Substernal subcutaneous implantable cardioverter-defibrillator lead placement for the management of inappropriate shocks

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Introduction

The subcutaneous implantable cardioverter-defibrillator (SICD) has comparable inappropriate shock rates to the transvenous (TV) ICD. Although supraventricular tachycardia is the main culprit in TV ICD inappropriate shocks, T-wave or extracardiac oversensing is responsible for the majority of SICD inappropriate shocks.[1] We present a case where repositioning of the SICD lead to a substernal location led to correction of inappropriate sensing and elimination of inappropriate ICD shocks.

KEY TEACHING POINTS

- The predominant contributor to subcutaneous implantable cardioverter-defibrillator (SICD) inappropriate shocks is T-wave oversensing.
- A chest computed tomography (CT) scan is a useful tool to evaluate the amount of myocardium encompassed between the distal SICD electrode and generator. The CT scan can guide the approach to SICD revision in patients with suboptimal RT sensing.
- In carefully selected patients, relocation of an SICD electrode from subcutaneous to substernal position may address the problem of suboptimal R/T ratios and T-wave oversensing.

Case report

A 29-year-old man has been followed in our practice for the management of adult congenital heart disease with history of neonatal surgically repaired aortic coarctation, retroaortic innominate vein with absent left subclavian/axillary continuity and right subclavian vein atresia, and subsequent diagnosis of left ventricular noncompaction cardiomyopathy with reduced left ventricular ejection fraction (39% on cardiac magnetic resonance imaging). The patient was noted to have a high burden of ventricular ectopy by ambulatory recording and inducible ventricular tachycardia during programmed ventricular stimulation. Given the lack of a permanent pacing indication and his superior central venous anomalies, the SICD was recommended for primary prevention. Candidacy for the SICD was further confirmed with surface electrocardiogram screening demonstrating favorable signals only in the secondary vector with projected left parasternal electrode position.

The SICD electrode was initially implanted using a 2-incision technique and the pulse generator was implanted in the submuscular space at midaxillary position. The secondary sensing vector was chosen at implantation with appropriate detection of induced ventricular fibrillation. Routine step-down testing as previously described[2] showed a defibrillation threshold (DFT) of less than 10 J. The device was programmed with a 200 beats per minute (bpm) conditional zone and 240 bpm shock zone with output of 80 J.

The patient subsequently presented 3 months after implant with several episodes of inappropriate shocks due to T-wave oversensing. Inappropriate shocks recurred despite reprogramming to different sensing vectors and utilization of the sensing filtering algorithm. Chest radiograph demonstrated appropriate generator and electrode positions while SICD electrograms showed decreased R-wave amplitudes in the secondary vector from 9 to 7 mV and oversensed T waves (Figure 1).

Management options were presented to the patient which included revision of the SICD system to improve RT-wave sensing or epicardial ICD implantation. The patient was most in favor of pursuing device revision. Chest computed tomography was obtained to better evaluate the relationship

KEYWORDS Adult congenital heart disease; Device management; ICD; Inappropriate shocks; SICD; Subcutaneous implantable cardioverter-defibrillator
(Heart Rhythm Case Reports 2019;5:407–410)

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https://doi.org/10.1016/j.hrcr.2019.04.010

