Effectiveness of High-Intensity Interval Training for the Rehabilitation of Patients With Coronary Artery Disease

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We found that interval training provides an effective means to improve the cardiovascular fitness and health status of highly functional patients with coronary artery disease. We also revealed that interval training improves anaerobic tolerance to a greater extent than the traditional exercise training model without increasing the risk to the patient. This research supports the implementation of interval training for highly functional patients with coronary artery disease.
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Cardiac (exercise) rehabilitation is a valuable nonpharmacologic intervention to improve cardiorespiratory fitness and overall health status in patients with coronary artery disease (CAD). Furthermore, continuous aerobic exercise training has been effective in reducing all-cause and cardiac mortality rates.[1]. Despite these benefits, this form of training may be suboptimal for patients with CAD with higher baseline levels of fitness. We have shown that high-intensity interval training is an effective modality to improve maximal aerobic power in sedentary men.[2] Preliminary research has also supported the health benefits of interval training and/or circuit weight training in patients with cardiac disease (including chronic heart failure and CAD).[3–5] However, the interval training research has generally used low work to rest ratios and/or lower work intensities. Accordingly, the primary purpose of this study was to examine the effects of high-intensity interval training versus the traditional aerobic program in highly functional (>9 METs) patients with CAD. We hypothesized that interval training would be safely tolerated by patients and lead to a similar improvement in peak aerobic power (VO_2peak) as the traditional model. Due to the importance of anaerobic capacity for the performance of many activities of daily living,[6,7] we were also interested in evaluating the effects of interval and continuous aerobic training on anaerobic capacity. Given the anaerobic requirements of interval training, we hypothesized that this form of training would result in greater tolerance to an anaerobic challenge than the traditional program.

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Fourteen men with CAD (Table 1) who had underwent (≥6 months previously) bypass surgery or angioplasty were stratified (age, body mass, and VO_2peak) and randomly assigned to traditional (n = 7) or interval training (n = 7). Ethical approval and written informed consent were obtained. All participants were recruited from a pool of patients who had a negative stress test (i.e., no significant ST depression (>1 mm) during a symptom-limited exercise test) and a VO_2peak >9 METs. As such, these participants represented stable, highly functional patients with CAD.

All participants were assessed on 2 separate days at baseline and after 16 weeks of aerobic training. On testing day 1, the patients performed a symptom-limited, incremental to maximal exercise treadmill test (Bruce protocol) to assess VO_2peak. Patients were monitored continuously via 12-lead electrocardiography, and blood pressure was taken at rest, every minute during exercise, and for ≥3 minutes during the recovery. The participants' rating of perceived exertion was also evaluated throughout the test.[8] Expired gas and ventilatory parameters were acquired using a portable metabolic cart (K4, Cosmed, Italy). Anaerobic threshold and ventilatory efficiency were determined via standard procedures.[9] The major criteria for terminating the test were volitional fatigue and a plateau in VO_2.

On testing day 2, the participants performed a high-intensity time to exhaustion test on a treadmill at 90% of heart rate reserve. This test provides an objective marker of endurance capacity, with the later stages of the test being particularly dependent upon anaerobic capacity. Each participant had previously engaged in 1 familiarization time to exhaustion test. Heart rate and the electrocardiogram were monitored continuously via 3-lead telemetry. Blood pressure was also taken before, throughout (every minute), and for ≥3 minutes after exercise. The speed and grade of the treadmill were kept identical between the baseline and post-training tests.

The traditional cardiac rehabilitation model consisted of a standardized 10-minute warm-up, 30 min-

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TABLE 1 Participant Characteristics

Measure	Interval Training (n = 7)	Traditional Training (n = 7)	All Participants (n = 14)
Age (yrs)	55 ± 7	57 ± 8	56 ± 7
Height (cm)	173 ± 7	173 ± 8	173 ± 7
Body mass (kg) (before training)	78 ± 7	86 ± 15	82 ± 12
Body mass (kg) (after training)	75 ± 7*	82 ± 13*	79 ± 12*
CAD			
Myocardial infarction†	3	2	5
Percutaneous coronary intervention	3	3	6
Coronary bypass†	3	3	6
No. of narrowed coronary arteries			
1	2	2	4
2	2	1	3
3	2	1	3
4	1	2	3
5		1	1
Medications			
Angiotensin-converting enzyme inhibitor	4	5	9
Cardiac glycoside		1	1
Diuretic	1	2	3
Nitrate	1	1	2
β Blocker	5	5	10
Calcium channel blocker	3	2	5
Anticoagulant	1		1

Data presented as mean ± SD or numbers.

*Significant change with exercise intervention ($p < 0.05$).

