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Relationship between the occurrence of late potential on the body surface ECG and cardiac performance in myocardial infarction

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Summary

Comparative evaluations of the percent of the perimetric circumference of infarction and cardiac performance for the occurrence of late potential were performed in 12 normal subjects and 22 patients with old myocardial infarction (MI). All patients were in normal sinus rhythm without bundle branch block. Bipolar X, Y, and Z leads were signal-averaged using a bandpass filter with a low-cut frequency of 100 Hz and a high-cut frequency of 300 Hz. The filtered signals for the three leads were displayed and combined into a vector magnitude, $\sqrt{X^2+Y^2+Z^2}$. The percent ratio of the root mean square voltage in the last 40 msec of the QRS complex was calculated against that of the total filtered QRS (%RMS40). The value of the standard deviation (SD) in the phase distribution was obtained by the Fourier analysis of multi-gated blood pool images.

Significant differences were observed among MI with late potential, MI without it and the normal subjects for %RMS 40 (5.7±2.8% vs 26.9±8.1, 37.5±10.8%). Left ventricular ejection fraction was lower in MI with late potential (19.7±7%) compared to that of MI without it (33±18%) and the normal subjects (60±4%); the value of SD was higher in MI with late potential (64±21 degrees),

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compared to that of MI without it (43±20 degrees) and the normal subjects (9±4 degrees).

These findings showed that the percent ratio of the last 40 msec RMS voltage (%RMS 40) was found to discriminate effectively among MI with and without late potential and normal subjects. It was suggested that the amount and structure of the infarcts may be important factors in the occurrence of late potential.

Key words
Signal averaged ECG Late potential Fourier analysis Multigated cardiac blood-pool image
Myocardial infarction

Introduction

Recently, several investigator groups have demonstrated that the high-frequency analysis of the signal-averaged surface electrocardiogram (ECG) can detect low amplitude signals in the terminal portion of the body surface QRS of myocardial infarction with ventricular tachycardia (VT)[1~4]. These signals have been labelled as arrhythmogenic ventricular activity or as the late potential and they correlate with the fragmented activity recorded from the epicardial and endocardial ischemic myocardium in animals and in man[5].

We have previously reported the usefulness of the temporal Fourier analysis[6~8] of gated blood pool images for evaluating post-infarction left ventricular aneurysms. In essence, the value of the standard deviation in the histogram of the phase distribution was correlated with the percent of the perimetric circumference of infarction[9]. The purpose of the present study was to evaluate the relationship between the percent of the perimetric circumference of infarction, cardiac performance, and occurrence of the late potential in patients with myocardial infarction.

Materials and Method

Twenty-two patients more than four weeks post-transmural MI were studied. Eighteen were anterior and four were inferior MI, their average age was 55 years. Each was in normal sinus rhythm, and none had a right or left bundle branch block by the standard ECG. The control group consisted of 12 normal subjects whose average age was 29 years, and who had no clinical histories of complex ventricular arrhythmias.

Equilibrium blood-pool studies

Red blood cells were labeled with 20 mCi of technetium-99m in vivo. After reaching equilibrium, the blood pool data were collected to obtain the imaging datausing an Anger camera (Hitachi Gamma View-H) with an all-purpose, low-energy parallelhole collimator. Each study consisted of 16 frames comprised a 64×64 matrix spanning in cardiac cycle, and data were collected during normal sinus rhythm in the 45 degree left anterior oblique projection for 500 sec for each patient. The actual gated blood-pool data were transfered to a nuclear medicine computer system (Sopha Informatek Simis 3). Left ventricular global ejection fraction was calculated from the time-activity curve. The temporal Fourier transform[6] at the fundamental frequency (the heart rate) was obtained on a pixelby-pixel basis. Each pixel's time activity curve was fitted with a single cosine which period equalled the R-R interval. After obtaining a single cosine fit, differences were fully characterized by two parameters: amplitude and phase. Phase data were expressed by degree from 0 to 360, and the standard deviation (SD) of the phase distribution in the left ventricle, which represented left ventricular wall motion abnormalities, was calculated (**Fig. 1**).

