EVALUATION OF EFFECTS OF AGING, TRAINING AND MYOCARDIAL ISCHEMIA ON CARDIAC RESERVE BY EXERCISE ECHOCARDIOGRAPHY

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Exercise tolerance and heart response were examined by cross-sectional echocardiography before and during exercise tests to assess the effects of aging, training and myocardial ischemia on the cardiac reserve of 40 healthy men, 20 athletes and 25 patients with angina on effort.

The cardiac response to exercise can be divided into 4 types according to parameters derived from a short axis section echocardiogram. Type A: The left ventricular end-diastolic volume (LVEDV) increased slightly in the early stage of exercise, and thereafter, the cardiac response was maintained by a gradual increase of myocardial contractility and heart rate. Type B: Initial response to exercise was similar to Type A, but cardiac output was maintained only by an increase of heart rate under additional exercise load. Type C: LVEDV, LVESV (left ventricular end-systolic volume) and contractility remained virtually unchanged throughout the exercise. Type D: The contractility decreased from the early stage of the exercise, and LVEDV and LVESV increased. Most young subjects and all athletes showed Type A response, while in the aged healthy subjects the Type B response was more frequent. Anginal cases tolerating 125-watt load responded as Type B or C, and those tolerating only 75 watts showed Type C or D. All patients in Type D had multi-vessel disease.

THE estimation of cardiac reserve is important for evaluating the cardiac functions of patients with ischemic heart disease. Cardiac reserve is likely to be influenced by active sports or aging. Therefore, the evaluation of the effect of ischemia on cardiac reserve is complex. In the present study, an exercise tolerance test using a bicycle ergometer was applied to the patients with angina on effort, and healthy controls, and

their cross-sectional echocardiograms were recorded during exercise. The cardiac response to this exercise which was assessed from parameters derived from cross-sectional echocardiograms were compared in angina patients and healthy controls.

MATERIALS AND METHODS

Study Population

Twenty-five patients (21 males and 4 female averaging 53.0 ± 13.8 years) with angina on effort who had sinus rhythm served as the subjects of this study. All patients had experienced chest pain that was considered consistent

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Fig.1. Two dimensional echocardiographic images and their endocardial traces at end-diastole and end-systole at the papillary muscle level.

with angina pectoris. They had no medication at least for 3 days before the exercise and they had angiographically documented significant coronary artery disease with over 70% stenosis in one or more vessels. The control consisted of 9 healthy male sedentaries (average age 24.2 ± 2.0 years) and 20 athletes (average age 20.1 ± 1.7 years) who had been active in high school and university basketball for more than 5 years.

To study the influences of aging on cardiac reserve, the cardiac responses of 40 healthy men who had no past history or evidence of heart disease were examined. These subjects were divided chronologically into groups 1–5 in terms of age: those in their twenties having a mean age of 24.5 ± 2.0 ; those in their thirties averaged 33.3 ± 3.2 ; forties, 44.4 ± 3.1 ; fifties, 52.2 ± 2.5 ; and sixties, 61.0 ± 0.8 years were composed of 9, 8, 8, 7 and 8 men, respectively.

Exercise Echocardiography

A phased-array ultrasonic sector scanner (Toshiba SSH-11A) was used in this two dimen-

sional echocardiographic study. The left ventricular short-axis tomograms (LVT) at the papillary muscle level were recorded on a videotape recorder (Victor CR-6060) before and during bicycle ergometer exercise in the supine position. A transducer was fixed manually on the left sternal border of the third or fourth intercostal region so as to obtain a good cross-sectional echocardiogram. To estimate the left ventricular ejection time and heart rate, an M-mode echocardiogram was recorded simultaneously on a linear scan recorder (Toshiba LSR-20A) at a paper speed of 50 mm/sec with a phonocardiogram and an electrocardiogram (ECG) in lead II. A twelve-lead ECG recording and blood pressure measurement by the cuff method were performed at the end of every exercise load.

