The Significance of Abnormal Systolic Blood Pressure Response during Supine Ergometer Exercise and Postexercise in Ischemic Heart Disease, Studied by Exercise Radionuclide Ventriculography

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SUMMARY

The prognostic value of abnormal postexercise systolic blood pressure (BP) response has not been investigated. Therefore, the significance of abnormal BP response during exercise and postexercise was examined in 169 patients with ischemic heart disease subjected to supine ergometer exercise gated equilibrium radionuclide ventriculography, coronary arteriography, and follow up averaging 3.6 years.

Abnormal BP response during exercise (exertional "hypotension") was defined as 1) a failure of BP to rise by at least 11 mmHg or 2) an initial rise in BP but subsequent fall by more than 10 mmHg during exercise. Abnormal BP response during postexercise (postexercise "hypertension") was defined as an increase of more than 10 mmHg above the peak exercise BP.

Of 169 patients, 51 (30%) had an abnormal BP response. Four types of BP response were identified: exertional "hypotension" (group 1a, n=11), postexercise "hypertension" (group 1b, n=30), exertional "hypotension" with postexercise "hypertension" (group 1c, n=10) and normal BP response (group 2, n=118). Both average exercise duration and peak heart rate were significantly lower in groups 1a, 1b and 1c than in group 2. The severity of exercise ST-segment depression was greater in groups 1b and 1c than in group 2. However, there was no significant difference in the severity of exercise ST-segment depression between group 1a and group 2. A decline in ejection fraction occurred more frequently in groups 1b and 1c than in group 2. Pa-

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Received for publication June 4, 1988.

Accepted August 26, 1988.

tients in groups 1a, 1b and 1c had more extensive coronary artery disease (CAD) than did patients in group 2. Medically treated patients with an abnormal BP response (groups 1a, 1b and 1c) had a poorer prognosis than did those with a normal BP response (group 2).

These findings suggest that an abnormal BP response during supine exercise is infrequent, but is usually associated with impaired exercise tolerance and severe CAD. An abnormal postexercise BP response is also infrequent, but is more closely associated with evidence of myocardial ischemia and global left ventricular dysfunction than exertional "hypotension". In conclusion, postexercise "hypertension" has the same value as exertional "hypotension" as a predictor of poor prognosis.

Additional Indexing Words:

Left ventricular function Prognosis Postexercise "hypertension"

IT is well established that an abnormal systolic blood pressure (BP) response during exercise, including exertional hypotension, is strongly associated with severe coronary artery disease (CAD)¹⁾ and an unfavorable prognosis.²⁾⁻⁴⁾ In these investigations, exercise was conducted by upright treadmill testing. Although supine ergometer exercise is also frequently used for the evaluation of CAD, the significance of an abnormal BP response in this procedure has not been studied extensively.⁵⁾

Recently, postexercise BP response was examined by Amon et al⁶⁾ in normal subjects and in patients with CAD to evaluate its diagnostic value and relationship to the severity of the disease. They concluded that the ratios of early recovery BP to the peak exercise BP were more sensitive than exercise electrocardiographic changes and angina for identifying patients with CAD.⁶⁾ Kawakubo et al also reported that an abnormal rise of BP in the recovery phase of a treadmill exercise test was useful as a predictor of severe CAD.⁷⁾ However, the relationship between exercise-induced myocardial dysfunction and postexercise BP response has not been studied extensively. The prognostic value of an abnormal postexercise BP response has not been reported.

This study examines the significance of an abnormal BP response during supine ergometer exercise and that of an abnormal postexercise BP response and elucidates their prognostic value.

