A theoretically and practically more effective method for interruption of ventricular tachycardia: self-adapting autodecremental overdrive pacing


ABSTRACT The efficacy and safety of a new antitachycardia pacing technique, self-adapting decremental overdrive pacing, was assessed in patients with clinical ventricular tachyarrhythmias who underwent programmed ventricular stimulation and serial drug testing. The three phases of this study involved a learning/experience phase, followed by intrapatient comparison of decremental overdrive pacing with conventional antitachycardia pacing modalities of overdrive burst ventricular pacing, and diastolic scanning with single (S₁) and double (S₂S₃) ventricular extrastimuli. The final phase involved an intrapatient comparison of automated decremental overdrive pacing with overdrive burst ventricular pacing in patients with ventricular tachycardia (VT) cycle lengths of 280 msec or greater. Decremental overdrive pacing was superior to overdrive burst pacing and diastolic scanning (S₂S₃ and S₂) (83% vs 38%, 50%, 9%) in patients with VT cycle lengths of 280 msec or greater. Automated decremental overdrive pacing as applied in the final phase was the most efficacious modality, terminating 92% of VT episodes compared with 56% for overdrive burst pacing in the same patients.


INTERRUPTION and prevention of recurrent sustained ventricular tachycardia (VT) remains a therapeutic challenge because of the limitations of standard and investigational antiarrhythmic agents. In response to these limitations, a variety of cardiac surgical procedures and implantable electrical devices have been devised for termination of VT.1-4 To date, no single antitachycardia pacing method has gained widespread acceptance and application because of technical limitations, lack of reproducibility, and the serious potential risk of acceleration of VT with resultant ventricular fibrillation.5 The implantable cardioverter-defibrillator is a mode of terminating ventricular tachycardia-fibrillation in patients who are refractory to antiarrhythmic drugs and who are not candidates for, or have failed, cardiac surgical procedures. However, this method is not without problems; for the majority of patients who have symptomatic recurrent sustained VT without cardiac arrest, the internal defibrillator is by no means free of unacceptable and unpleasant side effects. Furthermore, faulty recognition of VT and inadvertent defibrillation continue with the present version of the implantable cardioverter-defibrillator.6

Currently available modes of antitachycardia pacing include diastolic scanning with one to several extrastimuli and overdrive or burst pacing, which can be either automatic or activated by patient or physician with an external programmer.5 Recently an investigational implantable cardioverter has been used in patients with well-tolerated, slower VT.7 However, implantable antitachycardia pacers and cardioverters have achieved conversion efficacy rates ranging from only 30% to 80%, and an incidence of acceleration to decompensating VT and/or ventricular fibrillation has been observed in 35% to 43% of patients.3, 4, 6, 7, 8-10

In 1976, Mandel et al.11 reported on a decremental implantable pacemaker for the termination of supraventricular tachycardia. This device was patient-activated with a magnet. In 1977 Waldo et al.12 evaluated overdrive pacing for conversion of atrial flutter. These investigators described a technique of entrainment that involved manual decrement of the pacing cycle length.
(gradual increase in pacing rate) for the termination of this arrhythmia.

We have developed and tested an external beat-by-beat self-adapting autodecremental overdrive pacing system for termination of VT in patients with recurrent symptomatic ventricular tachyarrhythmias undergoing programmed ventricular stimulation and serial drug testing. With this device, we sought to test the hypothesis that this beat-by-beat autodecremental overdrive pacing method may be more effective and theoretically safer for the termination of VT. We compared this method to previously described antitachycardia pacing methods, in particular those used in commercially available implantable antitachycardia pacemakers.

