The Vectorcardiogram in Pulmonary Emphysema

—Studies on Autopsy Cases—

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Upon analysis of QRS and T loops in Frank lead vectorcardiograms of 44 patients with autopsy proved pulmonary emphysema, the fairly large terminal portion of QRS loop directed to the right and superiorly with shift of the half-area QRS vector posteriorly and superiorly was found to be characteristic. A small or abnormally directed T loop was also frequently observed. Although thirteen of the 44 patients also had mild right ventricular hypertrophy, there was no significant vectorcardiographic difference between the groups with and without right ventricular hypertrophy. The direction of the terminal appendage in the sagittal and horizontal plane, S_x/R_x , S_y/R_y , and the ratio of the magnitude of terminal appendage to the maximum vector of the body of QRS loop in the frontal and horizontal plane provided good indices of the emphysema type vectorcardiogram. A set of criteria was proposed with the discussion on positivity and false positivity in the diagnosis of such condition.

IT HAS BEEN well known that the pulmonary emphysema alters the electrocardiogram in the absence of cor pulmonale. Thus it is indispensable to establish the characteristics of the electrocardiographic changes from the heart itself. Although there have been several reports on vectorcardiogram¹⁻⁵ or electrocardiogram⁶⁻¹³ in pulmonary emphysema or cor pulmonale, only a few studies are based on postmortem examinations which enable accurate recognition of the associated right ventricular hypertrophy and exclusion of the cases associated with left ventricular hypertrophy and ischemic heart disease. In the present study of the vectorcardiographic analysis on autopsy proved cases of pulmonary emphysema associated with or without right ventricular hypertrophy, some criteria for the vectorcardiogram in pulmonary emphysema are proposed.

METHOD

All available Frank lead vectorcardiograms of the patients diagnosed as having pulmonary emphysema of above moderate degree on autopsy at the Yokufukai Geriatric Hospital were reviewed. Cases found to have valvular disease, myocardial infarction, left ventricular hypertrophy, severe coronary sclerosis, extensive amyloid infiltration of the myocardium on autopsy and complete bundle branch block on electrocardiogram were excluded. Among the remaining 44 cases, 16 males and 26 females, 13 had mild right ventricular hypertrophy. The age of the patients ranged from 62 to 90 with the average of 79. In the clinical course, resting or exertional dyspnea was noted in 20, chronic cough and sputum in 18 and cyanosis in one.

The 39 normal controls, 9 males and 27 females, were selected from the autopsied cases having pulmonary emphysema below the minimum degree and no significant pathological findings in the heart. The average age was 77 years, ranging from 65 to 94 years.

The coronary arteries were sectioned at intervals of 0.3 to 0.5 cm. A reduction in diameter of the coronary artery by more than 75 per cent in any section

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was designated as severe coronary sclerosis. Right ventricular hypertrophy was diagnosed when the right ventricular wall was 5 mm or more in thickness and/or definite hypertrophy of the trabecular and papillary muscles was evident. Examinations of the lungs were performed after the fixation of the organ

with injection of formalin into the bronchi. The severity of the pulmonary emphysema was classified as none, minimum, moderate, and severe according to the area of the emphysematous space and subpleural blebs on cut surfaces.

