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Does appropriate endurance exercise training improve cardiac function in patients with prior myocardial infarction?

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Objective The objective of the present study was to determine whether appropriate endurance exercise training improves cardiac function in patients with prior myocardial infarction.

Methods Twenty-nine patients with prior myocardial infarction were divided into three groups (Group 1: control, Group 2: low-intensity training, Group 3: high-intensity training). Low and high training intensities were determined according to the gas exchange threshold of each patient. The patients in Groups 2 and 3 performed 15 min of home-based physical training safely, twice a day, 5 days a week for 2 months. Prior to and following this training, each patient performed two constant work rate tests (moderate and heavy intensity) and a symptom-limited incremental exercise test.

Results Heart rates at rest and during exercise were decreased significantly after 2 months in all three groups. Stroke volume at rest increased significantly after 2 months only in Group 3. Stroke volume after 6 min of heavy-intensity exercise increased significantly in Groups 2 and 3. However, the ejection fraction at 6 min of heavy-intensity exercise increased significantly only in Group 3. The maximal work rate attained during incremental exercise testing increased significantly in Groups 2 and 3. This parameter did not significantly change in the control group.

Conclusions Effects of physical training on maximal exercise capacity were noted in both exercise training groups. However, improvement in cardiac function (such as stroke volume), both at rest and during exercise, was noted only in the high-intensity training group. Our results suggest that relatively high-intensity training may improve exercise capacity and cardiac function of patients with prior myocardial infarction.
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Key Words: Stroke volume, cardiac output, constant work rate exercise, exercise capacity.

Introduction

Home-based physical training is becoming very popular among patients with prior myocardial infarction and exercise training is known to improve their exercise capacity[1–5]. However, the most appropriate intensity of exercise training for improving the exercise capacity of these subjects has not been established. Low-intensity exercise may not sufficiently improve exercise capacity. On the other hand, high-intensity training may not be safe and may cause deterioration in cardiac functioning in patients with prior myocardial infarction.

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Recently, Ehsani *et al.*[3] have reported that endurance exercise training of sufficient intensity can improve left ventricular systolic performance in men without cardiac disease. It also has been reported by Schuler *et al.*[5] that regular physical exercise and a low fat diet can improve myocardial perfusion in patients with coronary artery disease. Thus, exercise training of appropriate intensity may improve both exercise capacity and cardiac function of patients with prior myocardial infarction if the optimum training intensity is determined for each patient according to their exercise capacity and the severity of their heart disease.

The gas exchange threshold, which is equivalent to the anaerobic or lactic acidosis threshold, has been considered an important exercise parameter by numerous investigators[6–11]. The gas exchange threshold demarcates the exercise intensity above which lactate accumulates and lactic acidosis occurs[12]. In this respect,

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exercise intensities above the gas exchange threshold differ physiologically from those below the gas exchange threshold[13–17].

The objective of the present study was to improve the exercise capacity of patients with prior myocardial infarction by determining the appropriate intensity of exercise training according to their gas exchange threshold. In addition, we evaluated whether the prescribed optimum training intensity could improve cardiac function.

Methods

Study patients

Thirty-one patients, admitted to the Yokosuka Kyosai Hospital from 1990 to 1992 because of acute myocardial infarction, were entered into the study programme. Any patient who had atrial fibrillation or could not perform exercise testing due to a physical limitation, was excluded. At the start of the study, every patient was clinically stable and in sinus rhythm. All patients were treated with nitrates and/or calcium antagonists. As reported by Ades *et al.*[18] and Ciske *et al.*[19], beta-blockers are known to strongly affect training effects on metabolic, ventilatory, and cardiovascular responses to exercise. Therefore, although only a few patients were taking beta-blockers prior to enrolment in this study, beta-blockers were withheld throughout the study period, including 7 days prior to the study. Medications were not altered during the training period. In addition, no patients underwent coronary artery bypass graft surgery or percutaneous transluminal coronary angioplasty during the study period. All of these patients were sedentary, and athletes were not included. All patients had stopped smoking after the onset of their myocardial infarction. The nature and purpose of the study, as well as the risks involved, were explained to each patient, and informed consent was obtained prior to enrolment.