LVT on the videotape was put on video discs (SONY). The transmitted images were observed in slow motion, stop motion and one-frame motion to determine the maximum (end-diastolic) and minimum (end-systolic) left ventricular section and to trace them by three experts in-

Fig.2 A, B. Response of heart rate and blood pressure to exercise. Data represent mean values in each group. Ps and HR in 75- and 125-watt groups reached a plateau at loads of 50-75, and 100-watt.

○ = athlete group; ● = sedentary group; △ = 125-watt group; ▲ = 75-watt group
Ps = systolic blood pressure; Pd = diastolic blood pressure

C. Time course of area.

Note that the values of Area D and Area S in 75- and 125-watt groups increased from the early stage of loading.

Area D = end-diastolic area; Area S = end-systolic area

D. Time course of % area change.

The values in 75- and 125-watt groups decreased gradually after 50 watt load.

E. Time course of mVcf.

The values of mVcf in athlete and sedentary groups increased linearly. On the other hand, the values in 75- and 125-watt groups decreased gradually from the early stage.

dependently (Fig. 1). After tracing the sections, their area (Area D, Area S) and their circumferential length (maximum and minimum perimeter) were measured with a lightpen digitizer (Mutoh Bit Pad 1). The mean of the determined length and area by the three experts were used in this study. The percent area change was calculated by the formula $[(\text{Area D} - \text{Area S}) / \text{Area D} \times 100]$. mVcf was calculated from the formula $[(\text{maximum perimeter} - \text{minimum perimeter}) / \text{maximum perimeter} \times \text{ejection time}]$.

An electronically controlled ergometer (Tatebe EM-401) was used. The multi-stage exercise method was performed increasing the work load by 25 watts every 3 min at 50 rpm/min. The amount of loading was symptom-limited by anginal pain or becoming impossible to continue exercise due to muscular fatigue of the lower extremities. The limit of the load was 150 or 175 watts in the healthy and athlete groups respectively. The angina group was further divided into 2 subgroups according to the work load, 13