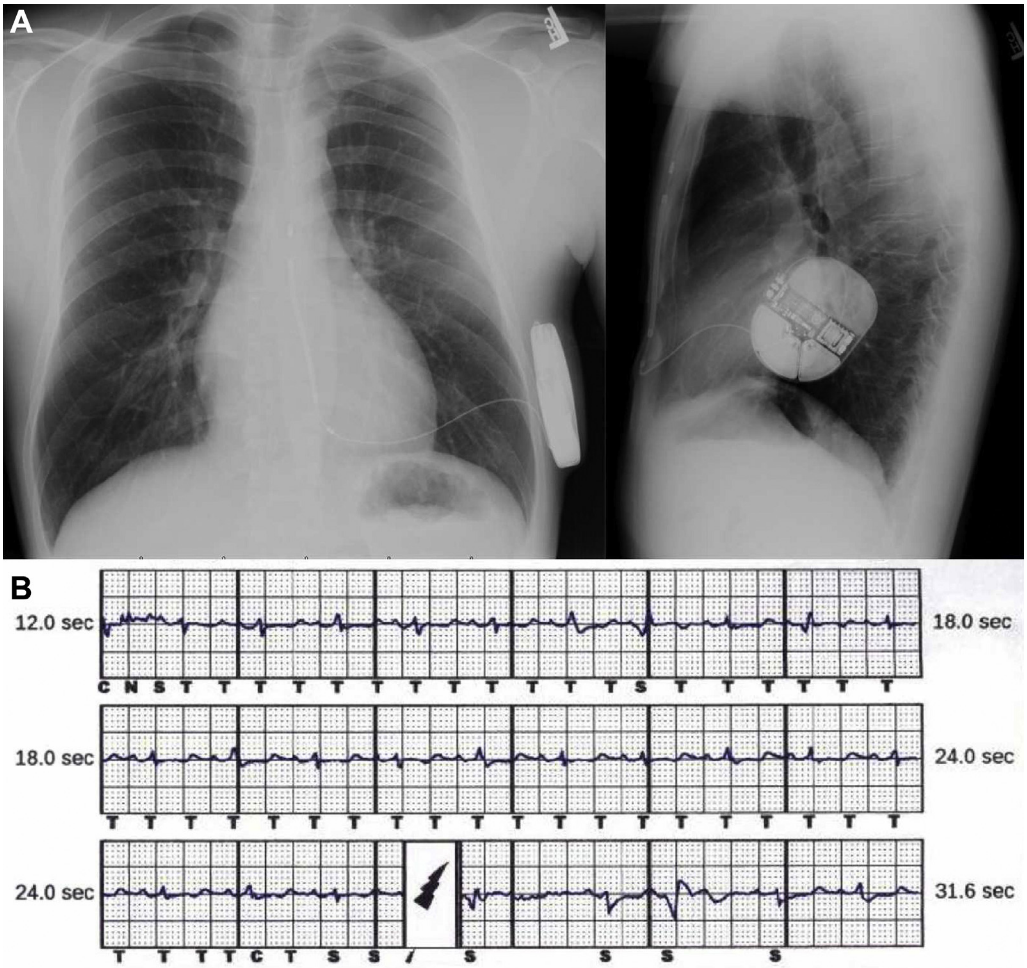

Figure 1 **A:** Posteroanterior and lateral chest radiograph of the subcutaneous implantable cardioverter-defibrillator with electrode in the left parasternal subcutaneous location. **B:** Stored electrogram tracing of an inappropriate shock due to T-wave oversensing.

between the electrode, generator, and heart prior to device revision. Imaging clearly revealed a sparse amount of ventricular myocardium within the sensing vector with the lead in the left parasternal position (Figure 2A). We decided not to reposition the pulse generator more posteriorly to increase coverage of myocardium because of his small stature and because, from our experience, repositioning could result in significant patient discomfort. We hypothesized that repositioning the lead to a substernal and more rightward location could improve sensing and reduce the risk of inappropriate shocks. After we reviewed these findings with the patient, recommendation was made to reposition the SICD electrode to a substernal position using a hybrid approach.

Given the patient's history of prior neonatal cardiothoracic surgery, we collaborated with our cardiac surgeon for the implantation of the substernal SICD lead. The patient was brought to a hybrid operating room with fluoroscopy capability. Under general anesthesia, the subxiphoid incision scar was opened and extended and the terminal end of the subcutaneous parasternal electrode was retracted under fluoroscopy. Next, the xiphoid was excised and a substernal tunnel was created under direct visualization. Owing to severe angulation of the sternum, a second incision was made at the right parasternal third intercostal space. The SICD electrode was then manually placed under the sternum in the appropriate space. The lead was sutured and secured to the fascia at the right third intercostal space and the subxiphoid space. The R-wave amplitude in the secondary sensing vector increased from 7 mV in the subcutaneous region to 10 mV in the substernal location. More importantly, the R/T ratio improved significantly in the new lead location and there was no evidence of T-wave oversensing. (Figure 3). Repeat cardiac imaging showed improved coverage of the myocardium from the right substernal position (Figure 2B and C).

There were no short-term complications related to the procedure. The patient was brought back to the hospital for DFT testing 6 weeks after SICD lead repositioning. Under anesthesia, step-down testing was performed starting at 40 J. The DFT was found to be 20 J with shock impedance 48 ohms. Over the ensuing 6 months of follow-up, there have been no further incidents of inappropriate sensing or shocks.

