Review

Indonesian Journal of Cardiology
Indonesian J Cardiol 2024:45:207-219
pISSN: 2830-3105 / eISSN: 2964-7304
doi: 10.30701/ijc.1751

Effects of High–Intensity Interval Training on Cardiovascular Function and Risk Factors, Functional Impairments, and the Quality of Life in Coronary Artery Disease Patients: A Narrative Review

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Abstract

Coronary artery disease (CAD) causes damage to the cardiovascular system that leads to functional and quality of life (QoL) deterrence. Cardiac rehabilitation (CR) aims to improve cardiorespiratory fitness (CRF) to prevent disease progression and its risk factors. Aerobic exercise (AE) causes different physiological effects depending on the applied intensity. High-intensity interval training (HIIT) is being developed because of better effectivity than moderate-intensity continuous training (MICT). However, HIIT is generally not prescribed. This review aimed to describe the effects of HIIT on cardiovascular function and risk factors, functional impairments, and the QoL. Articles were searched using PubMed and CINAHL databases with the keywords "high-intensity interval training", "cardiac rehabilitation", "exercise-based cardiac rehabilitation", and "coronary artery disease". HIIT improves ventricular function, left ventricular ejection fraction (LVEF), heart contractility, and endothelial function, which further improves systolic and diastolic function. Improvement in cardiovascular risk factors was better in HIIT compared to AE in lower intensities. Studies recommend HIIT for CAD patients due to significant cardiovascular adaptation in this exercise. Compared with MICT, most studies have found that HIIT is better at improving CRF. HIIT also positively affects executive and affective functions. Research on the impact of HIIT on functional activity and QoL is still limited. However, one study found no differences in physical activity level and QoL in groups given HIIT or MICT. To conclude, HIIT is considered an alternative exercise that is more time-efficient than continuous exercise in CAD patients.

(Indonesian J Cardiol. 2024;45:207-219)

Keywords: *Cardiorespiratory fitness, cardiovascular disease, coronary artery disease, exercise therapy, quality of life*.

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Introduction

Coronary artery disease (CAD) remains one of the main causes of mortality worldwide, with a prevalence of 126 million people (1,655 per 100,000 population), accounting for 1.72% of the world's population. Approximately nine million deaths are caused by CAD, and it is estimated to exceed 1,845 in 2030.[1]

The cardiac rehabilitation (CR) program is one of the interventions given to CAD patients. It aims to improve cardiorespiratory fitness (CRF), functional abilities, and quality of life (QoL). The CR program is also provided as a secondary prevention program for cardiovascular disease (CVD).[2-4] Aerobic exercise (AE), which is a major component of the CR program, plays an important role in achieving these goals.[5,6]

Exercise intensity is linearly correlated with CRF improvement. Moderate-intensity continuous training (MICT) is the most widely used training protocol for CR programs. However, several obstacles were found in its implementation, including a lack of patient compliance and tolerance.[7-9] For this reason, a program that is more efficient and well-tolerated is needed.

High-intensity interval training (HIIT) is a form of intervention given in a CR program including patients with CAD.[10,11] This exercise protocol has been extensively developed because, in addition to being more effective than MICT, several studies have stated that this exercise is safe and does not cause significant adverse events.[11,12] However, many rehabilitation practitioners are concerned about the side effects and risks of HIIT.[13] Therefore, this review aimed to synthesize articles describing the use of HIIT in CAD patients regarding its effect on cardiovascular function and risk factors, functional impairments, and QoL to improve the knowledge of rehabilitation practitioners and expand the use of HIIT.

Methods

We reviewed articles that were searched using PubMed and CINAHL databases. The inclusion criteria were original articles from any method of research, systematic review, and meta-analysis without limitation of publication year. The keywords used were "high-intensity interval training", "cardiac rehabilitation", "exercise-based cardiac rehabilitation", and "coronary artery disease". Non-full text and non-English articles were excluded. The results are presented in the form of text and tables.

Results and Discussion

Twenty-two articles were identified and used to explain the subtopics. Nine articles were used to explain the implementation of HIIT in CAD patients consisting of exclusion criteria, protocols, and safety of exercise. Twelve articles explained the effect of HIIT on cardiovascular function and risk factors and 11 articles explained the effect of HIIT on CRF. The effects of this exercise on executive and affective functions were explained in one and three articles, respectively. Only one article has explained the effect of HIIT on Qo.

