Ventricular tachycardia detection with the subcutaneous implantable cardioverter-defibrillator: Tracing the cause of an absent tracing

Fadi Mansour, MD,* Paul Khairy, MD, PhD†

From the *Electrophysiology Service, Centre Hospitalier de l’Université de Montréal (CHUM), Montreal, Canada, and †Electrophysiology Service, Montreal Heart Institute, Université de Montréal, Montreal, Canada.

Introduction

Management of patients with pacemakers and implantable cardioverter-defibrillators (ICDs) relies in part on the diagnostic features of these sophisticated devices.1 In ICD recipients, appropriately identifying arrhythmias is critical considering that misclassification errors can have dire consequences. Inappropriate shocks from transvenous ICDs adversely impact quality of life and patient well-being, and have been linked to increased mortality.2 Withholding therapies for a misclassified ventricular tachycardia (VT) can lead to hemodynamic collapse before it degenerates into ventricular fibrillation (VF). An analysis of misclassified rhythms is essential in identifying underlying reasons and informing tailored ICD programming to minimize future errors. Effective troubleshooting, therefore, requires the ICD to record and store arrhythmic events. Herein, we present the case of a VT that was not detected or recorded by a subcutaneous ICD (S-ICD).

Case report

A 52-year-old man presented with a first episode of hemodynamically stable monomorphic VT at 230 beats per minute (bpm) 9 years after an anterior myocardial infarction (Figure 1A). Direct current cardioversion was performed after an ineffective trial of intravenous amiodarone. The electrocardiogram in normal sinus rhythm revealed Q waves from V1 to V4 (Figure 1B). On echocardiography, a left ventricular ejection fraction of 50% was noted along with an apical aneurysm containing organized thrombus. Coronary angiography was unremarkable, with a patent old stent in the left anterior descending artery and no new lesion. The referring cardiologist and patient expressed a clear preference for a secondary-prevention S-ICD despite the lack of antitachycardia pacing, reasoning that it was the first episode of VT after nearly a decade of follow-up post myocardial infarction. An Emblem MRI S-ICD (Boston Scientific, Marlborough, MA) was implanted with the secondary vector automatically selected. The recorded signal was 1.0 to 1.5 mV, with an excellent R-to-T ratio. Few dropped beats were observed upon induction of VF, with sinus rhythm successfully restored by an 80 J shock. The S-ICD was programmed with a conditional zone at 210 bpm and VF zone at 250 bpm. Concomitant antiarrhythmic therapy with sotalol was initiated.

After the patient returned to the referring hospital, monomorphic VT at 230 bpm recurred. He was mildly symptomatic and received no shock from the S-ICD. External electrical cardioversion was performed 1 hour after a failed attempt at conversion with intravenous amiodarone. Upon retransfer to our institution, a chest radiograph showed the position of the device and lead to be unchanged. Interrogation of the S-ICD revealed a good-quality secondary vector with appropriate sensing. However, no arrhythmic event was logged. Why did the S-ICD fail to recognize and record a rapid monomorphic VT lasting greater than an hour?

Discussion

In brainstorming potential reasons as to why the S-ICD failed to identify and document a prolonged episode of rapid monomorphic VT, the differential diagnosis includes the following 2 broad categories: under-sensing of VT and classification errors by discriminators.

In considering under-sensing of VT, it is important to understand Boston Scientific’s S-ICD binning algorithm. A tachycardia state is declared when the average of the last 4 intervals is greater than or equal to the lowest programmed zone (ie, the conditional zone). The criterion to exit the tachycardia state consists of detecting 24 consecutive beats at least 40 ms slower than the programmed conditional zone (ie, programmed zone + 40 ms). The
objective of this hysteresis function is to avoid exiting the tachycardia state for a VT that straddles the lower limit of the programmed interval or in the event of occasional under-sensing. In the case presented, the VT at 230 bpm was well organized, lasted over an hour, and was not near the lower limit of the conditional programmed zone (ie, programmed to 210 bpm, which corresponds to 184 bpm with hysteresis). These observations, combined with excellent detection of finer VF during induction testing, render the scenario of VT under-sensing unlikely.

Troubleshooting of classification errors by ICDs requires an appreciation of their discrimination algorithms. The patient’s VT fell squarely within the programmed conditional zone and was, therefore, likely to have been subjected to discriminators. The S-ICD’s discriminators are based solely on rate and morphology. As shown in Figure 2, the 3-step discrimination process begins with a static morphology algorithm that compares the sinus template to the tachycardia template. If the static match is poor, as would be expected in the case presented, the next step is to apply the dynamic morphology algorithm to compare consecutive beat-to-beat morphologies. A poor dynamic morphology algorithm match triggers a shock on the basis of suspected polymorphic VT. Monomorphic VTs are not expected to meet this polymorphism criterion and rely on the third step to elicit a shock: QRS width. To qualify as a wide QRS tachycardia, a proprietary algorithm compares the average QRS duration perceived by the S-ICD during the tachycardia to a QRS width threshold established using the stored sinus rhythm template. Although the patient’s QRS complex was clearly wider in VT than in sinus rhythm, marked lead-to-lead variability renders it conceivable that the arrhythmia failed to consistently meet the QRS width criterion. For this reason, the device may have classified the rhythm as supraventricular tachycardia (SVT).

