A Quantitative Analysis of the Vectorcardiogram in Normal and Left Ventricular Hypertrophy Groups

Using the Frank and the Takayasu Lead Systems*

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SINCE the introduction of vectorcardiography by SCHELLONG^{1,2} and by KIMURA³ respectively, it has been widely studied and used by many investigators. Up to the present, innumerable different lead systems have been established or modified by many vectorcardiographers, i.e. as combinations of bipolar leads such as DUCHOSAL⁴, GRISHMAN⁵, KIMURA³, and MILNOR's⁶ lead systems, and as for examples of a combination of unipolar or unipolar and bipolar leads, MILOVANOVICH⁷, JOUVE⁸, or WILSON-BURCH's⁹ system.

BURGER and VAN MILAAN¹⁰ advanced the excellent theory of "Lead vector" while Mc FEE and JOHNSTON¹¹ also proposed the theory of "Lead field" and these two newly created concepts greatly advanced the theoretical considerations of vectorcardiography. In the so-called "corrected orthogonal" lead systems, which are widely used today, FRANK¹², BURGER¹⁰ and TAKAYASU's¹⁴⁻¹⁷ lead systems are included.

In the present series, the FRANK and the TAKAYASU lead systems were adopted. The latter system was established in 1955 by TAKAYASU, SUGAWARA, KATO, as one of the ideal "corrected orthogonal" lead systems.

The primary purpose of this study was to investigate the distinctive points of the instantaneous vectors both in the depolarization and

repolarization phases of the normal and left ventricular hypertrophy groups respectively, and secondarily to compare the two "corrected orthogonal" lead systems, FRANK's and TAKAYASU's, and to clarify the differences of the QRS-T angles in the normal and left ventricular hypertrophy groups in the planar and spatial vectorcardiograms.

MATERIALS AND METHODS

The subjects used in this study were 102 normal persons of both sexes, ranging from 16 to 71 years of age, and 105 person with left ventricular hypertrophy (LVH) of both sexes, ranging in age from 16 to 75 years.

The normal subjects consisted of in- and out-patients without any cardiovascular diseases at our hospital, members of the hospital personnel and students. The cases in the LVH group were selected on the basis of their previous histories, physical examination and routine laboratory data, including the standard 12-lead electrocardiograms. For the determination of left ventricular hypertrophy on the electrocardiograms, the criteria for LVH given by HATTORI¹³ of our clinic, which were determined by measuring the left ventricular wall thickness in the late stage of diastolic phase on the human angiocardograms, were used (Fig. 1). Coronary artery diseases and other factors, e.g. tachycardias that would make interpretation of ST- and T wave changes difficult, were omitted from this series. In each subject of both the normal and LVH groups, the standard 12 lead electrocardiogram, the three

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orthogonal scalar leads (X, Y and Z scalar leads) and the vectorcardiogram, using the FRANK¹² and the TAKAYASU¹⁴⁻¹⁷ lead systems, were recorded simultaneously. For the FRANK lead system, the electrodes were placed in the fifth intercostal space with the patient in the sitting position. For registration of the vectorcardiogram, a Nihon-Kohden 3-dimensional vectorcardiograph MVC-30 with its three pre-amplifiers RB-2 was used. The QRS and T loops were recorded on 35 mm X-ray film and analysed on the enlarged photographic paper. Simultaneously the three orthogonal leads (X, Y and Z) were recorded on the 6-channel YEW oscillograph. Subsequently, the values on each scalar lead, X, Y and Z, both in the de- and repolarization phases, were measured and the Remington USS-II (UNIVAC) digital computer was used for further data processing and analysis. For measurement of QRS wave from scalar lead, the PR-segment was used as the base line¹⁸ of the lead. The earliest deflection in any one of the three simultaneously recorded leads was taken as the beginning of the wave or the complex. By this method, as PIPBERGER¹⁹ mentioned, the measurements differ somewhat from those derived from one lead. As the beginning of the T wave shows gradual transition from the ST-segment to the T wave, the five points on the QT interval were fixed on each lead and the so called "QTc" was calculated with the formula of TAKAHASHI²⁰. For the QRS complex, the eight instantaneous vectors (from 0.01 to 0.08 second) were determined at the fixed time intervals of 0.01 second without any time normalization. The QT interval, QTc vectors

were determined at five points: 0.20, 0.25, 0.30, 0.35 and 0.40 second from the beginning of the first deflection of the Q wave on the three scalar leads and corrected by the formula²⁰. This procedure of time normalization in the QT intervals was carried out to get better comparability among persons with different pulse rates. The spatial amplitude and direction (azimuth and elevation) of the thirteen instantaneous vectors were thus determined and analysed. Also, maximal QRS-T angles in space and spatial amplitude and orientation of the maximal QRS and T vectors were determined. For the planar vectorcardiogram, the QRS-T angles and T/QRS ratios in each plane projection were calculated, and the "bisection" QRS and T vectors¹³ were used as the mean QRS and T vectors.

The following formulas were used in the quantitative analysis of the vectorcardiogram:

- (1) for the correction of the QT intervals,

$$QTc = \frac{QT \text{ duration}}{K\sqrt{RR}} (\text{sec})$$

- (2) for the spatial magnitude and orientation of the instantaneous QRS and T vectors as well as the max. QRS and the max. T vectors,

- (i) spatial magnitude (mV)

$$M = \sqrt{X^2 + Y^2 + Z^2}$$

- (ii) spatial orientation

- a. azimuth (degree)

- 1) $Rv5(6) + Sv1 \geq 40(45)_{\text{mm}}$
- 2) $S_{III} > S_{II}$
- 3) Comparative Ratio R/S
on Chest Leads is over 10.

- A. When 1) or 2) is satisfied,

Positivity	90.0 %
False Posit.	23.1 %

- B. When 1) + 2) or 1) + 3)
is satisfied,

Posit.	50.0 %
False Posit.	1.5 %

Fig. 1. Criteria for LVH.

$$QA = QAc \times \sqrt{RR}$$

$$QAc = 0.20$$

$$QBc = 0.25$$

$$QCc = 0.30$$

$$QDc = 0.35$$

$$QEc = 0.40$$

Fig. 2. Five points of the QT interval.

$$\tan^{-1} H^\circ = \frac{Z}{X}$$

b. elevation (degree)

$$\cos^{-1} V^\circ = \frac{Y}{\sqrt{X^2 + Y^2 + Z^2}}$$

(3) for the spatial QRS-T angles (A),

$$\cos A = \frac{X_1 X_2 + Y_1 Y_2 + Z_1 Z_2}{\sqrt{(X_1^2 + Y_1^2 + Z_1^2) \times (X_2^2 + Y_2^2 + Z_2^2)}}$$

The (X_1, Y_1, Z_1) and (X_2, Y_2, Z_2) coordinate for the spatial maximal QRS and T vectors respectively.

The QRS-T angle in each plane was determined as the algebraic difference from the angle of "bisec-

tion" QRS vector to that of "bisection" T vector.

RESULTS

The results are shown in Table I to X. The data consist of the quantitative analysis of the vectorcardiograms in the normal and LVH groups, using the instantaneous vectors in the depolarization (QRS) and repolarization (QTc) phases. The upper figures indicate the mean values of each item with its standard deviations and the lower figures, the range (the largest and

Fig. 3. Inst. QRS vector (Frank lead system).

the smallest values). Table I illustrates the planar QRS-T angles and T/QRS ratios of each frontal, horizontal and right sagittal plane projections.

As mentioned before, the QRS-T angle indicates the algebraic difference from the angle of the bisection QRS vector¹³ to that of the T vector. The T/QRS ratios show the ratios of the magnitude of the bisection T and QRS vectors.

Table II to IX illustrate the quantitative analyses of the instantaneous vectors of the QRS complex and the QT interval. Table II and III show scalar amplitude, spatial magnitude and orientation of the instantaneous QRS vectors in the normal group by the FRANK and the TAKAYASU lead systems. Table IV and V illustrate those of the LVH group. Again, for determination of the beginning of the Q wave, the earliest deflection in the three leads was

Fig. 4. Inst. QRS vector (Takayasu lead system).

taken. Scalar amplitude, spatial magnitude and orientation of the instantaneous QT vectors in the normal and LVH groups are shown in tables VI to IX. As mentioned above, the time normalization of each 0.05 second instantaneous vector after the beginning of the Q deflection was carried out by the formula (1).

