SPATIAL ORIENTATION OF THE VECTORCARDIOGRAM IN PATIENTS WITH MYOCARDIAL INFARCTION

SHIGEO HORINAKA, M.D., HIDEO YAMAMOTO, M.D.
AND SHIGERU YAGI, M.D.

We studied the rotation angles on the each of 3 axes and the planarity and roundness of QRS loop when its plane was laid close to horizontal in 4 groups of patients. Thirty five had anterior myocardial infarction, 34 inferior infarction, 15 non Q wave inferior infarction, and 34 were normal subjects. The rotation angles of the QRS loop were significantly different from the controls, on the Y and Z axes in the anterior infarction group, on the Z axis in the inferior infarction group and on the X axis in the non Q wave inferior infarction group ($p < 0.01$). The planarity index in the inferior infarction group was significantly higher ($p < 0.01$) than in other groups. The significantly smallest value of the roundness index was noted in the anterior infarction group ($p < 0.01$). Significant features of the early segmental planarity indexes were shown in the non Q and Q wave inferior infarction groups ($p < 0.01$). We conclude that the rotation angles and the planarity and roundness indexes are characteristic parameters for the infarct group and may be useful for diagnosing myocardial infarction, which is difficult with electrocardiography and vectorcardiography.

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IN vectorcardiography, only the directions and the magnitudes of the maximum QRS and T vectors and half-area vectors are widely used, but a few features with notching and indentations are quantified in terms of planarity and roundness. We have used the lead-axis rotations to obtain more simple parameters than the conventional-plane projection and present them as simply as possible. Vectorcardiography after lead-axis rotations has been reported by McFee et al^{1,2} and others, but only a few studies have been carried out. Several investigators have reported that, in normal subjects, the QRS loop viewed after lead-axis rotation has a more

uniform configuration than the QRS loop in conventional-plane projection. Consequently, lead-axis rotation can improve the analysis of abnormalities, both in direction and configuration^{3,4}. We have tried to evaluate statistically their diagnostic usefulness in non Q wave myocardial infarction as well as in Q wave infarction. Because certain vectorcardiographic parameters have not been studied in detail, especially in non Q wave infarction, the parameters were as follows: the angles of 3 axes and the planarity and the roundness of QRS loop when its plane is laid close to horizontal after lead-axis rotation.

Key words:

Vectorcardiogram
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Planarity
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MATERIAL AND METHODS

Material

One hundred eighteen subjects were studied; 84 with acute myocardial infarction and

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Department of Medicine, Division of Hypertension and Cardiorenal Disease, Dokkyo University School of Medicine, Mibu, Tochigi 321-02, Japan

Mailing address: Shigeo Horinaka, M.D., Department of Medicine, Division of Hypertension and Cardiorenal Disease, Dokkyo University School of Medicine Mibu, Tochigi 321-02, Japan

Planarity

total planarity (D)

$$D = \frac{\sum fn^2}{\text{max. vector}}$$

segmental deviation (dn)

$$dn = \frac{fn}{\text{max. vector}}$$

Frontal plane

Horizontal plane

Roundness

$$R = \frac{\text{area}}{(\text{max. vector})^2}$$

Fig.1. Schematic representation of the measurements taken in the frontal and horizontal planes of QRS loop after lead-axis rotation and formulas for calculating planarity and roundness.

34 normal subjects. The control group included 24 men and 10 women, mean age 52 ± 14 years. They were all healthy volunteers who on complete physical examination, electrocardiography, and chest X ray, were considered normal. Patients had the first myocardial infarction attack established by typical chest pain and abnormal serum enzyme increasing and asynergic location of the left ventricle as shown on left ventriculography, with significant stenosis in at least one major coronary artery. All subjects were recorded vectorcardiographically. Patients with myocardial infarction had left ventriculography and coronary angiography within 1 week of the vectorcardiographic recording at 1 month later from onset of first myocardial infarction attack. The patients with myocardial infarction were divided into 3 groups: the anterior infarction group (anterior MI group) included 32 men and 3 women, mean age 55 ± 11 years with anterior associated and/or septal hypokinesis of the left ventricle and coronary stenosis according to the American Heart Association reporting system⁵; the inferior infarction group (inferior MI group) included 30 men and 4 women, mean age 56 ± 13 years with electrocardiographic and/or vectorcardiographic signs^{5,6} of inferior infarction; the other in-

ferior infarction group was without these signs^{5,6} (non Q MI group) but had inferior associated and/or posterior, lateral hypokinesis on left ventriculography and coronary stenosis according to the American Heart Association reporting system.⁵ The latter group included 13 men and 2 women, mean age 51 ± 13 years. The mean ages were not statistically different between 3 groups.

