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Separation of Ventricular Tachycardia from Ventricular Fibrillation Using Paired Unipolar Electrograms

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Abstract

In third-generation implantable antitachycardia devices, immediate defibrillation is necessary for ventricular fibrillation (VF) while lower-energy therapies convert many ventricular tachycardias (VTs). Precise distinction between true VF and VT is required if tiered-therapy is to be effectively utilized. To separate VF from VT, this study employed a measurement to quantify the coherence between two unipolar electrograms from the same catheter, where incoherence between signals indicates VF. A normalized cross correlation (CC) measured similarity, and standard deviation (STD) and interquartile range (IQR) of the CC measured consistency for sinus rhythm (SR), VT, and VF passages from 10 patients. Patient-independent STD thresholds of 0.15-0.25 and IQR thresholds of 0.3-0.6 provided 100% sensitivity and 100% specificity. This method was able to successfully separate VF from coherent rhythms (SR, VT). Proper distinction of VT would allow defibrillation to be deferred for consideration of lower energy therapies, providing significant energy savings.

1. Introduction

Implantable antitachycardia devices (ATD) recognize ventricular fibrillation (VF), the predominant mechanism of sudden cardiac death, and automatically deliver electrical therapy. Third-generation ATDs can be programmed with multiple rate zones for detection of VF as well as less-threatening arrhythmias such as ventricular tachycardia (VT), and can provide a tiered therapeutic choice tailored to each rhythm and patient: antitachycardia pacing and low-energy cardioversion for many VTs, and defibrillation for VF. In recent reports, 70% [1] of new ATD implants have utilized multiple zones and therapies.

To distinguish between VT and VF, ATDs increment a counter associated with a detection zone based on the most recent cycle length. Measuring cycle length is dependent on accurate sensing of each depolarization by a trigger. Electrogram dropout (missed triggers) are common in VF because of rapidly changing peak amplitudes. Compensation for VF sensing limitations, in order to ensure detection of VF, is typically achieved by lengthening the fibrillation detection interval (FDI), the rate threshold between VT and VF [2]. The over-riding necessity of fail-safe VF detection bypasses the use of lower energy therapies tailored for VT since overly liberal FDI values invoke defibrillation for many episodes of VT.

Little information is available concerning discrimination of VT from VF for appropriate therapeutic choice of treatment [3]. Some studies claim defibrillation was delivered to *true* VF in only 10 - 21% of shock episodes [1,4]. A present challenge of ATD research is to optimize detection in order to direct appropriate therapy without sacrificing sensitivity of VF detection. This paper presents an improved detection algorithm to distinguish VF from VT which utilizes two unipolar electrograms.

2. Background

In addition to rate, two morphological algorithms for VF detection were implemented in earlier ATDs, probability density function (PDF) and temporal electrogram analysis (TEA). PDF, the original AICD™ detection scheme, used the derivative to define departure from baseline [5]. TEA, incorporated in some second-generation devices, identified a change in electrogram morphology by the order which depolarizations crossed predetermined thresholds [6]. Experience with PDF and TEA in first- and second-generation devices was disappointing due to its lack of specificity. As a result, by 1992, less than 15% of ATDs utilized either algorithm for tachycardia discrimination [7].

A number of studies have begun to address the problem of separating VT and VF. In several studies [8,9], the standard deviation of template-based (TB) algorithms (correlation waveform analysis (CWA), bin area method (BAM), difference of area (DOA), derivative area method (DAM)) was used as a discriminant function

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and achieved varying degrees of success [9]. Sensitivity range from 83% to 100% and specificity from 56% to 100%. Other algorithms utilized statistical methods [10,11]; however, neither study segregated the data into training and test sets thus results are inconclusive. Chen et al [12] examined autocorrelation function (ACF) using linearity of the peak values where more linearity indicated monomorphic waveforms and achieved 100% sensitivity and specificity. Lastly, two algorithms [13,14] using two distinct channels from the ventricle achieved significant success in discriminating VF from other rhythms. Throne et al [13] plotted corresponding pairs of the two channels on a scatter diagram (SD) and found that monomorphic VTs trace nearly the same path and occupy a smaller percentage of SD than nonregular rhythms such as polymorphic VT (PMVT) or VF. Ropella et al [14] developed a two channel algorithm based on the magnitude squared coherence (MSC) which measures the basic organization of the rhythm in the frequency domain.

