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Is Mode Switching Beneficial? A Randomized Study in Patients With Paroxysmal Atrial Tachyarrhythmias

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Objectives. **We sought 1) to compare three pacing modalities—DDDR with mode switching (DM), DDDR with conventional upper rate behavior (DR) and VVIR (VR)—in patients with a history of atrial tachyarrhythmias, and 2) to assess the efficacy of six mode-switching algorithms.**

Background. **A history of atrial tachyarrhythmias has been a relative contraindication to dual-chamber pacing. Several mode-switching algorithms have recently been developed to prevent rapid tracking of atrial tachyarrhythmias.**

Methods. **Forty-eight patients (mean age 64 years, 58% male) with a history of atrial tachyarrhythmias and heart block had a DM pacemaker implanted. Pacemakers were programmed to DM, DR and VR modes for 4 weeks each in a randomized crossover design. All subjects used a patient-activated electrocardiographic (ECG) recorder throughout the study and additionally underwent ambulatory ECG monitoring and a treadmill exercise test in each mode. They completed three symptom questionnaires at the end of each pacing period. At the end of the study, patients chose their preferred pacing period.**

Results. **DM was significantly better than VR mode objectively (exercise time DM 8.1 min, VR 7.0 min, $p < 0.01$) and subjectively (perceived well-being DM 69, VR 51, $p < 0.001$; functional class DM 2.2, VR 2.5, $p < 0.05$; subjective symptom score DM 21.2, VR 26.8, $p = 0.01$). Patient-perceived well-being was significantly better with DM than with DR mode (DM 69, DR 60, $p = 0.02$). DM mode was the preferred pacing period (DM 51%, DR 14%, VR 14%). Early termination of pacing because of adverse symptoms was requested by 33% of patients during VR, 19% during DR but only 3% during DM mode. A higher proportion of patients with a fast mode-switching device preferred DM mode (fast 55%, slow 49%), whereas no patients with a fast mode-switching device chose VR as the preferred mode (fast 0%, slow 19%). In the subgroup of patients who had had atrioventricular node ablation, DM was also preferred to VR mode (DM 53%, VR 27%). Overall, there were only two cases of inappropriate mode switching and one case of inappropriate tracking of an atrial tachyarrhythmia.**

Conclusions. **DM is the pacing mode of choice of patients with paroxysmal atrial tachyarrhythmias. With optimal programming, inappropriate mode switching and tracking of atrial tachyarrthmias was very uncommon.**

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Dual-chamber pacemakers will track atrial rates to the upper rate limit in DDD mode. If the atrial rate exceeds the upper rate limit, Wenckebach-like behavior will occur. Rapid tracking of atrial tachyarrhythmias in DDD mode can result in adverse symptoms. A history of atrial tachyarrhythmias was thus a relative contraindication to implantation of dual-chamber pacemakers in the past. The disadvantage of single-chamber ventricular pacing in these patients is the lack of atrioventricular (AV) synchrony during periods of sinus rhythm. This can result in symptoms of pacemaker syndrome (1) and theoretically may exacerbate the frequency of the atrial tachyarrhythmias (2).

A significant proportion of patients suitable for dual-chamber pacemaker implantation have a history of atrial tachyarrhythmias. They include patients with sinus node disease (tachybrady syndrome) and paroxysmal atrial fibrillation with pathologic or iatrogenic (post AV node ablation) heart block. Furthermore, long-term follow-up studies (3) have shown that persistent atrial fibrillation occurs in 10% of subjects with a dual-chamber pacemaker.

Several manufacturers have recently developed different mode-switching algorithms in an attempt to extend the indications for dual-chamber pacing to patients with a history of atrial tachyarrhythmias (4–7). In the presence of an atrial tachyarrhythmia, a mode-switching pacemaker changes from DDDR to a nontracking but atrial sensing mode (DDIR, VDIR), pacing the ventricle at the sensor indicator rate; on termination of the atrial tachyarrhythmia it resumes normal DDDR function. These algorithms should thus protect the patient from rapid ventricular rates during atrial tachyarrhythmias while maintaining AV synchrony during sinus rhythm.

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Abbreviations and Acronyms

AV = atrioventricular
DDD = dual-chamber universal mode
DDDR = dual-chamber universal rate-responsive mode
DM = DDDR with mode switching
DR = DDDR pacing with conventional upper rate behavior
ECG = electrocardiogram, electrocardiographic
VR = VVIR pacing
VVIR = single-chamber ventricular-inhibited rate-responsive pacing

DDDR with mode-switching capability (DM) pacemakers are significantly more expensive than VVIR (VR) pacemakers. Implantation of these pacemakers is also technically more demanding. To date, there have been no randomized studies comparing these two pacing modalities in patients with a history of atrial tachyarrhythmias; thus, it is not known whether DM pacing confers any additional clinical benefit over that of simple VR pacing.

Study aims. In this study we sought 1) to compare DM pacing with DDDR with standard upper rate behavior (DR) and VR pacing in patients with a history of atrial tachyarrhythmias; 2) to document the incidence and the factors contributing to inappropriate mode switching and inappropriate tracking of atrial tachyarrhythmias; and 3) to determine whether there are differences in patients' preferences for the different mode-switching algorithms.

