Implantable Cardioverter-Defibrillator Therapy in the Absence of Significant Symptoms

Rhythm Diagnosis and Management Aided by Stored Electrogram Analysis

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Background. This report describes the value of stored ventricular electrogram analysis in the diagnosis and management of patients experiencing minimal or no symptoms before implantable cardioverter-defibrillator (ICD) therapy.

Methods and Results. The study population included 48 patients who received the Cadence Tiered Therapy Defibrillator System, an investigational third-generation ICD with ventricular electrogram storage capabilities. Criteria for arrhythmia diagnosis were based on analysis of the electrogram rate, RR interval variability, and morphology. Twenty-nine of the 48 patients (60%) experienced at least one episode of antitachycardia pacing or shock (one shock or more in 25 of 29 patients) that was preceded by minimal or no symptoms during a mean follow-up of 15.1 ± 8.8 months. There were 194 tachycardia episodes registered by the device, including 101 for which ventricular electrograms were stored and available for analysis. Of the 101 stored electrograms, 74 were classified as ventricular tachycardia (VT), 24 as non-VT rhythms (atrial fibrillation, 13; supraventricular tachycardia, six; rate-sensing lead disruption, four; T wave oversensing, one), and only three as indeterminate rhythms. Based on the electrogram analysis, changes in tachycardia detection criteria and/or antiarrhythmic drug regimens were implemented and were associated with a reduction in the number of device responses for non-VT rhythms from 24 during the initial study period to three during 11.0 ± 7.2 months of additional follow-up.

Conclusions. ICD responses in the absence of symptoms are relatively common in third-generation devices with antitachycardia pacing capabilities. Despite potential limitations such as the effect of bundle branch block on the electrogram morphology during supraventricular tachycardia, the availability of electrogram storage capabilities allowed a presumptive diagnosis of the events precipitating asymptomatic device responses. Device reprogramming based on analysis of stored electrograms was associated with a dramatic reduction in the incidence of ICD responses for non-VT rhythms. (Circulation 1993;87:1897-1906)

KEY WORDS • implantable cardioverter-defibrillator • ventricular electrogram storage

The efficacy and safety of implantable cardioverter-defibrillator (ICD) therapy for the treatment of ventricular tachyarrhythmias has been well documented.1-10 Despite considerable improvements in the ICD since its introduction, a persistent limitation has been the relative lack of specificity of tachycardia detection criteria, thereby leading to shocks for rhythms other than sustained ventricular tachycardia (VT) or ventricular fibrillation (VF).2,3,5,11-17 Compounding this problem has been the inability to document the electrical events precipitating device discharge in the majority of cases. This has forced physicians to rely on the presence or absence of symptoms before shock therapy to determine the likelihood of appropriate intervention. Fortuitous ECG monitoring has demonstrated that appropriate ICD discharge for ventricular tachyarrhythmias may occur with no preceding symptoms.7,14-17 Thus, as a result of diagnostic nonspecificity and the lack of telemetry data, estimates of device responses for rhythms other than sustained VT or VF have been as high as 41% of patients.5

Third-generation ICDs offer several major advances, including multiple programmable tachycardia detection zones, features designed to improve specificity of tachycardia recognition, antitachycardia pacing, low- and high-energy cardioversion, a fully integrated bradycardia pacemaker, noninvasive programmed stimulation, and improved diagnostic information.18 One diagnostic feature present in some third-generation ICDs is the ability to store ventricular electrograms before and immediately after device intervention. We have shown previously19 in a report on three patients that by analyzing the electrogram rate, RR interval stability, and morphology relative to sinus rhythm, it was possible to establish whether the electrical events preceding device...
response represented a ventricular tachyarrhythmia, a supraventricular arrhythmia, or an electrical artifact.

The objectives of this study were twofold. First, we analyzed the stored ventricular electrograms obtained from a large group of patients experiencing minimal or no symptoms before ICD response to determine the incidence of responses for ventricular and nonventricular tachyarrhythmias. Second, in patients in whom analysis of stored ventricular electrogram recordings indicated that non-VT rhythms were responsible for device intervention, we sought to determine whether alterations in tachycardia detection criteria and/or antiarrhythmic drug regimens could reduce the incidence of device intervention for such rhythms during subsequent follow-up.