HIIT in CAD Patients

HIIT is defined as high-intensity AE or >85% peak oxygen uptake (VO2 peak), repeated for short periods (10 seconds to 5 minutes) and separated by rest periods of low-intensity exercise or complete rest. This form of exercise allows the patient to accumulate more time at a higher intensity than can be done during continuous exercise.[14]

HIIT is indicated in patients with CAD who have undergone revascularization procedures with percutaneous coronary intervention (PCI) or coronary artery bypass graft (CABG), non-obstructive CAD as evidenced by angiography, and CAD with a left ventricular ejection fraction (LVEF) >40%. Another indication is CAD patients with stable symptoms and no medication changes for more than 2 weeks. 10 Several conditions that cause HIIT exercise not to be given to patients with CAD based on previous research exclusion criteria are listed in Table 1.[10,15,16]

Other conditions that prevented researchers from providing HIIT in patients with CAD include hospitalization due to CVD in less than 6 months, symptomatic aortic stenosis, uncontrolled diabetes, symptomatic cerebrovascular disease for <6 months, severe shortness of breath at rest, severe exercise intolerance, thrombophlebitis, recent embolism, symptomatic aortic stenosis or pulmonary infarction, acute myocarditis or pericarditis, active endocarditis, and other acute non-cardiac disorders that may impair

Table 1. Conditions that cause high-intensity interval training not to be given in coronary artery disease patients.

	Research exclusion criteria
1.	Presence of ischemic symptoms
2.	Unstable angina pectoris
3.	New or revascularized acute myocardial infarction <4 weeks
4.	Significant (>50%) left main coronary artery stenosis
5.	The presence of proximal left anterior descending artery stenosis >75%
6.	Presence of vessel stenosis with minimal diameter (<2 mm)
7.	Presence of chronic heart failure with symptoms according to New York Heart Association class III (symptoms at rest or light physical activity)
8.	The presence of uncontrolled ventricular arrhythmias that cause hemodynamic disturbances
9.	Presence of significant valvular heart disease or shortness of breath on light exertion
10.	Use of pacemakers
11.	Presence of chronic obstructive pulmonary disease
12.	Presence of chronic renal failure
13.	Uncontrolled hypertension with blood pressure >180/100 mmHg,
14.	Pregnancy
15.	Inability to participate in training or practice tests according to the guidelines
16.	Presence of co-morbidities that preclude the patient from participating in exercise

exercise performance or be exacerbated by exercise, life expectancy <1 year, and drug abuse or alcohol in the last six months.[15,17]

HIIT protocols given to patients with CAD vary widely based on several studies and a review of the literature as described in Table 2.[10,16-19] The most commonly used protocol is an exercise consisting of a 10-minute warm-up followed by 4x4 min of interval training with an intensity of 85% - 95% heart rate peak (HR peak) or rating of perceived exertion (RPE) 15-18 and an active recovery period of 3 min with an intensity of 70% HR peak (RPE <13).[14]

Safety Issues of HIIT in CAD Patients

Most of the previous studies found no adverse events or significant adverse events that limited the ability of patients to perform HIIT programs. (15,17-19) A systematic review and meta-analysis of 17 studies found that only 1 study reported an incident of cardiac event, namely angina which caused the subject to leave the study and this occurred in both intervention groups who were given the HIIT or MICT. Compared to MICT or continuous training, other studies have found that cardiovascular events in both forms of exercise are very low.[15]

Adverse events that may occur during the HIIT program include death from all causes, hospitalization due to cardiovascular disease, atrial tachycardia, atrial fibrillation, or frequent ventricular arrhythmias. 15 Another study found one fatal event in 129,456 hours of MICT program and two non-fatal events in 23,182 hours of HIIT program.[20]

Data from 11 studies in stable CAD patients revealed three adverse cardiovascular events that were not clearly related to exercise. Two patients presented with angina and no arrhythmias were reported in any of the studies. It has been argued that HIIT is a safe exercise and does not differ in the frequency or increase in adverse cardiovascular events during exercise compared with continuous training. Before prescribing a HIIT program, the presence of angina symptoms, exercise intolerance, ischemic functional status, or arrhythmias during exercise should be carefully considered.[15]

Only a few studies reported additional adverse events, especially musculoskeletal and digestive problems, and these events were more frequent in the MICT-treated group. There were no deaths or cardiac events requiring hospitalization in the HIIT or MICT group. 15,20 The low fatality rate after the provision of supervised training is because the training is provided by officers who are trained in emergency management. It is said that the death rate will increase 6 times higher without proper management of cardiac arrest by trained personnel.[18]

Rognmo et al. obtained the adverse event rate was 1/129,456 hours of moderate-intensity exercise (one fatal cardiac arrest during moderate-intensity exercise) and one in 23,182 hours of vigorous-intensity exercise (two non-fatal cardiac arrests during HIIT). This

Table 2. HIIT Protocols and Its Effects of HIIT on Cardiovascular Function and Risk Factors, Functional Impairments, and the Quality of Life.

