Template Matching Analysis of Unipolar and Bipolar Electrograms in the Differentiation of Ventricular Tachycardia and Fibrillation from Sinus Rhythm

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Abstract

The failure of automated morphologic detection of ventricular tachycardia (VT) or fibrillation (VF) is a limitation of implantable cardioverter-defibrillators (ICDs). As an adjunct to rate-based criteria, this study evaluated the use of waveform analysis of intracardiac electrograms with correlation waveform analysis (CWA). Using digital signal processing, unipolar and bipolar electrograms were evaluated in sinus rhythm (SR), VT and VF at 1-500 Hz and 10-80 Hz in 15 patients. There was complete differentiation of SR from VF in 13/15 patients and VT in 14/15 with unipolar and 14/15 patients with bipolar electrograms at 1-500 Hz; at 10-80 Hz SR was differentiated from VF in 12/15 patients and VT in 13/15 with unipolar and from VF in 14/15 patients and VT in 13/15 with bipolar electrograms. Conclusions: Differentiation of intracardiac waveforms by CWA is independent of electrode configuration. and not significantly altered by moderate signal filtering.

Introduction

The current generation of implantable cardioverter-defibrillators (ICDs) are capable of a series of complex therapeutic algorithms for the termination of ventricular tachycardia (VT) as well as asynchronous electrical countershock for ventricular fibrillation (VF). Although these methods of tachycardia termination are well established, the automated recognition and differentiation of life-threatening arrhythmias remains problematic. With clinical experience, it has become evident that the utility of ICDs incorporating sophisticated VT termination algorithms will be predicated on the prompt and accurate discrimination between VT and VF, and the appropriate recognition of sinus and supraventricular tachycardias (1).

Currently, the automated detection of tachycardias by ICDs is based on electrogram rate criteria, where ventricular rate is derived as a function of the interval between local ventricular electrograms. However, various pathologic tachycardias (VF, polymorphic VT) may result in marked variation in both local electrogram amplitude and cycle length, rendering accurate electrogram detection, and hence tachycardia recognition, infeasible (2). Thus, methods of arrhythmia detection, complimentary to rate , have been proposed to enhance the diagnostic performance of ICDs.

Correlation waveform analysis (CWA), a time domain template matching algorithm, independent of amplitude and baseline variations, has been demonstrated in previous studies of ventricular electrograms to be effective in the differentiation of normal sinus rhythm (NSR) from VT (3,4). This study was performed to determine the accuracy of CWA in distinguishing NSR from VF as well as VT, and to compare the specificity of unipolar and bipolar electrograms in the differentiation of cardiac rhythms.

Methods

Fifteen patients undergoing programmed electrical stimulation for the evaluation of cardiac arrhythmias were evaluated. Unipolar and bipolar (1 cm) electrograms were recorded from the distal electrode(s) of two side-by-side catheters, which were positioned at the apex of the right ventricle. Electrograms were recorded on FM magnetic tape (Hewlett-Packard 3968A, San Diego, CA) following signal amplification and filtering at 1-500 Hz. Tape speed was 3 3/4 in/s.

Intracardiac ventricular electrograms were acquired at the initiation of each case during NSR, following the induction of VT by programmed electrical stimulation, and following the induction of VF by programmed stimulation or alternating current. Ventricular electrograms were digitally processed at a sampling rate of 1000 Hz, using a personal computer and a Tecmar analog-to-digital system (Scientific Solutions, Inc, Solon, OH). Individual intracardiac electrograms were identified by use of an integrated digital differentiator.

A template for the reference ventricular electrograms was derived from a 10-15 second signal averaged passage of NSR which was acquired at the initiation of each case. This reference electrogram was subsequently

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compared to individual ventricular electrograms during 10-20 second interval recordings of SR, VT, and VF. The similarity (statistical correlation) of the electrogram under analysis with the SR template was calculated utilizing CWA. Mathematically, the correlation coefficient (p) was calculated as:

$$\rho = \frac{\sum_{i=1}^{\mathcal{N}} (\mathcal{T}_i - \bar{\mathcal{T}})(\mathcal{S}_i - \bar{\mathcal{S}})}{\sqrt{\sum_{i=1}^{\mathcal{N}} (\mathcal{T}_i - \bar{\mathcal{T}})^2 \sum_{i=1}^{\mathcal{N}} (\mathcal{S}_i - \bar{\mathcal{S}})^2}}$$

where :

$\mathcal{T}_i$ = template points

$\mathcal{S}_i$ = signal points to be processed

$\bar{\mathcal{T}}$ = mean of the template points

$\bar{\mathcal{S}}$ = mean of the signal points

$\mathcal{N}$ = number of points in the template

ρ = the index of merit

The range of correlation values extended from -1 to +1, where +1 indicated identical waveforms in both the NSR template and electrogram under consideration, and -1 indicated absolute discordance between the NSR template and electrogram under consideration. Differentiation of VT and VF from NSR was defined as absolute separation (no overlap) of the range of correlation value of all electrograms during VT or VF compared to those during NSR. The absolute mathematical difference between the lowest NSR correlation value and highest correlation value for VT and VF was calculated for each patient for both electrode configurations. This measure of performance was defined as the magnitude of separation.

