Spectral Analysis of 87-Lead Body Surface Signal-Averaged ECGs in Patients With Previous Anterior Myocardial Infarction as a Marker of Ventricular Tachycardia

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Background. There were few studies on the relation between the body surface distribution of high- and low-frequency components within the QRS complex and ventricular tachycardia (VT).

Methods and Results. Eighty-seven signal-averaged ECGs were obtained from 30 normal subjects (N group) and 30 patients with previous anterior myocardial infarction (MI) with VT (MI-VT[+] group, n=10) or without VT (MI-VT[−] group, n=20). The onset and offset of the QRS complex were determined from 87-lead root mean square values computed from the averaged (but not filtered) ECG waveforms. Fast Fourier transform analysis was performed on signal-averaged ECG. The resulting Fourier coefficients were attenuated by use of the transfer function, and then inverse transform was done with five frequency ranges (0–25, 25–40, 40–80, 80–150, and 150–250 Hz). From the QRS onset to the QRS offset, the time integration of the absolute value of reconstructed waveforms was calculated for each of the five frequency ranges. The body surface distributions of these areas were expressed as QRS area maps. The maximal values of QRS area maps were compared among the three groups. In the frequency ranges of 0–25 and 150–250 Hz, there were no significant differences in the maximal values among these three groups. Both MI groups had significantly smaller maximal values of QRS area maps in the frequency ranges of 25–40 and 40–80 Hz compared with the N group. The MI-VT(+ ) group had significantly smaller maximal values in the frequency ranges of 40–80 and 80–150 Hz than the MI-VT(−) group. These three groups were clearly differentiated by the maximal values of the 40–80-Hz QRS area map.

Conclusions. It was suggested that the maximal value of the 40–80-Hz QRS area map was a new marker for VT after anterior MI. (Circulation 1992;85:2060–2064)

KEY WORDS • myocardial infarction • tachycardia, ventricular • electrocardiography, signal-averaged • spectrum analysis

Low-amplitude, high-frequency signals at the terminal QRS and early ST segment identified in the time domain (so-called late potentials) have been considered a good marker of ventricular tachycardia (VT) in patients with previous myocardial infarction (MI). However, there were few studies about the relation between the body surface distribution of high- and low-frequency components within the QRS complex and VT. An infinite impulse response (IIR) filter, such as a recursive Butterworth digital filter, has commonly been used to analyze the signal-averaged ECG. IIR filters can achieve a sharp frequency response and isolate late potentials, but they have a poor phase response, do not preserve QRS morphology, and are not suitable for making accurate measurements of amplitude or energy throughout the QRS. On the other hand, fast Fourier transform (FFT) filters have an ideal phase response, and the filtered ECG morphology is well preserved. In this study, we recorded 87-lead ECGs (ECG data were signal-averaged and filtered by use of the FFT filter) and investigated the relation between VT and the spatial distribution of the high- and low-frequency potentials within the QRS complex.

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Methods

Subjects

The study population consisted of 30 patients (26 men, four women; age, 35–68 years; mean, 55 years) with previous anterior transmural MI (MI group) and 30 normal volunteers (N group, all men; age, 21–36 years; mean, 25 years). In the MI group, all patients had 1) a history of typical prolonged chest pain; 2) characteristic serial elevation of serum enzymes (creatine phosphokinase, glutamic oxaloacetic transaminase, and lactic dehydrogenase); 3) abnormal Q waves in anterior precordial leads; 4) wall motion abnormalities in the anterior wall of the left ventricle (segments 2 and/or 3 according to the reporting system of the American
Heart Association4) proven by left ventriculography; and 5) significant stenosis of 70% or more in the left anterior descending artery. Patients with intraventricular conduction disturbance or those who had had an MI during the previous 4 weeks were excluded. In the MI group, patients were divided into two groups with the presence or absence of VT according to findings in a 24-hour ambulatory ECG: the MI-VT(+) group (n=10) and the MI-VT(−) group (n=20). VT was defined as five or more successive ventricular premature beats. Four patients had at least one documented episode of sustained VT, and six patients had nonsustained VT. In the N group, all subjects had normal standard 12-lead ECG, normal echocardiograms, and no history of cardiovascular disease. Informed consent was obtained from all subjects before the study was begun. This study was approved by the Yamagata University Ethical Committee.

ECG Recordings

Body surface ECG mapping was performed by means of the VCM-3000 system (Fukuda Denshi Co., Tokyo). The location of lead points and the procedure used for the data sampling and processing have been described in detail elsewhere.5–7 Eighty-seven body surface leads were arranged in a lattice-like pattern (13×7 matrix), except for four lead points in the midaxillary lines, and covered the entire thoracic surface (59 leads on the anterior chest and 28 leads on the back). ECGs from these 87 unipolar leads with Wilson’s central terminal as reference were sampled simultaneously. This system consisted of amplifiers that had a frequency response between 0.05 and 500 Hz and dynamic range of ±10 mV. The recorded analog data were digitized by a 12-bit or 16-bit analog/digital converter with a sampling rate of 1,000 samples per second per channel.