Methods

Study Population

The study population included 48 patients (39 men and nine women; mean age, 62±10 years) who received the Cadence Tiered Therapy Defibrillator System (Ventricetix, Sunnyvale, Calif.) for the treatment of sustained ventricular tachyarrhythmias. Written informed consent for implantation of this investigational device was obtained from all patients after approval by the Institutional Review Board of the Hospital of the University of Pennsylvania. Cardiac diagnoses included coronary artery disease with prior myocardial infarction (n=36), dilated cardiomyopathy (n=9), valvular heart disease (n=2), and long QT syndrome (n=1). The mean left ventricular ejection fraction determined by contrast or radionuclide ventriculography in 44 patients was 30±12%. The presenting arrhythmia or symptom was sustained hemodynamically tolerated VT in 19 patients, cardiac arrest in 18 patients, and syncpe in 11 patients.

Device Implantation

Defibrillation threshold testing and measurement of R wave amplitude and pacing threshold of the rate-sensing/pacing leads was performed intraproactively in the standard fashion.20 The energy delivery lead system used epicardial patches in all patients. Bipolar ratesensing/pacing/electrogram recording leads consisted of two left ventricular epicardial screw-in leads in 31 patients and a single right ventricular bipolar endocardial lead in 17 patients.

Programmable Tachycardia Detection Criteria in the Cadence

Table 1 summarizes the programmable tachycardia detection criteria most frequently used in the Cadence.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Programmable options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No. of detection zones</td>
<td>1–3 (FIB, TACH A, TACH B)</td>
</tr>
<tr>
<td>2. Cutoff rate for each zone</td>
<td>Minimum cycle length</td>
</tr>
<tr>
<td>3. Duration of tachycardia</td>
<td>FIB: Slow, nominal, fast</td>
</tr>
<tr>
<td></td>
<td>TACH A: Six to 100 tachycardia intervals</td>
</tr>
<tr>
<td></td>
<td>TACH B: Six to 100 tachycardia intervals</td>
</tr>
<tr>
<td>4. Sudden onset (TACH A only)</td>
<td>50–500 msec</td>
</tr>
</tbody>
</table>

In addition to these features, the Cadence includes an extended high-rate feature designed to provide a high-energy defibrillation shock after a programmable period of time (10 seconds to 5 minutes) for an arrhythmia that has failed to respond to less aggressive interventions or that has failed to satisfy the sudden-onset criteria but persists at a rate above the tachycardia detection cutoff. In contrast to previous-generation ICDs, the Cadence is a noncommitted device that allows a charge to be diverted in the event of spontaneous arrhythmia termination.

Diagnostic Information Available in the Cadence

Diagnostic information available after device intervention (antitachycardia pacing or shock) is listed in Table 2. Ventricular electrograms corresponding to one to seven tachycardia events of 16–64 seconds each (one 64-second event, three 32-second events, or seven 16-second events, depending on programmed values) are stored with the date and time of the event and may be transferred to a chart recorder for hard copy display. Storage of the ventricular electrograms is programmed routinely to be triggered by return of the heart rate to less than the minimum programmed cutoff rate after tachycardia detection. Thus, termination of the tachycardia is always the final portion of any stored event. If the total duration of tachycardia from onset to termination is greater than the programmed storage time for an individual event, the onset of the tachycardia will not be available for review. If the number of tachycardia episodes exceeds the programmed number of stored electrogram events, only the most recent tachycardia episodes will be available for review. In addition to permitting display of electrograms corresponding to a tachycardia, it is possible to record real-time electrograms at the time the device is interrogated, thereby allowing comparison of electrogram morphology between that recorded during a tachycardia and that recorded during the baseline rhythm.19 Electrograms are filtered by the device using a bandpass centered at 20 Hz and were displayed at a paper speed of 25–50 mm/sec.
Definition of Asymptomatic Device Response

Because it was our aim to document the electrical events precipitating device responses in the absence of severe symptoms, those patients experiencing symptoms compatible with hemodynamic compromise before device response are not included in this report. Thus, for the purposes of this study, patients were considered to be asymptomatic before device response if there were no symptoms or if they experienced only minor palpitations. Patients with symptoms of dizziness, light-headedness, or syncope were excluded.

