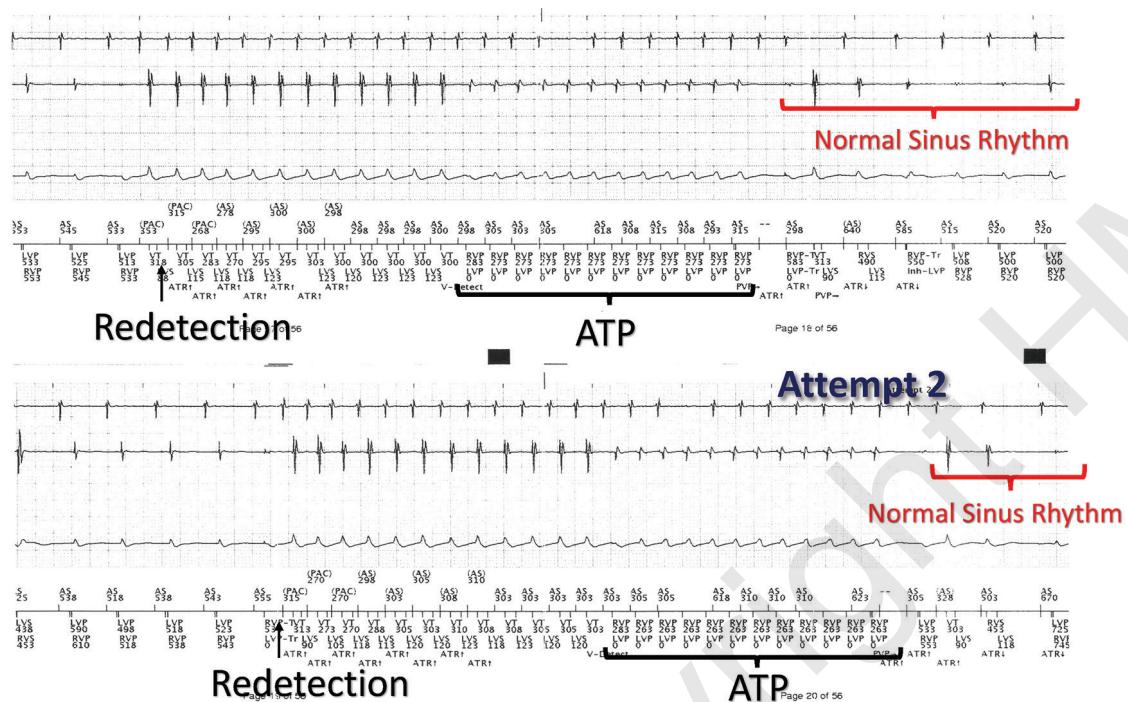
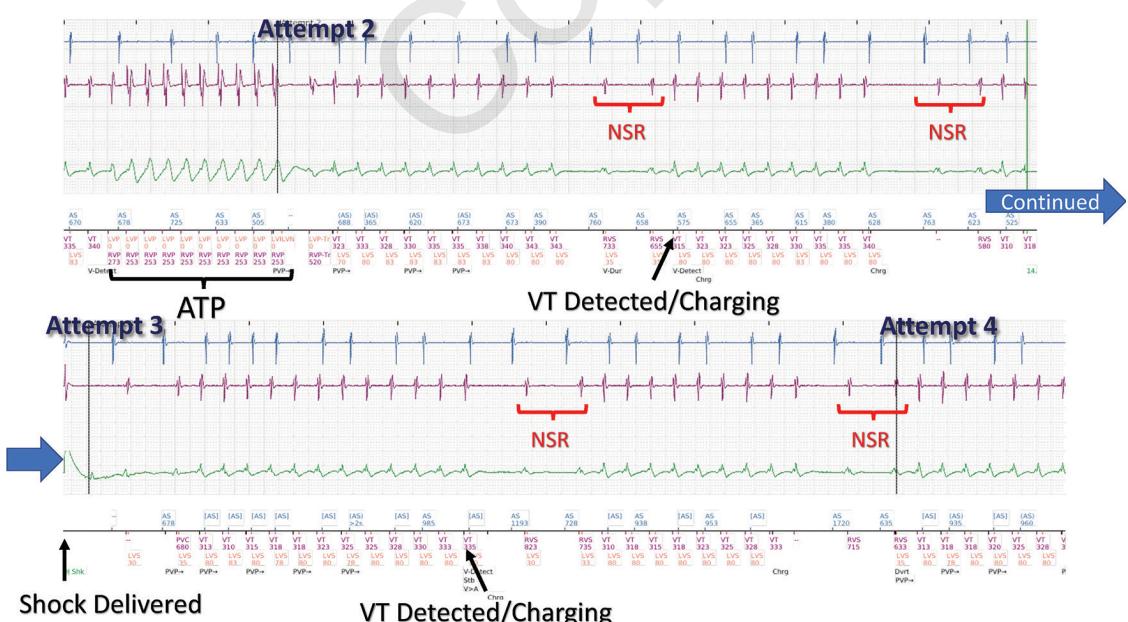


