Effective use of a novel rate-smoothing algorithm in atrial fibrillation by ventricular pacing

H. J. Duckers, N. M. van Hemel, J. C. Kelder, H. Bakema and R. Yee*

Department of Cardiology, St Antonius Hospital, Nieuwegein, The Netherlands; * Division of Cardiology, London Health Sciences Centre, London, Ontario, Canada

Background It is still unknown whether a fast heart rate or an irregular ventricular response in atrial fibrillation causes tachycardiomyopathy. Reduction in the variability of RR intervals without an increase in heart rate might be an alternative treatment when antiarrhythmic drugs fail to control the irregularity accompanying atrial fibrillation.

Subjects and methods Eight patients underwent temporary right ventricular pacing, using a novel rate-smoothing algorithm prior to DC cardioversion or His bundle ablation. A rate-smoothing algorithm was utilized by right ventricular apical stimulation. Spontaneous and paced RR intervals during atrial fibrillation were quantified and processed for statistical analysis.

Results The rate-smoothing algorithm resulted in a substantial reduction in the variance of the RR intervals (slow mode 73-1%, fast mode 40-0%) and RR range (slow mode 49-3%, fast mode 34-3%). In contrast to previous algorithms, the mean heart rate during pacing intervention in atrial fibrillation did not change significantly to the heart rate directly preceding the pacemaker intervention (+2%).

Conclusions This initial study of the novel rate-smoothing algorithm shows that pacing intervention is a relatively safe, rapid and reliable alternative therapy for controlling irregular ventricular rhythms due to atrial fibrillation. Incorporation of the algorithm in implantable pacemakers appears justified, but demands further prospective studies in patients to evaluate relief of symptoms and reduction of tachycardiomyopathy due to atrial fibrillation.

Key Words: atrial fibrillation, rate-smoothing, pacemaker algorithm.

Introduction

The most frequent cardiac arrhythmia is atrial fibrillation; this causes dizziness, discomfort, palpitations and a limited exercise tolerance in many patients[1,2]. It is still a matter of debate whether the perception of palpitations in atrial fibrillation and the evoked tachycardiomyopathy is based on the fast heart rate per se or the irregularity of the heart beat[3,4].

Conventional atrial fibrillation therapy comprises the use of antiarrhythmic drugs, DC cardioversion, His bundle ablation, and recently arrhythmia surgery[5-7]. Rate smoothing, or reducing the large variation in ventricular RR intervals in atrial fibrillation by ventricular pacing was recently advocated as a therapeutic option, but the resulting pacemaker-related faster heart rate was a clear disadvantage[8-11].

This study addresses the initial results of a novel rate-smoothing algorithm without this side-effect and evaluates its usefulness if incorporated in implantable pacemakers.

Materials and methods

Pacing algorithm

The novel rate-smoothing algorithm was programmed into an external pacemaker (Vitatron Diamond I). Two quadrupolar catheters were introduced through the femoral vein and positioned in the right ventricular apex and right atrium, respectively. The atrial catheter was for sensing atrial fibrillation. The mode of operation was dual-chamber pacing with the adaptive mode switched on. If the rate-smoothing function is switched off, the pacemaker will immediately cease tracking the atrium as soon as an atrial arrhythmia is detected. The escape rate or intervention rate will flywheel down to the sensor rate or the lower rate limit, and remain there until normal sinus rhythm has returned. With the rate-smoothing...
function switched on, the intervention rate will adapt to the average ventricular rate, which is usually higher in these patients.

The algorithm uses a dynamic average of successive sensed spontaneous or paced heart rates as a reference point. This is determined by continuously sampling and averaging the sensed ventricular events. The intervention rate follows the average ventricular rate and is set just below the sensed average ventricular rate (average rate minus 2-5 beats min⁻¹) when the sensed ventricular rate drops below 2-5 beats min⁻¹ of the average sensed ventricular rate, the programme starts pacing. The pacing algorithm can adapt to the average ventricular rate with programmable slow (steps of 0-25 beats min⁻¹) or fast (steps of 2 beats min⁻¹) decrements until spontaneous activity takes over.

