Frank Vectorcardiogram Correlated with Haemodynamic Measurements

Quantitative Analysis

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Vectorcardiography is being used increasingly as a supplement to conventional electrocardiography. In particular, the scalar tracings may not help in the recognition of right ventricular hypertrophy, because the usually accepted criteria are diverse and unreliable (Sokolow and Lyon, 1949; Milnor, 1957; Wasserburger and Brown, 1958). We have chosen a measurable quantity, namely mean pulmonary artery pressure or right ventricular systolic pressure, for correlation with the vectorcardiogram. The Frank vectorcardiogram, a corrected orthogonal lead system, was employed for the study (Frank, 1956).

SUBJECTS AND METHODS

Forty-two patients were selected in whom the anatomical diagnosis of right ventricular hypertrophy appeared tenable on clinical, radiological, and electrocardiographic assessment. Care was taken to exclude systemic hypertension, ischaemic heart disease, and valvular disease other than mitral stenosis, which might influence unduly the activation of the ventricular muscle as a whole and obscure the changes produced by right ventricular hypertrophy alone. Right ventricular pressures and mean pulmonary artery pressures were measured by right heart catheterization, using a Sanborn transducer (Model 267B) coupled to a Sanborn photographic recorder. The zero reference point was taken at 5 cm. below the sternal angle. The vectorcardiogram was recorded either on the day before or after cardiac catheterization. The method of recording was as described by Frank (1956), except for using the fourth intercostal space for the chest electrodes, with the patient supine. The Sanborn recording apparatus consisted of a Frank lead selector box, two electrocardiographic preamplifiers (Models 350, 2700), oscilloscope camera, and vector timer. Loops were displayed in the frontal, left sagittal, and horizontal planes on the oscilloscope. They were photographed at the end of an ordinary expiration. As the vector loops may be affected by atrial fibrillation, the mean results of calculations derived from 3 to 5 loops

were used when this dysrhythmia was present. Each loop was interrupted 400 times a second so that each dash measured 2.5 milliseconds. Each dash was modulated to give the direction of inscription of the loop. The photographed loops were copied over transparent paper for planimetric analysis. Throughout the study Helm's reference system was used for analysis (Helm, 1956). Fig. 1 illustrates this system for three planes of a vectorcardiogram with right ventricular hypertrophy (Case 40).

The following measurements were made for the three loops of each patient: (1) half-area angle QRS vector; (2) maximum angle QRS vector; (3) left/right millivolt ratio (L/R) (the ratio of the magnitude of the maximum leftward to the maximum rightward QRS vector as projected on the x axis); (4) posterior/anterior millivolt ratio (P/A) in horizontal plane; (5) area quadrant distribution expressed as a percentage of total area; and (6) rotation of the loop, clockwise (CW), counterclockwise (CCW), or figure-of-eight.

The patients were divided into 3 groups based on either mean pulmonary artery pressure (MPAP) or right ventricular systolic pressure (RVSP). *Group I*, MPAP 10–20 mm. Hg; *Group II*, MPAP 20–40 mm. Hg; and *Group III*, MPAP > 40 mm. Hg, or RVSP above 100 mm. Hg when MPAP was not available in cases with congenital heart disease.

Further subdivision was carried out depending upon anatomical diagnosis: *subgroup A*, mitral stenosis; *subgroup B*, pulmonary heart disease; and *subgroup C*, congenital heart disease.

Tables I, II, and III illustrate these groupings, together with the age and sex of the patients and the data calculated from the loops in the horizontal plane. Only the data obtained by calculations from the horizontal plane are presented, as it was found by the authors to be more informative than that calculated from the frontal and left sagittal planes.

RESULTS

The results of the analysis in all groups are given in Tables I, II, and III.

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FIG. 1.—The half-area angle and maximum angle QRS vectors are marked in each plane. Note the clockwise rotation (Case 40—Eisenmenger syndrome, atrial septal defect). Scale, 1 mV, Helm's notation.

