RELATIONSHIP BETWEEN VENTRICULAR GRADIENT AND THE IMPAIRMENT OF WALL MOTION OF THE LEFT VENTRICLE IN CORONARY ARTERY DISEASE

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Fifty patients with or without coronary artery disease were studied. Twelve of them showed no coronary artery obstruction, while 38 demonstrated obstruction of the left anterior descending artery (LAD). Of the latter 38, 16 had obstruction at LAD alone, 6 at LAD and right coronary artery (RCA), 8 at LAD and left circumflex artery (LCx) and 8 at LAD, RCA and LCx. Vectorcardiography, selective coronary cineangiography and left ventricular cineangiography were undertaken in all subjects. The vectorcardiogram (VCG) was recorded on a magnetic tape and QRS area vector ($\vec{A}_{qrs}$), T area vector ($\vec{A}_t$) and ventricular gradient ($\vec{G}$) were calculated by micro-computer. From left ventriculogram (LVG) "score" was computed to express the grade of impairment of the wall motion. Correlations between various vectorcardiographic parameters and this score were examined. The score correlated significantly ($p < 0.001$) with azimuth of $\vec{A}_{qrs}$ ($r = -0.545$), azimuth of $\vec{A}_t$ ($r = 0.661$), magnitude of $\vec{G}$ ($r = -0.705$), azimuth of $\vec{G}$ ($r = 0.533$), G/A_{qrs} ($r = -0.645$), spatial angles between $\vec{A}_{qrs}$ and $\vec{A}_t$ ($r = 0.591$) and between $\max \vec{R}$ and $\max \vec{T}$ ($r = 0.595$) and X component of $\vec{G}$ ($r = -0.758$). These results suggested the usefulness of ventricular gradient to grasp the grade of coronary artery disease.

IN 1934 Wilson and his associates defined the ventricular gradient as the time integral of the voltage of the electrocardiograms taken over a complete heart cycle and showed that it indicated the variation in duration of the recovery process throughout the ventricular myocardium! Since then many reports on theoretical, experimental and clinical analysis of the ventricular gradient have been published^{2-16,19,21,22}. In coronary artery disease, the ventricular gradient

is said to differ in magnitude and direction from that of normal subjects. Unfortunately, subsequent reports on its diagnostic usefulness are few^{8,16,22}. In this paper, ventricular gradient was compared with selective coronary arteriogram and left ventriculogram in patients with coronary artery disease and its diagnostic usefulness was evaluated.

MATERIALS AND METHODS

Materials

We selected 50 patients with chest pain on whom selective coronary arteriography and left ventriculography were performed at Shiga

Key Words:

Vectorcardiogram
Ventricular gradient
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LV wall motion abnormality

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TABLE I FINDINGS OF CORONARY ARTERIOGRAMS (CAG) AND LEFT VENTRICULOGRAMS (LVG)

No.	CAG			LVG					Score
	RCA	LCx	LAD	Seg 1	Seg 2	Seg 3	Seg 4	Seg 5	
Control Group									
1	0	0	0	*	*	*	*	*	0
2	0	0	0	*	*	*	*	*	0
3	0	0	0	*	*	*	*	*	0
4	0	0	0	*	*	*	*	*	0
5	0	0	0	*	*	*	*	*	0
6	0	0	0	*	*	*	*	*	0
7	0	0	0	*	*	*	*	*	0
8	0	0	0	*	*	*	*	*	0
9	0	0	0	*	*	*	*	*	0
10	0	0	0	*	*	*	*	*	0
11	0	0	0	*	*	*	*	*	0
12	0	0	25	*	*	*	*	*	0
LAD group									
13	0	0	75	*	*	*	*	*	1
14	50	0	99	*	*	D	*	*	3
15	0	0	99	*	*	A	*	*	3
16	0	0	90	*	*	H	*	*	2
17	0	0	75	*	*	*	*	*	1
18	0	0	75	*	*	*	*	*	1
19	0	50	75	*	*	*	*	*	1
20	0	0	90	*	*	D	*	*	3
21	0	0	90	*	*	*	*	*	1
22	0	0	90	*	*	H	*	*	2
23	50	0	75	*	*	*	*	*	1
24	0	0	90	*	*	*	*	*	1
25	0	0	90	H	H	H	*	*	2
26	0	0	90	*	*	*	*	*	1
27	0	0	90	*	*	*	*	*	1
28	50	0	100	*	D	D	*	*	5
LAD + RCA Group									
29	99	0	90	*	H	A	A	A	5
30	99	0	75	*	*	H	H	H	2
31	90	0	75	*	*	D	D	*	5
32	75	0	100	*	*	D	*	*	3
33	100	0	99	*	H	D	A	A	5
34	75	0	100	*	H	A	*	*	4
LAD + LCx Group									
35	0	99	90	*	H	A	H	*	4
36	0	100	90	*	*	D	*	*	3
37	0	100	99	A	A	A	*	*	5
38	50	90	90	*	A	A	*	*	5
39	25	75	90	*	*	*	*	*	1
40	50	75	90	*	H	H	H	*	2
41	0	100	100	*	H	H	*	*	2
42	50	75	99	A	D	D	*	*	5
LAD + RCA + LCx Group									
43	99	99	75	*	*	*	H	H	2
44	75	75	90	*	*	*	*	*	1
45	99	75	75	*	*	*	*	*	1
46	75	90	75	*	*	*	*	*	1
47	75	100	100	H	H	A	H	H	4
48	99	99	75	*	H	H	H	*	2
49	100	100	100	*	A	H	H	H	4
50	75	90	90	H	H	H	*	*	2