The intervention rate follows the average sensed ventricular rate at a maximum decrement or increment of 2 beats min⁻¹ per beat, thus avoiding the possibility of following a sudden brady- or tachyarrhythmia by pacing at a decelerating rate (see Fig. 1(b)).

It must be emphasized that the novel rate-smoothing algorithm tends to follow the average ventricular rate, but will not overdrive the spontaneous rate. In sinus rhythm, however, some fusion will occur as a result of normal atrial fluctuations.

Patient selection

Eight patients with chronic atrial fibrillation (mean age 68·3 ± 2·3 years) and scheduled for radiofrequency catheter His bundle ablation or DC cardioversion were studied after informed consent. The antiarrhythmic drug therapy was continued during the study. The patients were prepared for electrophysiological study in a supine position on the catheterization table. After completion of the protocol, the patients underwent the ablation procedure or DC cardioversion.

Data collection

Four ECG leads (I, II, III and V₁) were simultaneously recorded at a paper speed of 25 mm s⁻¹. The following study protocol was used: (1) 10 min for stabilization of the spontaneous heart rate during atrial fibrillation. (2) 30 min to record 1000 spontaneous QRS complexes with the ventricular pacing algorithm turned off. (3) 30 min to record 1000 spontaneous QRS complexes and/or ventricular paced complexes with the algorithm turned on, using the slow mode. (4) 30 min to record 1000 spontaneous QRS complexes and/or paced complexes with the algorithm turned on, using the fast mode.

Data analysis and statistics

RR intervals were manually quantified using a calliper, with an estimated inaccuracy of 20 ms. All measurements were stored on a computer file, allowing further processing and analysis. Both the mean RR interval (± standard deviation) and the mean value of the absolute difference between consecutive RR intervals were calculated (beat-to-beat variance). The relative RR interval difference between consecutive RR intervals was calculated as the ratio between the absolute difference and the mean RR interval for each programme modality. In addition, serial autocorrelograms and normalized histograms were determined. Rate-smoothing effects on RR variability were tested by an analysis of variance for repeated measurements. P<0·05 was considered to be significantly different. Data are presented in the graphs as means ± standard error of the mean (SEM). In this short-term study the changes in the perception of symptoms and palpitations were not investigated.

Results

Spontaneous RR intervals

The distribution of consecutive spontaneous RR intervals during atrial fibrillation prior to ventricular pacing depicts a random distribution (Fig. 2). The spontaneous RR interval was 568·7 ± 9·8 ms (SEM; median 605 ms) whereas the average standard deviation of the distributions was 124·5 ± 9·4 (mean range 670 ± 47 ms).

Rate smoothing with slow mode

Overall, rate-smoothing pacing using the slow mode in eight patients resulted in a substantial 59·4% reduction in the standard deviation (P=0·0001), and a 73·1% decrease in the variability per RR interval (P=0·0001; see Table 1). However, the average heart rate did not differ from the basal heart rate before pacing. The noted RR intervals with the rate-smoothing algorithm 'on' was 554·1 ± 6·0 ms, i.e. a reduction of −2·6% in this interval during the RS algorithm, showing no difference to pre-pacing basal values (P=0·222; median 610 ms). During this period, approximately 69% of the analysed complexes were paced.

Figure 1(a) shows the effect of rate smoothing in the fast mode. The randomness of spontaneous RR intervals prior to pacing is clearly changed. Apart from eliminating the relatively long RR intervals, the number of short RR intervals distributed was reduced by more than 40%, thereby reducing the standard deviation of distribution in this patient by 31%.

