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High-Intensity Interval Exercise in Chronic Heart Failure: Protocol Optimization

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ABSTRACT

Background: There are little data on the optimization of high-intensity aerobic interval exercise (HIIE) protocols in patients with chronic heart failure (CHF). Therefore, we compared acute cardiopulmonary responses to 4 different HIIE protocols to identify the optimal one.

Methods and Results: Twenty men with stable systolic CHF performed 4 different randomly ordered single HIIE sessions with measurement of gas exchange. For all protocols (A, B, C, and D) exercise intensity was set at 100% of peak power output (PPO). Interval duration was 30 seconds (A and B) or 90 seconds (C and D), and recovery was passive (A and C) or active (50% of PPO in B and D). Time spent above 85% of VO_{2peak} and time above the ventilatory threshold were similar across all 4 HIIE protocols. Total exercise time was significantly longer in protocols with passive recovery intervals (A: 1,651 ± 347 s; C: 1,574 ± 382 s) compared with protocols with active recovery intervals (B: 986 ± 542 s; D: 961 ± 556 s). All protocols appeared to be safe, with exercise tolerance being superior during protocol A.

Conclusion: Among the 4 HIIE protocols tested, protocol A with short intervals and passive recovery appeared to be superior. (*J Cardiac Fail 2012;18:126−133*)

Key Words: Intermittent exercise, prescription, cardiac rehabilitation, heart failure.

Exercise training improves symptoms, quality of life, and functional capacity in patients with chronic systolic heart failure (CHF) and may also have a favorable impact on mortality and hospitalizations.[1−4] Current guidelines primarily recommend continuous aerobic training at a moderate intensity in this population.[5−7] Recent data suggest that high-intensity aerobic interval training is superior to continuous training for improving quality of life, peak oxygen uptake (VO_{2peak}), and cardiac remodeling in CHF patients,[8] benefits that were also demonstrated in other populations.[9−13]

High-intensity aerobic interval exercise (HIIE) consists of alternating periods of high-intensity exercise and periods of low-intensity exercise or rest. Originally used by athletes for training purposes, the rationale for its use is to increase training time spent at a high percentage of VO_{2peak}, thus producing a stronger stimulus for cardiovascular and muscular adaptations.[13,14] However, most studies in CHF prescribed HIIE protocols empirically, with exercise parameters including work/recovery intensity and interval duration being selected arbitrarily.[8,15,16] That constitutes a substantial limitation, because manipulating these parameters significantly alters time spent at a high percentage of VO_{2peak} and time to exhaustion.[17−19]

We recently showed that repeated 15-second bouts of exercise at 100% of peak power output (PPO) interspersed by passive recovery intervals of equal duration may represent an optimal HIIE protocol in patients with coronary heart disease (CHD).[20,21] Optimization of HIIE protocols regarding time spent near VO_{2peak}, total time of exercise, safety, and perceived exertion has received little attention

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in CHF. We therefore sought to compare the acute cardiopulmonary responses to 4 different HIIE protocols varying in interval duration and type of recovery (active vs passive) in compensated CHF patients to define the optimal one among the 4 protocols.

Methods

Study Design

This was a crossover study investigating the acute cardiopulmonary responses to 4 different HIIE protocols. At baseline, anthropometric data, vital signs, and resting electrocardiogram (ECG) were collected, and all participants underwent a maximal cardiopulmonary exercise test. At least 3 days but <1 week after the maximal cardiopulmonary exercise test, subjects performed 4 different randomly ordered single HIIE sessions at least 3 days apart and within 3 weeks. All sessions were supervised by an exercise physiologist (E.N., G.B., or M.G.) and a cardiologist (P.M.). The protocol was approved by the Montreal Heart Institute Ethics Committee, and each of the patients gave written informed consent.