RCA = right coronary artery; LCx = left circumflex artery; LAD = left anterior descending artery; * = normal motion; H = hypokinetic motion; A = akinetic motion; D = dyskinetic motion

TABLE II $\vec{A}_{Qrs}$, $\vec{A}_t$ AND $\vec{G}$

No.	Years	$\vec{A}\text{-QRS}$			$\vec{A}\text{-T}$			Gradient		
		MAG	AZI	ELE	MAG	AZI	ELE	MAG	AZI	ELE
Control group										
1	48M	35.1	4	68	108.9	42	82	138.2	33	78
2	54M	55.8	7	56	141.8	58	78	182.2	46	70
3	52M	66.2	6	76	53.8	80	94	95.4	39	82
4	36M	83.3	-15	75	115.4	48	71	173.1	21	70
5	53F	64.4	0	56	47	50	72	106.3	22	60
6	47F	52	5	50	87.1	31	57	137.1	22	54
7	53M	45.6	-25	53	97.3	36	72	128.4	20	63
8	51M	49.5	-18	71	82.1	34	72	120.9	15	69
9	50M	50.1	8	51	112.1	48	61	156.3	37	57
10	56M	60.5	9	49	82.8	46	77	134.3	33	64
11	55M	57	-53	67	76.8	51	78	90.4	12	65
12	45M	42.1	-5	54	92	50	69	123.9	35	62
LAD group										
13	49M	44.4	-33	60	119.7	-174	42	124.6	-148	27
14	62M	49.6	-88	51	44.7	-160	53	83.8	-123	46
15	65M	33.5	-7	64	48.9	74	8	71	5	27
16	61M	41.4	-37	72	37.7	37	49	66.5	-7	55
17	41M	55	-75	78	108.3	94	71	69.7	83	47
18	44M	36	-25	74	78.3	51	72	96	29	69
19	55M	50.4	-9	61	43.3	33	65	86.3	10	61
20	41M	22.8	-58	22	51.4	154	64	59.3	161	42
21	46M	40.6	-73	99	48.1	-124	100	80.8	-101	101
22	58M	32.1	1	47	53.7	55	87	74.9	39	70
23	56M	74.9	-51	45	70.4	53	64	111.2	8	41
24	40M	78.5	-24	69	84.8	81	79	105.7	33	65
25	67M	31	28	51	36.8	90	54	62.2	63	48
26	61M	58.1	-54	66	89.2	116	71	62.9	99	32
27	58F	58.7	-4	40	28.9	-151	30	75	-21	21
28	50M	49.1	-103	74	36.2	124	26	59.8	-120	40
LAD + RCA group										
29	68M	54	-71	121	17.3	79	144	56.5	-64	138
30	59M	38.9	-25	79	69.2	68	79	79.6	38	75
31	52M	42.7	-6	64	71	79	95	84.5	52	82
32	53M	50.8	-88	68	76.4	99	77	47	110	38
33	55M	55.1	-54	77	36.5	113	106	22.2	-31	83
34	57M	45.5	-33	105	9.5	58	36	44.5	-25	95
LAD + LCx group										
35	57M	35.4	-99	107	60.1	112	85	38.2	140	97
36	53M	48	-92	70	47.7	133	65	50.3	-156	43
37	68M	61	-24	78	127.3	160	101	67.5	164	101
38	60M	86.4	-39	60	92.1	172	107	49.5	-131	69
39	59F	35.8	10	53	66.6	44	67	99.1	33	61
40	63M	49.3	-34	59	57	43	73	87.6	10	62
41	50M	53.8	-61	56	61	136	40	78.4	-119	10
42	56M	80.9	-105	68	50.4	-161	72	118.9	-126	67
LAD + RCA + LCx group										
43	46M	36.9	-3	99	55.8	87	101	68.3	53	104
44	60M	28.6	-11	38	61.4	80	66	75.8	63	51
45	60M	45	-13	47	104.3	63	89	121.4	47	75
46	52M	52.5	-11	76	70.2	56	79	103.7	28	75
47	53M	53.1	-44	97	54.3	94	74	39.2	24	78
48	55F	43.5	-12	75	41.4	108	83	45	47	69
49	52M	56.3	-19	77	60.1	123	98	38.8	59	83
50	58M	65.3	-49	69	72	-173	86	69.8	-120	66

