Shockingly shiny shoes—Inappropriate discharge from a subcutaneous defibrillator

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Introduction

Inappropriate shocks from subcutaneous implantable cardioverter-defibrillators (S-ICD) have been a common problem, but their incidence has decreased with contemporary devices, programming, and algorithms. We report an unusual cause for an inappropriate S-ICD shock.

Case report

A 41-year-old male endurance athlete experienced a syncopal episode while participating in a cycling race. An automated external defibrillator detected a shockable rhythm and successfully defibrillated the patient. His initial electrocardiogram showed inferior Q waves with anterolateral ST depression; however, his serum troponin remained within the normal range. Transthoracic echocardiography showed a left ventricular (LV) ejection fraction of 30% with inferior regional wall motion abnormalities. Coronary angiography demonstrated a well-collateralized chronic total occlusion of the right coronary artery and a moderate stenosis of the left anterior descending coronary artery. Coronary artery bypass grafting was performed with grafts to the left anterior descending, first diagonal, and posterolateral and posterior descending branches of the right coronary artery. Subsequent magnetic resonance imaging scanning showed recovery of LV systolic function (LV ejection fraction 50%) with late gadolinium enhancement involving the inferoseptal and inferior walls of <50% mural extent.

A decision was made to implant a secondary prevention defibrillator in view of his cardiac arrest without evidence of an acute coronary occlusion or reversible precipitant with significant residual myocardial scar. As he was young and had no indication for pacing, an S-ICD was implanted with right parasternal lead placement using a 3-incision technique (Generator: Boston Scientific Emblem A209, Lead: Boston Scientific 3401; Boston Scientific, Marlborough, MA) (Figure 1). At implant the device sensing was excellent from the primary and secondary vectors but poor from the alternate vector. Defibrillation threshold testing could not be performed owing to noninducibility of VF. The device was programmed according to manufacturer's recommendations with a shock zone of 240 beats per minute and a conditional shock zone 220 beats per minute. Sensing was programmed via the secondary vector with SMART Pass filtering enabled.

Four years after device implant, the patient abruptly experienced a single unheralded shock from his ICD while polishing his shoes. Shoe-polishing was an uncommon activity for

KEY TEACHING POINTS

- The cumulative incidence of inappropriate shocks remains substantial among recipients of subcutaneous implantable cardioverter-defibrillators (S-ICDs).
- The most common cause of inappropriate shocks in S-ICDs is oversensing of myopotentials.
- Strategies to decrease the incidence of inappropriate shocks include preimplant electrocardiographic screening, high ventricular rate cut-offs, dual-zone programming, and use of the SMART Pass filter.
- Provocative testing may help identify the best sensing vector to minimize the risk of myopotential oversensing.

KEYWORDS Subcutaneous implantable defibrillator; Inappropriate shock; Myopotentials; Oversensing; Arrhythmia discrimination
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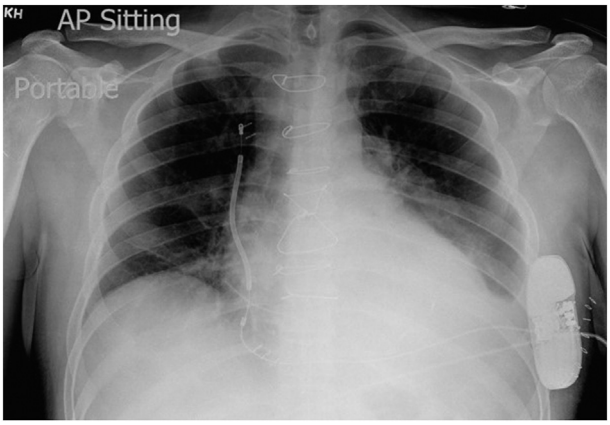

Figure 1 Chest radiograph taken after implant of subcutaneous implantable cardioverter-defibrillator demonstrating right parasternal lead placement.

him. There had been no recent changes to device programming or body habitus before this event. Figure 2 shows the electrograms recorded at this time downloaded via remote monitor. During the episode repetitive myopotential noise is observed. During a temporary pause in physical activity the myopotentials resolve before resuming with reinitiation of upper extremity motion. While the myopotentials were initially underdetected, the subsequent sensed potentials were detected in the therapy zone, triggering an ICD shock.

On review in the cardiac device clinic, the electrical noise from pectoral muscle activity was reproducible during shoulder movement (Figure 3). Oversensing of myopotentials was present in both the secondary and alternate vectors but not the primary vector. No noise, oversensing, or device malfunction had been identified on previous device downloads.