The method of recording the vectorcardiogram

TABLE I QRS AND T LOOP MEASUREMENTS

		Control	Emphysema	Emphysema without RVH	Emphysema with RVH
Maximal QRS body magnitude	Frontal	1.18 ± 0.42	1.10 ± 0.47	1.12 ± 0.47	1.06 ± 0.48
	Sagittal	0.76 ± 0.37	0.81 ± 0.28	0.74 ± 0.23	0.97 ± 0.36
	Horizontal	1.04 ± 0.39	1.02 ± 0.47	1.06 ± 0.47	0.95 ± 0.45
Half-area QRS vector direction	Frontal	38 ± 22	31 ± 32	27 ± 34	44 ± 17
	Sagittal	112 ± 31	$135 \pm 53^\dagger$	138 ± 58	130 ± 37
	Horizontal	348 ± 23	$330 \pm 29^*$	333 ± 28	325 ± 31
QRS magnitude along XYZ axis	Right (Sx)	0.17 ± 0.16	$0.28 \pm 0.22^\dagger$	0.28 ± 0.24	0.28 ± 0.15
	Left (Rx)	0.96 ± 0.38	0.89 ± 0.43	0.93 ± 0.42	0.81 ± 0.45
	Sx/Rx	0.20 ± 0.15	$0.40 \pm 0.38^*$	0.41 ± 0.40	0.37 ± 0.31
	Superior (Sy)	0.14 ± 0.13	$0.28 \pm 0.23^*$	0.28 ± 0.21	0.27 ± 0.29
	Inferior (Ry)	0.66 ± 0.27	0.54 ± 0.32	0.48 ± 0.28	0.68 ± 0.37
	Sy/Ry	0.30 ± 0.46	$0.88 \pm 0.86^*$	0.97 ± 0.95	0.67 ± 0.55
	Anterior (Rz)	0.24 ± 0.17	0.26 ± 0.20	0.26 ± 0.20	0.25 ± 0.23
	Posterior (Sz)	0.47 ± 0.32	0.54 ± 0.28	0.51 ± 0.29	0.63 ± 0.26
Terminal appendage magnitude	Frontal	0.34 ± 0.19	0.40 ± 0.23	0.40 ± 0.23	0.41 ± 0.24
	Sagittal	0.47 ± 0.24	0.58 ± 0.26	0.56 ± 0.25	0.64 ± 0.28
	Horizontal	0.53 ± 0.25	0.58 ± 0.30	0.59 ± 0.32	0.57 ± 0.30
Ratio of terminal appendage magnitude to maximal QRS body magnitude	Frontal	0.30 ± 0.20	$0.52 \pm 0.28^*$	0.51 ± 0.27	0.54 ± 0.30
	Sagittal	0.72 ± 0.39	0.80 ± 0.34	0.83 ± 0.36	0.73 ± 0.30
	Horizontal	0.58 ± 0.34	0.74 ± 0.42	0.71 ± 0.38	0.81 ± 0.54
Terminal appendage direction	Frontal	wide scattered			
	Sagittal	184 ± 27	199 ± 46	$205 \pm 45^\dagger$	185 ± 42
	Horizontal	260 ± 35	$233 \pm 32^*$	232 ± 35	236 ± 23
Maximal T direction	Frontal	57 ± 22	70 ± 30	68 ± 25	73 ± 36
	Sagittal	87 ± 13	78 ± 36	83 ± 34	72 ± 39
	Horizontal	4 ± 25	16 ± 45	17 ± 48	12 ± 48
QRS loop rotation	Frontal	16 cw.	19 cw.	12 cw.	7 cw.
		14 ccw.	15 ccw.	12 ccw.	3 ccw.
		9 fig. of 8	10 fig. of 8	7 fig. of 8	3 fig. of 8
	Sagittal	33 cw.	37 cw.	25 cw.	12 cw.
		6 fig. of 8	7 fig. of 8	6 fig. of 8	1 fig. of 8
		36 ccw.	37 ccw.	26 ccw.	11 ccw.
	Horizontal	3 fig. of 8	7 fig. of 8	5 fig. of 8	2 fig. of 8

* Significant at 1% level; † significant at 5% level

Mean values and standard deviations are shown.

Statistical significance in distribution between control and emphysema group is indicated by asterisks.

Directions are in angular degrees.

Amplitudes are in millivolts.

was the same as previously described¹⁴. The three planar projections of the vectorcardiogram were photographed from the oscilloscope screen. The QRS loop was interrupted 500 or 800 times per second. The sagittal plane was viewed from the right. An analysis was made only on the QRS and T loops. The measurements of the vectorcardiogram were made on the magnitude of the maximum vector of the body of the QRS loop, the direction of the half-area QRS vector, the magnitude of the left (Rx), right (Sx), inferior (Ry), superior (Sy), anterior (Rz), and posterior (Sz) forces of the QRS loop, the magnitude and direction of the terminal appendage, and the direction of the maximum T vector. The direction of the initial QRS vector was also checked. The terminal appendage was defined as an abrupt return of the terminal QRS loop to the isoelectric point in the horizontal plane. The corresponding spot with time interruption was used for the determination of the terminal appendage in the frontal and sagittal planes.

RESULTS

1. Normal control

The results of 39 normal vectorcardiograms are summarized in Table I. There are rather marked deviations of the half-area QRS vector to the left, superiorly and posteriorly and decrease of the magnitude of the maximum QRS vector compared with the normal vectorcardiograms of younger people¹⁶⁻¹⁸ as previously described¹⁹.