Author, Study (Year)/Study Design/Study Groups	HIIT Protocol	Cardiovascular Function and Risk Factors	Functional Impairments		Quality of Life
			CRF	Affective Function	
Madsen et al (2014)17/ Randomized controlled trial/HIIT vs usual program	• Frequency: 3 sessions of HIIT per week • Intensity, Time: • 4 x 4 min HIIT intervals (3 min active recovery between intervals) • HIIT: 85–95% of HRmax • Active recovery: 70% of HRmax • Type • Hospital: Walk or run on treadmills • Home: Walking uphill, running, cross-country skiing, or bicycling • Warm-Up: 8-10 min • Cooldown: No data • Program duration: 12 months.	• No changes in resting heart rate, heart rate recovery, and blood pressure in both groups • No between-group difference in resting heart rate, heart rate recovery, and blood pressure after 12 months • No changes in blood markers (serum glucose, total cholesterol, LDL cholesterol, HDL cholesterol, TG, Hs-CRP, and HbA1c) during follow-up in both groups	• No changes in VO2peak value from baseline to follow-up in both groups • No between-group difference in VO2peak value		There was an increase in quality of life (social domain) in the control group, but no be-
Maturana et al (2021)22/ Randomized controlled trial/HIIT vs MICT	• Frequency: 3 sessions per week • Intensity, Time • 4 x 4 min intervals (4 min active recovery between intervals) • HIIT: 90% of HRmax • Active recovery: 30 W • Total: 43 min (inc. warm-up & cool-down) • Type: Cycle ergometer • Warm-Up: 10 min (70% of HRmax) • Cooldown: 5 min (30 W) • Program duration: 6 weeks.	• No significant morphological changes in the heart as measured by echocardiography • A small change in the systolic and diastolic function especially in the right ventricle	• A significant increase in VO2max value in both groups with a greater increase in HIIT • The variability in the ΔV-O2max was associated with initial lower cardiorespiratory fitness, higher arterial stiffness, lower left ventricular mass, and higher diastolic function in HIIT. • The variability in the ΔV-O2max was associated with lower lower-limb microvascular responsiveness and higher right ventricular systolic function in MICT.		

Cardozo et al (2015)29/ Randomized controlled trial/HIIT vs MICT vs non-exercise	• Frequency: 3 sessions per week • Intensity, Time • HIIT: 90% of HRpeak • Active recovery: 60% of HRpeak every 2 min • Total: 30 min • Type: Treadmill aerobic • Warm-Up: 5 min • Cooldown: 5 min • Program duration: 16 weeks	No differences in hemodynamic variables (HRpeak, SBP, and DBP) after the training program both within and between groups	• VO2peak and peak O2P decreased in CG, increased in HIIT, and remained stable in MICT. • VE and VO2 at the ventilatory threshold and peak exercise were similar among groups. • The ventilatory threshold was achieved at 61% VO2 peak • The VE/VCO2 slope is maintained in trained groups and CG • The OUES is maintained in trained groups and CG • The O2P slope increased in HIIT, remained stable in MICT, and decreased in CG.
Prado et al (2016)30/ Randomized controlled trial/HIIT vs MICT	• Frequency: 3 sessions per week • Intensity, Time • HIIT: At respiratory compensation point (7 bouts) • The active interval at the ventilatory anaerobic threshold every 3 min • Total: 42 min • Type: Treadmill • Warm-Up: 5 min • Cooldown: 5 min • Program duration: 3 months	• No reduction in body weight in either group • No between-group differences in left ventricular ejection fraction	• No differences in peak RER or HR in either group after the intervention • There was a significant and similar increase in VO2 at VAT, peak VO2, and OUES in both groups

