CORRELATIVE STUDIES BETWEEN FRANK VECTORCARDIOGRAMS
AND THALLIUM-201 MYOCARDIAL PERFUSION IMAGES IN
PATIENTS WITH OLD ANTERIOR MYOCARDIAL INFARCTION

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A correlative study was performed on 70 patients with old anterior myocardial infarction between each of the orthogonal components of instantaneous QRS vectors and the anterior-wall, lateral-wall and septal myocardial uptake ratios (A-MUR, L-MUR and S-MUR, respectively). These MURs were calculated from the thallium-201 myocardial perfusion images at 5 projections and used as the index of the infarct size of the respective LV wall. The Z components of the 14-msec and 24-msec instantaneous QRS vectors significantly correlated with the S-MUR (r = -0.51) and the A-MUR (r = -0.66) respectively. The X component of the 32-msec instantaneous QRS vector also showed a significant correlation with the L-MUR (r = 0.59). The regression equations obtained in the present study seemed also applicable to patients with complete right bundle branch block. It is concluded that the quantitative analysis of the Frank vectorcardiograms could afford valuable information as to the size as well as the site of myocardial infarctions.

The size of myocardial infarction has been clinically estimated noninvasively by the analysis of serial changes in serum creatinine phosphokinase (CPK),1 electrocardiographic body surface mapping2 or technetium-99m pyrophosphate imaging3; or invasively by left ventriculography (LVG). The recent advent of thallium-201 myocardial perfusion imaging (201TI MPI) and computer technology have made it possible to determine the site of myocardial infarction noninvasively and also to estimate the infarct size semiquantitatively4–8.

Vectorcardiograms (VCG) as well as electrocardiograms (ECG) are quite popular and useful clinical tools to diagnose myocardial infarction. Although there have been several studies on the estimation of the infarct size by ECG, very few vectorcardiographic studies have been made for the estimation9,10. The purpose of the present study is to correlate the parameters of Frank VCGs with the infarct size estimated by 201TI myocardial perfusion images in patients with old anterior myocardial infarction.

MATERIALS

The subjects consisted of 70 patients with

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684 Japanese Circulation Journal Vol. 46, July 1982

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prior anteroseptal, anterior, anterolateral or extensive anterior infarction. There were 66 men and 4 women, ranging in age from 34 to 69, with an average of 53. All of the patients had a well documented history of acute transmural myocardial infarction and were classified into 4 subgroups on the basis of $^{201}$TI MPI: anteroseptal (34 patients), anterior (13 patients), anterolateral (8 patients) and extensive anterior infarction (15 patients). Forty-seven patients had undergone coronary arteriography and left ventriculography. Additional involvement of the inferior and/or posterior wall, which was confirmed by LVG and/or $^{201}$TI MPI, was found in 12 and 9 patients respectively. Three were complicated with complete right bundle branch block (CRBBB).

$^{201}$TI myocardial perfusion images were obtained one month to 14 years (an average of 14.3 months) after the acute episode of myocardial infarction. Vectorcardiograms were recorded within a week after the imaging study.

The average of the QRS duration was 94.2 msec (82–118 msec), except for 3 patients with CRBBB. The control vectorcardiograms were obtained from 55 normal men whose ages ranged from 50 to 59 years.

**METHODS**

$^{201}$TI myocardial imaging was performed with the Searle Pho/Gamma LFOV scintillation camera equipped with a converging collimator. Twenty minutes after intravenous injection of 2 mCi of thallium-201, images of a total of 500,000 counts were obtained in each of the 5 projections: the anterior, the 3 left anterior oblique (LAO) and the left lateral ones. The LAO images were obtained at 30°, 45° and 60°. All scintigraphic data were stored in the Shimazu Scintipac 200 minicomputer.

Nine equal, square regions of interest (ROI) were located to fit the left ventricular wall in each projection after background subtraction by Goris’ method. In each of the 5 projections, the count of each ROI was expressed in terms of the percentage of the count of the ROI showing the maximal one (projection regional myocardial uptake ratio: projection RMUR) (Fig. 1). In our previous correlation study between $^{201}$TI MPI and left ventriculograms, the 95% range of the minimum projection RMUR was 2 to 42% in akinetic or dyskinetic LV wall segments and 30 to 61% in hypokinetic ones. In the present study, therefore, anterior, lateral and septal infarctions were diagnosed when the minimum projection RMUR of the respective wall of the left ventricle was less than 65%. A central ROI was also used to evaluate en face views of either anterior or lateral wall of the left ventricle, and the diagnostic threshold for an infarction with respect to the central ROI was arbitrarily set at 40% in each projection, because projection RMURs in central ROIs were usually 60 to 80% of those in the circumferential ROIs in normal subjects in our laboratory.