Training protocol

Patients were consecutively divided into three groups according to their entry date. Patients in Groups 2 and 3 were instructed to perform 15 min of rapid walking at home, twice a day, 5 days a week for 2 months to maintain their heart rate as follows: Group 1 (control group): the patients in this group were instructed to avoid any special exercise programme during the study period of 2 months; Group 2 (low-intensity training group): the appropriate training intensity was defined when the heart rate reached 80% of the gas exchange threshold heart rate in each patient; Group 3 (high-intensity training group): the difference in heart rates between that at the gas exchange threshold and that at peak exercise was measured for each patient in this group. The training intensity was determined for each patient by adding 40% of this difference to the heart rate measured at the patient's gas exchange threshold.

The heart rate at peak exercise was determined from an incremental exercise test performed prior to (within 1 week before) enrolment in the training programme. In this test, oxygen uptake, carbon dioxide output, and the rate of respiratory air flow were measured using a Respiromonitor (RM-300, Minato Medical Science, Osaka, Japan). This system consists of a hot-wire flow meter and oxygen and carbon dioxide gas analysers (zirconium element-based oxygen analyser and infrared carbon dioxide analyser). Gas was sampled at a rate of 220 ml . min^{-1} via a suction pump and passed through a filter and gas analysers. The gas exchange threshold was determined as the breakpoint in the carbon dioxide output–oxygen uptake plot (V-slope method[20–23]). The patients of Groups 2 and 3 were instructed to attach a portable pulsemeter (SBBQ001, Seiko, Japan) to their second finger in order to maintain their heart rate at the prescribed level. A daily record was kept by patients in Groups 2 and 3 of the exercise form and duration, the attained heart rate, and the symptoms experienced during exercise.

Exercise tests

An upright, electromagnetically-braked cycle ergometer (WLP-400, Lode, Holland) was used for exercise testing. Two constant work rate tests (moderate and heavy intensity) and a symptom-limited incremental exercise test were performed by each patient prior to and following 2 months of physical training. All medications were withheld for 24 h prior to exercise testing.

The work rates selected as intensities of moderate and heavy work for each patient were determined on the basis of performance on the preliminary incremental exercise test. Moderate work rate corresponded to a work rate achieving 80% of the gas exchange threshold. After the difference in work rate between the gas exchange threshold and peak exercise had been calculated for each patient, the heavy work rate was determined by adding 40% of this difference to the work rate at the patient's gas exchange threshold. Both constant work rate tests were performed for 6 min starting from rest, and were performed by each patient prior to and following 2 months of physical training. For the incremental exercise test, exercise started with a 3-min warm-up period at 20 W and 60 rpm on the ergometer after a 3-min rest. This was followed by a 1-W increase in work rate every 6 s (ramp pattern[24]).

The interval between the three tests was approximately 40 min. Patients were monitored continuously with 12-lead electrocardiography throughout the tests (Q-5000, Quinton, Seattle, U.S.A.). Cuff blood pressures were obtained every minute via an automatic indirect manometer (STBP-680F, Collin Denshi, Aichi, Japan). Oxygen uptake at rest, at 6 min during moderate- and

heavy-intensity constant exercise and at peak exercise during the incremental exercise test was measured in each patient prior to and following 2 months of physical training using a Respiromonitor RM-300. Resting cardiac output preceding exercise and while on the ergometer was measured by the dye dilution method using indocyanine green dye[25] and an ear photoelectric transducer. The output as analysed by a cardiac output computer (EW-90, Erma Optical works, Ltd., Tokyo, Japan).

