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Cardiac output-based versus empirically programmed AV interval — how different are they?

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Aims: To compare empirically programmed and cardiac output-based programming of atrioventricular (AV) interval in patients with dual chamber pacemakers.

Methods and Results: In 19 patients with implanted dual chamber pacemakers due to AV block but otherwise normal hearts, cardiac output was assessed using an impedance cardiography device. In all patients, the AV interval had been previously programmed empirically by an experienced cardiologist. Cardiac output was estimated at AV intervals from 50 to 250 ms during VDD pacing. AV intervals adjusted by serial cardiac output estimations caused a rise in cardiac output in 84% of patients. The maximal achievable cardiac output was greater by 12% ± 8% (range 0–32%), $P<0{\cdot}001$, than was observed with empirically programmed AV intervals.

Conclusions: In patients with dual chamber pacemakers due to AV block and otherwise normal hearts, empirically selected AV intervals may lead to compromise of cardiac haemodynamics. Optimal AV intervals may be selected by serial cardiac output measurements.
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Key words: Optimal AV interval, cardiac output, dual chamber pacemaker, impedance cardiography.

Introduction

The synchronization of atrial and ventricular activation produced by a dual-chamber pacemaker does not guarantee optimal haemodynamics. The importance of atrioventricular (AV) interval in influencing cardiac haemodynamics has already been demonstrated[1–6]. When programmed incorrectly, AV interval may result in cardiac output equal to that achieved using ventricular pacing[1–5].

The aim of this study was to compare the cardiac output at empirically selected AV intervals to the maximal cardiac output achieved during serial AV interval changes in patients with dual chamber pacemakers.

Patients

Inclusion criteria

Patients were included if they visited the outpatient clinic and had had a dual chamber pacemaker implanted a minimum of 3 months before due to second- or third-degree AV block, and the systolic performance of whose heart was preserved or only mildly decreased as determined by echocardiography (at our institution preserved systolic left ventricular (LV) function corresponds to an LV ejection fraction from 55%–51% and mildly decreased from 50%–45%).

Exclusion criteria

Patients were excluded for the following:

(1) Spontaneous AV conduction determined during follow-up.
(2) Atrial fibrillation and other atrial or ventricular arrhythmias which could change cardiac output.
(3) Moderate or significant valvular disease.
(4) Moderate or significant LV dysfunction (determined by an echocardiographic EF <45%).
(5) Clinical signs of congestive heart failure (CHF).
(6) Pericardial or pleural effusion.
(7) Peripheral oedema.
(8) Tremor.
(9) Any acute illness.

The study was approved by the Ethics Committee and a written informed consent was obtained from every patient.

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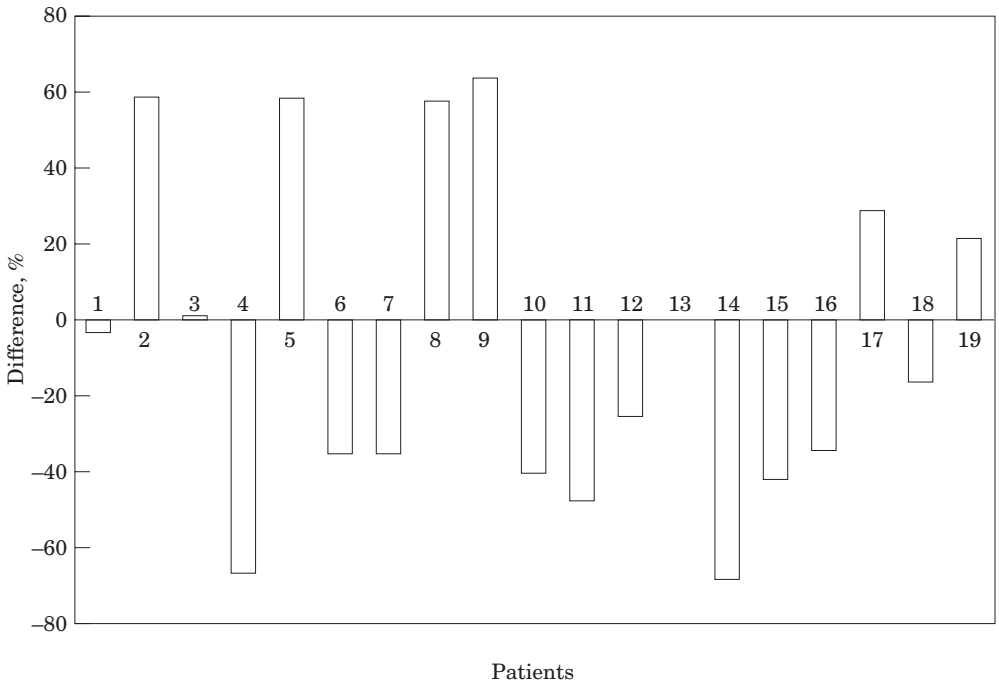