Criteria for Arrhythmia Diagnosis Using Stored Ventricular Electrograms

Ventricular tachycardia. A diagnosis of VT was based primarily on a change in the ventricular electrogram morphology during the tachycardia relative to that recorded during the baseline rhythm.19 Differences in electrogram morphology were considered present if, upon visual inspection, there was any alteration in the number or polarity of individual electrogram components. Previous work21 has demonstrated that this criterion is 93% sensitive in discriminating ventricular from supraventricular rhythms. Of note, the development of rate-dependent aberrancy during supraventricular tachycardia may alter the electrogram morphology relative to sinus rhythm, particularly when the recording electrodes are located ipsilateral to the side of bundle branch block.22 Ventricular electrograms of uniform morphology at very rapid rates (>250 beats per minute) or of continuously changing configuration at any rate were always designated as VT (uniform or polymorphic, respectively).

Atrial fibrillation. The presence of variability in RR intervals of more than 60 msec for three or more of 10 consecutive intervals with no change in the electrogram morphology relative to the baseline rhythm was used to classify a rhythm as atrial fibrillation.19,23 Of note, although there may be less RR interval variability during atrial fibrillation at very rapid rates, the ability to record ventricular electrograms for up to 30 seconds before device response in the majority of episodes permitted inspection of a large number of intervals for analysis of RR variability.

Supraventricular tachycardia. A tachycardia without the RR interval variability described for atrial fibrillation and with no change in the electrogram morphology relative to the baseline rhythm was classified as supraventricular tachycardia. The absence of an atrial recording lead precluded a more specific arrhythmia diagnosis, although a history of atrial tachycardia, atrial flutter, atrioventricular nodal reentry tachycardia, or activities consistent with sinus tachycardia before device response were helpful in establishing a probable diagnosis. Previous work21 has demonstrated that the ventricular electrograms recorded from the rate-sensing leads during ECG-documented VT are distinguishable from those during sinus rhythm in only 7% of cases.

Rate-sensing lead disruption. High-frequency, high-amplitude signals recorded from the sensing leads consistent with an intermittent make-break phenomenon were attributed to disruption of the rate-sensing lead system. The diagnosis was confirmed by an abnormal rate-sensing/pacing lead impedance recorded during real-time measurements and by reproducing the electrical artifact on a real-time electrogram recording channel with manipulation of the generator at the bedside or during intraoperative repair.

Indeterminate. Tachycardias with the same electrogram morphology as that during the baseline rhythm that terminated abruptly with antitachycardia pacing or shock were difficult to characterize. Whereas atrial fibrillation or atrial tachycardia occasionally terminate with delivery of a shock, termination of such rhythms with antitachycardia pacing is uncommon and may represent a fortuitous response. In such instances when electrogram analysis suggested a supraventricular arrhythmia but termination was consistent with an arrhythmia of ventricular origin, ventricular electrograms corresponding to all VTs induced during electrophysiological testing were reviewed to determine whether any VT demonstrated the same morphology as sinus rhythm. For purposes of clinical management, a probable arrhythmia diagnosis was established based on all the available information. For purposes of the present study, however, such events were characterized as indeterminate.

Follow-up and Management Strategy

Patients were seen 6 weeks after discharge from the hospital for a complete evaluation of device function, including induction and termination of VT and VF. Since the device is capable of noninvasive programmed stimulation, these studies were performed on an outpatient basis. Patients were then evaluated routinely, and their device was interrogated every 2 months for the first year and every 3 months thereafter. Patients experiencing a shock from the device or symptoms compatible with a ventricular tachyarrhythmia without a shock were instructed to return before the scheduled follow-up visit for interrogation of the device and analysis of the diagnostic information and any stored ventricular electrograms. Because of the limitations of storage capability in the device, electrograms corresponding to some arrhythmia episodes were replaced by subsequent events and were therefore unavailable for review. Data are presented only for those episodes in which ventricular electrograms were available for analysis.