Methods

Dysrhythmia Research Instrument for decremental pacing. The Dysrhythmia Research Instrument is an external programmable demand pacemaker (Medtronic Model 2319) that is computer controlled and can be programmed for self-adapting autodecremental demand pacing. The pacemaker recognizes VT through an indwelling right ventricular transvenous electrode; it is programmed to recognize any tachycardia that has both an abrupt change in rate and a rate that exceeds the preset programmable tachycardia sensing rate (trigger interval). The pacemaker is set in demand pacing mode; when it senses the tachycardia for a programmable number of beats (e.g., 10), it initiates the antitachycardia treatment program in the following manner: At the onset of a pathologic tachycardia, the pacemaker’s escape interval is shortened so that for the first paced beat it is identical to the cycle length of the tachycardia. Subsequently, it gradually overdrives the tachycardia beat-by-beat with a train of preprogrammed stimuli. Each interval in the train is decremented so that the pacemaker’s beat-to-beat interval is continuously shortened by a programmable decrement measured in either milliseconds or by a percentage of the cycle length of the patient’s VT. At the end of the initially programmed train of stimuli, the pacemaker reverts to its original backup demand pacing mode to protect against potential bradyarrhythmia after termination of VT. If the tachycardia is not terminated by the initial pacing train, the pacemaker again senses the pathologic tachycardia after a preset, programmable interval and repeats the beat-by-beat decremental pacing train, which is one beat longer than the initial train. This sequence, i.e., adding an additional beat to the train, is automatically and continuously repeated until the tachycardia is terminated or until a programmed maximum number of decremental stimuli in the train have been delivered. In this way, the program ensures that only a minimum number of decremental pacing stimuli are used to terminate the tachycardia. This pacemaker (Medtronic Model 2319), which is always in the demand pacing mode even during antitachycardia therapy, is linked to an HP85 computer with a tachycardia recognition algorithm and multiprogrammability.

The programmable variables in this external system are: beat-by-beat decrements (msec or percentage of VT cycle length), number of autodecremental pacing stimuli (minimum/maximum), upper rate limit for decremental pacing, pacemaker output, sensitivity, pulse width, back-up demand pacing rate, tachycardia trigger interval, and number of intervals of tachycardia for recognition as a pathologic tachycardia.

Patient selection. Patients with a known history of clinical sustained VT or resuscitation from arrhythmic sudden cardiac death who underwent programmed ventricular stimulation with serial drug testing in our laboratory were selected for entry into the study if, after induction of VT, they exhibited: (1) stable monomorphic VT of at least 30 sec duration requiring interruption and (2) VT that did not result in rapid hemodynamic decompensation requiring immediate cardioversion or defibrillation.

Patient demographics. This study was divided into three phases, and a total of 49 patients were exposed to self-adapting autodecremental overdrive pacing. The patients ranged in age from 25 to 80 years (mean 58 ± 11); there were 41 men and eight women. The predominant underlying disease in these patients was coronary artery disease with previous myocardial infarction (42 patients or 85%). Five patients (17%) had nonspecific congestive cardiomyopathy and two (5%) had idioventricular VT. The nuclear angiographic or contrast left ventricular ejection fractions of these patients ranged from 12% to 48% (mean 26 ± 13%).

Autodecremental antitachycardia overdrive pacing. At the inception of the study, it was not known what optimum number of beats of decremental overdrive pacing (DOP) and what optimum beat-by-beat decrement (msec) would be ideal or necessary for termination of VT. Consequently, the study was divided into three phases: (1) learning/experience, (2) comparison of antitachycardia pacing techniques, and (3) autodecremental overdrive pacing vs overdrive burst pacing (exact overdrive method of Fisher et al.3).

Learning/experience phase. In our initial evaluation of automatic (DOP), 15 patients satisfied the entrance criteria and had multiple episodes of VT exposed to DOP before and after antiarrhythmic therapy. When an “ideal” number of beats and the optimum beat-by-beat decrement was found that terminated VT, the arrhythmia was reinduced and reexposed to this program of DOP under the same conditions to establish reproducibility for termination of VT. In this way, both reproducibility and safety were established; success of DOP was considered to have occurred if VT was terminated on at least two consecutive occasions.

During these initial trials, the number of decrementing stimuli in the train (example five stimuli) and the beat-by-beat decrement (example 10 msec) were programmed manually. Subsequently, either the number of pacing stimuli or the beat-by-beat decrement was alternatively increased or decreased until a combination of the optimal pacing train and beat-by-beat decrement was established that reproducibly terminated each episode of induced VT. During this phase, the beat-by-beat decrement varied from 5 to 25 msec (mean 8.2) and the number of decremental pacing stimuli varied from five to 15 (mean 10.3).