# Review: A Comparison of How ICDs Determine the End of an Arrhythmia Episode

Craig Raphael, MD, and Daniel R. Frisch, MD, FACC



**Figure 1.** VT redetection in a Boston Scientific ICD despite brief, non-sustained returns to normal sinus rhythm.



**Figure 2.** Redetection and defibrillation therapy delivered on a Boston Scientific ICD. The therapy for VT is advanced to the next in the programmed cascade despite brief intervals of NSR in between.

Much attention is focused on implantable cardioverter-defibrillator (ICD) detection of ventricular arrhythmias. Investigations have focused on optimal programming and discrimination of ventricular tachycardia (VT) from supraventricular tachycardia (SVT).<sup>1,2</sup> Less focus has been placed on the conclusion of arrhythmia episodes, especially after therapy has been delivered. Here, we present several cases of patients who received therapy (appropriate or otherwise) and who continued to receive additional therapies for arrhythmias that had apparently stopped and restarted. This report is intended to clarify how devices determine the end of an episode such that the reader can better understand why a second-tier therapy for a first event is delivered, rather than a first-tier therapy for a second event.

## Case #1

A 68-year-old woman with a Boston Scientific biventricular defibrillator (implanted 9 months prior for dilated cardiomyopathy and left bundle branch block), now with improved systolic function and Class I congestive heart failure (CHF) symptoms, presented to the hospital for multiple shocks. On the day of presentation, the patient described a prolonged episode of palpitations and dizziness that ultimately led to 6 consecutive shocks from her defibrillator and resolution of her symptoms. Interrogation of her device showed approximately 30 episodes of sustained and non-sustained SVT ranging from 6 to 45 seconds. However, the final episode of tachycardia lasted approximately 6 minutes and was treated with 3 rounds of ATP and a total of 6 shocks. During attempt #1, the ICD identified a rapid ventricular rate and delivered 3 bursts of ATP with a brief return to normal sinus rhythm (NSR) after each attempt before the arrhythmia reoccurred. (Figure 1). During attempt #2, the tachycardia was again identified and the device delivered a 41J shock despite a brief spontaneous conversion to NSR during charging. Further non-sustained episodes of tachycardia were identified but continued to be treated as an ongoing episode (attempts #3-5) with defibrillation despite previous successful treatments with ATP. Why did the device deliver progressive therapies despite the apparent non-sustained nature of the arrhythmia?

## Case #2

A 74-year-old man with ischemic cardiomyopathy and a primary prevention Boston Scientific ICD presented to the hospital after ICD shocks in the setting of cardiac ischemia. His device interrogation revealed an episode of ventricular tachycardia falling within the programmed VT zone. The arrhythmia was first treated with 3 bursts of ATP that were unsuccessful, and then 2 shocks at 41J were delivered, terminating the episode (Figure 2). Upon review of the intracardiac tracings, it appears the episode of VT was in fact multiple runs

of non-sustained VT separated by brief intervals of sinus rhythm. However, because the arrhythmia was treated as a single episode, therapy was escalated to defibrillation instead of repeated attempts of ATP. Why were these non-sustained episodes treated as one continuous episode?