Figure 1 **Difference among empirically selected and optimized AV intervals. Empirically programmed AV intervals are the zero line. Optimal AV intervals are shown in columns as percentage differences from empirical AV intervals. As can be seen, optimal AV intervals were similar to empirical intervals in only three patients (patients 1,3,13 in the figure). In six patients (patients 2,5,8,9,17,19 in the figure, columns above the zero line) optimal intervals were greater than empirical by 23%–64%. In 10 patients (patients 4,6,7,10–12,14–16,18 in the figure, columns under the zero line) optimal intervals were shorter than empirical by 15%–67%.**

Methods

Cardiac output estimation protocol

Cardiac output was measured by an Impedance Cardiography Device NICaS-2001 (Teledyne-NIM, LLC, AL, U.S.A.). Cardiac output was calculated from the product of the mean stroke volume, averaged over eight beats, which were acceptable to the device, and the heart rate, which was derived from the ECG continuously recorded over the same period. Mean cardiac output was calculated by averaging three consecutive measurements. All patients were studied by the same operator under standardized conditions, and all measurements of cardiac output were made in the supine position after at least 15 min rest.

Cardiac output was estimated:

(1) With AV intervals programmed empirically at a previous follow-up visit.
(2) During the programmed lower rate of the pacemaker which was lower than the intrinsic atrial rate by at least 10 beats . min^{-1}.
(3) During various AV intervals from 50 to 250 ms in 50 ms increments. Three minutes were allowed to elapse between reprogramming and the measurement of cardiac output. Any complaint during reprogramming was an indication that the patient should be excluded from the study protocol.

The previously estimated variability of the device in cardiac output measurements in the supine position was $6\% \pm 5\%$[7].

Definitions

The empirical AV interval was defined as the AV interval programmed routinely by an experienced electrophysiologist at the time of the last follow-up visit prior to the beginning of the study without using any haemodynamic measurements and based only on the personal experience of the pacemaker specialist. The optimal AV interval was defined as the AV interval which resulted in maximal achievable cardiac output in a given patient.

Statistics

The data are presented as mean ± SD. Serial cardiac output measurements were statistically analysed by the paired Student t-test. Tests of the hypotheses were conducted at the probability level 0·05.

Results

Patients

Twenty patients fulfilled the inclusion criteria, but one patient was excluded from the study due to severe dizziness during reprogramming of the pacemaker. Mean age was 66 ± 10 years, 15 patients were male. Sixteen patients had complete AV block and three had second-degree AV block. All patients underwent echocardiography prior to the study. In three patients, mild aortic stenosis was observed, in eight patients there was mild mitral regurgitation, and in three mild tricuspid regurgitation was observed. Systolic left ventricular function was preserved in all patients. The pacemakers were DDD and DDDR in seven patients and VDD in 12. At the time of the study, all patients had spontaneous sinus activity in the atria.

Empirical and optimal AV interval

The average AV intervals programmed empirically 144 ± 42 ms (range 120–250 ms), and those optimized by cardiac output measurements 155 ± 64 ms (range 50–250 ms), were similar, $P>0{\cdot}05$. However, there was a broad range of differences between empirically programmed AV intervals and optimized AV intervals (Fig. 1). Empirical AV intervals were similar to haemodynamically optimal AV intervals in only three patients (16%) (Fig. 1). In the other 16 patients (84%), empirical AV intervals were different from optimal AV intervals. In six patients, the empirical AV interval was longer than the optimal AV interval by 23% to 63% (Fig. 1). In 10 patients, the empirical AV interval was shorter than the optimal by 15% to 67% (Fig. 1).

Cardiac output at empirical and optimal AV intervals

The mean maximal achievable cardiac output was significantly greater by 12% ± 8% (range 0–32%), $P<0{\cdot}001$, than the cardiac output with empirically programmed AV intervals (Fig. 2). The mean values were $5{\cdot}3 \pm 1{\cdot}4$ l . min^{-1} (range 3·9–10·0 l . min^{-1}) and $4{\cdot}7 \pm 1$ l . min^{-1} (range 3·3–7·61 l . min^{-1}), respectively (Fig. 2).

In three patients (16%), cardiac output during AV interval optimization did not change by more than the mean variability (6%) of the method; in the other 16 patients (84%), cardiac output increased during AV interval adjustment by more than 6% (Fig. 3). In seven patients (37%), cardiac output increased by more than 6%, i.e. the mean of the variability of the method utilized (Fig. 3). In five patients (26%), cardiac output increased by more than 11%, i.e. the mean of the variability plus one standard deviation (Fig. 3). In four patients (21%), AV interval adjustment according to the protocol increased cardiac output by more than 16%, i.e. the mean of the variability plus two standard deviations (Fig. 3).