Participants

Twenty men with stable CHF were recruited at the heart failure and transplantation outpatient clinics of the Montreal Heart Institute. Inclusion criteria were: age $\geq$18 years, left ventricular ejection fraction (LVEF) $<40\%$ (measured within 6 months of enrollment by echocardiography, radionuclide ventriculography or cardiac magnetic resonance), stage C CHF as defined by ACC/AHA guidelines,[22] New York Heart Association (NYHA) functional class I—III, optimal medical therapy including a beta-blocker and an angiotensin-converting enzyme inhibitor or angiotensin II receptor blocker for $\geq$6 weeks, ability to perform an exercise test limited by dyspnea, and capacity and willingness to sign the informed consent form. Exclusion criteria were: any relative or absolute contraindication to exercise testing or training according to current recommendations,[23] fixed-rate pacemaker or implantable cardioverter-defibrillator device with heart rate (HR) limits set lower than the exercise training target HR, major cardiovascular event or procedure within 3 months preceding enrollment, permanent atrial fibrillation, CHF secondary to significant uncorrected primary valvular disease (except for mitral regurgitation secondary to LV dysfunction), congenital heart disease, or obstructive cardiomyopathy.

Maximal Cardiopulmonary Exercise Test

A continuous progressive exercise test was performed on an electromechanically braked cycle ergometer (Ergoline 800S; Bitz, Germany). Pedal cadency was maintained between 60 and 80 rpm. After 2 minutes of warm-up at 20 W, the initial power output was set at 30 W and increased stepwise by 10 W every minute until exhaustion. PPO was defined as the power output reached at the last fully completed stage. Oxygen uptake (VO_2) was determined continuously on a breath-by-breath basis using an automated gas analyzer system (Oxycon Pro; Jaegger, Germany), for which the calibration procedure has been described previously.[20,21] The average value of VO_2 recorded during the last 15 seconds of exercise was considered to be VO_{2peak}.[20,24] The ventilatory threshold was determined by a consensus of 2 experienced observers (M.G. and P.M.) using a combination of the V-slope, ventilatory equivalents, and end-tidal oxygen pressure methods.[25] Heart rate, manual brachial blood pressure, and rating of perceived exertion using the Borg scale (level 6—20)[26] were recorded before the test and at 1-minute intervals during exercise and recovery. An 8-lead ECG (Marquette, USA) was continuously monitored and recorded every minute. A leveling off of oxygen uptake despite increased workload and a respiratory exchange ratio >1.05 were used as criteria for maximal oxygen uptake.[8] This was accomplished in 12 of 20 patients.

HIIE Sessions

Each HIIE session was preceded by 5 minutes of warm-up at 30% of PPO. Exercise intensity was set at 100% of PPO determined during the maximal cardiopulmonary exercise test. Protocols varied in interval duration (30 seconds for protocols A and B vs 90 seconds for protocols C and D) and type of recovery (active recovery at 50% of PPO for protocols B and D vs passive recovery [0% of PPO] for protocols A and C; Fig. 1). We did not investigate protocols of shorter or longer duration, because prestudy tests indicated that many patients could not reach the requested pedaling cadency after 15 seconds and could not sustain such intensity for >90 seconds. Each patient exercised for a maximum of 30 minutes or until exhaustion due to fatigue, dyspnea, dizziness, or inability to maintain pedal cadency at $\geq$60 rpm. Thereafter, patients had 2 minutes of active recovery at 20 W and then 3 minutes of passive recovery seated on a chair. Gas exchange and ECG were measured continuously during rest, HIIE, and recovery intervals, and manual blood pressure, HR, and perceived exertion were recorded every 2 minutes throughout all testing sessions.

