Filtering of the Intraventricular Electrogram and Its Effect on Signal Detection

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Abstract

Morphological waveform identification methods have been demonstrated to be effective for distinction of normal and abnormal conduction in intraventricular electrograms in small pilot tests. Yet these methods will find acceptance in future implantable devices only when computational demands and memory requirements are further reduced. A restricted passband allows reduced sampling rate and diminished storage for microprocessor based devices. In this study, we wished to determine the narrowest bandwidth that could be tolerated by a signal analysis morphometric (CWA) in order to distinguish ventricular tachycardia (VT) from sinus rhythm (SR). Twenty-five paired sets of bipolar intracardiac SR and monomorphic VT passages were analyzed. These signals were subjected to thirty-two different combinations of filter settings. Correlation coefficients were computed on a cycle-by-cycle basis for each signal passage to separate SR and VT. An absolute separation of ranges of CWA values was used as a discriminant function. Our results showed that a high frequency cutoff of 80 Hz yielded adquate performance of morphological separation of normal and abnormal rhythm, given that low frequency cutoff was no higher than 10 Hz. Low pass filtering has minor impact on the performance of CWA compared to high pass filtering.

1 Introduction

Implantable antitachycardia devices are capable of detecting cardiac arrhythmias and providing corrective electrical therapy. These devices now contain special purpose microprocessors and expanded memory capability. Thus detection of potentially lethal arrhytnmias and better separation of ventricular tachycardia and fibrillation are now feasible for new tiered-therapy devices. Mechanisms for storage and recovery of initiating events are available on some devices. Expanded digital electronics include analog-to digital converters, supplementary memory, and microprocessor control.

Appropriate therapy depends upon correct identification of malignant from benign rhythm, and the power required for more sophisticated detection schemes might easily be justified by conservation yielded from suppression of inadvertent delivery of therapy. False alarms continue to be problematic, and with the number of devices in place, patient tolerance has become an issue.

Morphological identification methods have been demonstrated to be effective for distinction of normal and abnormal conduction in small pilot tests [1, 2, 3, 4, 5, 6, 7]. Yet these methods will find acceptance only when computational demands and memory requirements are further reduced. A decreased frequency content of the signal under analysis would yield further savings of computational space and time. A restricted passband allows reduced sampling rate and diminished storage for resultant electrograms[13]. In this study, we wished to determine the narrowest bandwidth that could be tolerated by a signal analysis morphometric (CWA) in order to distinguish VT from SR as demanded[3].

2 Methods and Materials

Nineteen patients were evaluated during electrophysiologic studies. Distal bipolar intraventricular electrograms were recorded from an electrode catheter (USCI Division, C.R. Bard Inc., Billerica, MA, USA) located at the right ventricular apex during sinus rhythm (SR), and during a subsequent monomorphic ventricular tachycardia(VT) induced by programmed stimulation or AC current. All recordings were made with the patients lying supine. Ventricular electrograms were recorded on FM mag-

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netic tape at a speed of $3\frac{3}{4}$ inches/sec (Hewlett-Packard 3968A, San Diego, CA, USA) with filter settings of 1 – 500 Hz (Honeywell Electronics-for-Medicines, Pittsburg, PA, USA).

Three patients exhibited two different ventricular morphologies during separate protocols as confirmed by the 12-lead electrocardiogram (ECG), and one had four distinct VT morphologies. Each of the unique tachycardias, paired with the preceding sinus rhythm passage, was treated as a separate case for this study. Twenty-five paired sets of SR and VT passages were analyzed. For developmental purposes, intraventricular electrograms were digitized at a sampling rate of 1000 Hz using a personal computer with a LabMaster data acquisition system (Scientific Solutions, Inc., Solon, OH, USA) and a Codas display system(Dataq, Inc., Akron, OH, USA).

Two separate sinus rhythm passages and at least one passage for ventricular tachycardia of each patient were digitized. The first sinus rhythm was used to generate a template as a reference waveform. The second sinus rhythm passage was subjected to analysis to determine the extent to which each cardiac cycle yielded a match with the template, and the induced ventricular tachycardia passage was similarly analyzed. The range of correlation coefficients from the SR passage was tested against the VT range to establish whether separation of these valuse was present.