†Some patients had multiple diagnoses, including myocardial infarction and coronary artery bypass surgery.

utes of continuous aerobic exercise at 65% of heart rate/VO_2 reserve, standardized resistance training, and a 10-minute cool-down period. Interval training consisted of the identical warm-up, resistance training, and cool-down procedures as performed by the traditional training group. However, the interval training group exercised using 2-minute, high-intensity work phases (90% of heart rate/VO_2 reserve [range 85% to 95%]) followed by 2-minute recovery bouts (40% of heart rate/VO_2 reserve [range 35% to 45%]). Both groups were required to train for 30 minutes/day, 2 days/week for 16 weeks. Training involved 3 bouts of 10 minutes of exercise on 3 different types of exercise equipment, including a treadmill, a stairclimber, and combined arm and leg cycle ergometer. These different exercises were utilized to allow for total body training as per standard cardiac rehabilitation procedures. Each group was also instructed to engage in 3 additional training days per week consisting of continuous exercise at 65% of heart rate/VO_2 reserve (range 60% to 70%) (compliance rates 98.5 ± 2.0 vs. 98.8 ± 2.0%, respectively, for interval and traditional training).The electrophysiologic response to exercise was evaluated by 3-lead telemetry and a portable heart rate monitor (Polar Vantage XL, Kemple, Finland). Individual workloads were adjusted daily according to a heart rate range to reflect changes in fitness.[2] The average training volume was similar between groups.

All dependent measures were reported as mean ± SD. All variables were analyzed using repeated measures analysis of variance (with Tukey's post hoc comparisons) with the α level set a priori at $p \leq 0.05$.

At baseline, the groups were well matched according to body mass, VO_2peak, and age (Table 1 and Figures 1 to 3). Sixteen weeks of cardiac rehabilitation (both traditional and interval training) did not result in significant changes in resting measures of heart rate, systolic blood pressure, diastolic blood pressure, pulse pressure, and rate–pressure product, and maximal exercise measures of heart rate, systolic blood pressure, and rate–pressure product (Table 2). There were significant improvements in resting and maximal exercise oxygen pulse, VO_2peak, Bruce treadmill time, and time to exhaustion (Table 2 and Figures 1 to 3) after both training programs. There was also a concomitant reduction in the rating of perceived exertion and pulse pressure during maximal exercise in both training groups (Table 2). The improvement in time to exhaustion was significantly greater in the interval versus the traditional training group (Figure 3). Ventilatory efficiency (calculated from the whole test or before the anaerobic threshold) was not significantly changed as a result of either training program (Table 2). Anaerobic threshold was significantly increased in both groups but to a greater extent in the interval training group. Ventilation at stage 2 of exercise (submaximal) was decreased, and peak ventilation was increased to a similar extent in both groups ($p < 0.05$). There were no adverse effects as the result of participating in either training program.

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The key finding of this investigation was that high-intensity interval training results in similar improvements in aerobic fitness and a greater tolerance to an anaerobic challenge in comparison to traditional continuous aerobic exercise training. Also, it appears that high-intensity interval training can be conducted with minimal risk to highly functional patients with CAD.

Interval training is widely utilized in healthy populations to improve aerobic performance. In athletes, the greatest improvements in VO_2peak are observed when high-intensity (i.e., 90% to 100% heart rate reserve) exercise is incorporated into the training regime. Despite the widespread usage of interval training in healthy populations, few studies have evaluated the effect of interval training on the health status of patients with cardiovascular disease. In recent years, interval training has been advocated for the rehabilitation of patients with severe chronic heart failure.[10] Preliminary research also indicated that interval training may be more effective in improving exercise capacity than continuous aerobic training.[4] This research has generally dealt with less functional patients with cardiovascular disease. However, a recent study in

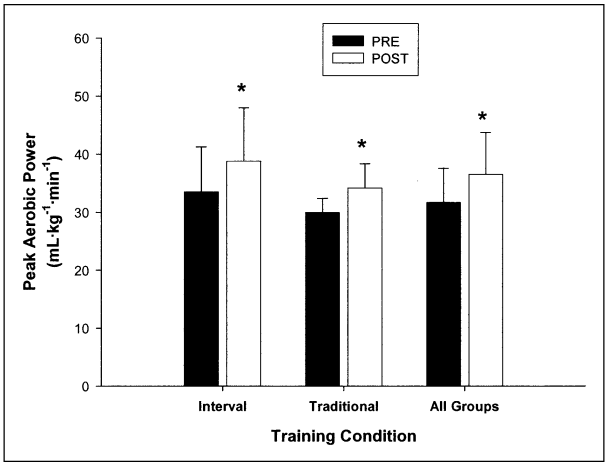

FIGURE 1. Effects of interval and traditional cardiac rehabilitation on peak aerobic power (mean ± SD). *Significant training effect ($p < 0.05$).

