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Spatial quantitative vectorcardiography in aortic stenosis: correlation with hemodynamic findings

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Thirty-four patients with hemodynamically documented valvar aortic stenosis without congestive heart failure were studied by the corrected Frank lead system vectorcardiography, with special emphasis on the angular characteristics of spatial *R* max to define the severity of the lesion. Spatial QRS-T angle demonstrated a highly significant correlation with the peak left ventricular systolic pressure ($r = 0.72$, $P < 0.001$) and a significant correlation with peak transvalvar aortic gradient ($r = 0.49$, $P < 0.01$). Furthermore, all patients with a QRS-T angle of more than 90° had significant aortic stenosis (TVG $\geqslant$ 50 mm Hg). The peak left ventricular systolic pressure and transvalvar aortic gradient also demonstrated a significant negative correlation with azimuth angle ($r = -0.36$ and -0.34, respectively; $P < 0.05$) and a positive correlation with spatial *R* max magnitude ($r = 0.38$ and 0.41, respectively; $P < 0.05$). There was no correlation between elevation angle of spatial *R* max and left ventricle systolic pressure or transvalvar aortic gradient.

Our study indicates that spatial quantitative vectorcardiographic angular characteristics, particularly spatial QRS-T angle, may be a useful adjunct to other noninvasive techniques to assess the severity of valvar aortic stenosis.

Key words: Spatial vectorcardiography; Aortic stenosis

Introduction

Noninvasive assessment of the severity of valvar aortic stenosis has been a difficult problem especially in asymptomatic individuals. Physical examination,

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although helpful, is known to underestimate the severity of the lesion especially in the elderly and in the presence of systemic hypertension and congestive heart failure [1–3]. Routine 14-lead electrocardiography also has limitations since patients with minimal or no stenosis also have been reported to have electrocardiographic evidence of left ventricular hypertrophy [5]. The limitations of the chest roentgenogram in this regard are well known [5]. The reliability of systolic time intervals and echocardiography in assessing the severity of aortic stenosis has also been recently questioned [6,7].

Spatial vectorcardiography, a noninvasive investigation which utilises spatial orientation of various electrical potentials, has also been tried for evaluating the degree of left ventricular hypertrophy and its correlation with the severity of aortic stenosis [8–11]. However, enthusiasm in this field has diminished because of the continued adherence to the absolute voltage values. The present study is an attempt to correlate the internal changes in the vectorcardiographic QRS and T loop characteristics with the severity of valvar aortic stenosis.

Using the spherical coordinate system, the azimuth and elevation angles and the spatial magnitude of R max, and spatial QRS-T angle were calculated and correlated with the hemodynamic parameters. This aspect of vectorcardiography, although promising [12], has received inadequate attention in the past.

Materials and Methods

The case material comprised 34 patients (30 males, 4 females) in the age range 8–56 (mean 22.82 ± 11.53) years with valvar aortic stenosis. Ten patients had associated trivial aortic regurgitation. The patients with mitral valve disease, aortic regurgitation (+ + to + + + + by angiographic criteria), congestive heart failure, hypertension, coronary artery disease and left bundle branch block were excluded from the study. No patient was receiving digitalis or diuretics.

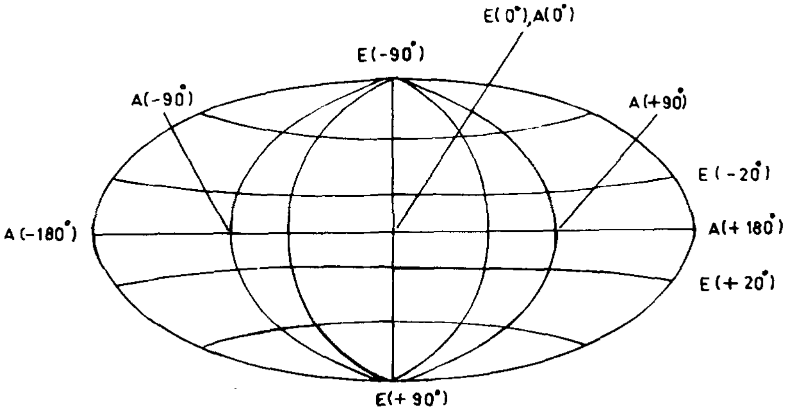

Fig. 1. The diagrammatic representation of the spherical coordinate system depicting the azimuth and elevation angles. A = azimuth; E = elevation.

