ICD discrimination of SVT versus VT with 1:1 V-A conduction: A review of the literature

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A B S T R A C T
Inappropriate ICD shocks are associated with increased mortality. They also impair patients' quality of life, increase hospitalizations, and raise health-care costs. Nearly 80% of inappropriate ICD shocks are caused by supraventricular tachycardia. Here we report the case of a patient who received a single-lead dual-chamber sensing ICD for primary prevention of sudden cardiac death and experienced inappropriate ICD shocks. V-A time, electrogram morphology, and response to antitachycardia pacing suggested atrioventricular nodal reentry tachycardia, which was confirmed in an electrophysiology study. Inspired by this case, we performed a literature review to discuss mechanisms for discrimination of supraventricular tachycardia with 1:1 A-V relationship from ventricular tachycardia with 1:1 retrograde conduction.

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Introduction
Implantable cardioverter defibrillator (ICD) use has been shown to reduce mortality among patients with heart failure and left ventricular systolic dysfunction [1–6]. However, up to 13% of patients who receive an ICD can receive inappropriate shocks and as much as 31% of total shocks delivered by ICDs are considered inappropriate [7,8]. Nearly 80% of inappropriate ICD shocks are caused by supraventricular tachycardia (SVT), which includes atrial fibrillation (AF), atrial flutter,
A diagnosis of AVNRT was strongly suspected on the retrospective review of the tachycardia episode, based on the short V-A time, the unchanged ventricular morphology on intracardiac electrograms, and the response to ATP. The patient was, therefore, scheduled for an electrophysiology (EP) study and possible radiofrequency catheter ablation. Meanwhile, in order to avoid further inappropriate shocks while awaiting the EP study, the VF zone was increased to greater than 233 bpm. At the EP study, dual AV nodal physiology was in fact revealed. A narrow complex tachycardia was reproducibly induced with single atrial extra-stimuli (Fig. 4). The tachycardia had a 1:1 VA relationship, a negative V-A time, and concentric atrial activation. Entrainment maneuvers were consistent with typical AVNRT. Slow pathway modification was performed, following which tachycardia was no longer inducible. Post-ablation, the device settings were returned to the primary prevention settings standard for our practice. On follow-up device interrogations, there have been no further episodes of tachycardia. The patient is relieved, but states that the anxiety caused by this experience has not completely resolved.

**Discussion**

The aim of this analysis is to highlight potential difficulties in device discrimination of non-AF SVT from VT and to review what is known about existing options to prevent inappropriate treatment in such cases. The negative consequences of inappropriate shocks are several-fold. A single inappropriate shock results in increased mortality, with a hazard-ratio (HR) of 1.6. The risk further increases with each subsequent shock until up to a HR of 3.7 after 5 inappropriate shocks [7]. Significant behavioral disorders, psychological distress, and a negative impact on quality of life have also been described following ICD shocks [21-24]. Furthermore, inappropriate shocks are pro-arrhythmic and have the potential to cause malignant ventricular arrhythmias [25,26]. Finally, they also lead to more frequent clinic visits and hospitalizations, with a subsequent increase in healthcare costs [27,28].

An observational analysis of 426 patients reported that 13.6% of inappropriate ICD shocks were attributed to AVNRT; the incidence of AVNRT among ICD recipients was approximately 3.5% [29]. Current multi-society guidelines give a Class I indication to catheter ablation for the treatment of symptomatic AVNRT [30]. Catheter ablation targeting the slow pathway of the AV node has a success rate greater than 95%, with a risk of heart block requiring pacemaker implantation of only about 1% [31,32]. In other words, identifying ICD patients with AVNRT has the potential to reduce or eliminate inappropriate shocks, thereby improving patients’ quality of life and possibly even their survival.

The commercially available algorithms used to discriminate SVT from VT differ depending on whether dual- or single-chamber sensing is available. In single-chamber sensing, the most used criteria are electrogram morphology, interval stability, and suddenness of onset. Both AVNRT and VT with 1:1 VA conduction typically have a sudden onset and high interval stability. Therefore, in single-chamber sensing, electrogram morphology is the only criterion capable of
discriminating between VT and abrupt-onset regular SVTs, such as AVNRT. While this distinction can be easily made in the setting of “normal” conduction, it is not uncommon for AVNRT to be associated with rate-related bundle branch block, thereby removing the usefulness of electrogram morphology [10].

In dual-chamber sensing, additional criteria for SVT-VT distinction include comparison of atrial and ventricular rates,

Fig. 1 – A short VA interval (50 msec) is observed in the tachycardia which resulted in ICD shock. A: atrial electrogram; AV: marker channel; FF: far-field electrogram; V: ventricular electrogram.

