Added Spectral Features in ECGs From Patients With Ventricular Tachycardia Detected by Phase and Group-Delay Analysis Over the Cardiac Cycle

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ABSTRACT

Fourier analysis of the signal-averaged ECG (SAECG) has previously revealed significant differences in magnitude spectra that differentiate patients with ventricular tachycardia(VT) from those without VT. To determine additional distinguishing features in the frequency domain, we analyzed phase spectra of SAECGs of sinus beats from 40 patients with VT, 41 without VT, and 20 normal controls. Unwrapped phase spectra from SAECGs of the entire cardiac cycle were calculated with respect to 3 fiducial points: the beginning of the P wave, the mean delay for frequencies in the DC to 100 Hz band, and the mean delay for frequencies in the band which accounted for 97.5% of the energy in the vector magnitude of the Frank SAECG leads. Phase spectra of SAECGs from patients with VT differed from those from non-VT patients ($p < 0.05$ to 0.000002) at frequencies > 20 Hz for the P-wave fiducial, for 1-19 Hz for the 100-Hz fiducial, and at frequencies > 1 Hz for the 97.5%-energy fiducial. Average group delays in SAECGs from patients with and without VT differed ($p < 0.05$) from 7 to 66 Hz for the P-wave fiducial and from 9 to 56 Hz for the 97.5%-energy fiducial. Group delays with respect to the P-wave fiducial in the VT patients in the 7-66 Hz band were on average 23 msec and 28 msec longer than those of the non-VTs and normals, respectively. Thus phase spectra of SAECGs contain previously undetected features that together with magnitude are essential in improving methods for stratifying risk of VT.

INTRODUCTION

Analysis of the terminal QRS complex of the signal-averaged ECG (SAECG) obtained during sinus rhythm in both the time and frequency domains has been a useful first step inthe detection of some of the occult electrophysiological abnormalities that distinguish patients with a history of sustained ventricular tachycardia (VT). In studies of the entire cardiac cycle of SAECGs from patients with sustained VT, we demonstrated previously undetected alterations in the magnitudes of 1-7 Hz, 13-56 Hz, and 70-128 Hz frequencies.

Here we report a spectral study in which the interval of interest is the whole cardiac cycle, but phase rather than magnitude characteristics are examined. One objective of this study was to determine the extent to which phase and group-delay analysis of the cardiac cycle could detect features which distinguish patients with VT from those without VT. A second objective was to use group delays to locate temporal origins in the cardiac cycle for frequency bands which distinguish patients with VT from those without VT.

METHODS

1. Patients Studied

TABLE 1. Characteristics of Subjects

	Normals	Non VT	VT
Number	20	41	40
Age (yr)	36 ± 10	58 ± 12	59 ± 10[1]
Male/female	14/6	24/18	35/5
MI locus			
Anterior	...	23	26
Inferior	...	19	14
MI occurrence			
Remote (>4 wk)	...	34	34
Recent (2-4 wk)	...	8	6
LV ejection fraction (%)	...	47 ± 15	32 ± 11[2]
QRS duration (msec)			
Mean	92 ± 8	99 ± 11	120 ± 27[2]
Range	72-116	80-124	88-188
Conduction abnormality			
LBBB	...	...	5
RBBB	...	1	2
IVCD	...	3	9
Cardiac cycle length (msec)			
Mean	805 ± 69	795 ± 96	777 ± 73[1]
Range	663-984	583-995	639-975

[1] No significant difference vs. non VT
[2] $p < 0.0001$ vs. non VT

2. Data Acquisition and Signal Averaging

Frank X-, Y-, and Z-lead ECGs were recorded during sinus rhythm over a bandwidth of 0.05-470 Hz. Data from 100 beats were averaged.

3. Frequency Analysis of the Cardiac Cycle

Spectral estimates of the entire cardiac cycle of each signal-averaged X-, Y-, and Z-lead ECG were computed using the fast Fourier transform (FFT) after padding each baseline-corrected SAECG lead with zeros for a total of 16,384 points.

4. Phase

Unwrapped phase was adjusted so that it was expressed relative to three temporal fiducials. Two of the fiducials were the onsets of the P and Q waves. The third was the mean delay of frequencies in the band which accounted for 97.5% of the energy in the vector magnitude. This energy criterion was chosen because it provided the maximum separation of those patients with VT from those without VT.

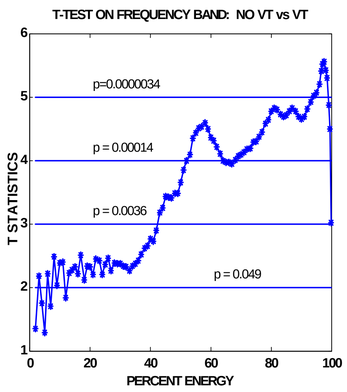


FIGURE 1. Probability of the similarity of VT and non-VT patients based on the bandwidth which accounted for a given percent of the total energy in the vector magnitude of each subject.

5. Group Delay

Group delay $\tau(\omega)$ gives a measureof the relative delay of each frequency component in a waveform.

$$\tau(\omega) = - d/d\omega\ [\phi(\omega)],$$

where $\phi(\omega)$ is the unwrapped phase at discrete frequency ω.