Methods

Rotation of lead axes: We recorded Frank lead system⁷ vectorcardiograms using the Fukuda Denshi vectorcardiographic machine (VA-3G, Tokyo) with a sensitivity of 4.0 cm/mV. The patients were supine, and a chest electroplate was placed on the fifth intercostal space. Three ordinary planar projections were shown simultaneously on a screen, and the screen was recorded by XY plotter. According to McFee's method,¹ the lead resolver of the vectorcardiogram (Fukuda Denshi VA-3G) was used to rotate the plane of the QRS loop close to the horizontal plane. The first rotation of the lead system on the Y axis through an angle A is adjusted so that the QRS deflection recorded from the Z output is equally positive and negative, with the principal deflection from the Z output being positive. The second

Fig.2. The rotation angles on the Y axis of the QRS loop and T loop in each group. Anterior MI=anterior myocardial infarction group, Inferior MI=inferior myocardial infarction group, Non Q MI=non Q wave infarction group, Control=control group, SD=standard deviation of mean, * $p < 0.01$

rotation through the angle B on the Z axis is adjusted so that the deflection from the Y output is equal phasic. The final rotation on the X axis through the angle C is adjusted so that the Y output is smallest, with the initial deflection of the Z output negative. When these steps were complete, the QRS complex in the new XYZ output was shown, and the 3 new planar projections were recorded by XY plotter simultaneously. Subsequently, angles A, B, C were measured. The procedure was repeated for the T wave.

Planarity of QRS loop: The frontal QRS loop after lead-axis rotation is Pipberger's edgewise view, which is perpendicular to the polar vector^{8,9}. Consequently, the degree of deviation of the frontal QRS loop after lead-axis rotations indicates the planarity of the QRS loop. The maximum left-side component and the maximum right-side component of the frontal QRS loop after lead-axis rotation were added. The total component was quartered for the axis perpendicularly. The points were defined P1, 2, ..., P7 so that quarter lines crossed the frontal QRS loop in the time sequence of QRS loop. The distance (f1) was measured from the point (P1) to a line parallel to the axis through the point of origin. The index of total deviation (D) of the frontal QRS loop after lead-axis rotation was calculated as the ratio of summation which is the square of fn to the

maximal QRS vector. Moreover, the segmental index of deviation (dn) of the frontal QRS loop after lead-axis rotation was calculated as the ratio of fn to the maximal QRS vector. Fig. 1 shows the measurements that were analyzed in the frontal QRS loop after lead-axis rotation.

Roundness of QRS loop: The area of the horizontal QRS loop after lead-axis rotation was measured by computerized planimeter. The index of roundness (R) was calculated as the ratio of the area of QRS loop to the square of maximal QRS vector in the horizontal plane after lead-axis rotation. Fig. 1 shows the measurements that were analyzed in the horizontal QRS loops after lead-axis rotation.

Statistical analysis: Results are reported as mean $\pm$ standard deviation of mean (SD). Differences were analyzed using a one-way analysis of variance, and significance is inferred at the < 0.01 level.

RESULTS

Rotation angles: The A angles of the anterior MI group were significantly more posterior than those of the control group, inferior MI and non Q MI groups in the QRS loop (mean $\pm$ SD: -60.9 ± 28.8 degrees vs -12.7 ± 19.3 , -5.2 ± 33.3 and -12.1 ± 25.5 degrees; $p < 0.01$, respectively) as shown in

Fig.3. The rotation angle on the X axis of the QRS loop and T loop in each group.
* $p < 0.01$

Fig.4. The rotation angle on the Z axis of the QRS loop and T loop in each group.
* $p < 0.01$