METHODS

The patient population was selected from among 500 consecutive patients undergoing supine ergometer exercise testing at our institution between April, 1982 and September, 1986. Seventy three patients with hypertension were excluded. Ninety four patients with clinical diagnoses of val-

Table I. Subjects

	N	M/F	Age
Effort angina	41	31/10	35-77 (58±10)
with old myocardial infarction	22	18/4	37-70 (57±9)
Old myocardial infarction	60	55/5	35-85 (54±10)
Vasospastic angina	18	15/3	35-68 (54±9)
Chest pain syndrome	28	10/18	38-64 (52±7)
Normal control	105	73/32	15-74 (42±14)

vular heart disease, congenital heart disease and cardiomyopathy were also excluded. Furthermore, patients with atrial fibrillation, left bundle branch block, other conduction abnormalities that would preclude evaluating ST-segment changes and those receiving digitalis preparations were excluded. The patients with marked bradycardia (less than 50/min) or marked tachycardia (more than 150/min) and those with aortitis syndrome were also excluded due to the difficulty in measuring their blood pressure. The remaining 274 patients were studied.

Table I presents their clinical profiles. The study group included 169 patients with ischemic heart disease and 105 normal control subjects. All had sinus rhythm and were normotensive. In 105 normal control subjects, cardiac examination was normal and no subject had clinical evidence of cardiomegaly. Although the majority of these subjects had been suspected of having coronary artery disease (CAD), none manifested chest pain or ST-segment depression during exercise testing. Eighty two of the 169 patients with ischemic heart disease had had a myocardial infarction at least 6 months before the study. Twenty two patients with old myocardial infarction and 41 other patients had experienced exertional angina pectoris. All 63 patients had stable angina pectoris that could be reproduced during exercise testing. Eighteen patients with vasospastic angina were diagnosed by the following criteria: (1) Transient ST-segment elevation of more than 0.2 mV from baseline ECG documented during chest pain occurring at rest; (2) both the chest pain and ST-segment elevation were promptly relieved by sublingual nitroglycerin without any changes in cardiac enzymes; (3) coronary vasospasm was demonstrated by coronary angiography during spontaneous angina or angina provoked by ergonovine maleate. Twenty eight patients with chest pain syndrome were included in this study population. All had typical angina pectoris relieved by rest and nitroglycerin, a positive exercise test response (ST-segment depression of more than 0.1 mV in at least one lead), no evidence of coronary artery spasm and angiographically normal epicardial coronary arteries. For 2 days prior to the com-

mencement of the test, almost all patients were on no medications except sublingual nitrates. However, in a few patients with severe CAD, cardiac medications were not discontinued.

Exercise stress testing was performed by an electrically-braked bicycle ergometer (Siemens^R) in the supine position. Exercise was begun at 0.5–1.0 watt/kg and increased every 3 min by 0.5 watt/kg. Reasons for stopping the test included moderate chest pain, dyspnea, severe leg fatigue, serious arrhythmia, marked electrocardiographic changes (0.3 mV or more of downsloping or horizontal ST-segment depression) and marked hypertension (systolic blood pressure of 250 mmHg or greater).

The blood pressure was measured indirectly in the left arm with a cuff sphygmomanometer at rest just before testing, during each minute of exercise and every minute thereafter for 5–10 min by any of 3 skilled physicians. A 12-lead electrocardiogram was recorded every minute during the test. An ischemic response was defined as horizontal or downsloping ST-segment depression of at least 0.1 mV of 0.08 sec duration or greater. If there were resting ST-segment changes present, an additional 0.1 mV of ST-segment depression was required to classify the exercise test as positive.

An abnormal systolic blood pressure (BP) response during exercise (exertional “hypotension”) was defined as: 1) a failure of BP to rise by at least 11 mmHg (flat BP response) or 2) initial rise in BP but subsequent fall by more than 10 mmHg during exercise. An abnormal BP response during postexercise (postexercise “hypertension”) was defined as an increase of more than 10 mmHg above the peak exercise BP.

