# Improved Discrimination of VT from SVT in Dual-Chamber ICDs by Combined Analysis of Dual-Chamber Intervals and Ventricular Electrogram Morphology

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## Abstract

*The PR Logic dual-chamber detection algorithm discriminates VT/VF from SVT using hierarchical rules based on the pattern and timing of AA, VV, AV, and VA intervals. It cannot always discriminate rapidly-conducted atrial fibrillation(AF) from double tachycardia. Coexisting AF and VT/VF, or SVT with 1:1 antegrade conduction from VT with 1:1 retrograde conduction.*

*This study evaluated a new tachyarrhythmia detection algorithm that supplements analysis of dual-chamber intervals with analysis of ventricular electrogram morphology based on the Wavelet Dynamic Discrimination Algorithm.*

*Combined analysis of dual-chamber intervals and ventricular electrogram morphology reduced inappropriate detection of SVTs by 79% compared to dual chamber intervals alone without compromising sensitivity for detection of VT/VF.*

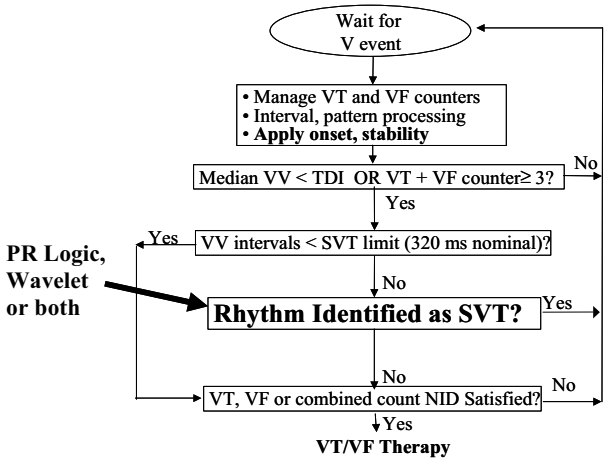


Figure 1: Flowchart for VT/VF detection in Medtronic ICDs

## 1. Introduction

### 1.1. PR logic

The PR Logic dual-chamber detection algorithm[1] has been used in all Medtronic dual-chamber ICDs since its introduction in the GEM DR, the first Medtronic ICD to utilize an atrial lead for dual-chamber pacing and tachyarrhythmia detection. PR Logic discriminates supraventricular tachyarrhythmia from ventricular tachyarrhythmia using hierarchical rules based on the pattern and timing of atrial and ventricular events. PR Logic uses three SVT rules that are programmable on or off. A programmable SVT limit criteria determines the fastest ventricular rate that the algorithm can classify as SVT.

Table 1: Classification rules of PR Logic

| Device Classification | Criteria Used |
|---|---|
| Double Tachycardia | • A:V > 1:1<br>• AV Dissociation<br>• Regular VV (VT zone)<br>• No FFRs |
| AF/AT | • A:V > 1:1 or reg. 2:1<br>• Irregular VV or Reg VV and AV assoc<br>• No FFR |
| Sinus Tachycardia | • Antegrade AV pattern<br>• Consistent FFR |
| Other 1:1 SVT | • Junctional AV Pattern |

Figure 1 depicts the general flow of detection in Medtronic ICDs. The flowchart shows not only an order for processing, but the hierarchy of detection decisions that results in withholding or delivering antitachycardia therapy. All detection processing occurs on ventricular events. When a ventricular event occurs, VT and VF counters and supplemental detection criteria are updated. If the rhythm is fast (median RR interval < VT detection interval or sum of the VT and VF counters ≥ 3), but not too fast (median RR interval ≥ SVT limit) then SVT rules are evaluated. If an SVT rule is satisfied, VT/VF

detection and therapy are withheld and the process continues. Otherwise, if rate-only detection criteria are satisfied, then VT/VF is detected and therapy delivered. Stability and onset criteria work by resetting the VT counter when satisfied so are shown at the top of the flowchart. SVT criteria for PR Logic are sinus tachycardia, AF/AFl and other 1:1 SVT that can be individually enabled. In addition, there is a higher priority double tachycardia criterion that causes VT/VF detection when rhythms with higher atrial than ventricular rate is caused by coexisting atrial and ventricular tachyarrhythmias.