Methods

Patients. We recruited 48 consecutive patients who had a history of atrial tachyarrhythmias before they underwent dual-chamber pacemaker implantation. They had a mean age ± SD of 64 ± 13 years; 28 patients (58%) were male. The predominant arrhythmia was atrial fibrillation in 73% and atrial flutter in the remaining 27%. The indications for pacing were heart block in 8 patients (17%), AV node ablation in 17 (35%) and sinus node disease with or without heart block in 23 (48%). Other coexisting medical conditions included ischemic heart disease in 33%, hypertension in 23% and history of treated thyroid disease in 15%. All class I and III antiarrhythmic drugs were discontinued before study induction. AV node blocking agents such as beta-blockers, digoxin or calcium channel antagonists were allowed in patients with intact AV conduction to control the ventricular rate during episodes of recurrent atrial tachyarrhythmias.

Study design. This was a randomized double-blind crossover study. Pacemakers were implanted and, for the 1st 30 days after implantation, were programmed to DDIR mode. This mode was not a study mode and acted as a "washout" period during the postoperative recovery phase. The pacemakers were then programmed in random order (by random number tables) to each of the three pacing modes for a period of 4 weeks each—DM, DR and VR. All patients were given transtelephonic self-activated electrocardiographic (ECG) devices for the duration of the study and were instructed to send ECG traces whenever they had symptoms. In addition, patients kept a diary of all symptoms. Patients underwent continuous 24-h ambulatory ECG Holter monitoring at the beginning of each pacing mode. At the end of each 4-week study period, a chronotropic assessment exercise protocol (8) (CAEP) test was performed, and patients completed three self-administered symptom questionnaires. The treadmill exercise tests were supervised by a technician who did not know the patients' study modes.

Pacemaker Holter monitors were interrogated at 24 h and at the end of each pacing period. *Significant atrial tachyarrhythmia* was arbitrarily defined as a mean of >2,000 beats/day of atrial arrhythmia on a pacemaker Holter monitor or atrial tachyarrhythmia persisting for >30 s on 24-h ambulatory ECG monitoring or throughout a transtelephonic ECG recording. Patients with intolerable symptoms were allowed early crossover to the next study mode. At the end of the study, patients were asked to choose their preferred pacing period.

Subjective assessment. Three self-administered questionnaires were used. The first utilized visual analog scales to assess patient-perceived general well-being and exercise capacity (9). Subjects were required to place a mark on a line 15 cm in length from 0% (signifying extremely unwell or inability to exercise) to 100% (extremely well or unlimited exercise capacity). The result was expressed as a percent of the distance from the discrete minimum point to the position of the mark divided by the length of the line.

The second questionnaire assessed patients' perception of their functional capacity with use of the well validated Specific Activity Scale functional status questionnaire (10). This grades patients from class I (unlimited physical capacity) to IV (grossly incapacitated). Finally, the Specific Symptom Prevalence questionnaire was used to assess the incidence and frequency of symptoms of mild heart failure or pacemaker-induced hemodynamic dysfunction. The symptom prevalence score was calculated by using 11 cardiovascular-related symptoms (11). The minimal score was 0 (no symptoms) and the maximal score was 84 (a score ≥25 has previously been shown to be suggestive of pacemaker syndrome or moderate heart failure).

Pacemakers. Six pacemakers were studied (Table 1). The Diamond DR (Vitatron) uniquely utilizes a mode-switching algorithm based on the rate of change of atrial rate; the algorithms of the other five are based on a programmable number of atrial events above a certain absolute rate limit. Pacemaker mode-switching algorithms were defined as *fast* (mode switching occurs with ≤5 beats of detected atrial tachyarrhythmia [Diamond, Meta 1254]) or *slow* (mode switching occurs after a minimum of 10 beats of detected atrial tachyarrhythmia [Vigor DR, Chorus RM] or when the mode switching algorithm is dependent on a calculated mean atrial rate [Thera DR, Trilogy DR+]).

Pacemaker programming. All pacemakers were programmed in conjunction with a research representative from

Table 1. Pacemakers and Mode-Switching Algorithms

Pacemakers	Mode Switches to	Mode Switch Algorithm
Diamond DR (Vitatron) (8 patients)	DDIR	Based on the rate of change of atrial rhythm; atrial rates within a "physiologic band" are tracked; mode switching occurs if rate of change exceeds upper limit of the band (*fast mode-switching device*).
Meta 1254 (Telectronics) (3 patients)	VR	Mode switching occurs if the atrial rate exceeds a programmable atrial tachycardia detection rate (independent of upper rate limit); the number of atrial events required for mode switching was programmed to 5 (*fast mode-switching device*).
Vigor DR (CPI) (13 patients)	VVIR	Mode switching occurs if atrial rate exceeds upper rate limit; minimum of 8 atrial beats required for arrhythmia detection; mode switching occurs after a further number (10 to 2,000) of atrial events (*slow mode-switching device*).
Chorus RM (ELA) (4 patients)	VR	Mode switching occurs after a programmable number of atrial events (10 to 2,000) above upper rate limit (*slow mode-switching device*).
Thera DR (Medtronic) (10 patients)	DDIR	Mode switching occurs if the mean atrial rate exceeds atrial tachycardia detection rate (independent of upper rate limit). In the presence of atrial tachyarrhythmia, the mean atrial rate is decremented by a fixed value per atrial event; mode switching occurs when mean atrial rate is greater than the atrial tachycardia detection rate (*slow mode-switching device*).
Trilogy DR+ (Pacesetter) (10 patients)	DDIR	

DDIR = atrioventricular sequential dual-chamber inhibited rate-responsive nontracking but atrial sensing mode; VR = VVIR (single-chamber ventricular-inhibited rate-responsive) pacing mode.

each manufacturer present in an advisory capacity with the sole aim of achieving optimal rate-response and mode-switching programming for each study patient. The lower rate limit was programmed to 60 beats/min, and the maximal tracking rate was based on each patient's age and concurrent clinical diagnoses. The sensitivity of the atrial channel was set at 0.25 to 0.5 mV; the atrial blanking period was programmed to the shortest value in the absence of far field sensing, to maximize sensing of atrial tachyarrhythmias. The sensor rate response was optimized at the end of the washout period by using a standardized daily activity protocol (12). Thereafter, all rate-response variables were kept constant for each patient throughout the study. The mode-switching option in the Diamond DR can be programmed to either "auto" or "fixed." In this study it was programmed to auto. Because the mode-switching function in this device cannot be turned off, we programmed a long atrial blanking period of 200 ms and switched the mode to fixed, thus mimicking conventional DR mode.

