KPC Kinesiology and Physiotherapy Comprehensive

P-ISSN: 2830-6317
E-ISSN: 2962-5491

Effect of high-intensity interval training in improving peak VO2 on cardiac rehabilitation patients phase II

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ABSTRACT

Background: Cardiac rehabilitation is a medical program designed to enhance cardiovascular health, quality of life, functional independence, and survival prospects. The objective of this study was to identify the impact of high-intensity interval training (HIIT) on the improvement of peak VO2 in patients with cardiovascular disease.

Methods: This study was conducted using a systematic literature review method through the analysis of articles from Q1-indexed journals, obtained from the PubMed, PEDro, and Elsevier databases and using the keywords of "Cardiac Rehabilitation", "Peak VO2", and "High-Intensity Interval Training", which selected based on inclusion and exclusion criteria. The selected articles included studies from the period 2020–2024, involving HIIT in cardiac rehabilitation patients.

Results: The results from several kinds of literature indicate that HIIT in cardiac rehabilitation patients significantly increases peak VO2. The improvement of peak VO2 in this study generally showed HIIT was far more superior than any other protocols, particularly moderate-intensity steady-state (MISS) or moderate-intensity continuous training (MCT).

Conclusion: Based on several collected literature and the discussion outlined above, it can be concluded that HIIT has a potential impact on increasing peak VO2 within a range of 8 weeks to 12 months of follow-up compared to other protocols such as MCT, MISS, or control/guideline protocols in improving peak VO_2 in cardiac rehabilitation patients.

Keywords: cardiac rehabilitation, high-intensity interval training, HIIT, interval training, peak VO2.

Received: December 11, 2024. **Accepted**: March 10, 2025.
Type: Review article; **Doi**: 10.62004/kpc.v4i1.57

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Introduction

Cardiac rehabilitation is a comprehensive multidisciplinary program tailored individually based on the needs of patients with cardiovascular disease. This program aims to restore the optimal physical, psychological, social, emotional, vocational, and economic conditions of heart disease patients.[1] The cardiac rehabilitation program also aims to improve quality of life, maintain functional independence, and serve as an indicator for survival.[2,3] The heart rehabilitation guidelines explicitly target the improvement of cardiorespiratory fitness, which is measured by the maximum oxygen consumption capacity (peak VO2). VO2 max is the highest value achieved during a high-intensity exercise test. Peak VO2 is an indicator that reflects both cardiovascular and skeletal muscle oxidative function (Fick equation: oxygen consumption = cardiac output × arteriovenous oxygen difference).[4,5] Peak VO_2 is accurately assessed through indirect calorimetry during graded, maximal exercise, usually conducted on a treadmill or cycle ergometer. When adjusted for age and other risk factors, it serves as one of the strongest indicators of cardiovascular and overall mortality in adults. It is also widely utilized in diagnosing mitochondrial disorders.[6]

The main measurement tool for peak VO2 is the cardiopulmonary exercise test (CPET) for practice tests to measure the performance of a person's heart and lungs, also known as the VO2 test. The VO2 max represents how much oxygen is consumed by the body and generated to be energy.[7] CPET aims to evaluate functional capacity and maximum aerobic capacity (VO_2 max). CPET has several contraindications that must be considered to ensure patient safety. These include acute myocardial infarction within the past 3–5 days, unstable angina, and uncontrolled arrhythmias that result in symptoms or hemodynamic instability. Additionally, acute myocarditis or pericarditis, acute pulmonary embolism or lung infarction, uncontrolled asthma, and oxygen saturation (SpO_2) below 85%. The CPET

KPC Kinesiology and Physiotherapy Comprehensive
P-ISSN: 2830-6317
E-ISSN: 2962-5491

protocol can use a treadmill or cycle ergometer.[8] The interpretation of CPET peak VO2 measurements is that a normal value is above 84% of the predicted value based on age, gender, and body weight. A low PVO_2 value (below 50% of the predicted value) indicates a significant impairment in functional capacity.[9]

The indications for cardiac rehabilitation are myocardial infarction, acute coronary syndrome, stable chronic angina, and heart failure. Individuals with myocardial infarction and coronary artery disease in cardiac rehabilitation have an important component, which is physical exercise. Physical exercise aims to improve both physical and mental health.[10] One of the physical exercises that can improve peak VO2 in cardiac rehabilitation patients is High-Intensity Interval Training (HIIT). HIIT is a type of exercise that involves short and intense activities interspersed with brief recovery periods. HIIT training can be administered to Phase II cardiac rehabilitation patients because, in this phase, patients have already been discharged from the hospital, making it feasible to implement HIIT. Additionally, HIIT effectively improves functional capacity, is safe, and well-tolerated, significantly enhances cardiovascular health, is time-efficient, and boosts patient motivation and engagement throughout the rehabilitation journey.[11]

This study aims to provide a comprehensive review of the effects of HIIT on cardiac rehabilitation patients. The review will focus on research published in the last 5 years in Q1-indexed journals to provide the latest scientific evidence regarding the effectiveness of HIIT as part of a comprehensive rehabilitation strategy in cardiac rehabilitation management.

