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Tremendous Improvement of Cardiovascular Fitness Level in a Patient with Chronic Heart Failure and Severe Impairment of Left Ventricular Systolic Function using Novel Progressive Interval-to-continuous Training on a Treadmill

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Abstract

Moderate-Intensity Continuous Training (MCT) and High-Intensity Interval Training (HIIT) have been widely adopted in cardiac rehabilitation centers. Multiple studies have sought to determine which of these two training models is more effective in improving functional capacity in cardiac patients. Two large trials showed that HIIT was non-inferior to MCT in a cohort of patients with coronary artery disease and chronic heart failure with reduced ejection fraction. However, scarce data are available on the alternative approaches to exercise training. We present a case of significant improvement in cardiovascular fitness level in a patient with chronic heart failure and severe impairment of left ventricular systolic function after two months of exercise training using a customized progressive interval-to-continuous training model on treadmill, commencing with a moderate-intensity interval approach with further progression to long intervals or steady state exercise following patients' adaptation.

Keywords: Chronic heart failure; Cardiac rehabilitation; Interval-to-continuous training; Physical activity; Exercise tolerance

Introduction

The cardiac rehabilitation program consists of physical exercise sessions, dietary counseling, educational classes on lifestyle changes, and psychosocial support to patients and their families [1]. Supervised exercise training remains a core component of the cardiac rehabilitation program, focusing on aerobic, resistance, neuromotor and flexibility components. Exercise training is strongly recommended for patients with Chronic Heart Failure (CHF) at a class 1 evidence level in combination with pharmacological treatment, due to cardiorespiratory, metabolic, and autonomic positive cardiac responses [2].

Exercise-based cardiac rehabilitation positively affects functional capacity, exercise tolerance, and quality of life in CHF patients [3]. Many patients with chronic heart failure attending cardiac rehabilitation programs are at high risk of occurrence of an unfavorable cardiac event, e.g., left ventricular decompensation or complex ventricular arrhythmia due to NYHA functional class II-III, poor exercise capacity, presence of atrial fibrillation or ventricular ectopy [4]. The most frequently practiced endurance training model for patients with CHF is the constant workload exercise at moderate intensity at steady state (moderate intensity continuous training-MCT). Those who tolerate the continuous approach well can be shifted after 4-8 weeks of progressive steady state training to high-intensity interval training [5,6]. We present a case of significant improvement of functional capacity as well as the left ventricular systolic performance in a patient with chronic heart failure after two months of exercise training using a novel, customized progressive "interval-to-continuous" training model on a treadmill, commencing with a moderate-intensity interval approach with further progression to long intervals or steady state exercise following the patient's adaptation.

Case Presentation

A 52-year-old male patient, diagnosed with dilated cardiomyopathy, arterial hypertension, diabetes mellitus, and dyslipidemia, was referred to the Cardiac Rehabilitation Unit at Prince Sultan Cardiac Center, Riyadh. The patient had a history of heart failure decompensation six weeks earlier. Upon admission to the Cardiac Rehabilitation Unit in September 2022 the patient complained of shortness of breath at New York Heart Association (NYHA) class II. His daily physical activity was limited to 10-15 minutes' walk. The patient's medication regimen included furosemide 2 mg × 20 mg, spironolactone 1 mg × 25 mg, metoprolol Furosemide 2 mg × 20 mg, Spironolactone 1 mg × 25 mg, Metoprolol 2 mg × 50 mg, Entresto (sacubitril and valsartan) 2 mg × 100 mg, atorvastatin 1 mg × 40 mg, and empagliflozin 1 mg × 10 mg. The patient has been clinically stable on this treatment for the preceding few weeks. On physical examination, his heart rate, blood pressure, and oxygen saturation were within normal limits (blood pressure of 134/84 mmHg, heart rate of 66 beats per minute, oxygen saturation of 98% in room air). The lung examination showed no crepitations or rales. Heart assessment revealed a grade 2/6 systolic murmur over the apex area. Transthoracic echocardiography revealed severely depressed left ventricular systolic function with Ejection Fraction (EF) of 30%. An initial graded exercise test on a treadmill using the modified Bruce protocol had been terminated due to excessive fatigue after attaining 7.39 METs.

For training purposes we used a customized, aerobic, progressive "interval-to-continuous" training model on a treadmill. Such a program was continued for 8 weeks. In addition to walking training, resistance training and stretching exercises were incorporated.