Statistical analysis. Results are reported as mean value ± SD. A paired Student *t* test was used for within-patient comparison of parametric data. Discrete variables were compared by using the Wilcoxon signed rank test. Whenever more than two comparisons were undertaken of a given variable, the Bonferroni correction was utilized. Multiple stepwise logistic regression was used to determine predictors of early termination of VR mode. All analyses were performed by using SPSS for Windows statistical package. A p value < 0.05 was considered significant.

Results

Chronic atrial arrhythmia. Chronic atrial tachyarrhythmia developed in five patients (10%). All five were found to have atrial tachyarrhythmia at the end of the washout period, and the arrhythmia persisted continuously throughout the 12-week study period. Consequently, these five patients were excluded from the overall analysis. In these patients DM was compared with VR mode. Three of the five patients preferred DM mode, and two had no preference, suggesting that the pacemakers had switched mode appropriately throughout; all five patients denied awareness of palpitation.

Subjective Assessment

Intolerable symptoms. Thirty-three percent of patients terminated VR mode pacing early because of severe symptoms consistent with pacemaker syndrome. Nineteen percent of patients requested early crossover during DR mode because of troublesome palpitation or fatigue, or both. Early termination of this mode increased to 29% in the subgroup of patients with significant atrial tachyarrhythmias. Only one patient (3%) terminated DM mode early, and the cause was found to be inappropriate tracking of atrial tachyarrhythmias. Clinical variables analyzed in an attempt to find predictors of early termination of the VR mode included age, gender, pacemaker model, etiology, anterograde AV conduction, intact ventriculoatrial conduction and amount of atrial arrhythmia; none of these predicted early termination. All patients who terminated the DR mode early had significant atrial tachyarrhythmias during the study period.

Visual analog scales (Fig. 1). Patient-perceived well-being was significantly higher with DM than with VR mode (DM 69 ± 21%, VR 51 ± 27%, $p < 0.001$) or DR mode (DM 69 ± 21%, DR 60 ± 25%, $p = 0.02$). Patient-perceived exercise capacity was also higher with DM (53 ± 27%) than with VR mode (43 ± 26%) but this difference was not statistically significant ($p = 0.08$).

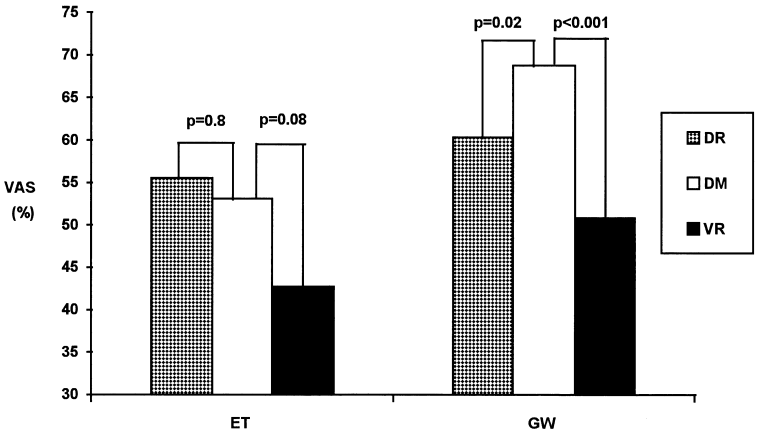

Figure 1. Patient-perceived exercise capacity (ET) and general well-being (GW). VAS = visual analog score (0% = unable to exercise/extremely unwell; 100% = unlimited exercise capacity/extremely well).

Functional class and subjective symptom scores (Table 2). Functional class and subjective symptom questionnaire scores were significantly lower with DM than with VR mode (i.e., patients were less symptomatic), but there was no significant difference between DM and DR modes.

Preferred pacing period (Fig. 2). Overall, 51% of patients preferred DM mode. Only 14% chose VR or DR as their preferred pacing period. Patient preference differed according to whether or not significant atrial tachyarrhythmias occurred during the study period. Of the 15 patients (35%) with little or no atrial tachyarrhythmia, 47% preferred DM mode, 33% had no preference and no one chose VR mode. Of the 28 patients (65%) with significant atrial tachyarrhythmias, a higher proportion (54%) preferred DM mode, only 4% had no preference and 28% preferred VR mode or had no preference between DM and VR modes.

Preferred pacing period according to mode-switching algorithm (Fig. 3). Pacing period preference of the patients was analyzed according to whether the pacemaker was defined as a fast or slow mode-switching device. A higher proportion of patients with a fast mode-switching device preferred DM mode (fast 55%, slow 49%). No patient with a fast mode-switching device chose VR mode, whereas 19% with a slow mode-switching device preferred this mode. The six patients with a slow mode-switching device who preferred VR mode had frequent daily episodes of atrial tachyarrhythmias. All were aware of recurrent short-lived palpitation lasting only a few seconds during DM mode pacing. The 24-h ambulatory ECG confirmed initial tracking of atrial tachyarrhythmias for several beats before mode switching occurred.