In table X spatial magnitudes and orientations of the maximal QRS and T vectors with three scalar amplitudes and the maximal QRS-

T angles in space are shown.

DISCUSSION

In the present study of the normal and LVH samples, no particular limitation was placed on age or sex. The ages in both groups ranged from the second to the eighth decade. Great care was taken to exclude persons with diseases such as angina pectoris, myocardial infarction, and other coronary artery diseases, which would

Fig. 5. Inst. T vector (Frank lead system).

make interpretation of ST- and T wave changes difficult.

There have been many investigations of the normal vectorcardiograms^{12, 18, 19, 21-25} to date. Among them, JOUVE⁸, WOLFF²¹, BURCH²², investigated the morphology or pattern of the vectorcardiograms, while PIPBERGER^{23, 24}, SIMONSON²⁶, MORI²⁵ and FORKNER²⁷ quantitated the initial and the terminal QRS vectors in the normal group. But only a few quantitatively

compared the ST- and T vectors in normal^{25, 26, 32} and LVH groups, which the author has attempted in the present study. Morphological, quantitative or statistical studies²⁶⁻⁵⁰ of the vectorcardiograms in LVH have appeared in the literature.

A relatively large number of the investigators have adopted or accepted the FRANK lead system¹², which is one of the corrected orthogonal lead systems that has been accepted in

Fig. 6. Inst. Tvector (Takayasu lead system).

TABLE I PLANAR QRS-T ANGLE AND T/QRS RATIO

		Frank Lead System		Takayasu Lead System	
		Normal	LVH	Normal	LVH
QRS-T ANGLE	(F)	10°03' -21°—+108°	34°24' -171°—+162°	12°18' -126°—+32°	31°36' -100°—+170°
	(H)	53°18' -22°—+108°	69°30' -161°—+165°	48°00' -178°—+103°	67°18' -170°—+169°
	(rS)	34°24' -133°—+92°	53°24' -177°—+102°	57°18' -150°—+159°	93°48' -165°—+170°
T/QRS RATIO	(F)	0.31±0.15	0.25±0.10	0.29±0.13	0.22±0.11
	(H)	0.37±0.12	0.27±0.10	0.35±0.14	0.28±0.16
	(rS)	0.31±0.15	0.29±0.13	0.36±0.14	0.30±0.13

TABLE II QUANTITATIVE ANALYSIS OF QRS VECTORS: TAKAYASU LEAD SYSTEM (NORMAL)

Instantaneous Vectors	Scalar amplitude (mV)			Spatial magnitude and orientation		
	X	Y	Z	Amplitude (mV)	Azimuth (degrees)	Elevation (degrees)
0.01 Sec. after QRS onset	-0.10±0.21	-0.02±0.10	0.21±0.21	0.33±0.23 (0.05—1.09)	106°28'±50°08' (0°00'—173°42')	-1°54'±25°24' (-90°00'—90°00')
0.02 Sec. after QRS onset	0.48±0.52	0.05±0.18	0.50±0.45	0.86±0.50 (0.14—2.74)	49°40'±30°13' (3°12'—130°24')	3°12'±11°24' (-25°36'—30°48')
0.03 Sec. after QRS onset	1.38±0.97	0.47±0.40	0.25±0.81	1.76±0.93 (0.45—5.49)	10°58'±34°13' (357°48'—153°30')	18°12'±16°30' (-15°30'—66°09')
0.04 Sec. after QRS onset	1.06±1.22	0.70±0.55	-0.37±0.92	1.88±0.94 (0.40—5.54)	336°45'±31°27' (351°48'—149°00')	26°36'±19°04' (-16°54'—82°05')
0.05 Sec. after QRS onset	-1.06±0.91	0.42±0.47	-0.96±0.76	1.49±0.74 (0.31—4.29)	271°54'±51°16' (316°06'—93°00')	17°12'±16°54' (-23°24'—69°03')
0.06 Sec. after QRS onset	-0.26±0.63	0.08±0.30	-0.58±0.48	0.84±0.66 (0.10—3.75)	268°03'±66°36' (306°12'—153°00')	6°12'±18°54' (-29°15'—69°54')
0.07 Sec. after QRS onset	-0.01±0.13	0.02±0.15	-0.17±0.28	0.26±0.28 (0.04—1.50)	211°47'±47°03' (294°12'—32°54')	3°48'±30°04' (-70°54'—60°36')
0.08 Sec. after QRS onset	0.01±0.05	0.06±0.06	-0.01±0.11	0.08±0.11 (0.03—0.58)	16°08'±25°54' (281°24'—48°30')	9°36'±32°30' (-90°00'—90°00')

TABLE III QUANTITATIVE ANALYSIS OF QRS VECTORS: FRANK LEAD SYSTEM (NORMAL)

Instantaneous Vectors	Scalar amplitude (mV)			Spatial magnitude and orientation		
	X	Y	Z	Amplitude (mV)	Azimuth (degrees)	Elevation (degrees)
0.01 Sec. after QRS onset	-0.02±0.17	-0.02±0.09	0.11±0.09	0.20±0.14 (0.03—0.88)	104°16'±49°42' (0°00'—180°00')	-4°36'±25°18' (-51°48'—90°00')
0.02 Sec. after QRS onset	0.28±0.31	0.11±0.25	0.21±0.29	0.50±0.36 (0.14—2.40)	41°26'±28°20' (4°03'—117°54')	8°48'±23°12' (-50°30'—78°54')
0.03 Sec. after QRS onset	0.74±0.56	0.55±0.42	0.01±0.48	1.13±0.57 (0.21—3.05)	8°06'±25°48' (356°30'—197°24')	30°12'±19°42' (-28°24'—68°36')
0.04 Sec. after QRS onset	0.45±0.73	0.89±0.67	-0.31±0.51	1.37±0.68 (0.34—3.93)	337°12'±26°14' (351°48'—35°30')	41°18'±21°24' (-28°48'—76°42')
0.05 Sec. after QRS onset	-0.17±0.59	0.48±0.56	-0.44±0.43	0.98±0.58 (0.15—2.90)	269°05'±46°18' (342°18'—21°15')	28°54'±26°42' (-43°18'—66°54')
0.06 Sec. after QRS onset	-0.07±0.34	0.10±0.29	-0.20±0.21	0.44±0.33 (0.03—1.81)	302°09'±50°48' (323°30'—90°00')	12°30'±39°05' (-90°00'—90°00')
0.07 Sec. after QRS onset	0.02±0.11	-0.03±0.38	-0.08±0.19	0.24±0.38 (0.02—1.77)	178°56'±44°12' (307°54'—41°30')	3°06'±44°18' (-90°00'—90°00')
0.08 Sec. after QRS onset	0.01±0.03	0.01±0.06	0.04±0.30	0.11±0.29 (0.02—1.09)	51°13'±26°18' (263°48'—28°30')	11°48'±36°12' (-90°00'—90°00')

TABLE IV QUANTITATIVE ANALYSIS OF QRS VECTORS: TAKAYASU LEAD SYSTEM (LVH)