Figure 1 Twelve-lead electrocardiogram (ECG) in tachycardia (A) and in sinus rhythm (B). Shown are 12-lead ECGs and corresponding rhythm strips (V1, II, and V5): A: in the presenting tachycardia and B: in normal sinus rhythm following electrical cardioversion.

It is important to note that Boston Scientific’s S-ICDs do not report or show events classified as SVT. As such, in assessing symptomatic patients with S-ICDs, the possibility that an episode of VT was misclassified as VT cannot be ruled out by device interrogation. In the case presented, a second induction test was performed to explore potential reasons for the missed diagnosis of VT. This time, self-terminating monomorphic VT was induced (Figure 3). The induction test was repeated and VF was successfully treated. Both VT and VF were appropriately sensed by the S-ICD. The tracing of the induced VT was sent to Boston Scientific’s technical services for review. It was confirmed that the QRS duration in VT was just shy of being classified as wide. The S-ICD was reprogrammed to remove the conditional zone, considering that discriminators are only programmable as “on” or “off” features, with no possibility for fine-tuning. A single shock zone was set and lowered to 190 bpm in anticipation of amiodarone therapy. The patient subsequently had recurrent VT while on sotalol, prompting a change to amiodarone, and received appropriate and successful S-ICD shocks. Upon echocardiographic confirmation that the apical thrombus had resolved on warfarin, VT ablation was performed.
In addition to highlighting the importance of understanding ICD binning and discrimination algorithms in troubleshooting misclassification errors, to our knowledge, this is the first report to implicate the S-ICD’s QRS width criterion in a missed diagnosis of VT. Moreover, this case calls attention to the need to rectify a limitation unique to the S-ICD: the lack of recordings for arrhythmias classified as SVT. Reviewing and analyzing tracings is essential to taking appropriate action.

Despite these limitations, it should be noted that the S-ICD’s discrimination algorithm has improved considerably over the years. In contrast to transvenous ICDs, the main cause of inappropriate shocks with the S-ICD is cardiac and noncardiac over-sensing. The high-pass Smart filter has resulted in a reduction in the rate of inappropriate shocks owing to cardiac over-sensing from 8% to 2%. Dual-zone programming with the morphology-based algorithm has relegated SVTs to a minority of inappropriate shocks. Although there are no data specific to patients with secondary-prevention S-ICDs, the total rate of inappropriate shocks with primary-prevention indications is now around 4%/year (ie, from over-sensing and SVTs). This compares favorably to transvenous systems (eg, 4% in patients under the age of 65 years in the Multicenter Automatic Defibrillator Implantation Trial—Reduce Inappropriate Therapy [MADIT-RIT] and 3.6% in the Primary Prevention Parameters Evaluation Study [PREPARE]). Setting a high cut-off rate for VT detection, dual-zone programming, and the Smart pass filter do not appear to adversely impact time to therapy or proportion of appropriate shocks with the S-ICD. However, without recorded tracings of arrhythmias classified as SVT, it is impossible to gauge the magnitude of the problem of VTs misclassified as SVTs.

In conclusion, knowledge of the limitations of ICD algorithms is critical in addressing under-sensing and misclassification errors that cannot be directly resolved by device interrogation. The presented case highlights limitations of the S-ICD’s QRS width criterion in distinguishing monomorphic VT from SVT. It also underscores the consequences of devices not logging the fastest/longest SVT episodes for review, a drawback that merits rectification in future updates.

Figure 2  Algorithm for classifying arrhythmias within the subcutaneous implantable cardioverter-defibrillator’s conditional zone. Detections are marked as “S” (sensed) or “T” (treatable), depending on the results of static and dynamic correlation waveform analyses. Rhythm examples of each case are provided on the right side of the figure. When the heart rate is in the conditional zone, a static waveform analysis score is calculated. If the result is a match, the underlying rhythm is classified as supraventricular tachycardia. If the match is poor, the dynamic waveform is evaluated. A poor match is considered indicative of polymorphic ventricular tachycardia and is designated treatable. If there is little beat-to-beat variability, the rhythm is considered monomorphic. A last decision calculates the width of the QRS complex in tachycardia and compares it to the width of the static template. If it is considerably wider, the rhythm is classified as ventricular. Otherwise, it is considered supraventricular in nature. NSR = normal sinus rhythm. Adapted with permission from Brisben A. J Electrocardiol 2018;51:S38–S43.
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Figure 3  Self-terminating monomorphic ventricular tachycardia (VT) on induction testing. Shown are electrogram tracings recorded by the subcutaneous implantable cardioverter-defibrillator during induction testing. Charge start is indicated by the letter C. Following a 4-second direct current burst, monomorphic VT is induced with some initial beat-to-beat variability that then stabilizes at a rate of approximately 230 bpm. Although the QRS complex is wider in VT than in sinus rhythm, tachycardia beats are designated “S” (sensed) as opposed to “T” (treatable). The VT subsequently terminated spontaneously.