Fig. 2 – Antitachycardia pacing with entrainment of the tachycardia, as evidenced by an atrial cycle length (CL) which is (1) shorter than the tachycardia CL and (2) exactly the same as the ventricular paced CL. In this case, ATP terminates the tachycardia after entrainment. This response does not differentiate AVNRT from VT with 1:1 retrograde conduction (see text for full explanation). A: atrial electrogram; AV: marker channel; F: far-field electrogram; V: ventricular electrogram.
AV association, and P:R pattern. [10] More than 90% of VTs are identified by a ventricular rate > atrial rate [10]. However, up to 20% of patients with VT demonstrate retrograde conduction and thus have the potential to develop VT with 1:1 retrograde conduction [33,34]. As in AVNRT, VT with 1:1 VA conduction presents with AV association and equal atrial and ventricular rates. Therefore, the distinction between AVNRT and VT with 1:1 VA conduction is highly dependent on timing relationships between atrial and ventricular electrograms, which is called P:R pattern analysis [10]. The V-A interval, measured from the onset of ventricular depolarization to the subsequent earliest demonstration of atrial activation, is used to characterize the P:R pattern [35]. Atrial and ventricular conduction occur almost concurrently in AVNRT; the V-A interval is therefore shorter than in VT [35]. Indeed, the V-A interval is typically longer than 80 msec in VT with retrograde conduction [36]. In the patient we present here, therefore, the V-A time of 50 msec is consistent with AVNRT.

While the use of V-A interval is obviously crucial in distinguishing between AVNRT and VT, it may not be sufficient for discrimination. Given the importance of atrial sensing in dual-chamber discriminators and the increased sensitivity required to detect low-amplitude atrial electrograms, there is a potential for oversensing of far-field R wave signals and subsequent overestimation of the atrial rate [10,37]. This phenomenon may lead to inappropriate rejection of VT as SVT or vice versa [10,38–40]. To prevent atrial oversensing of far-field R waves, some dual-chamber ICDs have a post-ventricular atrial blanking period, in which the atrial lead is unable to sense any events for up to 200 ms [10,41]. Undersensing of atrial events in the blanking period also has the potential to cause inappropriate shocks, because the ventricular rate can be mistakenly identified as greater than the atrial rate [10,14,41]. In fact, in the case here presented, atrial events were not recognized by the device, as they occurred within the postventricular blanking period. Thus, the ventricular rate was interpreted as greater than the atrial rate, and VT was (mistakenly) recognized.

Atrial undersensing (and misclassification of tachycardia as ventricular rate > atrial rate) is a major limitation of dual-
chamber ICDs, and may be accountable for the absence of benefit in avoiding inappropriate therapies when compared to single-chamber devices. In a randomized trial comparing single to dual-chamber ICDs, 75% of inappropriate therapies in the dual-chamber group were secondary to atrial sensing problems, mostly undersensing [15]. Manufacturers have developed different strategies to overcome the challenges of setting the post-ventricular atrial blanking period. In Biotronik SMART algorithm, the blanking period can be adjusted to a minimal value, in which case sensing of atrial events is not affected, thereby enabling accurate determination of the atrial rate and the V-A interval [42]. A similar option is available in St. Jude Medical and Boston Scientific devices [43]. The Medtronic PR Logic and ELA/Sorin algorithms maintain atrial sensing during the PVAB for the purpose of SVT-VT discrimination. When a 2:1 AV rhythm is identified, these algorithms analyze A-V and V-A intervals to reject far-field R waves and therefore prevent atrial oversensing [43].

Different manufacturers use the various discriminators in distinct sequences to establish an algorithm for VT/SVT discrimination. The DX Biotronik ICD system utilizes the SMART algorithm (Fig. 5), which includes heart rate, interval stability, A:V association, and P:R pattern analysis. Atrial and ventricular rates are analyzed first. If the ventricular rate is faster (Fig. 5, line 1), the rhythm is classified as VT. If the atrial rate is faster (Fig. 5, line 2), the rhythm is identified as SVT if either the RR is unstable (suggests variable AV conduction) or the A/V relationship shows an integral conduction ratio (e.g., 2:1, 3:1). If the ventricular and atrial rates are equal (Fig. 5, line 3), the system checks for stability and association. If the RR is stable but the PP is not, there is AV dissociation and VT is identified. If both RR and PP are stable, the rhythm is classified as VT if either the PR changes (AV dissociation) or if there is suddenness of onset. If the RR is unstable, a stable PR (AV association) indicates SVT, whereas an unstable PR (AV dissociation) indicates VT [44]. As shown in the bold sequence of Fig. 5, this algorithm cannot reliably differentiate AVNRT from VT with retrograde 1:1 conduction, given that both arrhythmias present with equal atrial and ventricular rates, stable RR and PP intervals (stability), no PR change (AV association), and sudden onset. In this particular sequence, the SMART system identifies VT. Therefore, the electrophysiologist should have increased awareness of the possibility of AVNRT and apply the concepts discussed here to successfully discriminate this potentially curable arrhythmia.

Unlike the SMART system, St. Jude Medical, Boston Scientific Rhythm ID, and Medtronic PR Logic algorithms utilize morphology assessments to discriminate SVT from VT [45]. In Medtronic devices that utilize PR Logic, SVT-VT discrimination can still occur in the VF zone. PR Logic uses three patterns of discriminators to identify SVTs (Table 2). Each of these rules is individually programmable and can be turned off. As in other dual-chamber sensing algorithms, a ventricular rate faster than the atrial rate identifies VT. If the rhythm cannot
be classified as VT based on rates, and none of the three SVT rules can be identified, PR Logic applies morphologic criteria for discrimination. This is done by checking for concordance between the unknown tachyarrhythmia and the baseline ventricular depolarization morphology \[45,47\].

