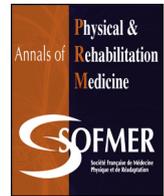




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Review

High-intensity interval training in patients with coronary heart disease: Prescription models and perspectives

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ABSTRACT

Recently, high-intensity interval training (HIIT) has emerged as an alternative and/or complementary exercise modality to continuous aerobic exercise training (CAET) in CHD patients. However, the literature contains descriptions of many HIIT protocols with different stage durations, nature of recovery and intensities. In this review, we discuss the most recent forms of validated HIIT protocols in patients with coronary heart disease (CHD) and how to prescribe and use them during short- and long-term (phase II and III) cardiac rehabilitation programs. We also compare the superior and/or equivalent short- and long-term effects of HIIT versus CAET on aerobic fitness, cardiovascular function, and quality of life; their efficiency, safety, and tolerance; and exercise adherence. Short interval HIIT was found beneficial for CHD patients with lower aerobic fitness and would ideally be used in initiation and improvement stages. Medium and/or long interval HIIT protocols may be beneficial for CHD patients with higher aerobic fitness, and would be ideally used in the improvement and maintenance stages because of their high physiological stimulus. Finally, we propose progressive individualized models of HIIT programs (phase II to III) for patients with CHD and how to ideally use them according to the clinical status of patients and phase of the cardiac rehabilitation program.

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1. Introduction

Older adults represented 13% of the total Canadian population in 2005 and will represent an estimated 24% in 2036 [1]. They represented 19% of the total population in France in 2015 and the proportion is still growing [2]. Aging is associated with increased risk of cardiovascular diseases such as coronary heart disease (CHD) [3]. Cardiovascular diseases are among the leading causes of death today in Canada (29%) and in the world (30%) and can lead to \$20 billion/year costs in physician services, hospital costs, lost wages and decreased productivity [3,4] and approximately €196 billion/year in the European Union (€106 billion in healthcare, €44 billion [22%] in informal care, €27 billion [14%] in early

mortality and €19 billion in absence from work or early retirement) [5].

Maximal aerobic power (VO_{2peak}) is an independent predictor of mortality and morbidity in CHD patients [6]. Therefore, cardiac rehabilitation programs with an exercise training component such as continuous aerobic exercise training (CAET) were found to be safe and to improve prognosis in CHD patients [7–11]. The additional clinical benefits of exercise training in CHD patients are well documented and include improvements in cardiovascular, lung and skeletal muscle functions, endurance, quality of life, inflammation, depressive symptoms, stress and cognitive functions [12,13]. Therefore, exercise training such as CAET is now a cornerstone of the non-pharmacological treatment of patients with CHD and is integrated into the North American and European guidelines [12–15].

Recently, a strong clinical interest has emerged in high-intensity interval training (HIIT) in patients with CHD, first mentioned in the American Heart Association recommendations for exercise prescription in 2007 [12]. Actually, HIIT is increasingly being mentioned as an exercise modality in the most recent North American and European guidelines for CHD patients [12–14].

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Here we review different forms of HIIT, their principles and their potential combination with CAET to optimize exercise training adaptations in CHD patients. We discuss only phase II (short-term) and III (long-term/maintenance) exercise training programs with HIIT and CAET separately or combined. Finally, we propose how HIIT with CAET can be integrated into theoretical/practical progressive exercise training models (phase II/III) for CHD patients.

2. CAET for cardiac patients

CAET is still the cornerstone of exercise training programs for CHD patients and is largely recommended worldwide [12–14,16]. The program improves prognosis, is safe and feasible and has almost no contra-indications for most patients with stable CHD [12–14,16]. CAET programs have shown good short- and long-term clinical benefits, including reduced mortality and/or morbidity [7–10,17–21], improved VO_{2peak} and ventilatory function, relieved clinical symptoms (dyspnea, sleep disorders and depressive symptoms), controlled dyslipidaemia, and reduced endothelial and muscle dysfunction [12–14,16]. The main goal of CAET is to perform longer exercise periods in steady-state, which favours oxidative metabolism. For beginners, walking programs remain the most prescribed modality for CHD patients because of the advantages: walking is safe, appropriate for starting exercising, needs no or little supervision and can be performed anywhere (indoor or outdoor). Exercise modalities for CAET include mostly walking, running, cycling, Nordic walking, rowing, swimming, stepping and stairs climbing [12–14,16]. In general, CAET leads to higher fat oxidation and longer exercising bouts at intensities from 40% to 50% VO_{2peak} for beginners with low physical function/greater cardiac risk (i.e., CHD patients) and 50% to 75% VO_{2peak} for CHD patients with higher fitness level or less cardiac risk [12–14,16].