Study End Points

Our 2 coprimary end points were time spent at a high percentage of VO_{2peak} and total exercise time during each exercise protocol. Time spent at a high percentage of VO_{2peak} was calculated by summing each 5-second VO_2 block above defined thresholds (eg, above ventilatory threshold, $>80\%$, $>85\%$, $>90\%$, $>95\%$, and $>100\%$ of VO_{2peak}). These parameters were used in several studies both in normal subjects and CHD patients to quantify the acute training stimulus during HIIE.[20,21,27] Secondary end points included the proportion of patients completing the entire 30-minute training session, perceived exertion assessed by the Borg scale, and safety assessed by the occurrence of significant arrhythmias during exercise and recovery, symptoms or signs of HF or myocardial ischemia, or any other clinical events during the study. We also evaluated, for each HIIE protocol, the time spent near peak ventilation (VE_{peak}), peak heart rate (HR_{peak}), and peak O_2 pulse (O_2 $pulse_{peak}$) defined as oxygen uptake divided by HR.

Statistical Analysis

Results are expressed as mean ± SD for continuous variables and as n (%) for categoric variables. Normal gaussian distribution of the data was verified by the Shapiro-Wilk test. Because none of the variables met this condition, a nonparametric procedure was used. A Friedman analysis of variance by ranks was performed to test the null hypothesis that there was no difference between HIIE sessions. Multiple comparisons were made with a Wilcoxon matched-pairs test. The proportion of patients completing each 30-minute HIIE session was compared with a chi-square test. Correlation of main end point variables with baseline characteristics were tested by the Spearman rank correlation coefficient. All

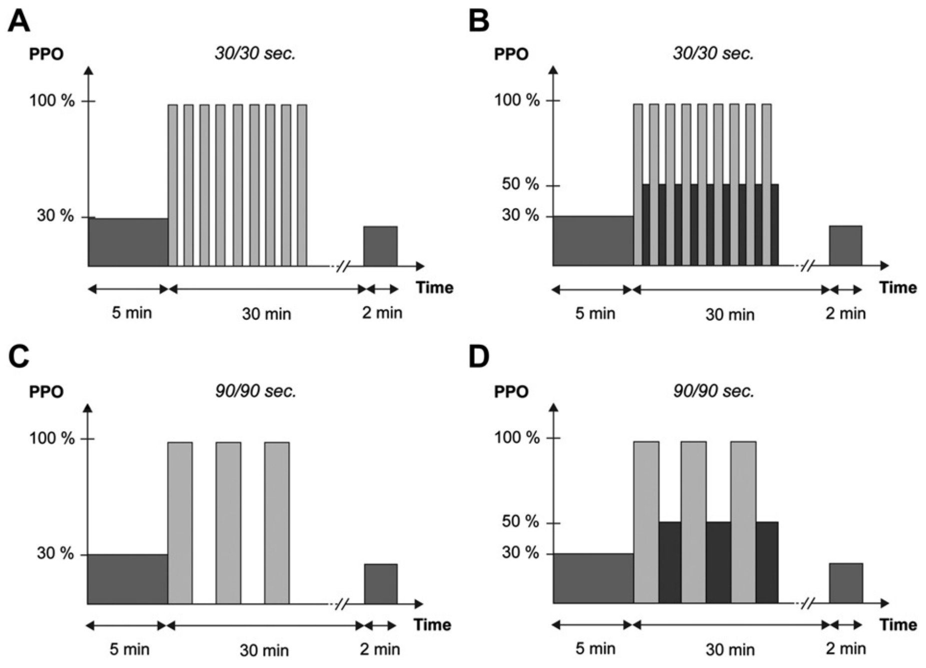

Fig. 1. Four training protocols of high-intensity interval exercise (A, B, C, and D). PPO, peak power output.

analyses were performed using Statistica 6.0 (Stasoft, USA). A *P* level of $<.05$ was considered to be statistically significant.

Results

Baseline Characteristics

Participants were 44–80-year-old men, most of whom had ischemic heart disease with mild to moderate symptoms and were receiving optimal medical therapy (Table 1).

Maximal Cardiopulmonary Exercise Test

Maximal cardiopulmonary exercise test variables are presented in Table 2. Mean VO_{2peak} was 17.2 ± 4.8 mL min^{-1} kg^{-1} (60 ± 13% of mean predicted value),[28] corresponding to a mean PPO of 105 ± 32 W.