Objective Assessment

Graded exercise treadmill tests (Table 2). The mean exercise time and peak heart rate were significantly greater with DM than with VR mode, but there was no difference between DM and DR modes.

Inappropriate tracking or mode switching. Inappropriate mode switching occurred in two patients. Only one case of inappropriate tracking of atrial tachyarrhythmia documented on 24-h ambulatory ECG monitoring, occurred with DM mode pacing.

Patients With AV Node Ablation

A subgroup of 17 patients (mean age 56 ± 13 years, 10 [59%] male) underwent AV node ablation for drug-refractory atrial tachyarrhythmias before entry into the study. Of the 17 implanted pacemakers, 15 were slow mode-switching devices. Chronic atrial tachyarrhythmia developed in two patients, who

Table 2. Comparison of Exercise Time, Peak Heart Rate, Functional Class and Subjective Symptom Score Among the Three Pacing Modes

	DR	DM	VR	p Value*
EX time (min)	7.6 ± 3.6	8.1 ± 3.6	7.0 ± 3.8	DM:DR 0.1 DM:VR < 0.01
Peak EX HR (beats/min)	128 ± 20	128 ± 18	116 ± 21	DM:DR 0.8 DM:VR < 0.001
Functional class QS	2.1 ± 0.8	2.2 ± 0.9	2.5 ± 1.0	DM:DR 0.5 DM:VR < 0.05
Subjective symptoms QS†	22.3 ± 12.2	21.2 ± 12.4	26.8 ± 15.3	DM:DR 0.4 DM:VR 0.01

*A p value < 0.05 is statistically significant. †A score >25 is suggestive of pacemaker syndrome or moderate heart failure. Data are expressed as mean value ± SD. DM = DDDR with mode switching; DR = DDDR with conventional upper rate behavior; EX = exercise; HR = heart rate; QS = questionnaire score; VR = VVIR.

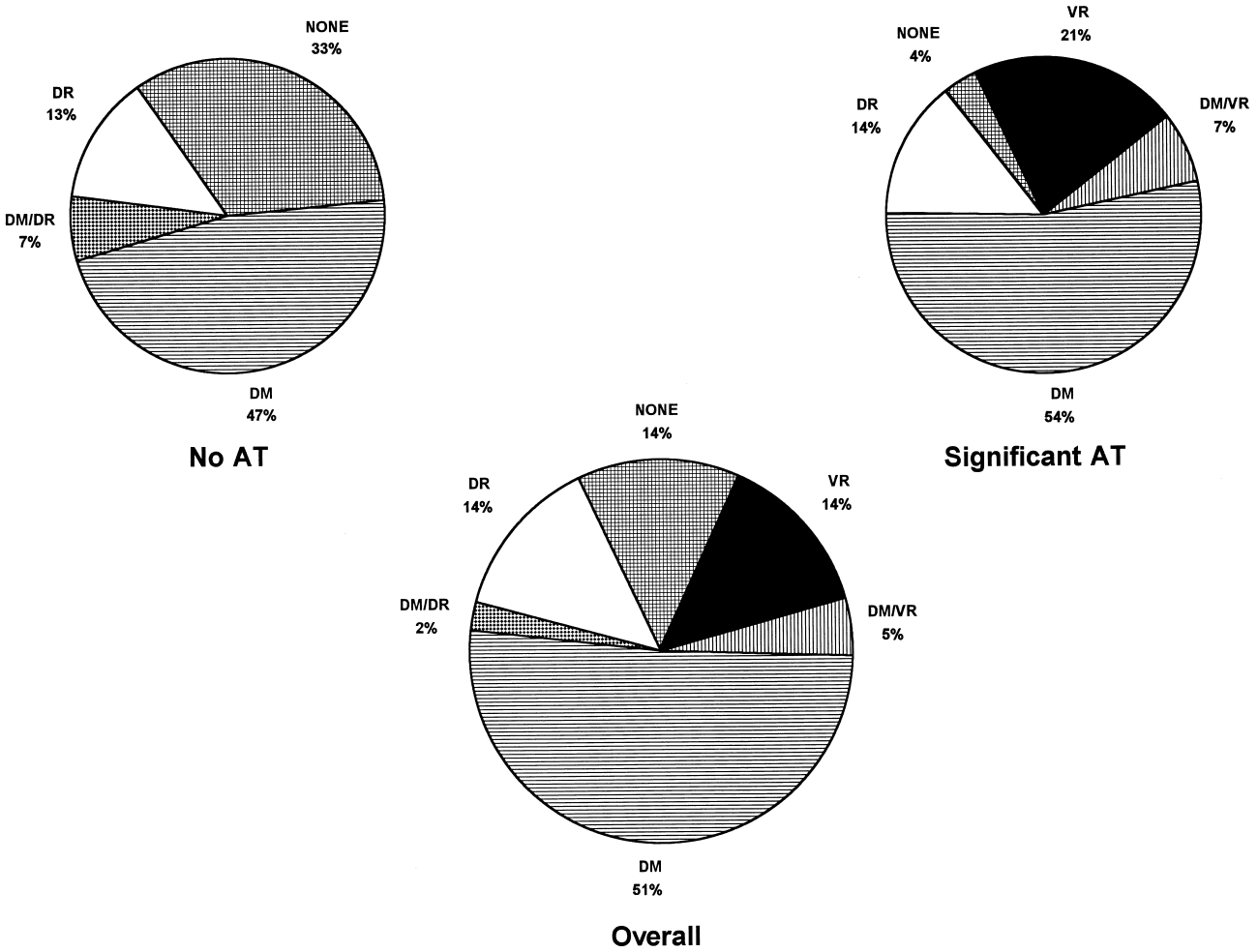

Figure 2. Preferred pacing period. **Upper panels,** Preferred modes in patients with no atrial tachyarrhythmias (AT) **(left)** or significant AT **(right)**; **Bottom panel,** Overall preferred modes. DM/DR = no preference between DM or DR; DM/VR = no preference between DM or VR; NONE = no preference among the three modes.

