A COMPARISON OF CORRELATION WAVEFORM ANALYSIS WITH A BIN AREA METHOD FOR RECOGNITION OF RETROGRADE ACTIVATION IN ATRIAL ELECTROGRAMS

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Abstract

Accurate detection of pacemaker mediated tachycardia requires a rapid and reliable method for discriminating retrograde atrial activation (RAA) from anterograde atrial activation (AAA). We compared two methods of morphology analysis for discriminating RAA from AAA applied to the atrial electrogram: Correlation Waveform Analysis (*CWA*) and the Bin Area Method (*BAM*). Both methods were tested on 19 patients undergoing clinical electrophysiology studies. Both *CWA* and *BAM* discriminated anterograde atrial activation from 1:1 retrograde atrial activation in 19/19 patients, but BAM reduced the computational demands by a factor of six.

Introduction

The introduction of dual chamber, dual sensing and inhibiting (DDD) pacemakers has allowed physicians more flexibility in the treatment of various cardiac disorders. Along with this increased flexibility has been the occurrence of pacemaker-mediated tachycardia (PMT). PMT is commonly initiated either by atrial sensing of a retrogradely conducted ventricular depolarization or atrial sensing of a ventricular depolarization followed by a sequentially initiated ventricular stimulus [1-5]. PMT can also be initiated by other methods such as loss of atrial tracking, atrial premature depolarizations, or myopotential tracking [2] [6].

Previous methods of detecting PMT utilizing the direct discrimination of retrograde atrial activation from anterograde atrial activation have included the use of amplitude and slew rate [4] [7-10], the Gradient Pattern Detection (GPD) method [11-13], and combinations of time and frequency domain parameters [14]. However, none of these methods has been found to be uniformly reliable.

Correlation Waveform Analysis (*CWA*) has been proposed for discriminating intracardiac ventricular electrograms occurring during ventricular tachycardia from those occurring during sinus rhythm [15]. *CWA* computes the correlation coefficient (ρ) between a template and the waveform under analysis. The correlation coefficient is independent of the relative amplitudes of two signals, independent of any baseline changes, and produces an index of merit between -1 and 1 (a value of 1 indicating a perfect match to the template).

The Bin Area Method (*BAM*) is a new method developed for computational simplicity which compares a template with subsequent waveforms using a different norm than *CWA*. *BAM* is also independent of the relative amplitude of two signals, independent of baseline changes, and produces an index of merit between -1 and 1. Again, a value of 1 indicates a perfect match to the template. However, *BAM* requires one-sixth the multiplications of *CWA*. This reduced computational complexity has been designed to replicate the discriminatory capability of *CWA* while addressing the power limitations in implantable devices.

Both of these methods have been applied to analysis of the atrial electrogram for distinction of retrograde from anterograde conduction.

Methods and Materials

Electrophysiology Study. Bipolar atrial endocardial electrograms were recorded during elective clinical cardiac electrophysiology studies. The patient population consisted of 12 men and 7 women (age 28 to 87 years). None of the patients had dual atrioventricular nodal pathways or accessory atrioventricular connections. Patients were studied in a fasting postabsorptive state after sedation with 1-3 mg of intravenous medazolam. After administering 1% lidocaine for local anesthesia, two 7 French side-arm sheaths (*Cordis Corporation*) were positioned in the right femoral vein using the Seldinger technique. Two 6 French quadrapolar electrode catheters with an interelectrode distance of 1 cm (*USCI division, C. R. Bard Inc.*) were introduced and advanced under fluoroscopic guidance to the high right atrium or right atrial appendage and right ventricular apex. Atrial electrograms were recorded on FM magnetic tape (*Hewlett Packard 3968 and 3964A*) from the bipolar endocardial electrodes positioned in either the right atrial appendage (14 patients) or the high right atrium (5 patients) using amplifiers (*Siemens Mingograf-7*) with filter settings of 0.5 to 500 Hz. Tape speed was $3\frac{3}{4}$ inches per second with a bandwidth of 0 - 1250 Hz. All recordings were made with the patients lying supine. Atrial electrograms were subsequently replayed and digitized on an IBM PC/AT compatible computer with a Tecmar Lab Master (*Scientific Solutions, Inc.*) analog-to-digital system at a sampling rate of

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1000 Hz. Programs for digitization and subsequent waveform analysis were written in the C programming language and 8086 assembly language.

