DIAGNOSTIC STUDIES

Value of Ventricular Electrogram Recordings in the Diagnosis of Arrhythmias Precipitating Electrical Device Shock Therapy

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An antitachycardia pacemaker-cardioverter-defibrillator that is capable of storing ventricular electrograms before and after delivery of device shock therapy was implanted in 16 patients. Three of the patients experienced out-of-hospital device shock therapy preceded by minimal symptoms. Although limitations of electrogram analysis exist and are discussed, careful analysis and registration of electrograms during all supraventricular and ventricular rhythms observed during in-hospital testing served as an important reference for subsequent arrhythmia diagnosis.

A major limitation of the current implantable cardioverter-defibrillator has been the inability to document the arrhythmia precipitating discharge of the device in outpatients. The presence of symptoms of palpitation or presyncope is not synonymous with recurrent ventricular tachycardia. Symptomatic supraventricular rhythms (1) and asymptomatic ventricular tachyarrhythmias (1.2) have been documented by electrocardiogram (ECG) before defibrillator discharge. Thus, it has been suggested (1.3.4) that new devices should incorporate telemetry to accurately assess the frequency of defibrillator discharge for sustained ventricular arrhythmia.

We recently implanted a new pacemaker-cardioverter-defibrillator in 16 patients with drug-refractory ventricular tachycardia. The investigational device combines an automatic cardioverter-defibrillator with antitachycardia pacing capability and ventricular electrogram storage (Ventritex Cadence Tiered Therapy Defibrillator System). It is capable of storing ventricular electrograms recorded from the bipolar ventricular rate-sensing leads for 1 to 60 s before and after device shock therapy on the basis of programmed criteria. Up to seven 16 s events can be stored and subsequently transmitted to the programmer for display and ultimate hard copy retrieval. Three of the 16 patients receiving this device had out-of-hospital defibrillator shock therapy preceded by no or minimal symptoms. This report documents that having ventricular electrograms stored before delivery of electrical device shock therapy is of value in the arrhythmia diagnosis and management of patients whose device discharges are preceded by minimal or no symptoms.

Case Reports

Case 1

A 69 year old man sustained an inferior myocardial infarction in 1986. He was asymptomatic until March 1989, when he experienced palpitation and was found to have ventricular tachycardia at a rate of 160 beats/min. He underwent electrophysiologic study with rapid, hemodynamically compromising ventricular tachycardia induced in the baseline state (cycle length 260 ms), and during quinidine, procainamide, flecainide and amiodarone therapy. There was no history of atrial arrhythmia or frequent nonsustained ventricular tachycardia. Because of the drug-refractory nature of the patient’s arrhythmia, treatment with an implantable cardioverter-defibrillator was elected. Despite the induction of only rapid ventricular tachycardia associated with prompt hemodynamic embarrassment, a device with antitachycardia pacing capability was chosen because the spontaneous arrhythmia was well tolerated hemodynamically and the potential for antitachycardia pacing as a therapeutic option was considered warranted.

Testing of the implanted cardioverter-defibrillator device (Fig. 1). The cardioverter-defibrillator implantation and postoperative course were uneventful. One week after implantation the patient underwent evaluation of the device
function. The cycle length for ventricular tachycardia detection (minimum of 10 intervals) was set at 350 ms. The cycle length for ventricular fibrillation detection was 270 ms, which is the minimal programmable cycle length of the device for fibrillation detection. He was taking no antiarrhythmic agent at the time of testing with the exception of digoxin for maintenance treatment of symptoms of congestive heart failure. Ventricular tachycardia with a cycle length of 260 ms was induced and was terminated with a discharge of 500 V (16 J). Ventricular fibrillation was then induced with a mean cycle length of 220 ms and was also successfully terminated with a discharge of 500 V. The resulting rhythm after defibrillation was atrial fibrillation (mean heart rate 90 beats/min), which spontaneously converted to sinus rhythm within minutes. Electrograms recorded from the rate-sensing leads during these episodes were retrieved and are displayed in Figure 1. Of note, the configuration of the electrograms during sinus rhythm, atrial fibrillation and ventricular tachycardia are virtually identical, showing a qRS pattern. However, the configuration of the electrograms during ventricular fibrillation were clearly different from those recorded during any supraventricular rhythm.

