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Assessment of the optimal atrioventricular delay in patients with dual chamber pacemakers using impedance cardiography and Doppler echocardiography

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Impedance cardiography and Doppler echocardiography are two non-invasive methods to investigate the haemodynamics in dual chamber pacing. The purpose of the study was to assess the haemodynamic effects of different atrioventricular delays (AVDs). Second aim was the comparison of these established techniques to find the easiest method for optimal AVD selection.

36 patients with dual chamber pacemakers were tested at rest and 32 of them at a higher rate (90 bpm) pacing. We measured the stroke volume by impedance cardiography at various AVDs. Doppler echocardiography was used to determine the maximum velocity of aortic flow and its velocity-time-integral.

The measurements show individually different optimal AVD between 78 and 300 ms. Compared with the most disadvantageous AVD we could improve the stroke volume at optimal AVD by 30.6 ± 24.7 % (at rest) and by 43.6 ± 18.9 % (at a higher pacing rate). These optimal AVDs were confirmed by measurements of maximum aortic flow and its velocity time integral, which were found to be in good correlation to the stroke volume measured by Impedance cardiography. The aortic flow and velocity time integral significantly increased at rest by 13.3 ± 10.1 % and 12.9 ± 9.7 % at higher rate pacing by 19.9 ± 15.8 % and 25.8 ± 19.7 % respectively.

The optimal AVD for haemodynamics in dual chamber pacing is always an individual value. Impedance cardiography and Doppler echocardiography both provide this optimal AVD. *J Clin Basic Cardiol 1999; 2: 237–40.*

Key words: dual chamber pacemaker, AV delay, impedance cardiography, Doppler echocardiography, cardiac haemodynamics

Adjustment of optimal atrioventricular delay (AVDs) in patients with dual chamber pacemakers is essential for cardiac haemodynamics, especially for an appropriately timed atrial systole and a maximum end-diastolic left ventricular volume [1–3]. The optimal AVD seems to be always an individual delay determined by a number of cardiac (haemodynamic and electrophysiological) and extracardiac factors. There are many methods to investigate the effects of different AVDs on left atrial and ventricular functions, but most of them are complicated and invasive to apply or too expensive for clinical routine.

Impedance cardiography and Doppler echocardiography are two non-invasive methods for easy selection of the optimal AVD in patients with dual chamber or atrial-triggered ventricular pacing [4–11]. The purpose of the study using the two methods was to assess the changes in stroke volume (impedance cardiography) and maximum aortic flow (Doppler echocardiography) caused by different AVDs and to find the easiest method for optimal AVD selection.

Methods

We tested 36 consecutive chronotropically competent patients (aged 59.2 ± 12.4) with AV node dysfunction (Table 1 and Table 2) and dual chamber pacemakers (15 Vitatron Diamond I/II, 15 ELA Chorus 6244, 2 Intermedics Relay, 1 Biotronik Diplos 05, 1 Biotronik Logos, 2 Medtronic Elite) during sinus rhythm and VDD stimulation at rest. In a second series, 32 of them were paced at a higher rate (90 bpm) during DDD stimulation to examine the effect of an increased heart rate.

For the haemodynamic studies we used a "Cardioscreen" bioimpedance measurement device (Medis, Ilmenau, Germany), which allows the non-invasive detection of changes in transthoracic electric impedance by skin surface electrodes. For the measurements two pairs of electrodes were placed at each side of the neck base, 5 cm apart, and two of them at both mid axillary lines at level of xyphoid, also 5 cm apart. The outer electrodes transmitted (longitudinally to the thorax) a constantly low amplitude (1 mA) high frequency (100 kHz) current, which is safe and unsensed; the inner electrodes were the detection electrodes.