Methods

A systematic literature review was conducted using secondary data based on research findings to evaluate studies on the impact of high-intensity interval training on peak VO2 in cardiac rehabilitation patients. The first step in the identification process was finding literature published in bibliographic databases like PubMed, PEDro, and Elsevier. The search terms included cardiac rehabilitation, high-intensity interval training, and peak VO2.

Inclusion and exclusion criteria were applied to ensure the studies were relevant. The inclusion criteria consisted of English-language research on cardiac rehabilitation patients who underwent high-intensity interval training therapies and had their peak VO2 evaluated, published in Q1-indexed databases between 2020 and 2024. Literature that contained review articles, comments, or editorials without original research data, or studies involving subjects other than cardiac rehabilitation patients, was excluded.

The selection process began by reading each article's abstract to determine its applicability based on the inclusion and exclusion criteria. The entire article was read for a more thorough analysis of relevant studies. Articles that met the criteria were subjected to a qualitative analysis, and duplicate articles were removed. The data from the selected studies were categorized based on subjects, training programs for the intervention and control groups, measurement methods, and results. To compare the efficacy of high-intensity interval training with changes in peak VO2, the findings were displayed in tabular form, using standard scales like CPET.

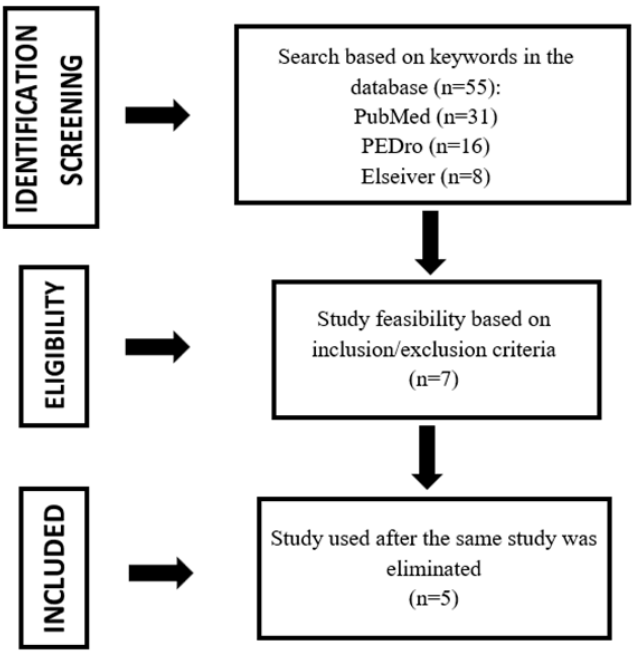

Figure 1. Flow-chart of articles screening processes

Results

From eligibility criteria and screening, we found a total of five studies from 2020-2023 (Figure 1). A total of 735 subjects were included in this study with mean of age ranging from 59-70 years. The sample sizes of the five studies varied from 24 to 382 subjects. All studies included generally having fair to excellent quality assessed by the PEDro Scale and showing the effectiveness of HIIT in improving peak VO2 in patients under cardiac rehabilitation programs (Table 1).

Four of the five studies used a similar protocol by comparing the effectiveness of HIIT with Moderate Intensity Continuous Training (MCT) or comparing HIIT, MCT, with standard treatment (control groups). One of the studies, McGregor et al, 2023 chose a different approach by comparing the effectiveness of HIIT with Moderate-Intensity Steady-State (MISS) in improving peak VO2. Studies reviewed were able to describe appropriate treatment protocols and follow-up periods. All the studies used either a cycle ergometer, a treadmill, or a combination of both on their exercise protocols with CPET being used to measure the primary outcome (peak VO2). To measure the post-treatment effect, the studies reviewed generally provide a follow-up at 8 weeks post-treatment to 12 months post-treatment follow-up. Longer follow-up duration was

P-ISSN: 2830-6317
E-ISSN: 2962-5491

expected to describe long-term effectiveness and comparisons of the intervention in improving peak VO2.