#### Case #3

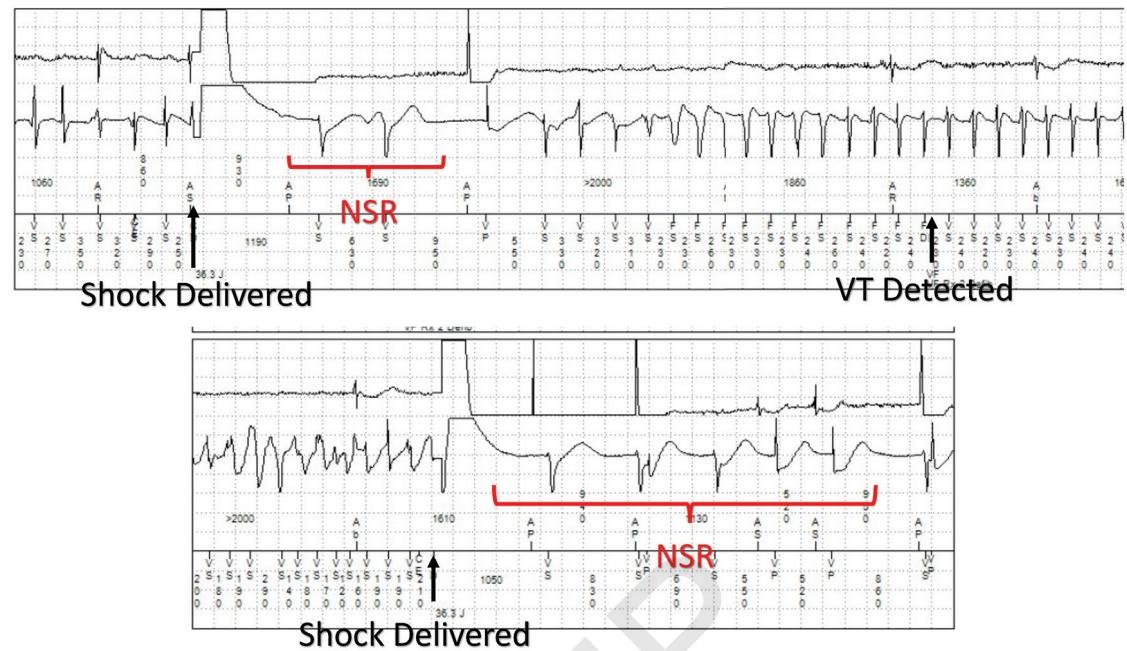
A 65-year-old man with ischemic cardiomyopathy (LVEF 16%), prior coronary artery bypass surgery, and ventricular tachycardia managed with sotalol and a Medtronic ICD, was admitted to the hospital for COVID-19 infection and acute kidney injury. Upon arrival to the hospital, he had episodes of torsade de pointes (TDP) treated by his ICD. Review of the electrograms from his ICD revealed a first occurrence of TDP treated by a failed attempt of ATP and ultimately a shock that restored sinus rhythm (Figure 3). TDP quickly reoccurred, and the ICD delivered another shock for the second episode, which also restored sinus rhythm. The second shock was the third attempt of therapies for what was considered by the ICD as a single arrhythmia episode. Why was a second shock delivered for the first episode instead of 2 first shocks delivered for 2 distinct episodes?