Device discharge for paroxysmal atrial fibrillation (Fig. 2). Approximately 2 months later, the patient experienced three discharges from the device on a single day and was instructed to return for evaluation. The patient reported experiencing palpitation, but denied symptoms of impending syncope before each shock. The electrograms preceding device discharge were retrieved and displayed on a single channel ECG recorder. All three episodes were similar: a representative example is shown in Figure 2. There was marked irregularity in the RR interval consistent with atrial fibrillation. The mean cycle length of approximately 260 ms was less than the cutoff level for detection of ventricular fibrillation (270 ms), leading to appropriate device discharge for presumed ventricular fibrillation.

The electrogram recordings allowed us to make the diagnosis of atrial fibrillation. The detection time for ventricular fibrillation was increased from the nominal value and the cutoff level for ventricular tachycardia was decreased from 350 to 315 ms. The minimal number of beats for detection of ventricular tachycardia was also increased from 10 to 20. Treatment with a beta-adrenergic blocking agent was instituted. The patient has had no subsequent device discharges although paroxysmal atrial fibrillation has been documented by ECG.

Case 2

This is a 39 year old woman with no prior cardiac history who sustained a cardiac arrest. The first rhythm documented was ventricular fibrillation. She was successfully resuscitated and transported to a local hospital where she sustained an episode of torsade de pointes resulting in loss of con-
Figure 3. Case 2. Continuous recording (25 mm/s) of ventricular electrograms before and after electrical device discharge (arrow). The initial rhythm demonstrates a normal rate with slight variability in RR intervals and a constant electrogram configuration. In the absence of any known history of slow atrial rhythm this most likely represents a sinus arrhythmia. A tachycardia begins abruptly after a short-long-short electrogram sequence and continues for 51 s until terminated by the device discharge. The cycle length of the tachycardia is 160 to 180 ms and is characterized by a continuously changing configuration. This is consistent with rapid polymorphic ventricular tachycardia or ventricular fibrillation.

Sciousness and requiring cardioversion to terminate. The QT interval was prolonged at 520 ms. The serum magnesium concentration was 1.5 mg/dl and the potassium level was 3.6 mEq/liter. The QT interval normalized with correction of the electrolyte abnormality. There was no family history of sudden death or long QT syndrome. Cardiac catheterization demonstrated normal coronary arteries and no structural abnormality. Electrophysiologic study showed no inducible ventricular arrhythmias. Anterograde atrioventricular (AV) node Wenckebach block occurred at a paced cycle length of 300 ms. The patient received an implantable cardioverter-defibrillator for treatment of presumed idiopathic long QT syndrome manifested in the presence of hypomagnesemia.

Device discharge for polymorphic ventricular tachycardia (Fig. 3). Six weeks after leaving the hospital she felt the defibrillator discharge after an episode of vomiting. The only symptom preceding this event was mild light-headedness. On evaluation, the serum magnesium level was 1.7 mg/dl and the potassium level was 3.9 mEq/liter. The QT interval was normal. Interrogation of the device showed that detection of an arrhythmia had triggered discharge of the device. The ventricular electrograms registered for 27 s before and 5 s after device discharge were retrieved (Fig. 3). The initial rhythm is slightly irregular with a cycle length of 650 to 700 ms and is presumably sinus. After this rhythm, there is a premature beat followed by a long pause, another ventricular depolarization and a second premature beat (short-long-short intervals) that then initiates a rapid tachycardia (cycle length 160 to 180 ms). This tachycardia continued for 11 s and was terminated with a 500 V (16 J) discharge from the device. This rhythm, characterized by an irregular rapid rate and changing electrogram configuration, was consistent with a recurrence of torsade de pointes.

Case 3

This 69 year old man had a history of childhood rheumatic fever and two episodes of myocardial infarction in 1975 and 1979. He underwent coronary artery bypass grafting and aortic valve replacement in 1985. He was well until April 1988, when he sustained a cardiac arrest. Cardiac catheterization revealed no evidence of graft occlusion or valve dysfunction. Electrophysiologic study revealed inducible sustained ventricular tachycardia in the baseline state that was slowed with a combination of amiodarone and encainide and he was discharged on this regimen. In July 1989, he presented with symptoms of amiodarone-induced pulmonary toxicity that prompted discontinuation of this medication. Repeat electrophysiologic study performed during quinidine therapy revealed three distinct configurations of inducible sustained ventricular tachycardia that were terminated by ventricular pacing. The cycle lengths ranged from 400 to 480 ms and were all well tolerated hemodynamically. It was therefore decided to implant an antitachycardia pacemaker-cardioverter-defibrillator.