Discussion

The SICD is generally considered a comparable defibrillator platform to the TV ICD in a wide array of patients without a

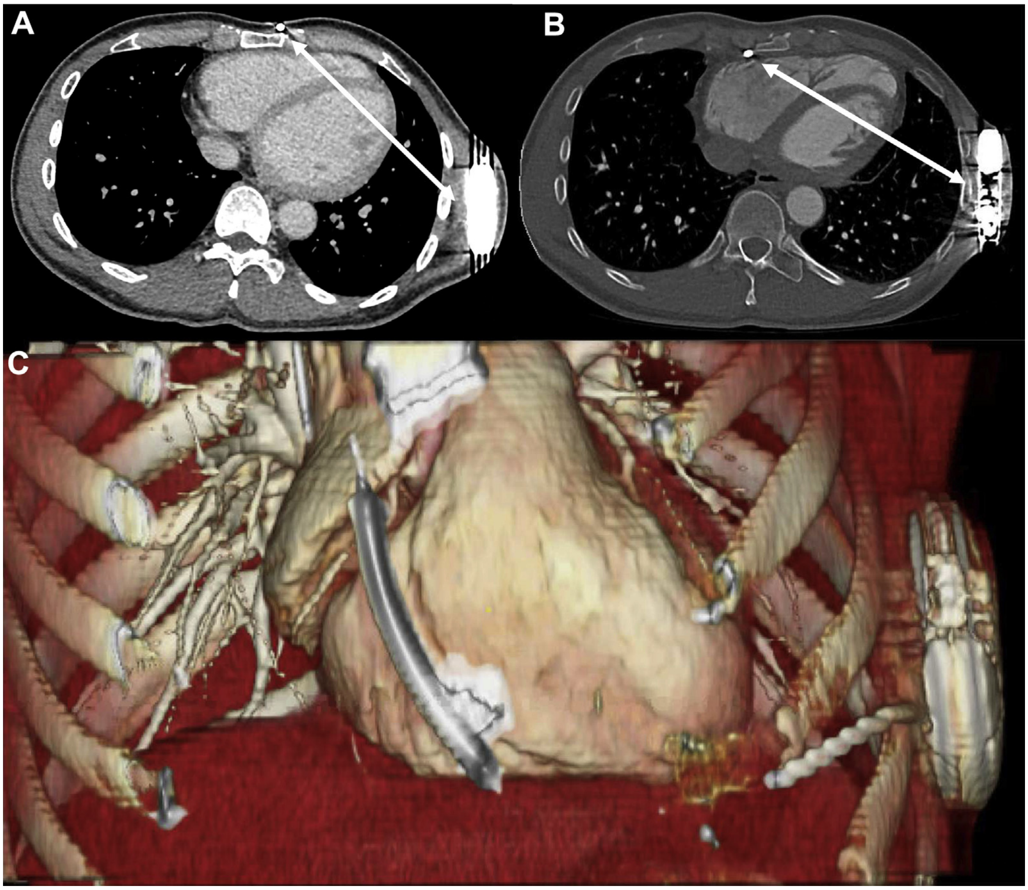

Figure 2 **A:** Chest computed tomography (CT) short-axis revealing the sparse amount of ventricular myocardium covered by the left subcutaneous lead within the sensing vector. **B:** Chest CT short-axis revealing improved coverage of ventricular myocardium by the right substernal lead. **C:** Three-dimensional reconstruction of the right substernal lead and generator position relative to the ventricles.

pacing indication. Recently, the 2017 Guidelines for Treatment of Ventricular Arrhythmias has considered SICD implantation a class I indication for patients with limited venous access who require ICD implantation and it has been shown to have comparable efficacy and similar postimplant complications compared to the TV ICD. Although the overall rates of inappropriate shocks are similar, T-wave oversensing is the dominant contributor to SICD inappropriate shocks.[1] A right parasternal approach for SICD electrode implantation has been suggested to improve R/T ratios; however, recent study in adults with congenital heart disease did now show significant sensing improvement with a right parasternal approach.[3] Guenther and colleagues[4] previously reported the relocation of an SICD electrode from subcutaneous to substernal position to address high DFT and failed SICD shocks at maximum output. This led to our decision to proceed with a substernal repositioning of the SICD electrode to provide more rightward position and greater myocardium coverage than the traditional parasternal approach. To our knowledge, this is the first case report of substernal SICD electrode repositioning to address inappropriate shocks due to suboptimal R/T ratios and T-wave oversensing.