TABLE I
HORIZONTAL PLANE: MEAN PULMONARY ARTERY PRESSURE 10–20 MM. HG

Case No.	Age (yr.)	Sex	MPAP (mm. Hg)	Right ventricular pressure (mm. Hg)	Half-area angle QRS vector	Maximum angle QRS vector	L/R ratio	P/A ratio	Anterior displacement (mV)	Area quadrant distribution as per cent of total area				Rotation of loop*
										1	2	3	4	
Subgroup A: Mitral Stenosis														
1	17	F	14	23/6	305	255	2.3	3	0.33	20	0	26	54	CCW
2	43	F	15	23/2	330	332	14	4	0.22	8	0	3	89	CCW
3	34	F	18	38/5	345	2	1.5	2	0.11	10	0	40	50	CCW
4	38	F	19	34/6	317	330	2	4	0.11	7	0	26	67	CCW
5	23	F	19	36/5	335	260	3.5	1.1	0.44	29	0	13	58	CCW
Subgroup B: Pulmonary Heart Disease														
6	63	F	11	20/1	290	337	2.5	4	0.11	10	5	20	65	CCW
7	50	F	12	23/2	353	353	9	2	0.11	20	0	5	75	CCW
8	53	M	12	28/0	300	252	2	1.5	0.55	22	0	19	59	CCW
9	45	F	14	29/1	330	330	7	5	0.11	4	0	8	88	CCW
10	56	M	15	30/2	245	275	5	3	0.11	42	0	0	58	CCW
11	49	M	16	32/1	335	247	5	2	0.22	27	0	13	60	CCW
12	51	F	18	34/2	305	320	5	13	0.11	2	0	20	78	CCW
13	61	M	20	37/0	275	265	1.3	12	0.11	5	0	46	49	CCW
Subgroup C: Congenital Heart Disease—Atrial Septal Defect (Secundum)														
14	14	M	15	27/7	355	350	2	0.9	0.31	49	0	17	34	CCW

* CCW = Counterclockwise.

Group I. Mean Pulmonary Artery Pressure 10–20 mm. Hg (Table I). In this group, the values for half-area angle QRS vector ranged from 275 (Case 13) to 355 (Case 14). Of the 14 patients, 6 (Cases 2, 3, 4, 5, 9, and 11) had half-area angle QRS vectors within the normal range of 313–349 (Bristow, 1961). Only 1 patient with mitral stenosis (Case 1) was outside the normal range (305). Of the 8 patients with pulmonary heart disease, 6 were outside the normal range, i.e. Cases 6, 7, 8, 10, 12, and 13. The only patient with congenital heart disease, atrial septal defect, was also outside the normal range (Case 14).

Only 2 patients (Cases 3 and 12) had a maximum QRS vector outside the normal range, 244–278, and 324–358 (Bristow, 1961). The left/right ratio invariably exceeded unity irrespective of the anatomical diagnosis. The posterior/anterior ratio and anterior displacement in millivolts were not useful, as will be seen when compared with Tables II and III. The significant finding in the area quadrant distribution was found in No. 2 (right anterior quadrant), where values were normal, i.e. 0 to 5 per cent (normal range less than 7%, Bristow, 1961). All the loops were normally rotated (counterclockwise).

TABLE II
HORIZONTAL PLANE: MEAN PULMONARY ARTERY PRESSURE 20-40 MM. HG

Case No.	Age (yr.)	Sex	MPAP (mm. Hg)	Right ventricular pressure (mm. Hg)	Half-area angle QRS vector	Maximum angle QRS vector	L/R ratio	P/A ratio	Anterior displacement (mV)	Area quadrant distribution as per cent of total area				Rotation of loop*
										1	2	3	4	
Subgroup A: Mitral Stenosis														
15	43	F	23	33/4	320	340	6	3	0.11	6	0	12	82	CCW
16	47	F	27	35/2	5	15	7	1	0.66	60	0	10	30	CCW
17	52	F	31	33/7	355	5	11	1.3	0.33	44	0	0	56	CCW
18	41	M	32	40/5	21	21	2	1	0.66	83	0	7	10	CCW
19	54	F	33	44/7	330	337	13	10	0.11	5	0	1	94	CCW
20	48	F	34	41/7	300	230	1.1	3.5	0.22	17	0	6	47	CCW
21	32	F	35	44/2	325	288	5	2	0.55	22	0	0	78	CCW
22	30	F	36	42/6	320	320	2	2	0.44	20	0	16	64	CCW
23	52	M	40	57/7	12	15	9	0.6	0.55	63	0	9	28	CCW
Subgroup B: Pulmonary Heart Disease														
24	63	M	22	48/2	240	228	0.3	4.5	0.22	13	0	74	13	CCW
25	61	M	32	50-56/0	Figure-of-eight	Figure-of-eight	0.9	1.1	0.26	—	—	—	—	CCW and CW
26	62	M	32	56/1	Figure-of-eight	Figure-of-eight	0.3	1	0.22	—	—	—	—	CW and CCW
27	45	F	38	58/4	235	225	0.4	3	0.33	8	2	90	0	CCW
28	46	F	40	62/6	280	235	0.8	6	0.11	18	0	41	41	CCW
29	58	M	40	62/8	260	255	0.5	10	0.11	0	0	66	34	CCW
Subgroup C: Congenital Heart Disease—Atrial Septal Defect (Secundum)														
30	34	F	26	41/9	345	345	2	2	0.22	20	2	8	70	CCW