TABLE I AREA/B.S. DURING EXERCISE IN EACH GROUP

		Exercise load (Watts)							
		Rest	25w	50w	75w	100w	125w	150w	175w
Area D/B.S.	control group (n = 9)	10.5 ± 1.5 †††	11.6 ± 1.4 *	12.7 ± 1.4 ***	11.6 ± 0.8 *	11.4 ± 1.3	10.4 ± 1.6 ††	9.7 ± 1.7 ††	
	sportsman (n = 20)	12.3 ± 1.2	13.2 ± 1.3 **	13.2 ± 1.2 **	12.3 ± 1.0 †	11.8 ± 0.8 †	11.4 ± 0.8 †††	10.8 ± 0.8 ††	10.2 ± 0.6 ***
	125-angina group (n = 12)	11.0 ± 1.0 ††	12.2 ± 1.2 *	12.7 ± 1.9 **	12.9 ± 2.2 †††	13.1 ± 2.3 †††	14.2 ± 2.2 ***		
	75-angina group (n = 13)	12.0 ± 1.3	13.2 ± 2.1 **	13.9 ± 2.3 **	14.2 ± 2.5 ***				
Area S/B.S.	control group (n = 9)	5.2 ± 0.8	5.0 ± 0.6	4.8 ± 0.9	4.5 ± 0.6 *	4.1 ± 0.8 ***	3.9 ± 0.7 ***	3.7 ± 0.6 ***	
	sportsman (n = 20)	5.1 ± 0.5	4.8 ± 0.5 **	4.6 ± 0.4 ***	4.2 ± 0.3 ††	3.9 ± 0.2 †††	3.7 ± 0.2 †††	3.3 ± 0.2 ***	3.1 ± 0.3 ***
	125-angina group (n = 12)	5.6 ± 1.4	5.1 ± 1.4	5.2 ± 1.7 †	5.6 ± 1.3 ††	5.8 ± 1.2	6.4 ± 1.4 *		
	75-angina group (n = 13)	5.8 ± 2.1	6.0 ± 2.5	7.2 ± 3.4 *	8.0 ± 3.8 **				
Area D/B.S.	20 ~ 29 (group 1, n = 9)	10.5 ± 1.5	11.6 ± 1.4 *	12.7 ± 1.4 ***	11.6 ± 0.8 **	11.4 ± 1.3	10.4 ± 1.6	9.7 ± 1.7	
	30 ~ 39 (group 2, n = 8)	11.9 ± 1.5	13.5 ± 1.8 **	13.6 ± 1.9 **	12.3 ± 1.6	11.7 ± 1.8	10.8 ± 1.8	10.9 ± 1.6	
	40 ~ 49 (group 3, n = 8)	11.4 ± 1.9	12.9 ± 1.0 **	12.9 ± 1.8 **	12.2 ± 1.9	11.0 ± 2.1	11.5 ± 1.8		
	50 ~ 59 (group 4, n = 7)	11.7 ± 1.3	12.1 ± 0.9	12.9 ± 0.9 **	12.1 ± 0.6	11.2 ± 0.8	11.6 ± 1.1		
	60 ~ 69 (group 5, n = 8)	10.9 ± 1.3	12.7 ± 2.5 *	12.9 ± 1.4 **	12.7 ± 1.3 **	12.4 ± 1.2 **	13.5 ± 0.4 ***		
Area S/B.S.	20 ~ 29 (group 1, n = 9)	5.2 ± 0.8	5.0 ± 0.6	4.8 ± 0.9	4.5 ± 0.6 *	4.1 ± 0.8 **	3.9 ± 0.7 ***	3.7 ± 0.6 ***	
	30 ~ 39 (group 2, n = 8)	5.4 ± 0.7	5.3 ± 0.9	5.0 ± 0.9	4.4 ± 0.7 **	4.2 ± 0.8 ***	4.0 ± 0.6 ***	4.0 ± 0.6 ***	
	40 ~ 49 (group 3, n = 8)	5.2 ± 1.5	5.2 ± 1.4	4.6 ± 1.4	4.3 ± 1.3 *	4.2 ± 1.5 *	4.4 ± 1.3		
	50 ~ 59 (group 4, n = 7)	5.0 ± 0.7	4.9 ± 0.5	4.6 ± 0.6	4.2 ± 0.7 *	4.1 ± 0.5 **	4.6 ± 0.9		
	60 ~ 69 (group 5, n = 8)	5.2 ± 0.2	5.1 ± 0.4	4.5 ± 0.6 ***	4.6 ± 0.5 ***	4.9 ± 0.4	5.2 ± 1.2		

mean ± S.D. (cm²/m²)

* = p < 0.05, versus rest, ** = p < 0.01, versus rest

† = p < 0.10, versus control, †† = p < 0.05, versus control, ††† = p < 0.01, versus control

patients could undergo up to 50–75 watts (average age; 61.6 ± 11.4 years, 75-watt angina group) and 12 patients could tolerate up to 100–125 watts (average age; 44.4 ± 10.6 years, 125-watt angina group). Ischemic ST depression appeared in 11 patients of the 75-watt angina group and 7 patients of the 125-watt angina group. All patients without ST change could attain the target HR.

Statistical Analysis

Changes between the rest and exercise values were compared using the paired t-test and the differences among group means were compared using the unpaired t-test.

RESULTS

I Cardiac Response to Exercise in the Patients with Effort Angina and the Healthy Control

1. HR and BP (Fig. 2-A, B)

The resting HR of the control, the athlete, the 75-watt angina and 125-watt angina groups was 76.3 ± 7.9 , 63.3 ± 12.7 , 66.1 ± 9.5 and 82.1 ± 19.0 beats/min, respectively. HR was increased with exercise in all of the groups except the 75-watt angina group, in which HR was reduced after 50-watt load. HR of the 125-watt group measured at rest and up to 100-watt load was the highest among the 4 groups, but HR did not increase thereafter. HR of the athlete group was the lowest among all groups, increasing linearly up to 175-watts.

The systolic blood pressure (BPs) at rest was high in the angina groups, and low in the healthy and athlete groups. Similar tendencies were seen during exercise. BPs of the angina groups elevated rapidly in the early stage of exercise. BPs in the 75- and 125-watt groups reached a plateau at 50–75 and 100 watts, respectively, whereas BPs of both the healthy and athlete groups elevated gradually and continuously until the late stage of loading. BPs of the athlete group during exercise were significantly lower than in the other groups at the same exercise load ($p < 0.05$).