MAG = magnitude ($\mu Vsec$), AZI = azimuth (degree); ELE = elevation (degree)

TABLE III OTHER VECTORCARDIOGRAPHIC PARAMETERS

No.	At/Aqrs	G/Aqrs	A-A ANG	Gx	T/R	R-T ANG
Control group						
1	3.1	3.93	39	113.1	0.47	35
2	2.54	3.27	52	118.5	0.35	54
3	0.81	1.44	76	73.1	0.16	40
4	1.39	2.08	60	151.5	0.25	51
5	0.73	1.65	47	85.5	0.18	53
6	1.68	2.63	22	102.3	0.28	13
7	2.13	2.82	57	107.3	0.29	32
8	1.66	2.44	49	108.9	0.3	41
9	2.34	3.12	35	104.9	0.44	34
10	1.37	2.22	42	101.7	0.32	34
11	1.35	1.59	97	79.5	0.26	81
12	2.19	2.94	50	88.9	0.32	15
LAD group						
13	2.7	2.81	95	-47.3	0.19	99
14	1.69	0.9	44	-32.4	0.36	56
15	1.46	2.12	63	31.2	0.26	73
16	0.91	1.61	67	53.9	0.19	22
17	1.97	1.27	147	6.5	0.29	157
18	2.18	2.67	72	77.8	0.33	42
19	0.86	1.71	37	74.2	0.18	15
20	2.25	2.6	83	-37	0.3	105
21	1.18	1.99	50	-14.9	0.39	13
22	1.67	2.33	61	54.6	0.22	47
23	0.94	1.48	81	71.4	0.21	69
24	1.08	1.35	100	79.9	0.2	100
25	1.19	2.01	48	21.3	0.21	70
26	1.54	1.08	136	-5	0.25	121
27	0.49	1.28	67	25.2	0.12	101
28	0.74	1.22	93	-19.1	0.26	90
LAD + RCA group						
29	0.32	1.05	91	16.9	0.1	60
30	1.78	2.05	90	60.4	0.33	47
31	1.66	1.98	88	51.3	0.34	85
32	1.5	0.93	144	-9.4	0.23	163
33	0.66	0.4	167	18.2	0.17	164
34	0.21	0.98	103	40	0.17	84
LAD + LCx group						
35	1.7	1.08	148	-28.2	0.4	137
36	0.99	1.05	120	-31.2	0.19	88
37	2.09	1.11	176	-62.9	0.28	175
38	1.07	0.57	149	-29.4	0.2	162
39	1.86	2.77	32	72.1	0.43	22
40	1.16	1.78	70	75.5	0.23	50
41	1.13	1.46	95	-6.4	0.27	81
42	0.62	1.47	52	-64.2	0.26	41
LAD + RCA + LCx group						
43	1.51	1.85	88	39.6	0.2	56
44	2.15	2.65	72	26.9	0.39	39
45	2.32	2.7	79	80.1	0.32	66
46	1.34	1.98	66	88.1	0.23	51
47	1.02	0.74	138	34.2	0.19	151
48	0.95	1.03	117	28.5	0.18	110
49	1.07	0.69	142	19.7	0.24	121
50	1.1	1.07	120	-31.6	0.25	92