Management of device responses for non-VT rhythms. If a device response for a non-VT rhythm was suggested from analysis of stored electrograms, several changes in tachycardia detection criteria and/or antiarrhythmic drug regimen were usually implemented in an effort to prevent either a recurrence of the arrhythmia or recurrent device response for the arrhythmia. In patients experiencing more than one non-VT device response, a recurrence during subsequent follow-up was considered present only if the same arrhythmia triggered device response after interventions directed at reducing such events had been implemented. Additional non-VT device responses were counted as separate events if the rhythm triggering device response was identified as a distinctly different electrical event.

Device responses for non-VT rhythms were divided into responses that occurred perioperatively (for which surface ECG monitoring permitted confirmation of the electrogram diagnosis) and responses that occurred only during outpatient follow-up. The reason for this is twofold: First, the primary purpose of electrogram storage is to permit analysis of rhythms precipitating...
device responses in unmonitored patients. Thus, we sought to define the incidence and types of non-VT rhythms responsible for device response in this setting. Second, supraventricular arrhythmias after cardiac surgery may be due in some patients to transient alterations in serum electrolytes, circulating catecholamine levels, and/or tissue inflammation related to the procedure. In assessing the efficacy of interventions designed to reduce recurrent device responses for non-VT rhythms, it was important to recognize that the propensity to develop a recurrent non-VT rhythm may not have been the same as in those patients whose initial non-VT rhythm occurred after hospital discharge.

Management of device responses for VT. For patients in whom electrogram analysis indicated VT as the rhythm leading to device response, interventions were individualized based on analysis of the stored event. If the initial therapy (antitachycardia pacing or shock) was successful, no alterations in the treatment algorithm were implemented. For patients in whom a shock was required after antitachycardia pacing had failed to terminate the arrhythmia, efforts were made to alter the antitachycardia pacing algorithm to improve the efficacy of antitachycardia pacing for spontaneous VT termination.

Results
Incidence of Asymptomatic Device Responses
Twenty-nine of the 48 patients (60%) experienced at least one episode (range, one to >100) of antitachycardia pacing or shock that was preceded by minimal or no symptoms during a mean follow-up of 15.1 ± 7.8 months (range, 3–27 months). Twenty-five of the 29 patients received at least one asymptomatic shock. Eight patients received device responses for VT only; 10 patients for non-VT rhythms only; eight patients for both VT and non-VT rhythms; two patients for VT; non-VT, and indeterminate rhythms; and one patient for VT and an indeterminate rhythm.

There were 194 episodes of asymptomatic therapy registered by the device, with electrogram storage available for 115 of these (59%). In five patients with responses for non-VT rhythms, a single arrhythmic event led to multiple device responses and several stored electrograms within minutes of each other. This was observed most often with episodes of atrial fibrillation and rate-sensing lead disruption. In these instances, the electrograms were pooled and counted as a single “arrhythmic” episode. Thus, the total number of stored electrograms reported is 101 rather than 115. All device responses for VT were counted individually.

Device Responses for VT
Eighteen patients experienced 74 episodes (range, one to 16 per patient) of device response for a ventricular tachyarrhythmia that was preceded by minimal or no symptoms (Table 3). Forty-five episodes in 16 patients were treated successfully with antitachycardia pacing (Figure 1); 28 episodes in 14 patients were treated successfully with shock therapy. In one patient, six shocks failed to terminate VT, and he was cardioverted externally after presenting to a local emergency room with hemodynamically well-tolerated VT. Each of the four patients in whom antitachycardia pacing failed to terminate VT also had several episodes (range, four to nine per patient) of VT treated successfully with antitachycardia pacing. Nonetheless, changes in the antitachycardia pacing algorithm and/or antiarrhythmic regimen were implemented in an effort to achieve complete success in VT termination with pacing. Three of the four patients received no further shocks during follow-up, with successful antitachycardia pacing for VT documented in 13 episodes (range, three to seven per patient).

In addition to the 18 patients listed above, another patient experienced over 100 episodes of VT over the course of 4 days in the hospital before her death. She received a total of 53 shocks during this time, most of which were delivered after antitachycardia pacing either had failed to terminate or had accelerated VT. With reprogramming of the antitachycardia pacing algorithm, virtually all of the remaining episodes were terminated with antitachycardia pacing.

