# Development of a Post-Processing Algorithm to Classify Rhythms Detected as Ventricular Tachyarrhythmias by Implantable Cardioverter Defibrillators

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## Abstract

*Implantable Cardioverter-Defibrillators (ICD) detect ventricular tachycardia /fibrillation (VT/VF) using atrial (A) and ventricular (V) electrograms (EGMs). ICD algorithms discriminate VT/VF from supraventricular tachycardias (SVTs), but misclassify some SVTs as VT/VF. Clinicians review detected episodes to identify true SVT episodes and guide appropriate clinical action. A post-processing, expert-system algorithm was developed to classify tachyarrhythmias detected and stored in ICD memory.*

*The algorithm was designed to diagnose rhythms with V EGM and/or timing of A/ V events. Rhythms that did not fulfill the criteria were classified as Unknown. The algorithm was tested using a dataset of 469 episodes.*

*The algorithm correctly classified 80% of the episodes with 99% accuracy. This accuracy may be sufficient that physician review may be required only for Unknown episodes.*

## 1. Introduction

By the year 2012, an estimated 590,772 patients will be implanted annually with an Implantable Cardioverter-Defibrillator (ICD) [1]. The patients' stored device data will need to be interrogated and evaluated approximately every 3 months. As the rate of implants increases, the number of patients being followed is growing exponentially. Thus, reviewing all stored data is a considerable workload for physicians, nurses, and technicians. As device memory increases in size along with the number of episodes, there is an increasing temptation to not review all episodes, especially as other demands increase for a physician's time. Reviewing all episodes to identify inappropriate detection of supraventricular tachycardia (SVT) is time-consuming and requires expert knowledge. Due to these factors there is a risk of rhythm misinterpretation by the clinician [2, 3]. Rhythm misinterpretation could lead to clinical decisions that result in further inappropriate therapies. Correct rhythm interpretation could lead better clinical decisions to reducing further inappropriate therapies by ICD programming, medications, and/or surgery (e.g. ablation).

The goal of this project was to develop and test a post-processing expert system algorithm that could automatically analyze the electrogram (EGM) and differentiate between appropriate ventricular tachycardia/fibrillation (VT/VF) and inappropriate SVT.

## 2. Methods

## 2.1. Definitions: three rhythm decisions

Currently, patients implanted with an ICD have two levels of decisions made about their heart rhythms. First, the real-time ICD detection algorithm (e.g. PR Logic) continuously monitors the atrial and ventricular EGMs to determine when to detect VT/VF. This decision is limited by duration of the rhythm available for analysis (usually < 5 seconds) and the processing power of the ICDs CPU. Once a rhythm has been detected (i.e. episode), the stored data including EGMs transferred to an external storage device (programmer or network computer), a human interpretation is made using the same atrial and ventricular electrograms. The purpose of this second decision is to assess the accuracy of the real-time detection algorithm. If the real-time detection decision is inaccurate, various interventions may be initiated, including reprogramming or medical therapy. A separate sinus rhythm EGM or predetection sinus rhythm EGM may also be available to assist with this human interpretation.

The proposed third decision is an Expert System algorithm classification – using the same information as human interpretation. This post-processing decision can be made using data and methods not available to the ICD at the time of real-time rhythm detection.

## 2.2. Clinical value and implementation

The clinical value of a post-processing algorithm is to improve the speed and accuracy of rhythm interpretation. To accomplish this goal, the algorithm must have very high classification accuracy. Unlike ICD detection algorithms, this algorithm is not required to classify all rhythms. Instead, it is required to make essentially 100% accurate classifications so physicians do not need to review detected rhythms just to validate accuracy of VT vs. SVT classification. The algorithm under study was developed and tested based on rhythms interpreted by an electrophysiologist(s). The expert system could be implemented on either an implantable device programmer or a computer server for remote ICD interrogations. Unlike an ICD, there would not be a limit to the CPU processing power or time needed to perform complex analyses.