These same 25 paired passages were subjected to digital filtering with thirty-two distinct passbands reflecting a variety of high and low cutoff frequencies. The digital filter was a finite impulse response (FIR, 100 point, 10 Hz resolution) bandpass filter with selectable cutoff frequencies (custom software developed in house). Thirty-two sets of filtered data for each of the 25 original cases were created at the following bandwidths: $1-500, 1-250, 1-100, 1-90, 1-80, 1-70, 1-60, 1-50, 1-40, 1-30, 10-500, 10-250, 10-100, 10-90, 10-80, 10-70, 10-60, 10-50, 20-500, 20-250, 20-100, 20-90, 20-80, 20-70, 20-60, 20-50, 30-500, 30-250, 30-100, 30-90, 30-80, 30-70, 30-60, 30-50$ Hz.

The window size of waveform analysis was customized for each patient to restrict analysis to the depolarization portion only of each cardiac cycle. This patient-specific analysis window was imposed on all subsequent analysis for the same patient. Discriminant analysis consisted of a signal-averaged SR template compared individually with each subsequent SR cycle and each cardiac cycle of the VT passage using correlation coefficient waveform analysis(CWA). The following equation is used to calculate the correlation coefficient:

$$\rho = \frac{\sum_{i=1}^{M}(T_i - \bar{T})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{M}(T_i - \bar{T})^2 \sum_{i=1}^{M}(S_i - \bar{S})^2}} \qquad (1)$$

where T_i = the template points, S_i = the signal points under analysis, $\bar{T}$ = the average value of the template points, $\bar{S}$ = the average value of the signal points, M = the number points in the template, and ρ = the performance measure. Accurate alignment of the waveforms under analysis was performed by a sliding window method to compensate for misaligned trigger points[11]. Successful separation of sinus rhythm and VT was defined as no overlap in the ranges of correlation coefficients of each rhythm.

3 Results

Using a discriminant function of absolute separation of classes, we wished to determine the robustness of the morphologic metric (CWA) in a wide variety of filter settings which reduced the frequency content of the signal. Results are shown in Table 1 in which the number of successful separations at each filter setting is shown in each cell. Results are also shown in Figure 1 in which the four graphs represent four groups of filter settings with different low cutoff frequencies. Results of this initial processing are considered to be optimal, given the dynamic range of the signal, optimization of waveform alignment, and mathematical robustness of the morphometric CWA. Results show that dramatic decreases in the high frequency cutoff make only a minor impact on the discriminatory power of CWA. The separation of rhythms in 21/25 patient-sets recorded at 1-500 Hz decreased to 19/25 patients at 1-80 Hz and remained constant even to such narrow bandwidths as 1-30 Hz. By contrast, the low frequency cutoff characteristic and effect oo the morphometric was much more pronounced. At all high frequency cutoff settings from 500 to 50 Hz, a low frequency cutoff of 20 Hz produced a serious deterioration of discriminatory power from 21/25 patients at 500 Hz to 17/25 at 50 Hz. The 30 Hz low frequency cutoff was even more deleterious, giving a serious degradation of discriminatory power at all settings.

4 Discussion

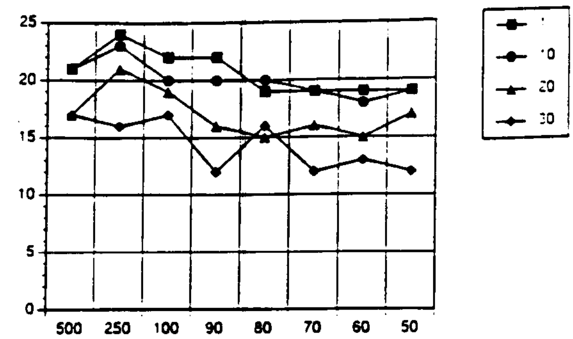
While there is a concern that introducing more complex digital logic for signal analysis in implantable

Table 1: Filtering of CWA

Filter	500	250	100	90	80	70	60	50
1	21	24	22	22	19	19	19	19
10	21	23	20	20	20	19	18	19
20	17	21	19	16	15	16	15	17
30	17	16	17	12	16	12	14	12

Separation of Sinus Rhythm from Ventricular Tachycardia. Results show number of successful separation cases out of 25 patient sets. CWA = correlation Waveform Analysis. Horizontal rendition shows effects of high frequency cutoffs and vertical rendition shows effect of low frequency cutoffs.