Algorithms described above could potentially be confounded by atrial fibrillation with ventricular response due to its variable rate (ACF), and ventricular premature depolarizations (VPDs) due to variable morphology (ACF, TB, SD). Other possible limitations of these algorithms include computational complexity and the necessity of a sinus rhythm template which is representative of all time.

Observing the promise of *two channel* ventricular algorithms for VT and VF separation, we sought to develop an algorithm which utilizes two electrodes located on the same catheter to eliminate the need for multiple leads. We hypothesized that two closely spaced unipolar electrograms would have similar morphology and consistency during rhythms with broad coherent activation (such as sinus rhythm and VT). However, for incoherent rhythms (VF and PMVT), activation between electrodes would be dissimilar and inconsistent. This hypothesis was tested using the cross correlation of the two depolarizations to measure similarity between electrogram morphology, and standard deviation and interquartile range to measure consistency in a passage.

3. Methods and Materials

Two unipolar electrograms were derived from the distal and proximal electrodes of a catheter with 1 cm spacing which was located in the right ventricular apex during electrophysiology studies. A wire located remotely in the femoral vein was used as the reference electrode. Sinus rhythm (SR), VT, and VF from 10 patients were recorded on FM tape at 3 3/4 ips, filtered at 1-500 Hz., and digitized at 1000 Hz. Example waveforms are shown in figure 1. Depolarization locations were determined using a custom auto-adjusting threshold trigger (sensitivity 0.75, time constant 0.5s). Two of the ten patients were used in the development of this method (training) and the remaining were used for testing.

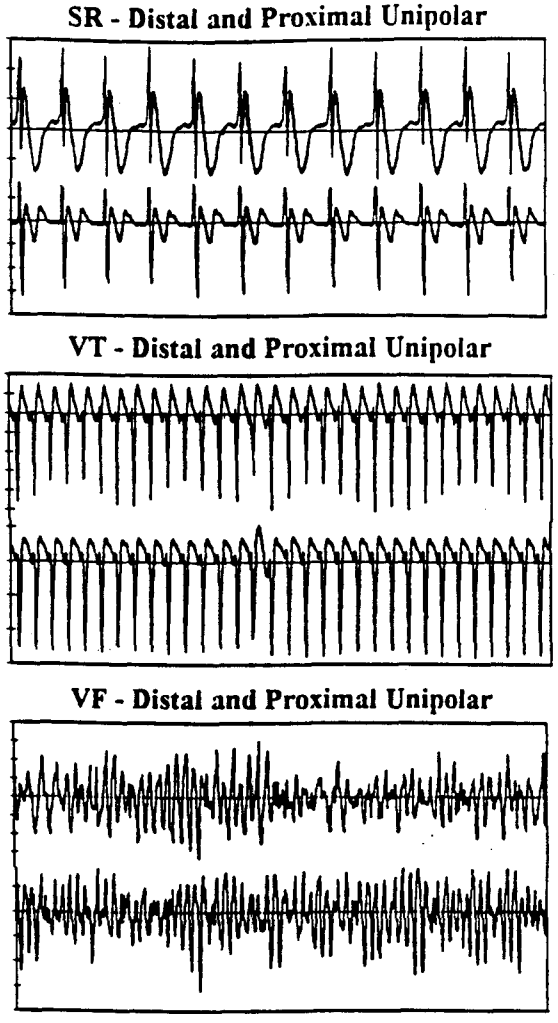

Figure 1. *Distal and proximal unipolar electrograms for SR, VT, and VF. 10 seconds of the passage are shown (AAEL234).*

