**Cardiorespiratory Responses to Standing Arm
Ergometry in Patients with Ischemic Heart Disease
Comparison with the Results of Treadmill Exercise**

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SUMMARY

To compare cardiorespiratory responses to standing arm ergometry and treadmill exercise, two graded exercise stress tests were performed in 30 patients with ischemic heart disease (IHD). Cardiac catheterization and expired gas analyses were also done. Standing arm ergometry was discontinued because of arm fatigue in 15 (50%) patients, whereas treadmill exercise was stopped due to leg fatigue in 8 (27%) patients. Maximal increase in rate-pressure product and oxygen uptake, and magnitude of ST-segment depression during standing arm ergometry were significantly smaller ($p < 0.01$, $p < 0.01$ and $p < 0.05$, respectively) than those during treadmill exercise. Furthermore correlations of maximal change in rate-pressure product, oxygen uptake and extent of ST-segment depression were not close between the two exercise tests ($r = 0.76$, $r = 0.67$ and $r = 0.54$, respectively).

Our results indicate that the ability to detect IHD with standing arm ergometry is lower than that with treadmill exercise and that it is not possible to predict accurately one's capacity for arm exercise from the treadmill exercise test.

Additional Indexing Words:

Standing arm ergometry   Treadmill exercise   Ischemic heart disease
Cardiorespiratory responses

GRADED exercise stress testing is of considerable value in the diagnosis and functional evaluation of patients with known or suspected ischemic heart disease (IHD).^{1),2)} However, currently available techniques including treadmill and bicycle ergometer tests require leg exercise and therefore these methods are not applicable to a large population at risk from IHD

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who also have peripheral vascular disease, large joint arthritis, amputation or neuromuscular problems involving the lower limbs. In addition, angina pectoris is precipitated in some patients primarily by arm exertion.³⁾ Arm ergometry has been proposed as a useful alternative to standard treadmill exercise or leg ergometry.⁴⁾⁻⁶⁾ Although there have been several reports comparing hemodynamic responses to arm ergometry and treadmill exercise,^{4),6),7)} arm ergometry has been performed in the seated position in all but one of these studies in healthy subjects.⁷⁾ Body weight must be lifted on standing, whereas body weight is supported in the sitting position. Furthermore, Vokac et al⁸⁾ reported some differences in cardiorespiratory parameters obtained during arm exercise in the sitting and standing body positions. Therefore, when the hemodynamic responses to different types of exercise are compared, we believe that other test conditions should be as similar as possible.

The purpose of this study was to compare the cardiorespiratory responses to arm ergometry while standing and treadmill exercise in patients with IHD.

METHODS

Patient population: The study group consisted of 30 patients (28 men and 2 women) referred for diagnostic evaluation of suspected or known IHD. The age range was 37 to 76 (mean 53 ± 2) years. Seventeen patients had a prior myocardial infarction documented by history, evolutionary electrocardiographic abnormalities and significant serum enzyme abnormalities (CPK, GOT and LDH) and 13 patients had a history compatible with exertional angina. All patients had sinus rhythm. Voluntary informed consent was obtained from all of the patients.

Exercise testing: All patients underwent two graded exercise stress tests in randomized order on the same day using an arm ergometer and treadmill. Tests were performed within 1 week of cardiac catheterization. Arm ergometry was performed in the standing position using a Monark type 881. Arm ergometry was begun at a work load of 25W or 37.5W for 3 min, followed by 12.5W increments every 3 min until the test was terminated. Cycling rate was kept constant at 60 revolutions/min. Treadmill exercise was performed using a Marquette CASE II according to a modified Bruce protocol. After the first test, patients rested in the supine position for at least 30 min until heart rate and blood pressure returned to baseline before the second test. Heart rate and 12 lead electrocardiogram (ECG) were obtained in the supine position, on standing, and at each minute during and imme-