In a separate study, the values of the standard deviations in the phase distribution histogram were compared with the percents of the perimetric circumference of infarction (ΔL), as estimated by the contrast levogram (**Fig. 2**). It was found that the values of the SD correlated well ($r=0.83$, $p<0.001$) with the percents of the perimetric circumference of infarction in patients

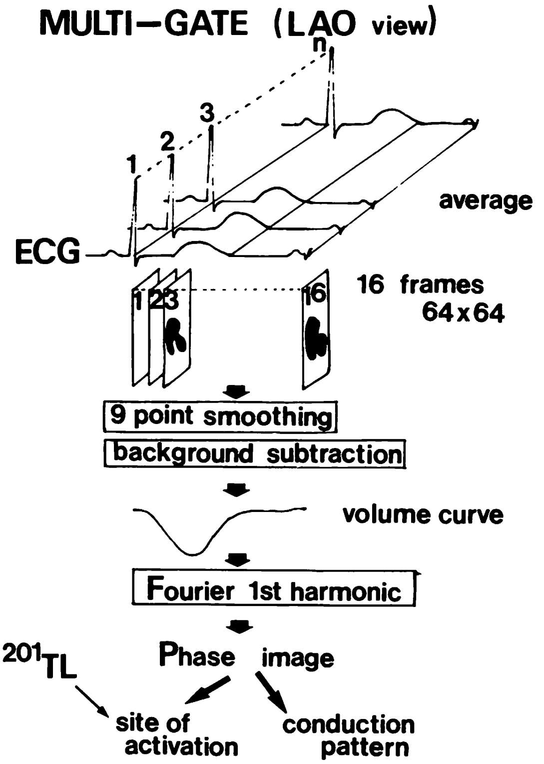


Fig. 1. Schematic diagram of ECG multigated cardiac blood-pool study.

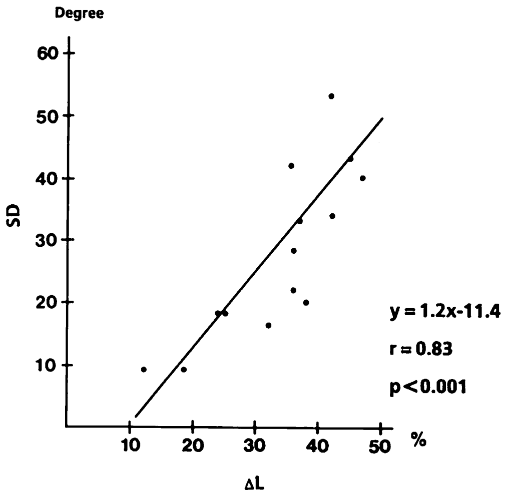


Fig. 2. Relationship between the standard deviation (SD) of the phase distribution and the percent of the perimetric circumference of infarction (ΔL).

ΔL is determined from the formula: $\Delta L = a/b \times 100$, where a is the length of akinetic or dyskinetic area and b is the length of the LV end-diastolic perimetric circumference.

