Myocardial Oxygen Consumption Index in Patients with Coronary Artery Disease

Arash Arya, MD, Majid Maleki, MD, Fereydoon Noohi, MD,
Ebrahim Kassaian, MD, Farideh Roshanali, MD

Department of Cardiology
Rajaie Cardiovascular Medical Center
Tehran, Iran

ABSTRACT

One hundred and thirty-six men with coronary artery disease were randomly assigned to a hospital-based or home-based exercise program of 3 sessions per week. A treadmill test was carried out with the modified Naughton protocol. After 3 months, 125 patients (92%) with a mean age of 55 ± 11 years had completed the study. Maximum workload achieved increased by 65% [(12.40 ± 1.32 vs. 7.50 ± 0.85 metabolic equivalent units (METs)] in the hospital-based group, and by 17% (8.86 ± 0.9 vs. 7.56 ± 0.78 METs) in the home-based group ($p = 0.0001$). The heart rate-blood pressure product, an index of myocardial oxygen consumption, decreased at rest by 19% in the hospital-based group but was unchanged in the home-based group ($p = 0.0001$). The heart rate-blood pressure product at 5 and 7 METs activity level decreased 28% and 26%, respectively, in the hospital-based group vs. 8% and 2% in the home-based group ($p = 0.0001$). It was concluded that hospital-based exercise training in patients with coronary artery disease improves functional capacity and decreases the myocardial oxygen consumption index at rest and during exercise.

(Asian Cardiovasc Thorac Ann 2005;13:34–7)

INTRODUCTION

Coronary artery disease (CAD) is the most important cause of mortality in developed countries.[1] Patients with CAD are commonly affected by physical and psychosocial disabilities. Comprehensive cardiac rehabilitation consists of exercise training and counselling services, which reduce symptoms and improve exercise tolerance, functional capacity, quality of life, and survival.[2–4] The double product of heart rate (HR) and blood pressure (BP) has a linear correlation with myocardial oxygen consumption (MVO_2) and is a noninvasive method of assessing MVO_2.[5,6] This study was designed to assess the effect of a hospital-based exercise program on the MVO_2 index in patients with CAD.

PATIENTS AND METHODS

The study was carried out between June and December 2000 on 136 male patients: 110 had undergone coronary artery bypass grafting (CABG), and 26 had suffered a myocardial infarction (MI). They were randomly assigned to a 3-month hospital-based cardiac rehabilitation program ($n = 68$) or a home-based exercise program ($n = 68$). One hundred and twenty-five (92%) patients (102 post-CABG and 23 post-MI; mean age, 55 ± 11 years) completed the program. The patients first visited our cardiac rehabilitation clinic 6–8 weeks after CABG or MI. Exclusion criteria were: age > 80 years, a physical or mental disability incompatible with exercise training, a high-risk positive stress test (exercise or myocardial perfusion scan), active pericarditis or myocarditis, uncontrolled congestive heart failure, an atrioventricular conduction defect (except first-degree atrioventricular block), history of sustained ventricular arrhythmia, uncontrolled atrial fibrillation, severe pulmonary hypertension, hepatic and/or renal failure, symptomatic valvular heart disease, a fixed-rate pacemaker, exercise-induced asthma, acute coronary syndrome, intermittent claudication, anemia

For reprint information contact:
Arash Arya, MD Tel: 98 21 219 2931 Fax: 98 21 878 4618 Email: arya@rhc.ac.ir
Rajaie Cardiovascular Medical Center, Mellat Park, Vali-Asr Avenue, Tehran 19969-11151, Iran.

Table 1. **Baseline Characteristics**

Variables	Hospital-Based Group	Home-Based Group	*p*-Value
No. of patients	65	60	
Age (years)	55.2 ± 9	53.5 ± 13	NS
Ejection fraction (%)	43.7 ± 7	41.5 ± 8	NS
Diagnosis			NS
MI	15	8	
CABG	50	52	
Systolic BP	121.5 ± 11	121.3 ± 11	NS
Diastolic BP	77.6 ± 5	78.3 ± 3	NS
Resting HR	82.8 ± 11	85.9 ± 10	NS
Medication			NS
β blocker	62	60	
CC blocker	12	6	
ACE inhibitor	12	19	
Digoxin	1	0	
Diuretic	0	0	
Diabetes	21	22	NS
Hypertension	15	21	NS
Smoking	10	12	NS
Body mass index	27.1 ± 3	26.3 ± 3	NS

ACE = angiotensin converting enzyme; BP = blood pressure; CABG = coronary artery bypass graft; CC = calcium channel; HR = heart rate; MI = myocardial infarction.

