Vectorcardiographic Evaluation of Myocardial Infarct Size

— Departure Parameters are Superior to Conventional Spatial Parameters —

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To determine whether the departure parameters derived from a “departure loop” of a vectorcardiogram are more accurate than conventional spatial parameters in evaluating myocardial infarct size, 74 patients with first-onset myocardial infarction (MI) were studied. The correlation between the departure parameters (amplitudes in scalar leads of the departure loop) and the percent defect volume of thallium myocardial scintigrams (%DV) was compared with that of the spatial parameters (magnitude, azimuth, and elevation of the original QRS loop). In anteroseptal MI, the amplitude of a 20-msec vector in the z-axis and the azimuth of a 30-msec vector (H30) were significantly correlated with %DV ($r=0.783$, $p<0.001$ and $r=0.572$, $p<0.05$). In anteroseptal MI with involvement of the lateral wall, the amplitude of a 30-msec vector in the x-axis and H30 showed significant correlation with %DV ($r=0.802$, $p<0.001$ and $r=0.772$, $p<0.01$). In inferior and inferoposterior MI, the amplitude of a 30-msec vector in the y-axis and the elevation of a 30-msec vector were significantly correlated with %DV ($r=0.920$, 0.891 , $p<0.001$ and $r=0.871$, 0.678 , $p<0.01$, respectively). In conclusion, the departure parameters are more accurate than the spatial parameters for evaluation of myocardial infarct size. (*Jpn Circ J* 1998; 62: 473–478)

Key Words: Myocardial infarction; Vectorcardiogram, Thallium-201 myocardial scintigram; Departure index

Myocardial infarct size has been proved to be closely associated with the occurrence of serious ventricular arrhythmia, the recovery of left ventricular function, and, consequently, the mortality rate of myocardial infarction (MI).^{1,2} Accordingly, the management of acute MI has focused on reducing myocardial infarct size, and many methods such as thrombolytic therapy and various kinds of invasive revascularization have been shown to be effective in limiting infarct size and as a result improving both short- and long-term survival.^{3–5}

To evaluate the effects of treatment and to predict the prognosis of the patients, it is essential to establish an easy and accurate method of assessing infarct size for clinical application. Although several techniques, including the 12-lead electrocardiogram (ECG), body surface mapping (BSM), measurement of released serum myocardial enzymes, and single-photon emission computed tomography of myocardium (SPECT), have been proposed; they are not very satisfactory in clinical settings because of limitations such as low accuracy of ECGs, complexity of BSM, high cost of and radiation produced by SPECT, and repeated blood samplings and the length of time required for biochemical measurement.^{6–10} Vectorcardiography (VCG) has been showed to be superior to ECG for the

diagnosis of MI in that it can provide more detailed spatial information, and it has recently been used to estimate the myocardium at risk and the final infarct size!^{11–15} However, like BSM, there is a variety of individual difference, and, the more information it contains, the more difficult it is to explain the results correctly, especially in the situation of quantitative analysis. Therefore, in the present study, a “departure loop” was made from MI patients’ and normal subjects’ VCGs, and we sought to determine whether the departure parameters derived from the departure loop were more accurate than the conventional spatial parameters for evaluating myocardial infarct size.

Methods

Subjects

The study population consisted of 74 patients (66 men and 8 women with a mean age of 61.7 ± 11.4 years). All patients were suffering from acute MI for the first time, and the diagnosis of MI was established from the ECG findings, peak creatine kinase (CK)-MB, echocardiography, and coronary artery angiography (CAG). VCG examination was performed 28.6 ± 5.3 days and thallium-201 SPECT myocardial scintigraphy 26.9 ± 6.8 days after the onset. Based on McConahay et al’s¹⁶ diagnostic criteria for MI, the patients were classified into 5 groups according to a consensus of 3 experienced VCG cardiologists who were blinded to other clinical findings: (1) anteroseptal MI (AS MI); (2) anteroseptal MI with involvement of lateral wall (ASL MI); (3) anteroseptal MI with involvement of apex (ASAp MI); (4) inferior MI (Inf MI); and (5) inferoposterior MI (IP MI). Patients with conduction abnormality or left