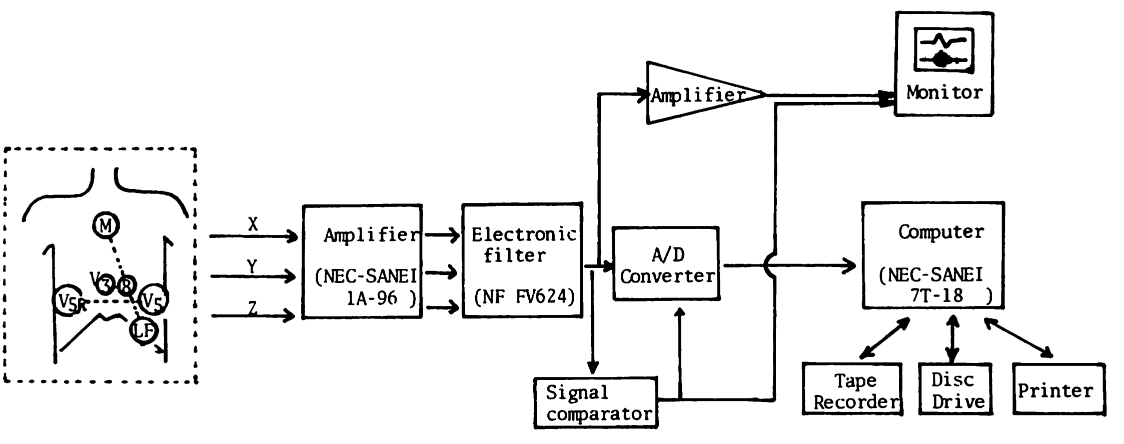


Fig. 3. System of signal averaging and filtering of the surface ECG.

with post-infarction left ventricular aneurysms. The lower limit of the SD was 21 degrees, which corresponded to a value of 35% of the perimetric circumference of infarction[9].

Signal-averaged ECG

Body surface ECG recording was performed using bipolar X, Y, and Z leads in a shielded room. One lead served as the reference. The