ASSESSMENT OF LEFT VENTRICULAR PERFORMANCE IN MAN WITH IMPEDANCE CARDIOGRAPHY

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THE evaluation of left ventricular performance by noninvasive techniques has received much attention in recent years. In terms of the measurement of left ventricular performance, the usefulness of systolic time intervals, such as preejection period (PEP), left ventricular ejection time (LVET) and the ratio PEP/LVET has been proposed by Weissler and associates.¹⁻³ And also, the apexcardiogram and its first derivative have been generally used as a noninvasive method to evaluate myocardial contractility.⁴⁻⁶

We designed the present study to evaluate left ventricular performance by means of the impedance cardiography which was devised by Kubicek.^{7,8} The impedance cardiography, like other noninvasive method, can be freely repeated without discomfort to patients and without affecting resting hemodynamic values. The impedance cardiography has been used for the measurement of cardiac output,^{9,10} intrathoracic fluid,^{11,12} peripheral blood flow¹³ and so on.¹⁴ Kubicek¹⁵ and Siegel¹⁶ suggested the possibility of the use of impedance cardiography in evaluating myocardial contractility, although so far there have been few reports concerning to this subject. We have been emphasizing the implication of Q-Z interval in the quantitative estimation of left ventricular performance. The Q-Z interval was measured from the onset of left

ventricular depolarization to the peak of the first derivative of the impedance cardiography during systolic phase.

The purpose of this study was to compare the indices of myocardial contractility with the Q-Z interval derived from dz/dt of the impedance cardiography and to evaluate the usefulness of the Q-Z interval as a noninvasive assessment of left ventricular performance.

MATERIALS AND METHODS

Thirty-six patients, 32 male and 4 female, with angina pectoris or old myocardial infarction, were studied. Their ages ranged from 33 to 67 years. Minnesota impedance cardiography (IFM 304 A) with a four band electrodes impedance system was used to estimate left ventricular performance. Two conductive strip electrodes (approximately 6 mm wide aluminum) were placed on the neck and abdomen. The outer two electrodes were spaced at least 3 cm away from the inner electrodes. The inner two electrodes were placed, one around the base of neck and the other about 2 cm below the xiphisternal joint (Fig. 1). The outer two electrodes were connected to a constant current source providing 4 milliamps, 100 KHz sinusoidal current. The inner two electrodes were connected to high impedance amplifier and suitable detection circuit to provide for the determination of basic impedance between the two inner electrodes and also for the impedance change that occurred during cardiac cycle.

The electrocardiogram, phonocardiogram, impedance cardiogram (ΔZ , dz/dt), left ventri-

Key Words:

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cular pressure and its first derivative (dp/dt) were simultaneously recorded with multichannel recorder (Sanei-Sokki 142-8) during cardiac

Fig.1. Schematic diagram of a four band electrodes impedance system. A constant sinusoidal current (100 KHz, 4 mA) was applied to electrodes 1 and 4. Voltage reflecting thoracic impedance changes was picked up from electrodes 2 and 3.

catheterization (Fig. 2). The electrocardiogram was obtained using standard lead placement. A lead showing a clear Q wave was selected. The impedance cardiography was recorded in 36 patients during expiratory apnea. Heart sounds were recorded with piezo-electric microphone (Fukuda MA-250). The microphone was placed on the left upper part of the precordium being the optimal position for recording the second heart sound. Left ventricular pressure was measured with a 7F catheter-tip micro-manometer (Millar Instrument) in 26 patients, while it was measured with a Statham P 23 Db strain gauge in other patients. Fig. 2 shows typical tracings recorded at 100 mm/sec. The Q-Z interval was measured as the interval between the Q wave of the electrocardiogram and the peak of the first derivative of the impedance cardiogram during systolic phase. And the Q- dp/dt was

Fig.2. Simultaneous tracings of electrocardiogram (ECG), phonocardiogram (PCG), impedance cardiogram (ΔZ), and its first derivative (dz/dt), left ventricular pressure (LV pr), and its first derivative (dp/dt) during cardiac catheterization, Q-Z=interval between the onset of ventricular depolarization and the peak dz/dt . Q- dp/dt =interval between the onset of ventricular depolarization and the peak dp/dt . (dz/dt)min=height of the first derivative of the impedance cardiogram during systolic phase.