Device Responses for Non-VT Rhythms
Twenty patients received device responses for 24 events determined to be non-VT rhythms. Twenty of the 24 events resulted in delivery of at least one shock before termination of the arrhythmia, with multiple shocks delivered in most cases. Twelve of the 24 responses occurred within 7 days of device implantation during surface ECG monitoring, and 12 events occurred in the absence of surface ECG monitoring after hospital discharge. The mean interval from implantation to asymptomatic device intervention for non-VT rhythms occurring after hospital discharge was 169 ± 124 days, with a range of 10 days to 14 months and a median of 150 days. The electrical events precipitating device response and the type of device response (antitachycardia pacing or shock) are listed in Table 4. Atrial fibrillation was the most common arrhythmia, accounting for more than 50% of all responses for non-VT rhythms (Figure 2). Eleven of the 13 episodes of atrial fibrillation resulted in delivery of at least one shock. In two of the 11 episodes of shock delivery, antitachycardia pacing precipitated by atrial fibrillation induced rapid VT, which then triggered the shock.

Supraventricular tachycardia accounted for six responses, including three episodes of perioperative sinus tachycardia documented by surface ECG recordings. Four of the six responses for supraventricular tachycardia resulted in shock delivery, including one episode in which antitachycardia pacing during sinus tachycardia induced rapid VT (Figure 3). The sudden onset feature had been enabled in only two of the six patients before device intervention for supraventricular tachycardia. In one patient, satisfaction of the extended high rate feature triggered shock therapy after the sudden onset.

### Table 3. Device Responses for Ventricular Tachycardia

<table>
<thead>
<tr>
<th>Total no. of VT episodes</th>
<th>Terminated with ATP</th>
<th>Terminated with shock</th>
<th>Initial therapy</th>
<th>Rescue shock*</th>
<th>External shock</th>
</tr>
</thead>
<tbody>
<tr>
<td>74 (18 patients)</td>
<td>45 (16 patients)</td>
<td>28 (14 patients)</td>
<td>19 (11 patients)</td>
<td>9 (4 patients)</td>
<td>1 (1 patient)</td>
</tr>
</tbody>
</table>

*VT, ventricular tachycardia; ATP, antitachycardia pacing. After failure to terminate or acceleration with ATP.
rate-sensing lead disruption accounted for four non-VT responses, resulting in at least one shock in each of four patients (Figure 4). T wave oversensing was documented as the cause of device response in one patient. This episode was characterized by a ventricular electrogram rate of 130 beats per minute. However, the local afterdepolarizations were of sufficient amplitude to be detected as distinct electrograms and resulted in a detected rate of 260 beats per minute. This satisfied detection within the “FIB” zone (see Table 1) (cutoff rate, 222 beats per minute) and led to shock delivery.

Perioperative events. Twelve non VT events in 12 patients occurred before hospital discharge after ICD implant. There were seven episodes of atrial fibrillation, four episodes of supraventricular tachycardia (sinus tachycardia in three, atrial tachycardia in one), and one rate-sensing lead disruption.

Outpatient events. Twelve non-VT events in eight patients occurred during outpatient follow-up. There were six episodes of atrial fibrillation, three episodes of rate-sensing lead disruption, two episodes of probable supraventricular tachycardia, and one episode of T wave oversensing.

Interventions Directed at Reducing Non-VT Device Responses

Multiple interventions were usually implemented in an effort to prevent recurrent device responses for non-VT rhythms. Table 5 lists these interventions for each category of arrhythmia or electrical event believed to be responsible for the non-VT device response.

Atrial fibrillation. Most commonly, the cutoff rate for tachycardia detection was increased, and a β-blocker or digoxin was added to decrease the ventricular response rate during atrial fibrillation. When the rate of atrial fibrillation satisfied detection criteria for either the “TACH A” or “TACH B” zone (see Table 1), the number of tachycardia intervals required to satisfy detection criteria was increased. This was done in anticipation that the intrinsic variability in RR intervals during atrial fibrillation would result in fewer consecutive tachycardia intervals above the device cutoff rate. When atrial fibrillation had exceeded the cutoff rate for the “FIB” zone, the detection time was increased from “nominal” to “slow.” Changes in antiarrhythmic drugs and/or dosage were implemented in an effort to either control atrial fibrillation or alter the ventricular tachy-
Cardiac rate and reduce the chance that the two arrhythmia rates would overlap.