Effects on Primary End Points

Time spent at $>100\%$, $>95\%$, and $>90\%$ of VO_{2peak} were significantly lower during protocol A compared with protocols B, C, and D ($P < .05$). There was no significant difference between time at $>85\%$ of VO_{2peak}, time at $>80\%$ of VO_{2peak}, and time above the ventilatory threshold across all HIIE protocols. Total exercise time was significantly longer in protocols A and C with passive recovery intervals ($P < .001$) compared with protocols B and D with active recovery intervals (Table 3). Mean % of VO_{2peak} attained during HIIE protocols was lower in protocols A and C with passive recovery intervals versus protocols B and D with active recovery intervals ($P < .001$; Table 3).

Effects on Secondary End Points

The proportion of patients completing the 30-minute training session was significantly higher during protocol A

Table 1. Baseline Clinical Characteristics (n = 20)

Clinical variable	
Age (y)	60 ± 9.9
Men	20 (100%)
Body weight (kg)	88.8 ± 15.1
Body mass index (kg/m^2)	30.1 ± 5.3
LVEF (%)	27.9 ± 6.5
Duration of heart failure (years)	5.6 ± 4.0
NYHA functional class	
I	5 (25%)
II	10 (50%)
III	5 (25%)
Etiology of heart failure	
Ischemic heart disease	11 (55%)
Idiopathic dilated cardiomyopathy	8 (40%)
Other cause	1 (5%)
Medical history	
Diabetes mellitus	6 (30%)
Hypertension	12 (60%)
Medications	
ACE inhibitors or ARBs	20 (100%)
Beta-blockers	20 (100%)
Digoxin	7 (35%)
Furosemide	16 (80%)
Spironolactone	10 (50%)
Devices	
ICD	15 (75%)
CRT	3 (15%)

ACE, angiotensin-converting enzyme; ARBs, angiotensin II receptor blockers; BMI, body mass index; CRT, cardiac resynchronization therapy; ICD, implantable cardioverter-defibrillator; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association.

Values are presented as mean ± SD, or n (%).

Table 2. Results of the Maximal Cardiopulmonary Exercise Test (n = 20)

Maximal exercise variables	
Total exercise time (s)	506 ± 195
Peak power output (W)	105 ± 32
VO_{2peak} (L/min)	1.51 ± 0.46
VO_{2peak} (% predicted)	60 ± 13
VO_{2peak} (mL kg^{-1} min^{-1})	17.2 ± 4.8
Weber-Janicki class	
A	5 (25%)
B	8 (40%)
C	6 (30%)
D	1 (5%)
METS	4.91 ± 1.37
Resting heart rate (beats/min)	67 ± 10
Resting systolic BP (mm Hg)	120 ± 22
Resting diastolic BP (mm Hg)	67 ± 13
Maximum heart rate (beats/min)	125 ± 22
Maximum heart rate (% predicted)	77 ± 14
Maximum systolic BP (mm Hg)	155 ± 30
Maximum diastolic BP (mm Hg)	71 ± 11
Maximal ventilation (L/min)	72.7 ± 21.6
Maximal VE/VCO_2	46.2 ± 5.8
RER max	1.05 ± 0.08
Exercise variables at ventilatory threshold (VT)	
Exercise $time_{VT}$ (s)	301 ± 152
Peak power $output_{VT}$ (W)	75 ± 25
$VO_{2_{VT}}$ (L/min)	1.16 ± 0.24
% of VO_{2peak}	79 ± 9
$VO_{2_{VT}}$ (mL kg^{-1} min^{-1})	13.1 ± 2.9
Heart $rate_{VT}$ (beats/min)	107 ± 19

BP, blood pressure; METS, metabolic equivalents of oxygen consumption; RER, respiratory exchange ratio; VO_2, oxygen uptake; VO_{2peak}, peak oxygen uptake; VE, minute ventilation; VCO_2, carbone dioxide output.

Values are presented as mean ± SD.

