Impact of Filtering Upon Ventricular Tachycardia Identification by Correlation Waveform Analysis

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JENKINS, J.M., ET AL.: Impact of Filtering Upon Ventricular Tachycardia Identification by Correlation Waveform Analysis. *Signal analysis of digitized waveforms has been postulated as a method for improving sensitivity and specificity of ventricular tachycardia (VT) detection in implantable antitachycardia devices. Such improvement may alleviate the problem of unwarranted delivery of therapy by adding precision to the identification of the pathological VT. Morphological analysis could also allow distinct therapies to be initialized for multiple VTs in the same patient. Correlation waveform analysis (CWA) has been demonstrated to be effective in separating benign rhythms from VT in wideband recordings (1–500 Hz) but the effect of filtering has not been previously examined. Bipolar (1 cm) intraventricular recordings (1–500 Hz) of sinus rhythm (SR) and 25 distinct VTs in 18 patients were analyzed by CWA using a signal-averaged SR template. Passages contained 65.9 ± 19.8 VT depolarizations (range 45–108). Digital filtering was performed on all data passages with varying passbands. Results for passages with a bandwidth of 1–250 Hz were equivalent to wideband results, i.e., ≥92% paired sets of SR and VT were separable at a 95% confidence level. A bandwidth of 1–100 Hz decreased discrimination to 84%. At a bandwidth of 1–80 Hz, 80% of cases were successfully separated, but at 10–80 Hz these results improved to 88%. Bandwidths of 20–80 and 30–80 Hz reduced reliability of CWA performance to 72% and 60%, respectively. Filtering at typical pacemaker/defibrillator passbands produced morphological analysis results equivalent to those yielded at wideband settings. Differences in the range between SR versus VT decreased in filtered recordings but overall detection of VT was not degraded. (PACE, Vol. 14, November, Part II 1991)*

tachycardia detection, antitachycardia devices, implantable defibrillator

Introduction

Pacemaker cardioverter defibrillator implantations for intractable ventricular tachyarrhythmias now exceed 15,000[1] and have become highly sophisticated in design and choice of therapeutic options. Digital circuitry has advanced to the level of embedded microprocessors with special purpose architecture and expanded memory capabilities, both random access memory and read-only memory.

In conjunction with and parallel to the development of new hardware designs, algorithms for smarter detection schemes have been considered for implementation. To complement the rate-related detection schemes employed by current systems, a variety of pattern recognition methods have been advanced that exploit the morphological information content present in the intracardiac electrogram signal itself. These techniques have emerged in anticipation of the addition of analog-to-digital converters for capturing intrinsic waveforms, adequate memory storage for software and data, and sufficient processor power to perform digital analysis of the signal. It is not unrealistic to expect these features in the next generation of implantable devices.

Most of the morphological methods proposed

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to date fall into the template matching category, some operating on the raw signal and some on the derivative of the signal.[2–8] A standard template matching scheme, correlation waveform analysis (CWA), which has long been used for automatic waveform classification on surface electrocardiograms (ECGs), has been shown to be effective as well in intracardiac electrogram analysis.[4] While this algorithm is computationally demanding, it has been adopted as a standard against which other time-domain methods may be compared because of its characteristic capability of waveform comparison independent of amplitude and baseline changes. CWA on the intracardiac electrogram has been effective in discriminating ventricular depolarizations in sinus rhythm (SR) from those in ventricular tachycardia (VT),[4] separating normal ventricular depolarization during SR from paroxysmal rate-related bundle branch block,[9] and in distinguishing distinct monomorphic VT from one another.[10]

These studies have been performed on intracardiac signals acquired with wide bandwidths (1–500 Hz). The effect of filter settings that are typically applied for signal conditioning in actual devices has not been examined. The present study was undertaken to assess performance reliability of CWA in the presence of more restrictive bandwidths.

Methods and Materials

Electrophysiological Study

Bipolar (1 cm) distal ventricular endocardial electrograms were recorded during elective clinical cardiac electrophysiological studies as previously reported.[4,9,11,12] Three 6 French quadrapolar electrode catheters (USCI, Billerica, MA, USA) with an interelectrode distance of 1 cm were introduced and advanced under fluoroscopic guidance to the high right atrium (or right atrial appendage) and right ventricular apex. Two catheters were positioned in the right ventricular apex with one dedicated to pacing, and the other to obtaining recordings from the distal electrode pair. All recordings were made with the patients lying supine.