Discussion

Peak VO_2 refers to the maximum oxygen uptake capacity achieved during exhaustive exercise involving large muscle groups. It is a physiological measure integrating the performance of the cardiovascular, pulmonary, and skeletal muscle systems, and is a key indicator of aerobic fitness. This indicator acts as a mortality predictor, therapeutic evaluation, and mitochondrial disease diagnosis in cardiac rehabilitation patients. HIIT improves peak VO_2 through physiological adaptations across the cardiovascular, respiratory, and skeletal muscle systems.[12,13] HIIT is known to improve both aerobic and anaerobic contributions to exercise, resulting in positive adaptations in peak VO_2. Following the Fick equation, where oxygen consumption (VO_2) is determined by the interaction between cardiac output and arteriovenous oxygen difference ($VO_2 = Q \times (CaO_2 - CvO_2)$), HIIT increases general cardiorespiratory fitness affecting augmented aerobic capacity and tolerance to greater efforts.[6,14] HIIT induces eccentric hypertrophy of the left ventricle, increasing the chamber size and wall thickness creating greater cardiac output (Q), followed by increased tidal volume (air per breath) and strengthening respiratory muscles such as the diaphragm. These changes enhance oxygen uptake and carbon dioxide elimination, improving arterial oxygen content (CaO_2). The isocapnic buffering period, the phase between the anaerobic threshold and respiratory compensation point, showed a significant increase only with HIIT.[15,16]

The included studies showed significant improvement in peak VO2 using the HIIT protocols compared to the other arm or control group. In four studies, MCT was relatively inferior and showed less improvement with time compared to HIIT exercise. The reviewed studies utilised HR Max, RPE/Borg Scale, or HRR to keep all the subjects reach the exercise volume threshold. In HIIT protocols, studies used HR Max ranging from 80-95% and RPE/Borg Scale ranging from 15-18. To reach this zone while exercising, modifying the media such as increasing the treadmill inclination, increasing the speed, and adjusting the cycle gear were done. In contrast with the HIIT threshold, MCT protocols used 35-50 HRR, 65-85% HR Max, and 11-13 Borg Scale.[11,17]

One of the 4 studies used HIIT-MCT protocols, from Mueller et al, 2021 were able to do a comparison between HIIT, MCT, and standard guideline protocol (control) in improving peak VO2, providing a wider analysis description of the effect of the two protocols with the contrasting result than the three other studies. Higher improvements in peak VO2 were noticed when comparing the HIIT group with the guideline protocol.19,20 Subjects with MCT protocols also showed significantly greater improvement in peak VO2 compared to the guideline control group, changes in peak VO_2 varied significantly among the HIIT, MCT, and guideline protocol groups after 3 months post-baseline. The observed changes were as follows: HIIT: 1.1 (3.0) mL/kg/min, MCT: 1.6 (2.5) mL/kg/min, and guideline control: −0.6 (3.3) mL/kg/min. However, the difference between the HIIT and MCT groups was not statistically significant.6 Notably, this study is considered to have a shorter follow-up period compared to three other studies with follow-ups extending up to 12 months. For instance, a study by Taylor et al. (2020) demonstrated a 10% improvement in peak VO_2 for the HIIT group and a 7% improvement for the MICT group at the 12-month follow-up (HIIT: 2.9 (4.5) mL/kg/min; MICT: 1.8 (4.3) mL/kg/min; MD: 1.1 mL/kg/min).[18,21,22]

The HIIT and MCT protocols in the studies reviewed depend only on the cycle ergometer or the treadmill for the exercise. We found one study combining aerobic training with unspecified resistance-coordination training in improving peak VO2. This study was a 2 arms RCT comparing the effectiveness of HIIT followed by resistance training (80% 1 RM) with MCT followed by resistance training (60-65% 1 RM) on 56 women undergoing cardiac rehabilitation. The HIIT arm showed greater improvement (23%) than the control group (7%) after 12 weeks. Improvement in the subject's 1RM was significantly superior in the HIIT group (HIIT, 15.3 (10.6) kg; MCT, 6.4 (7.7) kg).[21]

In McGregor's study comparing HIIT and MISS, it was observed that peak VO_2 increased more significantly in the HIIT group than in the MISS group following an 8-week intervention. This difference remained statistically significant even after adjusting for age, sex, and study location. However, by 12 months post-baseline, the difference was no longer statistically significant. Exploratory subgroup analyses revealed that HIIT led to greater improvements in peak VO_2 at the 8-week mark among participants with STEMI/NSTEMI or those who underwent CABG, but not among those who had elective PCI. The improvement of peak VO2 in this study generally showed HIIT was far more superior than any other protocols, particularly MISS or MCT.11,12 More trials with different protocols and exercise combinations should be done to determine whether HIIT was the best protocol to produce a greater effect on VO2.[12]