Instantaneous Vectors	Scalar amplitude (mV)			Spatial magnitude and orientation		
	X	Y	Z	Amplitude (mV)	Azimuth (degrees)	Elevation (degrees)
0.01 Sec. after QRS onset	-0.10 ± 0.23	0.04 ± 0.12	0.19 ± 0.20	0.33 ± 0.22 (0.08—1.14)	$112^\circ 41' \pm 55^\circ 01'$ ($0^\circ 00' - 175^\circ 54'$)	$5^\circ 36' \pm 22^\circ 01'$ ($-90^\circ 00' - 52^\circ 48'$)
0.02 Sec. after QRS onset	0.45 ± 0.62	0.15 ± 0.24	0.58 ± 0.52	0.94 ± 0.63 (0.24—3.29)	$53^\circ 10' \pm 52^\circ 54'$ ($0^\circ 00' - 146^\circ 30'$)	$10^\circ 24' \pm 14^\circ 30'$ ($-22^\circ 18' - 69^\circ 18'$)
0.03 Sec. after QRS onset	1.67 ± 1.38	0.56 ± 0.44	0.30 ± 0.97	2.14 ± 1.29 (0.33—7.20)	$5^\circ 19' \pm 23^\circ 54'$ ($352^\circ 24' - 125^\circ 42'$)	$17^\circ 03' \pm 10^\circ 36'$ ($-8^\circ 42' - 59^\circ 07'$)
0.04 Sec. after QRS onset	1.98 ± 1.98	0.84 ± 0.73	-0.74 ± 1.28	2.88 ± 1.72 (0.48—9.92)	$327^\circ 20' \pm 40^\circ 48'$ ($355^\circ 06' - 94^\circ 30'$)	$18^\circ 06' \pm 16^\circ 42'$ ($-31^\circ 54' - 79^\circ 03'$)
0.05 Sec. after QRS onset	0.25 ± 1.65	0.49 ± 0.65	-0.87 ± 0.95	2.21 ± 1.64 (0.19—10.19)	$283^\circ 37' \pm 56^\circ 54'$ ($323^\circ 05' - 30^\circ 13'$)	$11^\circ 54' \pm 20^\circ 24'$ ($-66^\circ 24' - 64^\circ 42'$)
0.06 Sec. after QRS onset	-0.43 ± 0.93	-0.01 ± 0.36	-0.89 ± 0.95	1.27 ± 1.12 (0.03—4.65)	$263^\circ 38' \pm 66^\circ 18'$ ($319^\circ 12' - 171^\circ 12'$)	$-0^\circ 03' \pm 26^\circ 36'$ ($-90^\circ 00' - 64^\circ 18'$)
0.07 Sec. after QRS onset	-0.11 ± 0.36	-0.04 ± 0.24	-0.36 ± 0.55	0.53 ± 0.60 (0.03—3.18)	$215^\circ 28' \pm 51^\circ 10'$ ($296^\circ 30' - 33^\circ 48'$)	$-2^\circ 18' \pm 30^\circ 30'$ ($-77^\circ 00' - 64^\circ 48'$)
0.08 Sec. after QRS onset	-0.01 ± 0.15	-0.01 ± 0.14	-0.55 ± 0.20	0.21 ± 0.21 (0.03—1.31)	$4^\circ 14' \pm 42^\circ 24'$ ($286^\circ 54' - 50^\circ 54'$)	$2^\circ 12' \pm 30^\circ 42'$ ($-79^\circ 30' - 66^\circ 36'$)

TABLE V QUANTITATIVE ANALYSIS OF QRS VECTORS: FRANK LEAD SYSTEM (LVH)

Instantaneous Vectors	Scalar amplitude (mV)			Spatial magnitude and orientation		
	X	Y	Z	Amplitude (mV)	Azimuth (degrees)	Elevation (degrees)
0.01 Sec. after QRS onset	-0.06 ± 0.17	0.01 ± 0.12	0.09 ± 0.11	0.20 ± 0.17 (0.02—0.94)	$100^\circ 48' \pm 56^\circ 30'$ ($0^\circ 00' - 180^\circ 00'$)	$0^\circ 48' \pm 30^\circ 48'$ ($-90^\circ 00' - 84^\circ 03'$)
0.02 Sec. after QRS onset	0.21 ± 0.31	0.10 ± 0.21	0.23 ± 0.31	0.49 ± 0.33 (0.09—1.76)	$48^\circ 57' \pm 56^\circ 18'$ ($0^\circ 00' - 113^\circ 42'$)	$14^\circ 12' \pm 22^\circ 54'$ ($-29^\circ 30' - 90^\circ 00'$)
0.03 Sec. after QRS onset	0.85 ± 0.67	0.58 ± 0.43	0.30 ± 0.48	1.23 ± 0.66 (0.23—3.42)	$4^\circ 46' \pm 33^\circ 10'$ ($356^\circ 54' - 180^\circ 00'$)	$28^\circ 36' \pm 15^\circ 24'$ ($-10^\circ 30' - 59^\circ 48'$)
0.04 Sec. after QRS onset	1.01 ± 1.01	1.06 ± 0.80	-0.46 ± 0.78	1.87 ± 1.07 (0.48—5.64)	$321^\circ 47' \pm 27^\circ 23'$ ($355^\circ 48' - 60^\circ 08'$)	$37^\circ 54' \pm 21^\circ 24'$ ($-49^\circ 06' - 71^\circ 30'$)
0.05 Sec. after QRS onset	0.07 ± 1.09	0.76 ± 0.87	-0.52 ± 0.79	1.50 ± 1.08 (0.26—7.23)	$280^\circ 16' \pm 43^\circ 03'$ ($350^\circ 04' - 285^\circ 30'$)	$26^\circ 18' \pm 29^\circ 06'$ ($-70^\circ 18' - 71^\circ 18'$)
0.06 Sec. after QRS onset	-0.29 ± 0.56	0.17 ± 0.47	-0.31 ± 0.47	0.75 ± 0.64 (0.06—3.87)	$290^\circ 47' \pm 54^\circ 54'$ ($319^\circ 18' - 60^\circ 48'$)	$7^\circ 36' \pm 32^\circ 24'$ ($-65^\circ 48' - 66^\circ 30'$)
0.07 Sec. after QRS onset	-0.11 ± 0.43	-0.01 ± 0.24	-0.07 ± 0.20	0.33 ± 0.43 (0.03—3.23)	$218^\circ 20' \pm 48^\circ 15'$ ($309^\circ 18' - 270^\circ 00'$)	$3^\circ 36' \pm 39^\circ 30'$ ($-81^\circ 42' - 64^\circ 54'$)
0.08 Sec. after QRS onset	-0.01 ± 0.09	-0.01 ± 0.13	0.02 ± 0.09	0.14 ± 0.12 (0.01—0.76)	$81^\circ 30' \pm 36^\circ 45'$ ($255^\circ 42' - 180^\circ 00'$)	$6^\circ 18' \pm 48^\circ 04'$ ($-90^\circ 00' - 90^\circ 00'$)

TABLE VI QUANTITATIVE ANALYSIS OF QTc VECTORS: TAKAYASU LEAD SYSTEM (NORMAL)

Instantaneous Vectors	Scalar amplitude (mV)			Spatial magnitude and orientation		
	X	Y	Z	Amplitude (mV)	Azimuth (degrees)	Elevation (degrees)
0.20 Sec. after QRS onset	0.10 ± 0.09	0.03 ± 0.04	0.17 ± 0.12	0.22 ± 0.13 (0.03—0.67)	$58^\circ 00' \pm 42^\circ 36'$ ($0^\circ 00' - 90^\circ 00'$)	$9^\circ 06' \pm 14^\circ 48'$ ($-48^\circ 06' - 64^\circ 05'$)
0.25 Sec. after QRS onset	0.23 ± 0.15	0.09 ± 0.08	0.25 ± 0.20	0.39 ± 0.22 (0.05—1.14)	$45^\circ 07' \pm 34^\circ 18'$ ($354^\circ 54' - 80^\circ 18'$)	$13^\circ 30' \pm 14^\circ 12'$ ($-44^\circ 18' - 58^\circ 54'$)
0.30 Sec. after QRS onset	0.38 ± 0.26	0.19 ± 0.14	0.27 ± 0.26	0.56 ± 0.71 (0.07—1.67)	$32^\circ 48' \pm 30^\circ 06'$ ($342^\circ 06' - 120^\circ 54'$)	$20^\circ 54' \pm 12^\circ 54'$ ($-11^\circ 54' - 65^\circ 18'$)
0.35 Sec. after QRS onset	0.23 ± 0.20	0.15 ± 0.12	0.13 ± 0.17	0.36 ± 0.23 (0.02—0.83)	$31^\circ 49' \pm 26^\circ 22'$ ($313^\circ 12' - 118^\circ 18'$)	$30^\circ 48' \pm 18^\circ 36'$ ($-7^\circ 36' - 90^\circ 00'$)
0.40 Sec. after QRS onset	0.03 ± 0.05	0.03 ± 0.03	0.02 ± 0.05	0.07 ± 0.06 (0.01—0.27)	$30^\circ 37' \pm 29^\circ 04'$ ($316^\circ 30' - 180^\circ 00'$)	$24^\circ 00' \pm 26^\circ 48'$ ($0^\circ 00' - 90^\circ 00'$)

recent years in many laboratories because of its accuracy and practical usefulness. In this series the FRANK and the TAKAYASU lead systems were used and compared with each other. The TAKAYASU lead system^{14-17,51,52} is also one of the "ideal" corrected orthogonal lead systems and this system, "Vectorial Lead"¹⁴, was devised by TAKAYASU and his associates in 1955, grounded on the most excellent theories of

"Lead Vector" by BURGER and VAN MILAAN¹⁰ and of "Lead Field" by MCFEE and JOHNSTON.¹¹ The electrode system for "Vectorial Lead" consists of four large silver plates, which are placed at front and back (15 × 12 cm each), left and right (15 × 9 cm each) of the chest to cover the projection of the cardiac silhouette sufficiently. Front and back electrodes (silver plates) are for Z lead, and those of left and right for X lead.