#### Case #4

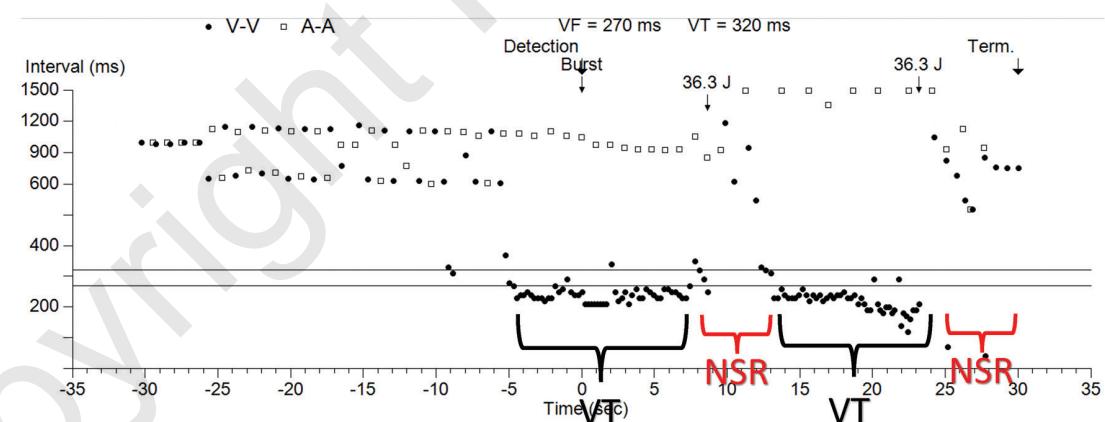
An 81-year-old man with a St. Jude Medical dual-chamber ICD (originally implanted for primary prevention in nonischemic cardiomyopathy) was found on remote interrogation to have received defibrillator therapy from his device. It was noted that the ICD appropriately detected an episode of ventricular fibrillation and the patient initially received a round of ATP while charging, but when the VF persisted, he subsequently received a 38J shock that successfully terminated the arrhythmia. Following the shock, the device correctly detected that the patient had returned to normal sinus rhythm, and further therapy is withheld (Figure 4). What criteria has been met for the ICD to determine that the episode of arrhythmia has ceased?

#### Discussion

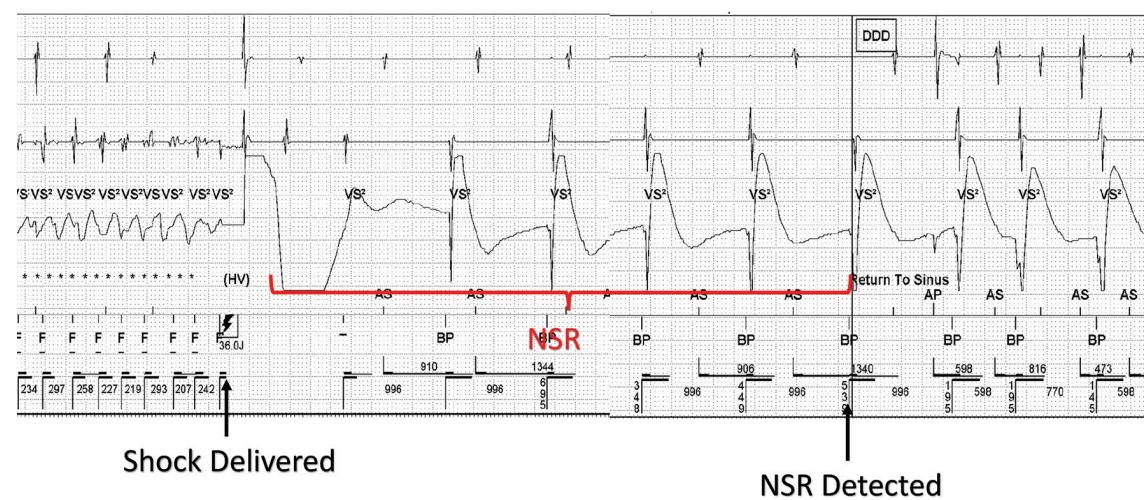
In the first three clinical vignettes, the patient had multiple runs of non-sustained or ATP-terminated tachycardia that appear to be unique and distinct episodes. However, the ICDs treated each of these arrhythmias as one sustained, continuous episode, and ultimately delivered a cascade of escalating therapy, leading to ICD shocks. In the fourth case, the patient received appropriate therapy for an episode of VF and the ICD successfully identified the end of the episode, withholding further treatment. These scenarios raise an important clinical question: what ICD parameters define the end of an arrhythmia episode? In other words, why did each patient receive more than one therapy for non-sustained or apparently treated arrhythmias rather than separate “first” therapies for each episode of tachycardia?



**Figure 3A.** Electrograms of therapy delivered on a Medtronic ICD. VT is redetected after a brief return to normal sinus rhythm and another shock is delivered.