Measurements of cardiac output

The detailed methods used in this study have been reported previously[26–28]. In brief, a computerized cardiac monitoring system (RRG-607, Aloka Co., Ltd., Tokyo, Japan) which contains a cadmium telluride detector (A-116, Radiation Monitoring Devices, Boston, MA, U.S.A.), was used to continuously monitor left ventricular function. After the patient's red blood cells had been labelled with 30 mCi of technetium-99m using a semi-in vivo method, the cadmium telluride detector was positioned over the left ventricular region using a vest designed specifically to hold the detector in place. The left ventricular region of interest was chosen as the position with the maximal ratio of stroke counts (end-diastolic counts minus end-systolic counts) to average counts (end-diastolic counts plus end-systolic counts/2)[29].

The counts over the left ventricular region of interest at 50 ms intervals during the cardiac cycle and throughout the exercise test were calculated by microcomputer[30]. As described previously[26], left ventricular ejection fraction was calculated using 70% of the end-diastolic counts as the background activity, as follows:

$$EF = SC/[0{\cdot}3 \times EDC]$$

where EF is ejection fraction, SC is stroke counts (end-diastolic counts minus end-systolic counts), and EDC is end-diastolic counts. An excellent correlation between the left ventricular ejection fraction measured with a cadmium telluride detector and that recorded with a gamma camera or contrast ventriculography has been demonstrated in prior studies[31,32].

The resting stroke volume was calculated from cardiac output using the dye dilution method, and was used to calculate absolute stroke volume from the ejection fraction according to the radioactive counting technique. Accordingly, exercise stroke volume was calculated using stroke counts by measuring the change from rest. After the test, stroke volume and cardiac output (stroke volume × heart rate) during exercise were determined using 10-s averaging. From our experience, this determination of cardiac output during exercise is reproducible in patients with a history of prior myocardial infarction[28].

Measurements of catecholamine concentrations

Blood was sampled at rest and 2 min following constant work rate exercise from a catheter inserted into the right cubital vein. From this adrenaline and noradrenaline concentrations were measured using high performance liquid chromatography (HPLC).

Data analysis

With the patients sitting on the ergometer and prior to the start of exercise, heart rate, oxygen uptake, left ventricular ejection fraction, stroke volume, and cardiac output at rest were all determined as an average value over 2 min. These variables were also determined as averages following 330 to 360 s of exercise during moderate- and heavy-intensity constant work rate tests. Peak oxygen uptake was determined as the highest oxygen uptake attained over a 10-s period during incremental exercise.

Statistical analysis

All data are presented as the mean ± SD. Comparisons of parameters among groups were made using analysis of variance (ANOVA). Parameters prior to and following 2 months of the training were compared using the paired t-test. A P value $<0{\cdot}05$ was considered significant.

Results

Two patients in the control group dropped out of the programme; one due to acute hepatitis and the other due to progressive dementia. Thus, the data of 25 males and four females (mean age 58 ± 11 years) were analysed (Table 1). The mean duration between onset of myocardial infarction and the study date was 48 ± 8 days. The mean training heart rate of patients in Groups 2 and 3 was 99·8 ± 12·6 beats . min^{-1} and 125·6 ± 10·9 beats . min^{-1}, respectively (Table 1).

Physical characteristics and resting cardiac function did not differ among the patients in the three groups by ANOVA. However, age was significantly lower in Group 3 (Table 1). For incremental exercise testing prior to physical training, the end point was leg fatigue in 23 of 29 patients, chest pain in four, and shortness of breath in two. Six patients demonstrated significant ST depression and seven revealed significant ST elevation during this test. Exercise regimes which patients performed at home mainly consisted of rapid walking. However, one patient in Group 2 sometimes walked up and down a stairway (stair climbing) and one patient in Group 3 performed cycle-ergometer exercise to maintain his heart rate at the prescribed level.