The SVT rules of PR Logic are described in Table 1. The sinus tachycardia rule uses an AV pattern criterion to distinguish antegrade from retrograde AV pattern. Figure 2 shows how these patterns are determined. For 1:1

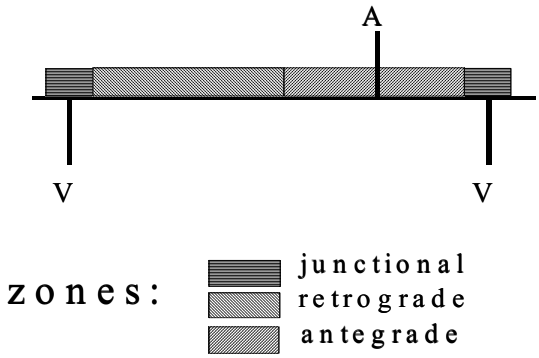


Figure 2: AV pattern analysis for PR Logic

rhythms, atrial events sensed in the antegrade zone are considered to originate in the atrium and conduct antegrade to the ventricle consistent with sinus tachycardia or atrial tachycardia. In the GEM DR, the antegrade zone starts at the midpoint between the ventricular sensed events and continues up to the junctional zone which extends from 80 ms prior to 50 ms after the ventricular event. In the GEM III and Marquis ICDs, the starting point of the antegrade zone is programmable. An atrial event sensed in the retrograde zone is considered to have originated in the ventricle and conducted retrograde to the atrium consistent with VT. PR Logic has been shown to be 100% sensitive to detecting VT/VF relative to rate-only detection[2], but cannot always discriminate rapidly conducted atrial fibrillation from double tachycardia (simultaneous ventricular tachyarrhythmia during SVT) or SVTs with 1:1 antegrade conduction from VT with 1:1 retrograde conduction. These ambiguous AV patterns are detected as VT/VF by PR Logic to err on the side of safety. During the GEM DR clinical trial, 457 of 1368 SVTs in 149 pts were detected as VT/VF. Of these 457 inappropriate detections, 205 were determined to have been caused by over- or under-sensing or ICD programming. The remaining 252 were determined to have been caused by detection algorithm characteristics. One hundred and seventy-four (46 pts) were 1:1 rhythms with long AV intervals detected as VT with 1:1 retrograde conduction. An example of this is shown in figure 3. Twenty-six episodes (7 pts) were AF with regular ventricular cycle lengths and AV dissociation that were inappropriately detected as double tachycardias. The remaining 52 episodes in 13 pts were less common SVTs of a pattern not recognized by PR Logic.

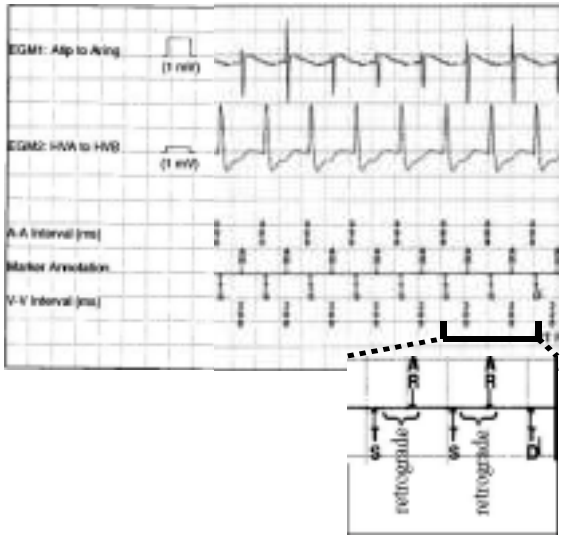


Figure 3: Sinus tachycardia with long AV detected as VT

## 1.2. Wavelet morphology

Ventricular electrogram morphology usually differs between SVT and VT due to different ventricular activation patterns inherent in the rhythms. Visual discrimination of rhythms by physicians usually includes morphologic analysis of ECG or electrogram. Until recently, the computational burden associated with morphologic analysis has exceeded the limited processing power available in ICDs. With advances in implantable processors, several morphology algorithms have been developed for ICDs. The Wavelet Dynamic Discrimination algorithm is currently undergoing clinical trials in the Medtronic Marquis VR. The Wavelet algorithm computes the concordance between an unknown tachyarrhythmia QRS and a baseline rhythm QRS. The electrogram source can be selected from RV coil-can, SVC coil-can, tip-RV coil and tip-ring. Electrograms are bandpass filtered 2.5-100 Hz. The Wavelet algorithm is programmable on, off or monitor and a match threshold that discriminates SVT and VT can be programmed between 40 and 97% (nominal 70%). QRSs are transformed into the wavelet domain using Haar wavelet basis functions. After normalization, the transformed QRS is compressed by zeroing small wavelet

coefficients. The match percentage is the ratio of the sum absolute difference of wavelet coefficients of the unknown and baseline QRSs divided by the sum of the absolute value of the baseline coefficients. Referring back to figure 1, an SVT rule based on this morphology discrimination will prevent inappropriate detection of VT/VF by the ICD. Details of the algorithm have been published[3]. The algorithm was evaluated clinically by downloading RAMware into implanted ICDs in 23 patients[4]. Using the nominal 70% match threshold, all 38 VTs were detected and 51 of 65 SVTs were appropriately rejected.