At/Aqrs = ratio of magnitude of $\vec{A}_t$ to magnitude of $\vec{A}_{qrs}$; G/Aqrs = ratio of magnitude of $\vec{G}$ to magnitude of $\vec{A}_{qrs}$; A-A ANG = spatial angle between $\vec{A}_{qrs}$ and $\vec{A}_t$; Gx = X component of $\vec{G}$; T/R = ratio of magnitude of max $\vec{T}$ to magnitude of max $\vec{R}$; R-T ANG = spatial angle between max $\vec{R}$ and max $\vec{T}$

Medical University Hospital. Twelve of them had no significant obstruction of the coronary arteries and 38 had significant obstruction of LAD. Of the latter 38, 16 had significant obstruction of LAD only ("LAD" group); 6, LAD and RCA ("LAD + RCA" group); 8, LAD and LCx ("LAD + LCx" group) and 8, LAD, RCA and LCx ("LAD + RCA + LCx" group). There were 45 men and 5 women whose ages ranged from 36 to 68 years with a mean of 54 ± 7.2 years. The patients with conduction disturbance, acute myocardial infarction, idiopathic cardiomyopathy and hypertensive heart disease were excluded from the study. One or two vessel diseases without significant LAD obstruction were also excluded.

Vectorcardiography

Vectorcardiograms of the Frank system were recorded in the supine position by Fukuda VA-3F. Chest electrodes were placed on the 5th intercostal space at the sternal border. Scaler lead electrocardiograms X, Y and Z were recorded on magnetic tape by TEAC R-260, digitalized at a rate of 400 Hz with an analogue-digital converter and calculated by micro-computer (TEAC PS-80). The QRS area vector ($\vec{A}_{qrs}$), T area vector ($\vec{A}_t$) and ventricular gradient ($\vec{G}$) were calculated as follows:

$$\vec{A}_{qrs} = \int_q^s (X\vec{i} + Y\vec{j} + Z\vec{k}) dt \quad (1)$$

$$\vec{A}_t = \int_s^t (X\vec{i} + Y\vec{j} + Z\vec{k}) dt \quad (2)$$

$$\vec{G} = \vec{A}_{qrs} + \vec{A}_t \quad (3)$$

where $\vec{i}$, $\vec{j}$, and $\vec{k}$ were the unit vectors in the direction of X, Y and Z, respectively. The following parameters were calculated:

$$\text{Magnitude (Mag)} = (X^2 + Y^2 + Z^2)^{1/2} \quad (4)$$

$$\text{Azimuth (Azi)} = \tan^{-1} (Z/X) \quad (5)$$

$$\text{Elevation (Ele)} = \cos^{-1} (Y/\text{Mag}) \quad (6)$$

$$\text{At/Aqrs} = |\vec{A}_t| / |\vec{A}_{qrs}| \quad (7)$$

$$\text{G/Aqrs} = |\vec{G}| / |\vec{A}_{qrs}| \quad (8)$$

$$\begin{aligned} \vec{A}_{qrs}\text{-}\vec{A}_t \text{ Angle (A - A Ang)} \\ = \cos^{-1} ((\vec{A}_{qrs} \cdot \vec{A}_t) / (|\vec{A}_{qrs}| \cdot |\vec{A}_t|)) \end{aligned} \quad (9)$$

$$\text{T/R} = |\max \vec{T}| / |\max \vec{R}| \quad (10)$$

$$\begin{aligned} \vec{R}\text{-}\vec{T} \text{ Angle (R-T Ang)} \\ = \cos^{-1} ((\max \vec{R} \cdot \max \vec{T}) / (|\max \vec{R}| \cdot |\max \vec{T}|)) \end{aligned} \quad (11)$$

The positive direction of the Z lead was forward. The $\max \vec{R}$ and $\max \vec{T}$ were the vectors which had the largest spatial magnitudes in QRS and T durations.

Cineangiography

Selective coronary angiography in more than 4 directions and left ventricular angiography in the right anterior oblique projection were carried out. The severity of obstruction of the coronary artery was expressed in accordance with the classification adopted by the Ad Hoc Committee on Grading of Coronary Arterial Disease of the American Heart Association¹⁸ and was defined as significant for more than 75 per cent obstruction. The left ventricular silhouette in the right anterior oblique projection was divided into five major segments in accordance with the report of the Ad Hoc Committee¹⁸ and the degrees of motion impairment were described as normal, hypokinetic, akinetic and dyskinetic. Patients were given a "score" according to the following criteria:

Score 0 = without significant coronary artery obstruction,

Score 1 = with significant coronary artery obstruction and without abnormal wall motion,

Score 2 = with hypokinetic segments,

Score 3 = with an akinetic or a dyskinetic segment,

Score 4 = with an akinetic or a dyskinetic segment and hypokinetic segments,

Score 5 = with 2 or more akinetic or dyskinetic segments and with or without hypokinetic segments (extensive myocardial infarction).