Traditionally, the exercise intensity for CAET is prescribed using percentage maximal heart rate (%HRmax), heart rate reserve (%HRR) and peak power output (%PPO) and patient's rate of perceived exertion (RPE) (Borg scale: 6–20), with considerable success [12–14,16]. The exercise intensity zones for CAET are usually classified as follows (see review [15] for details): light- to moderate-intensity zone (40–50% VO_{2peak} , RPE: 11–12) and moderate- to high-intensity zone (50–75% of VO_{2peak} , RPE: 12–15). These zones must be mainly considered with phase II (initiation-improvement) and III (maintenance) cardiac rehabilitation (see progression models in Table 1). Exercise prescription based on the intensity of the ventilatory threshold, measured during maximal cardiopulmonary exercise test, is also often used for CHD patients, especially those receiving

beta-blockers, and corresponds to 50% to 60% VO_{2peak} (initial moderate-zone intensity) [13].

3. General principles of HIIT and exercise training implementation for CHD patients

In this section, we review the general principles of HIIT prescription adapted to CHD patients and its place in the context of exercise training implementation. In a second section, we review the available studies comparing HIIT to CAET for CHD patients, an important topic in recent years (Table 2). Finally, we propose a guide for HIIT prescription and implementation combined with CAET for CHD patients (Table 1).

The main principle of HIIT is to perform brief periods of high-intensity exercise (e.g. > 85% VO_{2peak} or PPO), interspersed with periods of low-intensity exercise or passive rest, to allow patients to accumulate greater time at a higher-intensity than they would otherwise perform with continuous exercise [22,23]. In CHD patients, HIIT can be considered a time-efficient substitute and/or alternative to traditional continuous exercise training [22,23]. Different HIIT protocols (intensity, stage duration, nature of recovery, number of intervals) have been tested and used for CHD patients (see reviews [22,23] for details and Table 2 for protocols). Three different categories of HIIT have been described for CHD patients:

- long intervals: 3 to 15 min at 85% to 90% VO_{2peak} ;
- medium intervals: 1 to 3 min at 95% to 100% VO_{2peak} ;
- short intervals: 10 sec to 1 min at 100% to 120% VO_{2peak} [22,23].

Furthermore, HIIT can be performed with different exercise modes such as cycling, running, walking with inclination, rowing, swimming or other activities. Exercise intensity is generally determined with % VO_{2peak} , %HRmax, percentage maximal aerobic power, percentage maximal short exercise capacity or RPE (Borg scale) [22,23]. The HIIT choice in terms of exercise intensity, duration of intervals and use of active or passive recovery has a profound effect on acute physiological responses, exercise tolerance and RPE for CHD patients [22,23].

3.1. HIIT with short intervals

The acute physiological responses to different HIIT with short interval protocols have been studied in patients with CHD [22–26]. Our group investigated an optimal protocol that would allow CHD patients to spend more time near the VO_{2peak} values and exercise for a longer total time with less feeling of fatigue and dyspnea [24–26]. We compared the acute cardiovascular

Table 1
Progression models for aerobic exercise training—continuous aerobic exercise training (CAET) or high-intensity interval training (HIIT) – for patients with coronary heart disease (CHD) by functional status.