This study has several limitations that should be noted. There is variation in the High-Intensity Interval Training (HIIT) protocols used in the reviewed studies, including differences in duration, frequency, and training intensity, which may affect the consistency of the results. The heterogeneity of subject characteristics—such as age, gender, and clinical conditions like heart disease history and medical procedures undergone—also limits the generalizability of the findings. Furthermore, the varying follow-up durations, ranging from 8 weeks to 12 months, make it difficult to assess the long-term effects of HIIT interventions. Another limitation is the absence of a quantitative meta-analysis, resulting in findings being presented descriptively.

KPC Kinesiology and Physiotherapy Comprehensive

P-ISSN: 2830-6317
E-ISSN: 2962-5491

Table 1. Results summary overview of Effect of high-intensity interval training in improving peak VO2 on cardiac rehabilitation patients phase II

Authors	Titles	Methods	Results
Silveira et al, 2020[18]	High-intensity interval training is effective and superior to moderate continuous training in patients with heart failure with preserved ejection fraction: A randomized clinical trial	A total of 24 participants with a mean age of 60 years (±9) were randomly assigned to two intervention groups. The High-Intensity Interval Training (HIIT) group performed treadmill-based sessions at 85–95% of their maximum heart rate (RPE 15–17), consisting of 4 sets of 4-minute intervals, with a 10-minute warm-up, 3-minute active recovery between sets, and 3-minute cooldown, three times per week for 12 weeks. The Moderate-Continuous Training (MCT) group exercised continuously on a treadmill at 60–70% HR Max (RPE 11–13) for 47 minutes per session, three times weekly over the same duration. Cardiopulmonary exercise testing (CPET) was conducted at baseline and after 12 weeks to assess physiological changes.	Following baseline assessments, both groups exhibited significant improvements in peak VO_2, with the HIIT group showing a superior increase compared to the MCT group (HIIT: 22.7%; MCT: 11.3%; $p<0.001$). Furthermore, the rise in absolute peak VO_2 was significantly and inversely correlated with a reduction in the E/e' ratio (r = –0.475; p = 0.04), suggesting a potential link between enhanced aerobic capacity and improved diastolic function.
Taylor et al, 2020[15]	Optimizing outcomes in cardiac rehabilitation: the importance of exercise intensity	A total of 93 participants with a mean age of 65 years (±8) were included and assigned to either a High-Intensity Interval Training (HIIT) or Moderate-Continuous Training (MCT) group. The HIIT program involved aerobic exercise using machines at 85–95% HR Max (RPE 15–18), performed in 4 sets of 4-minute intervals, with a 3-minute warm-up, 3-minute active recovery between intervals, and 3-minute cooldown, three times per week for 4 weeks. The MCT group trained continuously at 65–75% HR Max (RPE 11–13) for 34 minutes per session, including warm-up and cooldown periods, also three times weekly for 4 weeks. Cardiopulmonary exercise testing (CPET) was conducted at baseline, 4 weeks, and follow-ups at 3, 6, and 12 months to monitor long-term physiological adaptations.	After the 4-week supervised program, VO_2 peak increased by 10% in the HIIT group (2.9 ± 3.4 mL/kg/min) and by 4% in the MCT group (1.2 ± 3.4 mL/kg/min), with a significant between-group difference (mean difference: 1.7 mL/kg/min; p= 0.02). VO_2 peak adjusted for lean body mass also showed a significant post-baseline improvement (p = 0.0004). At the 12-month follow-up, VO_2 peak improvements persisted (HIIT: 10%, MCT: 7%), though the between-group difference was no longer statistically significant (mean difference: 1.1 mL/kg/min; p = 0.30).
Khadanga et al, 2021[22]	Optimizing Training Response for Women in Cardiac Rehabilitation: A Randomized Clinical Trial.	A total of 56 women aged 43 to 98 years (mean age 65.2 ± 11.1) participated in a 12-week intervention, assigned to either a High-Intensity Interval Training (HIIT) or Moderate-Continuous Training (MCT) group. The HIIT group performed treadmill sessions at 90–95% HR Max in 4 sets of 4-minute intervals (with 5 minutes of warm-up and 4-minute active recovery), followed by 2 sets of 10 repetitions of leg	After 12 weeks, the HIIT group demonstrated a 23% improvement in VO_2 (0.30 ± 0.17 L/min), significantly greater than the 7% improvement observed in the MCT group (0.13 ± 0.18 L/min; p = 0.03). Additionally, there was a significant difference in lower body strength gains, with the HIIT group showing a greater increase in