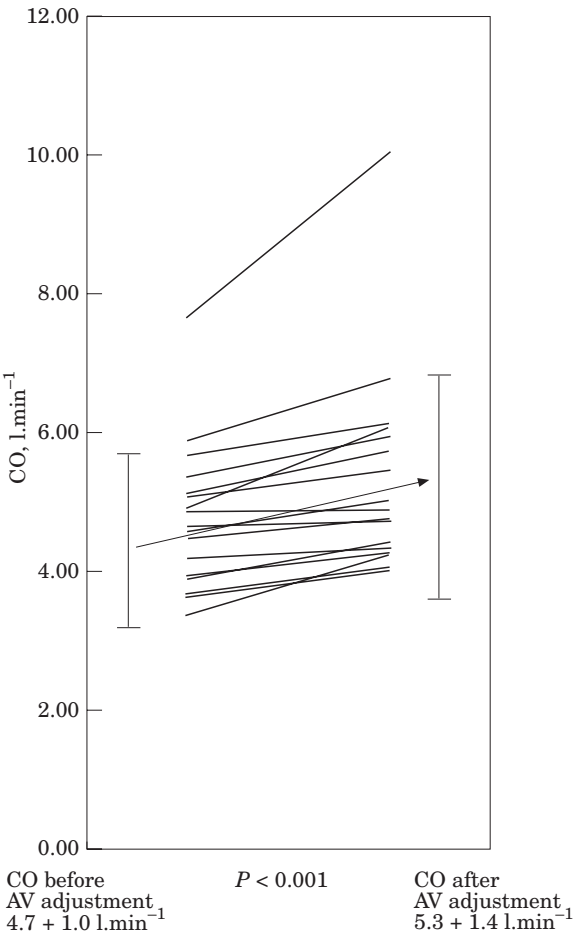

Figure 2 **Cardiac output following empirically selected AV interval versus cardiac output following AV interval optimization. As can be seen, cardiac output (CO) achievable during AV interval optimization was significantly greater than empirically programmed.**

Discussion

The aim of the study was to examine the haemodynamic consequences of empirical programming of the AV interval in patients with implanted dual chamber pacemakers due to AV conduction defects but otherwise normal hearts. To the best of our knowledge, this is the first study to investigate the haemodynamic significance of empirical programming of the AV interval. Disadvantages in haemodynamic terms of empirical AV interval selection were illustrated by significant differences in cardiac output during empirically selected AV intervals and AV intervals optimized by cardiac output measurement (Fig. 2). At this point estimated data on the variability of the method was applied to analyse the results in each patient (Fig. 3). The maximal cardiac output achieved by AV interval adjustment exceeded the cardiac output at the empirical AV interval by more than the mean variability of the method in 84% of patients (Fig. 3). When other criteria were applied to cardiac output assessment, i.e. mean variability plus one