* CCW = Counterclockwise; CW = Clockwise.

TABLE III
HORIZONTAL PLANE: MEAN PULMONARY ARTERY PRESSURE > 40 MM. HG

Case No.	Age (yr.)	Sex	MPAP (mm. Hg)	Right ventricular pressure (mm. Hg)	Half-area angle QRS vector	Maximum angle QRS vector	L/R ratio	P/A ratio	Anterior displacement (mV)	Area quadrant distribution as per cent of total area				Rotation of loop*
										1	2	3	4	
Subgroup A: Mitral Stenosis														
31	49	F	48	51/7	170	195	0.6	0.6	0.22	16	36	48	0	CW
32	44	M	57	67/9	185	190	0.6	1	0.37	9	31	60	0	CW
33	61	F	58	102/9	250	212	0.2	5	0.11	5	0	70	25	CCW
34	32	F	67	107/8	Figure-of-eight	Figure-of-eight	0.8	0.5	0.22	—	—	—	—	CCW and CW
35	42	F	70	110/9	200	197	0.06	6	0.11	3	5	90	2	CW
36	49	F	74	120/12	200	198	0.08	2.5	0.22	5	10	82	3	CW
Subgroup B: Pulmonary Heart Disease														
37	17	M	46	61/8	253	253	0.1	15	0.22	5	0	95	0	CCW
38	32	F	51	71/8	Figure-of-eight	Figure-of-eight	0.5	1	0.33	—	—	—	—	CCW and CW
39	41	F	90	136/11	Figure-of-eight	Figure-of-eight	1	2	0.33	—	—	—	—	CCW and CW
Subgroup C: Congenital Heart Disease														
40†	62	F	49	117/4	145	145	0.2	0.4	1.2	11	75	10	4	CW
41‡	31	M	NA**	134/2	200	190	0.05	10	0.11	0	5	95	0	CW
42§	5	M	NA**	107/7	105	95	0.6	0.2	1.5	28	61	9	2	CW

* CCW = counterclockwise; CW = clockwise.

† Eisenmenger syndrome (atrial septal defect).

‡ Transposition of great vessels.

§ Fallot's tetralogy.

** Not available.

Group II. Mean Pulmonary Pressure 20-40 mm. Hg (Table II). Two patients (Cases 25 and 26) in subgroup B showed a figure-of-eight configuration. The half-area QRS vector angle varied from 235 (Case 27) to 21 (Case 18). The significant finding was that all patients in subgroup B had an abnormal half-area QRS vector angle. Five patients (Cases

16, 17, 18, 20, and 23) of the 9 in subgroup A had abnormal half-area QRS vector angle. Two (Cases 15 and 19) of subgroup A, and 1 only (Case 29) of subgroup B had normal maximum angle QRS vectors. In subgroup B the L/R ratio was less than unity compared with subgroups A and C. Only Case 23 had a posterior/anterior ratio of less than

FIG. 2.—Distribution of half-area and maximum QRS vector angles in horizontal plane. A, B, and C represent the subgroups.

unity, and Cases 16, 18, and 26 had P/A ratio of unity which was also abnormal. Anterior displacement of the loop exceeding 0.5 millivolt was found only in subgroup A (Cases 16, 18, 21, and 23) (Taymor, Hoffman, and Henry, 1964). The quadrant area percentage distribution in quadrant 2 was normal, whereas in quadrant 3 in subgroup B only the QRS area was maximal. Apart from the figures-of-eight the loop rotations were normal.