Villelabeitia-Jaureguizar et al (2019)25/ Randomized controlled trial/HIIT vs MICT	• Frequency: 3 days per week • Intensity, Time • 1st month: 20 s repetitions of 50% maximum load reached with SRT (peak intervals) • Recovery period: 40 s of 10% maximum load • 2nd month: adjusted using the new SRT result • Total: 40 min (inc. warm-up & cool down) • Type: Bicycle ergometer • Warm-Up • Week 1 to 4: 12-10-7-5 min (25 W) • Week 4 to 8: 5 min (25 W) • Cooldown • Week 1 to 4: 13-10-8-5 min (25 W) • Week 4 to 8: 5 min (25 W) • Program duration: 8 weeks		• Both exercise programs significantly increase VO2peak with a higher increase in the HIIT group. • ME at VO2peak and VT2 only significantly increased in the HIIT group • ME at VT1, significantly increased in both groups, with a greater increase in the HIIT group	
Jung et al (2014)33/ Randomized controlled trial/HIIT vs VICT vs MICT	• Frequency: 4 visits • Intensity, Time • HIIT: ≈100% Wpeak (≈90 ± 7% HRmax) • Recovery period: ≈20% Wpeak every 1 min • Total: 20 min • Type: Cycle ergometer • Warm-Up: 3 min (Self-determined light intensity) • Cooldown: 3 min (Self-determined light intensity) • Program duration: 3 months			Participants reported greater enjoyment of HIIT as compared to VICT and MICT, with over 50% of participants reporting a preference to engage in HIIT as opposed to either VICT or MICT
Wu et al (2017)19/ Randomized controlled trial/ HIIT vs MICT	• Frequency: 5 days/week • Intensity, Time • HIIT: 80% VO2max • Recovery period: 40% VO2max every 3 min • Total: 30 min • Type: Bicycle ergometer • Warm-Up: 3 min (30% VO2max) • Cooldown: 3 min (30% VO2max) • Program duration: 6 weeks	HIIT simultaneously improves mitochondrial bioenergetics and suppresses dynamic thrombin generation in platelets undergoing hypoxia		

indicates that the incidence of adverse events is low.[18]

A systematic review by Kolmos et al. found that HIIT is safe, time efficient, and well tolerated in healthy subjects and patients with cardiovascular disease. No studies have reported adverse events or evidence of vessel wall damage or negative effects on endothelial function after exercise, regardless of the intensity applied. In healthy people, it has been found that HIIT is safe and causes a variety of changes in endothelial function. One study examined serum nitric oxide production before and after exercise and found no significant differences.[21]

The Effect of HIIT on Cardiovascular Function and Risk Factors

The cardiovascular benefits of AE are linearly related to intensity; the higher the intensity, the greater the cardiovascular benefits.[9,18] If the total energy expenditure from exercise is kept constant, high-intensity exercise shows a greater cardioprotective benefit than moderate-intensity exercise.[18]

Exercise for six weeks did not cause significant morphological changes in the heart, but there were small changes in systolic and diastolic function, especially in the right ventricle.[22] A systematic review by Kolmos et al. found that out of 17 studies, six studies showed no changes in endothelial function related to exercise, while 11 studies showed changes in endothelial function after moderate or high-intensity exercise.[21]

HIIT programs improve endothelial function like MICT or standard care. Improvement was independent of the interval training mode, patient population, and training duration. Not all studies have reported that HIIT improves endothelial function. One study found no significant changes in serum nitrate or nitrite; only an increase in nitric oxide concentration was found. Therefore, nitrate and nitrite are biomarkers that are not appropriate for determining endothelial function.[21]

The structure and function of the left ventricle also improved after being given HIIT. One study found that 36 sessions of HIIT reduced left ventricular dilatation and mass, increased ejection fraction, systolic or diastolic blood flow, and other systolic and diastolic parameters.[18] Variability in the changes in maximal oxygen uptake (VO2 max) was associated with greater arterial stiffness, lower left ventricular mass, and higher diastolic function in the HIIT group.[22]

In post-PCI patients, regular exercise is beneficial for increasing the LVEF and cardiac contractility. Less intensive training even when given at moderate intensity does not produce a better effect than HIIT in terms of increasing LVEF. This shows that exercise intensity has different effects on cardiovascular function.[23]

Madssen et al. obtained no difference in blood pressure and resting pulse, as well as blood gas analysis between the groups given the HIIT and MICT programs.[16] Previous clinical studies reported a higher increase in diastolic blood pressure after exercise with an intensity of >60% VO2 peak than after moderate-intensity exercise. There are no data regarding the effects of high-intensity exercise on systolic blood pressure.[18]