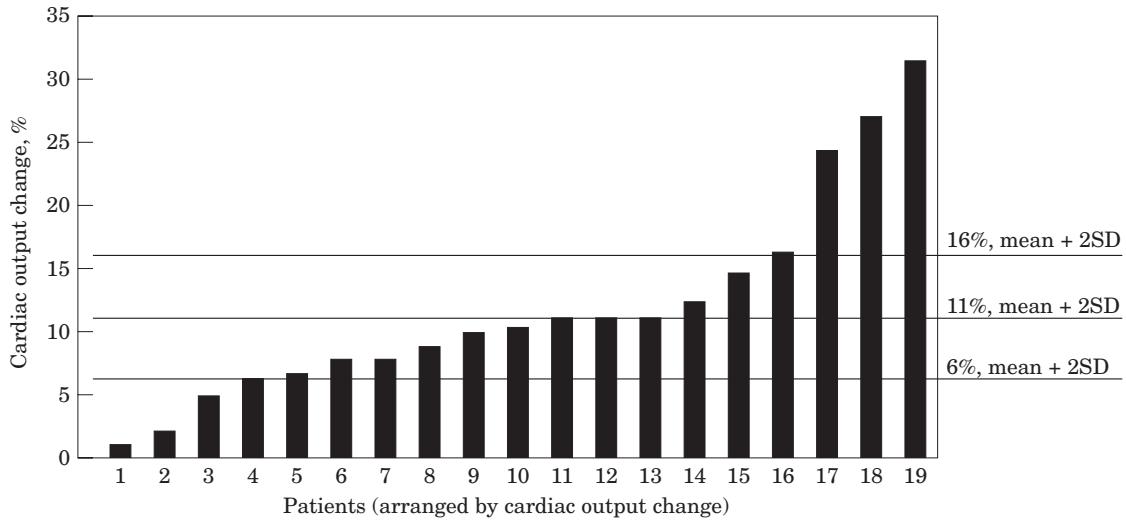

Figure 3 **Cardiac output change following AV interval optimization. In three patients (patients 1–3 in the figure) cardiac output did not change by more than the mean variability of the method for its estimation (6%); in seven patients (patients 4–10 in the figure), cardiac output increased by more than the mean of the variability of the method; in five patients (patients 11–15 in the figure), cardiac output increased by more than the mean of the variability of the method plus one standard deviation; in four patients (patients 16–19 in the figure), cardiac output increased by more than the mean of the variability of the method plus two standard deviations.**

standard deviation, 47% of patients had a higher cardiac output than during empirical AV selection. When stricter criteria were applied, i.e. mean variability plus two standard deviations, 21% of patients, i.e. one in every five patients, had a higher cardiac output than during empirical AV interval programming (Fig. 3).

Thus, at different levels of precision, superior haemodynamic results were achieved in most of the study pacemaker patients with preserved systolic left ventricular function when using haemodynamically optimized AV interval programming as opposed to empirical programming.

Many factors influence the AV interval, including parameters of atrial and ventricular sensing and capture latency, intra- and inter-atrial delay, intra- and inter-ventricular delay, underlying heart disease, catecholamine levels and concomitant medications.

In practice, it is very difficult to take into account all possible factors, therefore the AV interval may be adjusted individually by a comprehensive haemodynamic parameter such as cardiac output.

The clinical importance of haemodynamically-correct AV interval adjustment as part of dual chamber pacemaker programming has therefore clearly been demonstrated. Patients may not recognize or may not complain about symptoms related to compromised haemodynamics caused by improper AV interval programming because, before pacemaker implantation, they were in a relatively poor haemodynamic state, any haemodynamic improvement is welcomed. When effort tolerance and quality of life were analysed, most of the published data was from small groups of patients who underwent short periods of pacing[8–10]. The importance of these changes, here demonstrated, lies in the effect of them on the long-term quality of life of the pacemaker patient, but this has not yet been fully assessed.

The beneficial effects of atrial based pacing versus ventricular pacing on morbidity and mortality rates and on quality of life have been illustrated in a number of clinical studies, particularly in patients with sick sinus syndrome[11–16]. It should be noted that in these studies, the AV interval was empirically programmed. Dual chamber pacemakers with inappropriately programmed AV intervals may create haemodynamics similar to those of ventricular pacing, and, correspondingly perhaps, may have mortality and morbidity patterns similar to ventricular pacing. Therefore, we can speculate that optimized AV intervals, as demonstrated in this study, provide the opportunity to maximize the benefits of atrial based pacing with respect to haemodynamics and possibly morbidity and mortality.

In current practice, AV interval programming is usually empirically performed. The main reason for continuing empirical programming of the AV interval is a lack of a feasible, expeditious method for haemodynamic measurement in a large number of patients with dual chamber pacemakers. A wide range of changes in cardiac output (0–32%) during AV interval reprogramming (by 50 ms steps) might be expected. Therefore, only those methods with low variability, i.e. high precision, are appropriate for haemodynamic measurement. For the evaluation of cardiac performance in pacemaker patients, echo-Doppler and impedance cardiography may be used. Echo-Doppler is preferred for visualization of the details of intracardiac haemodynamics such as AV valve performance[3]. Impedance

cardiography is preferable for serial cardiac output estimations, but some simplified Doppler measurements may also be practical[17]. Echo-Doppler[1,16,17–20] and impedance cardiography[2,7,19] seem best to fulfil these criteria. These methods correlate well in cardiac output estimation in pacemaker patients[7] and accordingly, in haemodynamically guided AV interval programming.[21,22]

The main limitation of AV interval optimization by echo-Doppler and impedance cardiography is that it is performed only at rest. The non-linear adaptation of AV interval according to cardiac rate as used in present pacing devices is probably unsatisfactory. We believe that it should be replaced by automatic adjustment of the AV interval by a haemodynamic monitor incorporated into the pacing system.

Other limitations of the study

Only 'sensed' AV intervals have been studied and only patients with second or third-degree AV block have been included. These results cannot be automatically translated to patients with spontaneous AV conduction. Only one approach to empirical AV intervals programming has been used for comparison. These studies have all been made in supine, resting patients. The applicability of the results to erect posture and exercise cannot necessarily be assumed.

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