Atrial pacing–induced oversensing in subcutaneous implantable cardioverter-defibrillator

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Introduction

The subcutaneous implantable cardioverter-defibrillator (S-ICD) is an effective therapy for ventricular arrhythmias in patients who do not require either antibradycardia or antitachycardia pacing. The development of sinus or atrioventricular (AV) nodal conduction disease may present a challenge when pacemaker implantation is required. This case report highlights the potential for device-device interaction.

Case report

An 18-year-old man with hypertrophic cardiomyopathy and a primary prevention S-ICD (SQ-RS 1010; Boston Scientific, Marlborough, Massachusetts) developed first-degree AV block (200–250 ms) and right bundle branch block (QRS 134 ms) with right axis deviation. The patient had not previously undergone a septal myectomy. A dual-chamber permanent pacemaker (PPM) was implanted (Epyra-6; Biotronik, Berlin, Germany). Prior to his S-ICD implant a transvenous ICD had previously been extracted after becoming infected after 5 years.

The PPM was programmed DDD with a lower rate limit of 60 beats per minute (bpm) and an upper tracking rate of 150 bpm. The S-ICD conditional and shock zones were set to 250 bpm in the secondary vector. Primary and alternate vectors were not viable options owing to physiological oversensing of the patient's intrinsic sinus rhythm with right bundle branch block. Prior to pacemaker implantation there was appropriate sensing by the S-ICD of the intrinsic R wave (Figure 1).

Two months post PPM insertion an untreated episode was detected by the S-ICD displaying intermittent triple counting of the P, R, and T wave (Figure 2). The paced P-wave amplitude was similar to that of the intrinsic R wave (Figure 2, red box), resulting in sensing of both components. A fortuitous ventricular ectopic (Figure 2, green box) reset the sensing profile as the R-wave amplitude, which was significantly

KEY TEACHING POINTS

- It is pertinent to consider upgrade to transvenous implantable cardioverter-defibrillator (ICD), as it is not feasible to screen a patient preoperatively with paced and sensed morphologies.
- When screening patients for a subcutaneous ICD (S-ICD) in patients with a pre-existing PPM, it is necessary to review atrial sensing, atrial pacing, ventricular sensing, and ventricular pacing at maximum outputs in a bipolar configuration. If the pacing lead is unipolar, caution must be taken to ensure double counting of the pacing spike and P/R wave is not present.
- Intraoperatively, during defibrillation threshold testing, pacing asynchronously at maximum output is important so as to assess if the pacing artifact is sensed during arrhythmia, to ensure that the ventricular tachycardia / ventricular fibrillation therapy is not delayed or aborted owing to the inappropriate sensing.
- When programming the concurrent pacemaker, turning off the polarity switch and auto threshold testing algorithms can help limit oversensing by the S-ICD.

KEYWORDS Subcutaneous ICD; Pacemaker; Concurrent device; Oversensing; Inappropriate