Table 1 Physical characteristics, resting left ventricular ejection fraction, infarct site, angiographic data, training heart rate and maximum heart rate during incremental exercise

Patient	Age (years)	Sex	Height (cm)	Weight (kg)	Ejection fraction (%)	Infarct site	Angiographic findings			Training heart rate (beats min^{-1})	Maximum heart rate (beats . min^{-1})
							LAD	LCx	RCA		
Control group (Group 1)											
1	54	M	170	88	27·5	Inf			100		147
2	63	F	154	60	34·7	Inf			99		132
3	65	F	154	54	35·1	Ant	99				174
4	63	M	163	65	36·8	Ant	95				120
5	77	M	168	72	42·3	Ant	95	90			153
6	56	M	168	76	50·7	Lat		100			129
7	69	M	164	64	27·0	Ant	100				150
8	47	M	158	47	46·3	Ant	99				187
Mean	61·8		162·4	65 8	37·6						149·0
SD	9 3		6·4	12 9	8·4						22 7
Low intensity training group (Group 2)											
9	48	M	159	70	32·6	Inf		100		115	172
10	65	M	159	62	47·2	Inf			95	110	137
11	65	F	155	54	31·0	Ant	100			111	153
12	68	M	160	57	43·9	Inf	90		95	80	109
13	68	M	160	58	31·2	Ant	90			110	159
14	66	M	163	55	37·8	Ant	100			80	150
15	55	M	161	57	36 1	Ant, Inf	90	90	90	96	161
16	62	M	164	62	36·5	Inf		75		90	99
17	72	M	172	60	45 3	Lat	75	99		100	137
18	58	M	176	66	39·2	Ant	99	75		110	168
19	59	M	157	51	25·8	Ant	100			96	146
Mean	62·4		162·4	59·3	36·9					99 8	144·6
SD	6·9		6 3	5·5	6·6					12·6	23·1
High intensity training group (Group 3)											
20	58	M	163	56	31·3	Inf			75	130	142
21	26	M	170	74	32 9	Inf			100	140	170
22	44	M	172	60	35·7	Inf	75	75	100	120	166
23	48	M	163	71	34·9	Inf			95	127	153
24	58	M	163	50	32·1	Ant	99			113	156
25	62	M	167	69	34·0	Inf	90			124	140
26	60	M	167	57	25·5	Lat		99		116	136
27	43	M	171	64	28·3	Ant	99		75	140	176
28	48	M	158	53	38·5	Inf			100	110	162
29	62	F	159	55	32·2	Ant	99			136	164
Mean	50·9		165·3	60·9	32·5					125·6	156·5
SD	11·4		4·9	8·2	3·7					10·9	13·6

LAD=left anterior descending coronary artery; LCx=left circumflex coronary artery; RCA=right coronary artery; M=male, F=female, Ant=anterior; Inf=inferior; Lat=lateral.
Significant coronary stenosis was defined as ≥75% reduction in luminal diameter of a coronary vessel.

Training effects on resting cardiac function

Heart rate decreased significantly after 2 months in all three groups (Table 2). Stroke volume at rest increased significantly from 65·9 ± 13·8 to 79·4 ± 11·8 ml (P=0·01) after 2 months of high-intensity training in Group 3 patients (Table 2), but the change in this variable was not significant in the other two groups.

Training effects on exercise capacity

Exercise duration and maximal work rate obtained during incremental exercise testing increased significantly from 439·0 ± 96·3 to 511·5 ± 137·1 s (P=0·03) and from 93·1 ± 16·0 to 105·3 ± 22·9 W (P=0·03) in the low-intensity training group (Group 2), and from 536·3 ± 129·2 to 628·9 ± 178·5 s (P=0·02) and from 109·5 ± 21·6 to 125·0 ± 29·8 W (P=0·02) in the high-intensity training group (Group 3), respectively (Table 3). On the other hand, changes in these parameters were not significant in the control group. Peak oxygen uptake was increased significantly from 1335 ± 347 to 1560 ± 424 ml . min^{-1} only in Group 3 (P=0·03). Changes in this parameter were not significant in Groups 1 and 2 (Table 3).