6. Statistical Analysis

Both unwrapped phase and group delays from each subject category were compared statistically using an unpaired t test. Results of statistical analyses were reported as the t statistic and probability of the null hypothesis at intervals of 0.977 Hz.

PHASE

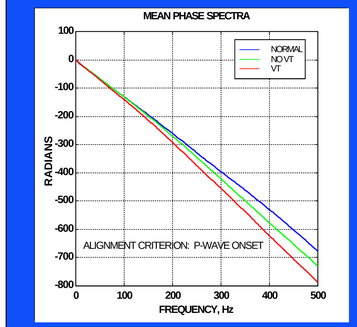


FIGURE 2. Mean phase spectra with respect to P-wave onset (upper). Spectra of SAECGs from VT and non-VT patients differed at all frequencies > 20 Hz (lower).

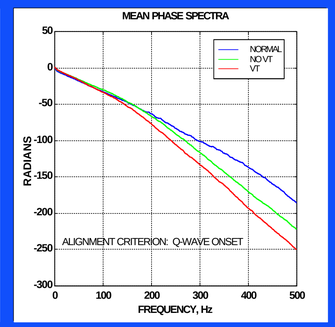


FIGURE 3. Mean phase spectra with respect to Q-wave onset (upper). Spectra of SAECGs from VT and non-VT patients differed at all frequencies > 59 Hz (lower).

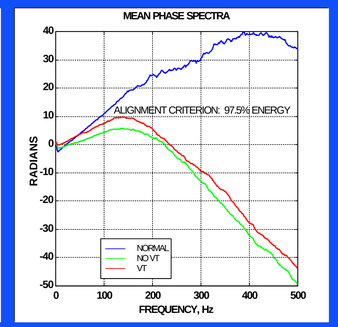


FIGURE 4. Mean phase spectra with respect to an energy fiducial (upper). Spectra of SAECGs from VT and non-VT patients differed at all frequencies < 63 Hz (lower).

GROUP DELAY

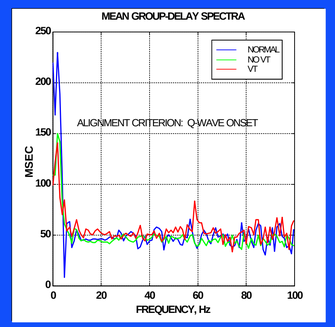
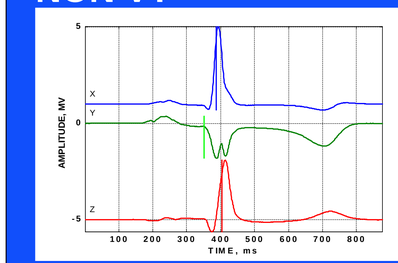


FIGURE 5. Mean group-delay spectra with respect to the onset of the Q wave (upper panel). Group-delay spectra of SAECGs from VT and non-VT patients differed ($p < 0.05$) for the 14-24 Hz band (lower panel).

NON VT



VT

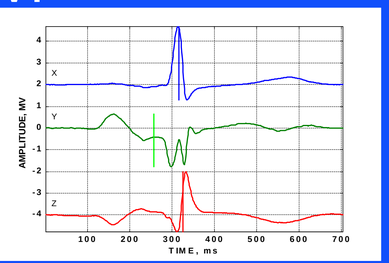
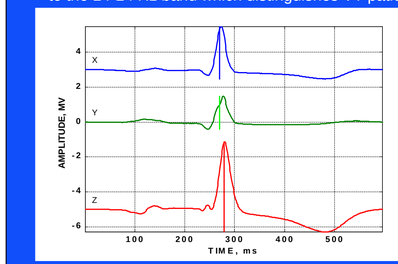


FIGURE 6. X, Y, Z leads of SAECGs from patients with remote inferior myocardial infarction. Average delay to the 14-24 Hz band which distinguishes VT patients from non-VTs is shown for each lead.



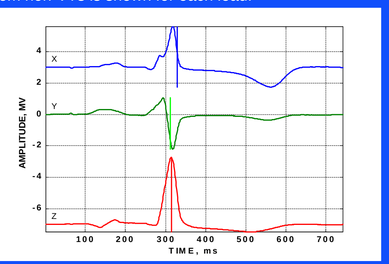


FIGURE 7. X, Y, Z leads of SAECGs from patients with remote anterior myocardial infarction. Average delay to the 14-24 Hz band which distinguishes VT patients from non-VTs is shown for each lead.

CONCLUSIONS

Based on phase and group-delay analyses of the entire cardiac cycle:

1. New features which distinguished patients with VT were identified.
2. These new features are excluded from detection with techniques that
   - — Limit the passband, restrict interrogation to the terminal QRS complex, or
   - — Examine only the magnitude spectrum of the signal-averaged ECG.

Our results do not represent a new index for SAECG analysis. Rather, they provide an objective basis and strong rationale for the development of new methods of analysis that incorporate all of the distinguishing spectral, temporal, and spatial features in ECGs from patients with sustained VT.

ACKNOWLEDGEMENT

This work was supported in part by National Institutes of Health Grant RO1-HL50295.