Patient profile	Stage of training	Prescription (weekly)	CAET	HIIT
Low functional status (< 5 METs)	Initiation (week 0–4)	2–3 × CAET	50–70% PPO (RPE: 11–15)	Not recommended
	Improvement (week 4–12)	2 × CAET and 1 × HIIT (SI)	50–70% PPO (RPE: 11–15)	HIIT-SI: 15 s to 1 min at 70–100% PPO (RPE: 15–18)
	Maintenance (week > 12)	2 × CAET and 1 × HIIT (SI + MI)	50–70% PPO (RPE: 11–15)	HIIT-MI: 1–3 min at 90–110% PPO (RPE > 15) HIIT-SI: 15 s to 1 min at 100–120% PPO (RPE: 15–18)
Normal and high functional status (≥ 5 METs)	Initiation (week 0–4)	2 × CAET and 1 × HIIT (SI)	50–70% PPO (RPE: 11–15)	HIIT-SI: 15 s to 1 min at 80–100% PPO (RPE: 15–18)
	Improvement (week 4–12)	1 × CAET and 2 × HIIT (SI + MI)	50–70% PPO (RPE: 11–15)	HIIT-MI: 1–3 min at 95–100% VO_{2peak} (RPE > 15) HIIT-SI: 10 sec to 1 min at 100–120% VO_{2peak} (RPE: 15–18)
	Maintenance (week > 12)	3 × CAET or HIIT (MI + LI)	50–70% PPO (RPE 14–16)	HIIT-MI: 1–3 min at 95–100% VO_{2peak} (RPE > 15) HIIT-LI: 3–4 min at 80–85% VO_{2peak} (RPE > 15)

HRR: heart rate reserve; PPO: peak power output; RPE: rate of perceived exertion; METs: metabolic equivalents; SI: short intervals; MI: medium intervals; LI: long intervals. HIIT proposal (SI, MI and LI) was based on references [27,29,31,37–52].

Table 2
Study characteristics of randomized clinical trials comparing HIIT and CAET for patients with CHD.

Author (year)	No. of randomized patients (HIIT/CAET)	Intervention (frequency/duration)	HIIT (intensity/duration)	CAET (intensity/duration)	Cardiovascular AEs (HIIT/CAET)	Other AEs, dropouts/losses and compliance (HIIT/CAET)	Delta of main effects (HIIT vs. CAET)
Rognmo et al. (2004)	11/10	F: 3 × week D: 10 weeks	I: 4 × 4 min 80–90% VO_{2peak} Rec: 3 × 3 min at 50–60% VO_{2peak} D: 25 min	I: 50–60% VO_{2peak} D: 41 min	0/0	3/1 HIIT: ankle fracture; ack of motivation; ow adherence. CAET: knee injury. Compliance: Compliance of 70% was set as criteria for completing the study, but data not shown	VO_{2peak} : 19% vs. 8% No effect on BP
Warburton et al. (2005)	7/7	F: 2 × week D: 16 weeks	I: 2 min intervals: 85–95% HR/ VO_2 reserve Rec: 35–45% HR/ VO_2 reserve D: 30 min	I: 65% HR/ VO_2 reserve D: 30 min	0/0	0/0 Compliance: HIIT: 98.5% ± 2.0 CAET: 98.8% ± 2.0	VO_{2peak} : 15% vs. 13% ^c AT: 32% vs. 10%
Moholdt et al. (2009)	33/36	F: 5 × week D: 4 weeks	I: 4 × 4 min at 90% HRpeak Rec: 3 × 70% HRpeak D: 25 min	I: 70% HRpeak D: 30 min	0/0	4/5 HIIT: 1 leg pain, 1 hip pain, 1 bronchitis and 1 withdrawal CAET: 2 hospitalizations, 1 low adherence, 1 withdrawal and 1 large pericardial effusion. Compliance: data not shown for 4 weeks	VO_{2peak} : 12% vs. 7%
Moholdt et al. (2012)	35/72	F: 3 × week (2 × hospital + 1 × home) D: 12 weeks	I: 4 × 4 min at 85–95% HRpeak Rec: 3 × 70% HR D: 38 min	I: NS D: 35 min	0/0	5/13 HIIT: 1 low adherence, 1 pancreatitis, 1 angina, 1 claudication and 1 gastroenteritis CAET: 7 low adherence, 1 gastrointestinal bleeding, 1 angina, 1 bronchitis, 1 knee surgery, 1 low-back pain and 1 psychiatric disease Compliance ^d : HIIT: 20.4 ± 5.0 sessions; CAET: 19.1 ± 4.0 sessions	VO_{2peak} : 15% vs. 8%
Rocco et al. (2012)	17/20	F: 3 × week D: 12 weeks	I: 7 × 3 min at RCP Rec: 7 × 3 min at VAT D: 47 min	I: VAT D: 50 min	NS	NS	VO_{2peak} : 25% vs. 23% AT 14% vs. 20%
Currie et al. (2013)	Total: 23	F: 2 × week D: 12 weeks	I: 1 min 80–99% of PPO Rec: 1 min at 10%PPO D: 20 min	I: 55–65% of PPO D: 30–50 min	NS	Total: 9 2 data unusable 3 medication changes 4 withdrawal Compliance per 24 sessions: HIIT: 20 ± 3 sessions CAET: 22 ± 2 sessions No difference between groups	VO_{2peak} : 20% vs. 22% AT: 22% vs. 23% No effect on BP
Keteyian et al. (2014) ^a	21/18	F: 3 × week D: 10 weeks	I: 4 min at 80–90% HRR Rec: 4 × 3 min 60–70% HRR D: 31 min	I: 60–80% HRR D: 30 min	During training: 1 knee pain (HIIT) 1 leg pain (MICET) No events that required hospitalization during or within 3 h after exercise	6/5 HIIT: 2 lost to follow-up. 2 low-back pain and 2 other medical reasons. CAET: 1 returned to work, 2 lost to follow-up, 1 MI and 1 other medical condition Compliance: HIIT: 71%; CAET: 72%	VO_{2peak} : 16% vs. 8% AT: 21% vs. 5% No effect on BP

