Managing cross talk between a subcutaneous implantable cardioverter-defibrillator and a dual-chamber unipolar pacemaker system

Konstantinos Kossidas, MD, FHRS,* Richard Kalman, RN,† William P. Follis, RN,†
Joshua M. Cooper, MD†

From the *Electrophysiology Section, University of Michigan Health System, Ann Arbor, Michigan, and
†Electrophysiology Section, Temple University Health System, Philadelphia, Pennsylvania.

Introduction

In cases of patients who have contraindications to transvenous pacing leads but still require pacing, surgically placed epicardial pacing leads are often used. If such a patient warranted implantable cardioverter-defibrillator (ICD), a subcutaneous ICD (S-ICD) system would be ideal from the standpoint of avoidance of transvenous leads, but device-device interaction with the epicardial pacemaker system is a concern. In this case report, we describe the interaction as well as the management of a patient who was previously implanted with a dual-chamber unipolar epicardial pacing system and subsequently required a subcutaneous defibrillator for secondary prevention of sudden cardiac death.

Case report

The patient is a 25-year-old man with a medical history that includes bacterial endocarditis related to intravenous drug use. He underwent a bioprosthetic tricuspid valve replacement. The surgery was complicated by complete atrioventricular block, but a brisk narrow complex junctional escape rhythm at 60 beats/min was well tolerated. Since heart block persisted, eventually a dual-chamber transvenous pacemaker was implanted 4 weeks later.

The patient abstained from intravenous drug use. Approximately 6 months later, however, after a dental cleaning he presented with fever to 103°F and positive blood cultures for *Streptococcus viridans*. A transesophageal echocardiogram revealed multiple vegetations on the bioprosthetic valve and pacemaker leads, resulting in both tricuspid valve stenosis and moderate regurgitation. He first underwent

transvenous lead and pacemaker removal and, after a course of intravenous antibiotics, had a repeat bioprosthetic tricuspid valve replacement surgery. During surgery, unipolar permanent epicardial pacemaker leads (Medtronic model 5071) were placed on the right atrium and right ventricle and connected to a dual-chamber pacemaker.

Two weeks postoperatively, while recovering in the hospital on intravenous antibiotics, he had 2 ventricular fibrillation (VF) arrests, each requiring emergency external defibrillation. No reversible etiology was found, and there was no observed single triggering premature ventricular contraction. An ICD system was felt to be appropriate for secondary prevention of sudden cardiac arrest, but because of a high concern for recurrent bloodstream infection, transvenous leads were undesirable. An S-ICD was ideal from an infection standpoint, but there was concern for device-device interaction with the dual-chamber unipolar pacemaker system.

Procedure

After standard sterile preparation and under general anesthesia, an S-ICD system was implanted in a left lateral submuscular pocket using a 2-incision approach (Boston Scientific Emblem S-ICD model A209 and S-ICD lead model 3401). Fluoroscopy was used to assist with incision location and subcutaneous tunneling in order to avoid physical interaction with the epicardial pacemaker leads (Figure 1).

After successful implantation, the possibility of device-device interaction was investigated. During both atrial sensing/ventricular pacing and atrial/ventricular pacing at 90 ppm with different atrioventricular delays, if unipolar pacing outputs were programmed at 3 V amplitude and 0.4 ms pulse width, the S-ICD sensed only native QRS complexes and not the unipolar pacemaker spikes in all 3 sensing vectors (Figures 2A and 2B). When pacing outputs were programmed at 7.5 V, the unipolar pacemaker spikes were sensed, leading to double counting, although many of the sensed events were binned by the S-ICD as "noise" (Figure 2C). Double counting was limited to the sensing of atrial pacing spikes and either the subsequent ventricular

KEY TEACHING POINTS

- During defibrillation threshold testing in patients with a separate pacemaker system, it is important for the pacemaker to be set in VOO mode at maximum output to watch for pacer output oversensing and ventricular fibrillation undersensing by the implantable cardioverter-defibrillator (ie, test the "worst-case scenario").