diately after both tests. ECG was monitored continuously throughout the tests using leads II, V_1 and V_5 . Blood pressure was measured by arm cuff in the supine position, on standing and immediately after both tests, concurrent with the recordings of the ECG. Since it was difficult to measure blood pressure accurately during arm ergometry, rate-pressure product was calculated using the data obtained immediately after both tests. Endpoints of the treadmill exercise test were as follows: 1) angina, dyspnea and fatigue, 2) attainment of 85% of age-predicted maximal heart rate, 3) systolic blood pressure ≥ 230 mmHg, 4) ST-segment depression ≥ 3 mm and 5) short run of premature ventricular contractions. The same endpoints as in treadmill exercise test, except for 3), were used for arm ergometry. ST-segment depression was evaluated at 0.08 sec after the J point and ST-segment elevation at 0.04 sec after the J point.⁹⁾ Ischemic ECG response was defined as horizontal or downsloping ST-segment depression ≥ 1 mm.

Gas analyses: Respiratory gas analysis was conducted every 30 sec in the first 8 patients using a Sensor Medics MMC Horizon System for measurements of oxygen uptake, carbon dioxide and minute ventilation, and O_2 -pulse, ventilation equivalent and respiratory exchange ratio were calculated.

Angiographic tests: Coronary arteriography was performed in 23 patients in multiple projections using Judkins technique and significant stenosis was defined as diameter narrowing of major coronary arteries $\geq 75\%$.

Patients on β -blockade were excluded from this study. Ca-antagonists and nitrates were withheld at least 12 hours before the exercise tests and cardiac catheterization.

All values are shown as mean $\pm$ SEM. Student's t-test and linear regression analysis of correlations were used for statistical analyses.

RESULTS

All 13 patients with a history of exertional chest pain showed ischemic ECG responses during treadmill exercise test and were diagnosed as having IHD. Although 19 of 30 patients had identical endpoints with both tests, arm ergometry was discontinued because of arm fatigue in 15 of 30 patients, whereas treadmill exercise was stopped due to leg fatigue in 8 patients (Table I).

The extent of maximal increase in heart rate during arm ergometry was not significantly different from that during treadmill exercise and there was a significant correlation between maximal change in heart rate during arm ergometry and that during treadmill exercise ($r=0.74$, $p<0.01$). The magnitudes of increase in systolic blood pressure and rate-pressure product

Table I. Correlations between Endpoints and Other Clinical Characteristics during Arm Ergometry and Treadmill Exercise

Endpoint	Arm ergometry		Treadmill exercise	
	No. of pts	$\Delta RPP_{PE} (\times 10^{-2})$	No. of pts	$\Delta RPP_{PE} (\times 10^{-2})$
Fatigue	15 (4)†	44 ± 7	8 (3)	75 ± 10
Chest pain	7 (6)	47 ± 13	9 (6)	55 ± 11
HR increase	6 (1)	68 ± 12	5 (3)	127 ± 8

Mean ± SEM. Abbreviations: HR increase=heart rate increase; No. of pts=number of patients; RPP_{PE} =immediately postexercise rate-pressure product.

* $p < 0.01$, ** $p < 0.001$, † number in parentheses indicates the number of patients who showed significant ST depression.

Table II. Comparison of Hemodynamic Changes during Arm Ergometry and Treadmill Exercise

	Arm ergometry	Treadmill exercise	P-value
ΔHR_{max} (bpm)	56 ± 3	59 ± 4	ns
ΔSBP_{PE} (mmHg)	24 ± 3	38 ± 5	<0.001
ΔDBP_{PE} (mmHg)	3 ± 2	4 ± 2	ns
$\Delta RPP_{PE} (\times 10^{-2})$	50 ± 5	81 ± 8	<0.01

Mean ± SEM. Abbreviations: DBP=diastolic blood pressure; HR_{max} =maximum heart rate; PE =immediately postexercise; RPP =rate-pressure product; SBP =systolic blood pressure; Δ =(max or PE -rest); ns=not significant.