Exercise radionuclide ventriculography was performed by a conventional gated equilibrium technique in 160 subjects (134 patients with ischemic heart disease and 26 normal controls). Red blood cells were labeled in vivo by intravenous administration of 4 mg of stannous pyrophosphate in 5 ml of physiologic saline solution, followed 30 min later by an injection of 20 mCi of technetium-99 m. The gamma camera with a parallel-hole collimator was positioned in the 30° left anterior oblique view with a caudal angulation of 15°. Imaging was performed both at rest just before exercise and during the last 3 min of exercise. Left ventricular ejection fraction (EF) was calculated using multiple regions of interest, with semiautomatic edge detection and computer-determined background areas. Ejection fraction was measured at rest and at peak exercise. Ejection fraction response to exercise was evaluated by Δ EF (EF at peak exercise minus EF at rest).

Of 169 patients with ischemic heart disease, 149 had undergone coronary angiography by Judkins' or Sones' technique within 2 weeks after the exercise test. Selective coronary angiograms were recorded after admin-

istration of sublingual nitroglycerin in multiple left and right anterior oblique views using caudal and cranial angulation where necessary. Coronary angiograms were evaluated by the authors who had not known the results of the exercise test. A significant coronary lesion was defined as one causing greater than 50% luminal diameter narrowing of the left main coronary artery or greater than 75% diameter stenosis of a major epicardial coronary artery.

All 169 patients with ischemic heart disease were followed up annually for 18 to 72 months (mean 43). Of 169 patients, 38 patients who had early (less than 1 year after the exercise test) coronary revascularization (coronary bypass surgery or percutaneous coronary angioplasty) were excluded from the follow up analysis. The adverse cardiac events were defined as cardiac death, non-fatal myocardial infarction and late coronary revascularization (more than 1 year after the test). Only one event was considered in each patient, and any event occurring after the initial one was not considered. The only exception was cardiac death. Deaths were interpreted as having a cardiac or noncardiac cause on the basis of evaluation of data on hospitalization and from a family interview.

Statistical analysis:

Comparisons of patient groups were evaluated with chi-square analysis, Fisher's method⁸⁾ or the unpaired Student's *t*-test. Differences were considered significant at probability *p* values of less than 0.05. Data presented are mean $\pm$ SD.

RESULTS

Table II presents the BP results in 105 normal control subjects. The change in BP (Δ BP) during exercise in normal control subjects was 40.1 ± 14.5 mmHg. Therefore, normal BP response to exercise was defined as a rise of BP by at least 11 mmHg (mean -2 SD). Of 105 normal control subjects, 6 subjects had BPs in the recovery period that were higher than the peak-exercise BPs. However, the rise of BP was less than 10 mmHg in all 6 subjects.

The effect of age on the BP response was further analyzed (Table II). Both the resting BPs and peak-exercise BPs were higher in the older subjects than in the younger subjects. In all age groups, postexercise BP fell in a linear fashion throughout the recovery period until the BP returned to the preexercise level.

The effect of gender on the BP response was further analyzed (Table II).

Table II. Systolic Blood Pressures (mmHg) at Rest, During Exercise and After Exercise in 105 Normal Control Subjects

	N	Rest	Peak EX	A 1	A 2	A 3	A 4	A 5
Age (yrs)								
≤ 30	(19)	120±11	157±18	145±16	135±14	130±13	127±12	123±11
31 ≤ 40 ≤	(29)	127±16	167±19	148±16	138±14	134±15	129±13	127±14
41 ≤ 50 ≤	(23)	122±11	164±16	143±17	134±15	129±13	127±12	125±12
51 ≤ 60 ≤	(24)	125±15	170±15	147±16	136±18	133±14	129±13	126±14
61 ≤	(10)	130±16	166±23	151±18	142±16	136±17	134±16	131±13
Sex								
Male	(73)	123±13	168±18	148±17	138±14	134±14	130±13	126±14
Female	(32)	128±16	158±16	144±16	136±14	131±15	128±13	125±12
Total	(105)	125±14	165±14	148±16	137±14	133±14	129±13	125±17

EX=exercise; A1,..., A5=1,..., 5 min after exercise.