The diastolic blood pressure (BPd) of the angina groups at rest was high. BPd of each group rose slightly in a load-dependent manner, and BPd in the angina groups was higher than in the other groups during exercise. At the same level of exercise, BPd of the athlete group was significantly lower than in the other groups ($p < 0.10$).

2. Area D and Area S (Fig. 2-C, Table I)

In the healthy group the left ventricular end-diastolic area per unit area of body surface (Area D/B.S. cm^2/m^2) at rest $10.5 \pm 1.5 \text{ cm}^2/\text{m}^2$ was increased to $12.7 \pm 1.4 \text{ cm}^2/\text{m}^2$ after loading of 50-watts. However, the index decreased thereafter, and was rather smaller at 150-watts ($9.7 \pm 1.7 \text{ cm}^2/\text{m}^2$) than at rest. The athlete response was similar to the healthy one, but Area D/B.S. of the athlete group at rest and for each load was significantly greater than that of the healthy group ($p < 0.05$). While the Area D/B.S. of the angina groups increased gradually with exercise and the values of the 75-watt angina group were larger than those of the 125-watt angina group at all stage.

The left ventricular end-systolic area per unit body surface area (Area S/B.S. cm^2/m^2) in the healthy and the athlete groups decreased gradually as loading was increased. The area S/B.S. of the former at rest ($5.2 \pm 0.8 \text{ cm}^2/\text{m}^2$) decreased significantly to $3.7 \pm 0.6 \text{ cm}^2/\text{m}^2$ at 150-watt ($p < 0.05$), and that of the latter at rest ($5.1 \pm 0.5 \text{ cm}^2/\text{m}^2$) decreased significantly to $3.1 \pm 0.3 \text{ cm}^2/\text{m}^2$ on a load of 175-watt ($p < 0.05$). The area S/B.S. of the 125-watt group at rest $5.6 \pm 1.4 \text{ cm}^2/\text{m}^2$ decreased slightly to $5.1 \pm 1.3 \text{ cm}^2/\text{m}^2$ at the load of 50-watt but it increased thereafter. The 75-watt angina group showed a continuous increase of the index on and after 25-watt load. The values of both the 75- and 125-watt angina groups differed significantly from those of the healthy and athlete groups ($p < 0.005$) at equivalent loads.

3. Percent area change (Fig. 2-D)

The % area change at rest in the healthy and athlete groups was 52.0 ± 3.4 and $53.4 \pm 3.1\%$, respectively, and increased significantly to 63.2 ± 2.2 and $65.5 \pm 5.8\%$, respectively, at maximal load ($p < 0.005$). The values in the athlete group at each load level were always higher than those in the healthy group. The values in the 125-watt group at rest ($50.8 \pm 8.5\%$) increased significantly to $61.8 \pm 5.6\%$ on exercise at 50-watt ($p < 0.05$), but after the exercise at 75-watt the increased value began to decrease gradually to $53.4 \pm 8.1\%$ on exercise at 125-watt. The % area change of the 75-watt angina group decreased significantly from $52.9 \pm 11.8\%$ at rest to $45.3 \pm 17.8\%$ on exercise at 75 watts ($p < 0.10$).

4. mVcf (Fig. 2-E)

mVcf of the healthy group (0.99 ± 0.15 at

Fig.3. The cardiac response to exercise could be divided into 4 types.

TABLE II THE DISTRIBUTION OF EACH GROUP CLASSIFIED ACCORDING TO THE TYPE OF CARDIAC RESPONSE

	<i>Athlete</i> <i>n</i> = 20	<i>Normal</i> <i>n</i> = 9	<i>Angina</i> (125) <i>n</i> = 12	<i>Angina</i> (75) <i>n</i> = 13
<i>Type A</i>	20 (100%)	8 (88.9%)		
<i>Type B</i>		1 (11.1%)	8 (66.7%)	
<i>Type C</i>			4 (33.3%)	5 (38.5%)
<i>Type D</i>				8 (61.5%)