three-channel amplifier used was a commercially available electroencephalography system (SANEI 1A-96). The common mode rejection ratio was 120 dB. The signal from each lead was amplified and passed through an analogue filter (NF FV624) with a low-cut frequency of 100 Hz and a high cut-frequency of 300 Hz, and then AD was converted with 12-bit accuracy

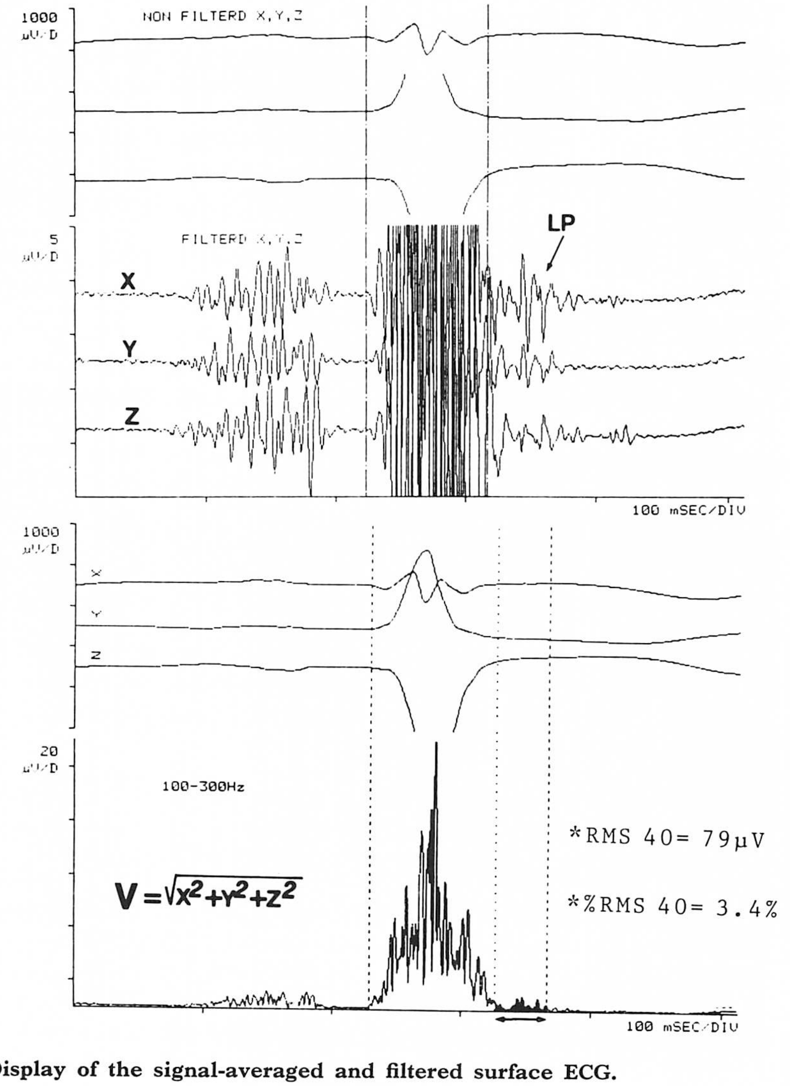
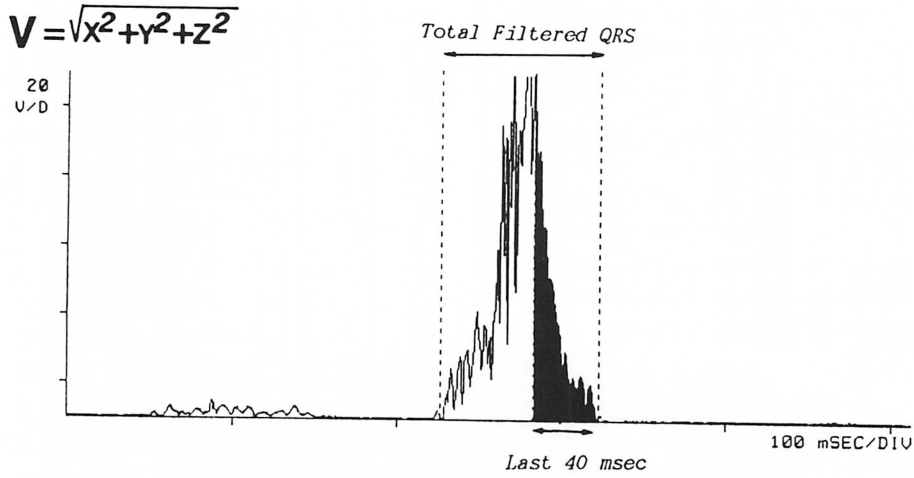


