The Automatic Implantable Cardioverter-Defibrillator: Evaluating Suspected Inappropriate Shocks

PETER D. CHAPMAN, MD, PAUL TROUP, MD, FACC

Milwaukee, Wisconsin

Two patients who received inappropriate shocks from an implanted defibrillator are presented. In one case, fracture of a sensing lead was responsible and in the other case, sensing of both pacemaker stimuli and the evoked ventricular electrogram resulted in inappropriate shocks. In both cases, phonograms recorded over the generator area with a magnet in place revealed audible tones synchronous with each sensed event which allowed noninvasive documentation of a sensing problem. This procedure appears to be a valuable step both in the confirmation of sensing problems, including pacemaker-defibrillator interactions, and in evaluating suspected inappropriate shocks.

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Case Reports

Case 1

History. A 69 year old man with atherosclerotic heart disease had an implanted defibrillator placed in June 1984 because of a history of ventricular fibrillation without myocardial infarction and inducible ventricular tachycardia not controlled by drug therapy. The implanted lead system consisted of two myocardial screw-in electrodes for rate counting (sensing) and two patch electrodes for shocking. The device had a rate cutoff of 155 beats/min and utilized the rate plus probability density function algorithm. The patient experienced no shocks for 11 months after implantation. In June 1985 he was bending over when he experienced a shock without symptoms of recurrent arrhythmia. A 24 hour ambulatory electrocardiographic (Holter) monitor revealed no ventricular tachycardia. An exercise stress test revealed a maximal heart rate of 127 beats/min. The following week, the patient experienced three shocks in a 10 minute span while changing his shoes, again without symptoms of recurrent arrhythmia.

Evaluation of the etiology of the shocks. He was admitted to the hospital and a phonogram was performed. Surface electrocardiographic leads I, aVF and V₃ and a phonogram of the tones emitted by the implanted defibrillator pulse generator were recorded simultaneously on pho-
sioning problems of implanted defibrillators

Figure 1. Case 1. Electrocardiographic leads I, aVF, and V1 are shown with a phonogram (Phono) that records an emitted tone for each sensed event. Time lines (T) are also shown (interval between the longer lines is 1 second). The paper speed is 25 mm/s. Both undersensing (lack of a tone with a QRS complex, as in the third complex from the left) and oversensing (multiple tones without a QRS complex, best seen with the QRS complexes second and third from the right) are shown.

It was thought that this probably represented a sensing electrode problem with one of the myocardial screw-in electrodes. The patient was subsequently taken to the operating room where the lead system was directly evaluated after the generator pocket was opened. An intermittent fracture of one of the myocardial screw-in electrodes was discovered, with a pacing system analyzer documenting intermittently infinite impedance during pacing through the myocardial electrodes. An endocardial bipolar sensing electrode was used to replace the myocardial sensing electrodes. The new sensing lead system functioned appropriately during intraoperative testing and there have been no further evidence of sensing malfunction and no further shocks.

Case 2

History. A 40 year old man with atherosclerotic heart disease, sustained ventricular tachycardia, a history of sudden cardiac arrest and an unsuccessful subendocardial resection for ventricular tachycardia was referred for defibrillator implantation. At the time of surgery, the lead system for the implanted defibrillator was installed and included two myocardial screw-in rate-counting electrodes on the high lateral left ventricular wall and two large patch electrodes for shocking. The implanted defibrillator generator had a rate cutoff of 150.2 beats/min and utilized rate plus probability density function in its detection algorithm. Two additional Medtronic model 6917-53T myocardial screw-in leads were placed, in the event that long-term ventricular pacing was necessary postoperatively.

Postoperatively, ventricular tachycardia recurred at a rate less than the rate cutoff for the automatic implantable cardioverter-defibrillator and initially was controlled with temporary atrial overdrive pacing at 100 to 120 beats/min. Eventually, drug therapy (amiodarone plus tocainide) resulted in partial control of the arrhythmia, but this drug combination resulted in the development of congestive heart failure and sinus arrest with a slow junctional rhythm of 35 to 45/min. Amiodarone was discontinued and the congestive heart failure responded slowly to conventional therapy. Subsequently, however, ventricular tachycardia recurred. Atrial pacing was reinstituted based on its previous success, but because of residual amiodarone effect, atrioventricular (AV) conduction was impaired and AV sequential mode (DVI) pacing was implemented. This was successful in suppressing ventricular tachycardia. Ventricular overdrive pacing was also successful, but less favorable hemodynamically.

Subsequently, a Medtronic 7006 pacemaker was placed.
The atrial lead was a positive fixation bipolar electrode (Oscor model PY) placed at the junction of the high right atrium and interatrial septum. The two epicardial screw-in electrodes previously placed on the inferior left ventricle at the time of surgery were used as the ventricular leads. The thresholds from the ventricular leads (bipolar) were 1.1 V and 2.1 mA (0.5 ms pulse width). Before implantation of the pulse generator, the atrial and ventricular outputs were increased to 10 V and the automatic implantable cardioverter-defibrillator was placed in the electrophysiologic test mode. No evidence of detection of either the atrial or ventricular pacing artifacts was apparent. The pacemaker was set in the DVI mode at a rate of 110/min. The AV interval was set at 200 ms, with an output of 5 V and a pulse width of 0.5 ms in each chamber.

The pacemaker was partially successful in preventing sustained ventricular tachycardia and obviating the need for additional antiarrhythmic drug therapy. Approximately 1 week after pacemaker insertion, the patient experienced a shock during paced rhythm. A second shock the following day was documented on a Holter monitor to occur during paced rhythm and was synchronous with the paced QRS complex (Fig. 2).