Statistical Methods

Coefficients of correlation between vectorcardiographic parameters and the score were calculated by the standard method. In calculating them, azimuths of $\vec{A}_t$ and $\vec{G}$ were used at their absolute values (0–180) because we thought their rightward shifts were important. For the test of significance of correlation, Fisher's t test was used.

RESULTS

Findings of coronary arteriograms and left ventriculograms are listed in Table I. Data of $\vec{A}_{qrs}$, $\vec{A}_t$ and $\vec{G}$ are listed in Table II. Other vectorcardiographic parameters are listed in

TABLE IV CORRELATIONS BETWEEN VECTORCARDIOGRAPHIC PARAMETERS AND SCORE

Parameter	R	T	
Aqrs Mag	0.03	0.201	
Azi	-0.545	4.359	($p < 0.001$)
Ele	0.413	3.045	($p < 0.01$)
At Mag	-0.46	3.471	($p < 0.01$)
Azi	0.661	5.91	($p < 0.001$)
Ele	0.177	1.208	
G Mag	-0.705	6.676	($p < 0.001$)
Azi	0.533	4.222	($p < 0.001$)
Ele	0.269	1.875	
At/Aqrs	-0.432	3.214	($p < 0.01$)
G/Aqrs	-0.645	5.663	($p < 0.001$)
A-A Ang	0.591	4.913	($p < 0.001$)
Gx	-0.758	7.8	($p < 0.001$)
T/R	-0.292	2.049	
R-T Ang	0.595	4.969	($p < 0.001$)

R = Coefficient of correlation; T = t value; P = probability

In calculating these coefficients, the patients with subendocardial infarction (cases 13, 21 and 27) were excluded and azimuth of $\vec{A}t$ and $\vec{G}$ were used at their absolute values.

Table III. Coefficients of correlation between the vectorcardiographic parameters and the angiographic score are listed in Table IV.

1) $\vec{A}qrs$: The magnitude had no significant correlation with the score. The azimuth was shifted more posteriorly as the score increased (Fig. 1). In patients with obstruction of RCA and LCx, the elevation had a tendency to shift in an upward direction as the score increased (Fig. 2).

2) $\vec{A}t$: The magnitude had a tendency to decrease as the score increased (Table IV). Azimuth was shifted more rightwards as the score increased (Fig. 3). The elevation had no significant correlation with the score.

3) $\vec{G}$: The magnitude had a good correlation with the score ($r = -0.705$, $p < 0.001$), especially between score 0 and 4 (Fig. 4). In patients without RCA obstruction, azimuth was shifted more rightwards as the score increased (Fig. 5). Elevation had no significant correlation with the score.

4) Other vectorcardiographic parameters: $G/Aqrs$ ($r = -0.645$, $p < 0.001$) and X component of $\vec{G}$ (Gx) ($r = -0.758$, $p < 0.001$) had good correlations with the score (Fig. 6 and 7). $\vec{A}qrs$ - $\vec{A}t$ Angle ($r = 0.591$, $p < 0.001$) and

Fig.1. Correlation between azimuth of $\vec{A}qrs$ and score
Concentric circles express the score.

Fig.2. Correlation between elevation of $\vec{A}_{qrs}$ and score
Symbols are the same as in Fig. 1.

Fig.3. Correlation between azimuth of $\vec{A}_t$ and score
The form of the expression is the same as in Fig. 1.

Fig.4. Correlation between magnitude of $\vec{G}$ and score
The form of the expression is the same as in Fig. 2.

Fig.5. Correlation between azimuth of $\vec{G}$ and score
The form of the expression is the same as in Fig. 1.

Fig.6. Correlation between $G/Aqrs$ and score
The form of the expression is the same as in Fig. 2.

$\vec{R}-\vec{T}$ Angle ($r = 0.595$, $p < 0.001$) had significant correlations with the score.