TABLE VII QUANTITATIVE ANALYSIS OF QTc VECTORS: FRANK LEAD SYSTEM (NORMAL)

Instantaneous Vectors	Scalar amplitude (mV)			Spatial magnitude and orientation		
	X	Y	Z	Amplitude (mV)	Azimuth (degrees)	Elevation (degrees)
0.20 Sec. after QRS onset	0.05 ± 0.06	0.06 ± 0.06	0.07 ± 0.07	0.13 ± 0.09 (0.02—0.39)	54°52' ± 31°02' (0°00'—137°12')	29°06' ± 25°24' (-57°42'—90°00')
0.25 Sec. after QRS onset	0.12 ± 0.09	0.14 ± 0.11	0.10 ± 0.11	0.27 ± 0.15 (0.04—0.58)	40°37' ± 23°36' (357°01'—96°18')	37°02' ± 20°30' (-30°18'—73°02')
0.30 Sec. after QRS onset	0.17 ± 0.15	0.26 ± 0.15	0.08 ± 0.14	0.36 ± 0.21 (0.07—1.32)	30°13' ± 21°42' (350°18'—180°00')	48°30' ± 18°36' (-13°18'—73°54')
0.35 Sec. after QRS onset	0.10 ± 0.11	0.21 ± 0.15	0.04 ± 0.10	0.24 ± 0.17 (0.02—0.41)	24°49' ± 20°24' (347°18'—180°00')	57°24' ± 21°12' (10°09'—90°00')
0.40 Sec. after QRS onset	0.01 ± 0.05	0.06 ± 0.08	0.01 ± 0.03	0.09 ± 0.08 (0.01—0.38)	29°15' ± 23°18' (309°03'—225°24')	45°00' ± 40°04' (-90°00'—90°00')

TABLE VIII QUANTITATIVE ANALYSIS OF QTc VECTORS: TAKAYASU LEAD SYSTEM (LVH)

Instantaneous Vectors	Scalar amplitude (mV)			Spatial magnitude and orientation		
	X	Y	Z	Amplitude (mV)	Azimuth (degrees)	Elevation (degrees)
0.20 Sec. after QRS onset	0.07 ± 0.17	0.03 ± 0.06	0.22 ± 0.15	0.29 ± 0.17 (0.04—0.66)	65°28' ± 58°42' (2°54'—149°42')	6°18' ± 11°24' (-21°24'—33°06')
0.25 Sec. after QRS onset	0.18 ± 0.23	0.09 ± 0.15	0.30 ± 0.20	0.43 ± 0.25 (0.08—1.33)	54°15' ± 52°50' (5°48'—138°42')	9°18' ± 11°54' (-29°30'—48°18')
0.30 Sec. after QRS onset	0.29 ± 0.32	0.15 ± 0.17	0.31 ± 0.37	0.58 ± 0.30 (0.13—1.36)	39°32' ± 44°04' (352°30'—113°11')	14°42' ± 15°36' (-60°36'—62°48')
0.35 Sec. after QRS onset	0.23 ± 0.30	0.13 ± 0.23	0.19 ± 0.36	0.49 ± 0.38 (0.09—1.84)	27°40' ± 42°18' (345°18'—282°42')	19°12' ± 19°24' (-64°48'—48°54')
0.40 Sec. after QRS onset	0.07 ± 0.12	0.05 ± 0.09	0.07 ± 0.21	0.19 ± 0.21 (0.02—1.31)	28°08' ± 40°01' (324°36'—180°02')	19°12' ± 25°48' (-63°18'—90°00')

TABLE IX QUANTITATIVE ANALYSIS OF QTc VECTORS: FRANK LEAD SYSTEM (LVH)

Instantaneous Vectors	Scalar amplitude (mV)			Spatial magnitude and orientation		
	X	Y	Z	Amplitude (mV)	Azimuth (degrees)	Elevation (degrees)
0.20 Sec. after QRS onset	0.05 ± 0.09	0.05 ± 0.07	0.09 ± 0.07	0.15 ± 0.10 (0.02—0.47)	65°09' ± 43°10' (0°00'—134°30')	21°54' ± 29°06' (-48°09'—90°00')
0.25 Sec. after QRS onset	0.05 ± 0.15	0.12 ± 0.12	0.12 ± 0.08	0.24 ± 0.12 (0.03—0.83)	58°45' ± 39°42' (0°00'—127°12')	27°54' ± 27°06' (-66°54'—67°48')
0.30 Sec. after QRS onset	0.15 ± 0.20	0.22 ± 0.20	0.13 ± 0.11	0.37 ± 0.23 (0.03—1.31)	47°08' ± 26°48' (352°42'—136°36')	37°24' ± 27°36' (-66°54'—71°18')
0.35 Sec. after QRS onset	0.11 ± 0.19	0.18 ± 0.24	0.08 ± 0.10	0.32 ± 0.25 (0.03—1.46)	40°49' ± 31°24' (348°24'—127°12')	41°24' ± 36°06' (-90°00'—80°54')
0.40 Sec. after QRS onset	0.03 ± 0.12	0.06 ± 0.12	0.03 ± 0.06	0.13 ± 0.14 (0.01—0.74)	33°45' ± 28°18' (332°54'—104°48')	42°48' ± 42°26' (-90°00'—90°00')

To make close contact of the electrode plates to the skin, cotton mats of the same size with each electrode, dipped in saline solution, are inserted between the skin and the electrodes. The electrodes and mats are kept in place with elastic rubber belts around the chest. The electrode of aVF is used as Y lead.

KATO^{17,51} has measured the lead field of this system for spatial vectorcardiogram with two dimensional models and made lead field maps of each axis on three planes, by which it was demonstrated that the lead field through the heart with this system was presumably similar to that of the ideal orthogonal lead system. Recently, TATEISHI and KATO, including the author⁵², confirmed the superiority of the TAKAYASU lead system as one of the orthogonal lead systems, using the plastic human "torso" mo-

dels in three dimensions.

The QRS-T angles in planes and in space have been investigated^{31, 51, 53, 58, 59} as one of the parameters of cardiac vectors in the de- and repolarization phases. In the present study, as mentioned before, the bisection QRS and T vectors¹³ have been substituted for the mean QRS and T vectors. The QRS-T angles in the normal group in three projections are smaller than that of the LVH group, agreeing in general with the results of electrocardiographers^{5, 53, 54}. The ranges of the angles are relatively narrower in the frontal plane, while those in the horizontal and right sagittal planes are widely scattered. No remarkable difference in the results between the two lead systems was noticed. As to the T/QRS ratios in the present series, i.e. the ratios of the planar magnitudes of bisection

TABLE X SCALAR AMPLITUDE, SPATIAL MAGNITUDE AND ORIENTATION AND SPATIAL QRS-T ANGLE OF MAXIMAL QRS AND T VECTORS

FRANK LEAD SYSTEM						
	Scalar amplitude (mV)			Spatial magnitude and orientation		
	X	Y	Z	Amplitude (mV)	Azimuth (degrees)	Elevation (degrees)
§ QRS Vector						
(Normal)	0.62±0.82	0.90±0.74	−0.30±0.60	1.57±0.63	343°41'±26°20'	35°24'±25°24'
(LVH)	0.91±1.29	1.12±0.88	−0.38±0.97	2.08±1.13	330°10'±28°30'	35°06'±19°54'
§ T Vector						
(Normal)	0.19±0.15	0.26±0.16	0.09±0.18	0.38±0.22	26°40'±20°24'	45°30'±18°24'
(LVH)	0.16±0.21	0.19±0.20	0.10±0.15	0.35±0.26	31°22'±26°20'	29°48'±28°48'
§ QRS–T Angle						
(Normal)	47°21'±37°49'					
(LVH)	52°50'±44°31'					
TAKAYASU LEAD SYSTEM						
	Scalar amplitude (mV)			Spatial magnitude and orientation		
	X	Y	Z	Amplitude (mV)	Azimuth (degrees)	Elevation (degrees)
§ QRS Vector						
(Normal)	1.50±1.30	0.63±0.54	−0.20±1.19	2.28±0.95	347°25'±30°27'	19°05'±15°06'
(LVH)	1.99±2.13	0.79±0.65	−0.52±1.18	3.22±1.66	342°27'±40°20'	15°54'±14°48'
§ T Vector						
(Normal)	0.37±0.22	0.17±0.13	0.27±0.26	0.55±0.27	33°30'±30°24'	19°42'±12°30'
(LVH)	0.28±0.36	0.16±0.19	0.29±0.33	0.57±0.38	40°12'±43°10'	13°12'±11°30'
§ QRS–T Angle						
(Normal)	51°14'±39°22'					
(LVH)	63°45'±47°17'					