Fig.3. Relation between Q-Z interval and Q-dp/dt in 23 patients.

Fig.4. Relation between Q-Z interval and V max in 23 patients.

measured as the interval between the Q wave of the electrocardiogram and the peak of the first derivative of the left ventricular pressure. The left ventricular ejection time (LVET) was measured from the aortic pressure tracing as the interval between the beginning of the upstroke and the dicrotic notch. The preejection period (PEP) was measured as the interval between the Q wave of the electrocardiogram and the beginning of the upstroke of the aortic pressure tracing. Heater index (H. I.) was calculated as $(dz/dt)_{\min}/Q-Z$ interval, where $(dz/dt)_{\min}$ is the height of the first derivative of the impedance cardiogram during systolic phase. Heart

Fig.5. Relation between Q-Z interval Max dp/dt in 23 patients.

rate was calculated from R-R interval. Time constant of the differentiator used was 0.5 msec.

Cardiac Catheterization

The catheterization was performed when clinically indicated for diagnostic or therapeutic purpose before cardiac surgery. Diagnosis verified by cardiac catheterization included arteriosclerotic heart disease and normal heart. Left ventricular pressure was recorded with catheter-tip micro-manometer in 26 patients. In 23 of these patients, maximal velocity of myocardial contractile element, V max, was calculated by the method of Mason¹⁷ et al. The values were determined by linear extrapolation of force velocity loop curve.

Cineangiography

Left ventricular 35 mm cineangiograms were filmed at 100 frames, with the patients in 30° right anterior oblique position, following the injection of approximately 1 ml/kg of 80% meglumine iodamide (Conraxin-H) in the left ventricle. Left ventricular volume was calculated by the method of Greene¹⁸ et al, with the single plane at the right anterior oblique position. Ejection fraction was also determined angiographically. Statistical analyses of the data were calculated by using Student's t test.

TABLE I CLINICAL, HEMODYNAMIC AND ANGIOGRAPHIC DATA IN THIRTY-SIX PATIENTS WITH CORONARY ARTERY DISEASE

Case no.	Age (yr) & Sex	Diagnosis	HR (1/min)	Q-Z (msec)	(PEP/LVET)	H. I.	Q-dp/dt (msec)	LVEDP (mmHg)	EF (%)	Maxdp/dt (mmHg/sec)	V _{max} (circ/sec)
1	62 M	OMI (Ant.)	67	176	0.473	8.7	110	10	47	1309	1.06
2	54 M	Angina	69	158	0.344	11.4	—	11	80	—	1.45
3	42 F	Normal	65	146	0.443	13.1	—	2	65	1125	1.60
4	46 M	OMI (Ant. & Inf.)	107	173	0.653	6.1	—	10	50	—	1.08
5	40 F	Variant	99	135	0.417	16.2	99	4	69	1496	1.85
6	56 M	OMI (Ant.)	58	194	0.522	6.4	—	10	44	—	0.76
7	47 F	OMI (Ant.)	72	157	0.359	13.0	—	7	84	—	—
8	58 M	Variant	62	139	0.308	11.1	90	15	—	1734	—
9	58 M	Variant	73	166	0.401	11.8	105	15	—	1485	—
10	33 F	Normal	70	140	0.351	28.0	89	6	80	1590	1.50
11	47 M	OMI (Ant.)	77	170	0.404	11.3	110	18	—	1284	—
12	50 M	OMI (Inf.)	67	172	0.457	8.8	110	8	68	831	1.35
13	46 M	OMI (Ant.)	57	175	0.356	14.5	110	8	58	893	1.29
14	62 M	Angina	46	182	0.364	12.9	122	11	—	759	1.09
15	47 M	OMI (Ant.)	81	173	0.464	11.4	122	11	66	1208	1.25
16	47 M	OMI (Ant.)	76	170	0.355	10.8	112	7	—	1039	1.38
17	50 M	OMI (Ant.)	66	181	0.418	7.8	131	11	76	1163	1.48
18	60 M	Variant	50	197	0.413	11.1	136	11	—	792	1.03
19	67 M	OMI (Subendocard.)	59	177	0.390	9.1	135	8	74	974	1.14
20	65 M	OMI (Inf.)	60	186	0.494	8.5	127	10	64	876	1.07
21	49 M	OMI (Ant.)	59	218	0.625	8.6	155	18	53	935	0.81
22	65 M	Angina	53	167	0.364	16.2	108	14	81	1274	1.37
23	60 M	OMI (Inf.)	61	160	0.269	11.7	93	12	—	994	1.48
24	53 M	Variant	63	154	0.379	8.8	—	7	79	—	—
25	53 M	Variant	59	141	0.327	13.9	—	18	77	—	—
26	63 M	Angina	60	178	0.273	15.1	—	18	70	—	—
27	41 M	Angina	64	166	0.337	10.6	—	12	70	—	—