Table 2 (Continued)

Author (year)	No. of randomized patients (HIIT/CAET)	Intervention (frequency/duration)	HIIT (intensity/duration)	CAET (intensity/duration)	Cardiovascular AEs (HIIT/CAET)	Other AEs, dropouts/losses and compliance (HIIT/CAET)	Delta of main effects (HIIT vs. CAET)
Madssen et al. (2014)	19/22	F: 3 × week D: 12 weeks	I: 4 × 4 min at 85–95% HR peak Rec: 3 min at 70% HR peak D: 28 min	I: 60% on HRpeak D: 46 min	HIIT: cerebral hemorrhage	4/1 HIIT: 2 missing data 1 pneumonia 1 cerebral hemorrhage CAET: 1 withdrawal Total compliance: more than 90%	VO_{2peak} : 11% vs. 7% ^b
Kim et al. (2015)	16/16	F: 3 × week D: 6 weeks	I: 4 × 4 min at 85–95% HRR Rec: 3 × 3 min 50–70% of HRR D: 25 min	I: 70–85% HRR D: 25 min	0/0	2/2 HIIT: Knee pain Return to work CAET: 2 did not complete the follow-up evaluations Compliance: NS	VO_{2peak} : 22% vs. 9%
Cardozo et al. (2015)	24/24	F: 3 × week D: 16 weeks	I: 2 min at 90% HRpeak Rec: 2 min at 60% HRpeak D: 30 min	I: 70–75% HR peak D: 30 min	0/0	0/0 Compliance: NS	VO_{2peak} : 18% vs. 0.5% AT 12% vs. –3% No effect on BP
Conraads et al. (2015)	110/100	F: 3 × week D: 12 weeks	I: 4 × 90–95% HR peak Rec: 3 × 50–70% HR peak D: 38 min	I: 70–75% HR peak D: 37 min	No AEs during training sessions CAET: 1 AMI, after the last training (PCI was performed). 2 significant ST-depression during the exercise test at 6 weeks (2 PCI performed)	15/11 HIIT: 3 work, 4 personal reasons, 1 disappearance and 4 medical reasons CAET: 3 work, 3 personal reasons, 2 no compliance and 3 medical reasons Compliance: HIIT: 35. ± 1.1 sessions; CAET: 35.6 ± 1.5 sessions; No difference between group	VO_{2peak} : 22% vs. 20% No effect on BP

HIIT: high-intensity interval training; CAET: continuous aerobic exercise training; I: intensity; F: frequency; D: duration; AE: adverse event; BP: blood pressure; AT: anaerobic threshold; RCP: respiratory compensatory point; PCI: percutaneous coronary intervention; MI: myocardial infarction; NS: data not shown.