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Fig 1. Top: original QRS loops of a 62-year-old woman with inferoposterior MI. Bottom: initial 0- to 40-msec components of the departure loop. The circles indicate the locations of 20-msec and 30-msec vectors. The shaded areas indicate the range within ± 2 SD of departure index. The patient had a total occlusion at segment 1 of RCA, and revascularization was obtained by intravenous thrombolysis within 6h after the onset. The abnormal parameters were as follows: %DV=22.44%; V_{20} =153.8°; V_{30} =109.5°; $[YD]_{20}$ =-5.3; $[YD]_{30}$ =-3.6.

Fig 2. Correlation between peak CK-MB and %DV of thallium myocardial scintigrams.

Table 1 General Characteristics of the Study Population

	Age (years)	Male/Female	CK-MB (<24 U/L)	%DV (%)	Culprit CA (n)
AS MI (n=15)	64.4 $\pm$ 12.7	13/2	271.3 $\pm$ 275.3	15.41 $\pm$ 12.61	LAD 15
ASL MI (n=14)	63.1 $\pm$ 9.89	14/0	550.6 $\pm$ 194.3*	23.81 $\pm$ 11.58	LAD 14
ASAp MI (n=10)	63.4 $\pm$ 13.5	8/2	343.0 $\pm$ 205.6	23.02 $\pm$ 7.24	LAD 10
Inf MI (n=10)	60.9 $\pm$ 9.98	9/1	200.3 $\pm$ 104.8	4.96 $\pm$ 4.32*	RCA 10
IP MI (n=25)	59.0 $\pm$ 11.2	22/3	301.1 $\pm$ 209.6	12.24 $\pm$ 11.25	RCA 20 LCX 5
Total (n=74)	61.7 $\pm$ 11.4	66/8	334.3 $\pm$ 234.3	15.54 $\pm$ 12.02	

AS, anteroseptal MI; ASL, anteroseptal MI with involvement of lateral wall; ASAp, anteroseptal MI with involvement of apex; Inf, inferior MI; IP, inferoposterior MI; CA, coronary artery; LAD, left anterior descending artery; RCA, right coronary artery; LCX, left circumflex artery; %DV, percent defect volume of thallium myocardial scintigrams.

*Significantly higher or lower than other groups ($p < 0.05$).

ventricular hypertrophy were excluded from the study.

VCG and Departure Loop

The computerized VCG was recorded using the Frank orthogonal lead system (VCM3000, Fukuda-Denshi). The sampling intervals were 1 msec and the data were stored on floppy disks for off-line analysis.

From the original QRS loop, the following spatial parameters were measured: the magnitude, the azimuth, and the elevation of the maximal vector, the vector at 20 msec and the vector at 30 msec (abbreviated to M_{max} , H_{max} , V_{max} ; M_{20} , H_{20} , V_{20} , M_{30} , H_{30} and V_{30} , respectively).

To estimate the deviation of patients' data from the normal values, the departure index was calculated as follows.

$$\text{Departure index} = (x - \text{mean}) / \text{SD}$$

where x represents individual values of QRS loop at 1-msec intervals for each patient and the mean and SD represent the corresponding mean values and standard deviations of QRS loop with age and gender corrections obtained from 608 normal subjects (376 men and 232 women with a mean age of 42 years, range 17–81) provided by the Japanese Circulation Society Task Force Committee on Criteria for Body Surface Potential Mapping (these data include the Frank VCG data recorded simultaneously with 87-lead mapping data). Based on the departure index acquired, a departure loop of QRS was reconstructed as

shown in Fig 1. As the initial 0- to 40-msec components of QRS are the most sensitive portions predisposing to changes in MI, the amplitudes of 20- and 30-msec vectors at x , y , and z scalar leads derived from the departure loop were taken as the departure parameters, which were abbreviated as $[XD]_{20}$, $[YD]_{20}$, $[ZD]_{20}$, $[XD]_{30}$, $[YD]_{30}$, and $[ZD]_{30}$, respectively.