**Supraventricular tachycardia.** For arrhythmias diagnosed by stored ventricular electrogram criteria as supraventricular tachycardia, an increase in the cutoff rate for tachycardia detection was usually implemented. In two patients who received shocks perioperatively for surface ECG-documented sinus tachycardia, the sudden onset feature was enabled. In another patient, the ventricular electrograms demonstrated a rate of 150 beats per minute and a morphology identical to that during sinus rhythm. It was believed that the underlying rhythm was probably atrial flutter or atrial tachycardia. Since this patient had also experienced multiple device responses for VT at very similar heart rates and was already receiving β-blocker and antiarrhythmic drug therapy, no changes were made in tachycardia detection criteria.

**Rate-sensing lead disruption.** Of the four patients in whom a diagnosis of rate-sensing lead disruption was suspected based on the stored ventricular electrograms, two demonstrated a markedly elevated pacing lead impedance (>2,000 Ω) during real-time measurements. Electrical artifact could be reproduced during manual manipulation of the generator in all patients either at the bedside or intraoperatively before repair. In two patients, a “Y” adaptor (DAIG LA 211) between the two epicardial rate-sensing leads and the ICD generator was found to be frayed, and in one patient, an insulation break was found in one of the rate-sensing leads. In another patient, one of the rate-sensing leads was loose in the generator header. Of note, the insulation break occurred in a patient in whom the Cadence generator was implanted as a replacement for another device at the time of battery depletion. The original energy delivery and rate-sensing leads had not been replaced at the time of Cadence generator implant. The “Y” adaptor was replaced in the two patients in whom this was defective, and a new right ventricular endocardial ratesensing lead was placed in the patient in whom an insulation break was present. The rate-sensing lead was secured to the ICD generator in the patient in whom this was loose in the generator header.

**T wave oversensing.** No changes in tachycardia detection criteria were implemented in the patient found to have T wave oversensing during sinus rhythm. Unlike bradycardia pacemakers, in which the ventricular refractory period may be increased and/or the sensitivity decreased to circumvent T wave oversensing, the requirement in the ICD for detection of rapid heart rates precludes the use of a relatively long fixed refractory period.

**Recurrent Non-VT Device Responses During Subsequent Follow-up**

The 20 patients who experienced device responses for non-VT rhythms have been followed for a mean of 11.0±7.2 months after the interventions listed above were instituted. Of the eight patients who experienced 12 non-VT device responses during outpatient follow-
Supraventricular Tachycardia

Pacing

Ventricular Tachycardia

Pacing

Shock

Rate < VT cutoff

1SEC

FIGURE 3. Continuous recording of stored ventricular electrograms from an episode characterized as supraventricular tachycardia. The electrogram morphology of the initial tachycardia was identical to real-time measurements recorded during sinus rhythm, suggesting a supraventricular origin. After two bursts of antitachycardia pacing there is a subtle although distinct change in the electrogram morphology consistent with the induction of ventricular tachycardia (VT). Termination of VT by the shock is characterized by a slower rate and return of the initial electrogram morphology. Surface electrographic recordings during this perioperative episode confirmed the diagnosis of sinus tachycardia triggering antitachycardia pacing with subsequent induction of VT.

up, none experienced further device responses for non-VT rhythms during 8.5±6.1 months (range, 1–21 months) of follow-up. Of the 12 patients experiencing non-VT device responses perioperatively, only three had recurrences during a mean follow-up of 11.3±7.6 months (range, 1–26 months). Recurrent atrial fibrillation was documented by ventricular electrogram analysis at 6, 15, and 26 months in these three patients.