Fig. 4. Display of the signal-averaged and filtered surface ECG.
Top shows the X, Y and Z leads and bottom shows the combined vector magnitudes (V). LP=late potential.



$$\%RMS\ 40 = \frac{\text{RMS for the last 40 msec of the filtered QRS}}{\text{RMS for the total filtered QRS}} \times 100$$

Fig. 5. The formula of the %RMS 40.

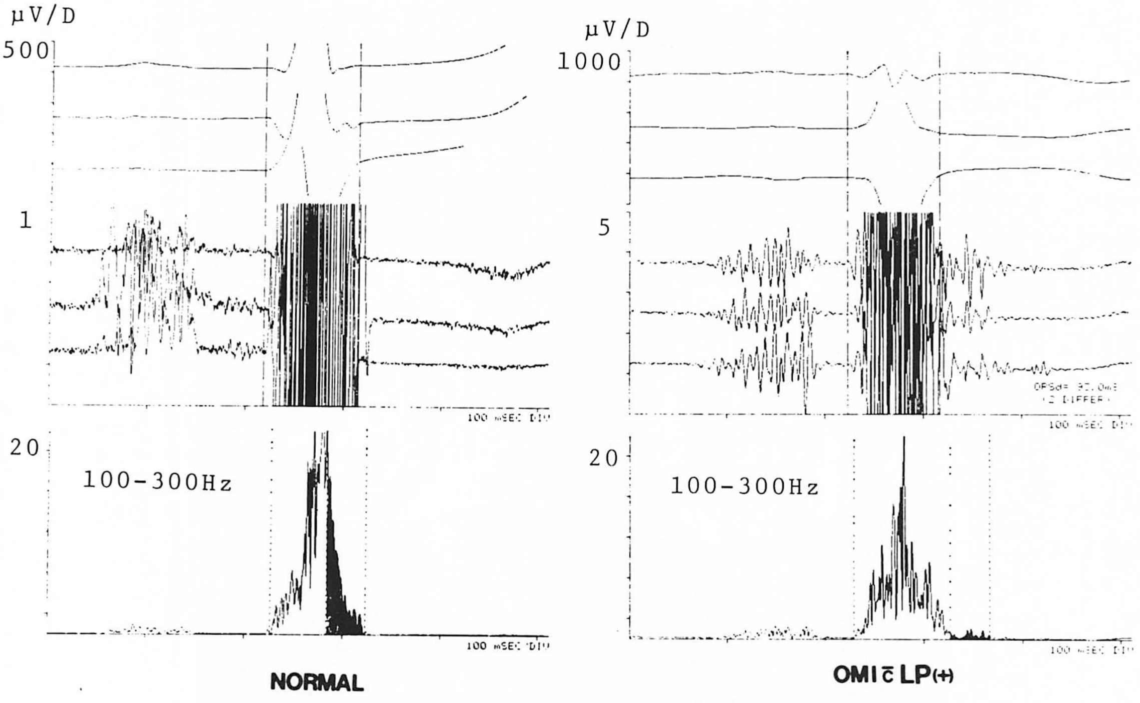


Fig. 6. Representative recordings of a signal-averaged filtered X, Y and Z leads and the vector amplitudes of the signal averaged and filtered composite X, Y and Z leads from a normal subject (left) **and an extensive anterior MI subject** (right).

at 1024 samples/sec. The gain was adjusted so that 1μV signals could be recorded. After band-passing the signals, the digital information was stored on a floppy disc (**Fig. 3**).

The ECG signals were averaged after rejecting ectopic beats. The filtered signals for the three leads were displayed separately for each channel and were combined into a vector magnitude, $\sqrt{X^2+Y^2+Z^2}$, which allowed the detection of high frequency voltage in any leads. The vector magnitudes of the filtered signals were referred to as a filtered QRS complex. The onset and end-point of a QRS were determined by a computer algorithm as segments where the average was greater than three standard deviations above the mean of the noise sample (**Fig. 4**). The percent of the ratio of the root mean square voltage for the last 40 msec of the QRS complex to that of the total filtered QRS (%RMS 40) and the duration of filtered QRS were calculated automatically (**Fig. 5**). These two parameters obtained from the three groups