Morphology is the only single chamber criterion that can discriminate sudden onset SVT with regular ventricular intervals such as atrial flutter or atrial tachycardia from VT. When dual-chamber detection criteria are enhanced with morphology, the combined algorithm will better discriminate 1:1 rhythms and rapidly conducted AF from double tachycardia. This paper describes an algorithm combining PR Logic and Wavelet. The algorithm was tested with clinical data and the results are reported.

## 2. Methods

### 2.1. Data

The testing database consisted of device-stored VT/VF episodes of the GEM DR dual-chamber ICD. SVT episodes stored as a VT/VF episode were inappropriately detected by PR Logic with patient-specific programmed parameters. By combining morphologic analysis with PR Logic it was expected that detection of these SVTs would be avoided without allowing any VT/VF episodes to be undetected. Stored spontaneous episode data consisted of 128 Hz sampled coil-can electrogram and atrial and ventricular markers. The electrogram data were interpolated to 256 Hz sampling so the Marquis VR Wavelet algorithm could be used. A template for morphology discrimination was created from a single beat prior to onset of tachyarrhythmia. In Marquis, templates are created from the average of 6 beats. There were 166 VTs, 10 VFs, 32 double tachycardias, 29 atrial or sinus tachycardias (1:1) and 10 AFs in the test database.

### 2.2. Combined algorithm description

The combined detection algorithm included the four PR Logic criteria plus the wavelet criterion as the lowest priority SVT criterion. The PR Logic double tachycardia criterion was modified to require abnormal morphology and the wavelet criterion was modified to apply only when the atrial rate was at least as fast as the ventricular rate.

### 2.3. Testing methods

The algorithms were implemented in C on a desktop computer. The program was parameterized such that testing of PR Logic and Wavelet separately and combined could be easily achieved. ICD detection parameters were selected to maximize the number of episodes discriminated by the SVT criteria. VF detection was programmed to <280 ms for 12/16 intervals. VT detection was programmed to 600 ms for 12 intervals. The SVT limit was programmed to 240 ms, stability and onset were programmed off. When the Wavelet algorithm was enabled, a match threshold of 70% was used. When PR Logic was enabled, the sinus tachycardia (ST) and AF rules were programmed on, and the other SVT rule was programmed off.

Table 2: Classification criteria of combined algorithm

| Device Classification | Criteria Used |
|---|---|
| Double Tachycardia | • A:V > 1:1<br>• AV Dissociation<br>• Regular VV (VT zone)<br>• No FFRs<br>• **Abnormal morphology** |
| AF/AT | • A:V > 1:1 or reg. 2:1<br>• Irregular VV or Reg VV and AV assoc<br>• No FFR |
| Sinus Tachycardia | • Antegrade AV pattern<br>• Consistent FFR |
| Other 1:1 SVT | • Junctional AV Pattern |
| SVT Morphology | • VV ≥ AA<br>• **Normal Morphology** |

## 3. Results

Table 3: Detection results for the three algorithms

| | Dual-Chamber Intervals | Single-Chamber Morphology | Both |
|---|---|---|---|
| AF/AT | 8/10 | 3/10 | 3/10 |
| ST | 25/29 | 7/29 | 4/29 |
| AF+VF/VT | 32/32 | 32/32 | 32/32 |
| VF/VT | 176/176 | 176/176 | 176/176 |

Results are given in table 3. All SVT episodes in the test database were inappropriately detected as VT/VF by the GEM DR during clinical use. Seven of these episodes were rejected by dual chamber analysis during testing because different detection parameters were used. The results show that all 3 algorithms have very high sensitivity; all 176 VT/VF and 32 double tachycardia