Thallium-201 Myocardial Scintigraphy

Thallium (74 MBq) was injected iv at rest, and the myocardial SPECT images were acquired within 40 min after injection using a 2-headed gamma-camera with low-energy, parallel-hole collimators (RC-2600-I, Hitachi, Japan). A total of 60 projection images were obtained over 360° in 6° increments with 30 sec per view, and the energy discriminator was centered on 70 keV for thallium-201. The data were recorded in 64 $\times$ 64 matrices into the magnetic disk and the reconstruction and analysis of the SPECT images were performed with a dedicated computer for nuclear medicine (RW 3000, Hitachi, Japan).

For quantitative analysis, the bull's-eye of patients reconstructed from short-axis images was compared with the bull's-eye of a normal file obtained from 20 normal volunteers (10 men and 10 women) with gender correction. The defect volume of myocardium was defined as the volume of myocardium in which the counts per pixel were less

Table 2 Conventional VCG Parameters of Different Groups

	M_{max} (mV)	H_{max} (degree)	V_{max} (degree)	M_{20} (mV)	H_{20} (degree)	V_{20} (degree)	M_{30} (mV)	H_{30} (degree)	V_{30} (degree)
AS MI (n=15)	1.86±0.37	-47.1±24.0	47.3±17.4	0.55±0.26	-30.0±61.3	53.6±37.4	1.32±0.31	-35.2±22.2*	50.9± 9.6
ASL MI (n=14)	1.65±0.51	-90.7±16.9	68.6±25.4	0.47±0.19	-72.1±75.3	60.7±22.6	0.97±0.44	-90.0±18.4**	57.6±23.1
ASAp MI (n=10)	1.24±0.35	-76.5±31.2	75.4±25.9	0.42±0.10	-74.7±32.1	123.0±26.9	0.72±0.41	-56.6±23.7	101.2±21.8
Inf MI (n=10)	1.65±0.36	3.48±11.5	81.4±15.8	0.70±0.16	42.8±16.9	115.2±15.4	1.34±0.32	14.7±11.4	93.4± 9.1***
IP MI (n=25)	1.78±0.51	10.4±37.8	77.0±19.1*	0.64±0.21	64.3±45.4	120.2±31.5	1.27±0.5	33.5±22.9	101.1±26.6***

AS, anteroapical MI; ASL, anteroapical MI with involvement of lateral wall; ASAp, anteroapical MI with involvement of apex; Inf, inferior MI; IP, inferoposterior MI; M_{max} , M_{20} , M_{30} , magnitudes of the maximal vector, 20-msec and 30-msec vectors; H_{max} , H_{20} , H_{30} , azimuths of the maximal vector, 20-msec and 30-msec vectors; V_{max} , V_{20} , V_{30} , elevations of the maximal vector, 20-msec and 30-msec vectors.

*, **, ***Correlated with the %DV of thallium scintigrams with a p value <0.05, 0.01, 0.001, respectively.

Table 3 Departure VCG Parameters of Different Groups

	[XD] ₂₀	[YD] ₂₀	[ZD] ₂₀	[XD] ₃₀	[YD] ₃₀	[ZD] ₃₀
AS MI (n=15)	-0.52±0.77	0.76±1.52*	-1.96±0.85***	-1.5 ±0.58	0.47±0.91	-1.7 ±1.04*
ASL MI (n=14)	-1.48±0.61	0.00±1.00	-2.56±0.93	-3.14±0.80***	-0.77±1.03	-2.34±1.07
ASAp MI (n=10)	-1.24±0.55	-2.21±1.04	-2.51±0.67	-2.19±0.79	-2.16±0.79	-1.59±1.18
Inf MI (n=10)	0.25±0.70	-2.36±0.83*	0.08±0.80	0.61±0.92	-2.06±0.69***	0.62±0.77
IP MI (n=25)	-0.59±1.05*	-2.66±1.40*	0.04±0.78	-0.20±1.78*	-2.28±1.33***	1.04±0.81

AS, anteroapical MI; ASL, anteroapical MI with involvement of lateral wall; ASAp, anteroapical MI with involvement of apex; Inf, inferior MI; IP, inferoposterior MI; [XD], [YD], [ZD], scalar values of 20-msec and 30-msec vectors in x-, y-, and z-axis of departure loop.