T and QRS vectors, the mean values of each plane of the normals are larger than those of the LVHs with narrower standard deviations. Most investigators^{53, 54, 68} have adopted the ratio of QRS/T, the reciprocal to that of the author. But the significance of the two ratios is essentially the same. In a sense, these ratios show the extent of the abnormal changes of the T and the QRS loops, and, in addition, they serve as keen parameters of the changes of the T loops. As to other parameters in the study of T loops morphologically, the ratio of the maximal length and width has been used^{62, 68}. KARNI^{60, 62} has investigated the morphology of the T loop in various diseases, i.e. in hypercholesterolemias, in myocardial lesions and in left ventricular hypertrophy of minor degrees, and he described in detail the factors changing the shape of the T loop⁶². TOYAMA^{82, 83}, SANO³⁵, MIZUNO⁵⁵, and MORI⁵⁴ carried out studies of T loops in different ways. That the shapes of T loops are changed to circular or oval in ventricular hypertrophy, myocardial lesions and in hypercholesterolemia is a well known fact. For the spatial vectorcardiogram in LVH, HORAN and BURCH³⁷ described the typical QRS and T loops in detail.

As mentioned above, in Tables II to V are illustrated the scalar amplitudes of the three orthogonal leads and the spatial magnitudes and orientations (azimuth and elevation) of eight instantaneous QRS vectors. Recently PIPBERGER³² quantitated the instantaneous QRS vectors, dividing the QRS complexes into eight equal parts for time normalization. In the present series, eight instantaneous QRS vectors were determined at fixed time intervals of 0.01 sec after the onset of the earliest QRS complexes of the three, which is the usual method employed by other investigators.

(A) QUANTITATIVE ANALYSIS OF QRS VECTORS

In the following the characteristics of the spread of depolarization with the time course in the normal and LVH groups are outlined and compared in each group.

1) 0.01-second ventricular activation (VA) vector:

(The normal and LVH groups by the FRANK and the TAKAYASU lead systems are abbreviated as groups FN and FL and groups TN and TL

respectively)

The 0.01 sec vector in the group FL tends to be directed somewhat more inferiorly and anteriorly in space than that of group FN, but no remarkable difference is noticed between the two groups. The 0.01 sec VA vector is regarded as the "septal VA vector", i.e. representing the septal depolarization of the phase, and is directed anteriorly also to the right in the normal. While in LVH, the vector is usually normal in direction and in magnitude, but it occasionally tends to be directed more anteriorly, inferiorly and to the right, just like in the present data. The behavior of the instantaneous vector in groups TL and TN is almost the same in that of FL and FN respectively, except for larger amplitude or magnitude in the TL and TN groups.

2) 0.02-second VA vector:

In the two lead systems the 0.02 sec vector is oriented more anteriorly, to the left and to some extent inferiorly in the normal, and in LVH it tends still more to the right and inferiorly. In this phase, the activation wave passes through the lower two thirds of the septum and to the apex-to-base. In the normal, the electrical forces by the activation is directed to the left and right of the long axis of the heart. Because of the preponderancy of the left ventricular forces than that of the right, it is directed anteriorly or to the left (in the present not so remarkable) and inferiorly. In LVH, the 0.02 sec vector, the apico-anterior vector, is larger than normal in magnitude as in this series, and is oriented in a more anterior, to the right or occasionally inferior direction in some exaggerated cases.

3) 0.03-second VA vector:

A very important observation in the present series is the magnitude of the values of the amplitudes in this phase of the groups FN and TN (normal groups) which are next largest to those of the 0.04 sec vector (nearly max. vector), whereas in the groups FL and TL (LVH groups), the 0.05 sec vectors are the next largest in magnitude to those of the 0.04 sec vector. The direction of the vector at 0.03 second is more left and posteriorly and slightly inferiorly in the normal and much more posteriorly and superiorly, also to the left, in LVH as compared

to the normal.

4) 0.04-second VA vector:

As shown in Table II to V, mean values of the spatial amplitudes in all groups (FL, FN, TL and TN) are the largest in this instant and those of the LVH are larger than the normal in the two systems. The direction of the vector tends to the left, posteriorly and somewhat inferiorly in the normal as shown in the Tables. In LVH, the vector is greater in amplitude than in the normal and is directed more posteriorly and superiorly and also to the left. (Table IV, V). The 0.04 sec vector is considered as the reflection of the activation process of the entire left ventricle. It spreads through the thick lateral wall of the left ventricle and thus results in the electrical forces of the largest magnitude, showing the most evident component of the left ventricle.

5) 0.05-second VA vector:

It was indicated in this study that the vectors of 0.05 second were again important or significant for differentiation of the normal from the LVH. The magnitudes of 0.05 sec vectors in the groups FL and TL (LVH) are again next largest in value, contrary to the relation in groups FN and TN (normal), and this is probably due to the delay in the depolarization phase in LVH than in the normal. The 0.05 sec vector in the present series takes a much more posterior and superior than the preceding vector in the normal. In LVH, the tendency is more marked and some of the cases in the LVH group showed the largest values in magnitude in this phase.

6) 0.06-second VA vector:

The magnitude of the vector in the normal decreases rapidly after 0.04 second, while in LVH, the value of the amplitude still remains relatively large. As shown in the Table, the vector of 0.06 second is directed to the left and superiorly, also more posteriorly than in the preceding vectors in the normal. In LVH, due to the prolonged ventricular activation process, the 0.06 sec VA vector is directed more posteriorly and superiorly than in the normal. The vector in this instant during the ventricular activation process is produced mainly by the activation of the thick posterolateral and basal wall of the left ventricle and is referred to as

“terminal” or “basal” VA vector.

7) 0.07- and 0.08-second VA vectors:

In the normal some of these vectors disappear, especially the latter one. This is because depolarization is almost completed and some of them begin to enter the repolarization phase. While in LVH, the interval of the left ventricle, especially in the portion of the base, is prolonged to 0.12 second occasionally. The direction of the vector scatters to a large extent and the amplitude of the vector in the normal is almost diminished, while that of the LVH continues to show relatively large values. The above mentioned process of the ventricular activation has been studied and investigated experimentally or clinically by many electrocardiographers⁶⁴⁻⁶⁷, but it is still a controversial subject. Since the investigations by LEWIS and ROTH-SCHILD⁵³ in 1915, septal activation has been thought to begin on the left side of the septum, and to spread as a double wave of envelopment from above downward and from without inward. Recently, SODI-PALLARES and his associates^{65,66}, BURCHELL and his associates⁶⁷ investigated this field and modified the concept of the ventricular activation. SODI-PALLARES and his associates examined and studied the spread of the ventricular activation experimentally, i.e. examined the excitatory process in detail of the septum and ventricle of the dog's heart under LANGENDORF's perfusion, and they described the spread of activation in the subendocardial muscle mass, and at least one-half of the thickness of the adjacent free ventricular wall reached values of 2000 or more mm per second.

TOYOSHIMA and co-workers determined the pattern of the QRS deflection by the propagation process of the ventricular activation, applying their unique “reconstruction” method in electrocardiograms and in vectorcardiograms in various diseases⁶⁹⁻⁷⁶. Accordingly, the generally accepted concept of the ventricular activation is that in the depolarization process of the septum and ventricular myocardium, the electrical forces change their directions and magnitudes in every instant and these are schematized in terms of a series of hypothetical “instantaneous cardiac vectors” or ventricular activation vectors⁴⁷ (VA vectors), the term commonly used by many electrocardiographers.