^a All patients were previously in a rehabilitation program for 2 weeks and attended 2 × week educational classes.

^b Calculated from medians.

^c Calculated from the study graph.

^d Data not specified in the study if it was for 24 sessions (hospital-based) or for total sessions (36 sessions).

physiological responses in 4 protocols (short interval duration: 15 s vs. medium interval duration: 1 min). The optimal protocol involved 15 s exercise intervals at peak power interspersed with passive recovery intervals of the same duration [23,25]. Compared with CAET, this optimized HIIT protocol was associated with lower mean VO_2 , lower ventilation, lower rate of perceived exertion and higher exercise session compliance and was preferred by patients. As well, this HIIT protocol had a lower main exercise time (20 vs. 28.7 min) with the same total energy expenditure (670 kJ) as CAET [23,26]. Thus, HIIT with short intervals is well tolerated by CHD patients, is safe and produces similar physiological responses as CAET [22,23], for possibly improved adherence to exercise training. This form of HIIT may be well suited for improvement and maintenance stages (see Table 1) as an efficient alternative or as a substitute for continuous CAET for CHD patients [22,23].

3.2. HIIT with medium to long intervals

Other medium to long HIIT protocols have been employed in the literature previously with length stages from 1 to 4 min (80% to 145% PPO) and involved mainly low-intensity active recovery (10% PPO to 70% HRmax) [27–33] with a close work/recovery ratio (see review [23] for details). Although as effective or even superior to CAET (see the Section 3.1), these HIIT protocols may have some limitations and most importantly were chosen arbitrarily [22,34]. Indeed, our previous work demonstrated that longer-stage HIIT protocols with active recovery had higher mean intensity (% VO_{2peak}), were less tolerated (higher RPE) and were associated with lower exercise session compliance for CHD patients [22,23,25]. Therefore, the use of those protocols should be proposed for the most fit patients or those with less cardiac risk when used very soon in the improvement stage of training. They may be more appropriate for the improvement stage for patients who are less fit and/or at a higher risk, after a certain period of CAET and/or short interval HIIT sessions with passive recovery [22,23]. Finally, those HIIT protocols may be of use in the maintenance stage because of their high physiological stimulus (e.g., 2 times a week); indeed, they were found feasible in a home-based program for CHD patients [35–38] (see Section 4).

4. Home-based HIIT

CAET has been widely studied in the long-term maintenance phase and in home-based settings for CHD patients [13], but less is known about HIIT used for this purpose. Previous study in CHD patients reported improved or similar exercise adherence after a cardiac rehabilitation program with HIIT as compared to CAET, with superior or similar long-term effects on VO_{2peak} and self-reported physical activity [37,38]. More recently, one study compared 3 different HIIT programs (12 weeks) for CHD patients, one home-based [35]:

- a treadmill HIIT (hospital-based);
- a multi-modality HIIT (hospital-based);
- a home-based HIIT.

This phase II home-based HIIT program was as efficient in terms of targeted exercise intensity, exercise adherence and VO_{2peak} increase [35]. The same authors reported the long-term effects (1 year) of home- versus hospital-based HIIT for CHD patients and found that home-based HIIT provided similar long-term exercise adherence (no differences in total time physical activity expended in moderate or vigorous intensity measured by accelerometry) and improved VO_{2peak} [36]. Thus, home-based HIIT may be as efficient as hospital-based CAET and/or HIIT programs for CHD patients.