immediately after arm ergometry were significantly smaller than those immediately after treadmill exercise ($p < 0.001$, $p < 0.01$, respectively) (Table II), but there were significant correlations of maximal change in systolic blood pressure and rate-pressure product between the two exercise tests ($r = 0.82$, $p < 0.001$; $r = 0.68$, $p < 0.001$, respectively) (Fig. 1). Twenty-three of 30 patients underwent coronary arteriography. Eighteen patients had significant stenosis ($75\% \leq$) in at least 1 major coronary artery. The rest of the patients ($n = 5$) showed no significant stenosis ($75\% >$) in a major coronary artery with or without significant stenosis in a minor coronary artery. Of the 18 patients who had significant stenosis in at least 1 major coronary artery, significant ST-segment depression was observed in 7 patients during arm ergometry and in 11 patients during treadmill exercise. Although maximal ST-segment depression during arm ergometry was less severe in comparison with that during treadmill exercise (-1.0 ± 0.1 vs -1.4 ± 0.2 mm, $p < 0.05$) (Fig. 2), there was a significant correlation of the extent of ST-segment depression between the two exercise tests ($r = 0.40$, $p < 0.05$). Correlation between endpoints and other clinical characteristics are shown in Table I. Increase in rate-pressure product immediately after

Fig. 1. Correlation of maximal increases in rate-pressure product (RPP) (A) and in oxygen uptake ($\dot{V}O_2$) (B) between the two exercise tests.

Fig. 2. Comparison of maximal ST-segment depression during arm ergometry and treadmill exercise.

arm ergometry in patients whose endpoint was arm fatigue was less marked in comparison with that in patients whose endpoint was increased heart rate ($p < 0.01$).

Although the extent of the maximal change in oxygen uptake and O_2 -

Table III. Comparison of Maximal Changes in Expired Gas Data during Arm Ergometry and Treadmill Exercise

	Arm ergometry	Treadmill exercise	P-value
$\Delta\dot{V}O_2$ (ml/kg/min)	17.6 $\pm$ 1.9	24.9 $\pm$ 2.4	<0.01
$\Delta\dot{V}E$ (l/min)	35.4 $\pm$ 4.7	42.3 $\pm$ 3.3	ns
ΔO_2 -pulse (ml/beat)	7.1 $\pm$ 1.0	9.6 $\pm$ 1.1	<0.01
$\Delta\dot{V}E/\dot{V}O_2$	-1.4 $\pm$ 1.6	-2.1 $\pm$ 1.2	ns
$\Delta\dot{V}CO_2/\dot{V}O_2$	0.18 $\pm$ 0.04	0.20 $\pm$ 0.03	ns

Mean $\pm$ SEM. Abbreviations: O_2 -pulse = oxygen pulse; $\dot{V}CO_2/\dot{V}O_2$ = respiratory exchange ratio; $\dot{V}E$ = minute ventilation; $\dot{V}E/\dot{V}O_2$ = ventilation equivalent; $\dot{V}O_2$ = oxygen uptake; ns = not significant.

pulse during arm ergometry was significantly lower in comparison with that during treadmill exercise (both $p < 0.01$) (Table III), there was a significant correlation of maximum changes in oxygen uptake and O_2 -pulse between the two exercise tests ($r = 0.76$, $p < 0.05$; $r = 0.80$, $p < 0.05$, respectively) (Fig. 1).

