Usefulness of Vectorcardiography for Assessment of Severity of Right Ventricular Overloading in Congenital Heart Disease

II. Atrial Septal Defect of Secundum Type

KAZUHIKO MURATA, SATORU MATSUSHITA AND KIZUKU KURAMOTO[†]

The Frank lead vectorcardiograms of 31 catheterized cases of atrial septal defect of secundum type were reviewed and the results were correlated with the hemodynamic observations. Although no definite relationship was demonstrated between the vectorcardiographic measurements and the hemodynamic data, there was a significant correlation between the QRS patterns in the frontal plane and the right/left ventricular work ratios. The vectorcardiograms were thought to be of some value for assessment of the severity of right ventricular overloading in atrial septal defect.

THE PURPOSE of the present paper is to determine the value of vectorcardiogram as an indicator of the hemodynamic status in atrial septal defect of secundum type.

MATERIALS AND METHODS

The Frank lead vectorcardiograms of 31 catheterized cases of atrial septal defect of secundum type, 7 males and 24 females, were reviewed. Four cases associated with partial anomalous pulmonary drainage were included in the present study, but the cases with other cardiovascular abnormalities or those with a significant pressure gradient across the pulmonary valve more than 20 mmHg were discarded. The cases under the age of 15 years or over the age of 50 years were not included.

The method of the recording of the vectorcardiograms was the same as in the previous report¹. The three planar projections of the Frank lead vectorcardiograms were recorded simultaneously. The QRS loop was dissected 500 times per second. The sagittal plane was viewed from the left. The measurements were made on the angle and the magnitude of the maximum leftward and maximum rightward QRS vectors and the maximum T vector in each plane. The magnitude of left, right, anterior and posterior component of the QRS vector was also measured. The spatial magnitude of the maximum leftward and

maximum rightward vectors was calculated by the Pythagorean theorem ($V^2 = X^2 + Y^2 + Z^2$).

The right heart catheterization was performed in the usual manner. The right ventricular peak pressure, pulmonary/systemic flow ratios, and right ventricular/left ventricular work ratios were correlated with the vectorcardiographic measurements. The flow was calculated by the Fick's method. Right or left ventricular work was calculated as follows²: Right ventricular work = Pulmonary flow $\times 1.055 \times (P_{Am} - R_{Am}) \times 1.36 \times 10^{-2}$ Kg/Min/M², Left ventricular work = Systemic flow $\times 1.055 \times (B_{Am} - 5) \times 1.36 \times 10^{-2}$ Kg/Min/M², where P_{Am} , R_{Am} and B_{Am} represent mean pressure of pulmonary artery, right atrium and brachial artery respectively.

RESULTS

1. Correlations of the vector loop patterns with the hemodynamic data

Frontal plane: The major part of the QRS loop was directed to the left and inferiorly. The body of the loop usually showed a clockwise inscription or a figure-of-eight configuration. A counterclockwise inscription of the entire QRS loop in this plane was seen in only 2 cases. There was a large terminal vector associated with conduction delay and directed to

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[†] The Third Department of Internal Medicine (Director: Prof. Kiku Nakao), Faculty of Medicine, University of Tokyo, Tokyo

the right and usually inferiorly. The T loop was directed to the left and inferiorly. The representative vectorcardiograms are illustrated in Figs. 1-4.

Among the hemodynamic parameters, the right ventricular/left ventricular work ratios were best correlated with the vectorcardiographic observations as seen in Table I. A counterclockwise inscription of the entire QRS loop or a linear QRS loop with a figure-of-eight configuration was seen in mild cases without marked increase in the right ventricular work. On the other hand, a significant increase in the right ventricular work of more than moderate degrees was present in 15 of 23 patients in which the major part of the QRS loop was in-

scribed clockwise. Moreover, a significant elevation of the right ventricular pressure and a marked increase in right ventricular/left ventricular work ratio was demonstrated in 8 of 9 cases in which a rightward displacement of the QRS loop was associated with the clockwise inscription of the loop. The configuration of the vector loops of the cases with a marked elevation of the right ventricular pressure simulated pure pulmonary stenosis of moderate severity.