5. HIIT versus CAET programs

VO_{2peak} consistently shows greater improvement in HIIT than CAET studies [39]. The most recent meta-analysis evaluating the effects of HIIT and CAET on VO_{2peak} included 8 studies of CHD patients ($n = 439$) and 4 studies of heart-failure patients ($n = 58$) [40–42]. To our knowledge, 4 different meta-analyses were conducted, with different combinations of studies; the results showed a summarized weighted mean difference of 1.78 [95% CI: 0.45, 3.11] [42], 1.60 [0.18, 3.02] [40] and 1.53 [0.84, 2.23] [41] in VO_{2peak} that favoured HIIT programs. These effects are not exclusive to CHD patients; the authors of the first 2 meta-analysis also included studies with heart-failure patients [40,42]. For other secondary outcomes, results were more conflicting. HIIT showed superior effects to CAET for VO_2 at anaerobic threshold in one meta-analysis [41] and no significant difference in a second [40]. HIIT and CAET programs were similar for systolic blood pressure, body mass and VE/VCO_2 [40–42]. For other outcomes such as BMI and resting HR, CAET had superior effects compared to HIIT [42].

To evaluate the benefits of HIIT programs exclusively in CHD patients, we reviewed protocols from randomized clinical trials that compared HIIT and CAET for at least 4 weeks of training, with no distinction in weekly frequency. The 11 studies are described in Table 2. Some were already included in the previous meta-analysis and represented part of the summarized effects, but some recent ones were not included [43–45]. From all reviewed studies, 4 showed a superior effect of HIIT over CAET on VO_{2peak} and prescribed long intervals (4-min intervals at 80–95% HRpeak) [29,45–47]. Similar benefits were found for HIIT versus CAET for VE/VCO_2 slope, oxygen uptake efficiency slope [43], partial pressure of end-tidal CO_2 [48], coronary atheroma and plaque characteristics [44] and quality of life [49]. Furthermore, some studies evaluated HIIT versus CAET for effects on blood pressure [43,47,50–52], HR recovery and HR variability [51] as well as systolic function and systolic volumes [29,49] and found no effects of training on these variables. Finally, CAET seemed to confer better improvement in endothelial function as compared with HIIT [52]. CHD patients may benefit from a combination of aerobic exercise training (HIIT and CAET), depending on the main goals of the exercise programs.

6. Safety aspects and risk classification for HIIT prescription for CHD patients

The clinical status and functional capacity are considered in prescribing any exercise program for cardiac patients [16] (see Table 3 for absolute contra-indications). Especially in CHD patients,

Table 3

Absolute contra-indications to HIIT for CHD.

Unstable angina
Recent MI and/or coronary revascularization (< 4 weeks)
Recent hospitalization for cardiovascular causes (< 6 months)
Fixed rate pacemaker
Uncontrolled cardiac arrhythmias causing symptoms of hemodynamic compromise
Symptomatic aortic stenosis
Uncontrolled hypertension > 180/100 mmHg
Uncontrolled diabetes
Symptomatic cerebrovascular disease (< 6 months)
Severe dyspnea at rest and/or severe exercise intolerance
Thrombopletitis
Recent embolism
Acute pulmonary embolus or pulmonary infarction
Acute myocarditis or pericarditis, active endocarditis
Acute non-cardiac disorder that may affect exercise performance or be aggravated by exercise (e.g., infection, renal failure, thyrotoxicosis)

Recommendations based on studies and analyses in the literature [16,39,53]. MI: myocardial infarction.

symptoms such as angina, exercise intolerance and functional status, in addition to ischemia and arrhythmias during exercise, must be highly considered before prescribing an HIIT program, but there is no evidence that patients with cardiac risk classes B and C should avoid HIIT [16,53]. A study comparing cardiovascular risk in HIIT and CAET that analysed 175,820 training hours showed the risk of a cardiovascular event very low for both modalities [50].