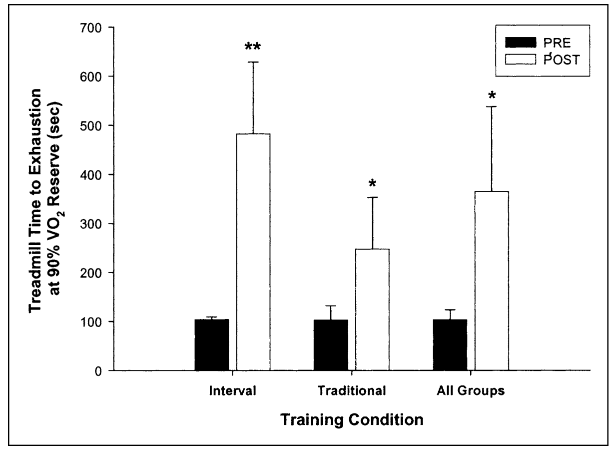

FIGURE 3. Effects of interval and traditional cardiac rehabilitation on treadmill time to exhaustion (mean ± SD). *Significant training effect ($p < 0.05$). **Significantly greater change after interval training ($p < 0.05$).

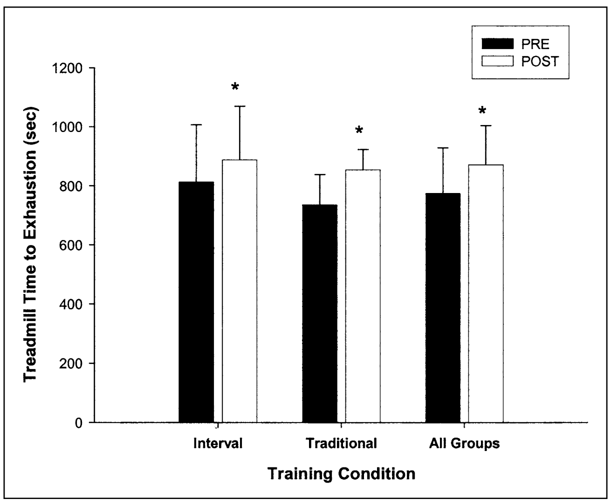

FIGURE 2. Effects of interval and traditional cardiac rehabilitation on Bruce treadmill time to exhaustion (mean ± SD). *Significant training effect ($p < 0.05$).

patients with CAD (with similar fitness levels to our participants) revealed that interval training may result in a 10% greater improvement in VO_2peak than lower intensity training,[11] which is contrary to our findings. This discrepancy is commonly found in the literature with healthy subjects and is likely to be the result of several factors related to differences in experimental designs and/or procedures.[2] In comparison to our study, Rogmo et al[11] utilized interval training bouts that were of longer duration and lower intensity. They also included rest phases (during interval training) that were similar to the average training intensity for the continuous training group. Therefore, although the authors attempted to maintain a consistent volume of work, the average training intensity and duration were different between conditions. Also, in the previous study, the control patients exercised at a markedly lower training intensity (i.e., 50% to 60% of peak VO_2) than our participants. These differences may explain the divergent findings between studies. We took every effort to create training environments that were comparable in terms of intensity, total work, and progression between groups. As such, we feel confident that we were able to comprehensively evaluate the differential effects of traditional versus interval training on VO_2peak in highly functional patients with CAD. It is also important to note, that we believed that it was imperative to maintain the average training intensity of 65% of VO_2 reserve between the traditional and interval training groups. This was due to several factors including: (1) previously showing that both intensity and duration have independent effects on cardiovascular function,[12] and (2) at our institution traditional cardiac rehabilitation for highly functional patients with CAD involves training at 60% to 70% of VO_2 reserve. Furthermore, research with endurance athletes has consistently shown that the average training intensity is approximately 65% of VO_2 reserve (even if 2 or 3 interval training sessions per week are included).[13] Because the aim of our study was to evaluate the effects of a training program that is commonly used in the healthy athletic realm it was essential that we keep the average training intensity at 65% of VO_2 reserve. Our findings are consistent with other research that has applied stringent controls between interval and continuous training.[2]

Another important and novel finding of the present investigation was that neither training program significantly improved ventilatory efficiency,[9], which is in contrast to what occurs after training in persons with chronic heart failure.[14] The ventilatory efficiency values of our participants were consistent with that observed in healthy age-matched men,[15], and well below the level (i.e., >34) that has been associated with an increased risk for premature mortality.[16] Thus, it would appear, based on our participants' ventilatory efficiency values, that they have a more favorable prognosis than less functional patients (such as patients with heart failure). This gives further support for the usefulness of ventilatory efficiency for the evalu-