The impedance changes dependent on the systolic aortic flow were measured and the results used to calculate the stroke volume and the cardiac output (Figure 1) at various AVDs (depending upon the type of pacemaker 60 ms–300 ms, steps of 40 ms) and

Table 1. Clinical and electrophysiological indications for pacemaker implantation

	Clinical indication			Electrophysiological indication			
	Heart failure	Cerebral syndrome	Prophylaxis	I° AVB and SAB	I° AVB and CSS	II° AVB	III° AVB
No. of patients	7 (19.4 %)	27 (75.0 %)	2 (5.6 %)	5 (13.9 %)	2 (5.6 %)	8 (22.2 %)	21 (58.3 %)

Table 2. Clinical characterisation of patients (n = 36)

	Left ventricular dysfunction (Ejection fraction < 50 %)	Valvular defect	Hypertension	Coronary heart disease
No. of patients	13 (36.1 %)	2 (5.5 %)	7 (19.4 %)	14 (38.9 %)

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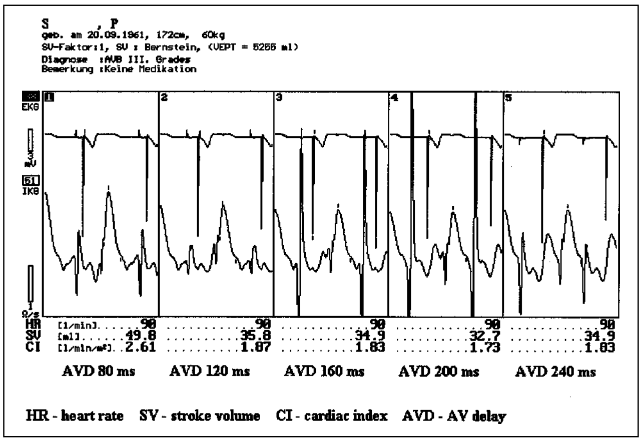

Figure 1. Pat. P. S. (male; aged 37, DDD pacemaker Biotronik Logos implanted for 3rd degree AV block). Stroke volume and cardiac output were measured by impedance cardiography at various atrioventricular delays (DDD stimulation, rate 90 bpm).

AVD extensions (31 ms–40 ms) during atrial stimulation. The average stroke volume over 20 accepted cardiac cycles was calculated in accordance with the Nyboer/Kubicek equation as modified by Sramek and Bernstein [12–14]. To achieve a steady state (stable conditions) measurements were taken in the supine rest position after a five-minute adaptation interval.

Doppler echocardiography (continuous wave Doppler) was used to determine the dynamics and timing of aortic flow at the same pacemaker adjustments as for impedance cardiography measurements. We analysed the maximum velocities and the velocity-time-integrals (VTI) of the aortic flow (Figure 2). The optimal AVDs found by impedance cardiography and the parameters of aortic flow were compared. The Doppler echocardiographic measurements were performed using a "Toshiba SSH 140 A" device. The 2.5 MHz transducer was placed at the apex position of the heart to image the apical five-chamber view with the patient lying in left lateral position. The Doppler beam was aligned parallel to aortic outflow. The peak flow and the area over the flow curve were marked and the maximum flow velocity and its VTI calculated.

Statistics

All data are expressed as the mean value ± standard deviation. The correlation between the optimal AVD calculated by impedance cardiography and the optimal AVD delay measured by Doppler echocardiography was determined according to the Pearson correlation coefficient. The variances of stroke volume, maximum aortic flow and aortic VTI were analysed by the t-test for paired data. A p value of < 0.05 was regarded as significant. Data analyses were performed by the SPSS® statistical program.

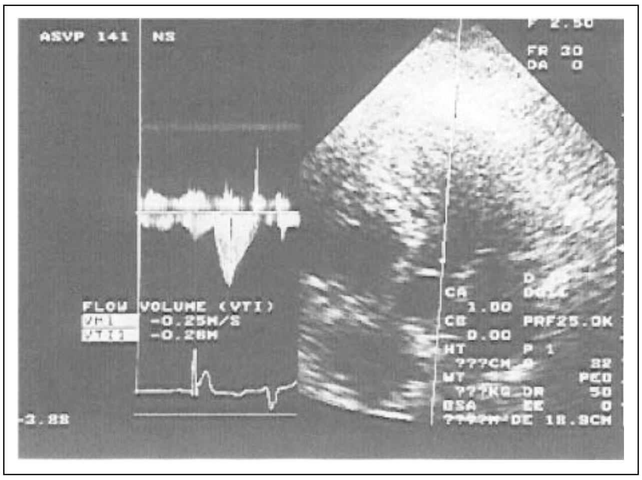

Figure 2. Pat. H. D. (male, aged 83, DDD pacemaker ELA Chorus 6244 implanted for 2nd degree AV block). Doppler echocardiographic measurement (continuous wave Doppler) of velocity-time-integral of aortic flow (atrial sensed AVD 141 ms).

