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A Comparison of High Intensity Interval Training with Circuit Training in a Short-Term Cardiac Rehabilitation Programme for Patients with Chronic Heart Failure

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Abstract

High intensity interval exercise may be a more effective training method than moderate intensity exercise more commonly applied in cardiac rehabilitation. This randomized controlled trial compared the effects of high intensity interval training with moderate intensity circuit training on exercise tolerance and quality of life in patients with chronic heart failure. Twenty six patients with systolic heart failure (left ventricular ejection fraction 15-40%, New York Heart Association class II-III, age 62-87 years) were randomly assigned to circuit training (n=13) or high intensity interval training (n=13) during a 6 week cardiac rehabilitation programme. At baseline and on completion peak oxygen consumption (VO_{2peak}), oxygen consumption at ventilatory threshold (VT), ventilatory efficiency and disease specific quality of life were assessed. There was a significant increase in VO_{2peak} after training in the circuit group only (0.97 ml.kg^{-1}.min^{-1} P=0.021). Both groups showed significant improvements in VT (circuit 0.55 ml.kg^{-1}.min^{-1} P=0.050; interval 1.70 ml.kg^{-1}.min^{-1} P=0.006) and in quality of life (circuit-7 points P=0.017; interval-5 points P=0.050). There were no significant differences between the two training methods. High intensity interval exercise offers an alternative training mode for improving sub maximal exercise tolerance and quality of life in patients with chronic heart failure. However, the improvements did not match those reported in studies using more frequent and longer duration training interventions.

Introduction

Current evidence indicates that exercise training is beneficial for patients with chronic heart failure (CHF) [1], but it is less clear whether this is transferable to clinical practice where the exercise dose is often lower and patient populations are older and more heterogeneous. Randomized controlled trials demonstrating the benefits of exercise-based cardiac rehabilitation (CR) include an exercise dose that is much higher than that offered in many clinical settings, including in UK practice. In Europe typical CR programmes offer a greater frequency (3-5 sessions per week) and duration (12-16 weeks) of supervised training than in other areas, including the UK [2,3]. Levels of physical activity both in and out of supervised exercise sessions may not be sufficient to enhance aerobic fitness or reduce disease risk factors in patients participating in short-term CR [4]. Indeed poor adherence and inadequate training stimulus, resulting in minimal clinical benefits, were reported in the large multicentre randomized controlled HF-ACTION trial [5]. There is a recognized need for studies that advance evidence-based practice for exercise prescription in CR programmes [6], particularly for CHF patients for whom referral and uptake onto these programmes is low [7,8].

Current guidelines acknowledge that there is no universal exercise prescription for patients with CHF. The most widely used method is continuous aerobic training at moderate to high intensity (40-80% peak oxygen consumption (VO_{2peak}), 40-70% heart rate reserve), although interval training may also be an appropriate method of endurance aerobic training [9-11]. High intensity interval training, where short bursts (~30 s) of very hard exercise are interspersed with recovery periods, allows individuals to increase the amount of time exercising at a higher percentage of VO_{2peak}, thus providing a stronger stimulus than moderate intensity aerobic exercise for improving cardio-respiratory fitness [12,13]. There is currently renewed interest in the potential of high intensity interval training to optimize the benefits of exercise training for CHF patients, particularly given the limited duration of

many CR programmes. Recently published data comparing high intensity training with "usual practice" continuous aerobic training in an 8 weeks programme demonstrated that interval training was more effective at improving maximal and sub-maximal exercise capacity [14]. In this study patients were younger (mean age 54 years) than the wider population of CHF patients now referred to CR, and they achieved a higher volume of physical activity (13 hours per week) than is likely in the majority of these patients.

Many CR programmes use circuit-training, during which patients move around a series of different aerobic and muscular strength and endurance work stations, rather than continuous training on a cycle ergometer or treadmill [15]. Recommended exercise intensity is 40-70% heart rate reserve or rating of perceived exertion (RPE) of 12-15 on the Borg 6-20 scale [16]. There is some evidence confirming that circuit training is appropriate for CHF, induces a similar oxygen and hemodynamic demand to continuous cycle ergometer exercise at 70-80% maximum heart rate [17] and improves cardio-respiratory fitness and skeletal muscle strength [18].