Although peak-exercise BP was higher in the male subjects than in the female subjects, postexercise BP fell in a linear fashion throughout the recovery period in both male and female subjects.

Of 169 patients with ischemic heart disease, 51 patients (30%) exhibited an abnormal BP response (group 1). The 51 patients were then classified into 3 subgroups: 11 patients with exertional "hypotension" (group 1a), 30 patients with postexercise "hypertension" (group 1b) and 10 patients with exertional "hypotension" and postexercise "hypertension" (group 1c). The other 118 patients (group 2) had normal BP responses.

Of the 21 patients with exertional "hypotension" (group 1a+1c), only 3 patients, comprising 2% of the total number of patients, had exertional hypotension according to the strict definition, that is, a fall in BP to below the resting level. Of the other 18 patients, 3 had an initial rise in BP but subsequent drop and 15 had a flat BP response.

Table III presents the clinical diagnosis in each group. The incidence of abnormal BP response was significantly higher in patients with effort angina (26 of 41 patients, 63%) than in patients with old myocardial infarction (OMI) (11 of 60 patients, 18%) ($p < 0.01$). The incidence of prior myocardial infarction in group 1a (exertional "hypotension") was 64% (7 of 11 patients), compared to 33% (10 of 30 patients) in group 1b (post-exercise "hypertension"), but the difference was not statistically significant. Although the incidence of effort angina in group 1a was 45% (5 of 11 patients), compared to 67% (20 of 30 patients) in group 1b, the difference was also not statistically significant.

Table IV presents mean exercise duration and mean maximal heart

Table III. Incidence of Abnormal Systolic Blood Pressure Response

	N	Group 1a	Group 1b	Group 1c	Group 2
EA	41	3	16 26(63%)	7	15
EA+MI	22	2	4 8(36%)	2	14
MI	60	5	6 11(18%)	0	49
VA	18	0	2 2(11%)	0	16
CPS	28	1	2 4(14%)	1	24
	169	11	30 51(30%)	10	118

EA=effort angina; MI=old myocardial infarction; VA=vasospastic angina; CPS=chest pain syndrome.

Table IV. Exercise Duration and Peak Heart Rate in Patients with Normal and Abnormal Blood Pressure Response

	N	Exercise duration (sec)	Peak HR (bpm)
IHD			
Group 1a	11	242±95*†	107±13*†
Group 1b	30	282±88*†	113±17*
Group 1c	10	196±82*†	103±21*††
Group 1 (1a+1b+1c)	51	258±93*†	110±17*†
Group 2	118	340±109*	120±17**
Normal control	105	385±99	126±18

* $p < 0.01$, ** $p < 0.025$ vs Normal control.

† $p < 0.01$, †† $p < 0.025$ vs Group 2.

HR=heart rate; IHD=ischemic heart disease.

rate in each group of patients and normal control subjects. Average exercise duration was significantly lower in patients with ischemic heart disease than in normal control subjects. The duration of exercise in patients with a normal BP response (group 2) was appreciably longer than that in patients with an abnormal BP response (group 1); the shortest duration was found in group 1c patients. Mean maximal heart rate was significantly different between the 2 groups (groups 1 and 2). The exercise heart rate achieved was significantly lower in group 1a and group 1b than in group 2, however, there was no significant difference in mean maximal heart rate between the normal and postexercise "hypertension" groups (groups 1b and 2).

The mean magnitude of exercise-induced ST-segment depression was

Fig. 1. The mean magnitude of exercise-induced ST-segment depression in each ischemic heart disease group.

Table V. Resting Left Ventricular Ejection Fraction and Its Response to Exercise

	N	Resting EF (%)	ΔEF (%)
IHD			
Group 1a	8	65±4	-1±9*
Group 1b	27	61±15**	-3±9*††
Group 1c	9	60±10*	-7±9*†
Group 1 (1a+1b+1c)	44	60±13*	-4±9*†
Group 2	93	64±11*	2±9*
Normal control	26	70±8	8±5

* $p < 0.01$, ** $p < 0.025$ vs Normal control.