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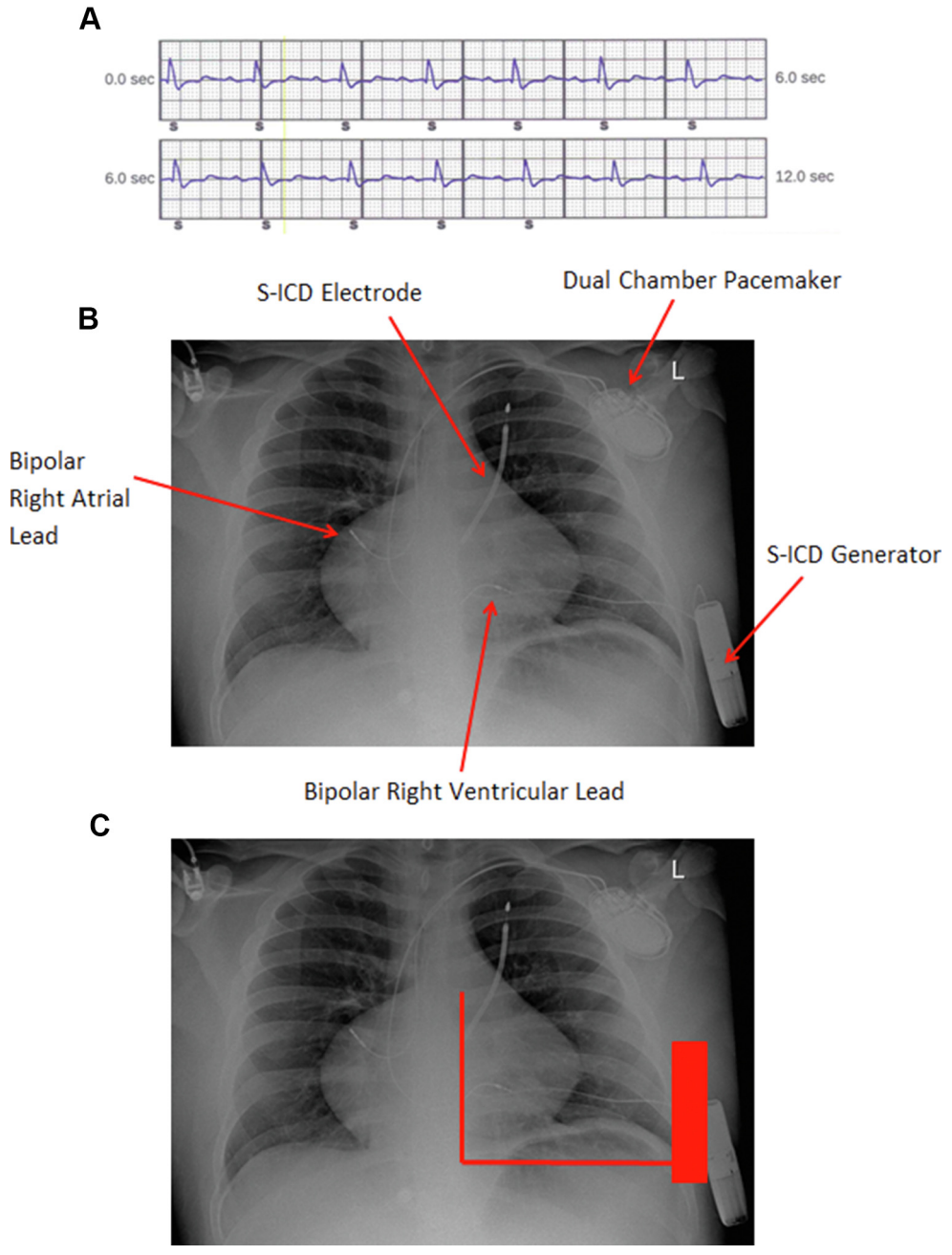

Figure 1 **A:** A captured subcutaneous implantable cardioverter-defibrillator (S-ICD) electrogram showing appropriate sensing prior to implantation of concurrent pacemaker in the Secondary Configuration. S = Sense. **B:** An anteroposterior chest radiograph. The S-ICD generator is located in the left midaxillary line, with the S-ICD electrode tunneled from the pulse generator to the left parasternal region. Dual-chamber pacemaker with IS-1, IS-1 header in the left pectoral region. Bipolar right atrial and right ventricular pacing leads. **C:** A suggested optimal position of the S-ICD electrode straight and within 1 cm of the sternum and the S-ICD generator encompassing the ventricular mass.

greater and momentarily avoided further oversensing and inappropriate therapy.

Simultaneous interrogation of the PPM and S-ICD was performed. During conduction of the atrial threshold test in AAI mode, the S-ICD P-wave oversensing was replicated (Figure 3A). The PPM was reprogrammed with a reduced lower rate limit of 40 bpm and atrial auto-capture turned off to allow intrinsic P-wave sensing. No further untreated episodes owing to oversensing were seen. When the S-ICD generator reached recommended replacement time, both systems were extracted and the patient was upgraded to a cardiac resynchronization therapy defibrillator in light of poor right ventricular function and severe heart failure and the risk of requiring increased/permanent right ventricular pacing owing to the prolonged AV delays.

Discussion

We believe this is the first reported case to highlight oversensing owing to atrial pacing in a patient with an S-ICD