Rate smoothing with the fast mode

In three of eight patients, rate-smoothing pacing was also carried out with the fast mode. This resulted in less
Figure 1  (a) Example of rate-smoothing in atrial fibrillation. A 69-year-old patient with chronic atrial fibrillation was provided with a DDD Vitatron pacemaker with RS smoothing software. In the figure, the pacemaker falls in when it detects a ventricular interval below the intervention rate. The pacemaker paces at the average sensed ventricular rate minus 2.5 beats min⁻¹ (intervention rate) and decelerates with each flywheel cycle by 2 beats min⁻¹, thereby reducing the RR variability by 31%. (b) The principle of the novel Vitatron rate-smoothing algorithm. This rate-smoothing algorithm averages the sensed spontaneous and paced ventricular rate and is updated with each beat. The intervention rate of the pacemaker is positioned just under the average ventricular rate and follows the averaged rate at a maximum increment or decrement of 2 beats min⁻¹ per beat (A). This will avoid sudden bradyarrhythmia caused by decelerating pacing. Whenever the sensed spontaneous rate falls below the intervention rate, the pacemaker will fall in, pacing at the intervention rate. The intervention rate will decelerate at programmable slow (0-25 beats min⁻¹ per cycle, B) or fast decrements (2 beats min⁻¹ per cycle, C) until the spontaneous rate takes over again. Taken together, the algorithm tends to follow the average ventricular rate, but will not overdrive the spontaneous rate. □ = spontaneous beats; —— = intervention rate; ———— = average rate.
Stabilization of the cardiac rhythm by pacing intervention is gaining interest\[3,8,10\]. This approach has been shown to improve cardiac output and it can relieve symptoms, including the perception of palpitations\[3,13,14\]. The rationale of ventricular pacing in rate-smoothing of atrial fibrillation is under study\[15,16\]. Ventricular pacing intervention may abolish long RR intervals, but the elimination of short RR intervals remains to be explained. It has been hypothesized that the effect of retrograde conduction of paced ventricular impulses could alter atrioventricular junctional refractoriness with slow recovery of excitability. This might facilitate the electrotonic inhibition of anterograde impulses\[8,9,15,16\].

Wittkampf et al.\[9,16\] demonstrated that rate smoothing by ventricular pacing in atrial fibrillation reduced RR interval variability significantly. However, these authors noted a concomitant increase of 21 to 29% in overall heart rate, hampering application of this method for daily use. In contrast, the current rate-smoothing algorithm did not alter the overall heart rate, but the RR interval irregularity was significantly reduced. The variability between consecutive RR intervals was reduced by 73% and the overall variability of RR intervals was diminished by 59%. The heart rate change by only 2% as compared to values prior to application of the ventricular pacing algorithm.

These data underscore the feasibility of rate-smoothing ventricular pacing in the treatment of atrial fibrillation. The slow mode modality of the algorithm appeared to be superior to the fast mode. This can be explained by the smoother rate decrements, resulting in more paced beats and consequently more retrograde atrioventricular penetration which contributes to the efficacy of the rate-smoothing.

The rate-smoothing algorithm appears to be a rapid, safe and reversible method of reducing RR variability in atrial fibrillation and therefore justifies further clinical investigation. This therapeutic strategy can be