The anterior-wall, lateral-wall and septal MURs were defined as the average of the projection RMURs obtained from the 10 ROIs of the LV anterior wall, the 8 ROIs of the LV lateral wall, and the 4 ROIs of the ventricular septum, respectively (Fig. 2). They were used as the semiquantitative index of the infarct size of the respective LV wall.

Signals of Frank orthogonal leads were recorded on magnetic tapes and were fed into a mini-
Fig. 2. Segmentation of the left ventricular wall by thallium-201 myocardial perfusion image. Anterior-wall, lateral-wall and septal MURs were defined as the average of the corresponding projection RMURs.

Fig. 3. Student’s $t$ value in the statistical test of the difference in the mean $Z$ component of instantaneous QRS vectors between patients with anterior infarcts and normal control. The curve in the figure indicates the $t$ values in the Student’s $t$-test of the difference in the mean $Z$ component of every 2-msec instantaneous QRS vectors between all 70 patients with anterior infarctions and normal controls (solid line), and also between 61 patients without posterior lesion and normal controls (dashed line). A statistically significant difference ($p < 0.001$) exists over the dashed horizontal line, and the maximal $t$ value was observed at 20 msec in all 70 patients and 22 msec in 61 patients without posterior lesion. Although two curves were similar in shape, $t$ values from 2 to 24 msec were rather larger in patients without posterior lesion than in all patients.

Fig. 4. Student’s $t$ values in the statistical test of the difference in the mean $X$ component of instantaneous QRS vectors between patients with anterior infarctions and normal controls. The curve in the figure represents the $t$ values in the Student’s $t$-test of the difference in the mean $X$ component of every 2-msec instantaneous QRS vectors between all 70 patients and normal controls. A statistically significant difference ($p < 0.001$) is present above the dashed horizontal line, and the maximal $t$ value was obtained at 34 msec.

According to Frank’s original description, the posterior, leftward and inferior directions were designated as positive.

*Japanese Circulation Journal Vol. 46, July 1982*
Fig. 5. Correlation coefficients between the Z component of instantaneous QRS vectors and the septal MUR in all 70 patients. The figure shows the correlation coefficients between the Z component of every 2-msec instantaneous QRS vectors and the septal MUR, and F values in the statistical test of the null hypothesis that the population correlation coefficient is zero. A statistically significant correlation exists above the dashed horizontal line, and the Z component of the 14-msec instantaneous QRS vector (Z_{14}) showed the largest F value and correlation coefficient (r = -0.51).

Fig. 6. Correlation between the Z component of the 14-msec instantaneous QRS vector and the septal MUR. The Z component of the 14-msec instantaneous QRS vector (Z_{14}) significantly correlated with the S-MUR (r = -0.51, p < 0.001). It is noteworthy that the regression equation also fits to the 3 patients with CRBBB (open circle).

The Student's t-test of the difference in means both of X and Z components of the instantaneous QRS vectors was performed between all 70 patients and normal control and also between those not complicated with posterior infarction and normal control. Linear regression analysis was made between each of the orthogonal components of 2- to 80-msec instantaneous QRS vectors and the MURs. A p level of less than 0.001 was arbitrarily selected for statistical significance.

RESULTS

Differences in Instantaneous QRS Vectors between Patients with Anterior Infarcts and Normal Controls

The t values in statistical tests of the difference in mean Z and X components of the instantaneous QRS vectors between all 70 patients and normal controls are shown in Figs. 3 and 4. A statistically significant mean difference was observed between the two groups in the Z component of the 4- to 50-msec vectors with the maximal t value at 20 msec, and also in the X component of the 28- to 42-msec vectors, the maximal t value being observed at 34 msec.

*Japanese Circulation Journal Vol. 46, July 1982*
Correlation between the Z component of the 24-msec instantaneous QRS vector and the anterior-wall MUR. The Z component significantly correlated with the A-MUR (r = -0.66, p < 0.001). The regression equation is also adequate in the 3 patients with CRBBB (open circle).