Sagittal plane: A clockwise inscription or a figure-of-eight configuration of the QRS loop was usually observed in the sagittal plane and the QRS loop was displaced anteriorly. The T loop was directed inferiorly and was frequently

TABLE I CONFIGURATION OF QRS LOOP IN THE FRONTAL PLANE AND HEMODYNAMIC OBSERVATIONS

	Counterclockwise inscription of QRS loop	Linear QRS loop with figure-of- eight configuration of the body	Clockwise inscription of QRS body Half-area QRS angle	
			<80°	≥80°
Number of cases	2	6	14	9
Right ventricular peak pressure (mmHg)	38	38±6	31±6	55*±19
-39 mmHg	1	3	12	1
40-59 mmHg	1	3	2	6
60 mmHg-	0	0	0	2
Pulmonary/Systemic blood flow	1.91	2.08±0.34	3.09*±0.93	3.62*±1.89
-1.99	1	2	0	2
2.00-2.99	1	4	8	2
3.00-	0	0	6	5
Right ventricular/Left ventricular work	0.34	0.37±0.13	0.54*±0.28	1.16*±0.34
-0.49	2	5	7	1
0.50-0.99	0	1	5	3
1.00-	0	0	2	5

*: Significantly greater than in other groups. ($p<0.01$)

Fig. 1. An unusual vectorcardiogram of atrial septal defect of secundum type. The QRS loop is inscribed entirely counterclockwise in the frontal plane. There is a large terminal vector directed to the right and posteriorly. The patient was a 44-year-old man with a right ventricular pressure of 30/0-3 mmHg. The pulmonary/systemic flow ratio was 2.48 and the right ventricular/left ventricular work ratio was 0.36.

inscribed clockwise. No obvious relationship was observed between the vectorcardiographic observations in the sagittal plane and the hemodynamic data.

Horizontal plane: The body of the QRS loop was inscribed counterclockwise in 8 and clockwise in 12. A figure-of-eight configuration of the major part of the QRS loop was observed in 11 cases. There was a prominent terminal vector directed to the right. This terminal vector was directed anteriorly in 18 and posteriorly in 12. There was usually a terminal

slowing.

The T loop was directed to the left and either anteriorly or posteriorly. The sense of inscription of the T loop was indeterminate in 8 cases because of a linear configuration of the loop, whereas the loop was inscribed clockwise in all of the remaining 23 cases. A clockwise inscription of the T loop was seen even when the direction of the loop was within normal range. A counterclockwise inscription of the T loop was not observed in the horizontal plane in the present series.

Fig. 2. A vectorcardiogram of a 26-year-old woman with atrial septal defect of secundum type and a mild right ventricular overloading. The QRS loop showed a characteristic figure-of-eight configuration in the horizontal plane. The major part of the loop in the frontal plane is linear and is directed to the left and inferiorly. The right ventricular pressure was 38/0-3 mmHg, the pulmonary/systemic flow ratio was 1.66 and the right ventricular/left ventricular work ratio was 0.29.

Fig. 3. A vectorcardiogram of a 34-year-old woman with atrial septal defect of secundum type and a moderate right ventricular overloading. The QRS loop shows a clockwise inscription in the frontal plane and a figure-of-eight configuration in the horizontal plane. A right axis deviation is not evident. The right ventricular pressure was 26/0-2 mm Hg, the pulmonary/systemic flow ratio was 3.50 and the right ventricular/left ventricular work ratio was 0.56.

As shown in Table II, no obvious relationship was demonstrated between the configuration of the QRS loop in the horizontal plane and the hemodynamic observations.

2. Correlations of vectorcardiographic measurements with the hemodynamic data

As seen in Table III and IV, a significant correlation was demonstrated only between the ratio of maximum right/maximum leftward vectors and the right ventricular peak pressure. The ratio was 1.00 or greater in 8 of 14 cases with the right ventricular peak pressure of 40 mmHg or more, while a ratio greater than 1.00 was found in only 2 of 17 cases without significant elevation of the right ventricular pressure.