- If oversensing of pacing artifact exists in the setting of complete heart block, the device cross-talk problem may be overcome if the tachycardia detection rate is set more than the double the maximum pacing rate. Lowering the pacing amplitude while maintaining an appropriate safety margin may also reduce the risk of pacer output oversensing.

- A conditional zone that has a longer ventricular refractory period should be programmed in patients with paced rhythm. In addition, the programmed atrioventricular delay should be shorter than the ventricular blanking period.

- During subcutaneous implantable cardioverter-defibrillator screening, both native and paced rhythms should be assessed, especially given the T-wave changes that occur during ventricular pacing as well as repolarization changes during native conduction due to T-wave memory.

spike or the QRS complex. When the pacemaker was programmed back to 3 V pacing outputs and a lower rate of 40 ppm to eliminate atrial pacing (DDD mode), no oversensing occurred in the supine position in any of the 3 S-ICD sensing vectors.

Defibrillator threshold testing was then performed to look for device cross talk during VF as well as to assess VF sensing and defibrillation efficacy. The first VF induction was performed while the pacemaker was programmed VVI 90 ppm with ventricular pacing output at 7.5 V (maximum) and pacemaker ventricular sensing at 4 mV (low sensitivity). The S-ICD tachycardia rate cutoff was set at 200 beats/min. In this first VF induction, the pacemaker continued to pace at 90 ppm at 7.5 V throughout the VF event. The S-ICD sensed many of the pacemaker spikes and undersensed VF, leading to an inadequate number of detected tachycardia events, so external defibrillation at 360 J was successfully performed (Figure 3A). A second VF induction was performed while the pacemaker was programmed VVI 90 ppm with pacing output at 3 V (good safety margin, with a ventricular pacing threshold of 1.25 V at 0.4 ms). Again at 4 mV sensing, the pacemaker did not sense VF and paced at 90 ppm throughout the VF event. This time, the S-ICD did not sense the pacemaker spikes and sensed VF very well, with no delay in detection and effective defibrillation at 65 J (Figure 3B).

After considering the potential risk of inappropriate shock delivery due to oversensing when in a paced rhythm as well as the risk of failure to deliver therapy due to undersensing when in VF, it was felt that these small risks were outweighed by the benefits of the S-ICD system in this patient and the device was left in place. The pacemaker was programmed at a lower pacing rate of 40 ppm and, without rate response, in the
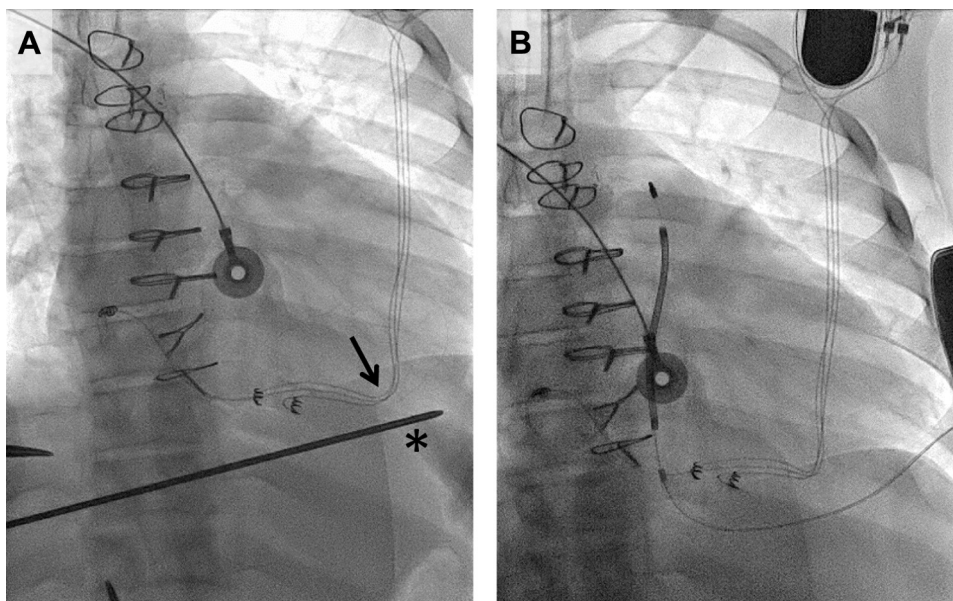