**Figure 3B.** Plot of A-A/V-V intervals and therapies delivered.



**Figure 4.** Appropriate detection of NSR after ICD shock in a St. Jude Medical ICD.

**Table 1. Manufacturer-specific descriptions of the end of an arrhythmia episode.**

Manufacturer	Determinants of the end of an episode
<b>Boston Scientific</b>	<ul style="list-style-type: none"> <li>Non-treated (no therapy delivered): 10 seconds of NSR</li> <li>Treated (only ATP): 10 seconds of NSR</li> <li>Treated (any shock): 30 seconds of NSR</li> </ul>
<b>Medtronic</b>	<ul style="list-style-type: none"> <li>Treated (any shock): “8 to terminate” algorithm <i>-Requires 8 consecutive V-V intervals (starting with the 2nd interval) slower than the tachycardia detection interval (TDI)</i></li> <li><b>-OR-</b></li> <li>20-second time out <i>-Median of last 12 V-V intervals slower than TDI</i></li> </ul>
<b>St. Jude Medical/Abbott</b>	<ul style="list-style-type: none"> <li>Treated (ATP or shock): Binning of NSR, VT, and VF intervals <i>-The bin that fills first determines the new rhythm that is “detected”</i></li> </ul>

An ICD defines “redetection” as the process of determining a cardiac rhythm in the period immediately following therapy. This process is crucial in ICD function as it determines when to deliver necessary treatment for malignant arrhythmias, but also when to withhold therapy if normal rhythm returns. If therapy is incorrectly withheld in a patient with sustained tachyarrhythmia, the patient could suffer significant morbidity from their untreated malignant arrhythmia including syncope, heart failure, and even death. On the other hand, if an ICD is unable to identify when a treated episode has returned to sinus rhythm, the patient may receive additional unnecessary ther-

apy, which can be proarrhythmic or cause injury. Each device manufacturer has developed specific, unique algorithms to determine when an episode of arrhythmia ends or when to escalate therapy.

Medtronic devices use an “Eight-to-Terminate” algorithm, in which the device continuously scans for 8 consecutive V-V intervals that fall below the tachycardia detection interval (TDI) to deem an episode as completed. If a single V-V interval falls above the TDI, the counter is reset, and the episode is considered ongoing until termination criteria is met. Alternatively, if 20 seconds have elapsed, the median of the last 12 V-V intervals is compared to the TDI to determine if the episode is complete.

St. Jude Medical/Abbott ICDs similarly use a rate-dependent algorithm during the period of redetection. Fol-

owing the treatment of the initial arrhythmia, each subsequent V-V interval is sorted by rate into bins corresponding with either NSR, VT, or VF. The number of intervals needed to fill the NSR and VT bins can be programmed (3, 5, or 7 intervals for NSR and 6-20 intervals for VT), whereas the VF bin is fixed at 6 intervals. If the NSR bin is satisfied, the episode is determined to be complete. However, if the VT or VF bins are instead filled first, the arrhythmia is still ongoing and will receive the next programmed therapy in the cascade. In addition, a provider may optionally program a timer (10 seconds to 5 minutes from the start of the episode) that limits the amount

of time the device can deliver VT therapy for an ongoing episode before switching to VF therapy. Unlike Medtronic and Boston Scientific devices, St. Jude Medical/Abbott devices have some programmability to determine the end of an episode.

Regardless of the specific redetection criteria, these cases highlight the importance of understanding how implantable devices are programmed to recognize malignant arrhythmias not only during initiation, but also after termination, when criteria are met for cessation of therapy. ICDs employ strict redetection algorithms to ensure that episodes of VT that fail to respond to initial therapy are quickly recognized and further escalation of treatment is provided with minimal delay. While an episode of tachycardia may seem to have been terminated from a provider’s perspective, it is important for cardiac devices to err on the side of caution and promptly escalate therapy when it is not clear if an arrhythmia is ongoing, avoiding unnecessary morbidity/mortality from missed cardiac events. Though some programming options exist, declaring the end of episode is much less programmable than determining the start of one. ■

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For Boston Scientific devices, an ongoing episode of VT is triggered by 8/10 consecutive V-V intervals that lie within the programmed VT detection zone, similar to its initial VT detection algorithm. However, an important distinction for redetection is the use of an “End-of-Episode” timer, in which the device continues to scan for VT for a predetermined interval before it deems the episode to be “timed out”. If the preceding episode of VT received either no treatment or ATP therapy, the patient