rest) increased linearly up to 1.83 ± 0.22 at 125-watt load and reached a plateau at 150-watt (1.88 ± 0.22). On the other hand, the value of the athlete group (1.06 ± 0.12 at rest) continued to increase almost linearly, and reached 1.98 ± 0.27 on 175-watt load. mVcf was significantly higher in the healthy group than in the athlete group ($p < 0.10$) on exercise between 50 and 125-watt, but the difference between groups became smaller at 150-watt. The values at rest in the 125-watt angina group (1.02 ± 0.25) increas-

ed significantly to 1.56 ± 0.23 on 50 watts ($p < 0.005$), and decreased gradually thereafter to 1.48 ± 0.17 at 125-watt. mVcf of the 75-watt group (1.00 ± 1.25 at rest) increased slightly to 1.23 ± 0.37 at 25-watt, but began to decrease rapidly (1.07 ± 0.51 at 75-watt).

5. Cardiac response to exercise

The cardiac response in 54 cases consisting of 25 angina patients, 9 healthy men and 20 athletes could be divided into 4 types (Fig. 3).

Fig. 4-A, B. Time course of HR and blood pressure.

HR of the subjects in their forties or over (groups 3, 4 and 5) attained a plateau after 100 watts. Ps and Pd in subjects at all ages (all groups) rose as loads increased.

20 = twenties (group 1); 30 = thirties (group 2); 40 = forties (group 3); 50 = fifties (group 4); 60 = sixties (group 5)

C. Time course of area.

The values of Area D/B.S. and Area S/B.S. decreased up to 150-watt in subjects below 39 years (groups 1 and 2).

D. Time course of % area change.

The increased values of % area change in subjects below 39 (groups 1 and 2) were maintained up to 150-watt. But the values in subjects older than 40 (groups 3, 4 and 5) decreased after 75-watt.

E. Time course of mVcf.

The values of mVcf in subjects below 39 (groups 1 and 2) increased linearly up to 150-watt, but at older than 40 (groups 3, 4 and 5) they decreased gradually after 100-watt.

In type A, Area D enlarged slightly in the early stage of exercise and decreased gradually thereafter concomitant with a decrease in Area S and increase in % area change and mVcf until the submaximum load.

In type B, Area D enlarged slightly in the early stage of exercise, and the enlarged area was maintained thereafter, whereas a small reduction in the size of Area S was observed. Percent area

change and mVcf increased parallel with an increase loading until the middle stage of exercise, and reached a plateau soon after. When the exercise was carried out at the submaximum load, a decrease in these contractile parameters and the dilation of Area D and S occurred.

In type C, each parameter remained virtually unchanged at all loads, % area change and mVcf decreased and the size of both Area D and S were

TABLE III THE DISTRIBUTION OF ALL SUBJECTS AT ALL AGES CLASSIFIED ACCORDING TO THE TYPE OF CARDIAC RESPONSE

	20-29 n = 9	30-39 n = 8	40-49 n = 8	50-59 n = 7	60-69 n = 8
Type A	8 (88.9%)	7 (87.5%)	5 (62.5%)	4 (57.2%)	2 (25.0%)
Type B	1 (11.1%)	1 (12.5%)	3 (37.5%)	3 (42.8%)	6 (75.0%)
Type C	0	0	0	0	0
Type D	0	0	0	0	0

enlarged at the sub-maximum load.

In type D, Areas D and S were enlarged continuously from the early stage of exercise, while % area change and mVcf decreased gradually.

Table II shows the distribution of the subjects according to the four types of cardiac response. The healthy or athletes demonstrated type A or type B response. On the other hand, approximately two-thirds of the angina patients showed type C or D response.

II Influence of Aging on Cardiac Response to Exercise

1. HR and BP (Fig. 4-A, B)

HR was increased as load was increased in each group. Although HR of groups 3, 4 and 5 (subjects older than 40 years) reached a plateau after loading at 100-watt, group 1 and 2 levels (subjects below 39 years) increased linearly up to 150-watt. BPs and Bpd at rest tended to be higher in old subjects or remained unchanged during exercise.

