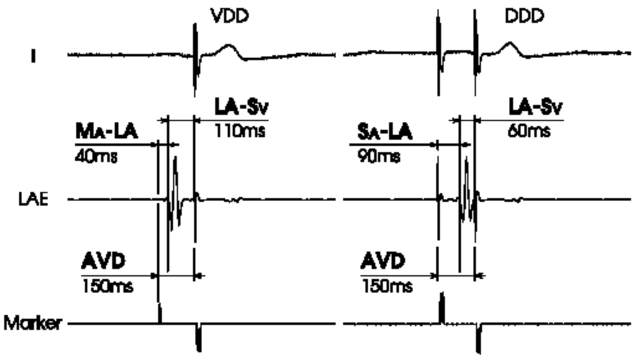

Figure 1. Principle of the programmer-based individualized AVD optimization using the EPR 1000 (BIOTRONIK). Measurement of interatrial time relations during VDD and DDD operation in a patient with AV block. Simultaneous recording of surface ECG lead I, left atrial esophageal electrogram, and telemetric marker channel. In VDD operation, M_A-LA is measured from the onset of the right atrial sense-event marker to the onset of the left atrial deflection in the left atrial electrogram. During DDD operation, the time interval S_A-LA is measured from the atrial stimulus to the left atrial deflection. AV delays were programmed to be 150 ms during both VDD and DDD operation. The intervals LA-S_V between left atrial deflection, LA, and ventricular stimulus, S_A, of 110 ms and 60 ms, respectively, differ from the mean optimal LA-S_V of 70 ms reported in sonographic studies.

AVD:	*AV delay*
LA:	*onset of left atrial deflection in the esophageal lead*
LAE:	*filtered left atrial esophageal electrogram*
M_A:	*onset of telemetric right atrial sense-event marker*
S_A:	*right atrial stimulus*
S_V:	*right ventricular stimulus*

pacing systems, measurement of M_A-LA should be preferred.

Results

To record the left atrial electrogram, the programmers CPI 2901, CPR I, RX 5000, Medtronic 9790, PMP 1000, APS II, and Vitatron 9790 needed an additional external high-pass preamplifier (Hörmann VV1000). Its input was connected to the esophageal catheter and the output to lead I of the programmer's ECG cable (Table 1). Interatrial conduction intervals could be measured either on screen using the screen-freeze and caliper option, or manually on the printed ECG strips. Present software versions of the CPR I and the Vitatron 9790 programmers showed a relevant telemetric marker delay of about 56 to 70 ms [10]. Therefore, they were excluded from programmer-based AVD optimization.

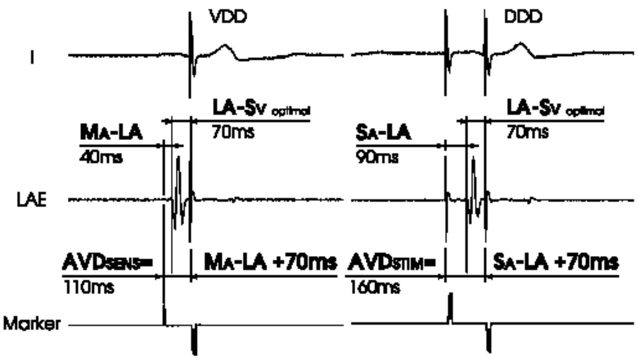

Figure 2. Approximated individual optimal AVDs during VDD and DDD operation in the same patient as in Figure 1. AV delays were calculated to be the sum of the measured interatrial time intervals MA-LA and SA-LA, respectively, and the representative mean optimal LA-SV interval of 70 ms from sonographic studies. After programming AVDSENS and AVDSTIM, LA-SV was found to be exactly 70 ms during both operations.