Fig. 2. The B angles of the inferior MI, anterior MI and non Q MI groups were significantly superior than those of the control group in the QRS loop (-3.4 ± 22.6 , 19.4 ± 20.2 and 20.8 ± 11.0 degrees vs 34.8 ± 14.7 degrees; $p < 0.01$, respectively); and those of the inferior MI group were significantly more superior than those of the anterior MI and non Q MI groups in the QRS loop ($p < 0.01$, respectively). Similar differences presented in the T loop, as shown in Fig. 3. The C angles of the non Q MI group were significantly more inferior

than those of the control and anterior MI groups in the QRS loop (7.2 ± 12.7 degrees vs -5.5 ± 15.4 , -20.1 ± 36.6 degrees, $p < 0.01$ respectively) as shown in Fig. 4. However, other groups did not significantly differ from the control group in the QRS and T loop, as shown in Figs. 2, 3 and 4.

Planarity index: The total deviation index (D) was 0.0275 ± 0.0127 (Mean $\pm$ SD) in the control group, 0.0622 ± 0.0614 in the anterior MI group, 0.2238 ± 0.2763 in the inferior MI group, and 0.0311 ± 0.0252 in the non Q MI group. The inferior MI group had a signifi-

Fig. 5. The total planarity indices were compared between 4 groups.

cantly higher value ($p < 0.01$), as shown in Fig. 5. Concerning the segmental planarity index (dn) (Fig. 6), the negative of the vertical axis in Fig. 1 corresponded with the upper part of Y axis, with the exception of P8 because the right components were not observed, except in few cases. The dn was studied from P1 to P7. The d1 was -0.1610 ± 0.1632 (Mean $\pm$ SD) in the inferior MI group, -0.0456 ± 0.0311 in the non Q MI group and -0.0048 ± 0.0537 in the control group. The d2 was -0.1205 ± 0.1599 in the inferior MI group, -0.0691 ± 0.0471 in the non Q MI group and -0.0217 ± 0.0478 in the control group. The inferior MI and non Q MI group readings were significantly greater than those of the control group (d1: $p < 0.01$, d2: $p < 0.01$, respectively); and those of the inferior MI group were significantly greater than the non Q MI group ($p < 0.01$, respectively). However, there were no significant differences between the control group and the anterior MI group (Fig. 6).

Roundness index: The roundness index (R) was 0.345 ± 0.172 (Mean $\pm$ SD) in the anterior MI group, 0.508 ± 0.189 in the control group, 0.445 ± 0.168 in the inferior MI group and 0.547 ± 0.254 in the non Q MI group. The roundness index was lowest in the anterior MI group ($p < 0.01$). However,

there were no significant differences between other groups (Fig. 7).

DISCUSSION

Rotation angles: Although findings on rotation angles have been reported by several investigators^{1,4,10,11} few reports have compared anterior and inferior myocardial infarctions^{8,12}. This study reports on particular features of respective rotation angles of QRS loop in myocardial infarctions (Figs. 2, 3 and 4). It is possible that the differences in these angles of distortion are due to dropped-out electric forces of the infarcted myocardium. Few reports have considered rotation angles of the T loop!² Although those were partially statistically significant, our results show a trend like that of QRS loop. Reasonable reflects changes in the process of repolarization was suggested, as in the process of depolarization. Pipberger et al⁸ and Yamauchi!¹² reported that the mean direction of normal polar vectors by Frank's lead system in terms of azimuth and elevation angles were 198 ± 30 , -8.2 ± 27.9 and -50 ± 13 , 137.9 ± 12.3 degrees respectively (mean $\pm$ SD). The A and B angles equivalent to their methods were -18 ± 30 , -8.2 ± 27.9 and 50 ± 13 , 42.1 ± 12.3 degrees respectively (mean $\pm$ SD) in our method. Those from these studies in the normal group were almost similar as shown in Fig. 2 and 3. In the study by Pipberger et al⁸ the 134 cases with old myocardial infarctions showed the highest proportion of abnormal polar vectors (75%), and the wide scatter of abnormal polar vectors could not be reduced substantially when cases were separated according to localization of infarction. However in our study, the findings on rotation angles were significantly different according to localization of infarction. In conventional projection, anterior myocardial infarction is recognized in the horizontal plane by loss of the first forces, with the initial position of the QRS loop oriented posteriorly and to the left. The entire loop is displaced posteriorly with loss of anterior convexity,¹¹ as shown in Fig. 2. The degree of A angle was significant in anterior MI group. It was directed posteriorly. What attracted our interest was the degree of B, as shown Fig. 3. It angle was mild in anterior

Fig.6. The segmental planarity indices were compared between 4 groups. * $p < 0.01$

Fig.7. The roundness indices were compared between 4 groups.