By use of the VCM-3000 system, body surface mapping data were sampled for 8 seconds and saved on a 1.25-megabyte floppy disk. This procedure was repeated 20–30 times. Data recorded on 20–30 floppy diskettes were transferred to a personal computer (PC-9801 VX4, Nihon Electronic Co., Tokyo) and copied on a hard-disk unit. The 87-lead ECG data were stored on an optical disk (DD-S5001m2, Pioneer Electronic Co., Tokyo) and later analyzed.

Data Processing

ECG wave forms were averaged to reduce the random noise. The signal-averaging process took place with a 16-bit personal computer (PC-9801 VX4) as previously reported. Briefly, the averaging was achieved with the cross-correlation function in the time domain to reject ectopic beats and grossly noisy signals. The number of beats averaged was from 87 to 216 (mean, 129). The signal-averaged ECG data were stored on a floppy disk and an optical disk for further processing. The signal-averaged ECG data were further processed offline on a minicomputer (VAX 11/750, Digital Equipment Co., Maynard) by means of a program developed at our institution. The onset and offset of the QRS complex were determined manually from 87-lead root mean square (RMS) voltage. The RMS values were computed from the averaged (but not filtered) ECG wave forms. The RMS value of a signal was determined as follows.

\[ r(t) = \sqrt{\sum_{e=1}^{87} f(t,e)^2 / 87} \]

where t is sample point in a time domain, e is lead, f(t,e) is ECG amplitude at sample point t of an e lead, and r(t) is 87-lead RMS value at sample point t.

For analysis with the FFT, ECG data were padded with zeros for a total of 1,024 points. A time series \( f(t) \) representing the ECG complex was subjected to a 1,024-point FFT analysis to produce a frequency series \( F(\omega) \). A product of \( F(\omega) \) with a transfer function, \( H(\omega) \), was computed to produce a filtered wave form \( G(\omega) \) in a frequency domain.

\[ G(\omega) = F(\omega)H(\omega) \]

where \( H(\omega) \) is given by the following function, previously reported by Abboud et al.\(^3\)

\[ H(\omega) = \left[1 / \sqrt{1 + (WL/\omega)^2}\right] \left[1 - [1 / \sqrt{1 + (WH/\omega)^m}]\right] \]

with WL and WH being the low and high cut-off frequency of the filter. We used five frequency ranges; 0–25, 25–40, 40–80, 80–150, and 150–250 Hz. Parameters \( m \) and \( n \) determine the decay slope of the filter. In this study, parameters \( m \) and \( n \) were 1) 1–10, 2) 10–16, 3) 16–32, 4) 32–60, and 5) 60–100, respectively. Figure 1 shows the amplitude response of the FFT bandpass filter with the five frequency ranges. A filtered wave form \( g(t) \) was produced by transformation (inverse FFT) of the signal \( G(\omega) \) from the frequency domain back to the time domain. From the QRS onset to the QRS offset determined from unfiltered ECG, the time integration of the absolute value of reconstructed wave forms was calculated for each of the five frequency ranges. The body surface distributions of these areas were expressed as QRS area maps (0–25, 25–40, 40–80, 80–150, and 150–250-Hz QRS area maps).

**Statistical Analysis**

Statistical inferences were made by use of SAS-PC (SAS Institute Inc., Cary, N.C.). Comparisons within groups were made by ANOVA with SAS general linear
models procedure and Scheffe’s test. A value of $p<0.05$ was considered statistically significant. Data were expressed as mean±SD.

Results

Figure 2 illustrates examples of QRS area maps of 0–25, 25–40, 40–80, 80–150, and 150–250 Hz from three representative cases. The left maps were from a patient of the MI-VT(+) group, the middle maps were from a patient of the MI-VT(−) group, and the right maps were from a normal volunteer. Compared with the normal subject, patients with myocardial infarction (MI) had a smaller maximal value in the QRS area map of 25–40, 40–80, and 80–150 Hz. MI-VT, groups with previous myocardial infarction with (+) or without (−) ventricular tachycardia. FFT, fast Fourier transform; IFFT, inverse FFT.

Maps were located in the left anterior chest (leads around G.). The sites of maxima of other frequency ranges (25–40, 80–150, and 150–250 Hz) were similar to those of 40–80 Hz QRS area maps. There was no remarkable difference in the pattern of QRS area maps between the MI-VT(+) group and the MI-VT(−) group. In normal subjects, maxima of QRS area maps were located in the left anterior chest in both the 0–25 and 40–80 Hz ranges.