Using the corrected Frank lead system, spatial vectorcardiograms were recorded on a Stereokinematovectorcardiograph (Tonnies) with the electrodes placed in the 4th intercostal space. The orthogonal leads x, y, z were recorded at a paper speed of 100 mm/sec and a gain of 10 or 20 mm/mV. This equipment using the spherical coordinate system (Fig. 1) can calculate the magnitude, azimuth and elevation angles of *R* max and *T* max. The parameters obtained were also confirmed by manual calculation using the standard mathematical formulae [12]. The vectorcardiographic loops were recorded in the horizontal, frontal and left sagittal plane. These parameters were then correlated with the resting hemodynamic data i.e. peak left ventricular systolic pressure and peak transvalvar aortic gradient obtained within 24 hours of the vectorcardiographic study. Hemodynamic data were obtained using the standard catheterization procedure as practised in our laboratory. In 12 subjects in whom the aortic valve was not crossed by retrograde catheterization, percutaneous left ventricular puncture was done to obtain left ventricular systolic pressure and transvalvar gradient.

Results

Spatial Vectorcardiogram (Table 1)

The *R* max magnitude ranged from 0.9 to 2.9 (1.91 ± 0.54) mV. The azimuth and elevation angle of *R* max varied from $+55$ to $-110°$ (-36.82 ± 38.52) and 65 to $-15°$ ($25.74 \pm 21.4°$), respectively. The spatial QRS-T angle ranged from 15 to $180°$ ($124.12 \pm 46.16°$). In the horizontal plane, the QRS loop inscription was counter-clockwise in all cases, whereas in the frontal and (left) sagittal plane the QRS loop rotation was variable. In the horizontal plane, the T loop was located in the right and anterior quadrant in 31 patients and the inscription was counter-clockwise. In the remaining three patients the T loop was placed in the left and posterior quadrant with a clockwise inscription in two and figure of 8 in one.

Peak Left Ventricular Systolic Pressure and Transvalvar Aortic Gradient

The peak left ventricular systolic pressure at rest ranged from 120 to 250 (206.56 ± 30.85) mm Hg. All patients with peak systolic pressure equal to or more than 170 mm Hg had a transvalvar aortic gradient of more than 50 mm Hg. The transvalvar gradient ranged from 20 to 144 mm Hg (93.38 ± 30.61 mm Hg) and was hemodynamically significant ($\geqslant 50$ mm Hg) in 30 and insignificant (< 50 mm Hg) in the remaining four subjects.

Correlation with Hemodynamic Parameters

Table 2 shows the correlation of peak left ventricular systolic pressure and transvalvar gradient with the magnitude, azimuth and elevation angle of *R* max and spatial QRS-T angle.

TABLE 1

Hemodynamic and vectorcardiographic data ($n = 34$).

Pt. No.	Age (yr)	Sex	LVSP mm Hg	TVG mm Hg	*R* max (mV)	Azimuth (°)	Elevation (°)	Spatial QRS-T angle (°)
1	2		3	4	5	6	7	8
1	8	M	220	116	1.6	−35	−5	105
2	16	M	128	48	1.7	+25	+40	15
3	22	F	200	75	1.3	−20	+28	120
4	22	M	220	76	2.2	−25	+45	180
5	49	M	224	104	2.1	−45	+5	175
6	40	M	230	78	2.0	−40	−10	180
7	25	M	176	66	1.2	−60	+65	105
8	21	F	200	88	0.9	−75	−10	90
9	25	M	250	130	2.0	−45	+5	180
10	6	M	130	34	1.4	+35	+25	50
11	27	F	230	120	2.0	−35	+35	110
12	30	M	210	90	1.9	−40	+30	125
13	40	M	219	68	2.0	−20	+35	105
14	20	M	172	78	1.9	−40	−15	165
15	56	M	200	52	1.2	−15	−65	150
16	26	M	164	46	1.7	−35	+30	60
17	16	M	240	108	2.2	−60	+30	150
18	10	M	196	110	2.6	0	+45	20
19	18	M	218	100	1.9	−90	+35	140
20	21	M	160	20	2.2	−25	+45	90
21	23	M	248	120	3.0	−50	+52	180
22	23	M	196	96	2.7	−57	+45	130
23	12	F	204	104	3.0	−45	+40	120
24	18	F	240	140	2.8	−50	+45	175
25	30	M	234	118	2.5	−60	+20	180
26	25	M	216	104	1.4	−50	0	175
27	43	M	210	100	1.3	−60	+5	110
28	15	M	176	88	1.7	−85	+15	100
29	15	M	200	84	1.4	+10	+35	75
30	16	M	200	110	1.8	−105	+35	130
31	15	M	230	140	2.1	+45	+10	150
32	15	M	232	130	2.0	−45	0	165
33	20	M	250	144	2.1	−110	+30	135
34	8	M	200	90	1.1	+55	+20	80
Mean	22.82		206.56	93.38	1.91	−36.82	25.74	124.12
±SD	11.53		30.85	30.61	0.54	38.52	21.24	46.16

LVSP = left ventricular systolic pressure; TVG = transvalvar peak aortic valve gradient.