Exercise training in CHF is aimed at increasing VO_{2peak}, one of the strongest predictors of outcome in CHF [19]. Additional targets are the improvement of sub-maximal exercise tolerance, i.e. the workload that can be sustained before reaching the ventilatory threshold (VT) which

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is more relevant for achieving daily tasks [3], ventilatory efficiency, and quality of life (QoL). Improvements in cardio-respiratory fitness are likely to be proportional to the exercise volume or "dose", including the intensity. Given the low frequency and duration of many CR programmes, high intensity interval exercise might compensate for a low exercise dose by providing a higher training stimulus to induce greater health benefits. The aim of this study was to compare the effectiveness of high intensity interval training with current practice circuit training at improving cardio-respiratory fitness, ventilatory efficiency and QoL in CHF patients in a typical CR programme in the UK comprising twice weekly sessions for 6 weeks.

Methods

Study population

Participants were recruited from the Heart Failure clinic at the local District General Hospital. Inclusion criteria were: systolic heart failure with resting left ventricular ejection fraction <40% on echocardiography, clinically stable for at least 4 weeks and on optimized medication dosage according to current guidelines [20]. Exclusion criteria were: acute coronary syndrome or surgery within the previous 6 months, decompensated heart failure, severe valvular heart disease, hypertrophic obstructive cardiomyopathy, unstable angina, complex/sustained ventricular arrhythmia, severe systemic/pulmonary hypertension, severe aortic stenosis, presence of non-cardiac exercise limiting disorders or co-morbidities (e.g. severe osteoarthritis or chronic obstructive pulmonary disease), presence of any other absolute contraindications for exercise testing and training in CHF [21,22]. Statistical power analysis based on data from the literature identified that 22 participants would be required to achieve a Beta level of 80% for a 10% difference in change in VO_{2peak} between the two training interventions. The anticipated drop-out rate was 15% (4 patients), therefore 26 patients in were enrolled in the study (Figure 1) and randomly assigned by computer to circuit training or high intensity interval training. Patient characteristics are shown in tables 1 and 2.
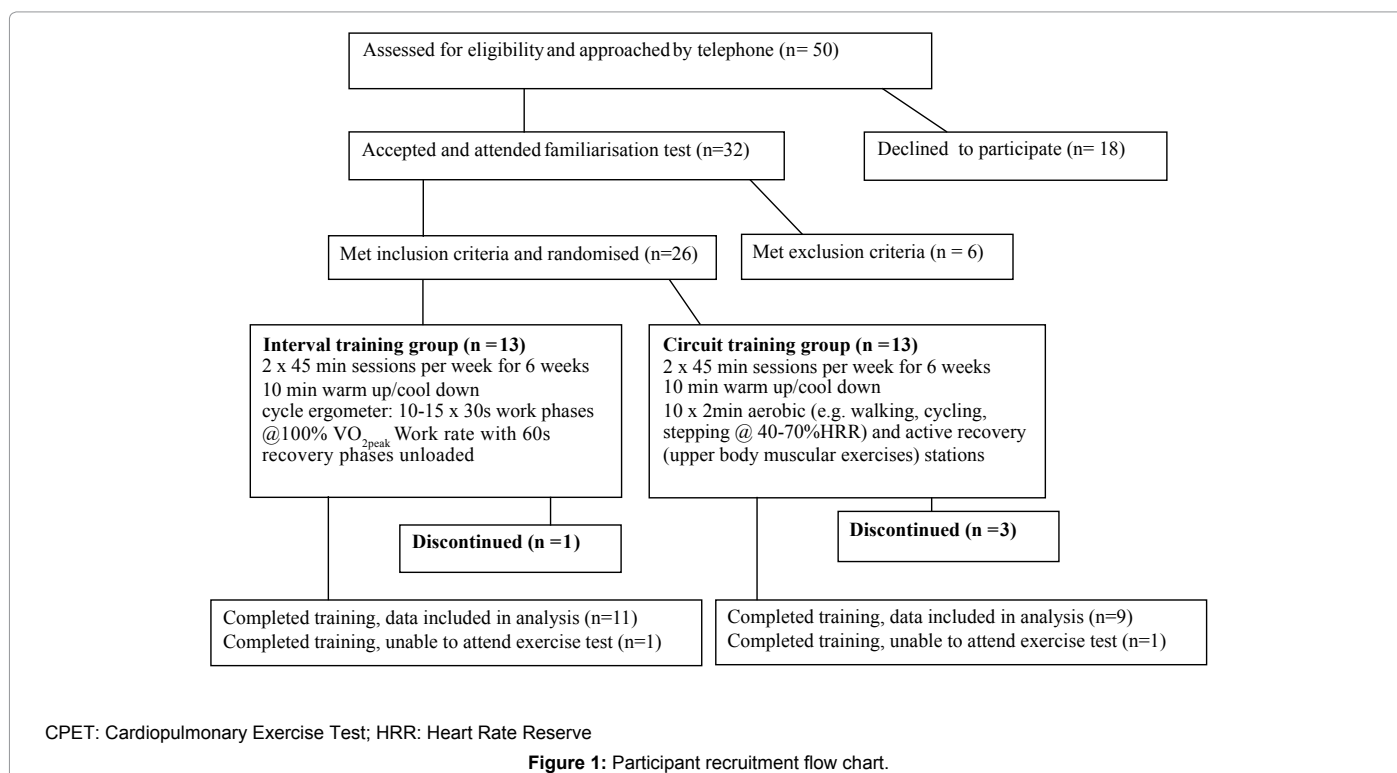
Study protocol