In addition to the previously mentioned V-A interval, the response to ATP may also help in discriminating AVNRT from VT with retrograde 1:1 conduction. Overdrive pacing by ATP with a cycle length (CL) that is slightly shorter than the tachycardia CL can lead to one of three responses in AVNRT. Entrainment occurs when pacing is able to continuously reset the full tachycardia circuit with each paced beat. In entrainment, the atrial CL exactly matches the paced CL (Fig. 2). AV dissociation develops when ventricular capture occurs, but the nodal tachycardia circuit is maintained; in this case, the ventricular CL matches the paced rhythm, but the atrial CL remains unchanged from the original tachycardia. Finally, termination of AVNRT by ATP is also a possibility. Up to 20% of SVTs can be terminated by ATP \[48–50\]. Termination and entrainment also occur in VT; therefore, these responses to ATP cannot reliably discriminate AVNRT from VT with 1:1 VA conduction \[51,52\]. However, maintenance of the same ventricular CL in the atria after ATP ventricular capture (AV dissociation; Fig. 3) and after ATP is finished demonstrates that atrial depolarization during the tachycardia is independent of ventricular origin. Thus, this finding excludes the possibility of VT with 1:1 retrograde conduction and atrioventricular reentrant tachycardia using a usual atrioventricular accessory pathway. In VT with retrograde 1:1 conduction, when ATP ventricular capture occurs, the CL in the atria either (1) follows the CL of the ventricular paced rhythm (if entrainment occurs), or (2) returns to a sinus/atrial paced rhythm if the paced stimuli are unable to reach the atria. The CL in the atria cannot, however, remain the same as the tachycardia CL, given that atrial depolarization arises from a ventricular stimulus in VT with 1:1 VA conduction.

![Table 2 - PR Logic algorithm for tachyarrhythmia discrimination (Medtronic Inc.)](image)

| SVT rule | Device classification |
|----------|-----------------------|
| A:V = 1 AND near simultaneous activation of A & V | 1:1 VT |
| A:V = 1 AND gradual onset AND AV interval consistent with antegrade conduction | Sinus tachycardia |
| Atrial rate > Ventricular rate | Atrial fibrillation/atrial tachycardia |

Fig. 5 – SMART algorithm for tachycardia analysis used in the Biotronik DX single-lead ICD. In our patient, atrial activity occurred during the post-ventricular atrial blanking period. Thus, the device identified VR > AR (Line 1), and (mistakenly) called the rhythm VT. In case the device had correctly identified VR = AR, the bold sequence illustrates how the rhythm still would have been called VT. Notice this sequence is unable to discriminate AVNRT from VT with retrograde 1:1 conduction (see text for full explanation). Modified from: Lori et al. Implantable cardioverter defibrillator system with floating atrial sensing dipole: A single-center experience. Pacing Clin Electrophysiol. 2014;37:1265–1273. AR = atrial rate; A/V \( \neq \) N:1 = conduction ratio not integral; SVT = supraventricular tachycardia; VR = ventricular rate; VT = ventricular tachycardia.
potentially misclassify the rhythm as SVT [10]. Interestingly, up to 42% and 10% of ICD therapies for ventricular arrhythmias occur at rates > 188 bpm and > 250 bpm, respectively, and thus have the potential to fall under the VF zone [54]. Ricci et al. showed that 50% of AF-related inappropriate shocks occur at rates > 200 bpm [55]. The concern for VF zone inappropriate ICD therapy in SVT is particularly worrisome in younger patients with rapidly conducting AV nodes, where the heart rate can reach nearly 250 bpm [29,56]. The patient in our case had received 2 ICD shocks for SVT with rates in the VF zone.

Conclusion

Differentiating SVT from VT in patients with ICDs is important in the optimization of clinical outcomes, but this can be challenging in rhythms with a 1:1 VA relationship. Programming of the post-ventricular atrial blanking period can result in undersensing of atrial activity (long PVABP) or oversensing of far-field R waves as atrial activity (short PVABP), which can misclassify a 1:1 rhythm into ventricular rate > atrial rate, or vice-versa, respectively. Setting dual-chamber devices to a minimal blanking period can allow accurate sensing during the refractory period and precise determination of the V-A interval, which can be extremely useful in distinguishing AVNRT (short V-A interval) from VT with 1:1 retrograde conduction. The response to ATP may also assist in discriminating such arrhythmias. Particularly, the persistence of the atrial tachycardia CL in the atria concomitantly with ATP ventricular capture (AV dissociation) is highly suggestive of AVNRT. Catheter ablation is a class I indication for the treatment of symptomatic AVNRT. Inappropriate shocks due to AVNRT in patients with ICDs provide further support for this potentially curative treatment. In this scenario, the procedure has the added benefit of preventing further inappropriate shocks and their negative consequences.

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