Ventricular electrograms were recorded on FM magnetic tape (Hewlett-Packard Model 3968A, San Diego, CA, USA) from distal bipolar electrodes using amplifiers with filter settings of 0.5–500 Hz (Siemens Mingograf-7, Siemens-Elema, Solna, Sweden) or 1–500 Hz (PPG Biomedical Systems, Lenexa, KS, USA). Tape speed was 3¾ inches/sec with a bandwidth of 0–1,250 Hz. Eighteen consecutive patients presenting with 25 distinct, sustained, monomorphic VT were studied. Each distinct VT, with a corresponding SR passage, was treated as a separate paired episode for purposes of evaluation.

Method of Analysis

Data sets (paired SR/VT episodes) for each patient consisted of the following: an initial passage of SR for template construction by signal averaging; a subsequent 30 second SR passage; and a passage from induced VT of duration 30 seconds when possible. VT passages contained 65.9 ± 19.8 depolarizations (range 45–108). A subsequent VT of different morphology in the same patient was confirmed by the 12-lead ECG.

The template was compared on a cycle-by-cycle basis with later SR and VT passages, and a correlation coefficient computed for each depolarization in each passage. A software trigger was used for alignment of waveforms.[11] All passages were digitized at 1000 Hz.

Correlation Waveform Analysis

The correlation coefficient (ρ) is independent of amplitude and baseline fluctuations, and produces an output between ±1, with a +1 reflecting a perfect match. Mathematically, the correlation is defined as

$$\rho = \frac{\sum_{i=1}^{i=N}(t_i - \bar{t})(s_i - \bar{s})}{\sqrt{\sum_{i=1}^{i=N}(t_i - \bar{t})^2}\sqrt{\sum_{i=1}^{i=N}(s_i - \bar{s})^2}}$$

where N = the number of sample points in the template; t_i = the template points; s_i = the signal points to be processed; $\bar{t}$ = template average; $\bar{s}$ = signal average, and ρ = correlation coefficient.

Filtered Data

All passages processed in the initial unfiltered (1–500 Hz) stage were subjected subsequently to digital filtering with six different passbands reflecting a variety of high and low frequency cutoffs. The digital filter was a finite impulse response (FIR, 100

Table I.
Results of Successful Discrimination of Sinus Rhythm and Ventricular Tachycardia

1–500 Hz	1–250 Hz	1–100 Hz	1–80 Hz	10–80 Hz	20–80 Hz	30–80 Hz
23/25 (92%)	24/25 (96%)	21/25 (84%)	20/25 (80%)	22/25 (88%)	18/25 (72%)	15/25 (60%)

In 25 episodes of distinct ventricular tachycardia (18 patients), the number of cases of successful discrimination (> 75% of all depolarizations at the 95% confidence level) is shown for seven separate bandwidths.

point, 10-Hz resolution) 2-pole bandpass filter with selectable cutoff frequencies. It was written in-house in the C programming language.

Six sets of filtered data files were created (for each of the original episodes) at the following bandwidths: 1–250 Hz, 1–100 Hz, 1–80 Hz, 10–80 Hz, 20–80 Hz, and 30–80 Hz. Each set (containing a SR passage for template construction, a second SR passage, and a distinct VT) was reprocessed as in the original method and results tabulated.

Statistical Validation

Statistical validation with nonparametric tolerance intervals was performed. This method was selected because the distribution of the correlation values has been shown to be nongaussian,[13] thus statistical measures that assume a normal distribution are inappropriate. Nonparametric tolerance intervals were constructed using the range of the similarity metric (ρ) to estimate, with a given confidence level, bounds within which 75% of all ρ occur with 95% confidence level.

Results

In initial processing of wideband recordings (1–500 Hz), CWA discriminated 23 of 25 (92%) episodes with 95% confidence level. A bandwidth of 1–250 was equivalent. (Table I.) Reduction of the high frequency cutoff to 100 Hz resulted in a