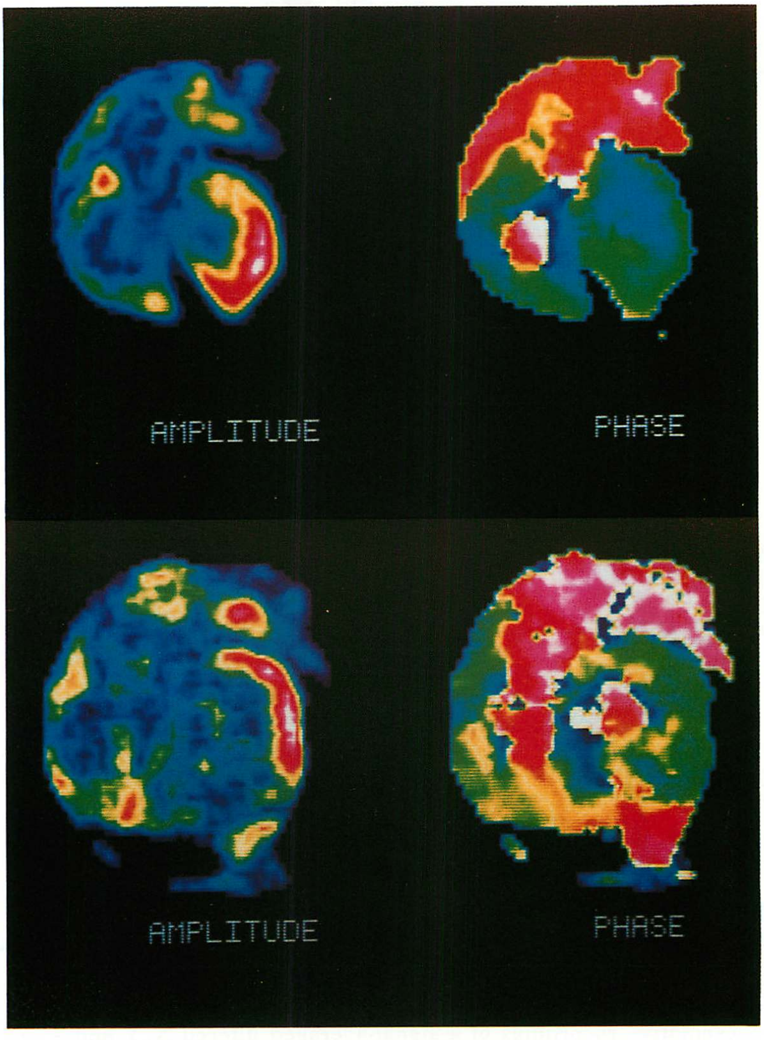


Fig. 7. Representative displays of phase images from a normal person (top) **and an extensive anterior MI with late potential** (bottom).

were compared.

Results

Fig. 6 shows the results of signal processing for both groups. The MI patients had low amplitude signals in the last 40 msec of the filtered QRS complex (3.4% in %RMS 40) which were not seen in the filtered EKG from the normal subjects (30.9% in %RMS 40).

Fig. 7 shows computer-generated phase and amplitude images from one normal subject and one patient who had a broad anterior MI and whose signal-averaged ECG contained the late potential. In contrast to the normal subject, there was significant fluctuation in the phase distribution.

Fig. 8 shows comparisons of the %RMS 40 in normal subjects, MI patients with and without late potential. The %RMS 40 was found to discriminate effectively between the three groups. The six MI patients (four anterior, two inferior) with late potential had low amplitude signals at the end of the filtered QRS complex. The %RMS 40 was 5.7±2.8% ($p<0.001$) in MI with late potential. In contrast, it was 26.9±8.1% ($p<0.01$) in MI without late potential, and 37.5±10.8% in normal subjects.

Fig. 9 shows comparisons of the left ven-

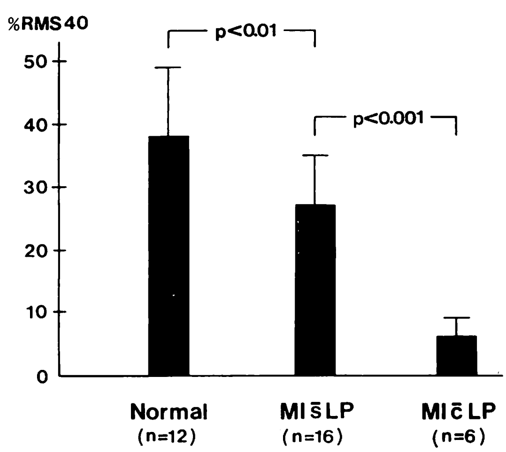


Fig. 8. Discrimination between normal, MI with late potential (LP)**, and MI without LP using % ratio of voltage in last 40 msec filtered QRS.**

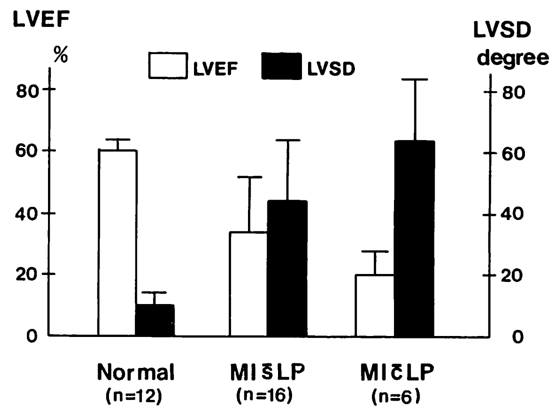


Fig. 9. Comparisons of left ventricular ejection fraction (LVEF) **and the standard deviation of the phase distribution histogram in the left ventricle** (LVSD) **in normal, MI without late potential** (LP) **and MI with LP.**

tricular ejection fraction (LVEF) and the standard deviation in the phase distribution histogram of the left ventricle (LVSD). The LVEF in MI with late potential was significantly lower (19.7±7%) compared with MI without late potential (33±18%) ($p<0.05$) and normal subjects (64±4%) ($p<0.001$). The value of LVSD in MI with late potential was higher (64±21 degrees) than that in MI without late potential (43±22 degrees) ($p<0.05$) and in normal subjects (9±4 degrees) ($p<0.001$).