This randomized, controlled, parallel two group study conformed to the Declaration of Helsinki and was approved by the Local Research Ethics Committee. Patients gave informed consent to participate in the study. At baseline and after training cardio-respiratory fitness (VO_{2peak} and VT), ventilatory efficiency and QoL were assessed. A schematic of the experimental design is shown in figure 2.

Cardiopulmonary exercise test

Patients performed a symptom-limited cardiopulmonary exercise test (CPET) on a semi-recumbent cycle ergometer (Schiller, Baar, Switzerland, safety ergometer 911 BP/LS, with ergosana measuring system, Ganshorn Medizin Electronic (GmbH), Bitz, Germany). The initial resting phase was 3 min, followed by a starting workload of 10 W, with increments of $10W.min^{-1}$. Patients were asked to maintain a pedal cadence of approximately 60 rpm, and were verbally encouraged to exercise to exhaustion, as defined by intolerable leg fatigue or dyspnoea. All patients performed a familiarization test approximately one week before the baseline test. Heart rate and rhythm were monitored continually via 3-lead ECG, and automated blood pressure measurements were taken every 2 min.

Ventilatory expired gases were obtained at rest and during exercise via a face mask using a breath-by-breath respiratory gas analysis system (Schiller ergo-spirometry unit with Ganshorn Power Cube gas analysis). Respiratory gas exchange variables were produced automatically over a 10 s average. Ventilatory threshold was identified by computerized V-slope method [23] and this was cross-checked and confirmed by an experienced observer, in conjunction with plots of ventilatory equivalents and end tidal gas tensions for VO_2 and VCO_2 [24,25]. VO_{2peak} was expressed as the highest value from a 30 s moving average

Assessed for eligibility and approached by telephone (n= 50)

Accepted and attended familiarisation test (n=32)

Declined to participate (n= 18)

Met inclusion criteria and randomised (n=26)

Met exclusion criteria (n = 6)

Interval training group (n =13)
2 x 45 min sessions per week for 6 weeks
10 min warm up/cool down
cycle ergometer: 10-15 x 30s work phases @100% VO_{2peak} Work rate with 60s recovery phases unloaded

Circuit training group (n =13)
2 x 45 min sessions per week for 6 weeks
10 min warm up/cool down
10 x 2min aerobic (e.g. walking, cycling, stepping @ 40-70%HRR) and active recovery (upper body muscular exercises) stations

Discontinued (n =1)

Discontinued (n =3)

Completed training, data included in analysis (n=11)
Completed training, unable to attend exercise test (n=1)

Completed training, data included in analysis (n=9)
Completed training, unable to attend exercise test (n=1)

CPET: Cardiopulmonary Exercise Test; HRR: Heart Rate Reserve

Figure 1: Participant recruitment flow chart.

during the final stage of, or within 30 s of completion of the exercise test. Ventilatory efficiency was assessed using the regression slope of minute ventilation to carbon dioxide output (V_E/VCO_2 slope) from 2 minutes from the start of exercise until the respiratory compensation threshold, i.e. the linear part of the slope [26].