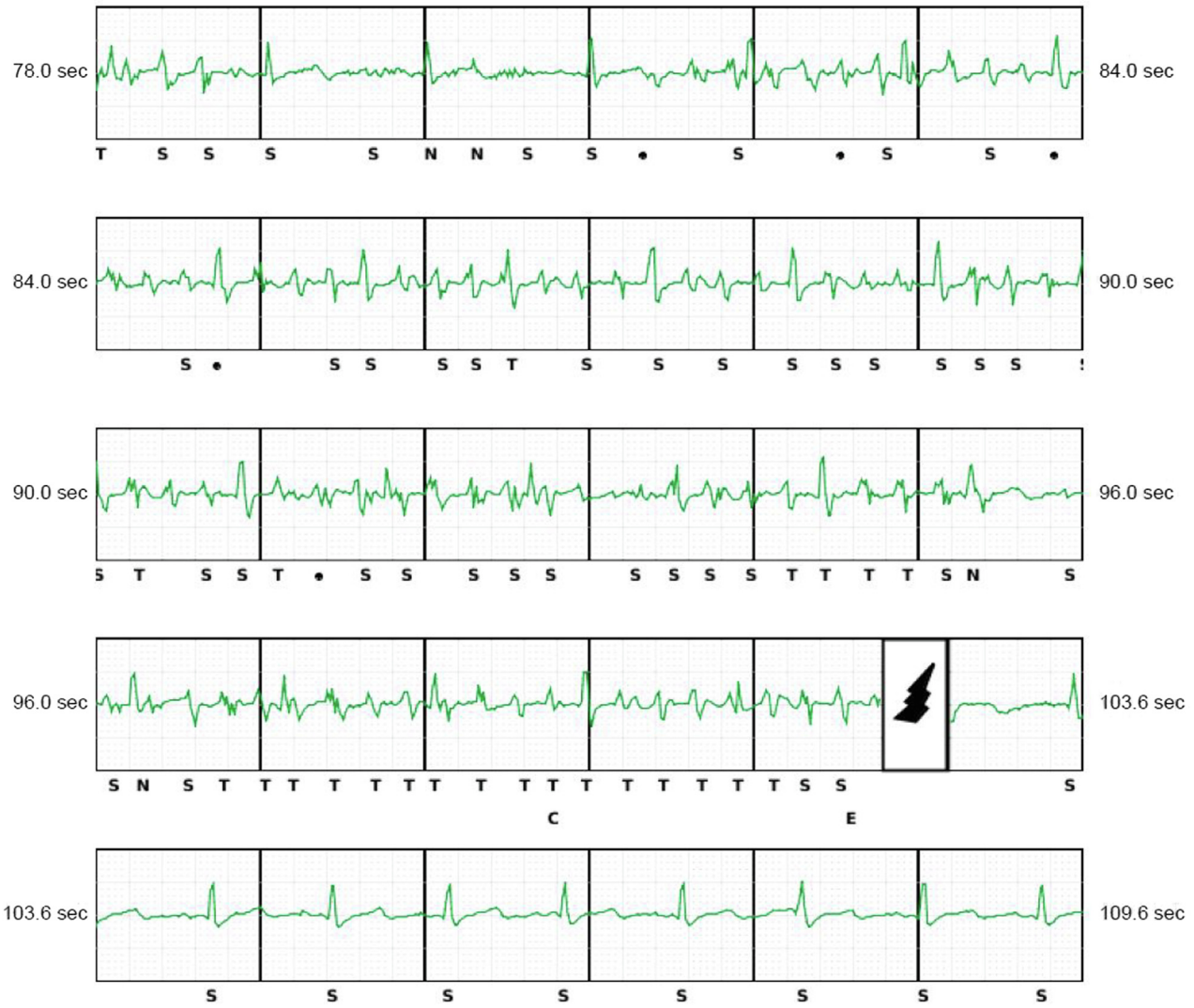

Figure 2 Electrograms demonstrating myopotentials leading to oversensing and inappropriate therapy from subcutaneous implantable cardioverter-defibrillator.