2. Area/B.S. (Fig. 4-C, Table I)

Area D/B.S. of groups 1 and 2 increased up to 50-watt and thereafter decreased gradually to resting or lower value at 125- or 150-watt load. The value of groups 3, 4 and 5 increased similarly to that of groups 1 and 2 up to 100-watt, but it rose again at 125-watt.

Area S/B.S. of each group decreased gradually up to 75-watt and continued to decline until 150-watt in groups 1 and 2, but the value of groups 3, 4 and 5 rather increased on 100 – 125-watt.

3. Percent area change (Fig. 4-D)

The percent change of group 1 rose to 150-watt continuously, and the value of group 2 was maximum at 100-watt; on the other hand, the

value of groups 3, 4 and 5 reached a peak at 50-watt, and began to decrease thereafter.

4. mVcf (Fig. 4-E)

mVcf of groups 1 and 2 continued to increase up to 150-watt but that of groups 3, 4 and 5 reached a plateau at 75–125-watt and decreased at 125-watt load.

Table III shows the distribution of each group into classified types. All groups belonged to either Type A or B. Most of the young subjects belonged to Type A, while the number of subjects belonging to Type B increased according to advancing age.

DISCUSSION

The cardiac function at rest in patients with effort angina is usually within normal limits. Therefore, the determination of contractile indexes during atrial pacing, afterload stress and various forms of exercise are necessary to determine the cardiac reserve and influence of ischemia. For this purpose, the exercise cross-sectional echocardiography¹⁻³ is a useful technique to observe in detail the virtual motion of the ventricular wall. In the present study the bicycle ergometer loading test was attempted in a supine posture in patients with angina on effort, and the cardiac response to exercise was compared with that of the healthy sedentary men and athletes. Moynihan⁴ et al. recorded LVT at the mitral and papillary muscle levels by the cross-sectional echocardiography to analyze quantitatively abnormal motion of the left ventricular wall, and they demonstrated that the cross-sectional area method at either the mitral or the papillary muscle level caused no difference for reproducibility and % area changes of LVT. Paris et al⁵ considered that the area method is

superior to the linear method (cross-sectional diameter) in accuracy for assessing regional contractility. In the experimental obstruction of the left anterior descending coronary artery, Gueret et al⁶ demonstrated that abnormal motion of the ventricular wall at the mitral level rarely occurred and that LVEDV and EF determined from angiography had a better correlation with those obtained by echocardiography at the papillary muscle level. These results suggest that the area method which can observe LVT at the papillary muscle level by two-dimensional echocardiography is suitable to evaluate the cardiac response of anginal patients.

The patients with angina on effort in this study could be divided into 2 groups (75- and 125-watt angina groups) according to the amount of exercise.

In the 125-watt angina group, Area D in the early phase of exercise was slightly enlarged due to the increase in venous return and Area S was reduced gradually with an increase of contractility, the mobilization of which was limited to such an extent that it resulted in an increase of LVEDV and LVESV at 75- or 100-watt load. In the 75-watt group the contractility increased slightly at 25-watt load, but it decreased soon on and after exercise of 50-watt load with a progressive increase in LVEDV and LVESV. BPs of this group decreased and the increase in heart rate also reached a plateau at 75-watt load which suggests the smallest cardiac reserve to work load⁷.

In the controls, the increased LVEDV due to mobilization of preload decreased gradually between 75 and 150-watt due to shortening of the left ventricular diastolic time caused by an increased HR and LVESV decreased gradually throughout the exercise. On the other hand, the cardiac response of the athlete group in their twenties was similar to that of the sedentary control in their twenties, although BPs, BPd and HR⁸ of the former were significantly lower than those of the latter ($p < 0.025$). This tendency continued during exercise, proving that the heart of athletes could respond to the load with a smaller amount of myocardial oxygen consumption. Large LVEDV and a high % area change at rest for the athlete indicates that a Frank-Starling mechanism becomes effective even in the rest state. In addition, owing to a great arterio-venous oxygen extraction in the peripheral region as reported by Rowel et al⁹, the athlete seemed to be able to respond to the middle stage of exercise

with less mobilization of sympathetic activity. Area S of the athlete group decreased significantly from 150-watt in comparison with that of the sedentary control group ($p < 0.05$). This fact suggests that a sufficient cardiac reserve was preserved in the athlete group even in the maximum stage of the sedentary control.