Concerning the instantaneous vectors of QRS loop in left ventricular hypertrophy, MAZZOLENI⁴⁰, SCOTT⁴⁴ described that the 0.03 second and maximal QRS vectors were affected in a particular orientation—toward a more posterior, superior and leftward direction and, in addition, also in LVH, marked increases in magnitude of these vectors have been pointed out by BRISTOW⁴¹. They concluded that the deviation of the vectors was due to the increase of free wall of the left ventricle and that it affected the late phase of QRS loops. As hypertrophy and the mass of muscle situated to the left and posteriorly increases, the distal portion of the QRSsE loop is directed upward and posteriorly³⁷. Recently the instantaneous vectors have been used in the diagnoses of various diseases, especially in myocardial infarction and ventricular hypertrophy, with greater accuracy. HUGENHOLTZ⁴⁵ described recently in antero-septal and anterolateral wall infarction that the 0.01- and 0.02 sec QRS vectors in the projections on the horizontal and left sagittal planes were displaced significantly posteriorly in relation to their orientation in normal individuals. The direction of the 0.03-sec and maximum QRS vectors showed less significant variation from the normal. The reliability of these criteria in the diagnosis was confirmed in a series of autopsied patients. While in left ventricular hypertrophy, the mass of muscle of the free left ventricular wall results in the displacement of the spatial QRS loop in a posterior, superior and leftward direction^{40, 44}. Recently HUGENHOLTZ⁴⁹ and his associates have examined the 0.030-, 0.035-sec and the maximal QRS vectors on the horizontal plane in relation to left ventricular hypertrophy. They concluded that a significant difference was found in the direction of the above-mentioned QRS vectors in the horizontal plane in almost all patients with aortic stenosis. Further study by HUGENHOLTZ and his associates⁴⁵ revealed that the direction of the 0.02 second QRS vector allowed the separation of the infarction group from the left ventricular hypertrophy group and the normal whereas the direction of the 0.03 second and maximum QRS vectors separated left ventricular hypertrophy from the normal. They also commented that the magnitude of the maximum

QRS vector was another highly reliable indicator of left ventricular hypertrophy and that it also served in separation of this group from those with associated anterior wall infarction. In the results obtained by the author the differences between the normal and the left ventricular hypertrophy groups in the magnitude and the direction of the three vectors, 0.03, 0.04 and 0.05 sec QRS vectors, in space are worthy of note. In the normal group the spatial magnitude of the 0.03 sec QRS vector (the instantaneous vector preceding the 0.04 sec QRS vector) is larger than that of the 0.05 second QRS vector (the instantaneous vector following the 0.04 sec QRS vector); on the other hand, in the LVH group the relation is reversed, that is, the 0.05 sec QRS vector is larger than that of the 0.03 sec QRS vector. Regarding the orientation (azimuth and elevation) of the above-mentioned vectors in the recorded series (before and after the 0.04 sec QRS vector) a noteworthy observation was the delay in the change of the 0.03 sec QRS vector in a more posterior, superior and to the left direction and the rapid turning of the 0.05 sec QRS vector posteriorly and inferiorly in the normal group, whereas, on the contrary, the 0.03 sec QRS vector turns relatively quickly posteriorly, inferiorly and to the left and the 0.05 sec QRS vector is slow in turning posteriorly and inferiorly, keeping its direction to the left in the LVH group. These observations could be considered as the reflection of the increase of muscular wall of the left ventricle or could be attributed to the retardation of the QRS complexes in left ventricular hypertrophy.

(B) QUANTITATIVE ANALYSIS OF QTC VECTOR

One of the main purposes of the present study was the attempt to find the presence of some distinctive point also in the repolarization phase as in the depolarization phase. As mentioned before, for the analysis of the T loop, it is difficult to determine the beginning of the T wave precisely on the orthogonal scalar leads, so the author measured the time from the beginning of the Q wave at intervals of 0.05 second (from 0.20 to 0.40 sec), corrected by the formula of TAKAHASHI²⁰. Thus five instantaneous QTC vectors were determined. In Table VI to IX,

the scalar amplitudes and the spatial magnitudes and orientation in the normal and LVH are illustrated.

1) 0.20-second QTc vector:

The vector at this instant in the LVH group is directed more anteriorly and superiorly with larger magnitude than in the normal. The 0.20 sec QTc vector is the reflection of the end of the ST-segment or the gradual beginning of the T wave on the orthogonal scalar lead.

2) 0.25-second QTc vector:

The vector of 0.25 second in the LVH group still remains directed anteriorly and superiorly, while in the normal, it is oriented more leftwards and inferiorly. A similar relation as in the QRS vectors was shown by the QTc vectors, i. e. in the series of 0.25, 0.30 and 0.35 sec QTc vectors, (the largest one is 0.30 sec QTc vector), the 0.25 sec QTc vector is next largest in amplitude in the normal, while in the LVH, the 0.35 sec QTc vector is the next largest one.

3) 0.30-second QTc vector;

The vector at this instant showed the largest amplitude and the behaviour of the preceding and the next vectors (0.25 and 0.35 sec QTc vectors) resembles that of the QRS vectors as mentioned before. The 0.30 sec QTc vector in the present series may correspond to the 5/8 (ST-T) vector demonstrated by PIPBERGER and his associates³².

4) 0.35-second QTc vector:

The amplitude of the vector at this instant of the normal diminishes relatively swiftly, while that of the LVH still shows larger mean values. It is directed most inferiorly in the normal, and in the LVH it is close to the next vector, more superiorly than in the normal.

5) 0.40-second QTc vector:

At this instant, the vectors in the normal almost finish repolarization, resulting in a marked decrease in amplitude. While in the LVH, the amplitude is 0.10 to 0.15 mV larger in mean value than in the normal, showing retardation also in the repolarization phase.

In 1957, PRINZMETAL and his associates proved the existence of time difference of repolarization potentials experimentally; the direction of repolarization is the reverse of that of depolarization. KOSSMANN and his associates⁷⁸ observed that the electrical energy expended during de-

polarization was equal to that used by repolarization, and this means that the area of de- and repolarization multiplied by the respective times are equal. When there is a retardation of repolarization potentials from certain parts of the myocardium, a phase difference will occur, causing a corresponding increase in the breadth of the TsE loop and its long axis decreases simultaneously, as stated by KARNI⁶², and he concluded that the phase difference was caused by the time delay of the repolarization potential in myocardial hypertrophy. Examination of repolarization is the best method for estimation of the conduction of the heart muscle and should be applied in the diagnosis of left ventricular hypertrophy. In the present study, at least, the 0.30 sec QTc vector is the most significant one in the series of the instantaneous vectors. Other investigations about the morphology of the T loops include those of MIZUNO and his co-workers who examined the spatial magnitude and orientation in normal⁵⁵ and hypertensive⁵⁷ individuals. Quantitative analytic studies of the T loop are relatively few and investigation of the propagation wave of repolarization is just as important as that of depolarization. By employing the instantaneous vectors for analysis of the time course, more accurate data will be obtained in the repolarization phase, for persuing the mechanisms of the process of this phase.

In Table X scalar amplitude, spatial magnitude and orientation and the QRS-T angle of spatial maximal QRS and T vectors are illustrated. As for the maximal QRS and T vectors in space, the results mostly coincide with the 0.04 second QRS vectors in depolarization and the 0.30 second QTc vectors in repolarization phases. For investigation of the QRS-T angles in the plane projections and in space, various studies have been reported. HELM and his co-workers have published a formula for the calculation of the angle between two spatial vectors⁷⁹, and they also made a table for the calculation of the angle⁸⁰ for practical use. In 1958, PIPBERGER and his associates³⁴ described and designed the usefulness and applicability of the spatial QRS-T angle. BRISTOW²⁸ also has shown that the angles of the half area vectors gave better measurements than the maximal QRS-T

angles as PIPBERGER suggested⁸¹. As to the results of the maximal QRS-T angles in the present series, the widening of the angle in the left ventricular hypertrophy group is apparent as compared to the others⁴¹. In the present series, the planer and spatial QRS-T angles of the LVH are widened significantly than in the normal.

Comparing the two "corrected orthogonal" lead systems (FRANK and TAKAYASU), no remarkable difference was noticed in orientation (azimuth and elevation) in the series of the instantaneous vector in space. But, in magnitude it differed much, i.e. the magnitude in the TAKAYASU lead system was about twice as large as those in the FRANK, and this has been advantageous for analyzing the smaller loops, e.g. P, T or U and the zero point of the vectorcardiogram.