MI group, but it is directed superior region as in inferior MI group, suggesting that it is affected by apical infarction. On the other hand, inferior myocardial infarction is best displayed in the frontal and sagittal planes. The initial portion of the QRS loop is directed superiorly with inferior infarction.¹³ As shown in Fig. 3 and 4, the degree of B angle was significant in inferior MI group and the degree of C angle was significant in non Q MI group, it was directed superiorly.

Yamauchi also reported QRS polar vector deviated posterior in the inferior infarction.¹²

Planarity: No findings have yet been reported on the QRS loop followed by axis rotation, and Pipberger et al⁸ reported that measurements divided from edgewise projections of the QRS loop did not lead to recognition of large percentages of abnormalities and ratios indicating the planarity of QRS proved to be of relatively poor diagnostic quality. However, Yamauchi reported the planarity of QRS loop in the anterior infarction but not inferior infarction was poorer than in normal.¹² Our study disagrees with these findings. These discrepancies may result from differences in analytic methods and differences between the subjects in Pipberger's and Yamauchi's infarct groups and those in the 3 infarct groups in our study. Indeed, inferior and non Q MI groups showed significant features (Fig. 5, 6). Schellong et al¹⁴ found that QRS loops in healthy subjects were fairly planar. Similar findings showing an inclination toward nearly horizontal planes were obtained from control group in our study. Although Mori¹⁵ reported planarity of the QRS loop is not so favorable in the initial and terminal part of the QRS loop, even in normal subjects, however it is generally favorable in the middle part. It is more convenient, approximate the whole loop to a plane than only the middle part. Nomura et al¹⁶ reported when the planarities were divided 2 parts of the QRS loop by the maximum magnitude, planarity of latter half did not so aggravate in

myocardial infarction. Similarly, in our study, the planarity of the middle and latter parts of the spatial QRS loop was favorable in control and infarct groups (Fig. 6). Recently, Arnaud et al¹⁷ introduced an index that provides information concerning QRS planarity and any kind of loop distortion, it could distinguish between normal and myocardial infarction subjects. QRS loops are considered either to assume planarity or to deteriorate in subjects with inferior infarction, since they are easily affected by infarction vector.

Roundness: In a previous study, roundness of QRS loop was expressed as length/width and right/left ratios. Cases with myocardial infarctions, however, deviated from normal by only a small percentage^{8,10}. In our study, the index of roundness (R) which was calculated with the new method, may be expressed more exactly and truly than the roundness in the previous study^{8,9}. From the points of relationship between a plane where normal QRS exist and a direction of infarction vector in myocardial infarction, it is postulated that the effect of the infarction vector on the roundness of QRS loop is largest in the anterior infarction and, in contrast, smaller in the inferior infarction. Our results have shown such a trend and anterior MI group was only significant difference in our study (Fig. 7), the strong reduction of roundness suggests an infarction of the anterior wall. The result was consistent with the report by Yamauchi¹².

Non Q wave inferior infarction: The significant features were demonstrated in non Q MI group, 15 of our patients (75%) beyond a mean minus standard deviation of d1 and d2 in the control group, and only 4 cases (12%) in the control subjects met a mean minus standard deviation of d1 and d2 in a non Q MI group. Thus, notable change took place in early stage of a QRS loop in the individuals with non Q MI (Fig. 6). Therefore, determining planarity followed by axis rotation may be useful method for diagnosing inferior infarction in situations where diagnosis is difficult¹⁸⁻²⁰.

In conclusion, these specific findings obtained from vectorcardiogram after lead-axis rotation may be useful way to diagnose myocardial infarction, especially localization of myocardial infarction and non Q wave

myocardial infarction. Furthermore, we suggested spatial orientation of the vectorcardiogram may include important characteristic information.