RESULTS

When left ventricular pressure was recorded with a catheter tip micro-manometer in cardiac catheterization, the electrocardiogram, impedance cardiogram and phonocardiogram were simultaneously recorded (Fig. 2). Table I reveals clinical information, results of the impedance cardiography and hemodynamic and angiographic indices of left ventricular performance in 36 patients. The Q-Z interval, Heather¹⁹ Index (H. I.) and PEP/LVET were compared with indices derived from cardiac catheterization and the significant correlations were obtained as shown in Table II.

The interval between the onset of ventricular depolarization and the peak of the first derivative of left ventricular pressure (Q-dp/dt) has a markedly excellent correlation ($r = 0.91$) with the Q-Z interval (Fig. 3).

A good correlation ($r = -0.87$) was observed between the Q-Z interval and V max determined from left ventricular pressure and its simultaneous first derivative (Fig. 4).

The Q-Z interval has a significant correlation ($r = -0.54$) with ejection fraction, being less close than that with V max. Maximal dp/dt has also a significant correlation ($r = -0.71$) with the Q-Z interval (Fig. 5) but left ventricular end-diastolic pressure has no significant correlation with the Q-Z interval. However, PEP/LVET emphasized by Weissler has less significant correlations than the Q-Z interval with V max, Max dp/dt, respectively (Table II).

DISCUSSION

The carotid arterial pulse tracing and apex-cardiography have been generally used as a noninvasive method for the assessment of left ventricular performance.¹⁻⁶ Since Garrod²⁰ and associates proposed that a close correlation between the ratio PEP/LVET and ejection fraction was demonstrated, this ratio has been evaluated as one of the noninvasive indices indicating left ventricular function. PEP and LVET, however, were considerably influenced by heart rate, preload, afterload and ventricular volume and accordingly, PEP/LVET was also influenced by these factors. There were a number of reports^{21,22} to discuss the usefulness and limitation of this ratio.

In 1967, Reale⁵ advocated that the time from the onset of ventricular contraction to the peak of the first derivative of apexcardiogram

28	48 M	Angina	79	156	0.407	11.4	—	9	83	—	—
29	63 M	OMI (Ant.)	91	170	0.496	5.1	114	13	38	972	1.01
30	63 M	Angina	95	151	0.469	8.9	101	11	63	1462	1.59
31	46 M	Variant	60	156	0.362	18.7	98	14	85	1046	1.54
32	42 M	OMI (Inf.)	71	185	0.544	9.1	133	8	37	781	1.13
33	49 M	Angina	60	170	0.433	11.1	—	14	65	—	—
34	59 M	OMI (Ant.)	72	146	0.287	10.4	—	16	72	—	—
35	57 M	OMI (Ant.)	72	156	0.437	11.0	—	8	73	—	—
36	43 M	Angina	61	187	0.410	14.7	122	8	65	—	—

Abbreviations: OMI=old myocardial infarction, Variant=variant from of angina pectoris, Ant.=anterior wall infarction, Inf.=inferior wall infarction, Subendcard.=subendocardial infarction, HR=heart rate, PEP=prejection period, LVET=left ventricular ejection time, LVEDP=left ventricular end-diastolic pressure, H.I.=Heather Index, V max=maximal velocity of contractile element, Q-Z=interval between the onset of ventricular depolarization and the peak dz/dt, Q-dp/dt=interval between the onset of ventricular depolarization and the peak dp/dt.