were excluded from further analysis. Forty-seven percent of the remaining 15 patients requested early crossover because of adverse symptoms during DR mode versus 20% during VR mode and 7% during DM mode. Overall, 53% of the patients chose DM mode as their preferred pacing period and 27% preferred VR mode; no one chose DR mode. Patients could exercise longer with DM mode than with VR mode (DM 8.9 ± 3.2 min, VR 7.5 ± 3.4 min, $p < 0.05$), and were less symptomatic with this mode as assessed by subjective symptom questionnaire (DM 23 ± 12, VR 27 ± 15, $p < 0.05$). There were no significant differences between the two modes in patient-perceived exercise capacity, well-being or functional class.

Discussion

Alternatives to mode switching. There are several possible methods of dealing with paroxysmal atrial tachyarrhythmias in DR mode. 1) The atrial sensitivity could be set to sense and track the atrial electrogram in sinus rhythm but not the lower amplitude signal of atrial fibrillation. However, such a setting is often not possible to achieve as there is no clear separation of amplitude during sinus rhythm and atrial tachyarrhythmia. 2) The pacemaker could be programmed to DDIR mode (13). Loss of AV synchrony will occur if the sinus rate exceeds the lower rate limit or the sensor-indicated rate (14). 3) In some devices, the maximal sensor rate can be programmed to be higher than the maximal tracking rate. This method prevents rapid tracking of atrial tachyarrhythmia while allowing high sensor-driven upper rates in response to exercise. The disadvantage is the occurrence of pacemaker Wenckebach phenomena at relatively low atrial rates during sinus rhythm. 4) Finally, conditional ventricular tracking limit (CVTL, Intermedics) can limit the ventricular pacing rate in the presence of an atrial tachyarrhythmia if there is no or minimal sensor activity (15–17). However, with physical activity the conditional limit is disabled, and the pacemaker tracks the atrial arrhythmia to the programmed upper rate with rapid irregular ventricular pacing. Thus, disadvantages are that a) the ventricular rate is highly irregular during atrial tachyarrhythmias, and b) Wenckebach phenomena can occur during sinus rhythm, also causing wide variation in ventricular pacing rate (18).

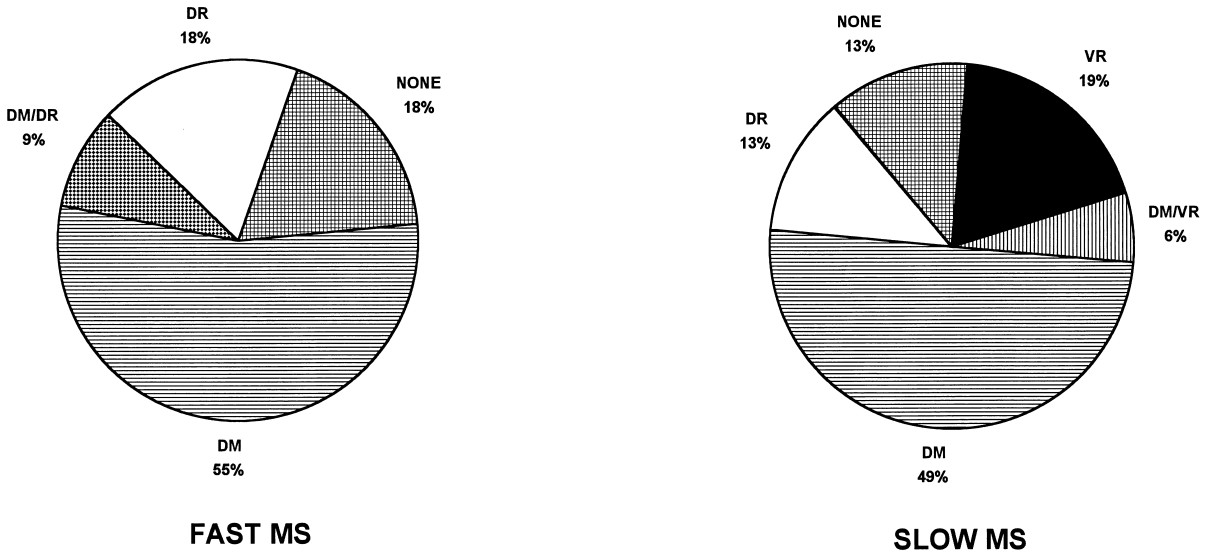

Figure 3. Preferred pacing period according to mode-switching algorithms. FAST MS = fast mode-switching devices; SLOW MS = slow mode-switching devices; other abbreviations as in Figure 2.

Mode-switching algorithms. In first-generation devices, inappropriate mode switching occurred in response to isolated atrial and ventricular extrasystoles with retrograde ventriculoatrial conduction, or in response to sinus tachycardia (18,19). The specificity of these devices for the detection of atrial tachyarrhythmias was thus low. To increase this specificity, several different mode-switching algorithms have since been developed.