(n = 15; 75%) compared with protocols B (20%; $P < .001$) and D (25%; $P = .016$). The mean rating of perceived exertion was significantly lower during protocol A (15 ± 3) compared with protocol B (18 ± 2; $P < 0.01$). Twelve participants (60%) rated protocol A as their preferred one. Time at a high percentage of peak minute ventilation was significantly lower during protocol A compared with all other protocols. Time spent at a high percentage of HR_{peak} was similar across all HIIE protocols, with the exception of time >90% of HR_{peak} which was significantly lower during protocol A compared with protocols with active recovery intervals (B and D), whereas time at a high percentage of peak oxygen pulse was consistently higher during protocol A compared with all other protocols (Table 4). No significant ventricular arrhythmias occurred. One patient had a single asymptomatic episode of atrial tachycardia at 160 beats/min which remitted spontaneously after 60 seconds. One CHD patient developed asymptomatic 2 mm ST-segment depression during all HIIE protocols. No other adverse events occurred during the study.

Correlation of Baseline VO_{2peak} With HIIE Protocols

Baseline VO_{2peak} correlated with total exercise time in protocols with active recovery intervals (B: $r = 0.61$; $P = .004$; D: $r = 0.54$; $P = .014$) and moderately in protocol A with passive recovery intervals ($r = 0.48$; $P = .033$) but not in protocol C ($r = 0.13$; $P = .571$). Exercise time >85% of VO_{2peak} was inversely correlated with baseline VO_{2peak} in protocols with passive recovery intervals (A: $r = -0.53$; $P = .015$; C: $r = -0.65$; $P = .002$) with no significant correlation in protocols with active recovery intervals (B: $r = -0.03$; $P = .895$; D: $r = 0.18$; $P = .435$). Typical VO_2 responses during each HIIE protocol in a patient with preserved exercise capacity (VO_{2peak} = 25.9 mL kg^{-1} min^{-1}) and in a patient with severely reduced exercise capacity (VO_{2peak} = 11.8 mL kg^{-1} min^{-1}) are illustrated in Figure 2.

Discussion

This study is the first to attempt to establish an "optimized" HIIE protocol by analyzing time spent at a high percentage of VO_{2peak} in subjects with stable compensated CHF. Furthermore, very few studies in this population have

Table 3. Acute Cardiorespiratory Responses to the 4 High-Intensity Interval Exercise Modes (A−D)

	A	B	C	D	*P* Value
Total exercise time (s)	1,651 ± 347[‡,§,¶]	986 ± 542	1,574 ± 382[‡,§,¶]	961 ± 556	<.001
Time above percentages of VO_{2peak} (s)					
>100%	109 ± 171[*,‖]	194 ± 253	132 ± 172	184 ± 222	.027
>95%	190 ± 277[*,‖]	332 ± 349	228 ± 226	324 ± 298	.041
>90%	316 ± 384[*,‖]	458 ± 426	344 ± 276	488 ± 371	.041
>85%	478 ± 501	590 ± 479	470 ± 312	635 ± 424	.425
>80%	688 ± 543	711 ± 505	600 ± 345	748 ± 473	.369
>VO_{2VT}	772 ± 433	779 ± 467	691 ± 311	769 ± 510	.398
Borg perceived exertion scale	15 ± 3[†,§]	18 ± 2	16 ± 3	17 ± 2	.001
Mean % of VO_{2peak} during session	75 ± 9[‡,§,¶]	87 ± 10	73 ± 9[‡,§,¶]	88 ± 8	<.001
n (%) completing training session (30 min)	15 (75%)[†,¶,‡,§]	4 (20%)[*,#]	10 (50%)	5 (25%)	.001

VO_{2peak}, peak oxygen uptake; VO_{2VT}, oxygen uptake at ventilatory threshold.

[*] $P < .05$.

[†] $P < .01$.

[‡] $P < .001$.

[§] Significantly different from B.

[¶] Significantly different from D.

[‖] Significantly different from B, C, and D.

[#] Significantly different from C.