† $p < 0.01$, †† $p < 0.025$ vs Group 2.

EF=ejection fraction.

greater in groups 1b and 1c than in group 2 (Fig. 1). The degree of ST segment depression, however, was not significantly different between group 1a and group 2.

Table V presents the resting ejection fraction and its response to exercise (Δ EF) in patients with ischemic heart disease and normal control subjects. Resting EF in patients with ischemic heart disease except for group 1a was lower than that in normal controls. The difference is probably due to the significant prevalence of old myocardial infarction in patients with ischemic heart disease. However, resting EF did not differ significantly among the 4 subgroups (groups 1a, 1b, 1c and 2).

There was a marked difference in Δ EF between patients with ischemic heart disease and normal control subjects (Table V). Among the groups with ischemic heart disease, Δ EF in groups 1b and 1c was significantly lower

than that in group 2. However, Δ EF was not significantly different between group 1a and group 2.

Therefore, exercise-induced left ventricular dysfunction in patients with postexercise "hypertension" even in the absence of exertional "hypotension" was more severe than that in patients with a normal BP response. On the other hand, exertional "hypotension" in the absence of postexercise "hypertension" may not always indicate severely impaired left ventricular function during exercise.

The incidence of significant coronary artery stenosis was higher in group 1 (1a+1b+1c) (33 of 39, 85%) than in group 2 (64 of 110, 58%) ($p<0.01$). Furthermore, severe coronary artery disease (3-vessel disease or left main trunk stenosis) was also more frequent in group 1 (1a+1b+1c) (10 of 39, 26%) than in group 2 (7 of 110, 6%) ($p<0.01$).

Among the abnormal BP response groups, the incidence of significant coronary artery stenosis was 83% (5 of 6 patients) in group 1a, 83% (20 of 24 patients) in group 1b and 89% (8 of 9 patients) in group 1c. Although the incidence of severe coronary artery disease in group 1c was 44% (4 of 9 patients), compared to 33% (2 of 6 patients) in group 1a and 17% (4 of 24 patients) in group 1b, these differences were not statistically significant ($p=NS$).

Patients with postexercise "hypertension" were divided into 2 subgroups according to the duration of postexercise "hypertension", that is, 25 patients with sustained "hypertension" ("hypertension" >1 min; 1-2 (min): 5, 2-3: 8, 3-4: 9, <5 : 3) and 15 patients with nonsustained "hypertension" (1 min or less). The mean exercise duration and the mean maximal heart rate were similar in the 2 groups. However, the incidences of both significant ST-segment depression and abnormal EF response (Δ EF $<5\%$) were higher in the former group than in the latter group ($p<0.05$, $p<0.05$). The incidence of significant coronary artery stenosis was also higher in the sustained "hypertension" group than in the nonsustained "hypertension" group ($p<0.05$).

Postexercise "hypertension" was also divided by the time when the peak postexercise "hypertension" occurred. Early "hypertension" was defined as the peak "hypertension" occurring within 3 min after exercise, while late "hypertension" as the peak occurring more than 3 min after exercise. The incidence of effort angina was 100% (14 of 14 patients) in the late "hypertension" group, compared to 62% (16 of 26 patients) in the early "hypertension" group ($p<0.05$). The incidence of significant ST-segment depression was also higher in the late "hypertension" group than in the early "hypertension" group ($p<0.05$). Both groups had a similar

Fig. 2. The incidence of adverse cardiac events in each ischemic heart disease group.

incidence of the other clinical and angiographic variables (exercise duration, maximal heart rate, EF response and coronary angiographic findings).