Method of Analysis. Data sets consisted of three 10-second passages from each patient. Two distinct passages were digitized from recordings made during sinus rhythm, the first for template creation and the second for analysis. A third passage was digitized from a segment recorded during pacing of the right ventricle at a rate sufficient to maintain 1:1 retrograde conduction to the atrium. A template, constructed by signal-averaging all depolarizations in the initial sinus rhythm (anterograde) passage, was employed for subsequent comparison with the second sinus rhythm passage and the passage of retrograde atrial activation. A careful selection of window size (34 to 70ms, mean = 44.5 ± 8.3) effectively excluded any local atrial repolarization in order to avoid the inclusion of injury current caused by temporary endocardial damage adjacent to the catheter. A software trigger was used for automatic detection of each sequential atrial waveforms.

Correlation Waveform Analysis (CWA). The correlation coefficient, a statistical measure of the similarity of two waveforms, produces a value (ρ) which falls between ± 1 such that identical signals have a value of +1, signals which are inverses of one another have a value of -1, and dissimilar signals fall within that range. Mathematically, the correlation coefficient is defined as follows,

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

where 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, N = the number points in the template, and ρ = the performance measure. In an actual implementation, the square of the correlation coefficient would be computed (avoiding the square root computation), i.e.

$$\wp = \text{sign}(\rho)\rho^2$$

After an initial threshold γ separating AAA from RAA is determined, and assuming all template processing is performed ahead of time, the computation of $\wp$ requires $2N+2$ multiplications, 1 division, $3N-3$ additions, and N subtractions.

Bin Area Method (BAM). BAM compares corresponding areas or *bins* constructed from the template with bins constructed from subsequent depolarizations using a simple norm. Consecutive sample points are summed to estimate the area under the waveform (forming *bins*) using a rectangular area rule. (See Figure 1.) The average of these bin values is then subtracted from all bins resulting in a correction of baseline deviation. Each corrected bin value is then normalized by the absolute sum of all corrected bins. As a final step, the sum of the absolute difference of these normalized and corrected bins with an identically processed template is computed. To ensure equal sized bins, templates were extended as necessary towards the onset of depolarization one or two milliseconds. To compute bin areas, we group P consecutive points to form M bins (where $MP = N$, and N represents the number of points in the template). This is given as follows:

$$B_i = \sum_{j=1}^{j=P} s_{(i-1)P+j} \qquad i = 1,2,...,M$$

$$T_i = \sum_{j=1}^{j=P} t_{(i-1)P+j} \qquad i = 1,2...,M$$

More simply, with 3-point bins, $B_1 = s_1 + s_2 + s_3$, $B_2 = s_4 + s_5 + s_6$, etc. Let

$$B = \sum_{i=1}^{i=M} \left|B_i - \bar{B}\right|$$

$$T = \sum_{i=1}^{i=M} \left|T_i - \bar{T}\right|$$

The resultant performance measure is:

$$\wp = 1 - \sum_{i=1}^{i=M} \left| \frac{B_i - \bar{B}}{B} - \frac{T_i - \bar{T}}{T} \right|$$

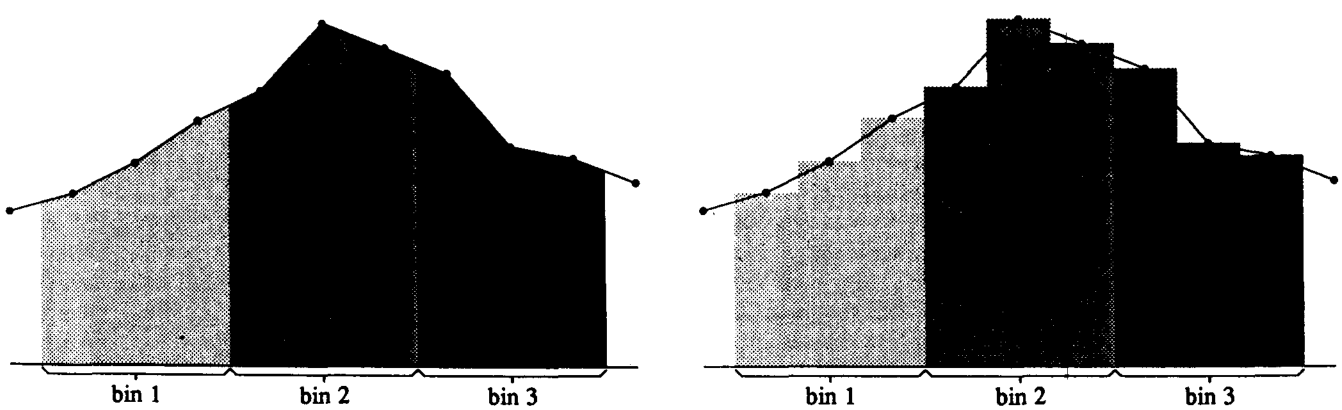

Figure 1: *Exact bin areas and approximate bin areas for the first three bins using 3-point bins.*