Table 4. Acute Responses of Secondary Cardiorespiratory Parameters to the 4 High-Intensity Interval Exercise Modes (A−D)

	A	B	C	D	*P* Value
Time above percentages of $\mathrm{HR_{peak}}$ (s)					
>100%	52 ± 102	109 ± 184	153 ± 303	147 ± 323	.633
>95%	184 ± 302	198 ± 230	271 ± 445	252 ± 344	.148
>90%	$365 \pm 511^{*,\ddagger}$	$389 \pm 308^{*,\S}$	419 ± 539	414 ± 376	.009
>85%	543 ± 659	641 ± 353	611 ± 594	617 ± 451	.915
>80%	889 ± 679	854 ± 457	905 ± 606	776 ± 500	.644
Time above percentages of $\mathrm{VE_{peak}}$ (s)					
>100%	$17 \pm 48^{\dagger,\P}$	50 ± 89	36 ± 45	78 ± 115	.004
>95%	$42 \pm 103^{\dagger,\P}$	$127 \pm 174^{*,\S}$	80 ± 101	150 ± 203	.001
>90%	$82 \pm 155^{\dagger,\P}$	$230 \pm 282^{\dagger,\S}$	$137 \pm 161^{*,\|}$	230 ± 266	<.001
>85%	$152 \pm 220^{\dagger,\P}$	$360 \pm 372^{\dagger,\S}$	$218 \pm 242^{*,\|}$	323 ± 314	.002
>80%	$258 \pm 324^{\dagger,\P}$	$469 \pm 438^{\dagger,\S}$	$324 \pm 314^{*,\|}$	435 ± 355	.010
Time above percentages of $\mathrm{O_2pulse_{peak}}$ (s)					
>100% $\mathrm{O_2pulse_{peak}}$ (s)	639 ± 535	540 ± 539	512 ± 517	502 ± 530	.125
>95% $\mathrm{O_2pulse_{peak}}$ (s)	$836 \pm 577^{\dagger,\S}$	637 ± 568	628 ± 527	637 ± 572	.004
>90% $\mathrm{O_2pulse_{peak}}$ (s)	$997 \pm 662^{*,\#}$	729 ± 564	756 ± 516	738 ± 584	.002
>85% $\mathrm{O_2pulse_{peak}}$ (s)	$1{,}171 \pm 513^{\dagger,\P}$	809 ± 549	908 ± 476	832 ± 579	.001
>80% $\mathrm{O_2pulse_{peak}}$ (s)	$1{,}343 \pm 467^{\dagger,\P}$	868 ± 538	$1{,}056 \pm 439$	885 ± 586	<.001

$\mathrm{HR_{peak}}$, peak heart rate; $\mathrm{O_2pulse_{peak}}$, peak O_2 pulse; $\mathrm{VE_{peak}}$, peak minute ventilation.
$^{*}P < .05$.
$^{\dagger}P < .01$.
‡Significantly different from B and D.
§Significantly different from C.
¶Significantly different from B, C and D.
$^{\|}$Significantly different from D.
$^{\#}$Significantly different from B and C.

used HIIE protocols using 100% of PPO. Despite unusually high power intensities, we did not encounter any safety issues. Our findings indicate that HIIE protocols with short intervals (30 s) interspersed with passive recovery intervals are better tolerated and allow subjects to increase their total exercise time compared with protocols with longer intervals or active recovery intervals without compromising training time spent at >85% of $\mathrm{VO_{2peak}}$. These results add important physiologic information regarding to the prescription of this potential modality of aerobic training.