During this study, we observed that slow mode-switching devices can take several seconds to recognize an atrial tachyarrhythmia, resulting in a delay in mode switching. During this initial period, the atrial tachyarrhythmia is tracked at rapid and irregular rates, and in some patients this tracking was associated with troublesome symptoms (Fig. 4). Thus, in an attempt to increase the specificity of these devices, the sensitivity for the detection and recognition of atrial tachyarrhythmias has been lowered. This limitation should not pose a major problem in patients with infrequent sustained atrial tachyarrhythmias. However, in those with frequent brief atrial tachyarrhythmias, it can result in adverse symptoms. This problem was not encountered with the fast mode-switching devices such as the Diamond DR and Meta 1254. With the Diamond device in particular, even though mode switching occurred immediately on detection of atrial tachyarrhythmia, there were no documented instances of inappropriate mode switching. This finding may explain why none of the patients with a fast mode-switching device preferred VR mode pacing, whereas 19% with a slower device preferred this mode. Ideally, mode-switching algorithms should be fully programmable so that they can be tailored to the individual patient. However, until such algorithms are available, it may be necessary to use different devices for different patients depending on the characteristics and frequency of their atrial arrhythmias.

AV node ablation. Ablation of the AV node is becoming an increasingly popular treatment of medically refractory atrial fibrillation. It reduces the number of hospital admissions and antiarrhythmic drugs and improves quality of life (20). In our study, DM mode pacing was preferred by the majority (53%) of patients who had undergone AV node ablation. Patients could exercise longer and were less symptomatic with this mode than with VR mode. DR mode pacing was poorly tolerated and was terminated early by 47% of patients. This response was due to a high incidence of atrial tachyarrhythmias. Twenty percent of patients terminated VR mode early due to the development of symptoms of pacemaker syndrome. Thus, DM mode pacing is the pacing preference of patients who have undergone AV node ablation for drug-refractory paroxysmal atrial fibrillation.

Inappropriate mode switching and tracking of atrial tachyarrhythmias. Inappropriate mode switching or arrhythmia tracking was very uncommon in our study. The two patients (one with Thera DR, one with Trilogy DR+) who had inappropriate mode switching were both in their 40s and had previously undergone AV node ablation. Their sinus rates exceeded the atrial tachycardia detection rate of the pacemakers (set at 170 beats/min) during treadmill exercise tests, resulting in inappropriate mode switching. One patient (with a Vigor DR) had inappropriate tracking of atrial tachyarrhythmias on 24-h ambulatory ECG (frequent episodes of atrial flutter with periods of mode switching as well as inappropriate tracking). The pacemaker only intermittently recognized the atrial arrhythmia, possibly because flutter waves fell within the pacemaker atrial blanking period intermittently and consequently were not sensed by the device.

The low incidence of inappropriate mode switching and tracking of atrial tachyarrhythmias in this study was due to careful programming of each pacemaker. To avoid problems, it is essential to understand the pacemaker mode-switching algorithm and to pay careful attention to the patient's clinical