Linear Correlations between Instantaneous QRS Vectors and MURs

The Z component of the 4- to 28-msec instantaneous QRS vectors showed a significant correlation with the septal MUR (S-MUR) in all 70 patients. Figure 5 shows the F values in the statistical test of the null hypothesis that the population correlation coefficient is zero. The Z component of the 14-msec instantaneous QRS vector (Z\textsubscript{14}) had the maximal F value, the correlation coefficient being -0.51 and the regression equation $S-MUR = -74.7 Z_{14} + 68.4$ (Fig. 6). There was no significant correlation between either the X or Y component of instantaneous QRS vectors and S-MUR.

The Z component of the 8- to 40-msec instantaneous QRS vectors showed a significant correlation with the anterior-wall MUR (A-MUR) in 61 patients not complicated with an additional posterior lesion (Fig. 7). The Z component of the 24-msec instantaneous QRS vector (Z\textsubscript{24}) showed the largest F value and correlation coefficient (r = -0.66) (Fig. 8). Linear regression analysis gave an equation, A-MUR = -45.3 Z\textsubscript{24} + 75.7. These results suggest that the infarct size of the anterior wall is greater in patients with a larger posterior component of the vector. The A-MUR was low (49%) in a patient with a large

Fig. 9. Two illustrative cases showing the significance of Z\textsubscript{24} in the estimation of the size of anterior infarctions. A patient with a large positive Z\textsubscript{24} (0.7 mV) showed a low A-MUR (49%) (upper panel), and another patient with a small Z\textsubscript{24} (0.06 mV) showed a high A-MUR (79%) (lower panel).

Abbreviations: ANT = anterior; LAO = left anterior oblique 45°; LL = left lateral; VCG = vectorcardiogram (horizontal QRS loop).
Fig. 10. Correlation between the Z component of the 24-msec instantaneous QRS vector and the anterior-wall MUR in 9 patients with both anterior and posterior infarctions. A less significant correlation \( r = -0.71 \) (\( P < 0.05 \)) was observed between the \( Z_{24} \) and the A-MUR. The \( Z_{24} \) was deviated less posteriorly in these 9 patients than in those not complicated with posterior lesion.

positive \( Z_{24} \) (0.7 mV) and, to the contrary, high (79%) in another patient with a small \( Z_{24} \) (0.06 mV) (Fig. 9). No significant correlation was seen between either the X or Y component of instantaneous QRS vectors and A-MUR.

In 9 patients with both anterior and posterior infarctions, a less significant correlation \( r = -0.71 \), \( P < 0.05 \) was also present between \( Z_{24} \) and the A-MUR (Fig. 10). A regression equation of \( A\text{-MUR} = -66.2Z_{24} + 55.5 \) was obtained. However, the \( Z_{24} \) was deviated less posteriorly in patients with an additional posterior lesion than in those without.

The X component of the 14- to 38-msec instantaneous QRS vectors showed a significant correlation with the lateral-wall MUR (L-MUR) in all 70 patients (Fig. 11). The X component of the 32-msec instantaneous QRS vector \( (X_{32}) \) showed the largest correlation coefficient \( r = 0.59 \) (Fig. 12). The linear regression equation was \( L\text{-MUR} = 18.4X_{32} + 64.5 \). The time when the X component showed the largest correlation coefficient was quite similar to the one (34 msec) at which the X component showed the most significant difference between the patients with anterior infarctions and normal controls. A patient with a large rightward component of the vector (0.39 mV) showed a low L-MUR (61%), and another patient with a large leftward component of the vector (0.61 mV) showed a high L-MUR (88%) (Fig. 13). Neither the Y nor Z component of instantaneous QRS vectors correlated significantly with L-MUR.

**DISCUSSION**

Although the clinical usefulness of quan-
Fig.13. Two representative patients indicating the significance of $X_{12}$ in the estimation of the lateral infarct size. The L-MUR was low (61%) in a patient with a large rightward component of the 32-msec instantaneous QRS vector (0.39 mV) (upper panel) and high (88%) in another patient with a large leftward component (0.61 mV) (lower panel). Abbreviations: ANT = anterior, LAO = left anterior oblique 45°; LL = left lateral; VCG = vectorcardiogram (horizontal QRS loop).

Identification of the myocardial infarct size by the technetium-99m pyrophosphate myocardial imaging is thought to be established, the quantitative analysis of $^{201}$Tl myocardial perfusion imaging is on the trial stage. The following factors, as suggested by Nelson et al., would make the quantification of $^{201}$Tl MPI difficult: 1) blurring of the edge of the defect due to myocardial motion, 2) masking of the edge of the defect by the activity of normal myocardium overlying the projection of the defect, 3) non-uniform distribution of infarcted myocardium, etc. The technical improvement developed in the present study may resolve some of the problems which were suggested by Nelson et al. In the present study, the counts from the 22 ROIs at 5 projections were used to calculate the index of the infarct size of LV wall segments.