The finding that HIIE protocols with passive recovery intervals result in a longer time to exhaustion compared with protocols with active recovery intervals regardless of the interval duration (30 vs 90 s) is consistent with earlier studies

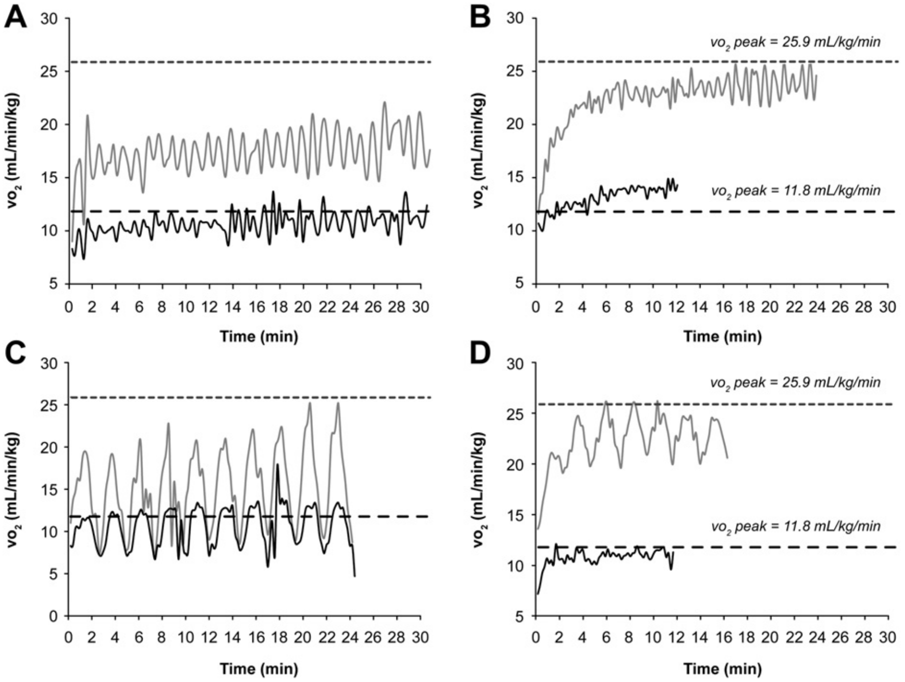

Fig. 2. Oxygen uptake (VO_2) during the 4 protocols of high-intensity interval exercise (A, B, C, and D) in a patient with a low exercise capacity ($\mathrm{VO_{2peak}} = 11.8$ mL kg^{-1} min^{-1}; *black lines*) and a patient with a preserved exercise capacity ($\mathrm{VO_{2peak}} = 25.9$ mL kg^{-1} min^{-1}; *gray lines*).

in athletes.[19,29] Recently, we also demonstrated in CHD patients with normal LVEF that 15 seconds of cycling at 100% of PPO alternating with 15 seconds of passive recovery resulted in a longer time to exhaustion compared with intervals of same duration but with an active recovery (50% of PPO).[20] Importantly, these variations would have been amplified had we not used a time limit, because significantly more patients reached the 30-minute time limit during training protocols with passive recovery intervals. One of the proposed mechanisms accounting for the observed difference in total exercise time between training protocols is the oxygen-dependent resynthesis of phosphocreatine, which has been shown to be higher during passive recovery.[18,29,30]

Time spent $>90\%$, $>95\%$, and $>100\%$ of VO_{2peak} was significantly lower during protocol A compared with the other protocols, but the absolute time differences were <3 minutes, which were not clinically significant in our opinion. In contrast, time $>85\%$ of VO_{2peak}, $>80\%$ of VO_{2peak} and above the ventilatory threshold, which already represent a strong training stimulus, were similar across all training protocols. Moreover, perceived exertion assessed by the Borg scale was lower in protocol A compared with protocol B. This may be due to a lower sensation of breathlessness associated with passive recovery intervals in protocol A, which could reflect the higher minute ventilation observed during protocols with active recovery intervals. Again, these results are consistent with those obtained in earlier studies in athletes[19,29] and patients with CHD.[20] Interestingly, oxygen pulse, which is known to depend on stroke volume and arteriovenous difference, was significantly higher during protocol A compared with all other protocols, suggesting that short intervals with passive recovery also produce a stronger stimulus on left ventricular contractility and/or and muscle O_2 uptake compared with longer intervals or active recovery.