Figure 1   **A:** Fluoroscopy was used to identify the site where the epicardial leads exited between the ribs to the subcutaneous space (*arrow*) as well as to direct the subcutaneous route of the tunneling tool (*asterisk*). **B:** Fluoroscopy image after subcutaneous implantable cardioverter-defibrillator implantation.

setting of normal sinus node function and a goal to avoid uni-polar atrial pacing. Although double counting of the ventric-ular pacing spikes and neighboring QRS complex was never seen during testing, this risk remained possible in other body positions. To eliminate the possibility of shock delivery due to this type of double counting, the pacemaker maximum tracking rate was programmed at 100 ppm and the S-ICD tachycardia detection cutoff was programmed at 210 beats/min. This conservative programming would result in a maximal potential double-counting rate of 200 beats/min, below tachycardia detection, but would result in inadequate ventricular rates with exertion. Given that the patient had pre-viously tolerated very well being in heart block with a junc-tional escape rhythm for several weeks out of the hospital, this pacemaker programming trade-off made sense as an initial iteration. The presence of this stable underlying rhythm also allowed the pacemaker to be programmed confi-dently with a 3 V ventricular pacing output, despite the pos-sibility of a substantial increase in ventricular pacing threshold, which is not uncommon with non–steroid-eluting epicardial leads. If the patient were subsequently found to require a higher programmed ventricular pacing output due to a higher pacing threshold, repeat defibrillator threshold

testing with pacing outputs between the previously tested 3 V and 7.5 V scenarios would have to be performed in order to identify potential device cross talk at intermediate pacing amplitudes.

Discussion

The S-ICD was released in the United States in 2012 and is an effective and attractive alternative to transvenous ICD sys-tems in patients without the need for ATP or antibradycardia pacing. Patients with preexisting epicardial leads were excluded from those studies.[1,2]