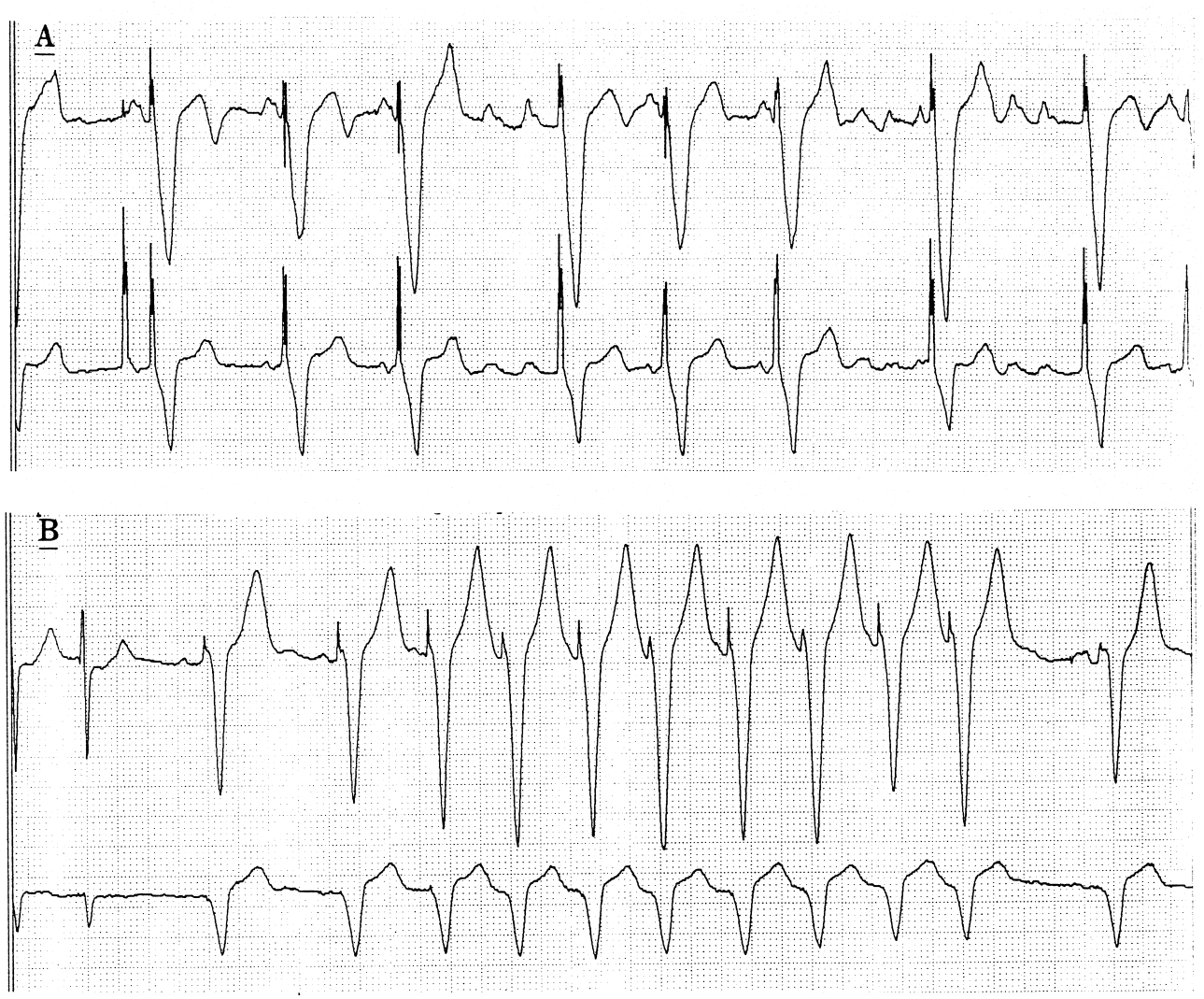

Figure 4. A, Response of a fast mode-switching device (Diamond DR) to atrial tachyarrhythmia. **The second and third ECG complexes from the left** are sinus beats with ventricular tracking; this is followed by atrial tachyarrhythmia and immediate mode switching (4th complex); two beats of sinus rhythm (complexes 5 and 6) follow with immediate resynchronization and tracking of p waves; longer run of atrial tachyarrhythmia with immediate mode switching (complexes 7 and 8). **B,** Response to atrial tachyarrhythmia of a slow mode-switching device (Trilogy DR+). **The second and third ECG complexes from the left** are sinus beats with ventricular tracking at a rate of 65 beats/min. These are followed by a short run of atrial tachyarrhythmia that is tracked at a rate of ~125 beats/min. The tachyarrhythmia terminates before mode switching occurs.

history. Atrial sensitivity should be sufficiently high so that the pacemaker consistently detects the atrial arrhythmia, especially during atrial fibrillation, as the atrial signal is often smaller and more variable in size than during sinus rhythm (21). Inappropriately long atrial blanking periods can result in undersensing of atrial arrhythmias. These periods should thus be programmed to be as short as possible. The atrial tachycardia detection rate should always be set higher than the patient's maximal sinus rate but below the atrial tachyarrhythmia rate to avoid inappropriate mode switching during sinus tachycardia.

Preferred pacing mode. VR mode has previously been advocated by some as the pacing mode of choice in patients with a history of atrial tachyarrhythmias. In this study, one third of patients terminated VR mode early because of marked symptoms consistent with the pacemaker syndrome. No clinical variables identified these patients. Only 14% of the patients chose VR as their preferred pacing mode. In contrast DM mode was preferred by 51% of the patients and was significantly better than VR mode as assessed both subjectively and objectively.

Previous studies in patients without a history of atrial tachyarrhythmias (22–24) have also shown that dual-chamber pacing is preferred to single-chamber ventricular rate-responsive pacing, Menozzi et al. (22), in a randomized crossover study of 14 patients with high degree AV block

showed that patients were less symptomatic with DDD than with VVIR pacing. In their study, 36% of patients crossed over early from VR to DDD pacing because of intolerable symptoms. A study of similar design (23) comparing four pacing modalities (DR, DDD, DDIR, dual-chamber inhibited rate-responsive, VR) showed that patients were less symptomatic and could exercise longer with DR than with VVIR mode. Overall, in this study, DR was the preferred and VR the least acceptable mode, and 24% of patients requested early termination of the VR mode. However, DR is not an acceptable pacing mode in patients with a history of atrial tachyarrhythmias. In our study, there were many cases of rapid tracking of atrial tachyarrhythmias in DR mode, and 29% of patients with significant atrial tachyarrhythmias terminated this mode early because of adverse symptoms.

It is likely that the objective and subjective superiority of DM over VR mode is predominantly due to maintenance of AV synchrony during periods of sinus rhythm, but the higher peak heart rates achieved during exercise may also be a positive contributing factor. The higher heart rates achieved in DR and DM modes occurred even though the sensor variables were kept constant for each patient throughout the study. In DM mode the physiologic sinus rate is tracked, whereas in VR mode the increase in heart rate is completely dependent on the sensor.

Study limitations. Our study had several limitations. 1) It was not possible to perform a within-patient direct comparison of different mode-switching algorithms (fast vs. slow) with the available devices. 2) As with all subjective assessment, results are dependent on patient mental state, and perception of palpitation is especially susceptible. 3) Continuous ECG monitoring throughout the study was unacceptable to all patients and patient-activated recorders were therefore used in addition to intermittent Holter monitoring. This is susceptible to the same constraints as in point 2 above.

Clinical implications. A history of atrial tachyarrhythmias is no longer a contraindication to implantation of dual-chamber pacemakers. Mode-switching pacemakers provide adequate protection against rapid sustained tracking of atrial tachyarrhythmias. Fast mode-switching devices are preferable in patients with short-lived or frequent atrial tachyarrhythmias. Because atrial tachyarrhythmias will develop in a significant proportion of patients with a dual-chamber pacemaker, mode switching may be a useful feature on all devices. Future studies are required to determine predictors for development of chronic atrial arrhythmias in patients with a history of paroxysmal atrial tachyarrhythmia before pacemaker implantation.