If an initial threshold γ separating RAA from AAA has been determined (i.e. if $\wp < \gamma$ than RAA), we can equivalently test

$$B - \sum_{i=1}^{i=M} \left| (B_i - \bar{B}) - B(\frac{T_i - \bar{T}}{T}) \right| < \gamma B$$

For comparison purposes, both ρ and $\wp$ can be written as

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

$$\wp = 1 - \sum_{i=1}^{i=M} \left| \frac{T_i - \bar{T}}{\sum_{k=1}^{k=M} \left| T_k - \bar{T} \right|} - \frac{B_i - \bar{B}}{\sum_{k=1}^{k=M} \left| B_k - \bar{B} \right|} \right|$$

BAM is independent of both baseline changes and amplitude fluctuations, and produces a performance measure between -1 and 1 (1 being a good fit to the template). Assuming prior template processing and choice of threshold γ, the computation of $\wp$ for N template points and M bins requires $M+1$ multiplications, 1 division, $N+2M-3$ additions, and $2M+1$ subtractions. For a 3-point bin, $P=3$ and $M=N/3$.

Triggering. In computing the performance measures ρ and $\wp$ between each depolarization and the template, a sliding window was used to effect the most precise alignment of each waveform. Both ρ and $\wp$ were computed using a *best fit* algorithm within an 11 millisecond window centered on the original trigger point.

Results

Results of applying both *CWA* and *BAM* with 3-point bins for 19 patients are given in Figures 2 and 3. Results for each patient are displayed as a column located on the horizontal axis, while the ranges of ρ or $\wp$ are displayed along the vertical axis. The range of ρ and $\wp$ for ***anterograde depolarizations*** is shown in black (with a white box at the mean), while the range for ***retrograde depolarizations*** is shown in white (with a black box at the mean). In 19 patients both *CWA* and *BAM* with 3-point bins was shown to be capable of discriminating normal anterograde atrial depolarizations from retrograde atrial depolarizations induced by right ventricular pacing with 100% accuracy at a sampling rate of 1000 Hz. However, individual thresholds were required for each patient and were based on the initial sinus rhythm passage. The computational requirements for each method are summarized in Table 1. This table assumes a threshold γ has been previously determined and all computations involving the template points have been previously computed. Data processed with *CWA* generally had smaller separation of the means and a smaller variation in ranges for both AAA and RAA than when processed with *BAM*. Using 3-point bins, *BAM* required only about $\frac{1}{6}$ the multiplications required by *CWA*.

Method	Mults	Divs	Adds	Subs
CWA	$2N+2$	1	$3N-3$	N
BAM (3-pt bin)	$N/3+1$	1	$\frac{5}{3}N-3$	$\frac{2}{3}N+1$

Table 1: *Computational complexity for CWA and BAM assuming an N point template.*