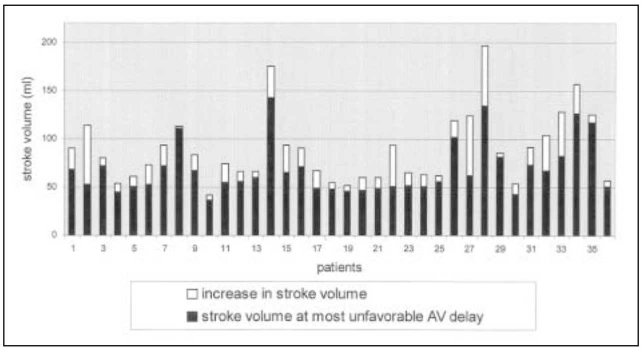

Figure 3. Increase in stroke volume (ml) following use of optimal atrioventricular delay measured by impedance cardiography at rest (VDD stimulation)

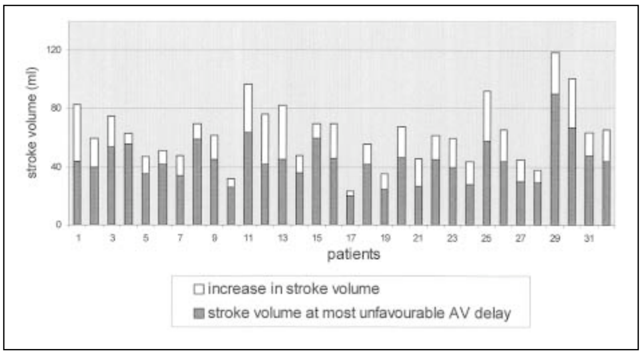

Figure 4. Increase in stroke volume (ml) following use of optimal atrioventricular delay at a higher rate DDD stimulation (f = 90 bpm)

Results

By means of impedance cardiography we analysed the stroke volume and cardiac output at rest (sinus rhythm) in 36 patients with pacemakers working in an atrial-triggered ventricular-paced mode (VDD) at different AVDs (60–300 ms depending upon pacemaker type). The mean optimal stroke volume was 88.7 ± 35.3 ml found over the whole range of AVDs (78 and 300 ms). The optimal AVD for all patients averaged 157.6 ± 62.3 ms. Using the most disadvantageous AVD (again individually different between 94 and 260 ms, averaging 178.9 ± 62.2 ms), the mean stroke volume was only 68.5 ± 26.7 ml. By programming each individual optimal AVD we could increase the stroke volume at rest by 30.6 ± 24.7 % ($p < 0.01$) against the worst case (Figure 3). By retaining the baseline "factory-set" pacemaker adjustment (basic AVDs lying between 125 and 175 ms) at rest there was a mean stroke volume of 70.6 ± 22.1 ml; the difference to the optimal stroke volume was 14.7 ± 8.9 % ($p < 0.05$).

In a second series, 32 patients were tested during DDD pacing at 90 bpm and various AVDs (absolute AVD between 78 ms and 260 ms; the AVD extension following atrial pacing was fixed depending upon the type of pacemaker). The maximum stroke volume measured by impedance cardiography averaged 63.1 ± 20.7 ml and was found at individually different AVDs between 90 ms and 300 ms. The average optimal AVD was calculated at 166.6 ± 61.9 ms. The most unfavourable AVD was measured between 90 ms and 281 ms, averaging 219.0 ± 62.4 ms. At this AVD the stroke volume was only 44.1 ± 14.3 ml. Without changing the basic "factory-made" pacemaker adjustments (baseline AVDs including AVD extension lying between 150 and 219 ms) we found a mean stroke volume of 52.0 ± 15.8 ml. By programming the best individual AVD we could reach a significant increase in stroke volume during higher rate DDD stimulation by 43.6 ± 18.9 % ($p < 0.05$) (Figure 4). Compared with the optimal stroke volume, the stroke volume on baseline pacemaker adjustments was 29.6 ± 22.4 % lower ($p < 0.05$).