Substernal defibrillation lead positioning has been previously reported using a tunneling tool and peel-away sheath under fluoroscopic guidance similar to the 2-incision SICD implant technique.[5,6] This type of defibrillation lead implantation has also been shown to be feasible in a novel defibrillator system currently undergoing clinical evaluation.[7]

We elected to perform our procedure in the hybrid operating room with an additional surgical incision in the right third intercostal space to permit firm anchoring of the electrode tip similar to the original 3-incision SICD implant technique. The deeper and more rightward electrode course modified the coil-to-generator relationship, thereby encompassing more ventricular myocardium, which improved sensing function while maintaining excellent DFT. Interestingly, the DFT was slightly higher at the right substernal position (20 J) than the left parasternal position (<10 J). In computer modeling, it has been shown that right parasternal lead position had higher DFT than left parasternal position owing to increased fascia layer between the lead and generator.[8] However, given our protocol to perform step-down testing in 10-J increments, it is difficult to say whether there was truly an increase in DFT.

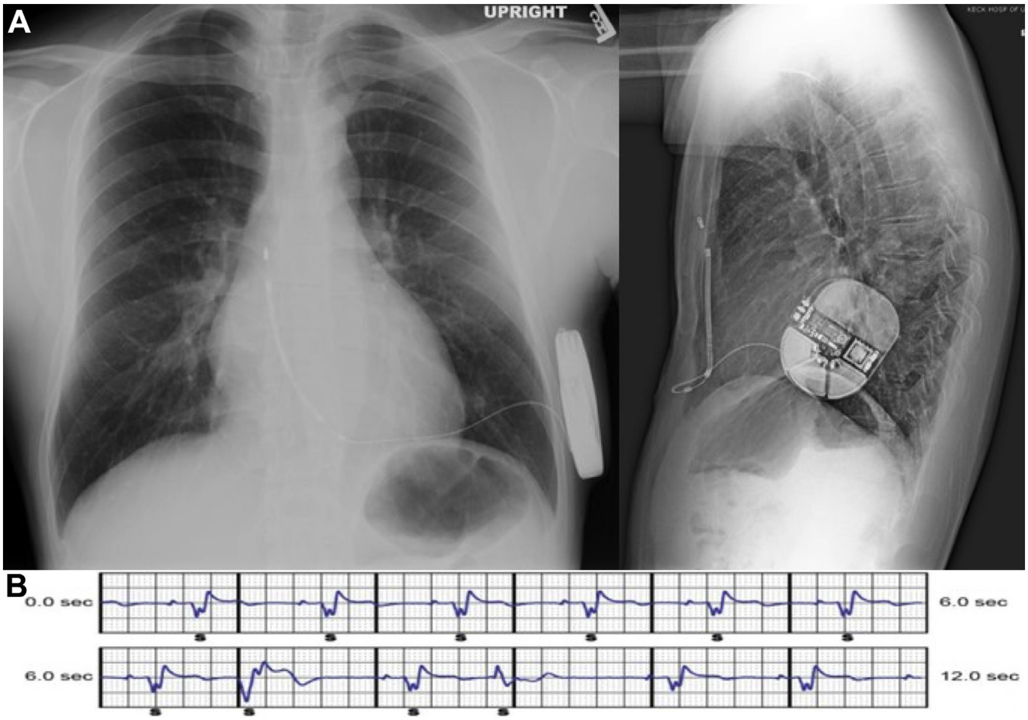

Figure 3 **A:** Posteroanterior and lateral chest radiograph of the subcutaneous implantable cardioverter-defibrillator with electrode in the right substernal location. **B:** Substernal electrode electrogram tracing showing improved R-wave amplitude and R/T ratio.

Although newer tools and lead design may allow for less invasive substernal lead placement, it should be noted that it was quite challenging in our case to deploy the lead, given the patient's sternal angle with the fear of traumatic injury to the anterior right ventricle. In addition, manual dissection creates a substernal space that would allow for lead movement and coiling. As such, direct suturing of the electrode tip would be advisable.

Conclusion

In this SICD patient with inappropriate shocks due to T-wave oversensing, repositioning of the SICD coil and sensing electrode to the substernal position improved the R/T ratio, thereby eliminating inappropriate shocks. Careful evaluation of the amount of myocardium encompassed between the distal electrode and generator can be helpful to guide the approach to SICD revision in patients with suboptimal RT sensing. Nevertheless, long-term clinical performance of substernal leads is unknown and the lead may become adherent to the surrounding tissues. This could lead to potential complications of increasing threshold and substernal lead erosion of contiguous structure in mediastinum, and—more importantly—the risk of infection and lead extraction is unknown. Thus, prior to considering substernal SICD lead placement, other safer alternatives such as repositioning of the SICD lead more medially or repositioning of the generator more posteriorly (if not limited by body habitus) should be first attempted.

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