

TABLE II Percentage of Cardiac Patients with ST-T Changes Induced by Physiologic Maneuvers

Study	Total Pts.	1 mm ST ↓	T-Wave		Provocation
			90° Change	180° Change	
Past studies					
Bellet & Roman ⁸	1,096	0.3	—	5	Position
Golden et al ⁹	72	—	1	1	Hyperventilation
Wasserburger et al ¹⁰	350	—	—	10	Hyperventilation
Present study					
Bertolet et al	100	6	23	8	Position
	100	3	10	2	Hyperventilation
	100	2	7	4	Valsalva

mal baseline. However, no ST-segment depression ≥ 1 mm was noted.

Our study demonstrates that ST-segment changes on AEM can be induced by position changes, hyperventilation or the Valsalva maneuver in almost one third of patients chosen for an electrocardiogram with a normal or near normal ST-segment baseline; however, ischemic-type ST-segment depression of 1 mm could be demonstrated in only 4%. ST-segment elevation ≥ 1 mm from an isoelectric baseline also was an infrequent occurrence. T-wave axis shifts of 180° were noted in 11% of patients after the physiologic maneuvers. Electrode shifts of 1 cm were more likely to induce ST-segment shifts from an abnormal baseline than from an isoelectric one; however, no ST-segment depression ≥ 1 mm was detected, regardless of the baseline.

This is the first study that examines the effects of various physiologic maneuvers on the electrocardiogram of cardiac patients as recorded by AEM. Deanfield et al⁷ used AEM to screen for ischemic-type electrocardiographic changes after postural variations in 100 normal volunteers. There were no episodes of ST-segment depression ≥ 1 mm, only 1 episode of ST-segment elevation ≥ 1 mm, and 2 episodes of 180° T-wave axis shift. Some previous studies of cardiac patients using other detection methods are compared with the present study in Table II. In all, these past studies demonstrated ischemic-type ST-

segment and T-wave changes in 0.3 and 1% of patients, respectively.

Screening for electrocardiographic changes induced by physiologic maneuvers is time- and labor-intensive for electrocardiographic technicians. However, we believe this practice should continue, because the results obtained may have an important role in the interpretation of ST-segment changes thought to be due to myocardial ischemia. Many of our patients manifested some ST-segment or T-wave changes during physiologic activities, which increased when the baseline was abnormal. These ST-segment and T-wave shifts (which alone may be insignificant) may be additive to other stimuli causing minor electrocardiographic changes resulting in the incorrect interpretation of myocardial ischemia. If AEM is to be performed for the detection of ischemic ST-segment changes, care should be taken to exclude those subjects who develop ischemic-type but artifactual electrocardiographic changes merely with changes of position or misplacement of the lead.

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Differentiation of Ventricular Tachycardia from Ventricular Fibrillation Using Intraventricular Electrogram Morphology

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Implantable antitachycardia devices are now capable of providing "ramp" therapy including antitachycardia pacing and low- and high-energy cardioversion for sus-

tained ventricular tachycardia (VT) in addition to defibrillation of ventricular fibrillation (VF).^{1,2} Appropriate therapy, however, is dependent on correct identification of VT and VF. Because of variations in ventricular electrographic amplitude during VF, currently implanted devices are unable to consistently detect consecutive ventricular depolarizations during VF.³ As a result, the rate criteria for VF detection may sometimes overlap with the rate criteria used for VT detection. Morphologic analysis of intracavitary ventricular electrograms using correlation waveform analysis has been demonstrated in previous studies to be effective in discriminating normal sinus

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rhythm from VT, paroxysmal bundle branch block of supraventricular origin, and retrograde atrial activation.⁴⁻⁷ Whether VF is distinguishable from sinus rhythm and VT with a similar method has not been determined. This study examined whether VT and VF can be distinguishable from sinus rhythm and from each other by correlation waveform analysis of intracavitary ventricular electrograms.