**Evaluation of the spurious shocks.** A phonogram was performed (as described earlier). On activation of the generator, the device demonstrated sensing of both the atrial and ventricular pacemaker spikes. Recordings were performed in several pacing modes. In the atrial asynchronous (AOO) mode, intermittent sensing of atrial pacing stimuli with double counting was noted (Fig. 3). Intermittent sensing of ventricular pacing stimuli with double counting, in addition to occasional sensing of only the ventricular pacing artifact and not the resultant ventricular electrogram, was noted in the ventricular demand (VVI) mode (Fig. 4). Sensing atrial and ventricular pacing stimuli by the automatic implantable cardioverter-defibrillator was documented with atrial and ventricular pulse amplitudes of 2.5 to 5.0 V, but intermittent loss of both atrial and ventricular capture was observed at pulse amplitudes of 2.5 V with pulse widths as wide as 1.5 ms. To minimize the chance for inappropriate shocks, the pacemaker was programmed to AOO mode at a rate of 70/min (less than half the rate cutoff for the implantable defibrillator). At this rate, 1:1 AV conduction occurred, obviating the need for ventricular pacing, and no further shocks were observed during paced rhythm. Before hospital discharge, the defibrillator was tested against alternating current-induced ventricular fibrillation to ensure that pacemaker spikes during the ventricular fibrillation would not cause the defibrillator to ignore the arrhythmia.

**Figure 3.** Case 2. A recording after the pacemaker was reprogrammed to the AOO mode (pulse width 0.5 ms, amplitude 5.0 V). The phonogram (Phono) shows continuous sensing of the QRS complex and intermittent sensing of atrial pacemaker stimuli (sixth atrial stimulus from the left). Paper speed 25 mm/s. Abbreviations as in Figure 1.

**Figure 4.** Case 2. Phonocardiogram (Phono) during VVI pacing (pulse width 0.5 ms, amplitude 5.0 V). Intermittent sensing of both the ventricular pacemaker stimulus and the evoked QRS complex is demonstrated with occasional double counting (fourth through sixth QRS complex from left). Paper speed 25 mm/s. Abbreviations as in Figure 1.

**Discussion**

**Evaluation of suspected spurious shocks.** The automatic implanted cardioverter-defibrillator, as it is currently manufactured, has no telemetry or memory function to allow the physician to document a patient's rhythm at the time of a shock. When shocks occur without symptoms of a recurrent arrhythmia, investigation should include assessment of maximal heart rate (to ensure that sinus tachycardia is not recognized as ventricular tachycardia by the implanted defibrillator) and cardiac rhythm by continuous recording, to determine whether "asymptomatic" ventricular tachyarrhythmia is present. If this evaluation fails to reveal a cause, the sensing system should be evaluated further with a phonogram (as described earlier). The cases described demonstrate the occurrence of spurious shocks due to a sensing lead fracture in one instance and to sensing of pacemaker stimuli and ventricular electrograms in the other. In both cases, the phonogram allowed for noninvasive determination of the
probable cause of the problem so that adjustments could be made to eliminate the occurrence of inappropriate shocks.

**Defibrillator-pacemaker interaction.** Because the current automatic implantable cardioverter-defibrillator does not pace, it must interact with a permanent pacemaker in patients requiring both devices. Winkle et al. (3) recommended that all pacemakers in these patients be bipolar and separated anatomically from the automatic implantable cardioverter-defibrillator sensing electrodes. This is important, because the automatic implantable cardioverter-defibrillator has automatic gain control circuitry that detects the largest amplitude signal and fails to detect relatively smaller signals. If ventricular electrograms and pacing stimuli are not of markedly different potentials at the sensing leads, it is not surprising that these may both be counted as electrograms by the sensing circuitry. It is theoretically possible for the defibrillator to sense pacemaker stimuli (especially if they are unipolar) and simultaneously ignore low amplitude ventricular arrhythmias. Additionally, the device may count pacer stimuli and the resultant local ventricular myocardial electrical signal electrograms if the conduction time between the pacing stimulus and local ventricular depolarization at the site of the rate-counting electrodes exceeds the automatic implantable cardioverter-defibrillator sensing refractory period (approximately 150 ms) (3,5). In our Patient 2, “double counting” was noted with a bipolar pacemaker, which to our knowledge has not been previously reported. We have documented one other case of “double counting” of pacemaker stimuli in a patient with a VVI bipolar pacemaker. This has not led to documented inappropriate shocks, but it should be noted that the pacemaker was programmed to a rate less than half of the automatic implantable cardioverter-defibrillator rate cutoff for arrhythmia recognition.

Even with double or triple counting of the pacemaker stimuli and ventricular electrical activity, Patient 2 would not have received a shock unless probability density function was also satisfied. Probability density function differs markedly between normal rhythms and ventricular fibrillation in the amount of isoelectric time (greater for normal rhythms) (6). In our patient, it is likely that the paced ventricular rhythm satisfied probability density function and that the double counting then satisfied the rate cutoff criterion, resulting in a shock.

**Conclusions.** Phonograms may facilitate the evaluation of patients with inappropriate shocks (which cause physical and psychological patient discomfort and unnecessary battery depletion) and help identify potentially adverse interactions between permanent pacemakers and implanted defibrillators. Bipolar pacemakers can cause inappropriate ventricular rate counting and, apparently in concert with the resultant ventricular electrograms, satisfy probability density function, which may lead to inappropriate shocks. Ultimately the automatic implantable cardioverter-defibrillator will have pacing capability (4), but until that time, thorough evaluation of defibrillator-pacemaker interaction should be carried out in patients requiring both devices. Because inappropriate sensing of pacemaker stimuli may be intermittent, multiple evaluations may be necessary in patients in whom an adverse interaction between these two devices is suspected.

**References**