Training effects on cardiac function during constant work rate exercise

Moderate-intensity constant work rate test

The heart rate after 6 min of moderate-intensity constant work rate exercise significantly decreased in every group (Table 4). However, the left ventricular ejection

Table 2 Heart rate, blood pressure, oxygen uptake and cardiac function at rest

	Control group (Group 1)			Low intensity training group (Group 2)			High intensity training group (Group 3)		
	Before	After	*P* value	Before	After	*P* value	Before	After	*P* value
Heart rate (beats . min^{-1})	75 ± 9	68 ± 10	0·001*	76 ± 13	65 ± 9	0·002*	76 ± 10	70 ± 10	0·006*
Systolic blood pressure (mmHg)	145 ± 25	146 ± 27	0·798	134 ± 20	132 ± 19	0·612	121 ± 15	125 ± 20	0·515
Diastolic blood pressure (mmHg)	81 ± 18	84 ± 16	0·570	75 ± 8	76 ± 13	0·773	81 ± 9	76 ± 14	0·051
Oxygen uptake (ml min^{-1})	226 ± 41	234 ± 63	0·690	196 ± 28	197 ± 31	0·871	242 ± 38	236 ± 36	0·280
Ejection fraction (%)	37·6 ± 8·4	37·2 ± 8·8	0·860	36·9 ± 6·6	37·5 ± 6·7	0·766	32 5 ± 3·7	33·2 ± 3·7	0·686
Cardiac output (l . min^{-1})	5·3 ± 1·4	5·2 ± 1·3	0·791	4·9 ± 0·7	5·1 ± 1·5	0·762	5·1 ± 1·0	5·6 ± 1·0	0·065
Stroke volume (ml)	72·2 ± 22·6	78·2 ± 24·7	0·305	64·1 ± 11·8	76·7 ± 21·9	0·076	65·9 ± 13 8	79·4 ± 11·8	0·014*

Values are expressed as the mean ± SD.
Cardiac output and stroke volume could not be obtained in two patients (patients 12 and 20 in Table 1).
P value was determined by the paired t-test. *Significant difference between before and after training.

fraction or cardiac output at 6 min did not change appreciably in any group. Although the stroke volume at 6 min appeared to increase slightly, from 79·3 ± 14·0 to 92·1 ± 24·7 ml in the low-intensity training group (Group 2) and from 83·8 ± 24·3 to 97·2 ± 16·5 ml in the high-intensity training group (Group 3), these differences were not statistically significant.

Heavy-intensity constant work rate test

Heart rate after 6 min of the heavy-intensity constant work rate exercise significantly decreased in all three groups. The stroke volume after 6 min of heavy-intensity exercise increased significantly from 73·4 ± 14·1 to 96·5 ± 23·0 ml (P=0·02) in the low-intensity training group (Group 2) and from 87·2 ± 24·4 to 103·9 ± 18·1 ml (P=0·02) in the high-intensity training group (Group 3). On the other hand, although the ejection fraction after 6 min of such exercise increased significantly, it did so only in the high-intensity training group (from 40·9 ± 6·2 to 43·6 ± 5·0%, P=0·02).

Training effects on ECG changes during constant work rate exercise

In Group 3, during the heavy-intensity, constant work rate exercise prior to training, five of 10 patients demonstrated ST segment depression, and the remaining five revealed ST segment elevation. The maximum ST depression measured after 6 min of heavy-intensity, constant work rate exercise was 0·14 ± 0·22 mm following training; this was significantly less than 0·96 ± 0·75 mm measured prior to training (P<0·05). Maximum ST elevation measured after 6 min of heavy-intensity, constant work rate exercise was 0·40 ± 0·42 mm following training; this did not significantly differ from the value of 1·40 ± 0·82 mm measured prior to training (P=0·06). In Group 2 patients, ST segment changes during exercise also decreased following training. However, these changes were less apparent than those in Group 3 patients.

Training effects on oxygen uptake during constant work rate exercise

Oxygen uptake at 6 min during moderate- and heavy-intensity constant work rate exercise did not significantly change following the training (Tables 4 and 5).