Group III. Mean Pulmonary Artery Pressure > 40 mm. Hg (Table III). Three patients (Cases 34, 38, and 39) showed a figure-of-eight configuration. The half-area angle vector ranges in all subgroups were grossly abnormal, varying from 105 (Case 42) to 253 (Case 37). In addition, the maximum QRS vector angle was also grossly abnormal, varying from 95 (Case 42) to 253 (Case 37). The L/R ratio was abnormal in all cases, either unity (Case 39) or less than unity. There was more variation in P/A ratio and anterior displacement. Quadrantic area percentage distribution No. 2 was abnormal in 5 out of 9 cases in which this value could be calculated (Cases 31, 32, 36, 40, and 42). The loop was abnormally rotated clockwise except in Cases 33 and 37.

Fig. 2 illustrates the distribution of the half-area and maximum QRS angles in the three groups and subgroups. Representative loops are illustrated in Fig. 3.

DISCUSSION

The results illustrate that the most useful parameters in the horizontal plane in assessing the significance of pulmonary hypertension in this series were the half-area angle QRS vector, the maximum angle QRS vector, and the left-to-right ratio in millivolts. Apart from significant changes in these measurements the figure-of-eight configuration and clockwise rotation were abnormal in all instances. The interesting deductions that can be made relative to the anatomical diagnosis include the following.

- (1) The abnormal changes in the above parameters, which occurred when the mean pulmonary artery pressure was 20 mm. Hg or more in pulmonary heart disease, contrasted with similar changes in mitral stenosis when the mean pulmonary artery pressure was 40 mm. Hg or more.

FIG. 3.—Representative horizontal loops. Figures-of-eight: A1 (Case 34), mitral stenosis; A2 and A3 (Cases 38 and 26), pulmonary heart disease. Mitral stenosis: B1 (Case 4, MPAP 19 mm. Hg): normal loop. C1 (Case 18) and D1 (Case 32) show anterior displacement and abnormal rotation in pulmonary hypertension. Pulmonary heart disease: B2 (Case 8), C2 (Case 25), D2 (Case 27). All loops show normal rotation. D2 shows typical changes associated with pulmonary hypertension. Congenital heart disease: B3 (Case 14), C3 (Case 30), atrial septal defect. Note terminal delay of right bundle-branch block. D3 (Case 41) transposition of great vessels. Note abnormal clockwise rotation and extreme rightward displacement of the loop.

- (2) Above the critical mean pulmonary artery pressures in both mitral stenosis (MPAP 40 mm. Hg) and pulmonary heart disease (MPAP 20 mm. Hg), there were no significant quantitative changes in the parameters measured.
- (3) In pulmonary heart disease the loops tended to be located in the third quadrant, i.e. the right posterior quadrant, in contrast to mitral stenosis, when the loop tended to be rotated into the second quadrant, i.e. the right anterior quadrant.

The results of these investigations indicate that the horizontal plane of the Frank vectorcardiogram is useful in mitral stenosis and pulmonary heart disease when related to critical levels of mean pulmonary artery pressure. In any individual patient such factors as duration, severity of the underlying disease process, and the age and state of the myocardium are other contributory factors. Only a few cases of congenital heart disease were included in this series, so no useful deductions are possible, though in the patients studied the changes closely resembled those of mitral stenosis.

SUMMARY

The Frank vectorcardiogram was studied in 42 patients with mitral stenosis, pulmonary heart disease, and congenital heart disease, and was quantitatively related to mean pulmonary artery pressure, or right ventricular systolic pressure in congenital heart disease. In the parameters chosen, the most useful were half-area angle QRS vector, the maximum angle QRS vector, and the left/right ratio in the horizontal plane. Apart from these the figure-of-eight and clockwise rotation of loop in the horizontal plane were always abnormal. A critical mean pulmonary artery pressure of 20 mm. Hg in pulmonary heart disease, and 40 mm. Hg in mitral stenosis and congenital heart disease determined the abnormal configuration of the horizontal loop.

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