2. Pulmonary emphysema

Four representative vectorcardiograms are illustrated in Fig. 1-4, while the results of the measurements are shown in Fig. 5, 6 and Table I. There was no significant difference of vectorcardiographic measurements between cases with and without right ventricular hypertrophy in this group.

Fig. 1. 79 year old male. Severe pulmonary emphysema not associated with right ventricular hypertrophy on autopsy. Note the large terminal portion of the QRS loop directed to the right, posteriorly and superiorly with deviation of half-area vector to the left and superiorly in the frontal plane.

Fig. 2. 78 year old female. Moderate pulmonary emphysema without right ventricular hypertrophy. The rotation of the QRS loop in the horizontal plane is figure of eight. The T loop is relatively small.

QRS loop

As shown in Table I and Fig. 5, 6 the half-area QRS vector was displaced posteriorly in the horizontal plane and superiorly in the sagittal plane. An unplotable half-area QRS vector was observed in two cases in the frontal plane, in one case in the sagittal plane, and in two cases in the horizontal plane. The rotation of the QRS loop in the horizontal plane was counterclockwise in 37 cases and figure of eight in seven cases. The terminal appendage was present in 38 cases (87%) of this group and in 20 cases (74%) of the control group. Although the angle of the terminal appendage was widely scattered in the frontal plane, a remarkable displacement of the terminal appendage to the right, superiorly, and anteriorly was observed in the horizontal and sagittal planes.

The magnitude of the maximum QRS vector

was almost the same as in the control group. The mean values of the magnitude of the terminal appendage were increased but not statistically significant at 5 per cent level. The ratio of terminal appendage to the maximum QRS body vector was significantly elevated in the frontal plane. The magnitude of right (S_x), and superior (S_y) force were significantly greater than in the control group and the ratios of right to left forces (S_x/R_x), and inferior to superior forces (S_y/R_y) were obviously increased. The magnitude of the anterior (R_z) and posterior (S_z) forces were not affected. In short, there was a fairly large terminal appendage directed to the right, and frequently superiorly, with displacement of half-area QRS vector to the left, superiorly, and posteriorly, and also an increase in S_x/R_x and S_y/R_y .

The initial QRS vector was directed posteri-

Fig. 3. 78 year old female. Severe pulmonary emphysema with mild right ventricular hypertrophy. There is fairly large appendage directed to the right posteriorly and superiorly, with deviation of the half-area vector to the right in the frontal plane. The inscription of the QRS loop in the horizontal plane is figure of eight nearly linear shape. The T loop is deviated posteriorly.

Fig. 4. 74 year old male. Severe pulmonary emphysema associated with mild right ventricular hypertrophy. Note the marked terminal portion of the QRS loop directed to the right and posteriorly. The inscription in the horizontal plane is counterclockwise. The half-area vector in the frontal plane is displaced to the right.

only with no anterior force in two cases. The routine electrocardiogram of both cases showed a QS pattern in V1 through V3.

T loop

The T loop was too small or not clearly detectable in 14 cases. In the remaining 28 cases, the direction of T loop was widely scattered, but the average T vector was oriented more anteriorly and superiorly in the sagittal plane and more anteriorly in the horizontal plane.

3. Diagnostic criteria for the vectorcardiogram in pulmonary emphysema.

Table II shows the proposed criteria of the QRS loop for the diagnosis of pulmonary emphysema in vectorcardiogram (Fig. 7). With the use of these criteria, diagnosis is possible in 40 to 30 per cent of cases with pulmonary emphysema giving rise to 10 per cent of false positivity. Although the presence of these criteria did not enhance diagnostic positivity with

decrease of false positivity, the multiple positive criteria in examining each vectorcardiogram, confirm the presence of emphysema.

DISCUSSION

There are relatively few reports on the vectorcardiogram in the isolated pulmonary emphysema². Although several investigators¹⁻⁵ have reported on the vectorcardiogram in cor pulmonale, most of them had chronic obstructive pulmonary emphysema as the underlying etiology. These investigators have noted a rightward, posterior, and frequently superior displacement of the QRS loop, especially the terminal part of the loop, as the characteristic finding of the vectorcardiogram in pulmonary emphysema. As a whole, our results are in good agreement with the previous reports. A relatively large terminal appendage directed to the right, superiorly was observed in the majority

Fig. 5. The direction of half-area QRS vector in the frontal, right-sagittal, and horizontal plane. Open circle indicates cases of emphysema with right ventricular hypertrophy.