Training effects on catecholamine concentrations

Adrenaline concentrations at rest tended to decrease from 0·056 ± 0·036 to 0·034 ± 0·017 pg . ml^{-1} in Group 1, from 0·066 ± 0·050 to 0·051 ± 0·049 pg . ml^{-1} in Group 2, and from 0·044 ± 0·020 to 0·035 ± 0·014 pg . ml^{-1} in Group 3. They also tended to decrease after 2 min of the heavy-intensity work rate test from 0·100 ± 0·047 to 0·075 ± 0·048 pg . ml^{-1} in Group 1, from 0·139 ± 0·103 to 0·080 ± 0·048 pg . ml^{-1} in Group 2, and from 0·069 ± 0·026 to 0·057 ± 0·038 pg . ml^{-1} in Group 3. However, there were no significant changes in venous noradrenaline concentrations following training between patients in the three groups.

Discussion

There have been numerous studies regarding the effects of endurance training on exercise capacity in normal subjects[1,3,33–38]. A training intensity of 60 to 90% of maximum heart rate or 50 to 85% of maximum oxygen uptake is thought to be enough to increase exercise capacity in normal subjects[3,36–39]. However, the appropriate training intensity needed to increase exercise capacity and improve cardiac function in patients with myocardial infarction has not been established.

The gas exchange threshold reportedly represents the exercise level above which lactate accumulates and lactic acidosis occurs[12]. However, only a few investigators[40] have tried to determine the appropriate training intensity level using the gas exchange threshold. In the present study, the appropriate training intensity was

Table 3 Parameters of exercise capacity obtained during the incremental exercise test

	Control group (Group 1)			Low intensity training group (Group 2)			High intensity training group (Group 3)		
	Before	After	*P* value	Before	After	*P* value	Before	After	*P* value
Heart rate at peak exercise (beats . min^{-1})	149 ± 23	142 ± 24	0·185	145 ± 23	145 ± 22	0·976	157 ± 14	152 ± 13	0·166
Blood pressure at peak exercise									
Systolic (mmHg)	192 ± 21	195 ± 20	0·528	191 ± 25	188 ± 25	0·509	169 ± 28	182 ± 39	0·154
Diastolic (mmHg)	101 ± 11	104 ± 10	0·533	103 ± 20	91 ± 27	0·103	99 ± 16	107 ± 29	0·180
Peak oxygen uptake (ml . min^{-1})	1196 ± 241	1333 ± 328	0·093	1106 ± 248	1211 ± 388	0·201	1335 ± 437	1560 ± 424	0·030*
Maximal work rate (watts)	98·4 ± 19·9	106·4 ± 22·5	0·065	93·1 ± 16 0	105·3 ± 22·9	0·025*	109·5 ± 21·6	125·0 ± 29·8	0·024*
Exercise time (s)	470·1 ± 120·3	518·1 ± 135·5	0·061	439·0 ± 96·3	511·5 ± 137 1	0·025*	536·3 ± 129 2	628·9 ± 178 5	0·023*

Values are expressed as the mean ± SD.
P value was determined by the paired t-test.
*Significant difference between before and after training.

Table 4 Performed work rate and cardiac function at 6 min of exercise on the moderate intensity constant work rate test

Parameters	Control group (Group 1)			Low intensity training group (Group 2)			High intensity training group (Group 3)		
	Before	After	*P* value	Before	After	*P* value	Before	After	*P* value
Work rate (watts)	42·1 ± 8·0			39 0 ± 7·2			39·8 ± 6·6		
Heart rate at 6 min (beats . min^{-1})	110·9 ± 21·2	101·1 ± 17·7	0 020*	105 8 ± 14·7	94·1 ± 13·0	0 006*	106·1 ± 13·3	94·3 ± 8·6	0·001*
Blood pressure at 6 min									
Systolic (mmHg)	175·6 ± 28·5	170·0 ± 26·8	0·447	175·2 ± 27·4	158 7 ± 20·6	0 003*	148·8 ± 26·1	139·5 ± 23·7	0·019*
Diastolic (mmHg)	93·8 ± 18·4	92·6 ± 13·3	0·820	89·1 ± 16·7	81·6 ± 14 4	0·143	80·8 ± 15·0	79·8 ± 15·0	0·752
Oxygen uptake at 6 min (ml . min^{-1})	792 ± 101	809 ± 132	0·694	686 ± 133	702 ± 149	0·620	759 ± 98	741 ± 93	0·294
Ejection fraction at 6 min (%)	41·2 ± 10·7	41·6 ± 11·4	0·878	44·2 ± 6·1	43·8 ± 7·4	0·831	40·8 ± 5·0	40 8 ± 5 3	0·984
Cardiac output at 6 min (l . min^{-1})	8·6 ± 2·2	8·8 ± 2·3	0·728	8·5 ± 1·2	8·7 ± 2·3	0·726	8·8 ± 2·3	9·1 ± 1·7	0·651
Stroke volume at 6 min (ml)	80·7 ± 30·9	90·9 ± 34·1	0·144	79·3 ± 14 0	92·1 ± 24·7	0·087	83·8 ± 24·3	97·2 ± 16·5	0·071