Twelve consecutive patients were evaluated while undergoing routine cardiac electrophysiologic studies. Distal bipolar (1 to 500 Hz) intraventricular electrograms were recorded from an electrode catheter positioned in the right ventricular apex during sinus rhythm, monomorphic VT induced by programmed electrical stimulation, and VF induced by programmed stimulation or alternating current. Ventricular electrograms were recorded on FM magnetic tape and digitized subsequently on a PC at a sampling rate of 1,000 Hz. The programs for digitizing and waveform analysis were written in C and assembly language. A digital differentiator was used to detect each of the individual intracardiac electrograms. A template was created from a 15-second passage of sinus rhythm for correlation waveform analysis of subsequent 15- to 30-second passages of sinus rhythm, VT and VF. Correlation waveform analysis was used as a statistical measure of the similarity or dissimilarity of the waveform under analysis with the sinus rhythm template. The correlation coefficient was defined as:

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

where t_k = the template points, S_k = the signal points to be processed, \bar{t} = the average value of the template points, \bar{s} = the average value of the signal points, N = the number of points in the template, and ρ = the index of merit. The value of the correlation coefficient therefore fell between ± 1 such that identical waveforms had a value $+1$, waveforms which were inverses of one another had a value of -1 , and all other, dissimilar waveforms had values between $+1$ and -1 . A patient-specific window was chosen during creation of the sinus rhythm template to include depolarization only and to exclude the potentially confounding repolarization injury current caused by the acute placement of the electrode catheters. This window size was imposed on all subsequently analyzed electrograms. The template was aligned with the trigger point of the electrogram under analysis, and then shifted a maximum of 10 ms in both directions in order to maximize the alignment of the 2 waveforms. The magnitude of the variance of cycle-to-cycle correlation waveform analysis was then used as a discriminant function for VT and VF.

Table I summarizes the results for all 12 patients. The types of electrograms analyzed are illustrated in Figures 1 and 2. The window sizes of the analyzed electrograms ranged from 52 to 106 ms. Mean correlation coefficient separated sinus rhythm from VT in 10 of 12

TABLE I Results of Correlation Waveform Analysis for Discriminating Ventricular Tachycardia from Ventricular Fibrillation

Pt. No.	Sinus Rhythm		VT		VF	
	Mean p Value	SD	Mean p Value	SD	Mean p Value	SD
1	0.986	0.008	0.852	0.115	0.714	0.221
2	0.987	0.006	0.836	0.072	0.355	0.348
3	0.995	0.003	-0.108	0.097	0.499	0.382
4	0.970	0.003	0.848	0.017	0.405	0.453
5	0.980	0.006	0.882	0.041	0.429	0.493
6	0.962	0.020	0.641	0.047	0.625	0.408
7	0.995	0.002	0.925	0.007	0.650	0.433
8	0.990	0.021	0.969	0.013	0.347	0.432
9	0.984	0.011	0.868	0.022	0.228	0.490
10	0.977	0.049	0.960	0.018	0.881	0.092
11	0.959	0.024	0.040	0.177	0.162	0.499
12	0.996	0.003	0.870	0.087	0.313	0.718

VF = ventricular fibrillation; VT = ventricular tachycardia.

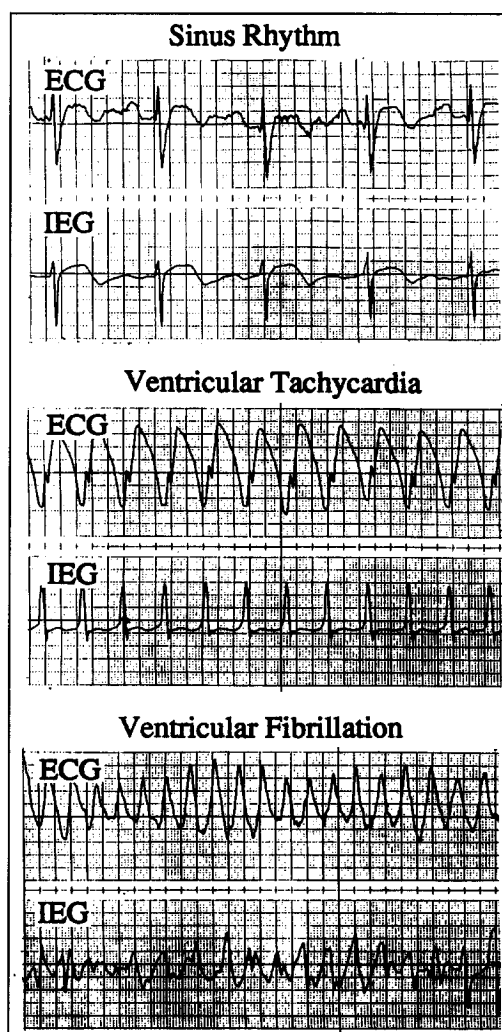


FIGURE 1. Examples of surface electrocardiographic (ECG) and distal bipolar intraventricular electrograms (IEG) of patient 11 during sinus rhythm, monomorphic ventricular tachycardia (VT) and ventricular fibrillation (VF). The difference in mean correlation coefficient from correlation waveform analysis of sinus rhythm (0.959) differentiated it from VT (0.040) and VF (0.162). The variance of VT (0.177)² differentiated it from VF (0.499)².

patients (83%) and sinus rhythm from VF in all 12 patients (100%). The range (and means) for standard deviation(s) were 0.004 to 0.049 (0.013) for sinus rhythm, 0.007 to 0.177 (0.059) for VT, and 0.092 to 0.718 (0.414) for VF. For each of the 12 patients, the individual variances for VT and VF were significantly different (*F* test, $p < 0.0001$). A threshold midway between the average variance in VT and VF, respectively, was a successful discriminant in 11 of 12 patients (92%).