The benefits of HIIT on the cardiovascular system are two times greater than those of MICT, so this is the basis for administering HIIT programs to patients with cardiovascular disease.[18] The advantages of HIIT with short intervals in CAD patients include the following: 1) HIIT is an optimal protocol that allows patients to perform exercises with an intensity close to the VO2 peak value; 2) the number of exercise bouts can be increased to fulfill the required volume; and 3) the rest periods between exercise bouts resulting in a lesser frequency of fatigue and shortness of breath.[24]

The HIIT protocol with short intervals was well-tolerated in patients with CAD. This protocol was also safe and elicited the same physiological response as MICT, allowing increased exercise compliance. The HIIT protocol with longer active intervals was more intolerable, with a higher rating of perceived exertion (RPE). This protocol was also associated with poorer adherence; therefore, it should be administered to patients who are fit or at low risk. In patients who are less fit and/or at higher risk, the HIIT protocol is more appropriate for administration at short intervals.[15]

In addition to increasing the VO2 peak, Villelabeitia-Jaureguizar et al. also found an increase in glycolytic metabolism in type 2 muscle fibers, which causes an increase in energy efficiency in terms of increasing strength and muscle resistance to fatigue. This process indicates an increase in mechanical efficiency (ME). Mechanical efficiency is an individual's ability to transfer the energy consumed by external work, which provides important information about biomechanical adaptation and the use of energy resources related to exercise and functional capacity. The decrease in ME, which indicates that the energy consumed is higher at a given work output, can represent the energy cost of breathing during exercise and the changes in production efficiency or ATP consumption per work output, which is higher. Individuals with lower ME scores are less efficient at exercising and have limited physical activity abilities. ME evaluation can be valuable for detecting muscle dysfunction and adaptation to exercise.[25]

Potential mechanisms that cause a greater increase in aerobic capacity with interval training include increased mitochondrial function and the maximal rate of calcium uptake into the sarcoplasmic reticulum, which in turn reduces the level of muscle fatigue.[26] Exercise causes an increase in oxygen delivery to the myocardial area but there is no certain explanation for the pathophysiology.[23]

Improved mitochondrial function is strongly associated with an increased VO2 peak. This supports the theory explaining the influence of mitochondrial function on cardiorespiratory capacity. Mitochondrial biogenesis is an important component in maintaining the structural integrity of skeletal muscles. Mitochondrial function is related to aerobic fitness and plays an important role in pathophysiological changes in patients with heart disease.[26]

Mitochondrial dysfunction is closely related to oxidative stress and is thought to be the most common mechanism underlying cardiovascular and metabolic diseases. Wu et al. found that exercise with 12% oxygen increased mitochondrial oxidative stress, which, in turn, led to hypoxia and thrombin generation. HIIT suppresses oxidative stress at the cellular level, thereby reducing the risk of thrombin generation due to hypoxia.[19]

The HIIT program is associated with a reduced risk of cardiovascular disease compared with AE at a lower intensity due to a greater cardioprotective effect. [18] A systematic review found that serum LDL and triglyceride levels did not increase significantly, whereas HDL and total cholesterol levels increased after administration of the HIIT program.[23] Findings by Abdelhalem et al. found different results on lipid and cholesterol profiles that varied widely with or without HIIT prescribing. This was caused by the insufficient number of samples, and the research samples continued pharmacological treatment, such as clopidogrel, aspirin, statins, and beta-blockers.[27] The increase in glucose control was higher after exercise with an intensity of >60% VO2 peak than after moderate-intensity exercise. There are no data regarding the lipid profile or loss of body fat following high-intensity exercise.[18]

The Effect of HIIT on CRF

Peak oxygen uptake (VO2 peak) is the amount of oxygen absorbed by the body in 1 minute when cardiorespiratory function and the ability of muscles to use oxygen reach their limits during long-term strenuous activity involving several large muscle groups. The higher the VO2 peak, the stronger the aerobic metabolism and the better the cardiorespiratory function.[23] Interval training with an intensity of 85%-95% HR peak is more effective in increasing VO2 peak than exercise with an intensity of 60%-70% HR peak.[18]