Similarity between electrode morphology was measured by a normalized cross correlation:

$$\rho(m) = \frac{1}{N-m} \frac{\sum_{n=1}^{n=N} (d(n-m) - \bar{d})(p(n-m) - \bar{p})}{\sqrt{\sum_{n=1}^{n=N} (d(n-m) - \bar{d})^2 \sum_{i=1}^{i=N} (p(n-m) - \bar{p})^2}}$$

$m = -M,\ldots,-1,0,1,\ldots,M$, where:

$\rho(m)$ = the cross correlation values

$d(n-m)$ = points of the distal unipolar electrogram

$p(n-m)$ = points of the proximal

$\bar{d}$ = average of the distal

$\bar{p}$ = average of the proximal

N = number of points in the window

M = number of shifts

The cross correlation was computed for a 150 point window (N) centered over the trigger point of the distal lead and then performed for shifts of ten (M) in each direction to ensure proper alignment. The peak value of the cross correlation (PCC) was used in discrimination. VF was separated from VT/SR by the standard deviation (STD) and the interquartile range (IQR). The IQR is defined as the PCC value at the 75th percentile minus the 25th percentile of the passage. This range is utilized as a simplified measure of variance.

4. Results

Sensitivity and specificity values were derived for all patients where: **Ho:** SR, VT and **H1:** VF. In this study, we were most interested in separating VF which would need immediate positive identification. A plot of the PCC for each beat of an exemplary patient is shown in figure 2. SR and VT exhibit values near 1 for the entire passage while VF exhibits a large variance.

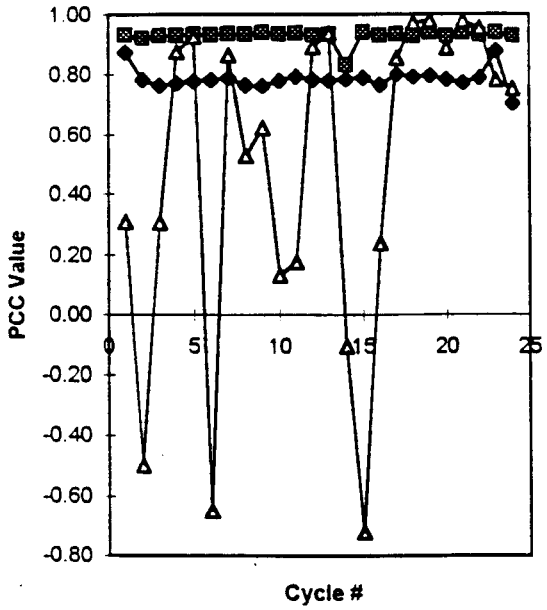

Figure 2. The peak cross correlation values (y-axis) for one patient (AAEL234) for each cycle (x-axis). Diamonds are SR, squares are VT, , and triangles are VF.

Quantifying the variance was achieved by both STD and IQR (figure 3). From the graph, patient-independent thresholds chosen between 0.15 and 0.25 for STD and 0.3 and 0.6 would give 100% sensitivity and 100% specificity in separation of VF from VT and SR.

In order to analyze the performance of this algorithm on coherent, but polymorphic rhythms, we tested two passages of sinus rhythm with VPDs and generated STD and IQR values. Results show STD and IQR fall in the SR/VT range; therefore, this rhythm would not be misdiagnosed by this method.

Two passages of polymorphic VT were also tested with the method and were easily diagnosed as incoherent (VF range). This is acceptable since this rhythm would require defibrillation therapy.