Sustained ventricular tachycardia was observed in two patients of MI with late potential and in none of the other patients.

Discussion

This study indicated that %RMS 40 estimated by the signal processing of the body surface ECG can discriminate patients with late potential from those without it, and the former patients were associated with massive infarct and reduced cardiac performance.

Low amplitude, high frequency signals have been observed in the terminal portion of the QRS of the signals of averaged and filtered ECGs of the patients with ventricular tachycardia. These signals have been labelled as late potential and correlated with the fragmented activity recorded from the epicardial and endocardial ischemic myocardium in animals and in man. Rozanski et al[2] observed a high frequency signal early in the ST segment that disappeared after aneurysmectomy.

Signal averaging reduces random noise in the ECG and enhances the detection of low amplitude signals. The common problem with the signal processing technique is filter-ringing and the definition of late potential. Filter-ringing occurred in some patients, because we used an analogue filter in the present study. Simson[3] has proposed the use of a bidirectional digital filter to eliminate the filter-ringing. To determine the QRS endpoints, amplitude, and duration of late potential, we used a vector magnitude that incorporated the characteristics of the filtered X, Y and Z leads. The percent ratio of the last 40 msec RMS voltage (%RMS 40) was found to effectively discriminate the MI with late potential from MI without late potential, and normal subjects. All six patients who had a low value of %RMS 40 (under 13%) had low amplitude and high frequency signals (late potential) in the terminal portion, for any leads. We used a band-pass analogue filter with a low-cut frequency of 100 Hz and a high-cut frequency of 300 Hz. In the Simson's original paper[3] the high pass filter frequency was set as 25 Hz, and RMS magnitudes in the last 40 msec of the filtered QRS were less than 25 μV in 92% of patients with VT. However, the vector magnitude of the RMS voltage may vary according to the filter characteristics used. In the future, standardization for the filter frequencies and characteristics will be necessary for the reasons mentioned above.

Adam et al[6] have described the temporal Fourier analysis (phase analysis) of gated blood pool studies. We previously reported that the standard deviation in the phase distribution was correlated with the percent perimetric circumference of infarction[9]. The present study revealed that the standard deviation in the phase distribution of left ventricular wall motion was higher in MI with late potential compared to MI without it and normal subjects.

The occurrence of the late potential may help to identify patients with myocardial infarction who are inclined to develop ventricular tachycardia. How does infarct structure relate to the origin of ventricular tachycardia? First, an appropriate infarct structure may result in the formation of an anatomically distinct re-entry circuit. It is our assumption that the late potential in patients with MI may relate to a nonuniform anisotropic structure[10] which results from a large size myocardial infarct separated by connective tissue. The conduction abnormalities caused by the anisotropic structure may easily occur in patients with massive infarcts. These findings are in agreement with a study of the origins of tachycardia in the canine heart[11].

Although only two of six patients with massive infarction had episodes of sustained ventricular tachycardia in the present study, the occurrence of the late potential may help to identify patients with myocardial infarction who are inclined to develop ventricular tachycardia.

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要　　約

心筋梗塞例における体表面加算心電図遅延電位発生と収縮動態の関連

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陳旧性心筋梗塞（MI）に伴う持続性心室頻拍（SVT）の成因として，体表面加算心電図による遅延電位の関与が指摘されている．遅延電位の成因として，心筋組織の不均一な構築異常に伴う興奮波の緩徐な心筋内伝播が考えられている．