Comparison of DOP and other antitachycardia pacing techniques. During this phase of evaluation, the DOP technique was compared with other antitachycardia pacing modalities that are incorporated into existing implantable pacing devices and/or are currently used in electrophysiologic laboratories for termination of induced VT. We induced VT successively on the same day, exposing each episode to one of several antitachycardia pacing methods, starting with DOP and following with diastolic scanning with single (S2) or/and double ventricular extrastimuli (S3,S4). Subsequently, overdrive burst ventricular pacing was used, consisting of trains of five to 15 stimuli up to a cycle length of 200 msec.

In each patient an attempt was made, when possible, to reduce VT and expose the arrhythmia to each of the four methods on at least two occasions on the same day or during the same interventional circumstances (antiarrhythmic agents). Because all patients were not able to tolerate multiple episodes of tachycardia and because VT acceleration developed at times, requiring cardioversion or defibrillation, not all patients were exposed to each of the methods of antitachycardia termination on the
same day. When VT was not interrupted by any one of the methods, it was exposed arbitrarily to a second method while the tachycardia continued. If VT still persisted, the arrhythmia was exposed to the third method. During this phase the application of the three antitachycardia methods for interruption of VT was not randomized. External cardioversion was used only if all methods of antitachycardia pacing failed or if hemodynamic decompensation or acceleration occurred.

On the basis of our experience in phase I, we used pacing trains of five to 15 stimuli with a fixed beat-by-beat decrement of 10 msec for DOP.

Diastolic scanning (S2, S2S3) was applied with S2 initially inserted so that the S1S2 cycle length was 20 msec shorter than that of the S1S1 cycle length. S2 was then scanned at 10 msec decrements until S2 reached S1S2 refractoriness. S2 was then fixed at 10 msec beyond refractoriness. Subsequently, S1 was inserted so that the S1S2 cycle length was equal to the S1S2 cycle length; S1 was then scanned at 10 msec decrements until it reached refractoriness in relation to S2.

Overdrive burst ventricular pacing involved calculation of the burst rate so that pacing trains (five to 15 stimuli) at least 25% faster than the patient’s VT rate were used or until a cycle length of 200 msec was reached.

Self-adapting DOP vs overdrive burst pacing method (Fisher et al.). In the first two phases it was demonstrated that DOP could be effectively and safely applied to induced VT, especially when the VT cycle length was greater than or equal to 280 msec. Because the vast majority of patients amenable to antitachycardia pacing would fall into this range of VT cycle lengths, and with the knowledge that OD burst pacing is generally more efficacious than diastolic scanning with one or two extrastimuli from our phase II experience and that of others, we sought to compare DOP to overdrive burst pacing in the same patients. In this phase of the study, the VT in individual patients was exposed to either of the two methods in a random crossover fashion. The methods were compared during multiple VT inductions both before and during serial drug testing, and each method was tested on two consecutive induced episodes of VT.

During phases I and II of DOP evaluation, it became clear that decremental overdrive pacing was successful and safe and that the vast majority of VT episodes, especially those with cycle lengths of 280 msec or greater, could be interrupted by a train of pacing stimuli ranging from five to 15 with a decrement of 10 msec between beats. Based on these data, an attempt was made to make the system adaptable to a variety of tachycardia rates by incorporating the VT cycle length into the program. Currently beat-by-beat decrements are calculated by the computer by multiplying the VT cycle length by 3.5%. With this modification decremental pacing is performed more gradually for the more rapid VTs, and the upper rate limit for pacing was set for safety reasons at 200 msec. As can be seen, larger decrements would occur in the slower VTs. In this way, automatic beat-by-beat decrements based on VT cycle length were made rather than fixing the decrement at 10 msec.

A further modification of the DOP program was effected if conversion of VT was not achieved: after an initial ineffective (VT persisting for 10 beats) train of five incremental pacing stimuli, automatically six decremental stimuli were delivered; if this failed then 7 beats of decremental pacing were administered and so on until either the tachycardia terminated or a train of 15 stimuli had been delivered. Once VT was terminated, the pacemaker reverted to its demand mode at 70 beats/min (programmable). At this point, the HP85 computer registered the number of stimuli that were required to terminate the VT. An example of VT termination with the automated DOP program can be seen in figure 1.