Figure 2 presents the incidence of adverse cardiac events in each ischemic heart disease group. There were 13 cardiac events among 42 group 1 patients, for an event rate of 31%; the events were 5 cardiac deaths, 7 myocardial infarctions and 1 late coronary bypass operation. On the other hand, there were only 4 cardiac events among 89 group 2 patients, for an event rate of 4%; the events were 1 cardiac death, 1 myocardial infarction, 1 late coronary bypass operation and 1 late percutaneous coronary angioplasty. When patients with and without an abnormal BP response were compared, there were more events, including death, in the group with an abnormal BP response ($p < 0.01$). When patients of group 2 were compared to patients of groups 1a, 1b and 1c, there were fewer events in group 2 ($p < 0.05$, $p < 0.01$ and $p < 0.01$, respectively). Although the incidence of adverse cardiac events was higher in group 1c than in groups 1a and 1b, the differences were not statistically significant ($p = \text{NS}$, NS).

DISCUSSION

Definition of abnormal BP response:

In this study, an abnormal BP response during exercise was defined as: 1) a failure of BP to rise by at least 11 mmHg or 2) an initial rise in BP but subsequent fall by more than 10 mmHg during exercise. This definition seemed to be reasonable because 1) the lower limit (mean -2SD) of the rise in BP in normal control subjects was 11 mmHg and 2) the limits of accuracy of the measurement by sphygmomanometer also seemed to be about

10 mmHg. The definition of abnormal BP response during exercise in this study was almost the same as that of Sanmarco et al.¹¹

Fraser et al reported that a second significant rise in systolic pressure (detected by a direct method) occurred between 10 and 30 sec after an immediate and significant fall by 6 to 10 mmHg during the first minute of recovery in older healthy subjects.⁹ Ellestad mentioned that in normal subjects systolic blood pressure declined steadily from 1 min after treadmill testing throughout the recovery period.¹⁰

Although the exercise method for this study differed from those for the previous studies with respect to patient position during exercise, 6 (6%) of 105 normal subjects had a rise in systolic blood pressure to above the peak systolic blood pressure during exercise at 1 min after exercise. However, none of the subjects had a rise in postexercise BP greater than 10 mmHg. Therefore, it may be an insignificant change because clinical sphygmomanometry has a limitation in accuracy. Therefore, abnormal BP response during postexercise (from 1 min after exercise) was defined as an increase of more than 10 mmHg above the peak exercise BP.

Incidence of abnormal BP response:

The frequency of abnormal blood pressure response varies widely between studies depending on the nature of the study population and the definition of abnormal blood pressure response. The prevalence of strictly defined exertional hypotension in the previous studies ranged from 2.7 to 9.3%.^{4),11)-13)} Although the 2% frequency observed in this study was less than that obtained in studies using upright treadmill exercise, it was consistent with the 3% frequency reported by Gibbons et al during supine ergometer exercise.⁵⁾

The 12% frequency of exertional "hypotension", which includes not only exertional hypotension but also a flat BP response and initial rise in BP with subsequent fall, was also lower than the 24% frequency reported by Sanmarco et al during upright treadmill exercise, using a similar definition.¹¹ Gibbons et al suggested that exertional hypotension was infrequent in the supine position because supine exercise was generally associated with a larger ventricular volume and a higher systolic blood pressure than upright exercise.⁵⁾

Kawakubo et al reported that the frequency of postexercise BP rise was 24% in patients with coronary artery disease.⁷⁾ If postexercise "hypertension" is defined using their definition (abnormal BP rise for more than 2 min during the recovery phase), the frequency is 9% in this study. Therefore, postexercise "hypertension" may also be less frequent in supine exercise

than in upright exercise.

Of 40 patients with postexercise "hypertension", only 10 patients (25%) also had exertional "hypotension". Although Kawakubo et al reported that 13 (81%) of 16 patients with postexercise "hypertension" also had exertional "hypotension", this discrepancy in the results was due mainly to the difference in the definition of postexercise "hypertension". The frequency of exertional "hypotension" accompanying postexercise "hypertension" in this study was increased from 25 to 60% (9 of 15) using their definition.