In the present study the cardiac response to exercise could be classified into 4 types (A, B, C, D) according to the changes in Area D, Area S and the contractility indexes of % area change and mVcf.

Type A responded to exercise by a significant increase in left ventricular contractility. The compliance to the increased LVEDV in the early stage of exercise seemed to be maintained by the increased venous return, which may lead to activation of the Frank-Starling mechanism. Type A which only the healthy and athlete groups had indicated sufficient cardiac reserve and should be a normal response to exercise.

Type B disclosed a response similar to that of type A in the early and middle stages of loading. However, LVEDV, LVESV and the contractility parameters of type B reached a plateau suggesting a limit of mobilization of cardiac contractility between the middle and later stages of loading. Increase in cardiac output in the late stage of exercise was dependent on an increase of HR. This type included the healthy (11.8%) and the 125-watt angina (66.8%) groups.

In type C, LVEDV, LVESV and % area change from the early stage through the late stage of loading remained almost unchanged. Many of the subjects with this response had a large LVEDV value at rest. Contractility was decreased even by low-grade exercise, which consequently resulted in a further increase of LVEDV and LVESV to show a definite reduction of cardiac reserve.

Type D indicated a decrease of contractility and an increase of LVEDV and LVESV from the early stage of exercise. The cardiac reserve was the smallest among the 4 types.

Type C included 33.4% of the 125-watt angina and 38.5% of the 75-watt angina groups. Type D included 61.5% of the 75-watt angina group. Both findings were indicative of a decrease in cardiac contractility due to extensive myocardial ischemia.

Coronary heart disease is essentially asymptomatic until middle age. Therefore, the influence of aging¹⁰⁻¹² on the disease should be considered in the estimation of cardiac reserve. Port¹¹ et

al. have described an age-related decline in left ventricular contractile reserve. In the present study, as shown in Table III, many subjects at ages below 39 years were categorized into type A. The subjects older than 40 years had Type B response, indicating that their cardiac reserve decreased as their age advanced. None of the healthy subjects had Type C or D response. Both types could be verified to be a response indicative of lowered cardiac reserve of the patients qualitatively. More than 60% of the patients in the 125-watt angina group were categorized as having Type B. But they had normal exercise thallium-201 myocardial perfusion images as reported by our colleagues; nevertheless, they had documented significant coronary artery stenosis. This indicates that their collateral circulation is adequate in the myocardial region subtended by diseased coronary artery vessels. Therefore, patients with Type B may show a normal cardiac function. It is understood that even though a patient shows a Type B response, we should not exclude the possibility of ischemic heart disease.

In the present study 80% of the 25 patients showed wall motion abnormality during exercise. The appearance of asynergy is very important to diagnose ischemic heart disease¹³⁻¹⁹ but it does not necessarily relate to cardiac reserve. Because patients with asynergy in Type B, C and D demonstrated highly variable exercise capacity from 50-watt to 125-watt. In Type B patients, if asynergy occurred, their intact left ventricular wall could compensate for the reduced wall motion in the ischemic region and thus their stroke volume increased significantly like healthy men. However, in Type C and D patients their Area did not increase significantly and their exercise performance was low since their intact wall could not completely compensate for the asynergy.

Therefore it is useful to classify the cardiac response into 4 types for predicting the cardiac reserve of patients with coronary heart disease.

LVDs, LVDd and contractility indexes during exercise have been documented elsewhere.²⁰⁻²³ Zwehl²⁴ et al. have reported that after exercise loading up to 125-watt, the LVT of healthy subjects showed a decrease in Area D and an increase in % area change. Rerych²⁵ et al. have reported that normal subjects showed no change or increase of LVEDV, and a decrease of LVESV and EF, whereas patients with ischemic heart disease showed an increase of both LVEDV and LVESV and a decrease in EF.

It is obvious than the response of ventricular volume and heart contractility to exercise varies depending on cardiac reserve and the load amount. Therefore, to evaluate the experimental results mentioned above, measurement of individual contractile indexes at each level of the load for the assessment of cardiac response is recommended.

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