(hemoglobin < 9 g·dL^{-1}), and a significant electrolyte abnormality.[7,8] No change in medication was made during the study period. All patients included in the study gave written informed consent for the exercise training and cardiac rehabilitation program. The study was approved by our institutional review committee.

A treadmill exercise test (Formula Archimed; Easote Biomedica, Genoa, Italy) was performed with the modified Naughton protocol for each patient. Heart rate (HR), blood pressure (BP) and perceived exertion according to the Borg scale were recorded at each stage. Maximum workload achieved (MWA) was measured in metabolic equivalent units (METs). Initial workload and maximum allowed workload (MAW) for exercise training were defined as 60% and 85% of MWA, respectively. For patients with ischemic changes and/or chest pain during the exercise test, the MAW was defined as the workload at which the HR was 10 beats·min^{-1} below the ischemic threshold (defined as chest pain and/or ST depression ≥ 1 mm).

Home-based exercise program

Patients who were randomized to the home-based exercise group were instructed in the method of manual pulse rate measurement. The Borg scale and its application to exercise level adjustment were explained. The patients were directed to perform 3 sessions of exercise each week. Each session consisted of 55 min of physical exertion. The warm-up phase comprised 5 min of calisthenics tailored to each patient by our physiotherapist, followed by 10 min of walking (speed gradually increased under the guidance of target HR). The aim in this phase was to reach a HR roughly 1–15 beats·min^{-1} less than the target HR of the endurance phase. This was followed by the endurance phase (fast walking for 30 min). The initial target HR for this stage was defined as HR at 60% of MWA for patients without ischemic changes or chest pain on the initial exercise test, and 10 beats·min^{-1} less than the ischemic threshold (see above) for patients with ischemic change and/or chest pain during the initial exercise test. The cool-down phase (10 min) was the final stage of exercise training; the patient was instructed to gradually reduce his level of activity to the baseline state. In cases of fatigue, chest pain, or Borg scale > 15 during the endurance phase, the patient was instructed to reduce the target HR by 10 beats·min^{-1}. After 6 consecutive exercise sessions, and in the absence of fatigue or chest pain and Borg scale > 15 during the endurance phase, the patient was recommended to increase the target HR by 10 beats·min^{-1}. The maximum allowed HR was defined as HR at MAW. Based on maximum allowed HR, a comprehensive tailored list of allowed daily activities (including leisure activities) was given to each patient by our physiotherapist. The patients were instructed to stop exercise and come to the clinic (or emergency room) if they felt chest pain, extreme fatigue, or dyspnea and dizziness during exercise.

Hospital-based exercise program

Patients randomized to the hospital-based program had 3 sessions of supervised exercise each week in our cardiac rehabilitation clinic. The program started with 5 min of calisthenics, guided by our physiotherapist, followed by 50 min on a treadmill (SportsArt 6150; SportsArt, Inc., Tainan City, Taiwan). In the warm-up phase (10 min), the initial treadmill speed was 2 mph (slope = 0). The workload was increased gradually during the warm-up phase to the calculated initial workload (60% of MWA). This workload was maintained for 30 min of an endurance phase. Then the workload decreased gradually and reached 2 METs at the end of the 10-min cool-down stage. During all these stages, the HR, BP, and Borg scale were recorded, and clinical symptoms were assessed by a trained nurse and a physiotherapist. The whole exercise session was supervised by a cardiologist. All patients were monitored for potential arrhythmias by a telemetry system (PCMS; SpaceLabs, Inc., Tulsa, OK, USA) during the entire exercise session. When the Borg scale was less than 13, and the maximum HR during exercise was less than the maximum allowed HR, and with no angina or fatigue during the endurance phase in 6 consecutive exercise sessions, the workload during the endurance stage was increased by 10%. The MAW was determined as 85% of MWA. Based on MAW, a comprehensive tailored list of allowed daily activities (including leisure activities) was given to each patient by our physiotherapist.