SUMMARY

Using the FRANK and the TAKAYASU lead systems, 102 clinically and electrocardiographically normal subjects and 105 subjects with left ventricular hypertrophy were each quantitated in a series of thirteen instantaneous vectors, both in the depolarization and the repolarization phases. Eight instantaneous vectors were determined at time intervals of 0.01 second from the beginning of the QRS complex. While in the QTc vectors, five instantaneous vectors were fixed at time intervals of 0.05 second from the beginning of the Q wave and normalized in time by the formula of TAKAHASHI²⁰.

Significant observations in this study were as follows:

(1) Both planer and spatial QRS-T angles in left ventricular hypertrophy had wider or larger mean values than in the normal. The T/QRS ratio in the LVH group was significantly smaller than in the normal.

(2) In spatial amplitude and orientation in the depolarization phase in the present series, the 0.04 sec QRS vector served to separate the normal from left ventricular hypertrophy by comparing the vectors preceding and following this prominent vector (0.04 sec QRS vector).

(3) Also in the repolarization phase, the 0.30 sec QTc vector served to separate the normal from the LVH, by comparing the preceding

and the following vectors of the 0.30 QTc vector.

(4) Between the two orthogonal lead systems, the FRANK and the TAKAYASU, there was no remarkable difference in the spatial orientation (azimuth and elevation) in the series of the instantaneous vectors. But, in magnitude, the latter lead system showed larger values, and this was advantageous for analyzing the smaller loops and the zero point of the vectorcardiogram.

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REFERENCES

1. SCHELLONG, F.: Elektrokardiographische Diagnostik der Herzmuskelerkrankungen. *Vehr. dtsh. ges. inn. Med.* **48**: 288, 1936.
2. SCHELLONG, F.: Vektorkardiographie des Herzens als klinische Methode. *Klin. Wschr.* **17**: 453, 1938.
3. KIMURA, N.: *Nippon Jour. of Clinical Angiocardiology* **8**: 125, 1942.
4. DUCHOSAL, P. W. SULZER, R.: "La Vectorcardiographie" Basel, Switzerland, Karger 1949.
5. GRISHMAN, A.: Spatial vectorcardiography: Technique for the simultaneous recording of the frontal, sagittal and horizontal projection I. *Am. Heart J.* **41**: 483, 1951.
6. MILNOR, W. R., TALBOT, S. A. AND NEWMAN, E. V.: A study of the relationship between unipolar leads and spatial vectorcardiograms, using the panoramic vectorcardiograph. *Circulation* **7**: 545, 1953.
7. MILOVANOVICH, J. B. et al.: Etudes pratiques de VCG. L'Expansion Scientifique Francaise, 1950.
8. JOUVE, A. et al.: La Vectorcardiographie en Clinique, Masson et Cie, Paris, 1950.
9. WILSON, F. N., JOHNSTON, F. D. AND KOSSMANN, C. E.: The substitution of a tetrahedron for the Einthoven triangle: *Am. Heart J.* **33**: 594, 1947.
10. BURGER, H. C. AND VAN MILAAN, J. B.: Heart vector and leads, I. *Brit. Heart J.* **8**: 157, 1946.
11. MCFEE, R., AND JOHNSTON, F. D.: Electrocardiographic leads; I. *Circulation* **8**: 554, 1953; II. *Circulation* **9**: 255, 1954; III. *Circulation* **9**: 868, 1954.
12. FRANK, E.: An accurate clinically practical system for spatial vectorcardiography, *Circulation* **13**: 737, 1956.
13. HATTORI, K.: Study on orthogonal VCG, using unipolar lead II. *Jap. Circul. J.* **27**: 641, 1963.
14. TAKAYASU, M., SUGAWARA, T. AND YANO, A.: *J. Jap. Soc. Int. Med.* **44**: 77, 1955 (in Japanese)
15. TAKAYASU, M., SUGAWARA, T. AND YANO, A.: Sai-

- shin-Igaku* **II**: 901, 1956.
16. TAKAYASU, M., SUGAWARA, T. AND YANO, A.: Clinical studies on the vectorial lead of the electrocardiogram. *Mie Med. J.* **8**: 1, 1958.
 17. TAKAYASU, M., KATO, S. AND INOUE, Y.: An ideal orthogonal lead system for spatial vectorcardiography, Preliminary analysis by the concept of "Lead Field." *Mie Med. J.* **8**: 373, 1958.
 18. WILSON, F. N., KOSSMAN, C. E., BURCH, G. E. AND COLDBERGER, E.: Recommendations for Standardization of electrocardiographic and vectorcardiographic Leads. *Circulation* **10**: 564, 1954.
 19. PIPBERGER, H. V.: Evaluation of quantitative methods for obtaining mean spatial QRS vectors. *Circulation* **16**: 926, 1957.
 20. TAKAHASHI, J.: On the relation between the production and the conduction of the impulse in the heart. *Acta School. Med. Univ. Imp. Kioto* **10**: 189, 1927.
 21. BURCH, G. E., ABILDSKOV, J. A. AND CRONVICH, M. S.: Studies of the Spatial Vectocardiogram in Normal Man. *Circulation* **7**: 558, 1953.
 22. YOUNG, E. et al.: The Normal Vectorcardiogram I; *Am. Heart J.* **51**: 713, 1956.
 23. PIPBERGER, H. V.: The normal orthogonal electrocardiogram and vectorcardiogram with a critique of some commonly used analytic criteria. *Circulation* **17**: 1102, 1958.
 24. MILNOR, W. R.: The normal vectorcardiogram and a system for the classification of vectorcardiographic abnormalities. *Circulation* **16**: 95, 1957.
 25. SIMONSON, E. AND KEYS, A.: The spatial QRS and T vector in 178 normal middle-aged men, body weight, height, Relationship of QRS and T and Preliminary standards. *Circulation* **9**: 105, 1954.
 26. MORI, H., NAKAGAWA, K., DAHL, J. C., SCHMITT, O. H. AND SIMONSON, E.: A quantitative study of initial and terminal QRS vectors in a group of normal older men. *Am. Heart J.* **59**: 374, 1960.
 27. FORKNER, C. E. JR., HUGENHOLTZ, P. G. AND LEVINE, H. D.: The vectorcardiogram in young adults. Frank lead system. *Am. Heart J.* **62**: 237, 1961.
 28. BRISTOW, J. D.: A study of the normal Frank vectorcardiogram. *Am. Heart J.* **61**: 242, 1961.
 29. JORDAN, R. C. AND BESWICK, F. W.: Lead field scalar and loop spatial electrocardiography, A preliminary survey on normal adult males and comparison with other methods. *Circulation* **18**: 256, 1958.
 30. MCFEE, R. AND JOHNSTON, F. D.: Electrocardiographic leads. I. Introduction. *Circulation* **8**: 554, 1953.
 31. KLJMAN, A., SHERF, L. AND KAULI, N.: The normal vectorcardiogram. A study of 150 normal adults. *Am. J. Cardiol.* **2**: 187, 1963.
 32. DRAPER, H. W., PEPPER, C. J., STALLMANN, F. W., LITTMANN, D. AND PIPBERGER, H. V.: The corrected orthogonal electrocardiogram and vectorcardiogram in 510 normal men (Frank lead system). *Circulation* **30**: 853, 1956.
 33. SEIDEN, G. E.: The normal QRS loop observed three dimensionally obtained with Frank precordial system. *Circulation* **16**: 582, 1957.
 34. BALL, M. F. AND PIPBERGER, H. V.: The spatial QRS-T angle of the orthogonal vectorcardiogram. *Am. Heart J.* **56**: 611, 1958.
 35. SANO, T., OSHIMA, H., TSUCHIHASHI, H. AND SHIMAMOTO, T.: The quantitative analysis of normal hearts and ventricular hypertrophy. *Jap. Heart J.* **1**: 226, 1960.
 36. SCERLIS, L., GRISHMAN, A., SANDBERG, A. A. AND DVORKIN, J.: Spatial vectorcardiography; Left bundle branch block and left ventricular hypertrophy II. *Am. Heart J.* **41**: 494, 1951.
 37. HORAN, L. G., BURCH, G. E., ABILDSKOV, J. A. AND CRONVICH, J. A.: The spatial vectorcardiogram in left ventricular hypertrophy. *Circulation* **10**: 728, 1954.
 38. DONOSO, E., SAPIN, S. O., BRAUNWALT, E. AND GRISHMAN, A.: A study of the electrocardiogram in congenital heart disease. II. Vectorcardiographic criteria for ventricular hypertrophy. *Am. Heart J.* **50**: 674, 1955.
 39. NIMURA, Y.: A vectorcardiographic analysis of left ventricular strain pattern comparatively studied with ST-T change of left bundle branch block and ventricular premature beat of right ventricular origin. *Am. Heart J.* **57**: 552, 1959.
 40. MAZZOLENI, A., WOLFF, R. AND WOLFF, L.: The vectorcardiogram in left ventricular hypertrophy. *Am. Heart J.* **58**: 648, 1959.
 41. BRISTOW, J. D., PORTER, G. A. AND GRISWOLD, H. E.: Observation with the Frank system of vectorcardiography in left ventricular hypertrophy. *Am. Heart J.* **62**: 621, 1961.
 42. BEREGOVICH, J., BLEIFER, S., DONOSO, E. AND GRISHMAN, A.: The vectorcardiogram and electrocardiogram in ventricular septal defect. *Brit. Heart J.* **20**: 525, 1959.
 43. WOLFF, L., WOLFF, R., SAMARTZIS, M. D. AND MATSUOKA, S.: Vectorcardiographic diagnosis. A correlation with autopsy findings in 167 cases. *Circulation* **23**: 861, 1961.
 44. SCOTT, R. C.: The correlation between the electrocardiographic patterns of ventricular hypertrophy and the anatomic findings. *Circulation* **21**: 256, 1960.
 45. HUGENHOLTZ, P. G., RYAN, T. J., WOERNER, T. AND LEVINE, H. D.: Recognition of anterior wall infarction in patients with left ventricular hypertrophy. A study by the Frank vectorcardiogram. *Circulation* **27**: 386, 1963.
 46. SEDZIWIY L. AND SHILLINGFORD, J.: Cardiographic patterns in systolic and diastolic overload of the left ventricle. *Brit. Heart J.* **22**: 533, 1961.
 47. MASSIE, E. AND WALSH, T. J.: Clinical vectorcardiography and electrocardiography. Chicago, Year Book Publishers, 1960.
 48. WALLACE, A. G., MCCALL, B. W. AND ESTES, E. H. JR.: The vectorcardiogram in left ventricular hypertrophy. A study using the Frank lead system. *Am. Heart J.* **63**: 466, 1962.
 49. HUGENHOLTZ, P. G., LEES, M. M. AND NADAS, A. S.: The scalar electrocardiogram, vectorcardiogram, and exercise electrocardiogram in the assessment of congenital aortic stenosis. *Circulation* **26**: 79, 1962.
 50. YANO, K. AND PIPBERGER, H. V.: Correlations between radiographic heart size and orthogonal electrocardiograms in patients with left ventricular load. *Am. Heart J.* **67**: 1964.
 51. KATO, S.: Studies on the orthogonal vectorcardio-