FIGURE 1. Termination of VT by self-adapting autodecremental overdrive pacing. The arrows denote pacer stimuli in the decremental overdrive pacing train. A train of seven decrementing pacing stimuli are delivered, each of which is decremented by a value of 3.5% of the VT cycle length. Transient entrainment of the reentry circuit is observed with persistence of the VT upon cessation of pacing. Persistence of tachycardia is detected by the Dysrhythmia Research Instrument and a subsequent train of eight decremental stimuli is delivered. Termination of the VT results. RVA = right ventricular apical electrogram; HBE = His bundle electrogram.
TABLE 1
Results of learning experience phase with DOP

<table>
<thead>
<tr>
<th>Description</th>
<th>No. of patients</th>
<th>No. of induced VT episodes</th>
<th>Cycle length of VT (msec)</th>
<th>Decremental pacing train</th>
<th>Beat-by-beat decrement (No. of pacing beats)</th>
<th>Success rate for VT conversion (%)</th>
<th>Success rate for patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>15</td>
<td>105</td>
<td>220-440 (mean 325)</td>
<td>25-15 (mean 10.3)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For the purposes of analysis, the method of application of overdrive burst pacing was also automated so that a computer-delivered burst rate would be calculated according to the formula devised by Fisher et al. A programmable number of beats (e.g., 10) of asynchronous burst pacing at this calculated burst rate could be applied repetitively and automatically. Ten beats of overdrive burst pacing were chosen in this phase of the study because our observations in phase I and II and those of Fisher et al. demonstrated the best efficacy with the least VT acceleration when bursts of 10 beats were used: burst rate for pacing = (VT rate + 47)/0.969.

For purposes of data analysis, acceleration of VT during attempted pacing termination methods was arbitrarily defined as a 25% or greater decrease in the VT cycle length with or without a change in axis that persisted for 5 beats after the termination attempt or any hemodynamic decompensation caused by an abrupt change in VT rate. For purposes of data analysis, VT cycle lengths were divided into those 280 msec and greater and those less than 280 msec.

Statistical analysis. Statistical analysis was performed with the chi-square test.

Results

Learning/experience phase. The initial experience with DOP is cited in Table 1. Fifteen patients with a total of 105 episodes of VT (cycle lengths ranging from 220 to 440 msec; mean 325) were exposed to trains of five to 15 pacing stimuli (mean 10.3) with beat-by-beat decrements of 5 to 25 msec (8.2 msec). An overall success rate of 60% for termination of VT was achieved. However, two episodes of VT acceleration were observed in one patient with a VT cycle length of 220 msec. Most episodes of VT that were exposed to decremental pacing were generally 280 msec or greater, since rapid VT (<280 msec) often did not allow time for exposure to pacing.

Comparison of antitachycardia pacing techniques. In this phase of the study, we compared the efficacy and safety of DOP to other antitachycardia pacing modalities for interruption of VT. The results are shown in Table 2.

Table 2 demonstrates that DOP was the most effective (83% and 60%) method of terminating VT episodes. During slower VT (cycle length ≥ 280 msec), and 83% efficacy was demonstrated for DOP compared with 38% for burst pacing (p < .005). Because of the small number of patients and VT episodes analyzed for each of the methods in patients with VT cycle lengths under 280 msec, no statistical comparison could be made in this group.

Regarding safety, there were relatively few episodes of VT acceleration observed with all methods (3% to 11%); no statistically significant difference was observed between the different pacing methods.

Self-adapting autodecremental overdrive pacing vs overdrive burst pacing (Fisher et al.). In the first two phases of the study, it became clear that the DOP method was more efficacious than the existing methods of interrupting VT, especially when it was applied to VT with cycle length of 280 msec or greater. In this third phase of the study, patients were exposed to both DOP and overdrive burst pacing (Fisher et al.), in a random crossover fashion. The results are listed in Table 3.