The primary method for tachycardia detection of VT and VF by currently implanted devices has been based on timing information derived from heart rate, including an abrupt increase in heart rate, detection of a rate that exceeds an arbitrary minimum, and observation of a stable RR interval during the tachycardia.⁸ However, such algorithms lack specificity for VT and VF recognition.

The complementary use of time and frequency domain analysis has been proposed for VT and VF detection.^{4-7,10-14} The only method now used in implanted

devices for VF detection — probability density function⁹ — has had limited applicability for patients who experience both recurrent VT and VF. Previous studies have demonstrated the efficacy of correlation waveform analysis in detecting VT when compared with other proposed time and frequency domain analyses of individual bipolar intraventricular electrograms.⁴⁻⁷ The results of this study suggest that a similar time domain analysis of intraventricular bipolar electrograms may also be useful in discriminating VF from sinus rhythm as well as from more organized and more stable monomorphic VT.

The present study had several limitations. The recordings analyzed were from supine patients during clinical electrophysiologic studies. No effort was made to optimize any filter characteristics to improve alignment. The impacts of changes in position, hydration and vascular tone were not examined. Changes in electrogram amplitude that might occur during everyday activity of a patient with a permanent lead also remain unknown.

Although correlation waveform analysis has the potential advantages of being independent of electrogram amplitude and baseline fluctuations, its incorporation in currently available, implantable microprocessors may prove to be impractical because of its computational demands. Further work is necessary to determine whether other, less computationally demanding time domain methods are similarly effective in detecting and distinguishing VT and VF.¹⁵

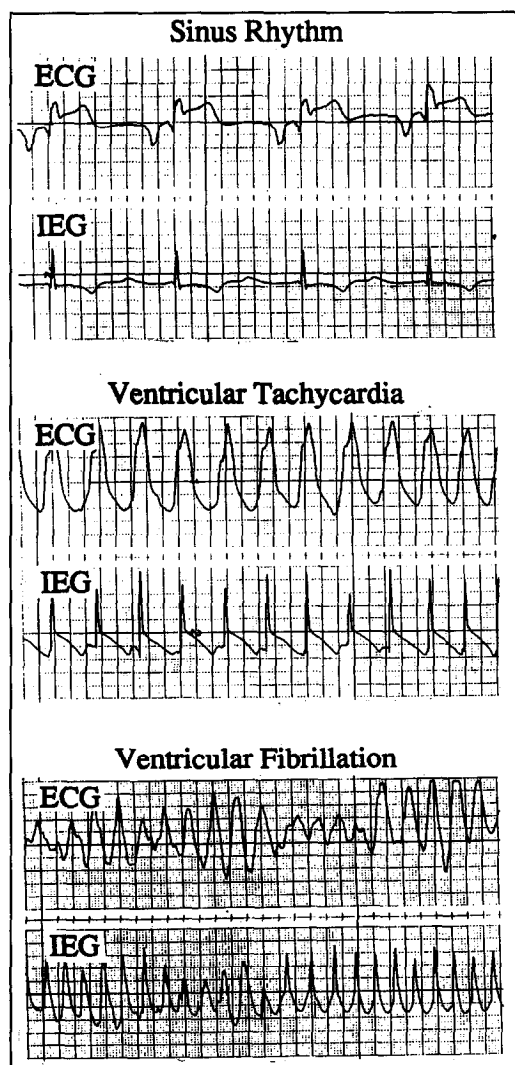


FIGURE 2. Examples of the electrograms of patient 10 during sinus rhythm, ventricular tachycardia (VT) and ventricular fibrillation (VF). The difference in mean correlation coefficient from correlation waveform analysis of sinus rhythm (0.977) differentiated it from VT (0.960) and VF (0.881). However, the variance of VT (0.018)² and VF (0.092)² were similar. Discrimination between these 2 tachyarrhythmias was not possible using this criterion. Abbreviations as in Figure 1.

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