Discussion

The management of patients experiencing shocks preceded by minimal or no symptoms in the absence of ECG monitoring has been one of the major limitations of ICD therapy.2,5,14,15,17,18 Because episodes of asymptomatic device response may be separated by months or may occur as isolated events in selected patients, long-term ECG monitoring is frequently not productive. Clearly, the ability to record and subsequently retrieve the electrical events precipitating device response represents a major advance in ICD therapy. In addition, multiple programmable tachycardia detection features in third-generation devices now permit individual detection prescriptions to be implemented in an effort to improve the specificity of device responses and prevent recurrences of device intervention for non-VT rhythms.

Incidence of Asymptomatic Device Responses

Previous studies2,5,14,18 that reported on devices capable of delivering shock therapy only have documented asymptomatic shocks in up to 52% of patients. Asymptomatic shocks occurring in unmonitored patients have typically been characterized as inappropriate. Fogoros et al14 classified such shocks as indeterminate and reported a 1-year actuarial incidence of 19%. Few studies have attempted to document specifically the rhythms preceding an asymptomatic shock; however, analysis of ECG recordings at the time of shock15–17 has indicated that up to 47% of VT episodes may be preceded by no symptoms. Thus, even in devices capable of delivering shock therapy only, the use of symptoms before device response is an unreliable index of the appropriateness of ICD intervention.

We found that 60% of patients (29 of 48) had at least one device response preceded by minimal or no symptoms during a mean follow-up of >15 months. Nineteen of 29 patients experienced at least one asymptomatic device response for VT. Thus, 40% (19 of 48) of all patients receiving the ICD and 68% (19 of 29) of patients experiencing an asymptomatic device response received appropriate intervention for VT. In comparing our findings with earlier reports, it is important to
FIGURE 4. Continuous recording of stored ventricular electrograms from an episode characterized as electrical artifact caused by disruption of the rate-sensing lead system. Note the high-frequency, high-amplitude signals present throughout the recording. After shock delivery, the electrical noise abates and the device detects a return to a rate less than the ventricular tachycardia (VT) cutoff rate.

recognize that antitachycardia pacing was the initial therapy for VT in the majority of patients. Forty-five of 74 episodes of VT were treated successfully with antitachycardia pacing and did not require a shock.

The availability of antitachycardia pacing has changed the patient selection criteria that we use for implanting a third-generation ICD. Nineteen of the 48 patients (40%) in this study presented with hemodynamically tolerated VT, whereas a significant number of the remaining patients had antiarrhythmic agents added in an effort to slow the tachycardia to rates amenable to antitachycardia pacing. This is in contrast to earlier studies of the ICD in which virtually all patients had sustained a cardiac arrest. As the selection criteria for implantation of third-generation devices expands, fewer patients may experience severe hemodynamic compromise before device response. Indeed, Leitch et al. found that only one of 25 patients experiencing spontaneous arrhythmic events developed syncope before device intervention when antitachycardia pacing was available in a third-generation ICD. With fewer patients experiencing severe symptoms before third-generation ICD responses, optimal patient management will depend on the ability to document the precipitating events with the use of stored ventricular electrogram analysis.

Electrical Events Triggering Device Responses for Non-VT Rhythms

We found that 20 of 48 patients (42%) received device responses for non-VT rhythms, including at least one shock in 20 of 24 episodes. Although delivery of antitachycardia pacing is not painful, it is not necessarily benign. We noted in three patients that pacing for supraventricular rhythms induced VT and led to a shock (Figure 3). Atrial fibrillation (13 episodes) and supraventricular tachycardia (six episodes) were the most frequently documented rhythms, accounting for 79% of all responses for non-VT rhythms. A preliminary re-

TABLE 5. Interventions Directed Toward Reducing Device Responses for Non-Ventricular Tachycardia Rhythms

<table>
<thead>
<tr>
<th>Arrhythmia</th>
<th>Inc cutoff rate</th>
<th>Inc no. intervals</th>
<th>Inc det time</th>
<th>Change A A</th>
<th>β-Blocker</th>
<th>Lead repair</th>
<th>None</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrial fibrillation</td>
<td>10</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supraventricular tachycardia</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate-sensing lead disruption</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>T wave oversensing</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Inc, increase; det, detection; A A, antiarrhythmic agent.
* Sudden onset feature enabled.
port has suggested that up to 35% of patients receiving an ICD will develop supraventricular arrhythmias perioperatively. Not surprisingly, 11 of the 19 combined episodes of atrial fibrillation and supraventricular tachycardia triggering device response occurred perioperatively. In four patients who received the device early in our experience for VT with slow rates, the minimum tachycardia detection cutoff rate was programmed to <150 beats per minute at the time of perioperative device response. We currently program a high cutoff rate perioperatively to decrease the risk of device responses for supraventricular tachycardias.