A novel finding of the present study is that patients with CHF appear to respond differently to HIIE according to their baseline exercise capacity. Patients with severely reduced exercise capacity were able to spend considerably more time at a high percentage of VO_{2peak} in protocols with passive recovery, especially protocol A, compared with patients with a higher exercise capacity. Conversely, patients with a higher exercise capacity were able to spend more time at a high percentage of VO_{2peak} in protocols with active recovery. Although this finding may appear to be intuitive, it was not observed in our previous study in coronary patients,[20] presumably because those patients were older and less heterogeneous in their baseline exercise capacity.

HIIE training was first investigated in patients with CHF by Meyer et al, who prescribed training intensity according to maximal short-time exercise capacity (MSEC) determined by a cycle ergometer steep ramp test (increments of 25 W/10 s).[31–33] The most commonly used training protocol was 30 seconds of cycling at 50% of MSEC ($\sim$100%−150% of VO_{2peak}) alternating with 60 seconds at 10 W. The physical responses during this protocol were judged to be equivalent to 2 other protocols with different exercise intensities and interval duration, but the time spent at high percentages of VO_{2peak} was not considered.[34] The questionable validity of the steep ramp test, which has never been widely implemented in cardiac rehabilitation, is another limitation of those training protocols.[35] More recent studies[8,16] used protocols with longer interval duration, such as the so-called "Norwegian HIIE protocol" consisting of 4 intervals of uphill treadmill walking during 4 minutes at 90%−95% of HR_{peak} interspersed by 3 minutes of active recovery at 50%−70% of HR_{peak}. However, in our experience few patients can sustain 4-minute intervals at high intensities, especially with active recovery. Furthermore, HR is a poorly reliable intensity parameter during HIIE, especially in patients with HF.[20,36,37]

This study adds important clinical information for those involved in the rehabilitation of CHF patients. The results of the HF-ACTION trial, a recent large randomized clinical trial of exercise training in systolic heart failure have been modest and disappointing.[3,4] Possible reasons for the lack of a major clinical benefit include poor adherence to the prescribed exercise program and the relatively low intensity of the continuous aerobic training protocol thus providing an inadequate training stimulus.[4] HIIE provides a stronger training stimulus than moderate-intensity continuous aerobic exercise for improving functional capacity, which is one of the best established predictors of outcomes in CHF. To our knowledge, there are no data on adherence to HIIE training programs in patients with HF. In a recent study on long-term effects of HIIE training after myocardial infarction, 82% of patients in the HIIE group reported to exercise twice weekly or more at 30 months compared with 58% in the usual care exercise group.[38] Potential reasons for better adherence include lower ratings of perceived exertion[21,39] and a more enjoyable training modality[40] compared with isocaloric continuous training. Rehabilitation training sessions in CHF patients could be performed in groups, with each ergocycle individually calibrated, in the same way as the very popular "spinning" sessions proposed by most fitness centers.

Study Limitations

Several limitations of this study need to be outlined. First, we included a relatively small number of patients, and our results, particularly regarding safety, should be interpreted with caution and confirmed in a larger study population. Second, the participants were relatively young men with few comorbidities. Therefore, our results cannot be generalized to all patients with CHF. Third, this study assessed only 4 protocols among an unlimited number of possible work/recovery interval combinations. However, the protocols used reflect a wide range of possible HIIE combinations at this intensity, because shorter duration is limited by the time needed for the patients to reach an adequate pedal cadency, and longer duration is limited by exhaustion. Finally, the impact on aerobic capacity and other fitness and clinical outcomes of our "optimized"

HIIE protocol should be assessed in a large randomized clinical exercise training study.

Conclusion

HIIE appeared to be safe in this selected population of men with mild to moderate systolic CHF. Overall, when considering lower perceived exertion ratings, better patient comfort and similar times spent at a high percentage of VO_{2peak}, the HIIE protocol with short intervals (30 s) and passive recovery (protocol A) appeared to be optimal among those tested. Larger studies are needed to confirm the safety and benefits of HIIE in CHF.

Disclosures

None.

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