Wackers et al. made a clinicopathological study in 23 patients who had been studied with $^{201}$Tl MPI during the acute phase and died from acute transmural myocardial infarction. The size of infarction determined from postmortem slices of the heart significantly correlated with the size estimated with the perfusion images ($r = 0.72$). In addition, Morrison et al. recently reported a significant correlation ($r = 0.65$) between the enzymatic infarct size and the thallium-201 perfusion index obtained by the method similar to ours from 28 equal, square ROIs at 4 projections (anterior, left anterior oblique 15° and 45° and left lateral projections). In our previous study, a significant correlation was shown between the asynnergy index obtained by

Japanese Circulation Journal Vol. 46, July 1982
LVG and the A-MUR in anterior infarction \((r = 0.58, p < 0.01)\). This suggests that the quantitative analysis of \(^{201}\)TI MPI could be a useful and reliable clinical tool for estimation of the myocardial infarct size. Berger et al.\(^{15}\) reported that resting \(^{201}\)TI defects may represent not only infarcted but also severely ischemic noninfarcted zones and delayed images obtained 2 to 4 hours later could differentiate between these two. As discussed above, however, significant correlation of initial \(^{201}\)TI myocardial defects with ventriculographic, serum-enzymatic and postmortem data have been reported.

Vectorcardiograms have been widely used usually to determine the infarct site but very rarely to evaluate the infarct size.\(^{16,17}\) In 1978, Wickline and McNamara\(^{18}\) reported a vectorcardiographic method for determining the absolute size of myocardial infarctions resulting from coronary artery ligation in 9 baboons. The maximum waveheight difference between pre- and post-ligation scalar waveforms was measured in the three orthogonal leads and used to derive the spatial vector voltage deviation. The chronic spatial vector voltage deviation showed a highly significant correlation with the histologically determined infarct size \((r = 0.92)\). The most profound changes occurred in the Z lead in baboons with antero-septal infarction caused by the ligation of the left anterior descending branch. The losses of the mid-phase inferior and leftward vectors were closely related to the inferior wall and the lateral free wall infarctions, respectively.

In the present study, extensive statistical analysis was made on the instantaneous QRS vectors and \(^{201}\)TI MPI to discover which one of the vectors deviated most sensitively from normals in anterior infarction and whether the QRS vectors can be used for estimation of the infarct size. It was found that the most significant waveheight difference existed in the Z component of the 20-msec QRS vector and also in the X component of the 34-msec vector between patients with anterior infarction and normal controls, and further that the Z component of the 14- and 24-msec QRS vector correlated most significantly with the septal and anterior-wall MUR, respectively and the X component of the 32-msec vector with the lateral-wall MUR. These findings strongly suggest that \(Z_{24}, Z_{24}\) and \(X_{32}\) can be a good indicator of the septal, anterior and lateral infarct size, respectively. The finding that these vector components are important in the estimation of the infarct size is compatible with the report of Durrer et al.\(^{19}\) concerning the time course and instantaneous distribution of the excitatory process in normal isolated human hearts.

Although \(Z_{24}\) was deviated less posteriorly in patients with an additional posterior infarct than in those without, neither \(Z_{14}\) nor \(X_{32}\) was influenced by the complication of the posterior infarction. In addition, a complication of an inferior infarct had no influence on either the X or Z components of the instantaneous QRS vectors.

Estimation of the infarct size by the instantaneous QRS vectors may be limited in patients with ventricular conduction defects such as bundle branch block or Wolff-Parkinson-White syndrome, which modifies the initial QRS vectors. However, the incidence of left bundle branch block (LBBB) is low in acute myocardial infarction (2%–6%) and seems to become further lower in the chronic phase because of high mortality of patients with complete LBBB.\(^{20,21}\) Okajima et al. reported a strong similarity of the initial 2- to 30-msec instantaneous QRS vectors between normal and CRBBB.\(^{22}\) The regression equations obtained in the present study seem applicable to patients with CRBBB (Figs. 6, 8 and 12).

In conclusion, the quantitative analysis of the Frank vectorcardiograms could afford valuable information as to the size as well as the site of myocardial infarctions. The predictive accuracy will be expected to be improved by application of multivariate analysis of Frank VCG parameters.

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REFERENCES