Table 1 summarizes the comparison of maximal values of QRS area maps among the three groups (MI-VT[+] group, MI-VT[−] group, and N group). The maximal value of the QRS area map in the 0–25 and 150–250 Hz ranges showed no significant differences among these three groups. In the 25–40 Hz range (Figure 4a), the MI groups had smaller maximal values of QRS area maps than the N group ($p<0.01$, MI-VT[+] versus N; $p<0.01$, MI-VT[−] versus N). In the 40–80 Hz range (Figure 4b), significant differences were found among these three groups. The MI-VT(−) group had smaller maximal values of QRS area maps than the N group ($p<0.01$), and the MI-VT(+) group had smaller maximal values than the MI-VT(−) group ($p<0.01$). In the 80–150 Hz range (Figure 4c), the MI-VT(+) group had smaller maximal values of QRS maps.

<table>
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<th>Table 1. Comparison of the Maximal Value of QRS Area Maps</th>
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<td>0–25 Hz</td>
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<td>MI-VT(+)</td>
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<td>MI-VT(−)</td>
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Values are mean±SD mV·msec.

MI-VT(+) previous anterior myocardial infarction with ventricular tachycardia; MI-VT(−), previous anterior myocardial infarction without VT; N, normal group.

*p<0.01 vs. N.
†p<0.01 vs. MI-VT(−).
An IIR filter, such as a recursive Butterworth digital filter, has commonly been used to analyze the signal-averaged ECG. IIR filters can achieve a sharp frequency response and isolate low potentials but suffer from "ringing" because of their nonlinear phase response. The use of a bidirectional implementation of this filter can circumvent this problem, but there are other potential problems with this technique. Because of nonlinear phase response, this filter distorts the signal and introduces temporal shift of the high-frequency signals. The mid-QRS area, where the bidirectional implementation meets, is not properly defined. IIR filters do not preserve QRS morphology and are not suitable for making accurate measurements of amplitude or energy throughout the QRS. On the other hand, FFT filters have an ideal phase response, and the filtered ECG morphology is well preserved. FFT filters are useful for investigating potentials within the QRS complex. To investigate the spectral change of QRS in patients with anterior MI, we used the FFT filter with the transfer function reported by Abboud et al. and analyzed five frequency ranges (0–25, 25–40, 40–80, 80–150, and 150–250 Hz).

Low-amplitude, high-frequency signals at the terminal QRS and early ST segment identified in the time domain (so-called late potentials) have been considered a good predictor of VT and sudden death in patients with previous MI. Some investigators reported that total high-frequency energy throughout the QRS decreased in patients with VT. However, these studies evaluated bipolar X-, Y-, and Z-lead ECGs, and few studies evaluated the spectral change by use of FFT filter in multiple-lead body surface ECGs. We analyzed 87-lead unipolar ECGs, which can provide information about the body surface distributions of high- and low-frequency potentials within the QRS complex.

In normal subjects, the maxima of QRS area maps were located in the left anterior chest (leads around G4) in both low- and high-frequency ranges. In the MI group, the maxima of QRS area maps of low-frequency components were located in the middle anterior chest (E4, E5, F4, and F5), corresponding to the QS area. However, in the high-frequency components, the maxima were located in the left anterior chest (leads around G4) and were shifted to the left compared with those of low-frequency components.

In this study, it was demonstrated that in the middle anterior chest, corresponding to the QS (infarcted) area, the magnitude of high-frequency components showed relatively lower values than those of low-frequency components. There were no remarkable differences in the pattern of QRS area maps between the MI-VT(+) and MI-VT(−) groups.

In this study, it was demonstrated that in patients with MI, signals between 25 and 80 Hz within the QRS complex were significantly reduced compared with normal subjects and that in patients with VT, high-frequency signals (40–150 Hz) also significantly decreased compared with those in patients without VT. These three groups were clearly differentiated by the maximal values of 40–80-Hz QRS area maps.

Bhargava, Goldberger, and coworkers reported the time domain and frequency domain analysis of QRS complex in patients with previous MI. They found that MI diminished high-frequency QRS potentials and suggested that loss of myocardial fibers as a result of infarction and slowing of conduction velocity might be associated with a decrease in high-frequency potentials. The present findings accord well with their findings.

In this study, we also speculate that the reduction of 25–80-Hz frequency components within the QRS complex in patients with anterior MI may reflect the pathological changes of MI, such as loss of myocardium, and that the reduction of 40–150-Hz frequency components in patients with VT after anterior MI may relate to the occurrence of VT associated with the abnormal activities within the QRS.

The present finding may provide a support for the marker of VT in patients with previous anterior MI. Because the present study was based on a retrospective analysis, the findings will require further confirmation in prospective studies. Further studies should include a larger patient population to compare this technique with the more conventional techniques used in analyzing the signal-averaged ECGs.

**Conclusions**

In patients with anterior MI, 40–80-Hz frequency components within the QRS complex were reduced compared with normal subjects. The reduction was more prominent in patients with VT than in patients without VT. These three groups were clearly differentiated by the maximal values of the 40–80-Hz QRS area map. It was suggested that this finding will provide a new marker for VT after MI.

**References**

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