Exercise training intervention

Patients attended 12 cardiac rehabilitation sessions over 6-8 weeks supervised by specialist nurses and an exercise physiologist. This frequency and duration of supervised training is typical of UK CR programmes. All patients performed a gradual 10 minute warm-up and 10 minute cool-down prior to and following the circuit or interval training [15]. Circuit training comprised 10×2 min aerobic stations (e.g. walking, cycling, stepping, arm ergometry) interspersed with active recovery stations (upper body muscular exercises, e.g. bicep curls and chest press, using light hand weights or therabands), plus 30s for patients to move to the next station. Patients started with a ratio of one aerobic station to one active recovery station. In subsequent sessions progressive overload was tailored to individual tolerance, e.g. increasing the exercising muscle mass by progressing from arm ergometry to rowing; increasing the ratio of aerobic stations to active recovery stations to 2:1. Exercise intensity for the aerobic stations was based on guidelines from the British Association for Cardiovascular Prevention and Rehabilitation: 40-70% HRR, calculated from predicted maximum heart rate, monitored by telemetry (Polar Electro 610, Polar Electro, Finland), in conjunction with a rating of perceived exertion of 12-15 on the Borg 6-20 scale [16]. Although the European Society of Cardiology recommend the use of CPET [11] to establish physiologically meaningful reference points for aerobic exercise prescription in CHF, this is not widely implemented in UK programmes. As this study aimed to compare the novel interval training programme with current practice, we did not use the CPET data to adjust the existing circuit training exercise prescription. Interval training was performed on a cycle ergometer after the 10 min whole group warm up. Patients performed 2 minutes of unloaded cycling followed by 10–15 repetitions, depending on individual progress, of 30 s work phases at 100% work rate (W) achieved in the CPET, interspersed with 60 s of unloaded pedaling [27]. During each work phase the resistance on the cycle ergometer was increased until the required work rate was reached while pedal cadence was maintained at 60-70 rpm. In the recovery phase patients were asked to pedal at a cadence that felt "easy", i.e. 50-60 rpm for the majority. During pilot work for this study, patients preferred active recovery where they were able to keep their legs moving by turning the pedals at a self-selected cadence, and found the transition to the work phases easier after active rather than passive recovery. Exercise training was followed by a 30-45 minute educational session on topics including medication, dietary behavior and physical activity. Patients were encouraged to perform 30 minutes of daily moderate physical activity in addition to the supervised exercise sessions. This was not formally monitored, although a physical activity record was kept.

Quality of life

QoL was assessed using the Minnesota Living with Heart Failure Questionnaire (MLHFQ) [28]. This self-administered disease-specific questionnaire consists of 21 items recording patients' perceptions of how CHF affects their physical, psychological and socioeconomic lives. The total scoring ranges from 0 to 105, with lower scores indicating a better QoL. Separate physical and emotional dimension scores were also identified to further characterize the effect of heart failure on a patient's life.

Physical activity record

Patients completed a daily physical activity record for the study period by making a note of physical activities undertaken for a period of ≥ 5 min) and listing the type and intensity of activity. From the information provided metabolic equivalent values (METs) were estimated from the Compendium of Physical Activities [29] and number of minutes of light (<3 METS) or moderate (3-6 METS) activity were classified, and the total duration calculated for each week [30].

Statistical analysis

Statistical analysis was performed using PASW for Windows (version 18, SPSS Inc). The Shapiro-Wilk test was used to verify Gaussian distribution of the data. The majority of variables did not meet the assumptions for normal distribution. Therefore data are expressed as median and range and non-parametric procedures were used. At baseline, after randomization, group differences were compared using the Mann-Whitney U test. The Wilcoxon signed ranks test was used to assess changes in variables from baseline to post CR in each group, and the Mann-Whitney U test was applied to compare the difference between groups in these changes. The relationship between changes in cardio-respiratory fitness and QoL following training was determined by Spearman's correlation coefficient. For all statistical analyses α level of $P \leq 0.05$ was accepted as significant.

Results

Baseline characteristics of patients who completed the study and those who did not are described in table 1. Six patients did not complete the study, two more than the anticipated four patient drop out. Within the first two weeks of training three patients in the circuit group withdrew for medical reasons unrelated to cardiac health and one in the interval group withdrew due to worsening heart failure symptoms. Two further patients (one from each group) were not well enough for the post-training exercise test due to worsening breathlessness. Exercise performance, ventilatory efficiency and QoL tended to be poorer in non-completers, but no statistically significant differences were detected between completers and non-completers with the exception of emotional component MLHFQ score (Table 1).