A further analysis of the data demonstrated that

TABLE 2
Comparison of DOP vs other antitachycardia modalities

<table>
<thead>
<tr>
<th>Antitachycardia pacing method</th>
<th>No. of patients</th>
<th>No. of VT episodes</th>
<th>Efficacy per VT</th>
<th>VT acceleration</th>
<th>Efficacy per patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>VT &lt; CL ≥ 280 msec (range 280-520, mean 355)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DOP</td>
<td>12</td>
<td>29</td>
<td>24/29(83%)</td>
<td>2/29(7%)</td>
<td>10/12(83%)</td>
</tr>
<tr>
<td>OD burst</td>
<td>6</td>
<td>29</td>
<td>11/29(38%)</td>
<td>1/29(3%)</td>
<td>5/6 (83%)</td>
</tr>
<tr>
<td>S₂S₃</td>
<td>8</td>
<td>12</td>
<td>6/12(50%)</td>
<td>0/12(0%)</td>
<td>1/8 (13%)</td>
</tr>
<tr>
<td>S₂</td>
<td>7</td>
<td>11</td>
<td>1/11 (9%)</td>
<td>0/11(0%)</td>
<td>2/7 (28%)</td>
</tr>
<tr>
<td>VT &lt; CL &lt; 280 msec (range 230-270, mean 265)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DOP</td>
<td>4</td>
<td>5</td>
<td>3/5 (60%)</td>
<td>0/5 (0%)</td>
<td>3/4 (75%)</td>
</tr>
<tr>
<td>OD burst</td>
<td>2</td>
<td>9</td>
<td>3/9 (33%)</td>
<td>1/9(11%)</td>
<td>1/2 (50%)</td>
</tr>
<tr>
<td>S₂S₃</td>
<td>1</td>
<td>2</td>
<td>1/2 (50%)</td>
<td>0/2 (0%)</td>
<td>1/1(100%)</td>
</tr>
<tr>
<td>S₂</td>
<td>1</td>
<td>1</td>
<td>0/1 (0%)</td>
<td>0/1 (0%)</td>
<td>0/1 (0%)</td>
</tr>
</tbody>
</table>

OD burst = overdrive burst pacing; CL = cycle length; S₂, S₂S₃ = diastolic scanning with single (S₂) and double (S₂S₃) ventricular stimuli.
when VT failed to respond to self-adapting DOP, overdrive burst pacing (Fisher method) also invariably failed to terminate VT. On the other hand, VT in four patients could not be terminated by the overdrive burst method but was terminated by self-adapting DOP. This occurred during 12 VT episodes in these four patients.

In our analysis, the vast majority of VT episodes was interrupted by a DOP train of 7 to 8 beats (80%). A histogram of the number of DOP beats required for termination of each VT episode is displayed in figure 2. Table 4 summarizes our total experience with DOP for induced VT in terms of efficacy and safety.

**Discussion**

A variety of antitachycardia pacing modalities have been applied during electrophysiologic study, thereby allowing repetitive induction and termination of VT without the need for frequent cardioversion and/or defibrillation. These different methods have been incorporated into implantable antitachycardia devices but have been associated with (1) variable efficacy despite laboratory confirmation of reproducibility in individual patients and (2) a significant risk of acceleration of VT. Roy et al. demonstrated that success in terminating an episode of VT is cycle length dependent, with slower VT responding most reliably to antitachycardia pacing methods. These investigators also demonstrated that overdrive burst ventricular pacing terminated inducible VT more reliably than diastolic scanning with single, double, and triple extrastimuli (76% vs 27%, 63%, and 44%). However, this improved efficacy was at the expense of an increased VT acceleration rate: 1.2% and 3.2% for single and double extrastimuli vs 35% of patients with burst right ventricular pacing. Fisher et al. also demonstrated the value of overdrive burst pacing for conversion of VT. This modality terminated 89% of 573 episodes of VT with a low VT acceleration rate (4%) per episode. In our study, we were initially able to demonstrate that relatively imprecise manual decremental overdrive ventricular pacing was a safe and reliable method for terminating VT and that 60% of VT episodes with cycle lengths between 220 and 430 msec (mean 325 msec) were terminated by a single application of this method. A breakdown of VT episodes with cycle lengths of 280 msec or greater and those with cycle lengths under 280 msec demonstrated only 43% efficacy with more rapid VT. Our initial experience suggested that a pacing train of 8 to 12 beats with a beat-by-beat decrement of 8 to 10 msec was the most successful combination in terminating VT. We then compared this DOP method to the overdrive burst pacing modality currently used in many laboratories and in implantable antitachycardia devices. Although diastolic scanning with one and two extrastimuli was compared with DOP and overdrive burst pacing during our initial evaluation, the lower success rate did not justify further comparisons. During all phases of the investigation, DOP was shown to be a reliable method with greater efficacy than overdrive burst pacing for both rapid and slow VT. VT acceleration did not differ significantly between the two modalities.