DISCUSSION

The purpose of this study was to compare the cardiorespiratory responses to standing arm ergometry and treadmill exercise in patients with IHD. Although there have been several reports comparing hemodynamic responses to arm ergometry and treadmill exercise,^{4),6),7)} arm ergometry was performed in the seated position in all but one of these studies in healthy subjects.⁷⁾ Since body weight must be lifted on standing, whereas body weight is supported in the sitting position, different posture may produce different cardiovascular responses to exercise. Vokac et al⁸⁾ compared cardiorespiratory parameters obtained during arm exercise in sitting and standing body positions and reported that the resting heart rate was significantly higher in the standing position and that the work load in the standing position was, on the average, 13% higher ($p < 0.05$) than when sitting. Therefore, comparison of hemodynamic responses to arm and leg work should be evaluated in the same posture to exclude the influence of different body position. In this investigation we compared cardiorespiratory responses to standing arm ergometry and treadmill exercise in patients with IHD.

Our findings showed that maximal increase in rate-pressure product and oxygen uptake during standing arm ergometry was significantly smaller than that during treadmill exercise (Tables II, III). Hagan et al⁷⁾ compared the cardiorespiratory responses to incremental-load treadmill work and arm work on standing in young healthy subjects and reported that maximal oxygen uptake produced during standing arm work represented 85%

of treadmill work in men and 76% in women. The reason maximal oxygen uptake is higher during treadmill exercise than during arm ergometry is that as additional muscle groups are incorporated into performance of maximal work, progressively greater maximal aerobic power will be achieved.^{10),11)}

ST-segment depression during standing arm ergometry was significantly less marked than that during treadmill exercise (Fig. 2). Since maximal increase in blood pressure during diastole, when coronary perfusion occurs, did not show any significant differences during these two tests, the lower rate-pressure product may contribute to the lower magnitude of ST-segment depression during standing arm ergometry. Our results showed that significant ST-segment depression was demonstrated in 39% of patients with documented coronary artery disease during standing arm ergometry and in 61% during treadmill exercise. Balady et al⁶⁾ reported that an ischemic response—angina or ST depression—was demonstrated in 26 (86%) of 30 patients with documented angina pectoris during treadmill exercise and in 12 (40%) patients during sitting arm ergometry. Sensitivity for detecting coronary artery disease during arm ergometry in our study was low, but was similar to that in Balady's study. Lower sensitivity during arm ergometry compared with that during treadmill exercise was attributed, in part, to a lower rate-pressure product. In addition, Balady et al⁶⁾ suggested that the change in rate-pressure product at peak exercise did not reflect total myocardial oxygen consumption and that other determinants of myocardial oxygen consumption such as myocardial contractility and the level of myocardial wall tension could be substantially lower during arm ergometry. The sensitivity for detecting coronary artery disease during treadmill exercise was lower in our study as compared with that in Balady's study, probably because our study group consisted of 17 patients with previous myocardial infarction and 13 other IHD patients, whereas all patients in Balady's study had angina pectoris. DeBusk et al¹²⁾ examined ischemic responses to arm and leg ergometry in patients with a previous myocardial infarction. The sensitivity of detecting coronary artery disease in this population was low for both tests (18% for arm vs 25% for leg, difference not significant), because all subjects being tested had a previous myocardial infarction and may not have had provokable ischemia.

Clinical implication: It has been reported that for any level of sub-maximal exercise, oxygen consumption and physiologic strain are higher when exercising the arms than when exercising the legs.¹³⁾ This difference is generally attributed to a lower mechanical efficiency in arm exercise owing to static muscular contractions in this form of work as well as the extra muscular work required to stabilize the torso during an exercise such as arm

ergometry.¹⁴⁾ In addition, our data indicate that the maximal increase in rate-pressure product and oxygen uptake was significantly smaller during standing arm ergometry than during leg exercise and that the correlation of maximal changes in rate-pressure product and oxygen uptake between the two exercise tests was not very high (Fig. 1). For these reasons exercise prescriptions based on running and bicycling cannot be applied to arm exercise, and furthermore it is not possible to predict accurately one's capacity for arm exercise from a test using the legs.¹⁴⁾ The physician and exercise specialist should formulate a prudent exercise program using both forms of work after understanding the differences in physiologic response between arm and leg exercise.¹³⁾

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