正常12例と心筋梗塞22例を対象に，遅延電位の発生の有無とマルチゲート心プール法(MGPI)位相解析による心収縮動態および梗塞周径比の関連について検討した．いずれの症例も洞調律で脚ブロックはなかった．加算心電図はX, Y, Z双極誘導を増幅，100～300 Hzの帯域を濾波したのち，R波同期による約200心拍を加算し，X, Y, Zの各誘導面および合成ベクトル量として表示した．遅延電位の判定には各誘導加算心電図および合成ベクトル量のfiltered (F)-QRSに対するF-QRS終了点より40 msec前までのroot mean square (RMS)量比(% RMS 40)を用いた．収縮動態の指標にはMGPI法による左室駆出率を，左室収縮協調性，梗塞周径比の指標にはMGPI法位相解析による左室内相位分布ヒストグラムの標準偏差(LVSD)を用いた．

遅延電位は22例のMIのうち6例が陽性例で(4例は前壁MIで内2例はSVTあり，2例は下壁MI)，正常者では陰性であった．% RMS 40は正常者37.5±10.8%，遅延電位陰性のMI群26.9±8.1%に対し，遅延電位陽性のMI群では5.7±2.8%と低値($p<0.001$)を示した．左室駆出率は遅延電位陽性MI群では19.7±7%で，遅延電位陰性のMI群33±18% ($p<0.05$)，正常群(60±4%) ($p<0.001$)に比し有意に低値であった．左室収縮協調性の指標であるLVSDは遅延電位陽性のMI群では64±21度と，遅延電位陰性のMI群(43±20度) ($p<0.05$)，正常群(9±4度) ($p<0.001$)に比し有意に高値であった．

遅延電位陽性のMIでは収縮動態および壁運動協調性の異常が顕著なことより，MIにおける遅延電位の発生には，一定量の壊死巣の存在に基づく特異な心筋組織構成が関与していると考えられた．

References

1) Berbari EJ, Scherlag BJ, Hope RR, Lazzare R: Recording from the body surface of arrhythmogenic ventricular activity during ST-segment. Am J Cardiol **41**: 697–702, 1978
2) Rozanski JJ, Mortara D, Myerburg RJ, Castellanos A: Body surface detection of delayed depolarization in patients with recurrent ventricular tachycardia and ventricular aneurysm. Circulation **63**: 1172–1178, 1981
3) Simson MB: Use of signals in the terminal QRS complex to identify patients with ventricular tachycardia after myocardial infarction. Circulation **64**: 235–242, 1981
4) Denes P, Santarelli P, Hauser RG, Uretz EF: Quantitative analysis of the high-frequency components of the terminal portion of the body surface QRS in normal subjects and in patients with ventricular tachycardia. Circulation **67**: 1129–1138, 1983
5) Simson MB, Untereker WJ, Spielman SR, Horowitz LN, Marcus NH, Falcone RA, Harken AH, Josephson ME: Relation between latepotentials on the body surface and directly recorded fragmented electrograms in patients with ventricular tachycardia. Am J Cardiol **51**: 105–112, 1983
6) Adam WE, Tarkowska A, Bitter F: Equilibrium (gated) radionuclide ventriculography. Cardiovasc Radiol **2**: 161–173, 1979
7) Links JM, Raichlen JS, Wagner HN, Reid PR: Assessment of the site of ventricular activation by Fourier analysis of gated blood-pool studies. J Nucl Med **26**: 27–32, 1985
8) Takahashi T, Katsuragawa S, Abe C, Yanagisawa T, Nakai K, Kato M: Quantitative analysis of global and regional cardiac performance in normal subjects and patients with coronary artery disease by rest / exercise radionuclide blood-pool study. Jpn Circ J **50**: 935–942, 1986
9) Kawamura A: Quantitative evaluation of postinfarction aneurysm by gated blood pool scan using phase analysis. Jpn Nucl Med **20**: 689–697, 1983 (in Japanese)
10) Josephson ME, Wit AL: Fractionated electrical activity and continuous electrical activity: fact or artifact? Circulation **70**: 529–528, 1984
11) Gardner PI, Ursell PC, Pham TD, Fenoglio JJ, Wit AL: Experimental chronic ventricular tachycardia: Anatomic and electrophysiologic substrates: Tachycardias (ed by Josephson ME & Wellwens HJJ), Lea & Febiger, Philadelphia, 1984, p 29