Conclusions. In patients with a history of paroxysmal atrial tachyarrhythmias, dual-chamber rate-responsive pacing with mode switching is preferred to single-chamber rate-responsive ventricular pacing. Fast mode-switching devices may be more appropriate in patients with frequent short-lived atrial tachyarrhythmias. With appropriate programming tailored to each patient, inappropriate mode switching and tracking of atrial tachyarrhythmias is very uncommon.

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References

1. Ausubel K, Furman S. The pacemaker syndrome. Ann Intern Med 1985; 103:420–8.
2. Rosenquist M, Brandt J, Schuller H. Long-term pacing in sinus node dysfunction: effect of stimulation mode on cardiovascular morbidity and mortality. Am Heart J 1988;116:16–20.
3. Gross J, Moser S, Benedek M, Andrews C, Furman S. Clinical predictors and natural history of atrial fibrillation in patients with DDD pacemakers. PACE 1990;13:1828–31.
4. Provenier F, Jordaens L, Verstraeten T, Clement D. The automatic mode switching function in successive generations of minute ventilation sensing dual chamber rate responsive pacemakers. PACE 1994;17:1913–9.
5. Osyshcher I, Katz A, Bondy C. Initial experience with a new algorithm for automatic mode switching from DDDR to DDIR mode. PACE 1994;17: 1908–12.
6. Den Dulk K, Dijkman B, Pieterse M, Wellens H. Initial experience with mode switching in a dual sensor, dual chamber pacemaker in patients with paroxysmal atrial tachyarrhythmias. PACE 1994;17:1900–7.
7. Mayumi H, Uchida T, Shinozaki K, Matsui K. Use of a dual chamber pacemaker with a novel fallback algorithm as an effective treatment for sick sinus syndrome associated with transient supraventricular tachycardias. PACE 1993;16:992–1000.
8. Wilkoff BL, Corey J, Blackburn J. A mathematical model of the cardiac chronotropic response to exercise. J Electrophysiol 1989;3:176–80.
9. Price DD, McGrath PA, Rafii A, Buckingham B. The validation of visual analog scales as ratio scale measures for chronic and experimental pain. Pain 1983;17:45–56.
10. Goldman L, Hashimoto B, Cook F, Loscalzo A. Comparative reproducibility and validity of systems for assessing cardiovascular functional class: advantages of a new specific activity scale. Circulation 1981;64:1227–34.
11. Sulke AN, Chambers JB, Sowton E. The effects of atrio-ventricular delay programming in patients with DDDR pacemakers. Eur Heart J 1992;13: 464–72.
12. Sulke AN, Pipilis A, Henderson RA, Bucknall CA, Sowton E. Comparison of the normal sinus node with seven rate responsive pacemaker during everyday activity. Br Heart J 1990;6:25–31.
13. Vanerio G, Maloney JD, Pinski SL, et al. DDIR versus VVIR pacing in patients with paroxysmal atrial tachyarrhythmias. PACE 1991;14:1630–8.
14. Provenier F, Deharo JC, Boudrez H, Tavernier R, Djiane P, Jordeans L. Quality of life in patients with heart block and atrial tachyarrhythmias: a comparison of DDIR versus DDDR pacing with mode switch [abstract]. Eur J Card Pacing Electrophysiol 1996;6 Suppl 1:172.
15. Lee MT, Adkins A, Woodson D, Vandegriff J. A new feature for control of inappropriate high rate tracking in DDDR pacemakers. PACE 1990;13: 1852–5.
16. Mahaux V, Verboven Y, Waleffe A, et al. Initial experience with a new sensor driven algorithm limiting ventricular pacing rate during supraventricular tachycardia. PACE 1992;15:577–81.
17. Lau CP, Tai YT, Fong PC, et al. Clinical experience with an activity sensing DDDR pacemaker using an accelerometer sensor. PACE 1992;15:334–43.
18. Barold SS, Mond HG. Optimal antibradycardia pacing in patients with paroxysmal supraventricular tachyarrhythmias: role of fallback and automatic mode switching mechanisms. In: Barold S, Mugica J, editors. New Perspectives in Cardiac Pacing. Vol 3. Armonk (NY): Futura, 1993:483–518.
19. Pitney MR, May CD, Davis MJ. Undesirable mode switching with a dual chamber rate responsive pacemaker. PACE 1993;16:729–36.
20. Fitzpatrick AP, Kourouyan HD, Situ A, et al. Quality of life and outcomes after radiofrequency ablation and permanent pacemaker implantation: impact of treatment in paroxysmal and established atrial fibrillation. Am Heart J 1996;131:499–507.

21. Gross JN, Ben-Zur UM, Andrews CA, Hanson S, Furman S. Effectiveness of automatic mode change is dependent on high atrial sensitivity settings [abstract]. PACE 1995;18 Suppl 4:884.
22. Menozzi C, Brignolle M, Moeacchini P, et al. Intrapatient comparison between chronic VVIR and DDD pacing in patients affected by high degree AV block without heart failure. PACE 1990;13:1816–22.
23. Sulke N, Chambers J, Dristas A, Sowton E. A randomized double blind crossover comparison of four rate-responsive modes. J Am Coll Cardiol 1991;17:696–706.
24. Lau CP, Tai YT, Lee PW, Cheung B, Tang M, Lam W. Quality of life in DDDR pacing: AV synchrony or rate adaptation? PACE 1994;17:1838–43.