Device discharge for electrical artifact (intermittent lead fracture [Fig. 4]). Approximately 6 months after implantation of the device he experienced a device discharge while at home. He reported that he had no symptoms before the shock was delivered. Interrogation of the device revealed 14 aborted discharges for detection of events that were nonsustained, three episodes of antitachycardia pacing therapy and one 600 V (22 J) discharge for detection of sustained tachycardia below the cycle length cutoff point for detection of ventricular fibrillation (300 ms). Because the device had been programmed to store the electrograms for three 32 s arrhythmia events, the electrograms from the majority of the sensed events were unable to be retrieved, including the episode initiating device discharge. However, retrieval of the stored electrograms corresponding to the aborted shocks suggested the probable cause of the event triggering shock therapy. All three recorded events were similar; an example is shown in Figure 4. The underlying rhythm is regular at a cycle length of approximately 660 ms and is probably sinus in origin. Large amplitude, high frequency electrical signals present intermittently throughout the tracing and independent of the underlying regular rhythm were recorded. By manipulating the generator pocket and moving the patient in a variety of
positions it was possible to reproduce this electrical artifact and record it on the real-time rate-sensing lead recording channel (see later). It was believed that the latter recordings were most consistent with an intermittent lead fracture in the rate-sensing leads. The intermittent make-break phenomenon led to inappropriate tachycardia detection and was suspected of resulting in the shock in the absence of symptoms. Because the implanted device is capable of sensing up to the time of discharge, most of the detected episodes resulted in an aborted shock.

Correction of disrupted lead system (Fig. 5). In the operating room the generator pocket was opened and visual inspection revealed an obvious disruption of the lead adapter (DAIG LA 211) between the two epicardial screw-in rate-sensing leads and the header of the defibrillator generator. Manual manipulation of this portion of the lead system was associated with artifact in the electrographic tracings recorded from the rate-sensing leads (Fig. 5), thereby confirming the diagnosis. The lead adapter was replaced, after which no artifact could be recorded from the leads during manual manipulation. Ventricular tachycardia was induced and effectively terminated with anti-tachycardia pacing, indicating appropriate sensing and pacing through the lead system.

Discussion

Asymptomatic defibrillator discharge. Asymptomatic defibrillator discharge has been reported to occur in approximately one-third of patients receiving the implanted device (1-3). Although the fortuitous documentation of surface ECG recordings has demonstrated a variety of sustained and nonsustained supraventricular and ventricular arrhythmias leading to device discharge, because the arrhythmic events are usually not known with certainty, the appropriate intervention to prevent their recurrence is difficult to prescribe. The three cases presented are illustrative of the importance of recording the ECG events in the form of the ventricular electrogram before electrical device discharge. Analysis of the rate and regularity of electrographic intervals can clearly point toward the appropriate arrhythmia diagnosis. Furthermore, recording of characteristics of the electrogram during sinus rhythm and during all atrial and ventricular tachycardias may serve as a valuable reference for analysis of ventricular electrogram configuration during subsequent arrhythmic events.

Role of stability of RR interval and electrogram configuration. There is no doubt given the marked variability in rate that the diagnosis of atrial fibrillation could be made with
The degree of RR interval variability ranged from 240 to 500 ms, consistent with the diagnosis of atrial fibrillation. The configuration of the ventricular electrogram, although consistent with a supraventricular rhythm in this patient, had to be considered much less reliable. Somewhat surprisingly, the configuration of the ventricular electrograms recorded during sinus rhythm, atrial fibrillation and ventricular tachycardia were identical in the earlier study in this patient (Fig. 1). The rate-sensing leads had been placed on the lateral left ventricular epicardium. It is conceivable that ventricular tachycardia arising from the septum could have the same pattern of epicardial activation at this lateral left ventricular site during ventricular tachycardia and sinus rhythm. Davies et al. (5), in reporting on a computer algorithm to distinguish different tachyarrhythmias based on changes in atrial and ventricular electrogram configuration, documented orthodromic AV tachycardia and ventricular tachycardia in the same patient. As was the case for our first patient, the ventricular electrogram configuration was identical during the supraventricular arrhythmia and ventricular tachycardia. The potential for similar ventricular electrograms during ventricular tachycardia and supraventricular rhythms points out the major limitation of using electrogram configuration as the sole means of arrhythmia diagnosis.