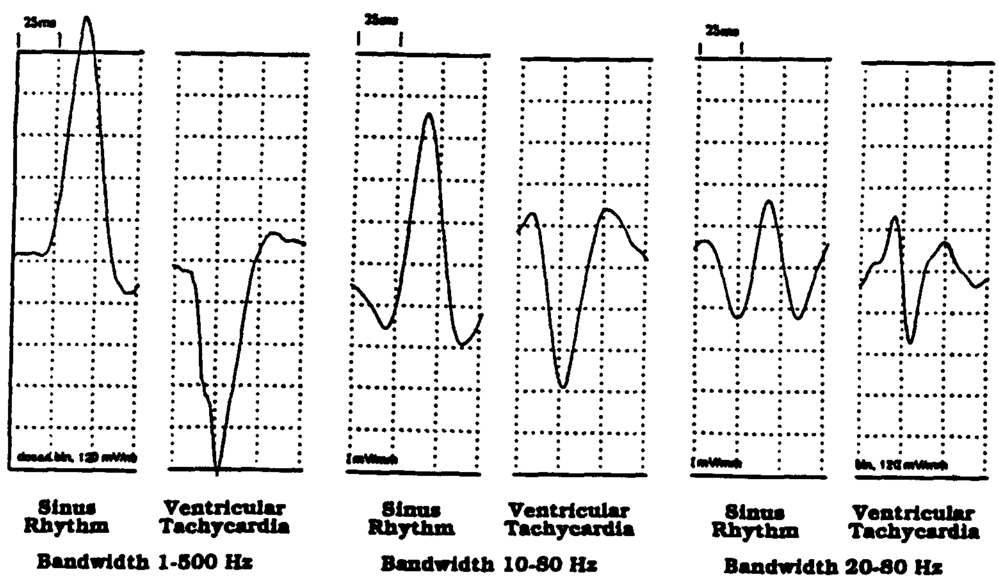

Figure 1. *Examples of ventricular waveforms from a patient during sinus rhythm (SR) and ventricular tachycardia (VT) at three distinct bandwidths (leftmost pair, 1–500 Hz, middle pair, 10–80 Hz, and rightmost pair, 20–80 Hz). In this patient, all depolarizations in SR were separable from those in VT at the 95% confidence level at the three bandwidths shown.*

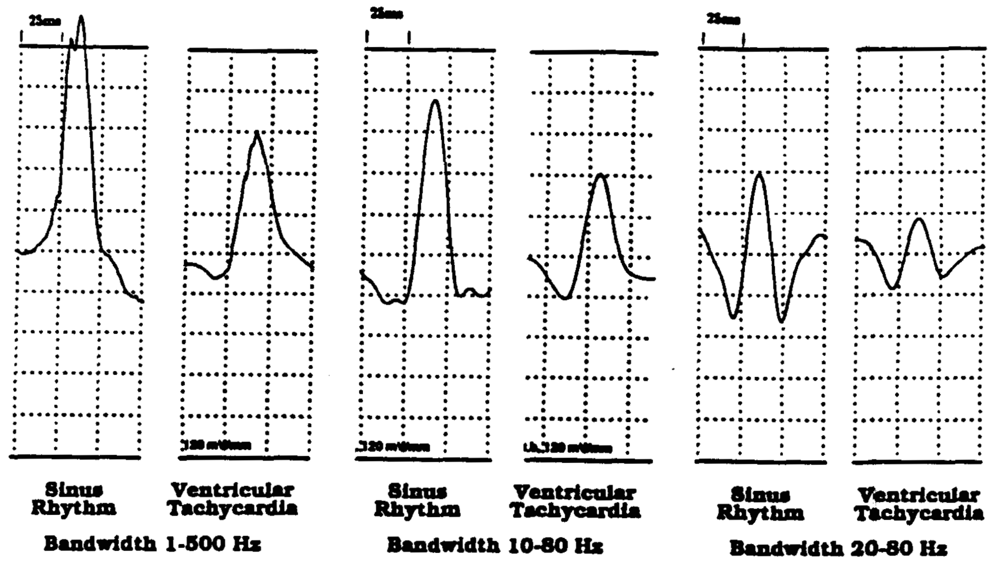

Figure 2. *Ventricular waveforms from a second patient ordered as in Figure 1. Sinus rhythm and ventricular tachycardia were separable (>75% of depolarizations, 95% confidence level) in all bandwidths shown. Separation was unsuccessful at bandwidth of 30–80 (not shown).*

decrease in discriminatory power to 21 of 25 (84%), and a bandwidth of 1–80 Hz gave 20 of 25 (80%) separability. Raising the low frequency cutoff to 10 Hz while maintaining the 80-Hz high cutoff improved discrimination to 22 of 25 (88%). A bandpass of 20–80 Hz gave 18 of 25 (72%) discrimination, and at 30–80 Hz this decreased to 15 of 25 (60%). Table I presents the number of episodes of discrimination with >75% success at the 95% confidence level for all seven bandwidths.