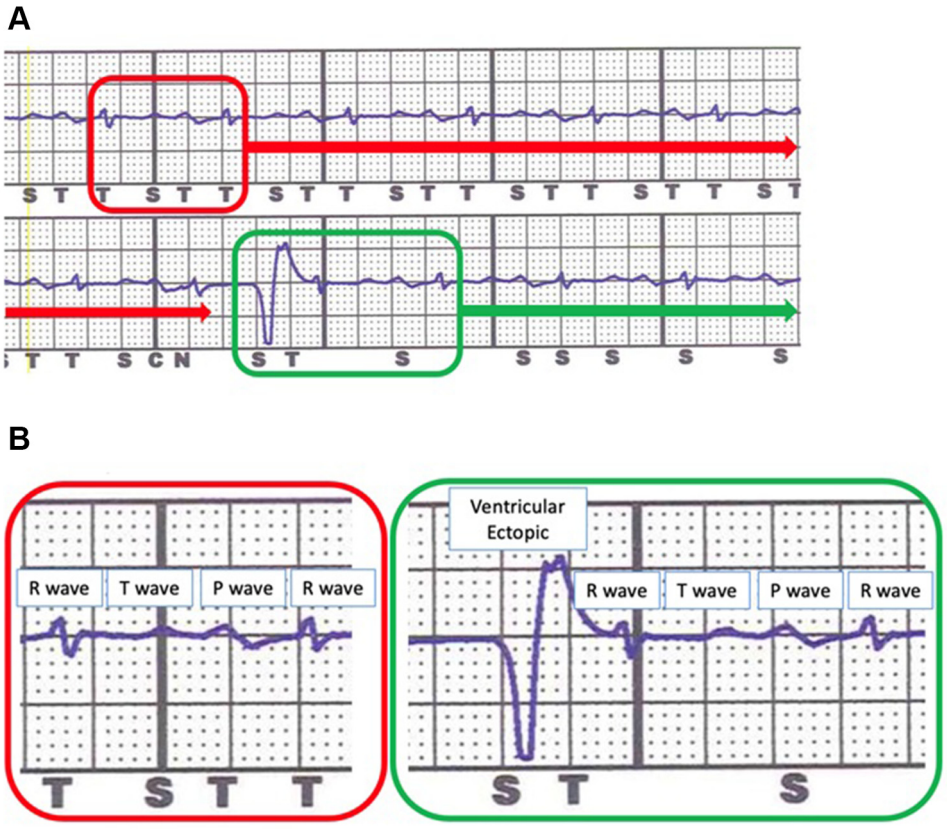

Figure 2 Electrograms of the untreated subcutaneous implantable cardioverter-defibrillator episode. **A:** The recorded trace during the tachycardia episode in Figure 1. **B:** Exploded sections of the trace. Panel A shows a continuous trace of the episode starting on the left of the top strip continuing to the strip below. The trace shows the patient in an atrial paced rhythm with intrinsic atrioventricular conduction. The markers below the trace show the device interpretation. The red box (exploded in panel B) shows a section of the trace in which the amplitude of the P, R, and T wave are of similar amplitude, the markers showing the device interpreting and detecting each component of the trace and starting the device counter. This continues (*red arrow*) until tachycardia detection is reached (conditional and shock zone set to 250 beats/min) and the device charges (**C**). A ventricular ectopic (S) (green box exploded in panel B) resets the auto gain control algorithm of the device, changing its sensitivity and improving its accuracy. S = sense; T = tachycardia detection; C = charge start; N = noise.

and concurrent dual-chamber pacemaker. While there was appropriate sensing by the S-ICD prior to the pacemaker implant, atrial pacing resulted in oversensing in the secondary configuration, which was the only configuration in which inappropriate sensing of myopotentials did not occur pre–pacemaker implant.

nappropriate sensing by the S-ICD occurred owing to the similarity in amplitude of the P, R, and T wave during atrial pacing with intrinsic AV conduction. As in the case of transvenous ICDs, the S-ICD uses auto gain control, whereby the average amplitude of the last 2 sensed signals is taken and the decay to sensing floor begins at 75% of this calculated amplitude. As the device consistently sensed the P wave, R wave, and T wave, the interval between the sensed intervals reduced. Consequently the average of the last 4 R-R intervals, in which heart rate is calculated, is greater than 167 bpm; therefore the sensing profile alters as it falls within the mid-rate zone. This resulted in a more aggressive decay to the sensing floor and shortened refractory period, which caused continued oversensing. The alteration in sensing profiles with rates >167 bpm or within the conditional or shock zone is to optimize detection of ventricular fibrillation. Consequently, a "tachycardia episode" was detected and the device began to charge. The ventricular ectopic triggered the auto gain control algorithm to reset owing to its significantly greater signal amplitude; therefore the decay to sensing floor was less aggressive and no longer oversensing small amplitude signals, and prevented potential inappropriate therapy.

Upon review of the chest radiograph (Figure 1B), the S-ICD generator and S-ICD electrode position were found to be suboptimal and not in a position that would be accepted nowadays. However, for the first-generation S-ICD devices (model 1010) implantation x-ray screening was not a recommendation made by the manufacturer; the position was based on satisfactory defibrillation threshold testing (DFT) and in-range shock impedance alone. It is unlikely that repositioning the S-ICD electrode or S-ICD generator to an optimal position as suggested in Figure1C would resolve the oversensing