## 2.3. ICD Episode

The algorithm used detected episodes stored in ICD memory (Figure 1). Based on ICD programming decisions (e.g. battery longevity), the stored atrial and ventricular filtered EGMs (128 Hz) may not begin until the $3^{rd}$ beat of the rhythm. This provides less opportunity to compare the EGM from the detected rhythm with pre-detected rhythm (e.g. sinus). The timing of each atrial and ventricular sensed and paced event was available for both the pre-detected and detected rhythms as displayed below the EGMs (Figure 1). With accurate sensing, PP, PR, RP, and RR intervals can be determined. As in an electrophysiology lab, the response to ventricular overdrive pacing delivered as Antitachycardia Pacing (ATP) therapy was used to discriminate VT from SVT for tachycardias with 1:1 AV relationships.
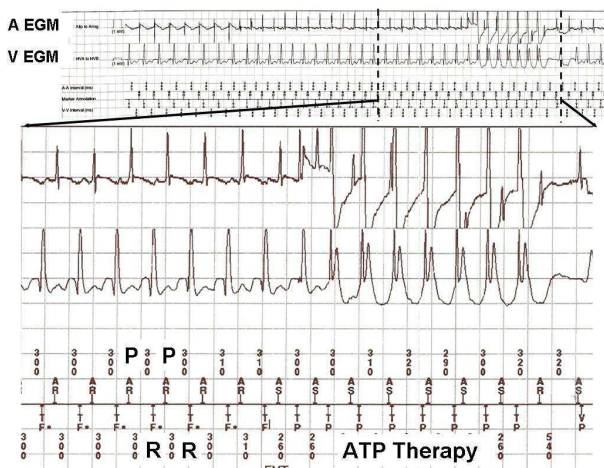


Figure 1. ICD detected episode

## 2.4. Algorithm

Twenty-two attributes were tested to differentiate SVT from VT/VF. Multiple iterations of the algorithm were made to select the best attributes based on results of real data and the likelihood of benefit based on feedback from electrophysiologist experts. R-wave morphology was compared across episodes and within the same episode using cross correlation. The algorithm was implemented using C sharp and .NET. Figure 2 shows the flowchart for the algorithm, which incorporates 8 attributes. Initially, the P and R sensed events are analyzed for patterns of correct sensing of the P and R waves ("Good Sensing"). When there was strong evidence of oversensing or undersensing the sensing was repaired by adding or removing events, if possible. Otherwise the episode was classified as unknown (UNK).
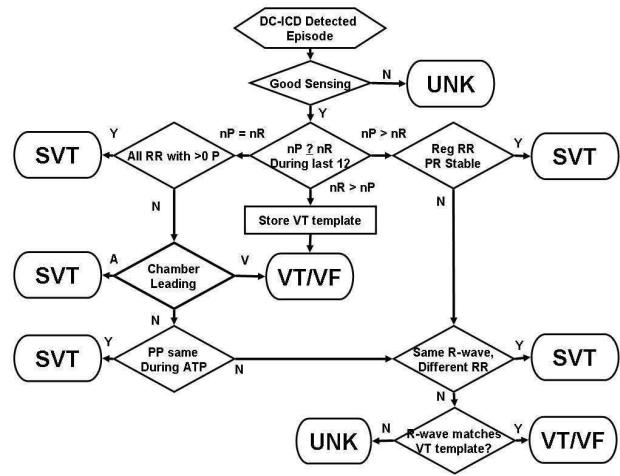


Figure 2. Flowchart

After "Good Sensing" was determined, the algorithm compared the atrial and ventricular rates using the number of P events in the last 12 RR intervals (Figure 3). If there were between 10 and 13 P events, then the rates were considered the same (nP=nR). If there were greater than 13 P events, then the atrial rate was greater (nP > nR). If there were less than 10 P events, then the ventricular rate was greater (nR > nP).

