An unusual ICD shock: What is the mechanism?

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Introduction
Tachyarrhythmia detection and therapy in implantable cardioverter-defibrillators (ICDs) are governed by specific algorithms for ventricular sensing, initial detection, atrial arrhythmia discrimination, redetection, and reconfirmation, and these are manufacturer-specific. We report a case of an unusual ICD shock in a Boston Scientific dual-chamber ICD and discuss the mechanism.

Case report
A 48-year-old man with nonischemic dilated cardiomyopathy, left ventricular ejection fraction ≤35% status post dual-chamber ICD (Boston Scientific Energen, model EI412) since September 2012, history of ventricular tachycardia with antitachycardia pacing (ATP) therapy, paroxysmal atrial fibrillation, and atrial tachycardia on beta-blocker therapy was seen in clinic following an ICD shock. The patient complained of palpitations but denied syncope or presyncope. Physical examination was without any abnormal cardiac findings and a 12-lead electrocardiogram showed atrial-paced rhythm at 60 beats per minute (bpm), normal intervals, and nonspecific inferolateral ST-T abnormalities. Device interrogation showed normally functioning atrial and ventricular leads with the following programmed parameters: Brady programming: DDD 60-115 with paced and sensed atrioventricular (AV) delay of 300 msec; Tachy programming: Three zones—VF zone (200 bpm [300 msec]) with ATP during charging, VT zone (170 bpm [353 msec]) with atrial arrhythmia discrimination [Rhythm ID]), and a VT-1 monitor-only zone with detection rate of 140 bpm [428 msec].

ICD tracings showing the arrhythmia episode that resulted in the 31 joule shock are shown in Figures 1–3 as a continuous strip. Why did this patient get shocked?

Review of Figure 1 shows a long RP tachycardia with variable cycle length (range 405–480 msec) and 1:1 AV relationship. During cycle length variability (“wobble”), A-A appears to predict V-V, suggesting a supraventricular mechanism, with a focal atrial tachycardia (AT) being the likely cause. Initial detection of this tachycardia was met in the monitor-only zone (marker channel showing VT-1). Boston Scientific ICDs require 3 consecutive “fast” beats with cycle lengths within a specified detection window (such as a VF or VT-1 zone) to initiate tachyarrhythmia detection. The detection window is satisfied and an episode is declared when 8 of 10 fast beats are counted and the device starts a duration timer, which is programmable. However, if the 8 of 10 fast intervals threshold is not met, the detection window remains open and detection can continue as long as 6 of 10 beats continue to be classified as fast. Figure 1A shows an isolated end-of-episode PVP (postventricular atrial refractory period after premature ventricular contractions) marker at VS 440 msec (black arrow). This indicates that the tachycardia no longer meets the 6 of 10 beats criteria required for continued detection in the VT-1 monitor zone and that the episode has ended. Therefore, a nonprogrammable 10-second end-of-episode timer is started.

Figure 1B, however, shows burst ATP therapy. How did this happen?

During the above-mentioned nonprogrammable 10-second timer, the initial AT appears to transition to a faster, short RP tachycardia, now with a cycle length of 275–308 msec and still maintaining 1:1 AV relationship, and gets redetected in the VT-1 zone (8/10 beats). This detection is met at the interval marked as VF 293 msec (red arrow). Simultaneously, detection is ongoing in the VT zone (8/10 beats) as well as in the VF zone (8/10 beats). VT zone detection is met at the interval marked VF 278 msec. At the next beat (interval marked VF 300 msec), the VF detection window is met (red asterisk), and therefore duration periods are started for all 3 zones. The duration period is a timer that denotes the amount of time in each zone that the tachyarrhythmia has to be sustained before therapy is delivered. If
more than 1 duration timer is running simultaneously, the highest zone is in control, and no therapy decision will be made until the highest-zone duration timer expires. Since the VF zone is in control, the duration of detection in this zone is 1 second and requires 6 of 10 VF beats plus the last-in-zone (LIZ) beat to be in the VF zone to declare end of duration and therapy delivery. Although this is still a 1:1 tachycardia, Rhythm ID is not active in the VF zone. Still on Figure 1, at the interval marked VT 308 msec (notched black arrow), VF duration is met (V-Dur), but the LIZ beat is in the VT zone by cycle length. Since LIZ is not met, the duration is extended by 1 more beat. So at VF 293 msec (black asterisk), there are 6 of 10 fast beats in the VF zone (actually 8/10 beats because there are 2 VT beats). The quick convert (QC) (ATP during charging) cycle length cutoff is $4^{240}$ msec. Averaging the cycle lengths of the 4 beats leading up to the V-Detect marker (indicating that VF zone detection criteria have been met) yields a mean cycle length of $298.5 \text{ msec}/201 \text{ bpm} = (293 + 308 + 285 + 308 \text{ msec}/4)$. So QC is initiated at 88% of tachycardia cycle length (260 msec) for 8 pulses.

Apparent resolution of the rapid 1:1 tachycardia is noted following QC (Figure 2A). However, the device continues to

**Figure 1**  
A: Upper panel shows a long RP supraventricular tachycardia (SVT) with 1:1 atrioventricular (AV) relationship (likely atrial tachycardia) with cycle length ranging from 405 to 480 msec that was detected in the VT-1 monitor zone (rate cutoff: 140 bpm). Black arrow shows PVP (postventricular atrial refractory period after premature ventricular contractions) marker indicating end of episode, as 6 of 10 beats required for continued detection is not satisfied. B: The initial SVT now transitions into a faster, short RP SVT, still with 1:1 AV relationship and cycle length from 275 to 308 msec. Red arrow shows detection of this SVT in the VT-1 zone and red asterisk indicates detection in the VF zone. Notched black arrow denotes expiration of VF duration timer. Black asterisk indicates that VF zone duration is met and device then delivers ATP at 260 msec cycle length. The red 4-pointed star following ATP denotes that this beat is ignored for reconfirmation purposes.
charge and delivers a 31 joule shock (Figure 2B) despite detection in the VT-1 monitor zone. Why did this happen?