Aerobic training consisted initially of 3 minutes of warm-up exercise, followed by Moderate-Intensity Interval Training (MIIT), with a subsequent 3-minute cool-down. The initial duration of 2 minutes for hard segments at speed 3.5 km/h and 2 minutes for the recovery segments at speed of 2 km/h were implemented to maintain the calculated training heart rate range (100 beats per minute-110 beats per minute) during hard segments. The initial goal included

progression of training duration. Once 40 minutes of total training duration has been obtained, training intensity was uptitrated with an increase in treadmill speed for hard segments up to 5 km/h and treadmill inclination of 3 degrees. The duration and speed of the recovery segments remained unchanged. The next step entailed a gradual increase in hard segment duration (by 2 minutes) following the patient's adaptation to the current exercise volume. Exercise training was monitored in terms of the patient's heart rate, blood pressure, electrocardiogram, and symptoms. Resistance training was initiated after 2 weeks and included an initial work-to-rest ratio of 1:2, *i.e.*, 30 seconds-60 seconds of exercise with a subsequent 1 minute-2 minute rest. Full resistance training progression was reached after 4 weeks. The whole exercise training program included 36 training units lasting 40 minutes-60 minutes. The final exercise protocol included two 20-min hard segments interspersed with a 2-min recovery phase. After 36 training units, the exercise tolerance test was repeated with a significant improvement of cardiovascular fitness of 13.68 MET attained. Results of the echocardiographic study carried out after an 8-week cycle revealed improvement of the contractility of the left ventricle with a favorable change in the left ventricular dimensions and ejection fraction. The favorable changes observed after 8 weeks of the exercise training program are listed in Table 1.

Parameter	Before cardiac rehabilitation program	After 8 weeks of exercise training
Exercise test-MET	7.39	13.68
Exercise test-DP	26 208	19 305
Echocardiography-LVEDD (mm)	56	56
Echocardiography-LVESD (mm)	34	32
Echocardiography-LVEDV (ml)	189	187
Echocardiography-LVESV (ml)	128	122
Echocardiography-LVEF (%)	30	34

Abbreviations: DP: Double Product (systolic blood pressure × heart rate); LVEDD: Left Ventricular End-Diastolic Dimension; LVEDV: Left Ventricular End-Diastolic Volume; LVEF: Left Ventricular Ejection Fraction; LVESD: Left Ventricular End-Systolic Dimension; LVESV: Left Ventricular End-Systolic Volume; MET: Metabolic Equivalent of Task

Table 1: Parameters of treadmill test and echocardiography measured before and after cardiac rehabilitation program.

Results and Discussion

Exercise training is strongly recommended for patients with Chronic Heart Failure (CHF) at a class 1 evidence level. Improvements of 18% to 25% in peak oxygen uptake have been documented in patients with CHF undergoing a cardiac rehabilitation program [7]. In a retrospective study by Martin, a cohort of 5400 patients with CHF was categorized into low, moderate, and high cardiorespiratory fitness groups based on an initial exercise test. After 12 weeks of exercise training, an improvement of 1.4, 1.0, and 0.8 METs, respectively, was observed, with a greater improvement in the lowest fitness group [8]. Continuous moderate-intensity exercise is the most popular mode of training performed in cardiac rehabilitation centers, with intensity set between ventilatory thresholds, or between 50% and 80% of heart rate reserve. MCT protocols typically consist of a 5-min warm-up (at intensity below the 1st ventilatory threshold), followed by a continuous exercise phase (20 min-40 min), and finish with a 5-min cool down [9]. The continuous mode of training is suitable for very-light, light, and moderate-intensity training. Moderate-to-high intensity training, *i.e.*, within 60%-80% of heart rate reserve, between the 1st and 2nd ventilatory threshold) can still be performed continuously or as interval training. High-Intensity Interval Training (HIIT) entails alternating periods of vigorous aerobic exercise with periods of passive or active recovery, usually at low intensity [10]. HIIT had been used by athletes for decades before it was applied in patients with coronary artery disease and in patients with chronic heart failure [11]. Of exercise/recovery variables (intensity, duration, number of repetitions, number of series, and between-series recovery duration) create different HIIT models and training progression. The most frequently applied HIIT model comprises a 10-min warm-up followed by 4 hard segments lasting 4 min each, at intensity above the second lactate threshold (typically at 90% of peak HR) interrupted by 3-min recovery segments [12,13]. Recent studies in animal models have demonstrated that intermittent ischemia provoked by HIIT resulted in formation of collateral coronary vessels [14]. Significant physiological disparity exists between exercising at MCT and HIIT. During HIIT, with a substantial increase of the total time at high intensity, the skeletal muscles are exposed to intense exercise training facilitating longer exercise time in comparison with moderate-intensity continuous mode. HIIT also seems to be a more attractive form of training than constant workload. Two large multicenter studies have compared HIIT vs. MCT in patients with coronary artery disease (SAINTEX-CAD study), and in patients with heart failure with reduced left ventricular ejection fraction (SMARTEX-HF). Both trials demonstrated no superiority of HIIT vs. MICE in terms of improving peak oxygen uptake [15,16]. The idea of a combined approach, *i.e.,* commencing with moderate-intensity continuous training, followed by the high-intensity interval approach, has been successfully implemented, and has been recently recommended [17]. Exercise intensity remains a key factor in cardiac rehabilitation programs as a strong predictor of the effectiveness of exercise training in terms of improvement in peak oxygen uptake. However, higher intensity is difficult to maintain for a longer period. The volume of exercise training is a result of its frequency, intensity, and time (volume=frequency × intensity × time); therefore, up-titration of any training variable results in an increase in exercise volume. We developed an exercise training model using adjustment of the time variable, *i.e.*, duration of hard segments. The exercise model which can be described as training with progressively longer intervals, or "interval-to-continuous" training, commences typically with hard blocks interspersed with recovery blocks (typically training commences with the hard and recovery segments' duration of 4 min and 2 min, respectively). The intensity of the first segment is reduced to allow a warm-up. With gradual tolerance of exercise training (lower heart rate and rating of perceived exertion), time or intensity of hard segments can be up-titrated accordingly (one variable at a time only). The primary goal is to attain 40 min-60 min of moderate or moderate-to-high intensity aerobic training per session; the secondary goal is to extend the duration of the hard segments (by 2 min) up to 15 min-20 min while maintaining the training heart rate with a horizontal heart rate curve (heart rate plateau) and adequate, repetitive heart rate reduction during recovery phases. In the case of this patient, exercise training commenced with 4 min hard blocks at speed 3.5 km/h,