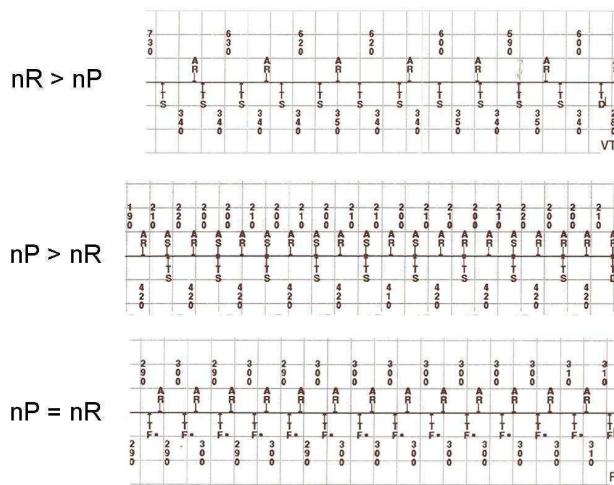Figure 3. Comparing number of P and R events

Depending on the nR vs nP decision, a rhythm was classified as VT/VF or SVT using following attributes:

### 2.4.1. nR > nP branch only

The most common and accurate decision for VT/VF can be made when there are more R events than P events. Since this is highly accurate, an R–wave template is stored for each VT episode that reached this branch to compare the R-wave morphology with other detected episodes from the same patient in the other two branches.

### 2.4.2. nP > nR and nP = nR branches

Three attributes were used in these branches (Figure 4):
- Regular RR with stable PR
- Same R-wave morphology, different RR
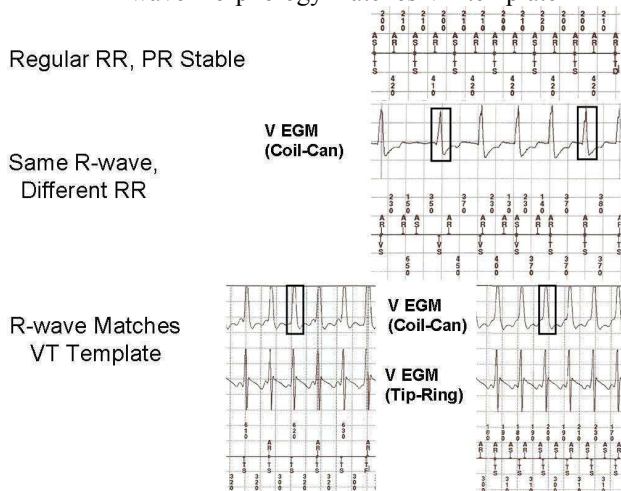- R-wave morphology matches VT template



Figure 4. nP>nR or nP=nR branch attributes

If a rhythm has nP > nR, at least 67% of the last 12 RR were one of two values (e.g. 320 and 330 ms), and the PR range (after removing minimum and maximum PR) of last 12 PR intervals was ≤ 20 ms, then the rhythm was SVT (e.g. 2:1 Atrial Flutter). For either nP > nR or nP = nR branches, the following decisions were made. If the R-wave morphology for two beats was the same with a RR difference >100 ms, then the rhythm was SVT. This primarily identifies atrial fibrillation with irregular RR intervals which become regular, resulting in an inappropriate detection. Finally, if the R-wave template from the same patient's VT rhythm matched the R-wave of the current rhythm, then the rhythm was VT. If none of the criteria in these two branches were met, the episode was classified as Unknown.

### 2.4.3. nP = nR branch only

Three attributes were used in this branch only (Figure 5):
- All RR with > 0 P
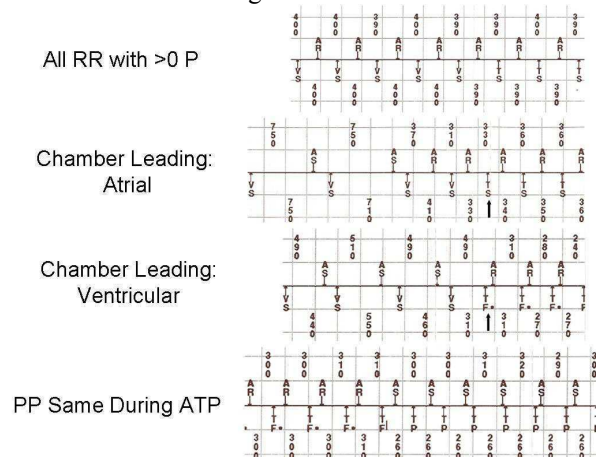- Chamber Leading: atrial or ventricle
- PP same during ATP