Twenty patients randomly assigned to the circuit (n=9) or interval (n=11) training attended >90% of the sessions. There were no significant

Characteristic	Completed (n=20)	Did not complete (n=6)
Age (years)	71 (62-87)	74 (70-86)
Sex (male/female)	14/6	5/1
Height (m)	1.72 (1.55-1.88)	1.73 (1.64-1.81)
Body mass (kg)	78 (50-134)	82 (74-89)
Aetiology (ischemic/DCM)	13/7	5/0
NYHA Class II/III	18/2	2/4
Ejection Fraction (%)	31 (15-40)	30 (24-44)
VO_{2peak} (ml.kg^{-1}.min^{-1})	13.18 (8.72-22.30)	11.49 (11.10-18.70)
Peak RER	1.11 (1.02-1.31)	1.16 (1.01-1.24)
Peak work rate (W)	70 (40-90)	55 (40-90)
VO_2 at VT (ml.kg^{-1}.min^{-1})	8.78 (5.49-13.80)	9.12 (7.40-9.90)
VE/VCO_2 slope	31.51 (25.02-38.78)	33.83 (27.99-37.86)
MLHFQ total score	22 (4-58)	39 (35-58)
MLHFQ physical	12 (2-29)	23 (14-16)
MLHFQ emotional	3 (0-17)	13 (11-18) *

NYHA: New York Heart Association; DCM: Dilated Cardiomyopathy; MLHFQ: Minnesota Living with Heart Failure Questionnaire
*P<0.05 difference between completers and non-completers

Table 1: Baseline characteristics of patients (median and range).

Characteristic	Circuit Group (n=9)	Interval Group (n=11)
Age (years)	71 (62-83)	70 (66-87)
Sex (male/female)	7/2	7/4
Aetiology (ischemic/DCM)	5/3	7/4
NYHA Class II/III	8/1	10/1
Ejection Fraction (%)	24 (15-40)	34 (17-39)
Implantable device (CRT-D/CRT-P)	3/2	3/2
Atrial fibrillation	2	4
Resting heart rate (beats.min^{-1})	66 (56-85)	70 (40-86)
Systolic blood pressure (mmHg)	107 (95-150)	121 (92-154)
Diastolic blood pressure (mmHg)	67 (54-98)	75 (51-95)
Medication:		
α blocker	1	0
Angiotensin converting enzyme inhibitor	5	6
Aldosterone antagonist	0	1
Angiotensin II receptor blocker	4	5
Anti-arrhythmic (amiodarone/digoxin)	2/3	2/1
β-blocker	8	10
Calcium channel blocker	1	0
Diuretic	5	9
Potassium channel activator	0	1
Statin	6	8

NYHA: New York Heart Association; DCM: Dilated Cardiomyopathy; NYHA: New York Heart Association; CRT-D: Cardiac Resynchronization Therapy With Defibrillator; CRT-P: Cardiac Resynchronization Therapy With Pacing

Table 2: Baseline characteristics of patients in the circuit and interval training groups (median and range). There were no significant differences between groups ($P > 0.05$).

differences between the circuit and interval groups in baseline measures ($P > 0.05$) (Tables 2 and 3). No adverse events occurred during exercise training. Measurement of heart rate via telemetry was not possible in the majority of patients, particularly in cases of atrial fibrillation and implantable devices. Heart rate data could only be obtained in four patients in the circuit group, in whom the theoretical heart rate training zones were not achieved. RPE for both groups was maintained at 12-15 during training and was not significantly different between groups. For patients in the interval group, the median high intensity workload was 70W (range 40-90W).

Exercise performance

CPET results at baseline and after 6 weeks' training in the circuit and interval training groups are shown in table 3. There was a significant improvement in VO_{2peak} in the circuit group ($P = 0.021$) but not in the interval group ($P = 0.477$). VO_2 at VT was significantly improved after training in both groups (circuit $P = 0.050$; interval $P = 0.006$), whereas VE/VCO$_2$ slope did not change (circuit $P = 0.953$; interval $P = 0.678$). There were no significant differences between the circuit and interval training groups in changes from baseline to post-training in any CPET variable ($P > 0.05$).