The other vectorcardiographic measurements did not significantly correlated with the hemodynamic data. Although the angle of maximum leftward vector in the frontal plane, the spatial magnitude of maximum rightward vector or the ratio of right/leftward forces were slightly greater, while the ratio of posterior/anterior forces was slightly smaller in the presence of a large shunt flow or an elevation of the right ventricular pressure as seen in Table III, the differences were not statistically significant.

DISCUSSION

There is no question on the usefulness of the electrocardiograms and vectorcardiograms for

Fig. 4. A vectorcardiogram of a 29-year-old woman with atrial septal defect of secundum type and a marked overloading of the right ventricle. The QRS loop is inscribed clockwise in the frontal plane and there is a significant right axis deviation. The right ventricular pressure was 43/0-4 mmHg, the pulmonary/systemic flow ratio was 3.52 and the right ventricular/left ventricular work ratio was 1.01.

TABLE II CONFIGURATION OF QRS LOOP IN THE HORIZONTAL PLANE AND HEMODYNAMIC OBSERVATIONS

	Counterclockwise inscription of QRS body	Figure-of-eight configuration of QRS body	Clockwise inscription of QRS body
Number of cases	9	10	12
Right ventricular peak pressure (mmHg)	32 ± 7	37 ± 7	45 ± 20
-39 mmHg	7	5	5
40-59 mmHg	2	5	5
60 mmHg-	0	0	2
Pulmonary/Systemic blood flow	3.06 ± 0.92	2.66 ± 0.93	2.55 ± 1.29
-1.99	0	2	3
2.00-2.99	5	4	6
3.00-	4	4	3
Right ventricular/Left ventricular work	0.62 ± 0.33	0.53 ± 0.18	0.66 ± 0.40
-0.49	4	6	5
0.50-0.99	4	2	3
1.00-	1	2	4

TABLE III VECTORCARDIOGRAPHIC MEASUREMENTS IN RELATION TO THE HEMODYNAMIC STATUS

	Right ventricular peak pressure			
	-49 mmHg Pulmonary/Systemic blood flow			50mm Hg-
	-1.99	2.00-2.99	3.00-	
Number of cases	3	14	10	4
Angle of maximum leftward vector				
Frontal	19	40 ± 19	52 ± 23	57
Horizontal	1	5 ± 22	350 ± 23	359
Angle of maximum rightward vector				
Frontal	160	161 ± 17	149 ± 41	153
Horizontal	156	183 ± 24	163 ± 26	178
Spatial magnitude of maximum leftward vector (mV)	1.31	1.39 ± 0.45	1.30 ± 0.46	1.84
Spatial magnitude of maximum rightward vector (mV)	1.36	0.71 ± 0.23	0.90 ± 0.49	1.64
Maximum right/maximum leftward vectors	1.13	0.64 ± 0.29	0.77 ± 0.34	1.15
Right/Left Forces	0.86	0.64 ± 0.32	0.86 ± 0.45	1.02
Posterior/Anterior forces	0.86	0.99 ± 0.66	0.85 ± 0.48	0.59
Angle of maximum T vector				
Frontal	21	42 ± 17	48 ± 28	29
Horizontal	334	354 ± 27	335 ± 26	359
Sagittal	39	88 ± 23	87 ± 29	63

TABLE IV CORRELATIONS BETWEEN THE VECTORCARDIOGRAPHIC MEASUREMENTS AND THE HEMODYNAMIC OBSERVATIONS

Spatial magnitude of maximum rightward vector	Correlation coefficient
Vs RVP	+0.34
PBF/SBF	-0.34 (-0.27)
RVW/LVW	+0.17
Maximum rightward/maximum leftward vectors	
Vs RVP	+0.73*
PBF/SBF	-0.27 (-0.05)
RVW/LVW	+0.21
Right/Left forces	
Vs RVP	+0.11
PBF/SBF	+0.02 (-0.02)
RVW/LVW	+0.16
Posterior/Anterior forces	
Vs RVP	-0.22
PBF/SBF	+0.13 (+0.02)
RVW/LVW	+0.25
Angle of maximum leftward vector in the frontal plane	
Vs RVP	+0.03
PBF/SBF	+0.17 (+0.23)
RVW/LVW	+0.01

*: Significant ($p < 0.01$)

Abbreviations: RVP Right ventricular peak pressure, PBF Pulmonary blood flow, SBF Systemic blood flow, RVW Right ventricular work, LVW Left ventricular work.