Figure 5. nP=nR branch attributes

A 1:1 SVT is characterized by 1:1 P to R relationship throughout the entire rhythm. If all RR intervals have at least 1 P event (<3 RR with 2 P and no RR with more than 2 P), then the rhythm was classified as SVT. The leading chamber was determined based on the number of P events during 7 RR intervals centered at the onset. The onset was defined as a 65% increase in the RR median starting from detection and moving backward. If all 7 RR intervals had 1 P, then the leading chamber was atrial (SVT). If 6 RR had 1 P and 1 RR had 0 P, then the leading chamber was ventricular (VT/VF). If the PP intervals of a 1:1 rhythm were unaffected by ventricular ATP, then the rhythm persisted in the atrium independent of the ventricle and was classified as SVT. Therefore, if

each PP interval during ATP was within 30 ms of the mean PP prior to ATP, then the rhythm was SVT.

## 2.5. Databases

The algorithm was developed with multiple development datasets until the desired results were achieved. Each data set included ICD detected episodes retrieved from stored memory. Each episode was interpreted (i.e. "truthed") by experts to compare with the algorithm results. The final independent test data set was from the PainFree II Rx study [4] and contained 306 VT/VF episodes and 163 SVT episodes from 72 patients.

## 3. Results

After deciding which of the three nP vs nR branches was satisfied, each attribute was individually tested. The number of episodes classified as SVT and VT/VF were ordered by frequency (Table 1) within each classification (first 5 SVT then 3 VT/VF).

Table 1. Individual attribute performance (episodes)

|  | Truth | |
| --- | --- | --- |
| Attribute | SVT | VT/VF |
| All RR with >0 P | 97 | 0 |
| Chamber Leading: Atrial | 48 | 1 |
| PP Same During ATP | 38 | 0 |
| Regular RR, PR Stable | 11 | 0 |
| Same R-wave, Different RR | 1 | 2 |
| nR>nP | 0 | 194 |
| R-wave Matches VT Template | 2 | 37 |
| Chamber Leading: Ventricular | 1 | 27 |

The overall algorithm (Table 2) classified 80.2% (376/469) of the episodes as SVT or VT/VF. The remaining episodes were unknown (UNK). Overall, 98.9% (372/376) of the episodes were correctly classified. Both SVT and VT/VF rhythms had a very high classification accuracy of 99.2% (118/119) and 98.8% (254/257), respectively.

Table 2. Overall performance (episodes)

|  | Algorithm Classification | | | |
| --- | --- | --- | --- | --- |
| Truth | SVT | VT/VF | UNK | Total |
| SVT | 118 | 1 | 44 | 163 |
| VT/VF | 3 | 254 | 49 | 306 |
| Total | 121 | 255 | 93 | 469 |

## 4. Discussion and conclusions

An algorithm was developed to automatically classify a majority of ICD detected episodes as VT/VF or SVT with 98.9% accuracy. This high accuracy may provide clinicians a second-look during their rhythm review to decrease time to correctly interpret detected episodes and improve accuracy of their interpretation. This may lead to better patient care by reducing subsequent inappropriate detections and therapies.

Three VT/VF rhythms were misclassified as SVT. They included two VT rhythms with large RR variability and same R-wave morphology and one VT rhythm with 1:1 retrograde conduction. One SVT rhythm was misclassified as VT/VF because the atrial tachycardia was initiated by a premature ventricular contraction. The Unknown rhythm classifications included primarily atrial fibrillation, short runs of VT, dual tachycardias (e.g. VT plus SVT), and atrial sensing issues.

This analysis was limited to patients with dual chamber ICDs, but is applicable to patients receiving cardiac resynchronization ICDs, except that the baseline sinus EGM may not be available in cardiac resynchronization ICDs. This algorithm does not apply to episodes from patients with a single chamber ICD because there is no atrial information.

Post-processing ICD detected episodes with different constraints and clinical requirements than a real-time detection algorithm may benefit clinicians' ICD rhythm interpretation.

## References

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