Figure 1: Separation of SR Template from VT.



x axis = high cutoff frequency (Hz)
y axis = number of successful separation

devices will cause early depletion of batteries, the reduction of false delivery of therapy by as much as 30% could easily preserve the necessary power to maintain these digital circuits. From the Nyquist Sampling Theorem[13], the highest frequency present in the signal, as determined by the bandpass filter, defines the lowest possible sampling rate. Reducing sampling rate can reduce memory requirements and the load of computation. Our results showed that a high frequency cutoff of 80 Hz yielded adequate performance of morphological separation of normal and abnormal rhythms, given that low frequency cutoff was no higher than 10 Hz. Successful separation rate was 80 % using bipolar intraventricular electrograms. The potential for improving separations using other electrode lead polarities and/or configurations deserves further study. This demonstrated that the computational demands of CWA could be reduced sufficiently such that the algorithm might be practicable for implantable devices.

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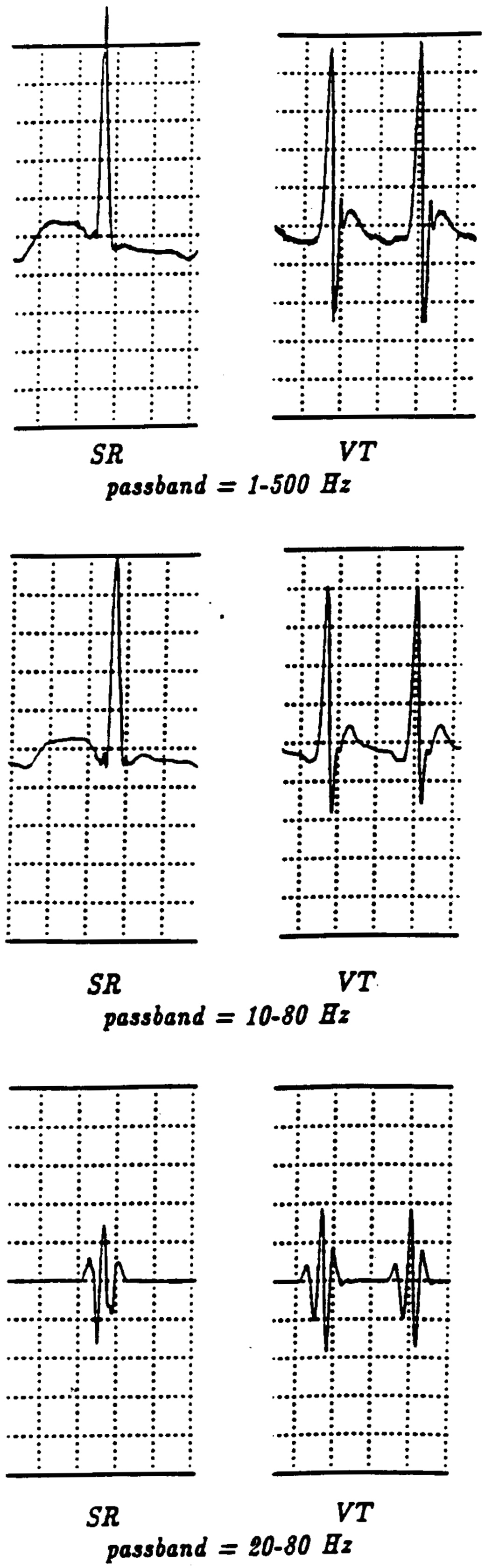
Figure 2: Waveforms of SR and VT at Various Filters.
patient no = AAEL149 AAEL = Ann Arbor Electrogram Library



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