The main concerns about interaction between the 2 de-vices are (1) oversensing of the large unipolar pacing spikes, leading to double or even triple counting with inappropriate shock delivery, and (2) saturation of the S-ICD sense ampli-fier from concomitant unipolar pacing during ventricular tachycardia or VF, leading to tachycardia undersensing and failure to deliver appropriate therapy. The S-ICD could potentially oversense the atrial pacing artifact, the ventricular pacing artifact, as well as the T wave. A preoperative screening process is used to simulate the 3 S-ICD sensing vectors and determine whether the baseline T-wave
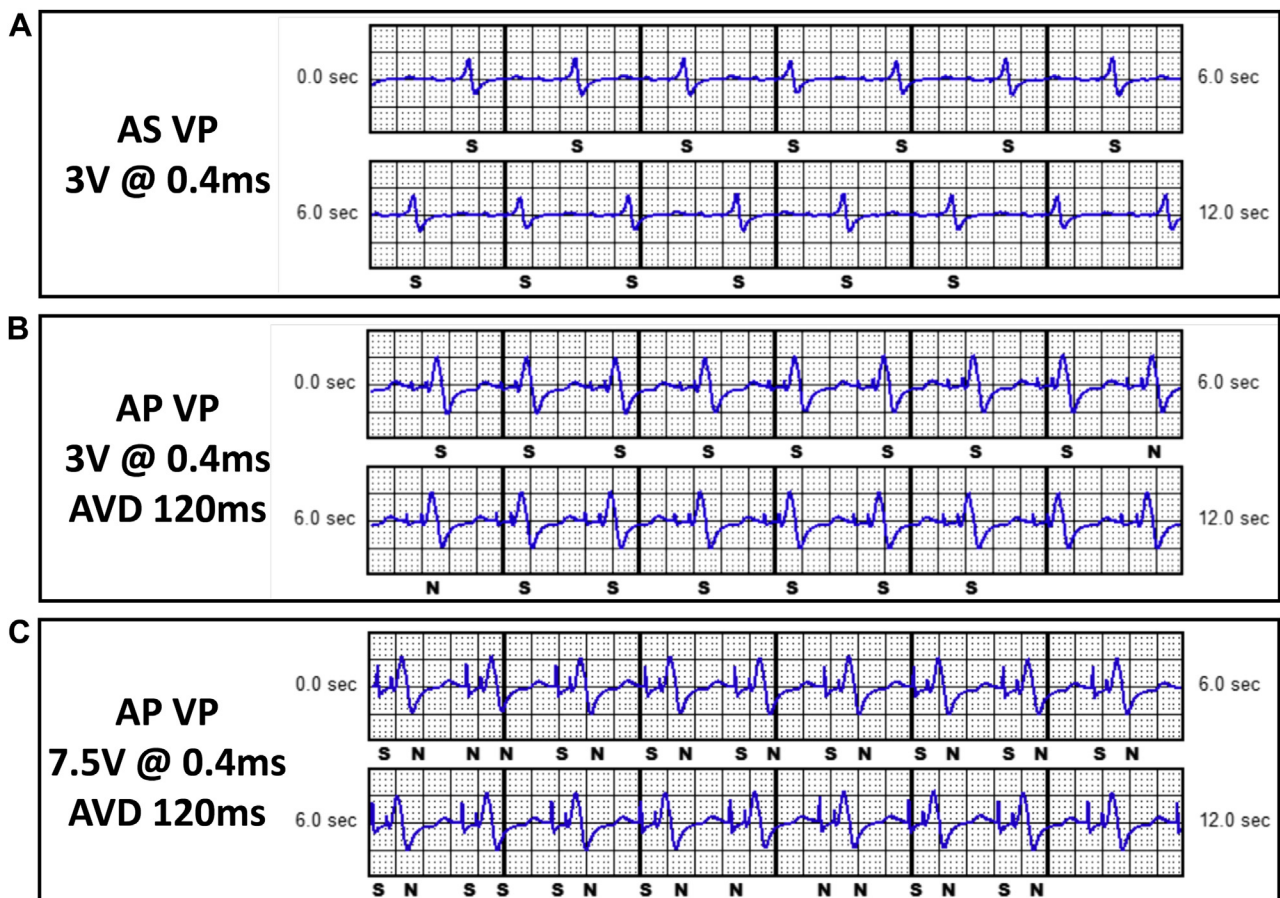