The investigators recommend using HIIT in a CR program for patients with CAD because of the significant cardiovascular adaptations to this exercise program.[20] HIIT programs are effective for improving health and physical fitness.[15] Research has found that the HIIT program has a beneficial effect on increasing VO2 peaks, while peak HR and resting HR do not change significantly.[23] The variability in VO2 peak changes was associated with low cardiorespiratory fitness at the start of exercise.[22] Ventilatory threshold and maximum workload increased significantly in post-PCI patients undergoing the HIIT program.[23] Interval training also causes an increase in VO2 peak, which is a strong predictor of all-cause death and death related to cardiovascular events.[26]

The increase in VO2 max varies based on the training component. Variations in the increase in VO2 max include the following: 1) interval training causes a slightly greater increase in VO2 max than continuous exercise; 2) more intense exercise causes a greater increase in cardiorespiratory fitness (VO2 max); and 3) longer training intervals combined with continuous high-intensity exercise lead to a more marked increase in VO2 max in almost all relatively young subjects.[24]

The HIIT program resulted in an increase in VO2 peak within <8 weeks compared with that in the control group without intervention.[28] Clinically significant increase in VO2 peak is >1.5 milliliter/kg/minute. HIIT programs improve aspects of fitness in healthy young or older individuals (> 60 years).[29]

Compared to MICT, the HIIT program significantly increased cardiorespiratory fitness to a greater extent.

The mean increase in cardiorespiratory fitness was 1.53 – 1.78 milliliters/kg/minute. HITT programs of 7-12 weeks lead to greater increases in cardiorespiratory fitness; therefore, training for less than 7 weeks or more than 12 weeks will yield suboptimal results.[20]

Madssen et al. provided a rehabilitation program for 12 months after the patient underwent a CR phase II program for 12 weeks at the hospital. Patients were given HITT three sessions per week at home and a supervised exercise program in the hospital 1 time a month. This study found that there was no difference in VO2 peak between the groups that continued the exercise program for 12 months after discharge from the hospital and the control group. Supervised exercise once a month was not sufficient to increase the VO2 peak. Even though the patient was given home exercises three times a week, his adherence to these exercises was not good, as evidenced by the physical activity questionnaire. Only one-third of the patients in the intervention group underwent HIIT 2-3 times a week.[17]

Intervals of 3-5 min are effective in improving the effectiveness of the exercise. Several studies have found a greater increase in VO2 max, which is around 0.85 liters/minute with an interval of 3-5 min. A literature review and meta-analysis found that interval training alone or in combination with continuous exercise increased VO2 max by an average of 0.5 liters/minute. This result is higher than that obtained in previous studies with an average increase in VO2 max of 0.4 liters/minute in response to exercise for 20 weeks. An increase in VO2 max of 0.2-0.3 liters/minute has also been reported in other studies.[24]

The increase in VO2 max with exercise was due to cardiac output and peripheral oxygen extraction. The role of changes in stroke volume, blood volume, capillary density, muscle mitochondrial content, and several factors associated with an increase in VO2 max due to exercise vary among individuals and due to the interaction of the specific components of the exercise program.[24]

Cardozo et al. conducted a study to compare the effect of a 16-week program of HIIT and MICT on cardiorespiratory fitness in patients with CAD. This study found that cardiorespiratory fitness (VO2 peak) and ventricular function were better in the HIIT group than those in the MICT group.[29] Maturana et al. in their research found that the HIIT and MICT programs significantly increased VO2 max. Greater improvement was found in the HIIT group than in the MICT group.[22]

In their study of patients with CAD, Prado et al. found that cardiorespiratory function improved significantly from baseline in the two groups given the HIIT and MICT programs. The improvement in cardiorespiratory function was the same in both groups because the MICT group received training with a relatively higher volume and intensity. The MICT group exercised for 50 min with intensity at the ventilatory anaerobic threshold, which was around 70%-80% VO2 peak for 41 min with an episode of 10 weeks.[30]

The Effect of HIIT on Executive Function

Acute HIIT programs tend to have a positive effect on overall executive function. Executive function refers to a specific category of cognitive control processes that operate in a top-down manner to support intentional and goal-oriented actions. Executive function later can be categorized into two sub-domains: 1) core executive functions, which include inhibition, shifting, and updating/working memory; and 2) higher-order EF, such as planning. The facilitation of executive functions is likely due to physiological changes induced by HIIT, such as heart rate, lactate, catecholamines, and blood flow. Executive function was assessed using several instruments including the Flanker task incongruent, Stroop test, Corsi block test, digit span test-backward, and several other instruments. These changes can lead to increased attention when performing activities that require executive function.[31]

Previous studies have found evidence that acute HIIT affects the prefrontal cortex and the area of the brain associated with executive function by increasing the activation and oxygenation of the prefrontal cortex. The facilitation of executive function is related to a biomarker that determines executive function, namely brain-derived neurotrophic factor (BDNF), which is induced by exercise.[31]

Exercise with an intensity of 95% maximum power output caused a decrease in overall cognitive performance improvement 30 min after stopping the exercise. This is associated with a higher neuromuscular fatigue during exercise. Acute HIIT interventions with a total time between 11 and 20 min or 21 and 30 min are likely to have a positive effect on executive function.