P-ISSN: 2830-6317
E-ISSN: 2962-5491

		press at 80% 1RM, three times per week. The MCT group completed 25 minutes of treadmill training plus 20 minutes of additional aerobic activity at 70–85% HR Max, followed by 10 leg press repetitions at 60–65% 1RM, also three times weekly. Cardiopulmonary exercise testing (CPET) was conducted at baseline and after 12 weeks to evaluate physiological adaptations.	one-repetition maximum (1RM) leg press performance (15.3 ± 10.6 kg) compared to the MCT group (6.4 ± 7.7 kg; p = 0.004).
Mueller et al, 2021[21]	Effect of High-Intensity Interval Training, Moderate Continuous Training, or Guideline-Based Physical Activity Advice on Peak Oxygen Consumption in Patients With Heart Failure With Preserved Ejection Fraction: A Randomized Control Trial.	A total of 180 participants with a mean age of 70 years were allocated into three groups: HIIT (arm 1), MCT (arm 2), and a guideline-based rehabilitation group. The HIIT group performed cycling sessions at 80–90% heart rate reserve (HRR; Borg RPE 15–17) in 4 intervals of 4 minutes, preceded by a 10-minute warm-up, 3-minute passive recovery between intervals, and 3-minute cooldown, three times weekly for 12 weeks. The MCT group cycled at 35–50% HRR for 40 minutes, five times per week for 12 weeks. The guideline group received general fitness counseling without supervised training. Cardiopulmonary exercise testing (CPET) was conducted at baseline and at 3 months to assess physiological changes.	Following the 12-week intervention, significant differences in peak VO_2 were observed across groups. The HIIT group improved by Following the 12-week intervention, significant differences in peak VO_2 were observed across groups. The HIIT group improved by 1.1 ± 3.0 mL/kg/min, the MCT group by 1.6 ± 2.5 mL/kg/min, while the guideline control group declined by −0.6 ± 3.3 mL/kg/min (p = 0.002). HIIT yielded significantly greater gains compared to the guideline group (mean difference: 1.5 mL/kg/min; 95% CI: 0.4 to 2.7; p= 0.01), and MCT also outperformed the guideline group (2.0 mL/kg/min; 95% CI: 0.9 to 3.1; p = 0.001). However, no significant difference was found between HIIT and MCT (p = 0.41).
McGregor et al, 2023[12]	Effects of Early Stimulation Using Baby Walker and Balance Bike on Children's Motor Development	A total of 382 participants with a mean age of 59 years (SD 9.6) were enrolled in a cardiac rehabilitation study comparing two exercise interventions. The first group underwent high-intensity interval training (HIIT) using a cycle ergometer at intensities greater than 85% of maximum heart rate, performed in 10 sets of 1-minute intervals, twice per week for 8 weeks. The second group received moderate-intensity steady-state training (MISS), following a standard cardiac rehabilitation protocol at 40–70% of heart rate reserve, lasting 20–40 minutes per session, also twice per week for 8 weeks. Cardiopulmonary exercise testing (CPET) was conducted at baseline, at 8 weeks, and at 12 months to assess outcomes.	Peak VO_2 values were similar between the groups at baseline (p > 0.05). After 8 weeks, the HIIT group showed significantly greater improvement in peak VO_2 compared to the MISS group, with an adjusted difference of 1.04 mL/kg/min (95% CI: 0.38–1.69; p = 0.002). However, at the 12-month follow-up, there was no significant difference in peak VO_2 between the two groups (p = 0.23).

KPC Kinesiology and Physiotherapy Comprehensive

P-ISSN: 2830-6317
E-ISSN: 2962-5491

Conclusion

Based on several collected literature and the discussion outlined above, it can be concluded that HIIT has a potential impact on increasing peak VO_2 within a range of 8 weeks to 12 months of follow-up compared to other protocols such as MCT, MISS, or control/guideline protocols in improving peak VO_2 in cardiac rehabilitation patients.

Funding

This study has no conflicts of interest to declare.

Conflict of interest

This study was conducted without any external funding.

Author contributions

PKKV conducted the literature search and prepared and edited the manuscript; IGEJP and AJ designed the research framework; PSPL and NKPR contributed to the literature search and reviewed the manuscript.

Ethical consideration

This review study relied exclusively on publicly available published articles and, therefore, did not require informed consent or ethical approval.

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