***R* max Magnitude.** The *R* max magnitude revealed a significant correlation with peak left ventricular systolic pressure ($r = 0.38$, $P < 0.05$) and transvalvar gradient ($r = 0.41$, $P < 0.05$).

TABLE 2

Correlation coefficients between hemodynamic and vectorcardiographic parameters.

Hemodynamic parameter		Vectorcardiographic parameter			
		R max magnitude	Azimuth	Elevation	QRS-T angle
LVSP	*r*	0.38	−0.36	−0.16	0.72
	P	< 0.05	< 0.05	NS	< 0.001
TVG	*r*	0.41	−0.34	−0.24	0.49
	P	< 0.05	< 0.05	NS	< 0.01

LVSP = left ventricular systolic pressure; TVG = transvalvar peak aortic valve gradient.

***R* max Azimuth.** The azimuth angle was zero or negative (directed to the left and posteriorly) in all but three patients with significant aortic stenosis. In the four patients with nonsignificant aortic valvar gradient (< 50 mm Hg) it was positive (directed to the left and anteriorly) in two and negative in the remaining two. There was a significant correlation of azimuth angle with both peak left ventricular systolic pressure ($r = -0.36$, $P < 0.05$) and transvalvar gradient ($r = -0.34$, $P < 0.05$).

***R* max Elevation.** The elevation angle was negative (superiorly directed) in four, zero in two and positive (inferiorly directed) in the remaining 28 subjects. The *R* max elevation angle did not demonstrate any significant correlation with either peak left ventricular systolic pressure or transvalvar aortic gradient. However, all patients with zero or negative elevation angle (superiorly directed) had a significant ($\geqslant$ 50 mm Hg) transvalvar gradient.

QRS-T Angle. The spatial QRS-T angle was $\geqslant 90°$ in all except three patients with significant aortic stenosis. In these exceptional patients with severe aortic stenosis, the QRS-T angle was more than $75°$ in two and in one patient it was only

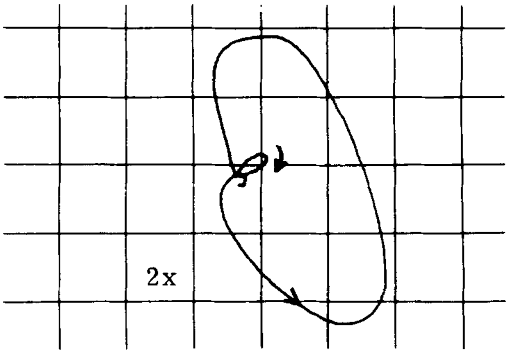

Fig. 2. QRS and T loops in horizontal plane in patient No. 34. The QRS loop shows normal counter-clockwise rotation and abnormal location and rotation of the T loop.

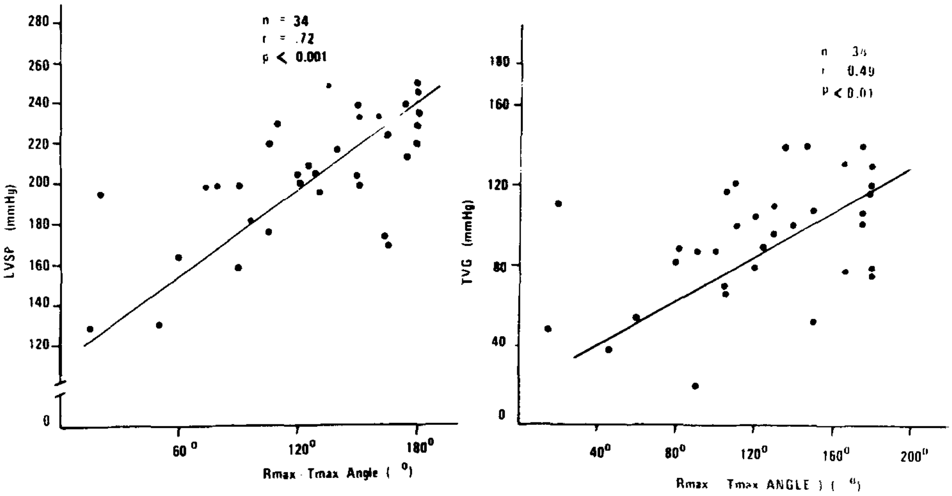

Fig. 3. Correlation of QRS-T angle with LVSP and TVG. LVSP = peak left ventricular systolic pressure; TVG = transvalvar aortic gradient.