*, **, ***Correlated with the %DV of thallium scintigrams with a p value <0.05, 0.01, 0.001, respectively.

than the mean counts - 2SD of normal subjects. In this study, the percent defect volume (%DV), defined as (defect volume of myocardium/total volume of myocardium) × 100%, was taken as the nuclear parameter for measuring myocardial infarct size.

Statistical Analysis

Continuous variables were expressed as mean±SD and categorical data as absolute values and percentages. Linear regression analysis was performed to determine the correlation of VCG parameters with the %DV of thallium myocardial scintigrams. Unpaired Student's t test was used to investigate differences in each parameter between 2 groups. A p value <0.05 was considered statistically significant.

Results

Clinical Characteristics of the Study Population

The baseline characteristics of the patients are summarized in Table 1. There were no significant differences in age and gender among the groups. The value of peak CK-MB in anteroapical MI with involvement of lateral wall was significantly higher than in the other groups (p <0.0001-0.05). The %DV of thallium myocardial scintigrams of inferior MI was significantly lower than in the other groups (p <0.0001-0.05), whereas the %DV of inferoposterior MI, although not significantly different from that of anteroapical MI, was significantly lower than those of anteroapical MI with involvement of either the lateral or apical portion (p <0.0201).

A weak but significant correlation was observed between peak CK-MB and the %DV of thallium myocardial scintigrams when all patients were taken into account, as illustrated in Fig 2, although no such correlation was present in individual groups.

The culprit coronary arteries included left anterior

descending artery (LAD) in 39, right coronary artery (RCA) in 30, and left circumflex (LCX) in 5 patients.

The patients received routine treatments randomly on admission, which included intravenous thrombolysis in 28, intracoronary thrombolysis in 3, percutaneous transluminal coronary angioplasty (PTCA) in 28, and thrombolysis with adjunctive PTCA in 15 patients.

Conventional VCG Parameters and Their Correlation With the %DV of Thallium Myocardial Scintigrams

The averages of conventional spatial parameters are listed in Table 2. The azimuth of the 30-msec vector showed a significant correlation with the %DV of thallium myocardial scintigrams in anteroapical MI with and without involvement of the lateral wall (r =0.572, p <0.05, and r =0.772, p <0.01, respectively), whereas no significant correlation with the %DV was found in anteroapical MI with involvement of apex. In patients with inferior MI, the elevation of the 30-msec vector demonstrated an excellent correlation with the %DV of thallium myocardial scintigrams (r =0.871, p <0.01) and, in inferoposterior MI, the elevations of both the maximal and the 30-msec vectors were correlated significantly with the %DV of thallium myocardial scintigrams (r =0.483, p <0.05 and r =0.678, p <0.001, respectively).

Departure VCG Parameters and Their Correlation With the %DV of Thallium Myocardial Scintigrams

The averages of departure parameters are summarized in Table 3. In anteroapical MI, [ZD]₂₀ showed a high correlation with the %DV of thallium scintigrams (r =0.783, p <0.001), whereas a weak correlation between [ZD]₃₀ and [YD]₂₀ and the %DV was indicated (r =0.569, p <0.05, and r =0.615, p <0.05, respectively). In anteroapical MI with involvement of lateral wall, [XD]₃₀ showed an excellent correlation with the %DV (r =0.802, p <0.001), whereas [ZD]₂₀ and [ZD]₃₀, although abnormally high, did not cor-

Fig 3. Comparison of correlations with the %DV of thallium myocardial scintigrams between the azimuth of the 30-msec vector and [ZD]20 in anteroseptal MI.