In an attempt to identify an antitachycardia modality

### Table 3

**Automatic DOP vs overdrive burst pacing (VT cycle length ≥280 msec, range 280-520, mean 348)**

<table>
<thead>
<tr>
<th></th>
<th>DOP</th>
<th>OD burst</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Efficacy</strong></td>
<td>20/21 (95%)</td>
<td>←p = NS→ 18/21 (86%)</td>
</tr>
<tr>
<td><strong>Acceleration</strong></td>
<td>0/21 (0%)</td>
<td>←p = NS→ 2/21 (10%)</td>
</tr>
</tbody>
</table>

**OD burst = overdrive burst pacing.**

### Table 4

**Experience with DOP to date for induced VT**

<table>
<thead>
<tr>
<th></th>
<th>No of patients</th>
<th>No. of VT episodes</th>
<th>Efficacy for VT</th>
<th>Efficacy per patient</th>
<th>Acceleration per patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL ≥280</td>
<td>43</td>
<td>204</td>
<td>158/204(78%)</td>
<td>37/43(86%)</td>
<td>1/43(2%)</td>
</tr>
<tr>
<td>CL &lt;280</td>
<td>6</td>
<td>7</td>
<td>3/7(43%)</td>
<td>3/6(50%)</td>
<td>1/6(17%)</td>
</tr>
<tr>
<td>CL 220-440</td>
<td>49</td>
<td>211</td>
<td>161/211(77%)</td>
<td>40/49(82%)</td>
<td>2/49(4%)</td>
</tr>
</tbody>
</table>

CL = cycle length.
that would deliver the least number of decrementing stimuli per application, we modified the DOP technique to start with a pacing train of five stimuli. In conjunction with a tachycardia detection algorithm, the computer assesses the result of each application of pacing and delivers additional decremental stimuli as needed until termination of VT is achieved. DOP with the above modifications terminated 92% of VT episodes, whereas only 56% of VT episodes could be terminated by overdrive burst pacing. A low rate of VT acceleration occurred. The current version of automatic DOP was more reproducible than overdrive burst pacing in terminating VT. Furthermore, VT that failed to terminate with DOP also failed with overdrive burst pacing. On the other hand, there were four patients whose VT responded only to DOP.

The method of DOP in its present form offers many theoretical advantages over overdrive burst pacing. Each stimulus, including the first in the pacing train, is delivered during the final segment of diastole, thereby ensuring capture of the ventricle at the pacing site even when the excitable interval is extremely short. Clinical experience with this new modality of pacing for VT is encouraging; however, the potential for VT acceleration, even if infrequent, is still a hazard and must be recognized. It must also be emphasized that this type of pacemaker is in the demand mode of pacing even during antitachycardia therapy. The latest modification of the technique allows for computerized analysis of the results of each application of DOP. With the current program, the minimum number of stimuli necessary for termination of VT is applied; when persistence of VT is detected, an automatic reapplication of DOP with one additional decremental stimulus is given. Use of this minimum number of stimuli may decrease the risk of VT acceleration.

A histogram of the successful minimum number of beats required for termination of VT was developed (figure 2) and a median of 7 to 8 beats was demonstrated. In this regard, it should be noted that certain VT episodes in individual patients may respond to as few as 5 pacing beats or as many as 12 beats. When the number of decremental paced beats necessary for termination of a given VT was defined, it could be shown repeatedly that this sequence of termination was reproducible within 1 or 2 beats.

Finally, the advantage of DOP with overdrive burst pacing can be examined in terms of the theory of pacing for termination of VT. Several factors must be considered when one evaluates the ability of pacing to terminate VT with a presumed reentry mechanism, including (1) distance between the stimulation site and the location of the tachycardia circuit, (2) the electrophysiologic properties of the intervening tissue, and (3) duration of refractoriness in the reentry circuit.