20 °. However, in these cases, the T loop in the horizontal plane was abnormal (Fig. 2) in inscription (clockwise or figure of 8) and location (left and posterior). The QRS-T angle in the four patients with insignificant aortic stenosis was 90 ° in one and less than 60 ° in three. The QRS-T angle showed a significant correlation both with peak left ventricular systolic pressure ($r = 0.72$, $P < 0.001$) and transvalvar gradient ($r = 0.49$, $P < 0.01$) (Fig. 3).

Regression Equation. On stepwise multiple regression analysis of the various parameters studied, the spatial QRS-T angle revealed the most significant correlation ($r = 0.72$, $P < 0.001$) with peak left ventricular systolic pressure. Using the method of linear correlation, the regression equation was thus derived to find out the peak left ventricular systolic pressure from the spatial QRS-T angle which is as follows:

Peak Left Ventricular Systolic Pressure = 146.77 + (0.48 × QRS-T angle).

For the computed equation the coefficient of determination is 52%. Further addition of one or more vectorcardiographic parameters did not improve the coefficient of determination significantly.

Discussion

Assessment of the severity of aortic stenosis is of crucial importance in deciding the necessity and timing of surgery [8]. The severity is reflected in the magnitude of the left ventricular systolic pressure and hence the degree of left ventricular hypertrophy that develops in response to the pressure overload. The crux of the problem is to quantify accurately the left ventricular hypertrophy so that an assessment of the severity of the aortic stenosis can be made with reasonable certainty without/before invasive hemodynamic studies.

Standard 14-lead electrocardiographic changes have been reported to correlate poorly with the degree of left ventricular hypertrophy and hemodynamic parameters [4]. ST segment depression in precordial leads after submaximal exercise may be of help to differentiate mild and severe cases [13] but has obvious limitations and risks. The severity of aortic stenosis can be assessed noninvasively by carotid pulse tracing, phonocardiography [6,7], vectorcardiography [9–11], echocardiography [14,15] and Doppler studies [16,17]. Each of these methods has reported shortcomings and only Doppler studies have shown promising results. However, a recently published study has pleaded reconsideration of Doppler assessed gradients in aortic stenosis [18]. Hemodynamic studies, although diagnostic, are not easily repeatable on account of their invasive nature and are therefore, reserved only for selected cases preoperatively, where the clinical diagnosis of significant aortic stenosis is relatively certain.

Vectorcardiographic corrected orthogonal system studies have also been attempted to evaluate the degree of left ventricular hypertrophy in aortic stenosis with variable results [9–11]. Most of these studies have taken into account only the voltage variables and have overlooked the angular characteristics. The only study [11] where this has been attempted suffers from the drawback that correlation with hemodynamic variables of severity has not been made.

To the best of our knowledge the present study is the only one reported in the English literature where detailed angular characteristics of R max were studied. The most significant correlation in our study was observed between spatial QRS-T angle and peak left ventricular systolic pressure: the spatial QRS-T angle widening linearly with increasing left ventricular systolic pressure. In all but three patients with significant aortic stenosis, the QRS-T angle exceeded 90°. These remaining patients however, had posterior location of the T loop. Thus the presence of spatial QRS-T angle of more than 90° or abnormal posterior location and clockwise inscription of T loop could identify patients with significant aortic stenosis. The correlation between R max magnitude with peak left ventricular systolic pressure and transvalvar gradient in our study, has not been as strong as shown by others [8,10,11]. However, this observation is consistent with the result of an earlier study [9]. We believe that observations by Witham [19] regarding variability are pertinent that hypertrophic response to a given pressure overload may not be constant in adults since extracardiac factors may account for variability in surface voltages.

The present study has certain limitations viz. the small number of patients with insignificant gradients and older age. Moreover, the suggested parameters have only been tested in patients without associated significant aortic regurgitation and ischemic heart disease. These problems, however, have been universal as emphasized by Krafchek et al. [18] that among the various Doppler correlative studies in valvar aortic stenosis, more than half of the cases have been children and young adults, and not more than 10% had insignificant gradients.

In conclusion, our study emphasizes that quantitative spatial vectorcardiography may be a useful adjunct to other noninvasive techniques including Doppler echocardiography to assess reliably the severity of valvar aortic stenosis.

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