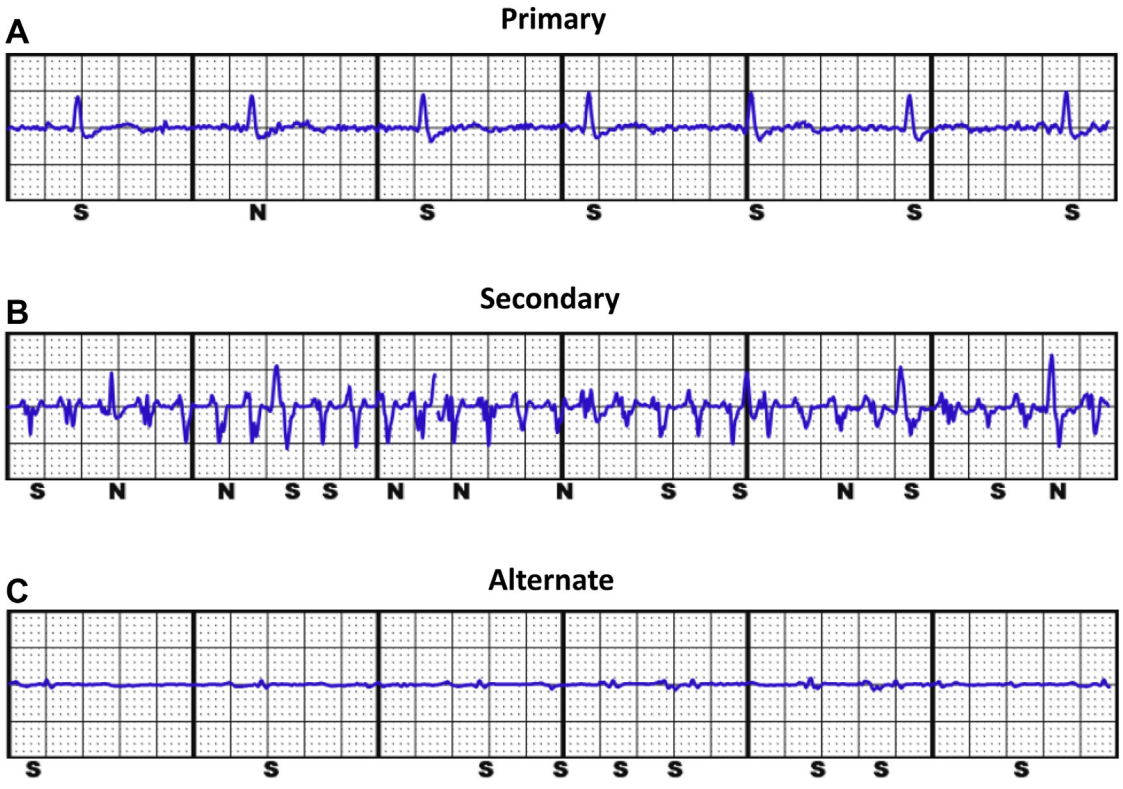

Figure 3 Electrograms recorded in clinic during shoulder movement from primary vector (**A**), secondary vector (**B**), and alternate vector (**C**).

The device was reprogrammed to sense via the primary vector. No further inappropriate shocks have occurred during follow-up.

Discussion

The S-ICD is an alternative to transvenous ICDs. Despite their demonstrated effectiveness in the treatment and prevention of arrhythmic death, conventional transvenous ICD systems are associated with considerable morbidity owing to endovascular lead failure. In response, the S-ICD has been specifically developed to address the risk of lead failure, a major limitation of transvenous ICDs. In contrast to the endovascular leads, the S-ICD lead lacks a central lumen, providing increased tensile strength. Moreover, extrathoracic placement of the S-ICD lead exposes the lead to less environmental stress. While these features have been associated with lower lead failure rates, extrathoracic lead placement has been associated with higher rates of inappropriate shocks (10% to 26%, or 2–5× the rate of traditional transvenous ICDs).[1–3] In contrast to traditional transvenous ICDs, which detect local intracardiac myopotentials, the S-ICD system detects changes in the ventricular rate using subsurface electrocardiography, rendering the system susceptible to arrhythmia misdiagnosis owing to errors in discrimination or oversensing.