5) Relations between impaired segments and $\vec{G}$: Twenty-five patients had wall motion impairments and 24 of them had impairment in the apical region (seg. 3). Case 43, who had no impairment at apical region but had it at the infero-posterior region (segs. 4 and 5), had $\vec{G}$ with normal azimuth and upward shifted elevation. Patients with wall motion impairments in the apical or apical and antero-lateral region (seg. 3 or segs. 1, 2 and 3) had a tendency to shift of $\vec{G}$ to the right but patients with wall motion impairments in the apical and infero-posterior region (segs. 3, 4 and 5), cases 29, 30, 31 and 33, had $\vec{G}$ with normal ranged azimuths and upward shifted elevations.

DISCUSSION

Coronary Artery Disease and Ventricular Gradient

Since Wilson and his associates introduced the concept of ventricular gradient,¹ many investiga-

tors have reported its theoretical, experimental and clinical significance^{2-16,19,21,22}

Ventricular gradient is said to be derived from the different durations of action potential which is shorter in epicardium than in endocardium and shorter at the apex than at the base of the heart.¹⁷ Gradient vector directs to the site of shorter action potential, and accordingly, orients left-inferiorly in normal subject. In the anoxic region of the heart, the duration of action potential is prolonged except in the early stage of myocardial infarction.²³

Thus in patients with coronary artery disease the ventricular gradient shifts away from the ischemic regions. Since all the patients in the study had a significant obstruction of LAD, the apex and antero-lateral regions of their left ventricle were in an ischemic state. Therefore, ventricular gradient of these patients shifted away from the apex and anterolateral region of the left ventricle. This evidence was consistent with the results of this study in that the ventricular gradient ($\vec{G}$) became smaller in magnitude and

Fig.7. Correlation between X component of $\vec{G}$ and score
The form of the expression is the same as in Fig. 2.

shifted more rightwards as the grade of ischemia increased in "LAD" and "LAD + LCx" groups. Azimuth of $\vec{G}$ in "LAD + RCA" group did not shift rightwards probably due to cancellation of the shifts to the right and to the left.

Clinical Significance of $\vec{Aqrs}$, $\vec{At}$ and $\vec{G}$ in Coronary Artery Disease

$\vec{Aqrs}$ had significant correlation in the azimuth with the score. The azimuth shifted more posteriorly and more rightwards as the impairment of wall motion of the left ventricle increased.

However, this phenomenon was seen not only in coronary artery disease but also in left or right ventricular hypertrophy and is thought to be of little diagnostic significance. The magnitude and azimuth of $\vec{At}$ had significant correlations with the score. As the grade of impairment of wall motion increased, the magnitude became smaller and the azimuth shifted more rightwards. This phenomenon was attributed to the electrophysiological change in the ischemic region, where the duration of action potential was prolonged, and was thought to be one of the important signs of

VCG in coronary artery disease^{8,16,23} Magnitude and azimuth of $\vec{G}$ had significant correlations with the score. The magnitude of $\vec{G}$ correlated well with the score, especially between score 0 and 4 the correlation was better. Score 5 represented an extensive myocardial infarction, and the magnitude and the azimuth of $\vec{G}$ in this grade varied.

Correlations between the Score and the Other Vectorcardiographic Parameters

The score had the best correlation with the value of the X component of ventricular gradient (G_x). The G_x decreased more as the score increased. This was an expression of the decreased magnitude and the rightward shift of the ventricular gradient. The ratio of the magnitude of ventricular gradient to the magnitude of $\vec{Aqrs}$ ($G/Aqrs$), the spatial angle between $\max \vec{R}$ and $\max \vec{T}$ (R-T Ang) and the spatial angle between $\vec{Aqrs}$ and $\vec{At}$ (A-A Ang) were significantly correlated with the score. These three parameters have been reported to be of use in detecting altered repolarization.¹⁶