- graphy. *Mie-Igaku* 4: 1471, 1960. (in Japanese)
52. TATEISHI, Y., KATO, S., KANEKO, S. AND FUJITA, T.: *Jap. Circul. J.* (in press)
 53. MORI, H., SHIBATA, T., OSHITA, K. AND KAWAMURA, H.: Spatial analytico-geometrical analysis of vectorcardiogram by electronic computer. Vectorcardiogram of Frank system of the healthy middle-aged men. *Jap. Circul. J.* 30: 1017, 1966.
 54. MORI, H. et al.: *Nihon-Rinsho* 24: 159, 1966. (in Japanese)
 55. TOBATA, I., YASUI, S. AND MIZUNO, Y.: *Nihon-Rinsho* 23: 170, 175, 1965. (in Japanese)
 56. TAKAYASU, M. AND KANEKO, S.: *Nihon-Rinsho* 23: 172, 1965. (in Japanese)
 57. TOBATA, I. et al.: *Nihon-Rinsho* 23: 175, 1965. (in Japanese)
 58. ELEK, S. R., ALLERSTEIN, B. J., GRIFFITH, G. C., COSBY, R. S. AND LEVINSON, D. C.: *Am. Heart J.* 47: 369, 1954.
 59. PIPBERGER, H., LUCHSINGER, P., KAELEN, R. AND SCHAUB, F.: *Cardiologia* 27: 65, 1955.
 60. KARNI, H.: The TsE loop in myocardial lesion, *Am. Heart J.* 52: 867, 1956.
 61. KARNI, H.: The TsE loop in hypercholesterolemia, *Am. Heart J.* 54: 269, 1957.
 62. KARNI, H.: The TsE loop in left ventricular hypertrophy, *Am. Heart J.* 56: 518, 1958.
 63. BAZETT, H. C.: An analysis of the time relation of electrocardiogram. *Heart* 7: 353, 1920.
 64. LEWIS, T. AND ROTHSCHILD, M. A.: The excitatory process in the dog's heart: II. The ventricles. *Phil. Tr. Roy. Soc.* 206B: 181, 1915.
 65. SODI-PALLARES, D., BISTENI, A., MADRANO, G. A. AND CISNEROS, F.: The activation of the free left ventricular wall in the dog's heart. *Am. Heart J.* 49: 587, 1955.
 66. SODI-PALLARES, D., RODRIGUEZ, M. I., CHAIT, L. O. AND ZUCKERMAN, R.: The activation of the interventricular septum. *Am. Heart J.* 41: 569, 1951.
 67. BURCHELL, H. B., ESSEX, A. E. AND PRUITT, R. D.: Studies on the spread of excitation through the ventricular myocardium: II. The ventricular septum, *Circulation* 6: 161, 1952.
 68. SHIBATA, O.: The quantitative analysis of the normal vectorcardiogram.—Using the Frank lead system. VCG of the normal young men. *Jap. Circul. J.* 30: 1402, 1966.
 69. YASUI, S.: Analysis of ECG by mean of reconstruction method on the direct unipolar lead ECG. *Jap. Circul. J.* 23: 1025, 1959.
 70. KATO, H.: Analysis of ECG and VCG by means of reconstruction method. *Jap. Circul. J.* 22: 551, 1958.
 71. TOYOSHIMA, H. AND YAMADA, K.: *Annual Report. Inst. Environmental Med., Nagoya Univ.* 4: 137, 1953. (in Japanese)
 72. TOYOSHIMA, H., KATO, H., ISOBE, T., NAGAYA, T. AND SARUHASHI, Y.: Electrocardiogram and vectorcardiogram reconstruction and its application to clinical diagnosis of myocardial infarction complicated by left bundle branch block. *Jap. Circul. J.* 22: 69, 1958.
 73. TOYOSHIMA, H., KATO, H., ISOBE, T., NAGAYA, T., SARUHASHI, Y. AND KATSUNA, Y.: Electrocardiogram and vectorcardiogram reconstruction and its application to clinical diagnosis of myocardial infarctions complicated by right bundle branch block. *Jap. Circul. J.* 22: 125, 1956.
 74. TOYOSHIMA, H., MIZUNO, Y., HATTORI, M. AND SARUHASHI, Y.: *Am. Heart J.* 52: 711, 1956.
 75. TOYOSHIMA, H.: *Jap. Circul. J.* 27: 73, 1963.
 76. NONOGAWA, A.: An improved method for reconstruction of vectorcardiogram. *Jap. Heart J.* 6: 346, 1965.
 77. HUGENHOLTZ, P. G., FORKNER, C. E. JR. AND LEVINE, H. D.: A clinical appraisal of the vectorcardiogram in myocardial infarction. II. The Frank system. *Circulation* 24: 285, 1961.
 78. KOSSMANN, C., BRILLER, S. AND MARCHAND, N.: *Circulation Res.* 3: 203, 1955.
 79. HELM, R. A., AND FOWLER, N. O. JR.: Studies on the QRS-T angle. *Am. Heart J.* 46: 299, 1953.
 80. HELM, R. A. AND FOWLER, N. O.: A simplified method for determining the angle between two spatial vectors. *Am. Heart J.* 45: 835, 1953.
 81. PIPBERGER, H. V.: Evaluation of quantitative methods for obtaining mean spatial QRS vectors. *Circulation* 16: 926, 1957.
 82. TOYAMA, S.: Abnormal T loop in vectorcardiogram. *Jap. Circul. J.* 27: 57, 1963.
 83. TOYAMA, S., ISHIYAMA, T., YAMAGAMI, T. AND TAIRA, H.: The length of abnormal T loop in vectorcardiogram. *Jap. Circul. J.* 22: 785, 1959.