A patient specific interval of electrogram analysis was determined from the NSR template during both unipolar and bipolar recordings, and subsequently utilized during CWA analysis of NSR, VT, and VF electrograms. This template "window" size was selected to include depolarization only, and exclude any acute injury artifact due to repolarization current associated with placement of the catheter. The electrogram was aligned with the NSR template by use of a trigger point (determined by digital differentiator as the maximal dV/dT within an 11 ms interval of the electrogram under analysis), and then shifted a maximum of 10 ms in either direction in order to obtain optimal alignment of the 2 waveforms.

CWA was performed independently for both unipolar and bipolar electrograms for SR, VT, and VF. Following initial processing of the data at bandwidth 1-500 Hz, signal processing was repeated following digital filtering of the electrograms at 10-80 Hz. This passband was selected to simulate signal processing parameters utilized in current ICDs.

Results

A high degree of correlation (p >.95) was observed in all patients between the NSR template and subsequent electrograms recorded during NSR passages in both the unipolar and bipolar electrode configurations.

Fourteen of 15 patients (93%) had complete differentiation of NSR from VT with the unipolar electrode configuration at a bandwidth of 1-500 Hz; in comparison, 14 of 15 patients (93%) had complete differentiation of SR from VT when bipolar electrograms were evaluated. Differentiation of VT from SR was not demonstrated with either electrode configuration in one patient. At signal frequencies 1-500 Hz, the magnitude of separation of SR from VT was greater for bipolar electrograms in 8 patients.

Table 1 Magnitude of Separation of p values 1-500 Hz

Pt	Bipolar		Unipolar	
#	SR / VT	SR / VF	SR / VT	SR /VF
1	0.037	0.057	0.023	-0.06*
2	1.246	0.018	0.010	0.022
3	0.078	0.038	0.155	0.073
4	0.298	0.013	0.012	0.004
5	1.056	0.050	1.258	0.089
6	0.033	0.017	0.052	0.097
7	0.454	0.509	0.329	0.048
8	-0.01*	0.051	-0.013*	0.189
9	0.477	0.027	0.135	0.146
10	0.006	0.006	0.062	0.026
11	0.014	0.028	0.034	0.061
12	1.505	-0.45*	0.676	-0.04*
13	0.022	0.028	0.602	0.042
14	1.101	0.200	0.040	0.086
15	0.208	0.114	0.097	0.089

* = failure to differentiate VT or VF from NSR

Thirteen of 15 patients had complete separation of SR from VF with CWA of unipolar electrograms; 14 of 15 patients had complete SR/VF differentiation with bipolar waveform analysis. There was failure to differentiate VF from SR by CWA in one patient with both electrode configurations. In contrast to SR/VT, the magnitude of SR/VF differentiation was greater for unipolar signals in 9 patients at a passband of 1-500 Hz.

In an attempt to limit the computational demands which are required to perform CWA, the unipolar and bipolar electrograms were re-evaluated following digital filtering at a 3 dB range of 10-80 Hz. There was one additional patient that failed to separate for SR from VT in both the unipolar or bipolar configuration (Table 2). At this level of bandpass filtering, differentiation of VF from SR was observed in 12 of 15 patients in the unipolar configuration, and 14 of 15 patients in the bipolar configuration. The magnitude of separation of SR from VT at 10-80 Hz was greater in the bipolar signals in 10 patients; however, the magnitude of separation of SR from VF was greater for unipolar signals in 9 patients.

Table II: Number of patients separated

	SR / VT		SR / VF	
Hz:	1-500	10-80	1-500	10-80
Unipolar	14/15	13/15	13/15	12/15
Bipolar	14/15	13/15	14/15	14/15

Discussion

Implantable cardioverter-defibrillators have become the dominant strategy in the treatment of patients resuscitated from, or at high risk for sudden cardiac death. In spite of the impact of these devices on the short term survival of patients, an unacceptably high rate of inappropriate therapies continues to represent a major liability of these devices. In particular, the automated recognition of VF or polymorphic VT have been problematic, when electrogram rate-criteria are utilized. Thus, the need for hierarchical methods of automated arrhythmia analysis has become evident.

This study was performed to evaluate whether the configuration of the sensing electrode significantly affects the ability of CWA to differentiate NSR from VT and VF. The results suggest that the discriminatory power of CWA is retained in either configuration. The absolute magnitude of differentiation of NSR from VT or VF was greater for either unipolar or bipolar configuration, depending on patient specific local electrogram characteristics.

CWA has previously been demonstrated to be effective in the differentiation of NSR from supraventricular tachycardia with bundle branch block, VT and VF when bipolar electrograms are studied (4,5,6). This study suggests that the discriminatory power of CWA is retained, and in fact, may be enhanced in certain patients, when unipolar electrograms are utilized. In this study, the indifferent unipolar electrode was positioned to simulate the location of an ICD. Although sensing of "far-field" signals, such as myopotentials may limit use of a unipolar sensing configuration, the finding that unipolar sensing may enhance electrogram sensing suggests that interelectrode spacing of bipolar leads may need to be increased for optimal electrogram detection.

Although the computational demands of CWA currently exceed the capabilities of ICDs, continued advances in low-power microprocessors may permit future implementation of CWA or derivative methods. Assuming enhanced computational capabilities, an algorithmic structure allowing both sensitivity and specificity in the recognition of life-threatening arrhythmias will become critical. The finding in this study that specificity of arrhythmia detection is retained at moderate bandpass filtering (10-80 Hz), which will allow a lower sampling rate and hence reduced computational memory, suggests clinical applications of CWA may become feasible within the next decade.

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