Several authors reported these parameters calculated by digital computer^{9,12,15-17} however, no report has been made on the roundness and planarity which were calculated by our method. In future, it will be easy to calculate our parameters by the progression of digital computer.

REFERENCES

1. McFEE R, WILKINSON RS, ABILDSKOV JA: On the normalization of the electrical orientation of the heart and the representation of electrical axis by means of an axis map. *Am Heart J* 1961; **62**: 391-397
2. McFEE R, PARUNGAO A, MUELLER W: An electronic coordinate transformer for electrocardiography. *IRE Trans Biomed Electronics* 1961; **8**: 52-54
3. MILNOR WR: The normal vectrocardiogram and a system for the classification of vectrocardiographic abnormalities. *Circulation* 1957; **16**: 95-106
4. SEIDEN GE: The normal QRS loop observed 3 dimensionally obtained with the Frank precordial system. *Circulation* 1957; **16**: 582-585
5. AUSTEN WG, EDWARDS JE, FRYE RL, et al: A reporting system on patients evaluated for coronary artery disease: report of Ad Hoc Committee for grading of coronary artery disease, Council on Cardiovascular surgery, American Heart Association. *Circulation* 1975; **51**(Supple): 5-40
6. CHOU TC, HELM RA: Clinical vectorcardiography. 2nd ed. New York. Grune and Statton, 1974: p85-113
7. FRANK E: An accurate clinically practical system for spatial vectorcardiography. *Circulation* 1956; **13**: 737-749
8. PIPBERGER HV, CARTER TN: Analysis of the normal and abnormal vectorcardiogram in its own reference frame. *Circulation* 1962; **25**: 827-840
9. PIPBERGER HV: Use of computer in interpretation of electrocardiograms. *Circ Res* 1962; **11**: 555-561
10. OHSHITA K: Study on vectorcardiogram. Planarity of normal spatial vectorcardiogram. *Jpn Circ J* 1966; **30**: 237-244
11. STARR JW, WAGNER GS, DRAFFIN RM, REED JB, WALSTON A II, BEHAR VS: Vectorcardiographic criteria for the diagnosis of anterior myocardial infarction. *Circulation* 1976; **53**: 229-234
12. YAMAGUCHI K: Computer analysis of vectorcardiograms in myocardial infarction with spatial reference to polar vector and planarity of the QRS and T loops. *Jpn Heart J* 1979; **20**: 587-601
13. STARR JW, WAGNER GS, BEHAR VS, WALSTON A II, GREENFIELD JC Jr: Vectorcardiographic criteria for the diagnosis of inferior

- myocardial infarction. *Circulation* 1974; **49**: 829–836
14. SCHELLONG F: Grundzuge einer klinischen vektordiagraphie des herzens. *Ergeb Inn Med Kinderheilkd* 1939; **56**: 657–743
  15. MORI H, SHIBATA T, OSHITA K, KAWAMURA H: Spatial analytico-geometrical analysis of the vectorcardiogram by electronic computer. Vectorcardiogram of Frank system of the healthy middle-age men. *Jpn Circ J* 1966; **30**: 1017–1029
  16. NOMURA Y, TAKAKI Y, TOYAMA S: Computer analysis of the spatial vectorcardiogram with Frank's lead system. *Jpn Circ J* 1967; **31**: 1441–1451
  17. ARNAUD P, MORLET D, RUBEL P: Planarity of the spatial QRS loop. Comparative analysis in normals, infarcts, ventricular hypertrophies, and intraventricular conduction defects. *J Electrocardiol* 1989; **22**: 143–152
  18. TOUTOUZAS P, AVGOUSTAKIS D, KOROXWNIDEX G, ATHANASSIOU V: The electrocardiogram and vectorcardiogram in the diagnosis of old inferior myocardial infarction. *J Electrocardiol* 1973; **6**: 319–323
  19. ABBOTT JA, SCHEINMAN MM: Nondiagnostic electrocardiogram in patient with acute myocardial infarction. Clinical and anatomic correlations. *Am J Med* 1973; **55**: 608–613
  20. YOUNG E, WILLIAMS C: The frontal plane vectorcardiogram in old inferior myocardial infarction. Criteria for diagnosis and electrocardiographic correlation. *Circulation* 1968; **37**: 604–623