Fig 4. Comparison of correlations with the %DV of thallium myocardial scintigrams between the azimuth of the 30-msec vector and [XD]30 in anteroseptal and lateral MI.

Fig 5. Comparison of correlations with the %DV of thallium myocardial scintigrams between the elevation of 30-msec vector and [YD]30 in inferior MI.

Fig 6. Comparison of correlations with the %DV of thallium myocardial scintigrams between the elevation of the 30-msec vector and [YD]30 in inferoposterior MI.

relate with the %DV. In patients with anteroseptal MI with involvement of apex, no significant correlation with the %DV was obtained, although [YD]₂₀, [ZD]₂₀, [XD]₃₀, and [YD]₃₀ were high abnormally high. In inferior MI, [YD]₂₀ and [YD]₃₀ in particular correlated strongly with the %DV of thallium myocardial scintigrams ($r=0.632$, $p<0.05$ and $r=0.920$, $p<0.001$, respectively). In inferoposterior MI, [YD]₃₀ showed a strong correlation ($r=0.795$, $p<0.0001$) compared with [YD]₂₀, [XD]₂₀, and [XD]₃₀, which were found to be weakly but significantly correlated with the %DV of thallium myocardial scintigrams ($r=0.421$, 0.421 , and 0.419 , respectively, $p<0.05$).

Comparison Between Conventional and Departure Parameters

As mentioned above, a significant correlation was found between the %DV of thallium myocardial scintigrams and different parameters of VCG, both conventional and departure, according to different locations of MI. To determine whether the departure parameters are superior to the conventional parameters, both conventional and departure parameters that showed the highest correlation with the %DV of thallium myocardial scintigrams for each location of MI were compared. In anteroseptal MI, [ZD]₂₀ had a higher coefficient of correlation and a lower p value than the azimuth of the 30-msec vector, as shown in Fig 3. Similarly, in patients with anteroseptal MI and involvement of the lateral wall, [XD]₃₀ also showed a higher coefficient of correlation and a lower p value than the azimuth of the 30-msec vector, as illustrated in Fig 4. For patients with inferior MI or inferoposterior MI, [YD]₃₀ indicated a higher coefficient of correlation and a lower p value than the elevation of the 30-msec vector, as shown in Figs 5 and 6.

Discussion

Although myocardial infarct size is of prognostic significance, its accurate evaluation is not easy in clinical practice. Thallium SPECT myocardial scintigraphy has been accepted as the most accurate method for evaluating quantitatively the extent and the severity of myocardial infarction, and therefore in the present study it was used as a "gold standard" to assess the accuracy of other parameters.^{17,18} But, as mentioned previously, the necessity of special apparatus, the high cost, and the radiation preclude its routine clinical application.

The conventional 12-lead ECG, the most simple and feasible method for clinical practice, has been used most widely for qualitative diagnosis of MI. For quantitative estimation, the Selvester QRS scoring system was developed in the prethrombolytic era, and the score system has been validated against anatomic measurement of infarct size in both anterior and inferior MI.¹⁹⁻²¹ Clinical studies have shown that the QRS score is inversely correlated with left ventricular systolic function after myocardial infarction.^{22,23} However, with the use of reperfusion therapy such as thrombolysis, the validity of the QRS score as an index of infarct size has been questioned.²⁴ Studies with [¹⁸F]-2-deoxyglucose and positron emission tomography show that viable myocardium may persist within the infarct region despite Q waves on the surface ECG, and residual viability is more likely after thrombolysis.²⁵ Although the QRS score is scaled according to the size of Q-wave and R- and S-wave amplitudes, the score might be an unreliable measure of infarct size nowadays with reperfusion therapy having

become a routine treatment for acute myocardial infarction. In addition, the measurement and the calculation of the score are performed manually, and this may not be as convenient and objective in some ways.