Fig. 6. The direction of the terminal appendage in the frontal, right-sagittal, and horizontal plane. Open circle indicates cases of emphysema with right ventricular hypertrophy.

TABLE II CRITERIA FOR THE DIAGNOSIS OF VECTORCARDIOGRAM IN PULMONARY EMPHYSEMA AND POSITIVITY AND FALSE POSITIVITY OF THE DIAGNOSIS. FIGURES INDICATE THE NUMBER OF CASES OF FALSE POSITIVITY OR DIAGNOSTIC POSITIVITY

	Control (39 cases)	Emphysema (44 cases)	Emphysema without RVH (31 cases)	Emphysema with RVH (13 cases)
$Sx/Rx > 0.4$	3 (8%)	19 (43%)	14 (45%)	5 (38%)
$Sy/Ry > 0.7$	3 (8%)	18 (41%)	14 (45%)	4 (31%)
Terminal appendage angle in the horizontal plane $< 230^\circ$	3 (8%)	18 (41%)	14 (45%)	4 (31%)
Terminal appendage angle in the sagittal plane $> 220^\circ$	3 (8%)	15 (34%)	13 (42%)	2 (15%)
Terminal appendage magnitude/maximal QRS body magnitude in the frontal plane > 0.5	4 (10%)	16 (36%)	12 (39%)	4 (31%)
Terminal appendage magnitude/maximal QRS body magnitude in the horizontal plane > 0.9	4 (10%)	12 (27%)	9 (29%)	3 (23%)

of the cases and the half-area QRS vector was displaced posteriorly and superiorly. However, instead of a rightward shift of the QRS loop, a superior and leftward displacement was observed in the frontal plane though not significant at 5 per cent level. This displacement was obviously a result of a superior displacement of

the large terminal appendage. The disagreement of the present findings with the previous reports may result from the difference in materials. Our series consisted of old patients above the age of 62 years without the association of marked hypertrophy of the right ventricle. In routine electrocardiogram, a left as well as right axis deviation has been noted among the frequent findings in pulmonary emphysema²⁰.

In general, the effects of emphysema on the vectorcardiogram appear to be due to three basic factors; a change in the anatomical position of the heart, the intervention of a hyperinflated lung, and right ventricular hypertrophy. Of these three factors, the former two³¹ appeared to be mainly responsible for the development of vectorcardiographic changes, since there were no definite vectorcardiographic differences between the groups with and without right ventricular hypertrophy. This is consistent with the previous observation that the emphysema markedly alters the electrocardiogram in the absence of cor pulmonale and tends to obscure the electrocardiographic manifestation of right ventricular hypertrophy³⁰.

The crista supraventricularis and its adjacent region has been shown to be one of the last regions of the heart to depolarize completely²². The anatomical hypertrophy of this part of the right ventricle has been suggested to give an explanation of the development of a rightward, superior and posterior, frequently anterior, terminal vector in pulmonary emphysema to-

Fig. 7. Plotting of each case according to the values of Sx/Rx , Sy/Ry , terminal appendage/QRS body magnitude in the frontal and horizontal plane. Cont. indicates control and Emph. indicates emphysema. Open circle indicates cases of emphysema associated with right ventricular hypertrophy.

gether with the above mentioned extra-cardiac factors^{1,2,20}. Although a detailed quantitative examination on crista supraventricularis was not performed, our observation on autopsy series does not conform with this concept.

The frequent association of the left ventricular hypertrophy in pulmonary emphysema or cor pulmonale²³⁻²⁶ has been considered to be an important modifying factor in the vectorcardiogram and electrocardiogram. However, the vectorcardiographic changes described in this paper should mainly represent the direct or indirect effect of pulmonary emphysema per se, since other possible factors such as left ventricular hypertrophy, significant coronary sclerosis, or myocardial disease were excluded.

The similarity of vectorcardiogram in pulmonary emphysema and mitral stenosis has been known²⁷; the rightward shift of the terminal vector in the horizontal plane. The anatomical evidence of the emphysematous and fibrotic changes²⁸⁻³⁰ in lungs in patients with mitral stenosis has probably contributed to such similarity. However, there is usually a right axis deviation in mitral stenosis²⁷ in contrast to a mild left axis deviation in pulmonary emphysema as shown in our study. Difference in the underlying hemodynamic conditions³¹ should also be considered for the development of these different vectorcardiographic findings.