QC results in conversion of the faster supraventricular tachycardia (SVT) back to the initial AT with cycle length of \(\sim 420\) msec (Figure 2). In the Boston Scientific reconfirmation algorithm, following QC, the ICD looks to see if 2 out of 3 beats are fast or 2 out of 3 beats are slow. In this algorithm, “fast” denotes any rate/cycle length faster than that of ventricular sense (VS) or ventricular pace (VP). Thus, a cycle length that falls within any programmed tachy zone, irrespective of whether there is therapy in that zone, is considered fast. This reconfirmation algorithm applies following QC as well as following charge completion in all zones with programmed shocks. Thus, continued detection was met in the VT-1 monitor zone (2/3 beats faster than VS or VP). This is illustrated in Figures 1 and 2. In Figure 1, a “-” marker following the ATP (red 4-point star) indicates that this beat is ignored. The next 3 beats following this are VS 450 msec, VT-1 418 msec, and VT-1 425 msec. Since 2 of 3 are fast (compared to VS or VP), the device starts charging. Although this is a 1:1 tachycardia in the VT-1 monitor zone, Rhythm ID is not active during reconfirmation.

During charge, the device looks for 4 consecutive beats slower than the lowest tachy zone cutoff (again, only VS and VP events are considered slow). However, there are a total of 3 VS beats but never in a row (Figure 2). The first VS at 478 msec is followed by 6 VT-1 beats, the next VS at 455 msec is followed by 4 VT-1 beats, and the last VS is at 440 msec. Charging is complete and is noted with a “--” sign (notched black arrow, Figure 2A). Following this, 2 VT-1 events at 375 and 378 msec are noted, denoting that 2 out of 3 beats are fast again, and so the device delivers the programmed 31 joule shock (red circle, Figure 2B).

The delivered shock appears to interrupt the AT briefly, but it soon reinitiates. Marker channels in Figure 2B and
Figure 3 show that there is continued detection in the VT-1 monitor zone, but the patient does not receive another shock. How would you explain this?

Following the shock (Figure 2B), tachyarrhythmia redetection employs the same detection window process (8/10 beats) and programmed zone rate thresholds as the initial detection. The primary differences between initial detection and postshock redetection are the duration timer and detection enhancements that are available. For example, the morphology aspect of Rhythm ID, termed vector correlation and timing, will not be available following a shock. The AT reinitiates and continues to get detected (8/10 fast beats) in the VT-1 monitor zone. The redetect duration timer starts and VT-1 duration is met as indicated by the V-Dur notation (Figure 3, red asterisk). However, an episode is not declared, as there is no therapy in this zone, but detection is continued. The AT then slows slightly and eventually drops out of detection in the VT-1 zone, as only 5 of 10 fast beats does not meet the criteria (6/10 is required for continued detection). A PVP marker (red arrow) is seen in Figure 3 and denotes the end of this episode, the total duration of which was 1 minute and 30 seconds.

Conclusion

This case thus represents a scenario where a programmed monitor zone in a Boston Scientific dual-chamber ICD resulted in an inappropriate shock. To the best of our knowledge, this is the first report of such an incident in a Boston Scientific ICD. Further shocks were avoided, as redetection criteria were not met in a therapy zone owing to slowing of the culprit SVT. The “weak link” in this case, depending on interpretation, is the post-QC reconfirmation algorithm, which requires only 2 of 3 beats to be “fast” (ie, faster than VS or VP) for the device to declare that the episode is continuing. In our case, although QC converted the SVT to a slower one, it still was considered fast because of the 2 out of 3 beats detected in the VT-1 monitor zone. Rhythm ID is not employed in these situations. So the device charges for the next therapy, which is a 31 joule shock. Following completion of charging, the criterion for reconfirmation is still 2 of 3 fast beats in any zone (including the monitor zone), which unfortunately is still the case here, and so the device delivers the shock, which is inappropriate for the patient but appropriate device function per the detection and therapy algorithm. However, the logic behind the 2 of 3 fast beats criteria following QC or reconfirmation following charging for a shock is to avoid undersensing of VF/fast VT in a zone. Thus this algorithm decision is conservative by design to avoid VF undersensing. The downside, as seen in this case, is that SVTs can be treated inappropriately. The behavior of the device is consistent with the programmed algorithm and therefore represents normal device function, albeit resulting in an undesirable outcome.

Programming changes to help mitigate this scenario would be: 1) discontinue the monitor zone; 2) increase duration timers in all zones, thereby lessening the chance of sustaining 6 of 10 detection and allowing Rhythm ID to classify the tachycardia as SVT in the VT and VT-1 zone during the duration timer; and 3) increase the rate detection for VF zone (for example, from 200 bpm to 220 bpm/above the fastest SVT rate) to reduce the chance of SVT being detected in the VF zone. In our case, the monitor zone was discontinued and the patient was started on sotalol for secondary prophylaxis of both atrial and ventricular arrhythmias. He subsequently underwent electrophysiology study and successful catheter ablation of a focal right atrial tachycardia arising from the crista terminalis. No further
Arrhythmias or ICD therapies were noted during a 9-month follow-up. Boston Scientific intends to provide a software update in its new ICD devices to avoid this issue.

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Reference
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