REFERENCES

1. WILSON FN, MacLEOD AG, BARKER PS, JOHNSTON FD: The determination and the significant of area of the ventricular deflection of the electrocardiogram. *Am Heart J* 10: 46, 1934
2. SIMONSON E, SCHMITT OH, DAHL J, FRY D, BAKKEN E: The theoretical and experimental bases of the frontal plane ventricular gradient and its spatial counterpart. *Am Heart J* 47: 1, 1954
3. BURCH GE, ABILDSKOV JA, CRONVICH JA: A study of the spatial vectorcardiogram of the ventricular gradient. *Circulation* 9: 267, 1954
4. BURGER HC: A theoretical elucidation of the notion "ventricular gradient". *Am Heart J* 53: 240, 1957
5. BURCH GE, DePASQUALE N: The electrocardiogram and ventricular gradient in atrial septal defect. *Am Heart J* 58: 190, 1959
6. BURCH GE, DePASQUALE N: The electrocardiogram, spatial vectorcardiogram and ventricular gradient in congenital ventricular septal defect. *Am Heart J* 60: 195, 1960
7. DePASQUALE N, BURCH GE: The electrocardiogram and ventricular gradient in isolated congenital pulmonary stenosis. *Circulation* 21: 181, 1960
8. DePASQUALE NP, BURCH GE: The spatial vectorcardiogram and ventricular gradient in apical myocardial infarction in necropsied patient. *Am J Med Sci* 239: 462, 1960
9. BURCH GE, DePASQUALE NP: The electrocardiogram, vectorcardiogram and ventricular gradient in combined pulmonary stenosis and interatrial communication. *Am J Cardiol* 5: 646, 1961
10. DePASQUALE NP, BURCH GE: The electrocardiogram, vectorcardiogram and ventricular gradient in the tetralogy of Fallot. *Circulation* 24: 94, 1961
11. MASHIMA S, FU L, FUKUSHIMA K: The normal ventricular gradient determined with Frank's lead system and its relation to the heart rate change induced by various procedures: Studies on the ventricular gradient (I). *Jpn Heart J* 5: 337, 1964
12. COSMA J, LEVY B, PIPBERGER HV: The spatial ventricular gradient during alterations in the ventricular activation pathway. *Am Heart J* 71: 84, 1966
13. MASHIMA S, FU L, FUKUSHIMA K: The ventricular gradient and the vectorcardiographic T loop in left ventricular hypertrophy. *J Electrocardiol* 2: 55, 1969
14. ABILDSKOV JA, BURGESS MJ, MILLAR K: New data and concept concerning the ventricular gradient. *Chest* 58: 244, 1970
15. ISHIZAWA K: Mean QRS, ventricular gradient and left ventricular mass in patients with eccentric left ventricular hypertrophy. *J Electrocardiol* 8: 227, 1975
16. KAWASHITA K, HIRAKAWA A, KAMBARA H, KADOTA K, KAWAI C: A factor analytic assessment of prognosis in ischemic heart disease using Thallium-201 myocardial scintigraphy, radiocardiography and orthogonal electrocardiography. *Jpn Circ J* 45: 24, 1981
17. SPACH MS, BARR RC: Ventricular intramural and epicardial potential distributions during ventricular activation and repolarization in intact dog. *Circ Res* 37: 243, 1975
18. American Heart Association Committee Report: A reporting system on patients evaluated for coronary artery disease. *Circulation* 51 (4): News from the ANA, page 6, 1975
19. PLONSEY R: A contemporary view of the ventricular gradient of Wilson. *J Electrocardiol* 12: 337, 1979
20. YOUNG E, COHN PF, GORLIN R, LEVINE HD, HERMAN MV: Vectorcardiographic diagnosis and electrocardiographic correlation in left ventricular asynergy due to coronary artery disease. *Circulation* 51: 467, 1975
21. ABILDSKOV JA, GREEN LS, EVANS AK, LUX RL: The QRST deflection area of electrograms during global alterations of ventricular repolarization. *J Electrocardiol* 15: 103, 1982
22. MOTOMURA M, KAWAGUCHI Y, KINOSHITA M, KAWAKITA S: Clinical significance of ventricular gradient with a right orientation. *Jpn Circ J* 46: 669, 1982
23. REYNOLDS EW, VANDER ARK CR, JOHNSTON FD: Effect of acute myocardial infarction on electrical recovery and transmural temperature gradient in left ventricular wall of dogs. *Circ Res* 8: 730, 1960
24. LAGUENS RP, WEINSCHELBAUM R, FAVALORO R: Ultrastructural and morphometric study of the human heart muscle cell in acute coronary insufficiency. *Human Pathology* 10: 695, 1979
25. BRAUNWALD E, KLONER RA: The stunned myocardium: Prolonged, postischemic ventricular dysfunction. *Circulation* 66: 1146, 1982
26. GEFT IL, FISHBEIN MC, NINOMIYA K, HASHIDA J, CHAUX E, YANO J, Y-RIT J, GENOV T, SHELL W, GANZ W: Intermittent brief periods of ischemia have a cumulative effect and may cause myocardial necrosis. *Circulation* 66: 1150, 1982