interspersed with 2 min recovery blocks at speed 2 km/h, gradually increasing the total training time from 28 min to 40 min including the warm-up and cool-down phase. Speed of the treadmill was increased (by 0.5 km/h) to 5 km/h to keep the heart rate within the programmed range (100-110 beats per minute) during hard blocks. Gradual tolerance of the training allowed for a further training progression with treadmill inclination of 3% added over 8 weeks. The final training protocol included two 20 min hard blocks interspersed with one 2-min recovery block. After completion of the 8-week exercise program we documented significant improvement of cardiovascular fitness and improvement of left ventricular systolic performance (Figure 1).

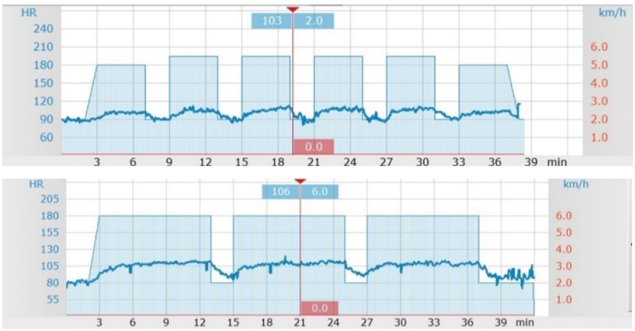

Figure 1: Progression of moderate-intensity interval training into interval-to-continuous training.

Conclusion

We present an interesting alternative to the conventional exercise training prescription (MCT or HIIT) in patients with chronic heart failure and reduced left ventricular ejection fraction. There are many potential disadvantages of traditional approaches, e.g., continuous mode is found to be less attractive and more boring, whereas high-intensity interval training can be impractical as a long term training mode for, e.g., the elderly. Both approaches entail a gradual increase in intensity and time with a concomitant shift of training heart rate up, whereas during ITC training the heart rate is fixed, with adjustment of speed and/or inclination to maintain the programmed heart rate range. The final goal is to increase the duration of hard segments to attain nearly constant or constant workload at discharge from the cardiac rehabilitation program. The gradual lengthening of hard segments seems to be attractive and motivating for a patient, whereas recovery segments allow for a sufficient rest. In addition, such training performed on a treadmill mimics the most physiological form of movement and can be easily implemented by patients on the days off training (outpatient cardiac rehabilitation) or after completion of the program (residential form). The authors are aware that future research is required to directly compare this novel training mode with both moderate-intensity continuous training and high-intensity interval training. The present case report is only a promising introduction to further observations and analyses.

Author Contributions

Conceptualization: A.N-L. and A.S; methodology: A.S.; validation: A.N-L.; investigation A.S.; resources: A.S.; writing-original draft preparation, A.N-L.; writing-review and editing: A.S.; funding acquisition, A.S. All authors have read and agreed to the published version of the manuscript.

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