Figures in parentheses show the results when the cases with right ventricular pressure of 50 mmHg or more were excluded.

diagnosis of atrial septal defect. However, many previous investigators are sceptical on the value of these methods as the indicators of the hemodynamic status³⁻⁷, although some significant correlation between the electrocardiographic or vectorcardiographic findings and right ventricular pressure or shunt flow has been observed by BARTH and associates⁸, DIEDERICH and associates⁹, ENGSTFELD and associates¹⁰, ITO¹¹, LEE and SCHERLIS¹², LIEBMAN and NADAS¹³ and OLIVEIRA and ZIMMERMAN¹⁴. In agreement with the previous reports, a characteristic vectorcardiographic abnormalities were observed in the present study. Furthermore, the present results suggest that the vectorcardiograms may give some useful informations on the hemodynamic status in atrial septal defect of secundum type.

The most prominent finding in the vectorcardiograms in the present study was a presence of a large terminal vector directed to the right and usually inferiorly, while the major part of the QRS loop was directed to the left and inferiorly. The terminal vector was directed either anteriorly or posteriorly, and there was a slowing at this terminal portion in the majority of the cases. Although the QRS loop was usually inscribed clockwise or in a figure-of-eight configuration in the horizontal plane, a counterclockwise inscription of the major part of the loop in this plane was not rare. Another interesting finding in the present series was the frequency of a clockwise inscription of the T loop in the horizontal plane. This abnormal direction of inscription was observed even when the direction of the loop was within normal range. The high incidence of an abnormal inscription of the T loop in atrial septal defect has been pointed out by HARUMI and associates¹⁵ and HAYASHI⁵.

Although the correlation between the vectorcardiographic and hemodynamic observations was not very remarkable in general, there was some significant relationship. A counterclockwise inscription or a linear configuration of the body of the QRS loop in the frontal plane was seen in the mild cases with relatively low right ventricular work, while an increase of right ventricular work of more than moderate degrees was present in 15 of 23 cases in which a clock-

wise inscription of the QRS loop was observed. A significant elevation of the right ventricular pressure and an increase in right ventricular work of more than moderate degrees were almost always present when a rightward displacement of the entire QRS loop was associated. Correlation of the vectorcardiographic findings and the right ventricular work has been suggested by LIEBMAN and NADAS¹³. On the other hand, a marked increase in the ratio of maximum right/maximum leftward vectors was usually observed in the presence of a significant elevation of the right ventricular pressure. Thus, some useful informations on the hemodynamic status may be obtained by vectorcardiograms, although the prediction of the severity of the disease by this method is not very accurate in individual cases because of a wide range of variations in the hemodynamic and vectorcardiographic data.

It is noteworthy that the horizontal projection was less useful than the frontal projection for assesment of the hemodynamic status. Although the previous investigators have considered that the right ventricular overload is most clearly detected by the observations of the QRS loop in the horizontal plane^{5, 7, 10-13}, no clear-cut relationship was demonstrated in the present study between the vectorcardiographic findings in the horizontal plane and the hemodynamic data.

SUMMARY

The Frank lead vectorcardiograms of 31 catheterized cases of atrial septal defect of secundum type were reviewed and the results were correlated with the hemodynamic observations. Although the correlation between the vectorcardiographic and hemodynamic data was not very remarkable, a significant relationship was observed between the QRS patterns in the frontal plane and the right/left ventricular work ratios and between the ratios of maximum right/maximum leftward vectors and the right ventricular peak pressure. No obvious relationship was observed between the QRS pattern in the horizontal plane and the hemodynamic data. The vectorcardiograms may give some useful informations for assesment of the severity of the disease, in atrial septal defect of secundum type.

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