TABLE II CORRELATION MATRIX FOR 36 PATIENTS WITH CORONARY ARTERY DISEASE

	<i>V max</i>	<i>Max dp/dt</i>	<i>Q-dp/dt</i>	<i>EF</i>
<i>Q-Z</i>	-0.87**	-0.71**	0.91**	-0.54*
<i>PEP/LVET</i>	-0.56*	N. S.	0.67**	-0.70**
<i>Heather Index</i>	0.54*	N. S.	-0.50*	0.54*

All figures represent correlation coefficients (*r* valuse).

* $p < 0.01$ ** $p < 0.001$

Abbreviations: *V max* = maximal velocity of contractile element, *EF* = ejection fraction, *Q-dp/dt* = interval between the onset of ventricular depolarization and the peak *dp/dt*, *Q-Z* = interval between the onset of ventricular depolarization and the peak *dp/dt*, *PEP* = preejection period, *LVET* = left ventricular ejection time.

Fig. 6. Changes in Q-Z interval by atrial pacing in 10 patients with sinus bradycardia. HR=heart rate.

Fig. 7. Changes in PEP/LVET by atrial pacing in 5 patients with sinus bradycardia. PEP= preejection period, LVET=left ventricular ejection time, HR=heart rate.

($t\Delta ACG$) could be applied to the assessment of myocardial contractility.

In 1972, Vetter⁶ and associates proposed that the interval from the onset of ventricular depolarization to the peak of the first derivative of apexcardiogram (R to dA/dt) had a close correlation with indices of myocardial contractility.

We attempted to evaluate left ventricular performance by using the impedance cardiography. For that purpose, observations were made on the Q-Z interval. The Q-Z interval obtained from the impedance cardiography was compared with various hemodynamic and angiographic indices, each of which had been regarded as a parameter relating to left ventricular performance. From

the results obtained in this study, it was revealed that the Q-Z interval had good correlations with hemodynamic and angiographic indices of myocardial contractility. And the impedance cardiography was regarded as a suitable technique for noninvasive assessment of left ventricular performance. The Q-Z interval had better correlations than PEP/LVET with the other indices of left ventricular function.

Accordingly the effects of heart rate on the Q-Z interval, PEP/LVET and H. I. were studied

Fig.8. Changes in Q-Z interval, Q-dp/dt, V max and Max dp/dt by atrial pacing in 5 anesthetized mongrel dogs. HR=heart rate, Open circles indicate mean value $\pm$ S.E.

Fig.9. Changes in PEP/LVET and H.I. by atrial pacing in 5 anesthetized mongrel dogs. HR=heart rate, H.I.=Heather Index.

in patients with sinus bradycardia and anesthetized mongrel dogs. In atrial pacing of 10 patients with sinus bradycardia, the Q-Z interval was scarcely changed at variable pacing rate (Fig. 6).

Although the Q-Z interval was free from the influence of heart rate, significant increase of PEP/LVET was induced by an increase of heart rate in 5 patients with sinus bradycardia (Fig. 7). A significant increase of PEP/LVET indicates a decrease in the left ventricular performance. In order to elucidate the effects of heart rate on the left ventricular performance, the experimental

Fig.10. Changes in Heather Index by atrial pacing in 5 patients with sinus bradycardia. HR=heart rate.

Fig.11. Component of characteristic wave on impedance cardiogram. ECG=electrocardiogram, PCG=phonocardiogram, ΔZ =impedance cardiogram, dz/dt =first derivative of impedance cardiogram, (A) wave occurs during atrial contraction, (C) wave occurs during systolic phase, (V) wave occurs during diastolic phase.

study was carried out in 5 anesthetized mongrel dogs. In our examination, Max dp/dt, V max and Q-dp/dt as indices of the left ventricular performance were scarcely changed at variable pacing rate (Fig. 8). The Q-Z interval was also scarcely changed when the heart rate was increased. On the other hand, an increase of PEP/LVET was induced by an increase of heart rate (Fig. 9). It is, thus, postulated that the Q-Z interval is a better index than PEP/LVET for the assessment of left ventricular performance.