Table 2. **Results of Basal and Final Treadmill Exercise Tests**

Variables	Hospital-Based Group			Home-Based Group			p-Value*
	Basal	Final	p-Value	Basal	Final	p-Value	
Mean MWA (METs)	7.50	12.40	0.0001	7.56	8.86	0.001	0.0001
Mean DP at rest	10055	8169	0.0001	10411	10466	0.44	0.0001
DP at 5 METs	15421	11028	0.0001	16149	14892	0.004	0.0001
DP at 7 METs	17627	12978	0.0001	17371	17041	0.08	0.0001
DP (maximal)	18826	18649	0.45	19425	19579	0.35	0.07

*Between final findings of the 2 groups.
The p-values for differences between basal parameters were all non-significant.
DP = double product of heart rate-blood pressure; METs = metabolic equivalent units; MWA = maximum workload achieved.

All patients were studied for 3 months. Patients in the home-based group attended our rehabilitation clinic each month. The patient's medical condition and adherence to the exercise program were assessed. If the MAW was achieved (or maximum allowed HR), another treadmill stress test with the modified Naughton protocol was performed to re-evaluate and recalculate the MWA, MAW, and maximum allowed HR. On completion of the study period, the treadmill test was repeated to evaluate MWA, Borg scale, and HR-BP response to each level of physical exercise. If the patient stopped the exercise program and/or the number of sessions missed amounted to a third of all sessions, the patient was withdrawn from the study.

Variables were expressed as mean ± standard deviation, and as a percentage. Differences in characteristics between the 2 groups were assessed by the independent sample Student's t test for continuous variables and the chi-squared statistic (or Fisher's exact test, if necessary) for discrete variables. A p-value < 0.05 was considered significant. Statistical analysis was carried out with SPSS version 10.0 software (SPSS, Inc., Chicago, IL, USA).

RESULTS

Of the 125 patients who completed the study, 65 were in the hospital-based program and 60 were in the home-based group. The baseline characteristics of the patients in both groups are listed in Table 1. There were no differences in baseline characteristics between the 2 groups. Table 2 shows the initial exercise test findings in both groups. The MWA and HR-BP product at rest and at various activity levels were comparable in the 2 groups. The results of the final treadmill exercise test in both groups are also shown in Table 2. While MWA improved significantly in both groups: by 65% (from 7.50 ± 0.85 to 12.40 ± 1.32 METs) in the hospital-based group; and by17% (from 7.56 ± 0.78 to 8.86 ± 0.9 METs) in the home-based group, the magnitude of this effect was more marked in the hospital-based group ($p < 0.0001$). The improvement in HR-BP product was also more pronounced in the hospital-based group: it decreased by 19% at rest, by 28% at 5 METs and by 26% at 7 METs; while in the home-based group, it was unchanged at rest and decreased by 8% and 2% at 5 and 7 METs, respectively. The maximum HR-BP product before and after the exercise program was comparable in both groups.

Three patients in the hospital-based group and 8 in the home-based group failed to complete the study. In the hospital-based group, 2 were withdrawn because of the high number of missed sessions, and the third was unwilling to continue the program. In the home-based group, 6 were unwilling to continue the program and 2 developed low-threshold angina and subsequently were referred for coronary angiography. No death or major complication (MI, ventricular arrhythmia, or exacerbation of heart failure) occurred during the study period.

DISCUSSION

Comprehensive cardiac rehabilitation reduces symptoms and improves exercise tolerance, functional capacity, quality of life, and survival in patients with CAD. A meta-analysis of randomized trials of cardiac rehabilitation in patients with CAD showed a survival benefit (20%–25% reduction in all-cause mortality) in those who enrolled in such programs.[2] Our study showed that the HR-BP product (as an index of MVO_2) at rest and during physical activity improved significantly in patients enrolled in the hospital-based program compared to those who were randomized to the home-based program. The maximal HR-BP product remained unchanged after 3 months of exercise training. This indicates that maximal MVO_2 and coronary blood flow remained constant despite exercise training, and while short-term exercise training can reduce myocardial oxygen demand during rest and exercise, it does not affect maximal coronary blood flow and reserve.

Several reports documented a reduction in exercise-induced ischemia as manifested by either ST-segment depression or thallium perfusion abnormalities after exercise training.[9–11] Our findings suggest that the reduction in exercise-induced ischemia after cardiac rehabilitation is due to decreased myocardial oxygen demand rather than increased supply in the coronary blood flow. Rowell[12] showed that regular exercise improves the performance and metabolic efficiency of the peripheral muscles and myocardium, and this reduces the MVO_2 and ischemic burden in patients with CAD. Our data show that the favorable effect of exercise was more marked in a supervised hospital-based rehabilitation program. This underscores the need for the establishment of more cardiac rehabilitation centers to decrease the morbidity and mortality of patients with CAD. Although the initial cost of these centres might be a concern for healthcare officials, several studies have shown that cardiac rehabilitation indeed decreases the overall healthcare spending and re-hospitalization, and is considered a cost-effective strategy in the secondary prevention of CAD.[2,13,14]