AVD$_{SENS}$:	*optimal AV delay during VDD operation*
AVD$_{STIM}$:	*optimal AV delay during DDD operation*
LA:	*onset of left atrial deflection in the esophageal lead*
LAE:	*filtered left atrial esophageal electrogram*
M_A:	*onset of telemetric right atrial sense-event marker*
S_A:	*right atrial stimulus*
S_V:	*right ventricular stimulus*

With the EPR 1000, esophageal lead recording is supported by the internal software. Activating this option, EPR 1000 was used in 28 patients with AV block to program individual AVD during pre-discharge programming. The AVD programming could be performed routinely within approximately 10 min. An example is shown in Figures 1 and 2, recorded from a pacemaker patient (Logos, BIOTRONIK). To measure the interatrial conduction interval M_A-LA, the pacing rate was programmed below the sinus rate. Simultaneous recordings of the left atrial electrogram and sense-event marker were frozen on the display (Figure 1). Caliper measurement of the M_A-LA interval yielded 40 ms and was completed by adding 70 ms, resulting in an optimal AVD$_{SENS}$ of 110 ms. The rate was then increased to about 10 bpm above the sinus rate to measure S_A-LA during DDD operation. Adding 70 ms to the S_A-LA interval of 90 ms results in an optimal AVD$_{stim}$ of 160 ms. Upon calculation of the optimal AVD, selection of the programmable AVDs was controlled by visualization of the intervals LA-S_V, which were exactly 70 ms after optimization (Figure 2).

Discussion

Applying esophageal electrography, an individual optimal AVD during resting conditions can be approximated by only two measurements of interatrial conduction intervals. The resulting AVD represents the relationship between the right atrial triggers of the programmed AVD (M_A during VDD and S_A during DDD operation, respectively) and left atrial depolarization. Hemodynamic aspects will be taken into account when using the mean value of the optimal interval between left atrial deflection and right ventricular stimulus determined by sonographic studies [8]. Because the use of the mean value is a simplification, other methods for more accurate AVD optimization may be required in special cases.

Adding an external left atrial electrogram filter, simplified AVD programming can be performed by a variety of modern programmers in less time and with less device expense.

If the left atrial electrogram software filter is integrated into the programmer, no further devices are needed. This particular solution of the EPR 1000 (BIOTRONIK) enables an entirely programmer-based AV-delay optimization to economize individualized AVD programming.

Applying the proposed method, rate modulation of the AVD can also be taken into consideration. Assuming individual constancy of the interatrial conduction intervals as has been reported [11,12] and a linear correlation between approximately 5 ms AV interval decrease for every 10 bpm rate increase [13], the rate-modulated delay, AVD(f), can easily be calculated: To this end, the 70 ms are reduced by half of the value of the difference, Δf, between the current activity rate and the resting rate. Thus, based on the interatrial conduction intervals during rest, AVD(f) during activity can be approximated by the following equations:

$$\mathrm{AVD_{SENS}(f)} = M_A\text{-LA} + 70\text{ms} - \Delta f\ \text{ms}/2 \quad \text{and}$$

$$\mathrm{AVD_{STIM}(f)} = S_A\text{-LA} + 70\text{ms} - \Delta f\ \text{ms}/2.$$

In practice, Δf will be less then 140 bpm in most cases. Thus, AVD(f) does not undercut the interatrial conduction intervals M_A-LA and S_A-LA, respectively.

Conclusion

The function of a variety of programmers can be expanded by equipping them with additional external high-pass amplifiers to use left atrial electrography for individual AVD optimization. Operation is even more facilitated in the EPR 1000 programmer by internal left atrial electrogram software support. This simplifies AVD programming during routine checkup considerably and allows accomplishing this task routinely within approximately 10 min. To calculate the approximated resting AVD, the interatrial conduction intervals M_A-LA and S_A-LA must be measured from the telemetric sense- event marker, M_A, and the atrial stimulus, S_A, in the marker channel and the left atrial deflection, LA, in the left atrial electrogram. The rate-modulated AVD(f) during activity can be programmed by reducing the resting AVD by half of the difference between the current activity rate and the resting rate.

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