In 1969, Heather¹⁹ proposed that H.I. was useful as a noninvasive index of left ventricular performance ($H.I. = \frac{(dz/dt) \text{ min}}{Q-Z}$). But the present study elucidated that H.I. had less significant correlations with hemodynamic and angiographic indices representing left ventricular performance than the Q-Z interval. Five patients with sinus bradycardia were studied to evaluate the influence of the change in heart rate by atrial pacing on H.I. A significant decrease of H.I. was induced by an increase of heart rate in 5 patients (Fig. 10). And a decrease of H.I. was also observed in parallel with an increase of heart rate in 5 anesthetized mongrel dogs (Fig. 9). H.I. appeared to change to reversely to the left ventricular performance when heart rate was increased. It was, thus, suggested that H.I. was not a valuable index of left ventricular performance. From these points of view, the Q-Z interval is considered to be a better index of left ventricular function than PEP/LVET and H.I. It is still controversial what kind of index is not affected with heart rate, preload and afterload. An ideal index to represent the left ventricular contractility which is not affected with heart rate, preload and after load has to be established in near future.

Mason²³ and associates reported that the time from ventricular depolarization to the peak dp/dt was independent of preload and afterload. In our study, it was indicated that the Q-Z interval related to the time from ventricular depolarization to the peak of the first derivative of left ventricular pressure (Fig. 3). Therefore, the Q-Z interval seemed to be relatively independent of preload and afterload, and it was regarded as a good index of noninvasive assessment of left ventricular performance.

It has not yet been univassally accepted to identify the characteristic of impedance wave.^{7,8} According to Kubicek and associates, it was suggested that the origin of dz/dt measured by

the 4 band electrodes impedance system might consist of 3 components (Fig. 11). The first component occurs after P wave of the electrocardiogram and it is called "A" wave of the impedance cardiogram. The second component^{8,24} occurs immediately after QRS of the electrocardiogram and its impedance variations may be due to the volume change of ascending aorta. And its component is called "C" wave of the impedance cardiogram. On the other hand, it was reported that C wave might be induced by the volume change of main pulmonary artery following right ventricular ejection.²⁵ According to Ito²⁶ and associates, C wave was responsible to the volume change of both ascending aorta and main pulmonary artery. But they indicated that C wave related about three times more closely to the aortic blood flow than to the pulmonary blood flow. And also, Kanai²⁷ proposed that C wave was mainly related to the aortic blood flow. The third component occurs during diastolic phase and its impedance variations may be due to change in vena cava or pulmonary vein. And it is called "V" wave of the impedance cardiogram but its origin is not still clear.

In 1967, Kubicek^{7,15} proposed that the Q-Z interval was closely related to the interval from the onset of ventricular depolarization to the peak flow of ascending aorta. Assessment of left ventricular performance with the impedance cardiogram is based on the facts mentioned above. Thus, the Q-Z interval is assumed as the time from ventricular depolarization to the peak flow of ascending aorta and the present study reveals that the Q-Z interval has good correlations with left ventricular performance. Therefore, the Q-Z interval is useful as a noninvasive index of left ventricular performance.

A shortening of the Q-Z interval always corresponded to an increase of myocardial contractility, on the other hand a prolongation of its corresponded to a decrease of myocardial contractility.

SUMMARY

The present study was designed to evaluate the left ventricular performance in man with the impedance cardiography which was devised by Kubicek and associates. The Q-Z interval was compared with hemodynamic and angiographic indices of left ventricular performance in 36 patients in whom cardiac catheterization was carried out. Correlation coefficients between the Q-Z interval and other indices, that is Q-dp/dt,

V max, Max dp/dt and Ejection Fraction were 0.91, -0.87, -0.71 and -0.54, respectively and all of them were statistically significant. A shortening of the Q-Z interval always corresponded to an increase of myocardial contractility and a prolongation of it corresponded to a decrease of myocardial contractility. In atrial pacing of 10 patients with sinus bradycardia, the Q-Z interval was not influenced by the heart rate.

The usefulness of impedance cardiography is based on the good correlation between the interval from the onset of ventricular depolarization to the peak of the first derivative of the impedance cardiogram (Q-Z interval) and the interval from the onset of ventricular depolarization to the peak of the first derivative of left ventricular pressure (Q-dp/dt).

From these results, it is postulated that the Q-Z interval is one of the valuable indices for the assessment of left ventricular performance.

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