Quality of life

MLHFQ scores at baseline and after training are shown in table 4. There were no significant differences in MLHFQ scores between groups at baseline ($P > 0.05$). Total MLHFQ score improved significantly in both groups following training (circuit $P = 0.017$, interval $P = 0.050$). Physical component score improved significantly in the circuit group only ($P = 0.038$), while emotional component score improved significantly in the interval group only ($P = 0.024$). However, there was no significant difference between groups in changes in MLHFQ scores. There were
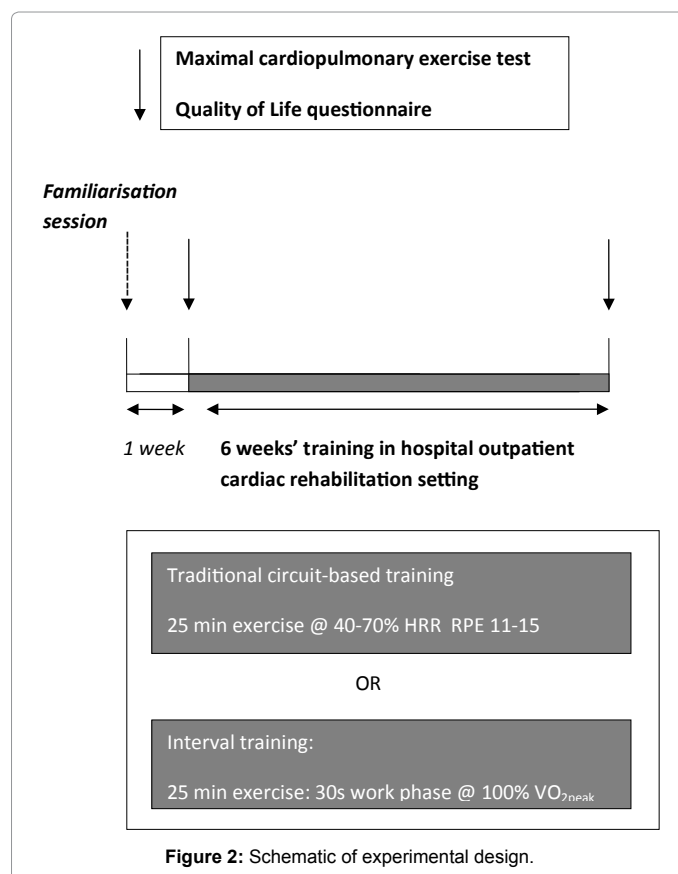
no significant correlations between changes in VO_{2peak}, VT and QoL after training ($P > 0.05$).

Physical activity record

There was inter-individual variability in time spent in physical activity outside the CR classes; minutes spent in light (<3 METS) activity ranged from 0 to 720 min (median: circuit 208 min, interval 228 min) and moderate (3-6 METS) activity from 60 to 600 min in different patients (median: circuit 310 min, interval 282 min). There was evidence of differences in subjective interpretation of what constitutes light or moderate physical activity. Some patients listed housework and meal preparation as light activity; others did not consider it to "count" as activity and did not include it. Nevertheless, the data collected indicates that physical activity did not change significantly during the 6 weeks training intervention, nor were there any differences in physical activity levels between the circuit and interval groups ($P > 0.05$).

Discussion

This is the first study to compare high intensity interval training with circuit training in a representative sample of CHF patients attending a CR programme in the UK. Circuit training, but not interval training, resulted in a small but significant improvement in VO_{2peak}. Both circuit and interval training significantly improved VT and QoL but neither intervention resulted in improvements in ventilatory efficiency. There were no significant differences between the two training methods in changes from baseline to post-training in any of the outcome measures. The implication is that two exercise sessions per week for six weeks will enable patients to achieve routine daily activities with fewer symptoms and to benefit from clinically meaningful improvements in QoL, but that high intensity interval training offers no advantage over circuit training.

Maximal cardiopulmonary exercise test

Quality of Life questionnaire

Familiarisation session

1 week   6 weeks' training in hospital outpatient cardiac rehabilitation setting

Traditional circuit-based training

25 min exercise @ 40-70% HRR RPE 11-15

OR

Interval training:

25 min exercise: 30s work phase @ 100% VO_{2peak}

Figure 2: Schematic of experimental design.

Exercise Test Variables	Circuit Group			Interval Group		
	Baseline	Post-training	Change	Baseline	Post-training	Change
Test duration (s)	393 (317-521)	422 (301-600)	29 (-85-80)	503 (248-559)	492 (212-580)	56 (-83-82)
Peak work rate (W)	70 (50-90)	70 (50-100)	0 (-10-20)	90 (40-90)	90 (40-100)*	10 (-10-20)
VO_{2peak} (ml.kg^{-1}.min^{-1})	12.7 (9.2-21.4)	14.9 (10.0-25.0)*	1.0 (-0.2-3.6)	13.7 (8.7-22.3)	14.4 (8.2-20.3)	0.2 (-3.6-4.6)
Peak RER	1.15 (1.06-1.31)	1.11 (1.01-1.21)	-	1.09 (1.04-1.22)	1.10 (1.05-1.24)	-
VO_2 at VT (ml.kg^{-1}.min^{-1})	9.0 (7.1-13.8)	10.4 (6.3-16.1)*	0.6 (-0.8-4.0)	8.6 (5.5-12.6)	10.3(5.1-15.8)**	1.7 (-0.4-3.3)
V_E/VCO_2 slope	31.8 (25.5-38.8)	30.0 (26.3-43.3)	0.0 (-7.2-6.6)	29.2 (25.0-34.9)	28.1 (23.1-36.8)	-1.1 (-7.9-6.3)

**$P \leq 0.01$ (significantly different from baseline)
*$P \leq 0.05$ (significantly different from baseline)

Table 3: Exercise performance at baseline and after 6 weeks' training in the circuit and interval training groups (median and range).The median and range value for change from baseline to post-training is also shown. There were no significant differences between the circuit and interval training groups in change from baseline to post-training.