TABLE 2 Individual Cardiorespiratory Measures During Exercise Before and After 16 Weeks of Rehabilitation

Patient	Heart Rate (beats/min)		Pulse Pressure (mm Hg)		RPP (mm Hg/min)		RPE		Oxygen Pulse (ml/beat)		V_E-VCO_2		Stage 2 V_E (L/min)		Peak V_E (L/min)		VO_2 at AT (ml · kg^{-1} · min^{-1})	
Interval training																		
1	144	143	123	108	29,952	27,170	6	8	18.6	19.0	24	28	35	19	75	78	22	25
2	181	179	64	54	25,340	24,344	7	7	15.1	17.1	25	26	40	22	98	103	21	30
3	159	152	110	94	28,620	25,536	5	6	21.9	27.2	26	24	40	31	113	115	32	46
4	146	139	108	96	26,280	24,464	8	4	13.0	17.9	36	32	52	36	84	109	20	27
5	152	137	64	60	21,888	19,180	9	5	16.8	19.8	28	28	45	41	78	94	18	25
6	187	184	104	98	34,408	33,120	5	5	11.5	12.9	22	26	34	38	63	72	21	24
7	153	154	72	94	23,562	26,488	7	6	16.4	19.3	32	35	35	31	112	124	22	27
Mean ± SD	160 ± 17	155 ± 19	92 ± 25	86* ± 21	27,150 ± 4,229	25,757 ± 4,158	7 ± 1	6* ± 1	16.2 ± 3.5	19.0* ± 4.3	28 ± 4	28 ± 4	40 ± 6	31* ± 8	89 ± 19	99* ± 19	22 ± 4	29† ± 8
Traditional																		
1	151	147	84	86	24,764	23,520	7	9	16.2	20.7	32	29	45	40	87	100	25	26
2	178	176	118	90	34,176	29,920	9	7	14.9	15.8	33	32	45	42	127	132	18	20
3	158	161	104	90	28,124	27,370	9	8	12.8	15.1	24	30	35	30	74	82	23	26
4	158	174	74	85	24,332	29,580	9	6	16.5	17.9	27	28	45	43	64	91	16	20
5	154	152	82	60	24,640	21,888	7	5	21.5	19.3	31	36	43	49	123	127	22	23
6	150	169	126	110	30,000	32,448	9	5	14.6	14.5	25	26	39	34	68	86	18	23
7	134	135	108	96	24,120	23,490	7	3	20.5	20.8	32	32	60	42	97	99	23	24
Mean ± SD	155 ± 13	159 ± 15	99 ± 20	88* ± 15	27,165 ± 3,820	26,888 ± 3,989	8 ± 1	6* ± 2	16.7 ± 3.2	17.7* ± 2.6	29 ± 4	30 ± 3	45 ± 8	40* ± 6	92 ± 26	102* ± 20	21 ± 3	23* ± 2

Values reported for heart rate, pulse pressure, rate–pressure product (RPP), rating of perceived exertion (RPE), oxygen pulse, and ventilation (peak V_E) were measured during peak exercise.
*Significant change with exercise intervention ($p < 0.05$).
†Significantly greater change after interval training ($p < 0.05$).
Stage 2 V_E = ventilation at the end of Bruce stage 2; V_E-VCO_2 = slope of the relationship between ventilation and carbon dioxide during exercise; VO_2 at AT = oxygen consumption at the anaerobic threshold (AT).

ation of the risk of premature mortality in persons with cardiovascular disease.

Unique to this investigation, we revealed that interval training resulted in a greater improvement in time to exhaustion during a high-intensity exercise test and anaerobic threshold during incremental exercise. This is consistent with findings in healthy individuals.[17] Thus, although interval training may not necessarily improve VO_2peak to a greater extent than the traditional rehabilitation program, it does appear to lead to adaptations that allow for a greater tolerance to a strenuous exercise challenge. These adaptations would be of particular benefit for the performance of many activities of daily living.[6,7] Further support for the importance of high-intensity training for functional status is provided by research that revealed that this form of training improves cardiac function (including submaximal stroke volume, improved myocardial contractility, and an increased ejection fraction at peak exercise) and exercise tolerance.[18–20] These adaptations have also been shown to be greater after high-intensity training in comparison to low-intensity training.[19] Furthermore, high-intensity training has been shown to reduce the incidence of angina and to decrease ST-segment depression at a given rate–pressure product during exercise in previously symptomatic patients.[18] Thus, it is apparent that high-intensity training can improve submaximal and maximal cardiovascular function while reducing ischemia at the same myocardial oxygen consumption. Accordingly, our research has important implications for overall health status, as our participants may be able to perform activities of daily living with less effort and for a longer period of time. Thus, it appears that interval training may provide additional health benefits to highly functional patients with CAD.

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