Values are expressed as the mean ± SD.
Cardiac output and stroke volume could not be obtained in two patients (patients 12 and 20 in Table 1)
P value was determined by the paired t-test.
*Significant difference between before and after training.

Table 5 Performed work rate and cardiac function at 6 min of exercise on the heavy intensity constant work rate test

Parameters	Control group (Group 1)			Low intensity training group (Group 2)			High intensity training group (Group 3)		
	Before	After	*P* value	Before	After	*P* value	Before	After	*P* value
Work rate (watts)	70·9 ± 14·1			66·4 ± 13·0			73·4 ± 13·4		
Heart rate at 6 min (beats . min^{-1})	139·6 ± 23·6	127·4 ± 19·9	0 023*	134·1 ± 18·7	119·4 ± 16·1	0·001*	139·5 ± 13·4	121·0 ± 10·9	0·001*
Blood pressure at 6 min									
Systolic (mmHg)	189·4 ± 18·8	185·1 ± 21·6	0·391	191·7 ± 24·3	185·5 ± 28·1	0·237	161·1 ± 27·6	156·8 ± 26 9	0·343
Diastolic (mmHg)	98·0 ± 13·4	96·9 ± 13·5	0 799	100·7 ± 17·9	90·0 ± 16·6	0·036*	94·1 ± 18·0	91·6 ± 21·1	0·547
Oxygen uptake at 6 min (ml . min^{-1})	1091 ± 203	1153 ± 242	0·163	998 ± 219	1006 ± 283	0·491	1135 ± 243	1122 ± 197	0·742
Ejection fraction at 6 min (%)	35·9 ± 10·4	38·4 ± 9·7	0·327	41·6 ± 5·9	43·8 ± 8·2	0·333	40·9 ± 6 2	43·6 ± 5·0	0·024*
Cardiac output at 6 min (l . min^{-1})	10·1 ± 3·1	10·1 ± 2·0	0·990	9·8 ± 1·5	11·6 ± 3·2	0·180	12·1 ± 3·3	12·4 ± 2·2	0 690
Stroke volume at 6 min (ml)	74·6 ± 28·6	82·7 ± 27·7	0·313	73 4 ± 14·1	96·5 ± 23 0	0·023*	87·2 ± 24·4	103·9 ± 18·1	0·022*

Values are expressed as the mean ± SD.
Cardiac output and stroke volume could not be obtained in two patients (patients 12 and 20 in Table 1).
P value was determined by the paired t-test.
*Significant difference between before and after training.

defined as a heart rate below (Group 2), or above (Group 3) the gas exchange threshold, and was determined for each patient.

It has been hypothesized that physical training influences exercise capacity in two ways: by the peripheral adaptation of skeletal muscle and by the central adaptation of cardiac function. Peripheral adaptation may play an important role in improving exercise capacity which was noted in both the low- and high-intensity training groups in the present study. However, improvements in the stroke volume, both at rest and during exercise, and the ejection fraction during heavy-intensity work rate exercise were noted only in patients in the high-intensity training group. As changes in the ST segment during exercise decreased following training in Group 3 patients, improvements in cardiac function at submaximal exercise in this group may have been due to an improvement in myocardial perfusion. An improvement in myocardial perfusion after physical training has been reported by several investigators. Roth *et al.*[41] have demonstrated an improvement in myocardial functioning and coronary reserve in collateral-dependent myocardium during exercise following long-term exercise after the gradual occlusion of the left circumflex coronary artery in the pig. Schuler *et al.*[5] and Sebrechts *et al.*[42] have demonstrated, by thallium-201 scintigraphy, that exercise training improves myocardial perfusion in patients with coronary artery disease.