Figure 2 Real-time electrogram recordings and annotations from the subcutaneous implantable cardioverter-defibrillator system during different pacing stra-tegies. **A:** Atrial sensing and ventricular pacing in DDD mode, with pacing outputs set at 3 V @ 0.4 ms. **B:** Atrial and ventricular pacing in DDD mode at 90 ppm with AVD delay 120 ms, with pacing outputs set at 3 V @ 0.4 ms. **C:** Atrial and ventricular pacing in DDD mode at 90 ppm with AVD 120 ms, with high-output pacing set at 7.5 V @ 0.4 ms. AP = atrial pacing; AS = atrial sensing; AVD = atrioventricular delay; N = noise; S = sensed event; VP = ventricular pacing.
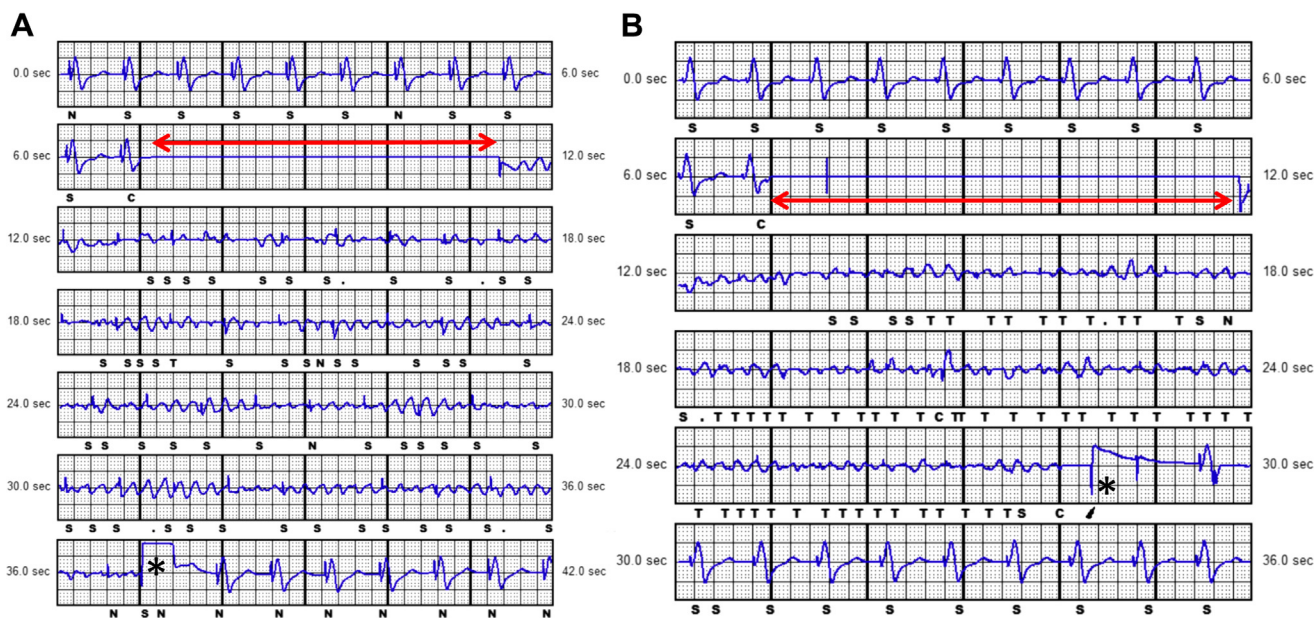
Figure 3   **A:** Continuous real-time S-ICD electrogram recording and annotation during DFT while the pacemaker was set at VVI 90 ppm at 7.5 V @ 0.4 ms output and pacemaker ventricular sensitivity was set at 4 mV. The electrogram channel is blanked during direct current delivery to induce ventricular fibrillation (*red double-headed arrow*). Many of the high-output pacemaker spikes are sensed by the S-ICD, and not enough tachycardia sensed events occur to trigger tachycardia detection and shock delivery. An external rescue shock is used to defibrillate successfully (*asterisk*). **B:** Continuous real-time S-ICD electrogram recording and annotation during DFT while the pacemaker was set at VVI 90 ppm at 3.0 V @ 0.4 ms output and pacemaker ventricular sensitivity was set at 4 mV. The 3 V output pacemaker spikes are not sensed by the S-ICD, tachycardia sensing works well, and a successful S-ICD shock is delivered (*asterisk*). . = discarded event; C = charge start; DFT = defibrillator threshold testing; N = noise; S = sensed event; S-ICD = subcutaneous implantable cardioverter-defibrillator; T = tachycardia sensed event.

amplitude and vector fall within acceptable sensing parameters during supine and upright postures. Pacing artifact oversensing and other device cross talk, however, can only be evaluated after device implantation. S-ICD uses a 3-step process during tachycardia evaluation: detection phase, certification phase, and rhythm decision phase. All sensed signals above the determined amplitude threshold are entered in the certification phase where are deemed to be true cardiac events or noise on the basis of the frequency and slew rate. During that phase, algorithms that detect double counting and T-wave oversensing are also implemented.[3]

As stated earlier, double counting was limited to the sensing of atrial pacing spikes and either the subsequent ventricular spike or the QRS complex, but there were no observed instances where the ventricular pacing spike and adjacent QRS complex were sensed on the same beat. This is related to the ventricular blanking period that is a nonprogrammable feature in the S-ICD and is 200 ms in the conditional zone and 160 ms in the shock zone.[3] Hence, in patients with paced ventricular complexes, a conditional zone that offers a longer post–ventricular blanking period has additional value besides discrimination for supraventricular tachycardia (which would not be an issue in this patient with complete heart block).