Quality of Life	Circuit Group (n=9)			Interval Group (n=11)		
	Baseline	Post-training	Change	Baseline	Post-training	Change
Total score	21 (7-58)	14 (2-39)*	-7 (-23-1)	31 (4-55)	19 (4-53)*	-5 (-43-5)
Physical component	11 (2-29)	9 (0-19)*	-3 (-10-4)	16 (3-28)	10 (2-27)	0 (-17-4)
Emotional Component	3 (0-17)	1 (0-14)	-1 (-11-7)	7 (1-16)	3 (0-15)*	-2 (-13-1)

*P ≤ 0.05 (significantly different from baseline)

Table 4: Quality of life (Minnesota Living with Heart Failure Questionnaire) in the circuit and interval training groups at baseline and after 6 weeks' training (median and range). The median and range value for change from baseline to post-training is also shown. There were no significant differences between groups in changes from baseline to post-training.

VO_{2peak}, one of the strongest predictors of outcome in CHF[19], typically increases by 10-30% (1.0 to 3.5 ml.kg^{-1}.min^{-1}) following exercise training and is usually proportional to the exercise dose [1,31]. The low frequency and duration of supervised training in our study may partly explain the minimal changes in VO_{2peak} (circuit group median 1.0 ml.kg^{-1}.min^{-1} 9% $P<0.05$; interval group median 0.2 ml.kg^{-1}.min^{-1} 2% $P>0.05$). The HF-ACTION trial reported smaller than expected increases in VO_{2peak} (median 0.6 ml.kg^{-1}.min^{-1} or 4%) after 3 months in the exercise group and this was attributed to lack of adherence to the prescribed 1.5 hours per week of moderate intensity training [5]. Nevertheless, a modest increase in VO_{2peak} (6%) over 3 months was associated with a more favourable outcome in the HF-ACTION trial [32]. The improvement in VO_{2peak} in the circuit group may therefore have clinical significance. High intensity training theoretically provides a greater stimulus than moderate intensity training for improving VO_{2peak}. This is supported by studies showing increases in VO_{2peak} of 20 and 27% after 5 sessions per week for 3 weeks and 3 sessions per week for 8 weeks respectively [13,14]. This was not the case in the current short-term intervention, where supervised training only occurred twice weekly. It may be that cardio-respiratory training benefits are less pronounced in the wider CHF population on current medical therapy than in earlier study populations restricted to homogenous samples of younger CHF patients. We noted particular inter-individual differences in patients with CRT-D in whom a lower training effect has previously been reported [33]. Further studies in these patients may shed light on any possible interaction between CRT-D and training mode. We acknowledge that a limitation of the current study was the higher than anticipated drop-out rate. Twenty-two participants were required to detect significant differences in outcome measures and comparisons between groups, but only 20 participants completed the study.

Our study found no difference in the effect of circuit or interval exercise on changes in exercise performance following training. By contrast, Freyssin et al. study on 26 patients with CHF reported that high intensity interval exercise was more effective than moderate intensity continuous exercise at improving functional physical capacity [14]. In our study, VT improved by 20% following interval training (median 1.7 ml.kg^{-1}.min^{-1}), similar to the 22% improvement reported by Freyssin et al. Their study was similar to ours in sample size and setting as it compared a novel interval training programme with current practice. However, their patients were younger and performed a greater volume of physical activity over the 8 weeks programme. The mean interval training cycle workload was also higher than in our study (92W for weeks 1-4, increasing to 146W for weeks 4-8, compared to median (range) 70 (40-90) W in our interval training group, although their protocol included 60 s complete rest, or passive recovery, compared with 60 s active recovery in our study. Despite this, initial VO_{2peak} and VO_2 at VT values in Freyssin et al. patients were considerably lower than in our patients, although this may be due to the difference in CPET protocol; they used a treadmill rather than a cycle ergometer protocol, and applied relatively large increments in workload per minute, resulting in a short test duration of less than 4 minutes. Their interval training protocol also combined cycle and treadmill training. For these reasons, comparisons between the two studies are difficult. It has been suggested that the optimal protocol for exercise tolerance in patients with a low baseline capacity is 30 s at 100% CPET peak workload (the same intensity as our high intensity intervals), but with passive recovery (as used in Freyssin's study) [34]. Passive recovery may allow patients to spend more time exercising at a higher percentage of VO_{2peak} thus providing a greater exercise stimulus.