However, improvements in cardiac function also may be due to increased end-diastolic volume by the Frank-Starling mechanism, as suggested by Stratton *et al.*[43]. Although the mechanisms of the improvements in cardiac function have not been fully clarified by the present study, these changes were more readily induced by relatively high-intensity training.

In the present study, two constant work rate tests were performed to evaluate cardiac function during exercise. Most haemodynamic variables reached a steady state after 6 min of constant work rate exercise. However, it would be difficult to accurately measure stroke volume or cardiac output at a certain work rate, and to compare these variables with those obtained during incremental exercise prior to and following training.

Improvements in cardiac function during exercise were detected only during the heavy-intensity work rate test. The exercise intensity of the moderate-intensity work rate test was probably too low to detect such improvements, because deviations in heart rate, ejection fraction, and stroke volume measured during the moderate-intensity test from the resting values were very small (Tables 2 and 4).

Previous studies of the haemodynamic response to training in normal subjects[1,3,33–35,37] and in patients with coronary artery disease[44–47] are available. Most of the studies agree with our findings, that heart rate at rest and during submaximal exercise becomes lower after physical training[44–47]. However, effects of physical training on cardiac function (cardiac output or stroke volume) are controversial[1,3,33–35,37,45–47]. Several investigators showed that physical training increases stroke volume and cardiac output during heavy-intensity exercise both in normal subjects[1,3,33–35,37] and in patients with coronary artery disease[45,46]. However, Detry *et al.*[47] noted that physical training decreases cardiac output during exercise in patients with previous myocardial infarction. The discrepancy in these findings might be due to the training programme, such as the intensity or duration of the physical training.

Heart rate decreased during the follow-up period of 2 months in the control group, while cardiac output and ejection fraction values were unchanged. Although activity during this period was not monitored, participation in a regular exercise programme, including jogging or swimming, was prohibited in the control group. However, the activities of daily living in some patients in Group 1 may have been similar to the prescribed physical training in Group 2 patients. This might explain the changes in heart rate and other variables of cardiac function in the control group.

A non-significant decrease in catecholamine concentrations was noted 2 months after the start of the study in all three groups, and may have further influenced heart rate during the study period.

Heart rate, ejection fraction, stroke volume, and cardiac index during exercise have been reported to decrease with age[48–51]. The mean patient age in Group 3 was significantly lower than that in the other two groups. However, endurance exercise training of sufficient intensity is known to improve left ventricular systolic performance, even in older normal subjects[3]. It has also been reported by Stratton *et al.*[43] that the effects of endurance exercise training on cardiovascular responses (ejection fraction and cardiac index) to exercise in healthy elderly subjects are similar to those in young subjects.

In the present study, the safety of both low- and high-intensity training programmes was confirmed prior to exercise training by having each patient perform moderate- and heavy-intensity constant work rate exercises. Except for Patient 10 (Table 1) in Group 2, no patient in any training group developed anginal pain or a serious arrhythmia during the training period. Patient 10 experienced progressive coronary artery stenosis and could not perform heavy-intensity exercise testing 2 months following the training. Although beta-blockers were withheld throughout the study period, beneficial effects of training on cardiac function noted in the present study could be achieved even in the presence of beta-blockers.

In conclusion, the effects of physical training on maximal exercise capacity were noted in both the low- and high-intensity training groups. However, improvement in cardiac function (such as increased stroke volume), both at rest and during exercise, was noted only in the high-intensity training group. Our results suggest that relatively high-intensity training may help to improve not only exercise capacity, but also cardiac function, in patients with prior myocardial infarction.

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