Most patients who require pacing currently receive a transvenous lead system. In the setting of tricuspid valve surgery, the presence of a mechanical tricuspid valve is a contraindication to placement of a transvenous right ventricular lead[4] and a bioprosthetic tricuspid valve is a relative contraindication, although placement of a right ventricular

lead through a tricuspid bioprosthesis does not necessarily lead to significant valve dysfunction.[5]

There are situations where transvenous leads are best avoided altogether, such as in patients with recurrent endocarditis or venous access limitations. In these circumstances, epicardial pacing systems can be of great value. In our case, unipolar epicardial leads presented an unforeseen challenge when late postoperative VF arrests created the need for a secondary prevention ICD system, as unipolar pacing has been reported as a contraindication for use of the S-ICD.

There are a few case reports that examine the interaction of pacemaker and S-ICD systems. In a case reported by Porterfield et al,[6] a transvenous right-sided pacemaker system was combined successfully with an S-ICD. To reduce the risk of cross talk, some programming recommendations were made, including the suggestion to turn off the safety feature of automatic conversion from bipolar to unipolar pacing in the event of abnormal pacemaker lead impedance and disabling postshock pacing in the S-ICD to avoid inhibition of pacing by the pacemaker.

In another case report by Schmitt and coworkers,[7] a failed transvenous dual-chamber ICD system was replaced by a left ventricular bipolar epicardial lead pacemaker and an S-ICD. Pacing did not affect S-ICD tachycardia detection, as bipolar stimulation did not produce pacing artifacts of sufficient amplitude to be sensed by the S-ICD. Steinberg et al[8] also demonstrated the feasibility and safety of the addition of an S-ICD to a bipolar epicardial pacemaker system. To our knowledge, however, there has not been a report of S-ICD

implantation and assessment in a patient with a unipolar epicardial pacing system.

Conclusion

A unipolar epicardial pacing system can be used in combination with an S-ICD. Certain critical steps must be taken, however, at the time of device implantation and in follow-up monitoring and programming to assess and minimize the risk of cross talk between the 2 systems. In certain clinical contexts, one might also conduct exercise testing to promote upper rate pacing in the context of motion, posture, and myopotential generation. More patient experiences are needed with the combination of unipolar epicardial pacing and S-ICD in order to draw general conclusions about safety.

References

1. Lambiase PD, Barr C, Theuns DA, et al. EFFORTLESS Investigators. Worldwide experience with a totally subcutaneous implantable defibrillator: early results from the EFFORTLESS S-ICD Registry. Eur Heart J 2014;35:1657–1665.

2. Weiss R, Knight BP, Gold MR, Leon AR, Herre JM, Hood M, Rashtian M, Kremers M, Crozier I, Lee KL, Smith W, Burke MC. Safety and efficacy of a totally subcutaneous implantable-cardioverter defibrillator. Circulation 2013; 128:944–953.

3. Swerdlow CD, Asirvatham SJ, Ellenbogen KA, Friedman PA. Troubleshooting implantable cardioverter-defibrillator sensing problems II. Circ Arrhythm Electrophysiol 2015;8:212–220.

4. Epstein AE, Dimarco JP, Ellenbogen KA, et al. American College of Cardiology; American Heart Association Task Force on Practice Guidelines; American Association for Thoracic Surgery; Society of Thoracic Surgeons. ACC/AHA/HRS 2008 Guidelines for device-based therapy of cardiac rhythm abnormalities. Heart Rhythm 2008;5:e1–e62.

5. Eleid MF, Blauwet LA, Cha YM, Connolly HM, Brady PA, Dearani JA, Espinosa RE. Bioprosthetic tricuspid valve regurgitation associated with pacemaker or defibrillator lead implantation. J Am Coll Cardiol 2012; 59:813–818.

6. Porterfield C, DiMarco JP, Mason PK. Effectiveness of implantation of a subcutaneous implantable cardioverter-defibrillator in a patient with complete heart block and a pacemaker. Am J Cardiol 2015;115:276–278.

7. Gemein C, Haj M, Schmitt J. Combining an subcutaneous ICD and a pacemaker with abdominal device location and bipolar epicardial left ventricular lead: first-in-man approach. Europace 2016;18:1279.

8. Steinberg C, Chakrabarti S, Krahn AD, Bashir J. Nothing inside the heart—combining epicardial pacing with the S-ICD. HeartRhythm Case Rep 2015; 1:419–423.