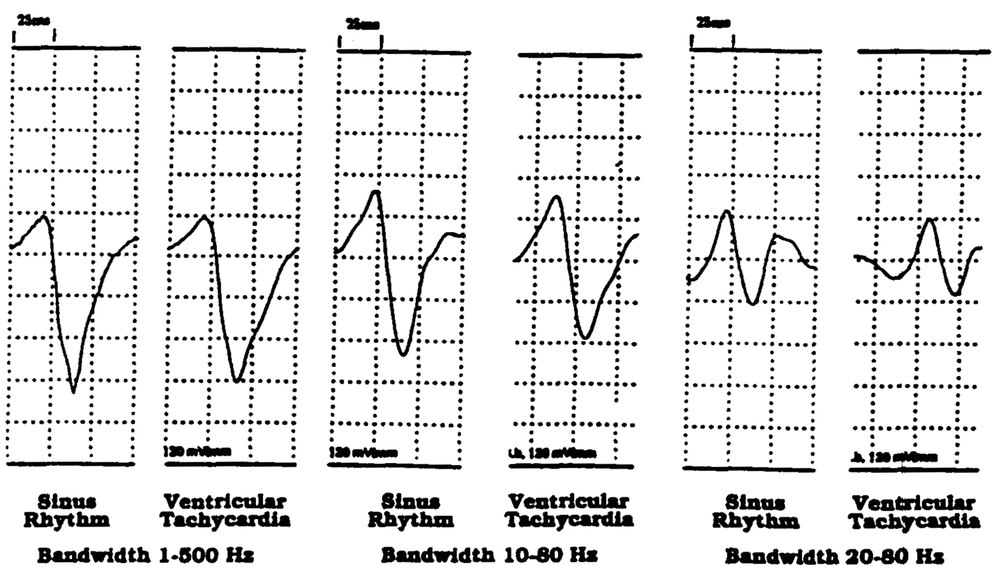

Figure 3. *Ventricular waveforms from a third patient ordered as in Figure 1. Separation of sinus rhythm and ventricular tachycardia (>75% of depolarizations, 95% confidence level) was successful at the original bandwidth (1–500 Hz) but failed for the remaining bandwidths.*

Figures 1–3 show exemplary waveforms from three patients selected for illustration.

Discussion

A preliminary study in our laboratory reported, in abstract form,[14] similar results for the 10–80 Hz bandwidth in a smaller patient population. Filtering at typical pacemaker/defibrillator passbands produced morphological analysis results equivalent to those yielded at wideband settings. The differences of ranges between SR versus VT decreased in filtered recordings but overall detection of VT was not degraded.

An earlier report presenting results of spectral analysis of the intraventricular electrogram[4] showed no appreciable frequency content beyond 230 Hz. Although high frequency notching has been observed on the waveforms, its contribution to CWA discrimination appears to be minimal. Notches were noticeably smoothed on the data filtered at 1–100 Hz, but separation results achieved a success of 84%. Indeed, low pass filtering at levels down to 80 Hz may be acceptable. But, raising the low frequency cutoff to a frequency >10 Hz has a major impact on this morphological measure, yielding 72% or less successful discrimination, and rendering it essentially ineffective.

In the interest of determining whether automated signal analysis of intracardiac electrograms had potential value for antitachycardia devices, computational demands of originally developed algorithms were largely ignored.[4] After demonstrating feasibility,[4,7–9] more recent efforts have addressed the design of fast algorithms, which duplicate CWA performance at $\frac{1}{6}$ to $\frac{1}{10}$ the computational complexity.[8] These fast algorithms, to date, have not been subjected to bandwidth analysis.

The use of reduced bandwidth for intracardiac electrogram analysis should yield important advantages in terms of sampling rate, which in turn affects memory requirements and computational demands.

Although CWA is not proposed as an expedient method for adoption in future devices (because its computational intensity makes it unsuitable), it has nevertheless been selected as a benchmark for assessing the effect of narrower bandwidths because its pattern matching capability is unaffected by amplitude and baseline changes. Other time domain techniques whose discriminatory power rests on amplitude fluctuation and/or baseline shifts (for separating SR and VT) will need to be examined in light of these observations.

Results of the present study, however, suggest that narrow bandlimits may compromise the expected advantages to be reaped from automated morphological electrogram analysis. Design criteria for next generation implantable antitachycardia devices will require cognizance of these limitations of reduced bandwidths if digital signal processing and pattern recognition are to be considered.

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