Our interval training protocol was also different to the aerobic interval training used in other studies where the work and recovery phases are longer (4 min at 85-95% maximum heart rate, 3 min at 50-70% maximum heart rate) [35,36]. Wisloff et al. have demonstrated that this type of training achieves superior benefits in exercise performance and associated mechanistic parameters compared to continuous isocaloric training at 70-75% maximum heart rate [35].

The current study took place in a "real world" setting and did not equalize the workload of interval and continuous training. Patients in the interval group were encouraged to complete as many work intervals as possible in the time available. Patients in the circuit group were instructed to exercise according to current practice (target heart rate of 40-70% HRR, estimated as maximal exercise testing is not routinely available, and RPE 12-15). It was not feasible to estimate exercise intensity by heart rate measurement, thus we had no objective measure of intensity or work done by the circuit group. Although the

guidelines recommended that patients exercise at a moderate intensity, setting and monitoring this intensity based on predicted heart rate and RPE is imprecise, and some patients in the circuit group may have been working at high intensities [37], thus receiving a similar physiological stimulus to the interval training. In patients with a low functional capacity, e.g. those with a peak workload of 50W, the absolute difference in workload at high or moderate intensity is small and may have a minimal effect on the physiological stress imposed. Recent data from our research group, based on the same circuit training and maximal cycle CPET protocols described in the current study and in a similar group of CHF patients, shows that average VO_2 during circuit training is 81% of CPET VO_{2peak}, and that VO_2 during some ambulatory exercises exceeds CPET VO_{2peak} (14.9 ± 2.6 ml.kg^{-1}.min^{-1} and 13.2 ± 2.6 ml.kg^{-1}.min^{-1} respectively) [38]. This lends further support to the possibility that patients in the circuit group were exercising at high intensities, and might explain why there were no differences between the circuit training and high intensity interval training.

Ventilatory efficiency is an additional predictor of long-term survival in CHF, and can be improved following exercise training [39], yet neither circuit nor interval training resulted in improvements ventilatory efficiency in the current study. This is consistent with reports that exercise training did not improve this parameter in older patients on optimal medication [40,41], even with a higher training frequency and duration. β-blocker therapy may limit the additional benefit of exercise training on ventilatory efficiency [42], or our training stimulus may simply have been inadequate to reduce the ergo reflex response which contributes to ventilatory inefficiency [43].

One of the most important aims of CR is to improve QoL. The current study demonstrates that significant reductions in MLHFQ scores can be achieved after either circuit or interval training, and that improvements are unrelated to changes in cardio-respiratory fitness. The majority of patients exceeded the 5 point reduction considered to be clinically relevant [44], illustrating that even short-term CR is beneficial, and some patients experienced sizeable positive changes in physical and emotional QoL. The median improvement is comparable to or better than that experienced by similar groups of elderly CHF patients following CR [31,40,45].

Patients did not significantly change their weekly physical activity levels outside the supervised classes, another explanation for the minimal improvements following CR. Differences in patient perceptions of what to include as light or moderate activities, as well as inaccuracies when applying generalized MET intensities to the CHF population, might have disguised any changes. For example, walking at 2 miles per hour is equated to 2.5 METs in Ainsworth's Compendium of Physical Activities [29], but for a patient with very limited exercise tolerance this walking pace might be closer to 4 METs. A study comparing MET values between post-myocardial infarction patients and age-matched asymptomatic individuals reported that the cardiac patients had higher MET values at the same walking speeds [46]. This highlights the need for population-specific MET values to guide exercise prescription rather than applying MET values derived from healthy individuals.

This study demonstrates the feasibility of including high intensity interval training in an existing CR programme for a heterogeneous group of CHF patients. Circuit training and high-intensity interval training are equally effective at improving sub-maximal exercise performance and disease-specific QoL, meaning that patients are more able to achieve and enjoy daily activities. Circuit training, but not interval training, resulted in small but significant increases in

VO_{2peak}, but the short-term twice-weekly intervention did not achieve the magnitude of improvements reported in other studies using a higher frequency and longer duration of training. In terms of real world rehabilitation, it is unlikely that circuit or interval training can be sustained long-term, and exercise interventions that can be continued long-term by the patients to result in lasting increases in physical activity are required.

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