**Table 1  Rate smoothing in atrial fibrillation**

<table>
<thead>
<tr>
<th>RR interval (ms)</th>
<th>AF/RS off mean (ms)</th>
<th>AF/RS on (slow mode)</th>
<th>Change (%)</th>
<th>P value</th>
<th>AF/RS on (fast mode)</th>
<th>Change (%)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean RR</td>
<td>568.72 ± 9.77</td>
<td>554.05 ± 6.03</td>
<td>-2.60</td>
<td>0.222</td>
<td>595.37 ± 17.70</td>
<td>+4.70</td>
<td>0.198</td>
</tr>
<tr>
<td>RR SD</td>
<td>124.46 ± 9.36</td>
<td>50.54 ± 3.70</td>
<td>-59.39</td>
<td>0.0001</td>
<td>84.00 ± 12.45</td>
<td>-32.51</td>
<td>0.044</td>
</tr>
<tr>
<td>Beat-to-beat variance</td>
<td>139.04 ± 11.38</td>
<td>37.39 ± 3.41</td>
<td>-73.11</td>
<td>0.0001</td>
<td>83.37 ± 14.37</td>
<td>-40.04</td>
<td>0.025</td>
</tr>
<tr>
<td>Variance/mean RR</td>
<td>0.224 ± 0.012</td>
<td>0.063 ± 0.007</td>
<td>-71.67</td>
<td>0.0001</td>
<td>0.135 ± 0.012</td>
<td>-39.55</td>
<td>0.002</td>
</tr>
<tr>
<td>Maximal RR interval</td>
<td>1025.00 ± 33.75</td>
<td>720.00 ± 15.12</td>
<td>-29.76</td>
<td>0.0001</td>
<td>813.33 ± 48.07</td>
<td>-20.65</td>
<td>0.008</td>
</tr>
<tr>
<td>Minimal RR interval</td>
<td>353.00 ± 17.63</td>
<td>380.00 ± 16.90</td>
<td>+7.04</td>
<td>0.323</td>
<td>373.33 ± 13.33</td>
<td>+5.16</td>
<td>0.563</td>
</tr>
<tr>
<td>RR range</td>
<td>670.00 ± 47.06</td>
<td>340.00 ± 22.68</td>
<td>-49.25</td>
<td>0.0001</td>
<td>440.00 ± 61.10</td>
<td>-34.33</td>
<td>0.026</td>
</tr>
</tbody>
</table>

In eight patients with chronic atrial fibrillation (AF) 1000 consecutive RR intervals (RR) were analysed from each pacemaker modality: without algorithm (RS off, n=8), with algorithm on in slow mode (rate-smoothing: RS on slow mode, n=8) and with algorithm on in fast mode (n=3).

Max RR=longest RR interval; Min RR=shortest RR interval; SD=standard deviation.

**Figure 2  RR interval distributions.** Eight patients with chronic atrial fibrillation were provided with an external Vitatron pacemaker with rate-smoothing software. One thousand consecutive RR intervals using all pacing programme modalities were analysed (RS off (-----), RS on slow (---) and fast (-----) mode). The solid line depicts the average RR interval distribution in patients with atrial fibrillation when the pacemaker is turned off (n=8). The dotted line depicts the average RR interval distribution while the rate-smoothing algorithm is turned on in the slow mode (0-25 beats . min⁻¹ deceleration per cycle, n=8). The broken line depicts the average RR interval distribution with the rate-smoothing algorithm turned on in the fast mode (2 beats . min⁻¹ deceleration per cycle, n=3).

Effective stabilization of the variability, although the heart rate was not affected. Rate smoothing using the fast mode reduced the RR variability by 40% and the average standard error of the means by 32.9%. In this mode, 45% of the ventricular complexes were paced. The average RR interval of 595.4 ± 17.7 ms did not differ from the pre-existing average spontaneous RR interval (P=0.198).

Figure 2 depicts the normalized averaged RR interval distributions of the different pacing programmes. The long RR as well as the relatively short RR intervals were markedly eliminated from the distribution.

**Discussion**
applied in chronic as well as paroxysmal atrial fibrillation. It is emphasized that rate-smoothing is relatively simple to impose in chronic atrial fibrillation by introducing only a ventricular lead, whereas in paroxysmal atrial fibrillation an atrial lead is needed for sensing of atrial fibrillation.

We conclude that the novel rate-smoothing algorithm is a rapid, safe and effective approach to multidrug-resistant atrial fibrillation which circumvents the pacemaker-related tachycardia. Therefore, among conventional antiarrhythmic approaches rate smoothing becomes an attractive new option.

References