In the second patient, the rapid rate (more than 100 ms faster than the Wenckebach cycle length documented during atrial pacing) and the changing configuration of the electrogram left little doubt as to the likelihood of recurrence of a life-threatening polymorphic ventricular arrhythmia.

The third patient illustrates how electrical events stored before device discharge or aborted discharge can also be used to diagnose potential causes of oversensing. Electrical signals consistent with the make-break phenomenon seen with intermittent interruption of the lead integrity were noted on the electrogram recording channel and reproduced with manual manipulation of the lead adapter. This allowed immediate intervention and correction of the likely problem leading to device discharge in the absence of symptoms. Thus, in all three patients with device discharge preceded by minimal or no symptoms it was not necessary to reassure the patient without knowing the cause of the discharge. Rather, in all cases, the accuracy of the diagnosis was near absolute and the appropriate reassurance and therapy could be immediately instituted.

Criteria for distinguishing supraventricular and ventricular rhythms. Table 1 lists the characteristics of the ventricular electrograms with respect to rate, RR interval variability and configuration that might be expected with the more common supraventricular and ventricular arrhythmias (5-8). While 60 ms in RR interval variability is an arbitrary cutoff point for distinguishing between ventricular tachycardia and atrial fibrillation, Geibel et al. (6) observed a mean maximal absolute change in ventricular tachycardia cycle length of 62 ms in their analysis of 100 consecutive beats of uniform ventricular tachycardia in 20 patients. Olson et al. (7) also noted a mean maximal RR interval variability of 51 ms at the onset of 22 episodes of spontaneous uniform sustained ventricular tachycardia. Fisher et al. (8) found that beat to beat changes in RR intervals at the onset of exercise-induced sinus tachycardia were <40 ms in 45 of 50 patients. Thus, the stability of the RR interval may be useful in distinguishing these more stable rhythms from atrial fibrillation.

As indicated in Table 1, the major limitations of using the ventricular electrogram in arrhythmia diagnosis are related to the similarity of local electrogram characteristics that one can see with supraventricular and ventricular arrhythmias in some patients and the change in electrogram configuration that may develop when bundle branch block occurs during supraventricular tachycardias. Obviously, the rate and regularity of some supraventricular and ventricular arrhythmias may also overlap. Furthermore, the long-term stability of ventricular electrogram configuration recorded from epicardial lead systems during sinus rhythm and tachyarrhythmias

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Table 1. Expected Characteristics of Ventricular Electrogram Rate, Cycle Length or RR Interval Variability and Electrogram Configuration of the More Common Supraventricular and Ventricular Arrhythmias

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Rate (beats/min)</th>
<th>RR Interval Variability (ms)</th>
<th>Configuration</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinus tachycardia</td>
<td>&lt;200</td>
<td>&lt;40</td>
<td>Same as NSR</td>
<td>*</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>Variable</td>
<td>&gt;60</td>
<td>Same as NSR</td>
<td>*</td>
</tr>
<tr>
<td>Atrial flutter</td>
<td>140-160</td>
<td>&lt;40</td>
<td>Same as NSR</td>
<td>*</td>
</tr>
<tr>
<td>Monomorphic VT</td>
<td>Variable</td>
<td>&gt;60</td>
<td>Ventricular</td>
<td>*</td>
</tr>
<tr>
<td>Polymorphic VT/VF</td>
<td>Variable (usually &gt;250 if no drug therapy)</td>
<td>&gt;60</td>
<td>Polymorphic</td>
<td>*</td>
</tr>
</tbody>
</table>

*Any regular supraventricular tachycardia and monomorphic ventricular tachycardia may be indistinguishable if the electrogram configuration is not different. Note that the configuration of the local electrogram may be identical if the activation wave front is similar. The effect of bundle branch block on electrogram configuration during any supraventricular rhythm is unknown and obviously critically dependent on the bundle branch block pattern and electrode location. Less variability at rapid rates may make atrial fibrillation indistinguishable from ventricular tachycardia if the electrogram configuration is not dissimilar. Degree of variability in cycle length is directly proportional to the mean heart rate. At very fast heart rates the RR interval may vary by <40 ms. NSR = normal sinus rhythm; VF = ventricular fibrillation; VT = ventricular tachycardia.
remains to be defined. Documentation of electrograms recorded during induced arrhythmias intraoperatively and postoperatively may serve as a valuable reference when analyzing subsequent arrhythmic events.

References