In both measurement series there was no significant difference relative to acute increase in stroke volume between patients with or without heart disease.

Using Doppler echocardiography at the same pacemaker adjustments as for impedance cardiography (with various AVD settings) measurements of transaortic flow were made. The respective VTIs were calculated. At the optimal AVD at rest found by impedance cardiography we measured a maximum average aortic flow of 1.34 ± 0.31 m/s; the mean VTI of aortic flow was 0.30 ± 0.09 m. At the most unfavourable AVD the average aortic flow was 1.18 ± 0.29 m/s with the respective VTI being 0.28 ± 0.12 m. We found an average increase in the aortic flow by 13.3 ± 10.1 % at rest ($p < 0.05$), relative to the VTI it was 12.9 ± 9.7 % ($p < 0.05$). The correlation between the optimal AVD found by impedance cardiography and the optimum AVD showed by VTI measurements was 0.97; relative to the maximum aortic flow it was 0.75.

With the optimal AVD found by impedance cardiography at a higher rate pacing (f = 90 bpm) the maximum aortic flow was 1.35 ± 0.35 m/s, the respective VTI being 0.26 ± 0.09 m. Programming the most disadvantageous AVD of impedance measurements we found a mean aortic flow of only 1.12 ± 0.33 m/s and an average VTI of 0.23 ± 0.15 m. The maximum aortic flow increased by 19.9 ± 15.8 % with optimal AVD ($p < 0.05$), the rise of VTI was 25.8 ± 19.7 % ($p < 0.05$). The correlation between the optimal AVD found by impedance cardiography and the optimal AVD found by VTI and maximum, aortic flow measurements under higher rate pacing was < 0.5.

There was also no significant intraindividual correlation between the increase of stroke volume during VDD stimulation at rest and higher rate DDD pacing.

Discussion

Our measurements confirm the existence of individually different haemodynamic optimal AVDs at rest and at an increased heart rate [3, 4, 8, 11, 15, 16]. The mean optimal and worst AVDs show a high standard deviation and are a statistical value only, which could never be used for individual pacemaker adjustment. The optimal individual AVD depends on a number of cardiac (characteristics of heart disease, intra- and interatrial conduction time, sinus node function) and extracardiac (lead position, drugs, catecholamine activation status) factors. Using the optimal individual AVD we could obtain a significant increase in stroke volume and cardiac output at rest. At a higher rate pacing we could even improve those favourable effects, which were caused by an appropriately timed atrial systole, an increase in the atrial contribution to cardiac output and an increased ventricular preload according to the Frank-Starling law. To achieve maximum haemodynamic benefit and to secure a nearly physiological atrial-sensed-ventricular-paced stimulation form it is necessary, in most cases, to change the basic "factory-set" adjustment of the pacemaker.

Impedance cardiography allows easy and efficient non-invasive determination of stroke volume and cardiac output at various AVDs to find its optimum. Several studies, comparing impedance cardiographic measurements with other cardiac output determination methods such as thermodilution, indirect Fick (CO_2) method or radionuclide ventriculography, have shown an acceptable correlation of 0.7 to 0.9 [17–25]. The impedance cardiography measurements show a high reproducibility [26, 27] and permit a reliable detection of small changes of stroke volume dependent on various pacemaker adjustments. The known limitations and problems (calculation of the volume of electrically participating tissue by differences in weight and height, variations of thoracic anatomy and volume, influence of respiration and blood rheology, cardiac diseases such as dilated cardiomyopathy with low cardiac output, valvular regurgitation and intra-cardiac shunts) were discussed controversially [28, 29], but they are more problematic for an accurate assessment of an absolute amount of stroke volume and cardiac output. To find the optimal pacemaker adjustment it is sufficient to assess the relative intraindividual changes of stroke volume and they are independent of these inter-individually different factors [30]. By using a special software the "Cardioscreen" device is able to recognise and remove the respiratory fluctuations.