Clinical significance of abnormal BP response:

The exercise tolerance evaluated by exercise duration and maximal heart rate was impaired more severely in patients with exertional "hypotension" than in patients with normal BP response in this study. This observation is consistent with both the study using supine exercise⁵⁾ and those using upright exercise.^{3),4),11),13)}

The exercise tolerance was also impaired more severely in patients with postexercise "hypertension" than in patients with normal BP response. There are little, if any, data available regarding the relationship between exercise tolerance and postexercise BP response.

The patients with exertional "hypotension" in the absence of postexercise "hypertension" (group 1a) and the patients with normal BP response had a similar degree of ST-segment depression. There are conflicting reports regarding the relationship between exertional hypotension and exercise-induced ST-segment depression. Levites et al reported that the incidence of positive treadmill tests was significantly higher in the hypotensive group.¹¹⁾ Weiner et al also showed that the severity of the exercise ST-segment abnormalities in patients with exertional hypotension was demonstrated by their greater extent, as well as by the greater number of leads in which the depression occurred compared with findings in patients without a decrease in systolic pressure.¹³⁾ On the other hand, Morris et al¹²⁾ and Hammermeister et al⁴⁾ reported that no significant differences were observed between those with and without exertional hypotension in the frequency of ST-segment abnormalities with exercise. Hakki et al also reported that ST-segment depression was not different among the 3 groups (normal, blunted and hypotensive BP responses).¹⁴⁾

Mean maximal ST-segment depression in patients with postexercise "hypertension", regardless of the BP response during exercise, was greater than that in patients with a normal BP response. This observation is consistent with the results of Kawakubo et al though upright treadmill exercise was

used in their study.⁷⁾

Relation to left ventricular function :

Mean resting left ventricular ejection fraction in patients with ischemic heart disease was significantly lower than that in normal control subjects because the former included patients with previous myocardial infarction. However, there was no significant difference in mean resting EF between patients with and without an abnormal BP response. This finding is consistent with the previous studies using treadmill exercise.^{1),3),13),15),16)} However, Hammermeister et al reported that the mean resting EF was lower in patients with exertional hypotension than in patients without hypotension.⁴⁾ Hakki et al also observed a similar finding.¹⁴⁾

There was no significant difference in resting EF between patients with and without postexercise "hypertension" in the present study. This result was consistent with the result of Kawakubo et al.⁷⁾

The relationship between exertional hypotension and exercise-induced left ventricular dysfunction has not been studied extensively. Gibbons et al reported that the frequency of a decrease in ejection fraction during supine exercise was significantly greater in patients with exertional hypotension than in patients with a normal BP response.⁵⁾ Ehsani also showed that the ejection fraction during exercise was significantly lower in patients with exertional hypotension than in patients with a normal BP response.¹⁶⁾ This study confirmed these results since all 3 patients with exertional hypotension by strict definition showed a decrease in EF during exercise. However, the patients with exertional "hypotension" in the absence of postexercise "hypertension" (group 1a) had a small decrease in mean EF, and this change was not different from that in patients with a normal BP response (group 2).

There have not been any reports regarding the relationship between postexercise "hypertension" and exercise-induced left ventricular dysfunction. This study revealed that postexercise "hypertension", regardless of the BP response during exercise, was associated with exercise-induced left ventricular systolic dysfunction.

Relationship between abnormal BP response and coronary artery lesions :

This study showed that exertional "hypotension" was a reliable predictor of coronary artery disease and that the prevalence of severe coronary artery disease (left main trunk stenosis or 3-vessel disease) was significantly higher in patients with exertional "hypotension" than in patients with a normal BP response. Previous studies have shown a strong association of exertional hypotension with multivessel coronary artery disease.^{3),12)} How-

ever, Hammermeister et al reported that exertional hypotension was an insensitive indicator of significant left main coronary artery stenosis or 3-vessel disease.⁴⁾

Patients with postexercise "hypertension" also had extensive coronary artery disease. This finding is similar to the data from Kawakubo's report in that the frequency of 3-vessel disease was greater in patients with postexercise "hypertension" than in patients with a normal BP response.⁷⁾

Prognostic significance:

Multiple previous studies have demonstrated that exertional hypotension and/or a flat BP response during upright treadmill exercise is clearly associated with impaired survival.²⁾⁻⁴⁾ However, the prognostic significance of postexercise "hypertension" has not been reported.