Serial vectorcardiographic tracings in the previous reports^{1,4,5} have shown that the emphysema type vectorcardiogram with counterclockwise inscription in the horizontal plane often proceeded to the classical right ventricular hypertrophy pattern with clockwise inscription in the horizontal plane. Therefore, this particular emphysema type vectorcardiogram has been suspected to represent another pattern of right ventricular hypertrophy⁵. However, as shown in our studies on autopsy series, this type of vectorcardiogram is not necessarily indicative of right ventricular hypertrophy. Unfortunately, our autopsy series are in want of cases with severe right ventricular hypertrophy which will elicit more information as to the differentiation of emphysema with and without cor pulmonale. A classical pattern of right ventricular hypertrophy with clockwise inscription of the QRS loop in the horizontal plane which was

not observed in our pulmonary emphysema group, is rather exceptional in Frank lead vectorcardiogram in acquired valvular heart disease²⁷. Moreover, in an aged group such as ours, a severe right ventricular hypertrophy is a rare condition compared with the younger group.

The T loop abnormality frequently observed in pulmonary emphysema has been ascribed to myocardial anoxia, metabolic changes, or associated right or left ventricular hypertrophy. The left ventricular hypertrophy was discarded in our present study. Our study did not reveal steady T loop deviations, but findings of wide distribution in its direction and frequent small T loop are consistent with those of previous studies. As to the diagnostic criteria or its significance, further collection of cases is necessary.

In vectorcardiographic diagnosis of pulmonary emphysema, the accuracy of criteria seem to be somewhat unsatisfactory from the nature of the disease itself, since these vectorcardiograms are chiefly affected by extracardiac factors. And it should also be emphasized that these vectorcardiograms tend to obscure the manifestation of right ventricular hypertrophy causing the overlap between the criteria of emphysema and cor pulmonale. The ratio of right to left (Sx/Rx) forces above 0.4 or posterior to left (Sz/Rx) forces above 1.2 was proposed by TOYAMA et al.³² as a criterion of the right ventricular hypertrophy even in cases of pulmonary emphysema. However, as shown in our study, such findings are not necessarily indicative of right ventricular hypertrophy in cases of pulmonary emphysema. Their criterion Sz/Rx above 1.2 was not as accurate as the other proposed criteria in our study, when applied to our autopsy series.

When a large terminal appendage directed to the right, frequently superiorly with counterclockwise and often figure of eight inscription in the horizontal plane is manifested, the presence of pulmonary emphysema should always be considered; however, a normal vectorcardiogram does not rule out its presence. Other findings such as a posteriorly directed initial QRS vector³³ or unplotable half-area QRS vector because of terminal portion directed to the right superiorly reverse to the initial and mid QRS vector should also be taken into account. The

P loop which was not analysed in this study will afford more reliable diagnostic signs of pulmonary emphysema^{13,34}. With combination of QRS and P loop criteria, more accurate diagnoses should be possible as illustrated in routine electrocardiographic study³⁴. In dealing with the younger cases than our series, the false positivity would decrease less than in our series, since our control vectorcardiograms were rather close to emphysema group than the previously reported normal vectorcardiograms of younger people.

For the diagnosis of right ventricular hypertrophy in the presence of pulmonary emphysema, there are difficulties as described previously. However, a rightward half-area QRS vector in the frontal plane or a clockwise or a figure of eight inscription in the horizontal plane with anterior displacement or QRS loop could be more suggestive of cor pulmonale.

SUMMARY

Frank lead vectorcardiograms of 44 cases which proved to have pulmonary emphysema on autopsy were analyzed on the QRS and T loops. The terminal portion of the QRS loop was displaced to the right and superiorly with shift of the half-area QRS vector posteriorly and superiorly. The magnitude of the right (Sx) and superior (Sy) forces, Sx/Rx, Sy/Ry, and the ratio of the magnitude of terminal appendage to the maximum vector of the body of QRS loop in the frontal plane was increased significantly. A small or abnormally directed T loop was frequently observed. Although thirteen of 44 cases also had mild right ventricular hypertrophy, there was no significant vectorcardiographic difference between the groups with and without right ventricular hypertrophy. These abnormal vectorcardiograms were considered to originate chiefly from the change in the anatomical position of the heart and the intervention of a hyperinflated lung. A set of criteria for the vectorcardiographic diagnosis of pulmonary emphysema is proposed.

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