We did not observe device responses for nonsustained VT. This reflected the ability of the device to sense continuously during capacitor charging and divert the shock when the tachycardia terminated spontaneously. Rate-sensing lead disruption represented a high percentage (16%) of responses for non-VT rhythms. This problem has been obviated by the use of endocardial rate-sensing leads with the Cadence ICD and by the development by the manufacturer of a generator header that accepts epicardial leads directly without requiring an adaptor.

Reduction in Device Responses for Non-VT Rhythms

Because we were able to establish a presumptive diagnosis of the electrical events triggering the device response in each patient, alterations in ICD programming and/or antiarrhythmic regimen could be individualized based on the specific precipitating arrhythmia. This was facilitated by the availability of multiple programmable detection parameters. With this strategy, the number of patients experiencing device responses for non-VT rhythms was reduced from 20 during a mean of 15 months of follow-up after implant to three during the subsequent 11 months after device reprogramming and antiarrhythmic drug alterations. Since it was our intention to prevent recurrent device responses for non-VT rhythms, we did not study a control group of patients in whom no changes in ICD detection criteria or antiarrhythmic regimen were implemented. Thus, we cannot definitively conclude that the reduction in responses for non-VT rhythms during the second follow-up period was the result of the interventions listed in Table 4. Furthermore, because 11 of the combined 19 episodes of atrial fibrillation and supraventricular tachycardia occurred perioperatively, it might be expected that many of these arrhythmias would not recur. On the other hand, there were eight initial episodes of supraventricular arrhythmias that occurred relatively late after implantation, and the only three recurrences noted were in patients whose first episode occurred perioperatively. These findings and the presence of significant structural heart disease in this population suggest that many of these patients remained at risk for recurrent supraventricular tachyarrhythmias after the perioperative period. Clearly, in those patients in whom ratesensing lead disruption precipitated shock delivery, the ability to document electrical artifact on the stored electrogram recordings was critical in restoring proper device function.

Criteria for Arrhythmia Diagnosis Using Stored Electrograms

Eccentric activation of the ventricles during VT typically results in a change in the electrogram relative to that during sinus rhythm. Identification of this change has been performed automatically using fast Fourier transformation, template matching, and gradient pattern detection. Since these techniques are not currently available in any ICD, we relied on visual analysis of the stored ventricular electrograms. In a previous study of 101 episodes of uniform VT recorded intraoperatively during ICD implantation, visual analysis of bipolar ventricular electrograms from the rate-sensing leads permitted discrimination of VT from supraventricular rhythms in 93% of cases. In the present study, 98 of 101 electrical events triggering electrogram storage were classified as either VT (n=74) or non-VT (n=24), with only three events characterized as indeterminate. Although surface ECGs were not available to confirm the electrogram diagnoses in the majority of episodes, the reduction in device responses for non-VT rhythms after specific intervention suggests that visual electrogram analysis can play an important role in the clinical management of these patients. Conclusions

ICD responses including shock delivery in the absence of symptoms are common in third-generation devices, occurring in 60% of patients in this study. Importantly, these responses appear to represent appropriate intervention for a ventricular tachyarrhythmia in a significant number of patients. Despite considerable advances in third-generation ICD therapy, responses for non-VT rhythms still occur quite frequently. Analysis of stored ventricular electrograms does, however, allow a presumptive diagnosis of the rhythm precipitating device response. Interventions based on the diagnostic information provided by electrogram analysis may reduce the frequency of recurrent device responses for non-VT rhythms and may also improve the efficacy of antitachycardia pacing, thus limiting the need for shock therapy of VT.

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