Doppler echocardiography is a further non-invasive technique to study the influence of varying AVDs on cardiac function. The visual evaluation of early (E) and atrial (A) wave relationship of transmitral flow allows only a rough estimation of the best possible AVD adjustment. Analysing the E and A wave VTIs it is possible to evaluate the optimal timing of ventricular filling dependent on atrioventricular delay [9, 10, 26, 31–33]. However, these measurements are too complicated to use and also too investigator-dependent for clinical routine. As a second problem at longer AVDs and higher pacing rates the atrial filling wave become progressively superimposed on the early filling wave and it is very difficult to assess the exact changes in this relationship. Therefore a purpose of this study was to analyse the valence of maximum velocity and VTI of aortic flow as simple Doppler echocardiographic parameters for the AVD adjustment. Acceptable correlations between stroke volume found by impedance cardiography or thermodilution and Doppler echocardiographic technique (stroke volume as a product of aortic flow VTI and area of aortic outflow tract) have been described [29, 34–37]. The optimal AVDs measured by impedance cardiography were confirmed by assessing the maximum aortic flow velocity and its VTI; by programming these AVDs we could obtain a significant increase in the VTI and also in the maximum aortic flow. At rest there is a good correlation between optimal AVD calculated by impedance cardiography and optimal AVD delay found by evaluation of VTI (0.97) and maximum aortic flow velocity (0.75).

Several studies using impedance cardiography or Doppler echocardiographic techniques have shown significant changes in stroke volume depending on AVD. The improvement rates at rest using Doppler echocardiography were described between 7.8 % [38] and 19 % [39]. Using impedance cardiography the changes were shown to be between 7 % and 32 % [6]. In the literature we could not find a direct comparison between the increase in stroke volume found by impedance cardiography and Doppler echocardiographic measurements of aortic flow. Comparing impedance cardiographic measurements and Doppler echocardiographic studies of mitral flow in VDD paced patients acceptable correlations (0.66) between these two methods were described.

Impedance cardiography and Doppler echocardiographic measurement of maximum aortic flow and its VTI both allow to assess the optimal AVD. Modern impedance cardiography devices are portable and require only one minute for a single measurement and calculation. They are easy to use and the observer variability is slight [37, 40, 41]. Doppler echocardiographic devices are more expensive, are not easily portable and more investigator dependent. For these reasons, impedance cardiography seems the easier method for AVD assessment during clinical routine.

Limitations

• During higher rate dual chamber stimulation in our study the correlation between the optimal AVD found by impedance cardiography and Doppler echocardiographic techniques was limited to 0.50 (VTI 0.45; maximum flow 0.45). A comparison between impedance cardiography and Doppler echocardiographic assessment of optimal mitral flow in atrial paced patients showed only a small correlation (0.53) too [4]. Either of the two methods has specific limitations, which were determined by a number of impedance or ultrasound detection problems. Relative to impedance cardiography this was caused by problems in detecting and processing additional atrial spikes by the impedance cardiography device. Then it was impossible to set correct automatic trigger points for the impedance curve and to calculate an exact stroke volume. It was necessary to correct the set points and impedance curve by hand, but in some of these patients it was very difficult to find these exact trigger points. Doppler echocardiographic studies were limited by difficulties in marking exact VTI in some patients with bad ultrasound conditions. During higher rate stimulation the reliability of both measurements depends more on the individual patient characteristics and on the experience of the investigator.

• In addition, in dual chamber stimulation it is difficult to distinguish between the effects of stimulation (lead position, electromechanical delay, intra- and interatrial conduction) and the real rate effects. Therefore it will be necessary to carry out several examinations using different stress models for rate improvement.

• Our data show only the acute haemodynamic effects of programming different AVD. In a second study we are now assessing the long term effects relative to quality of life. These data will be published in the near future.

The AVD is essential for stroke volume and cardiac output. The optimal AVD is an individually different parameter and, in most cases, it is necessary to change the basic adjustment of the pacemaker AVD. Impedance cardiography is a reliable and easy method for assessing relative changes of stroke volume and cardiac output dependent on AVD. The optimal AVDs found by impedance cardiography were confirmed by Doppler echocardiographic measurements of the maximum aortic flow and its VTI. Impedance cardiography and Doppler echocardiography both provide the optimal AVD for a particular patient.

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