This study demonstrated that both a "hypotensive" response during supine exercise and a "hypertensive" response during postexercise were associated with poor prognosis.

Comparison between exertional "hypotension" and postexercise "hypertension":

Although it may have been an unexpected result that the coincidence of exertional "hypotension" and postexercise "hypertension" was rather infrequent, the two abnormal BP responses may be ascribed at least in part to different mechanisms. Although the two abnormal BP responses were useful as markers of severe CAD, postexercise "hypertension" was more closely associated with exercise-induced left ventricular systolic dysfunction probably secondary to extensive myocardial ischemia. On the other hand, in the absence of postexercise "hypertension", exertional "hypotension" was not related to severe exercise-induced left ventricular dysfunction. Recently, Mazzotta et al showed that abnormal BP responses (hypotensive and flat responses) during exercise were not always related to the severity of left ventricular dysfunction in some patients with acute myocardial infarction.¹⁷⁾

Causes of postexercise "hypertension":

In patients with coronary artery disease, an increase in BP after upright exercise is likely to be associated with a transient increase in stroke volume because of improvement in myocardial asynergy during the recovery period.¹⁸⁾ However, Rozanski et al showed that regional wall motion improvement after upright stress was at times not observed after supine stress.¹⁸⁾ Since radionuclide ventriculographic examination was performed in the first 2 min after exercise in their study, improvement in asynergy which occurred more

than 2 min after exercise was excluded.

Stein et al reported that during recovery from supine exercise the continuing high level of venous return is dissociated from the decreasing heart rate, resulting in a transient increase in end-diastolic volume.¹⁹⁾ Wyatt et al suggested in their experimental study that a primary increase in preload improves cardiac output, but at the expense of aggravated ischemia in the presence of severe coronary stenosis.²⁰⁾ On the other hand, Nichols et al showed that left ventricular function improves promptly after cessation of transient myocardial ischemia because of a pronounced fall in pulmonary blood volume immediately after cessation of upright exercise.²¹⁾ Therefore, postexercise "hypertension" during the relatively late phase of recovery in this study may be associated with delayed improvement in asynergy because a transient increase in preload after supine exercise may aggravate myocardial ischemia.

Secondly, an increase in BP may be associated with myocardial ischemia itself in some patients. Figueras et al suggested that the increase in blood pressure during myocardial ischemia was due to a reflex mechanism.²²⁾ Several experimental studies have substantiated the occurrence of sympathetically mediated vasoconstrictor reflexes stemming from the ischemic myocardium.²³⁾⁻²⁵⁾

It is, however, beyond our investigation to elucidate the mechanisms of an increase in BP after supine exercise.

Sustained and/or late postexercise "hypertension":

Sustained postexercise "hypertension" and/or late postexercise "hypertension" were associated with more severe exercise-induced myocardial ischemia in this study.

The frequency of late phase (more than 3 min after exercise) postexercise "hypertension" in this study was greater than that in Kawakubo's study.⁷⁾ This difference is probably explained at least in part by the difference in the methods of exercise testing (supine ergometer vs treadmill) because delayed myocardial ischemia after exercise is thought to be more frequent following supine exercise than upright exercise.

CONCLUSION

A hypotensive or flat BP response during supine exercise is infrequent, but is associated with severe coronary artery disease.

An abnormal increase in BP during recovery from supine exercise is usually associated with exercise-induced left ventricular dysfunction second-

ary to myocardial ischemia.

Both abnormal BP responses are useful as predictors of poor prognosis.

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