VCG, theoretically, contains more information than 12-lead ECG, and it should be more accurate and more suitable for quantitative analysis. In fact, a few studies have shown VCG to be more sensitive than 12-lead ECG for qualitative diagnosis of MI based on its unique spatial information.¹¹⁻¹³ Recently, with widespread use of the computer, continuous on-line VCG monitoring has become available and the dynamic changes in QRS and ST were used to evaluate the myocardium at risk and the final infarct size.^{26,27} In an animal experiment, Tseng et al²⁷ described a slight correlation between VCG changes and histological myocardial infarct size, whereas, in a clinical study, Juhlin et al²⁶ demonstrated a good correlation between the changes in QRS complex configuration and the perfusion level of myocardial scintigrams. It may be difficult to evaluate the extent of ischemia and then to predict the final infarct size at acute phase by observing the changes in electrical activity of the myocardium as it is so unstable and the changes are so remarkable. That is why we used the VCG obtained about 1 month after the onset of MI.

In the present study, a significant correlation was found between the %DV of thallium myocardial scintigrams and the spatial VCG parameters in various locations of MI except anteroseptal MI with involvement of apex. For anteroseptal MI with or without involvement of lateral wall, the 30-msec azimuth manifested a significant inverse correlation with the %DV of thallium myocardial scintigrams, whereas, for inferior and inferoposterior MI, the 30-msec elevation demonstrated an excellent correlation with the %DV of thallium myocardial scintigrams. Moreover, the departure parameters [ZD]₂₀ for anteroseptal MI, [XD]₃₀ for anteroseptal MI with lateral involvement, and [YD]₃₀ for inferior and inferoposterior MI, showed a higher coefficient of correlation and lower p values with the %DV of thallium myocardial scintigrams than the conventional spatial parameters as expected, indicating that the departure parameters are more accurate for assessing infarct size.

Unfortunately, regardless of the conventional or the departure parameters, no significant correlation was found between VCG and the %DV of thallium myocardial scintigrams in anteroseptal MI with involvement of apex, although there seemed to be a weak correlation of the azimuth of the maximal vector [ZD]₂₀ ($r=0.429$ and 0.308 , respectively). Several factors may account for this. The most important one may be a cancellation of electrocardiographic changes between the anterior wall and the apical portion of inferior wall, an explanation similar to the results of Sevilla et al's²⁸ study in which he found that patients with multiple infarcts showed a lower degree of correlation than those with anterior or inferior MI only. Another reason may be the small sample of the patients enrolled. From this result, it is quite reasonable to assume that in patients with multiple myocardial infarction it may be difficult to use the VCG parameters to evaluate the infarct size because what VCG changes reflect is the change in the sum of electric forces of myocardial cells and the cancellation, an innate limitation of VCG, is unavoidable.

Although biochemical markers such as creatine kinase (CK) and CK-MB have also been used to evaluate the infarct size,²⁹⁻³¹ factors such as the amount of time taken for

measurements and repeated blood samplings make it less clinically practicable and, furthermore, the influence of the enzymes released from other organs such as skeletal muscle and the impact of different methods of revascularization may render the measurements less accurate nowadays with reperfusion therapy having become a standard treatment for acute myocardial infarction. As a result, it is not surprising to find that no significant correlation was present between the CK-MB and the %DV of thallium myocardial scintigrams in individual groups and that only a weak correlation was found when all patients were enrolled in the present study because the patients underwent various kinds of revascularization treatments, including thrombolysis, PTCA, or both. On the contrary, the parameters of VCG, especially the departure parameters, seemed to be less affected by the treatments.

The following conclusions may be drawn: (1) the VCG parameters show a significant correlation with the %DV of thallium myocardial scintigrams, and, therefore, it is possible to use VCG to predict myocardial infarct size easily and non-invasively; (2) with a higher coefficient of correlation with the %DV of thallium myocardial scintigrams than the spatial parameters, the departure parameters are more accurate for evaluating the myocardial infarct size than the spatial parameters.

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