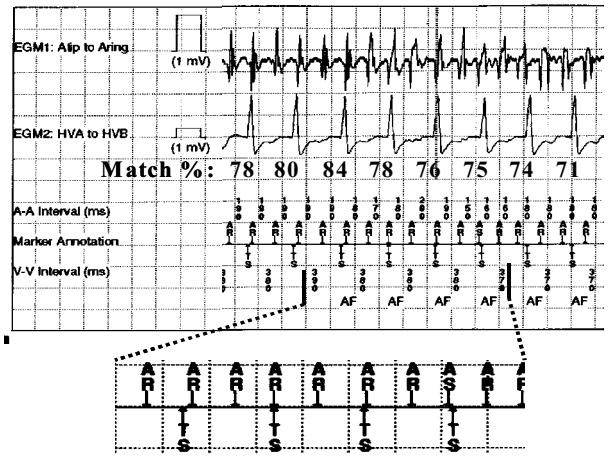


Figure 4: Example of long AV sinus tachycardia that was detected by PR Logic and rejected by combined algorirthm

episodes were detected by all 3.

Three of the 10 AF episodes (1 patient) were rapidly conducted 1:1 with aberrant conduction such that none of the tested algorithms was able to prevent inappropriate detection as VF. The remaining 7 were rejected by morphology analysis alone and by the combined algorithm.

Twenty-two of 29 sinus tachycardia episodes were appropriately rejected by morphology analysis. When

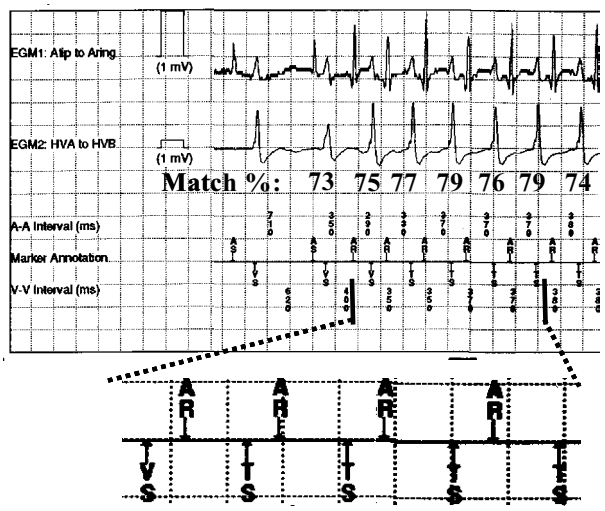


Figure 5: Example of rapidly conducted AF that was detected by PR Logic and rejected by combined algorithm

combined with dual-chamber interval analysis, 25 were rejected because the algorithms were able to complement each other when morphology and intervals shifted.

Figures 4 and 5 are examples where the combined algorithm provided SVT rejection of episodes that were detected by PR Logic alone.

## 4. Discussion

Test results indicate that the addition of morphology to PR Logic will improve discrimination of rapidly conducted atrial fibrillation from double tachycardia or SVT with 1:1 antegrade conduction from VT with 1:1 retrograde conduction. One limitation of the study is that the dataset was small so it is difficult to extrapolate performance in a large patient poplulation. Another limitation is that the electrogram data was interpolated from 128 Hz to 256 Hz sampling so that the Wavelet algorithm could be used. Testing has shown that match percentages are usually not much different between true 256 Hz sampling and interpolated 256 Hz sampling. For purposes of the comparison between wavelet only, PR Logic only and combined detection, a slight difference in match percentages would not alter the conclusions.

## 5. Conclusion

Combined analysis of dual-chamber intervals and ventricular electrogram morphology reduced the number of false positive detections from 33 to 7, a 79% reduction, compared to PR Logic alone without compromising sensitivity for detection of VT.

## References

[1] Olson WH. Dual chamber sensing and detection for implantable cardioverter-defibrillators. In: Singer I, editor. Nonpharmacological Therapy of Arrhythmias for the 21st Century. Armonk, NY: Futura Publishing Co, Inc, 1998:385-421.

[2] Wilkoff BL, Kuhlkamp V, et al. Critical analysis of dual-chamber implantable cardioverter-defibrillator arrhythmia detection: results and technical considerations. Circulation 2001;103:381-386.

[3] Koyrakh L, Gillberg J, Wood N. Wavelet transform based algorithms for EGM morphology discrimination of implantable ICDs. Computers in Cardiology 2000;26:343-346.

[4] Swerdlow CD, Brown ML, et al. Discrimination of ventricular tachycardia from supraventricular tachycardia by a downloaded wavelet-transform morphology algorithm: a paradigm for development of implantable cardioverter defibrillator detection algorithms. J Cardiovascular Physiology 2002;13:432-441.

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