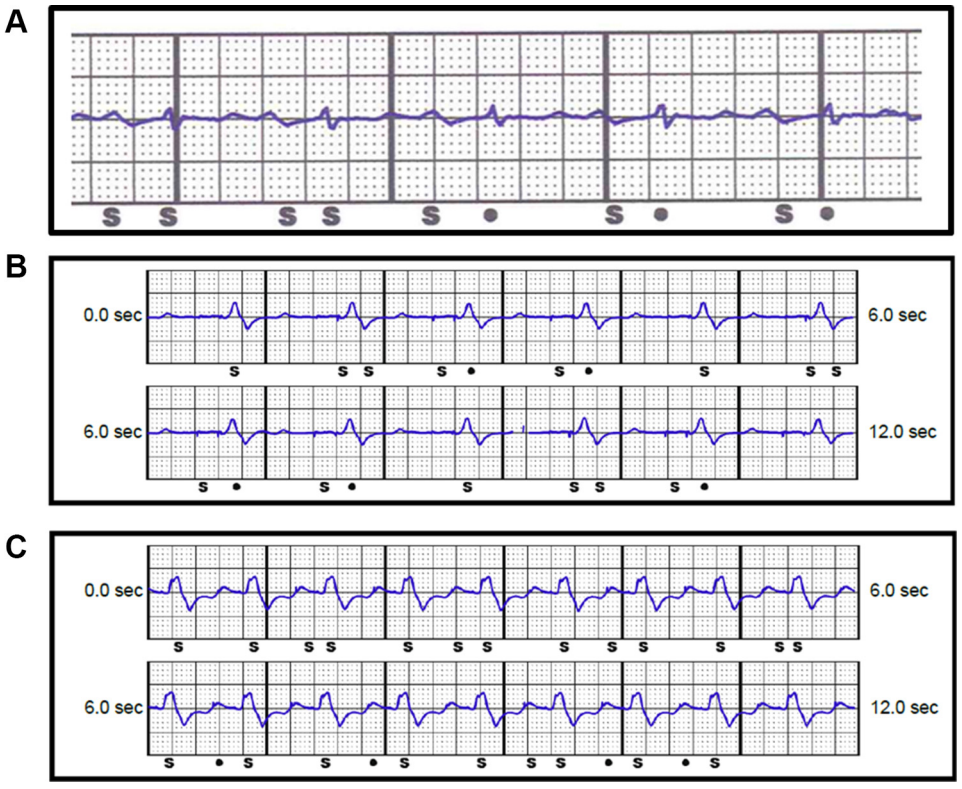

Figure 3 Captured subcutaneous implantable cardioverter-defibrillator electrograms during pacing. **A:** Captured trace when conducting atrial threshold in AAI in the case presented. The following 2 panels are from an additional example patient. **B:** The recorded trace during atrial pacing and ventricular pacing at 60 beats/min in the secondary configuration with intermittent oversensing of the terminal portion of the QRS and atrial pacing stimulus. **C:** The recorded trace during atrial pacing and ventricular pacing at 100 beats/min with intermittent P-wave oversensing. Dots indicate discarded beats. S = sense.

issue. With this reasoning the decision was taken not to undertake lead/generator repositioning.

There are limited reports of pacemaker and S-ICD interaction in the literature. Kossidas and colleagues[1] described a case of an S-ICD and a dual-chamber pacemaker with epicardial leads. Following implant, device interaction was assessed with atrial sensing and ventricular pacing at 90 bpm with different AV delays and pacing outputs. They found with pacing outputs of 7.5 V the unipolar pacing spikes were sensed and lead to double counting. Huang and colleagues[2] discussed the evaluation of sensed and paced beats in different vectors intraoperatively and postimplant. They suggested the PPM upper rate limit could be adjusted to less than or equal to 50% of the S-ICD tachycardia zones to minimize the risk of inappropriate shocks.

Important learning points have been identified in a patient with an S-ICD and concurrent PPM. Firstly, it is pertinent to consider upgrade to transvenous ICD, as it is not feasible to screen a patient preoperatively with paced and sensed morphologies. When screening patients for an S-ICD in patients with a pre-existing PPM, it is necessary to review atrial sensing, atrial pacing, ventricular sensing, and ventricular pacing at maximum outputs in a bipolar configuration. If the pacing lead is unipolar, caution must be taken to ensure double counting of the pacing spike and P/R wave is not present. Intraoperatively, during DFT, pacing asynchronously at maximum output is important so as to assess if the pacing artifact is sensed during arrhythmia, to ensure that the ventricular tachycardia / ventricular fibrillation therapy is not delayed or aborted owing to the inappropriate sensing. Finally, when programming the concurrent pacemaker, turning off the polarity switch and auto threshold testing algorithms can help limit oversensing by the S-ICD.

In our case, the older model S-ICD did not have the SMART Pass™ algorithm available. SMART Pass is an additional high-pass digital filter that attenuates lower-frequency signals while preserving higher-frequency signals greater than 10 Hz, designed to selectively filter out T waves and myopotentials. The same mechanism of oversensing was replicated in a different patient, but was not negated with the newer S-ICD model (Emblem A219) in which Smart Pass is a feature and was active (Figure 3B and 3C).

Conclusion

In patients who require an S-ICD and a concurrent pacemaker, the importance of screening all possible paced morphologies from both the atrial and ventricular chambers is required. Detailed knowledge of both device algorithms is essential to troubleshoot possible device interactions,

especially as oversensing and other cross-talk can only be evaluated after device implantation.

Acknowledgments

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