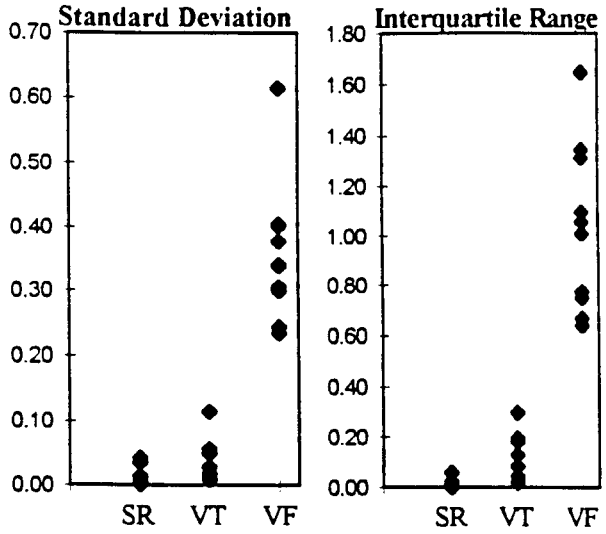

Figure 3. Standard deviation (left) and interquartile range (right) plotted for all patients for SR, VT, and VF.

The same dataset was also tested on simulations of three commercially available ATDs: Medtronic, Inc. *Jewel PCD 7219* (PCD), Ventritex, Inc. *Cadence V-100* (CAD), and Cardiac Pacemaker, Inc. *Ventak PrX 1700* (PRX), for their nominal settings. Sensitivity for VF detection was 100%, but specificity ranged from only 10 to 20% for all devices, i.e., 90% of VTs were misdiagnosed as VF (figure 4).

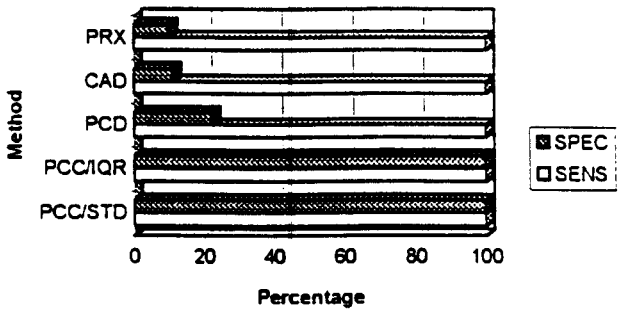

Figure 4: Comparison of ATD detection algorithm results with new methods, where SENS is sensitivity and SPEC is specificity.

5. Discussion

This method was successful in separating VF from VT and SR and showed a dramatic improvement over current

ATD rate methods in current use. Comparatively, ATDs had specificity of 10% versus 100% specificity for PCC with STD/IQR (figure 4). This method has an advantage over other morphology algorithms in that it does not require a SR template and is immune to the misdiagnosis of coherent rhythms with a variable rate or variable morphology. This method utilizes two channels for detection of VF. More information is available to make a diagnosis without requiring introduction of a second catheter.

Computational complexity remains a limitation of this method. However, the cross correlation is only one measure of similarity between electrograms. Replication may be possible by modifying simpler algorithms (DOA, BAM, DAM) whereby the second channel would replace the template. Both STD and IQR were successful in measuring consistency in order to derive an episode diagnosis. IQR has fewer computations and is robust against isolated occurrences of low PCCs.

This algorithm must be fully tested on a variety of other cases, such as polymorphic onsets of a stable VT and atrial fibrillation with fast ventricular response. We hypothesize that even in the face of these rhythms, this algorithm will still easily separate VF. One potential limitation is the possibility of VF appearing monomorphic and of similar morphology on both leads. This limited dataset did not show any cases of this type. However, triggering is more reliable on monomorphic waveforms (no missed triggers); therefore, an accurate rate could be determined and VF properly classified. One other arrhythmia, PMVT, would be diagnosed as VF and receive defibrillation, but this has achieved acceptance as appropriate therapy.

6. Conclusion

The overriding goal of the ATD is to rapidly detect VF in order to extend life. Significant problems in ATD arrhythmia detection remain to be addressed including a need for improved discrimination between VT and VF. The method proposed is able to quantify the nature of VF – incoherence – in order to achieve a diagnosis. Proper detection of VF would allow consideration of lower energy therapies for VT to provide significant energy savings. This algorithm which permits VT/VF distinction begins to fulfill the needs of the future ATD.

Acknowledgments

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