In this regard, the refractoriness of the local tissues

![Diagram showing the minimal number of decremental pacing stimuli needed to terminate VT. The number over each bar denotes the number of episodes terminated by a given number of stimuli.](image)

**Figure 2.** Histogram showing the minimal number of decremental pacing stimuli needed to terminate VT. The number over each bar denotes the number of episodes terminated by a given number of stimuli.

![Diagram depicting a spontaneous (induced) VT with a cycle length of 350 msec (1). Decremental overdrive ventricular pacing begins with the initial pacing stimulus in the train delivered synchronized to the R wave (2). Subsequent pacing stimuli delivered at 10 msec decrements progressively penetrate toward the reentry circuit (3 and 4). Once penetration of the reentrant loop occurs, the captured beats may "entrain" the circuit. At the same time, more myocardium is depolarized by the pacing stimulus. Progressive fusion of paced depolarization and VT depolarization results. Both the orthodromic and antidromic wave fronts of the previous paced beat are interrupted because of collision with the subsequent paced beat. If pacing is interrupted, the last paced beat exits from the reentry circuit and the VT continues (5). Theoretically, when further decremental pacing stimuli are delivered, a stimulus may eventually be delivered early enough so as to encounter refractoriness of the slow conducting pathway with resultant block. At the same time, both the antidromic and orthodromic wave fronts are abolished by the last paced stimulus and the VT is interrupted (320 msec) (6).](image)

**Figure 3.** Diagram depicting a spontaneous (induced) VT with a cycle length of 350 msec (1). Decremental overdrive ventricular pacing begins with the initial pacing stimulus in the train delivered synchronized to the R wave (2). Subsequent pacing stimuli delivered at 10 msec decrements progressively penetrate toward the reentry circuit (3 and 4). Once penetration of the reentrant loop occurs, the captured beats may "entrain" the circuit. At the same time, more myocardium is depolarized by the pacing stimulus. Progressive fusion of paced depolarization and VT depolarization results. Both the orthodromic and antidromic wave fronts of the previous paced beat are interrupted because of collision with the subsequent paced beat. If pacing is interrupted, the last paced beat exits from the reentry circuit and the VT continues (5). Theoretically, when further decremental pacing stimuli are delivered, a stimulus may eventually be delivered early enough so as to encounter refractoriness of the slow conducting pathway with resultant block. At the same time, both the antidromic and orthodromic wave fronts are abolished by the last paced stimulus and the VT is interrupted (320 msec) (6). (Modified from Waldo AL et al: J Am Coll Cardiol 3: 422, 1984.)
will, in general, influence the effectiveness of extrastimuli in invading the presumed reentry circuit. The decrease in local refractoriness that occurs after premature stimuli may allow for earlier activation of local tissues by subsequent stimuli, thereby explaining the effectiveness of burst pacing methods over single and double extrastimuli in terminating VT. In an attempt to apply antitachycardia pacing in a slow progressive manner, we chose a beat-by-beat decremental pacing system that would serially scan a variety of pacing rates in a progressive and beat-by-beat manner, thereby incrementally peeling back refractoriness of myocardial tissues. This pacing protocol should progressively penetrate toward the reentry circuit; subsequent impulses would then transiently "entrain the reentry circuit." Insertion of progressively earlier stimuli should eventually result in invasion and interruption of the reentry circuit, presumably when both the antidromic and orthodromic pathways are depolarized by the same pacing stimulus with resultant collision and block (figure 3). Thus the DOP method of scanning with a train of beats during one pacing sequence increases the likelihood that a critical rate for termination of VT will be achieved.

**Clinical implications.** We currently use this automated form of DOP for termination of VT in our electrophysiology laboratory. In our experience, it is a more rapid technique than diastolic scanning with single, double, and triple extrastimuli. Moreover, it does not require manual measurement of VT rate or trial-and-error burst pacing at different rates and/or number of stimuli. As a result, it does not take longer to apply and to be effective for VT interruption. Because of its high efficacy rate and low incidence of VT acceleration, it has decreased the need for cardioversion and/or defibrillation during electrophysiologic studies in our laboratory. We believe that this method can be applied as

the initial intervention in an implantable antitachycardia device for VT. Such a device would ideally incorporate backup internal defibrillation in the event the method should fail or result in VT acceleration.

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