Hambrecht and colleagues[15] recently conducted a randomized study to compare the effects of exercise training versus a standard percutaneous coronary intervention with stenting. Their findings showed that a 12-month exercise program in patients with stable CAD and documented stenosis suitable for angioplasty resulted in superior event-free survival and functional capacity at lower costs, due to reduced re-hospitalization and repeat revascularization. Furthermore, 125 of the 136 patients enrolled in our study completed the program, which is an acceptable compliance rate in rehabilitation studies.[2–4,15] It was concluded from these findings that cardiac rehabilitation in patients with CAD improves functional capacity and decreases the MVO_2 index at rest and during exercise, while its maximal value remains unchanged. Cardiac rehabilitation can decrease the ischemic burden (by decreasing myocardial oxygen demand rather than increasing supply) in patients with CAD.

Acknowledgment

The authors would like to thank Mrs Zahra Ghalandari and Ms Sima Rakian. Without their dedicated work in our rehabilitation centre, this study would not have been possible.

References

1. Yusuf S, Reddy S, Ounpuu S, Anand S. Global burden of cardiovascular diseases: part I: general considerations, the epidemiologic transition, risk factors, and impact of urbanization. Circulation 2001;104:2746–53.
2. Dalal H, Evans PH, Campbell JL. Recent developments in secondary prevention and cardiac rehabilitation after acute myocardial infarction. BMJ 2004;328:693–7.
3. Marchionni N, Fattirolli F, Fumagalli S, Oldridge N, Del Lungo F, Morosi L, et al. Improved exercise tolerance and quality of life with cardiac rehabilitation of older patients after myocardial infarction: results of a randomized, controlled trial. Circulation 2003;107:2201–6.
4. Murchie P, Campbell NC, Ritchie LD, Simpson JA, Thain J. Secondary prevention clinics for coronary heart disease: four year follow up of a randomised controlled trial in primary care. BMJ 2003;326:84.
5. Gobel FL, Norstrom LA, Nelson RR, Jorgensen CR, Wang Y. The rate-pressure product as an index of myocardial oxygen consumption during exercise in patients with angina pectoris. Circulation 1978;57:549–56.
6. May GA, Nagle FJ. Changes in rate-pressure product with physical training of individuals with coronary artery disease. Phys Ther 1984;64:1361–6.
7. Chaitman BR. Exercise stress testing. In: Braunwald E, Zipes DP, Libby P, editors. Heart Disease. Philadelphia: Saunders 2001:129–59.
8. Wackers FJ, Soufer R, Zaret BL. Nuclear cardiology. In: Braunwald E, Zipes DP, Libby P, editors. Heart Disease. Philadelphia: Saunders 2001:273–323.
9. Ehsani AA, Heath GW, Hagberg JM, Sobel BE, Holloszy JO. Effects of 12 months of intense exercise training on ischemic ST- segment depression in patients with coronary artery disease. Circulation 1981;64:1116–24.
10. Schuler G, Hambrecht R, Schlierf G, Grunze M, Methfessel S, Hauer K, et al. Myocardial perfusion and regression of coronary artery disease in patients on a regimen of intensive physical exercise and low fat diet. J Am Coll Cardiol 1992;19:34–42.
11. Schuler G, Hambrecht R, Schlierf G, Niebauer J, Hauer K, Neumann J, et al. Regular physical exercise and low-fat diet: effects on progression of coronary artery disease. Circulation 1992:86:1–11.
12. Rowell LB. Human cardiovascular adjustments to exercise and thermal stress. Physiol Rev 1974;54:75–159.
13. Levin LA, Perk J, Hedback B. Cardiac rehabilitation – a cost analysis. J Intern Med 1991;230:427–34.
14. Bondestam E, Breikss A, Hartford M. Effects of early rehabilitation on consumption of medical care during the first year after acute myocardial infarction in patients > or = 65 years of age. Am J Cardiol 1995;75:767–71.
15. Hambrecht R, Walther C, Möbius-Winkler S, Gielen S, Linke A, Conradi K, et al. Percutaneous coronary angioplasty compared with exercise training in patients with stable coronary artery disease: a randomized trial. Circulation 2004;109:1371–8.