A total time of less than 10 min or more than 30 min did not consistently have a positive effect on executive functioning.[31]

Regardless of whether the intensity is submaximal or maximal, acute HIIT tends to have a positive effect on executive function. This is in contrast to previous findings that acute HIIT exercises lead to impaired executive function.[31]

The Effect of HIIT on Affective Function

Most studies show the overall beneficial effect of HIIT programs on pleasure as measured during and after a workout session.[15] Studies that assess affective responses during exercise in overweight and inactive individuals have found a negative relationship between exercise intensity and affective functioning. When exercise intensity increases above the ventilatory threshold, the affective response to exercise becomes increasingly negative.[32] Several studies have found that affective responses decrease when exercise intensity increases above the anaerobic threshold.[15] Continuous exercise with vigorous intensity, such as cycling with an intensity of around 80% VO2 max for 30 min causes greater psychological distress and greater discomfort compared to moderate-intensity cycling of around 50% VO2 max.[33]

The relationship between the stimulus and duration of recovery is important for maintaining positive affect. HIIT sessions performed with a 120-second stimulus elicited lower affective responses compared to HIIT sessions with a stimulus for 60 s and 30 s, even though the stimulus-recovery ratio was maintained at 1:1 throughout the HIIT sessions.[15]

Oliveira et al. found that affective response and pleasure were dependent variables. Affect is a reflexive response to emotions, including the positive, neutral, and negative aspects. Pleasure is a more specific feeling characterized by cognition and evaluation. Both of these aspects are related to adherence to practice.[32]

Inactive individuals found that HIIT caused less discomfort than continuous exercise did at vigorous intensity. It was also reported that HIIT was more enjoyable and preferred than continuous vigorous-intensity exercise, and comparable to moderate-intensity continuous exercise.[33]

The affective experience experienced during exercise is influenced by metabolic needs related to intensity. The HIIT program induced the same health-promoting adaptations as the MICT, although the time required for HIIT was shorter. This shorter time is considered more promising for increasing physical activity levels. The feeling of pleasure when performing exercises consisting of 6 × 3 min of interval training with an intensity of 90% VO2 max is lower than that of continuous exercise with an intensity of 70% VO2 max for 50 min.[33]

The Effect of HIIT on Functional Activity and the QoL

Research on the effect of HIIT on functional ability and QoL remains limited. In a study by Madssen et al., there was no difference in physical activity level and QoL between groups given the HIIT and MICT programs.[17]

Conclusion

HIIT causes changes in ventricular structure and function, increases in LVEF and cardiac contractility, and improvement in endothelial function. These changes affect systolic and diastolic blood pressure. HIIT is also associated with a better reduction in the risk of CVD than AE at a lower intensity. Studies have recommended using HIIT in a CR program for patients with CAD because of the significant cardiovascular adaptability of this exercise. Studies have shown that HIIT has a beneficial effect on CRF; however, these improvements vary based on training protocols. Compared with MICT, most studies found that HIIT was better at improving CRF. Regarding executive function and affective function, it is known that HIIT has a positive effect on these two functions. Research on the effect of HIIT on functional activity and QoL is still very limited, but one study found no difference in physical activity levels and QoL between groups given HIIT or MICT programs. In patients with CAD, HIIT is considered an alternative exercise that is more efficient in terms of time compared to continuous training.

Acknowledgments

The authors would like to thank Padjadjaran University for the opportunity to conduct this review and database facilitation. The authors received no financial support or funding.

List of Abbreviations

AE	Aerobic Exercise
CAD	Coronary artery disease
CABG	Coronary Artery Bypass Graft
CR	Cardiac rehabilitation
CRF	Cardiorespiratory Fitness
HIIT	High-intensity interval training
MICT	Moderate-intensity Continuous Training
QoL	Quality of Life

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