Inappropriate ICD shocks can occur owing to lack of discrimination (eg, supraventricular or sinus tachycardia), oversensing of intrinsic cardiac activity (eg, oversensing of T waves and P waves), or oversensing of extrinsic physiologic (eg, myopotentials) and nonphysiologic noise (eg, electrical noise from the device header or lead, external interference). T-wave oversensing is the most common cause for inappropriate shocks in S-ICD recipients.[4]

Strategies to minimize inappropriate shocks with the S-ICD include the following: (1) rigorous preimplant electrocardiographic screening with optimization of vectors to achieve the best signal-to-noise ratio, which has significantly reduced the incidence of inappropriate shocks owing to T-wave oversensing at the expense of rendering ~10% of patients ineligible to receive an S-ICD[5]; (2) meticulous surgical technique including lead anchoring (eg, suture sleeve to prevent postimplant lead movement[6]) and complete expulsion of subcutaneous air[7]; (3) the use of high ventricular rate cut-offs (rates >220 beats per minute) to avoid therapies for sinus and supraventricular tachycardia[8]; (4) the use of dual-zone programming, with application of the S-ICD discrimination algorithm in the conditional zone; this algorithm, which includes 3 double-detection algorithms, and an analysis of beat-to-beat QRS width and QRS morphology changes, as compared to stored sinus rhythm template, has demonstrated a 98% specificity for appropriately withholding

therapy for SVT[9]; (5) the use of a morphology-based algorithm and a 9 Hz high-pass filter (SMART Pass), which has significantly reduced the incidence of inappropriate shocks owing to T-wave oversensing[10]; and (6) acquisition of a template during exercise stress testing to optimize sensing vector to minimize T-wave oversensing.[11]

These approaches have markedly decreased the S-ICD inappropriate shock rates, falling from 13.1% to 25% in the early IDE trials to 7% in the EFFORTLESS registry (dual-zone programming and high rate cut-offs) and 3.1%-4.8% in the PRAETORIAN trial (2020) and UNTOUCHED study (2021).[1,12,13] However, while the annual inappropriate shock rate has decreased, it is important to realize that the cumulative incidence of inappropriate therapies remains substantial, with nearly 1 in 10 patients in PRAETORIAN receiving an inappropriate shock by 48 months.[12]

In addition, while the screening and filtering algorithms (eg, SMART Pass) have dramatically reduced the incidence of inappropriate shocks owing to T-wave oversensing, myopotential interference is now the commonest cause of inappropriate ICD discharges with the S-ICD.[14] This is a clinically relevant concern, given S-ICD implantation is generally favored in young physically active patients, a group most at risk of myopotential interference. In most cases these repetitive low-amplitude high-frequency myopotentials result in undersensing of intrinsic QRS complexes (32% overall), although myopotential-induced oversensing continues to occur in a significant proportion of cases (8%).[15]

While nearly all S-ICD patients (93%) have clinically relevant myopotentials identified during physical exercise,[15] the presence of significant myopotential noise cannot be predicted by preoperative screening. As such, it has been suggested that provocative testing should be performed following S-ICD implant.[15] During a temporary period of therapy inhibition, trunk muscular contraction (abdominal crunch), isometric upper limb exercise (isometric chest press, side plank, and lateral arm raise), and strong forward movement against resistance can be used to determine the vectors affected by myopotential noise. These motions are chosen to engage the pectoral muscle, latissimus dorsi, serratus anterior, and abdominals, as these are the common source of myopotentials for S-ICD implants. Of note, prominent myopotential interference may be observed with different exercises and vectors (eg, primary vector is more susceptible with side plank, but secondary and alternate vector are more affected with isometric chest press).[15] In this case, the shoe-shining motion mimicked a chest-fly exercise with activation of the pectoral muscles. Prominent myopotential interference during this "stress test" enables preventive programming to avoid the affected vector(s). In extreme cases the lead and/or generator may need to be repositioned.

Despite the high incidence of myopotentials seen during provocative testing,[15] these lead to inappropriate shocks in only a small minority of patients. The SMART Pass algorithm significantly reduces the all-cause incidence of inappropriate shocks, including those due to myopotentials.[10] In a study of 1984 patients, the incidence of inappropriate shocks due to extracardiac oversensing was 0.5% in those patients with SMART Pass activated and 2.3% in those without SMART Pass.[10]

Right-sided lead positioning, as was present in this case, has previously been associated with a higher incidence of inappropriate shocks in some[14] but not all studies.[15] The mechanisms underlying this remain uncertain. Given the induction of myopotential with isometric chest press, we programmed him in the primary vector, which had less noise on provocative testing. It might be supposed that remote monitoring may offer the opportunity to identify short-lived myopotentials prior to delivery of an inappropriate shock. However, in this case, a shock occurred without preceding evidence of myopotentials.

Conclusion

Clinicians who implant and follow up S-ICDs should be aware of strategies to minimize the risk of inappropriate shocks. A thorough history should be taken regarding the circumstances surrounding an ICD discharge to detect unusual and avoidable causes.

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