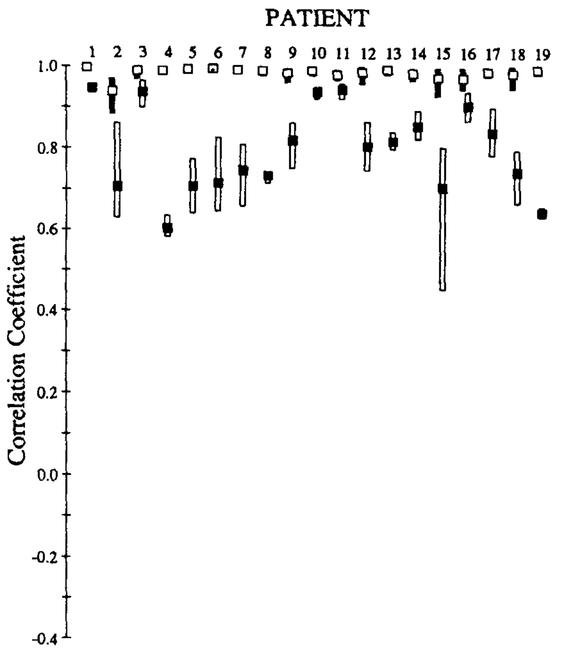

Figure 2: *Anterograde ranges (black) vs. retrograde ranges (white) for CWA.*

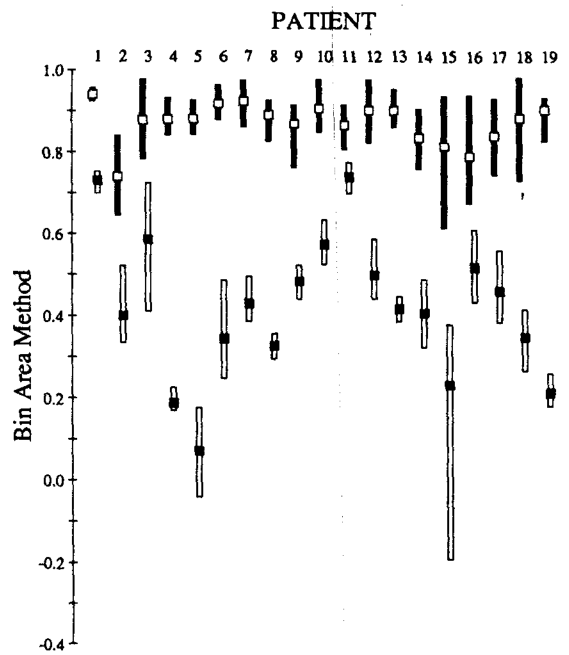

Figure 3: *Anterograde ranges (black) vs. retrograde ranges (white) using BAM with 3-point bins.*

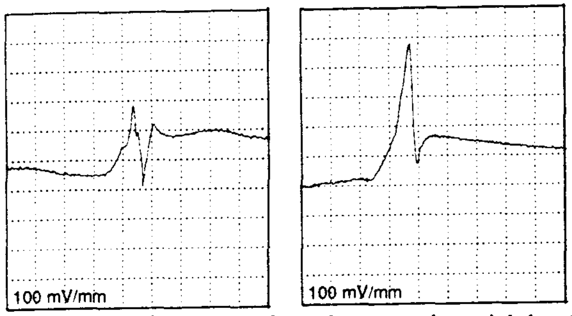

Figure 4: *Typical anterograde and retrograde atrial depolarizations (pt 8). The retrograde depolarization has a larger amplitude than the anterograde depolarization.*

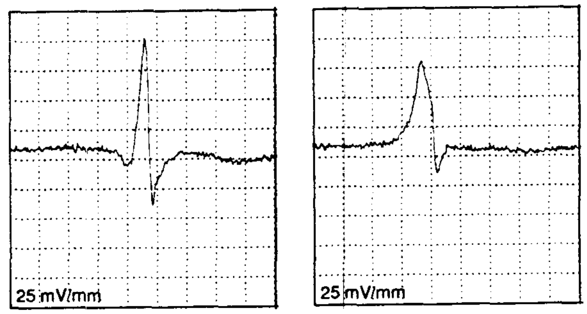

Figure 5: *Typical anterograde and retrograde atrial depolarizations (pt 13). The retrograde depolarization has a smaller amplitude than the anterograde depolarization.*

Figures 4 and 5 display a typical anterograde atrial depolarization and a typical retrograde atrial depolarization for patients 8 and 13, respectively. The paper speed is 200 mm/sec and both passages are displayed at the same gain settings for both retrograde and anterograde depolarizations. In Figure 4, the amplitude of the retrograde atrial depolarization is larger than the anterograde, while in Figure 5 the amplitude of the retrograde is larger than the anterograde. These figures demonstrate that discrimination based on amplitude alone may not be a reliable method [4] [7-12] As shown in Figures 2 and 3, both *CWA* and *BAM* separate the anterograde from the retrograde for these two patients.

Conclusion. Both Correlation Waveform Analysis and the Bin Area Method appear to be reliable methods of discriminating anterograde from retrograde depolarization using bipolar endocardial atrial electrograms and may be feasible for incorporation in dual chamber pacemakers for detection of PMT.

Acknowledgement. *This work was partially supported by NSF grant EET-835125 and a grant by Medtronic, Inc.*

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