In evaluating adverse events during HIIT programs, most of the authors in our review accounted for cardiovascular events (all-cause mortality, hospitalization for cardiovascular disease, atrial tachycardia, atrial fibrillation or frequent ventricular arrhythmias). Altogether, the 11 studies trained 631 stable CHD patients with no major cardiovascular events during the training period, with the exception of a cerebral hemorrhage in one HIIT group [44] and 2 myocardial infarctions in CAET programs [47,52]. These 3 adverse cardiovascular events were not clearly related to the exercise training and could be better described by authors to determine causality of adverse events of exercise programs in the future. Additionally, 2 patients showed angina and discontinued the programs (1 HIIT and 1 CAET) [29]. No arrhythmia events were described at any study. Therefore, HIIT seems to be a safe exercise modality and did not differ in frequency or magnitude of cardiovascular adverse events during exercise training as compared with CAET, as was shown previously [50].

7. Future perspectives: periodization models for HIIT in CHD patients

In this section, we develop the concept of progression principles and theoretical models of periodization applied to HIIT for CHD patients based on recent literature. The main progression principles for exercise training are progressive overload, specificity and periodization (variation), mostly applied previously in healthy populations (see reviews [54–57] for details). Periodization is defined by the variation in principal elements of an exercise training program such as intensity, duration and frequency (session/week) [54–57]. In healthy subjects, periodization aims to optimize exercise training adaptations as compared with non-periodized training (NPT), to prevent overtraining and to avoid plateauing of training adaptations [54–57]. The classical approach to periodization is linear periodized training (LPT), consisting of an initial high volume and low-intensity. As exercise training progresses, the intensity is increased and the volume is decreased (reduced duration and/or frequency) [54]. This linear model appears in exercise training guidelines for cardiac patients [13,58] but has never been compared to NPT in this population. LPT has superior benefits for aerobic power and muscle function as compared with NPT in healthy subjects or athletes [54,55]. As well, LPT was superior to NPT for certain cardiometabolic risk factors in obese adolescents [59]. According to the progressive overload principle, body adaptations depend on exercise stress and the principle is highlighted by the super-compensation phase of physical adaptations in response to a stressor [54]. However, if this stress continues at the same level for an extended period, the body may enter a phase of maladaptation or exhaustion [54,56]. Because exercise intensity and volume reduction cannot be increased definitively, other periodization models such as the non-linear periodized training (NLPT) have been studied in healthy [54,60,61] and clinical populations [59,62,63]. NLPT is characterized by a type of periodization in which training intensity, duration, and repetition-volume are altered frequently. In patients with chronic obstructive pulmonary disease, improvements in aerobic endurance (+125%), maximal strength (leg press +25%), and quality of life (48–96% for different scores) were greater with NLPT than LPT [62]. In overweight subjects, improvements in insulin resistance

and muscular strength were greater with NLPT than NPT [63]. However, which exercise training program components such as frequency, intensity, time (duration) and type (FITT), and their combination [13], are the most efficient to optimize cardiovascular adaptations to exercise training for CHD patients remain unclear.

More research is needed on HIIT protocols and their use into optimal exercise training programs, such as testing different individualized progressive models with HIIT (short, medium and long intervals) to optimize training adaptations in CHD patients. In addition, short interval HIIT has not been assessed in home-based and/or community settings for cardiac patients. As well, no studies have compared different HIIT protocols (e.g., short vs. long intervals) for their cardiovascular effects, adherence, safety and tolerance/preferences for cardiac patients. In this context, the study of LPT and/or NLPT for HIIT as compared to more traditional NPT methods (CAET and/or HIIT) is a promising area of research. Moreover, the effects of high-intensity interval training on morbidity and mortality were never tested. The dose–response effect is recurrently discussed concerning the total amount of weekly physical activity (time and metabolic equivalents), but there is no evidence for exercise intensities, for example [11]. Since the time spent in physical activity is still an important barrier to exercise adherence in cardiovascular rehabilitation programs, documenting whether similar cardiovascular benefits could be obtained with programs involving higher-intensity exercise and lower total weekly exercise volume would be of interest [13,36].

8. Conclusions

For CHD patients, HIIT showed greater or equivalent benefits as compared with CAET for most of the parameters reviewed. The use of HIIT does not seem to decrease exercise compliance or increase cardiovascular events (when properly prescribed) and is well tolerated and appreciated by the patients. We question why HIIT is still not yet a standard for exercise training (at least in partial substitution of CAET) in clinical routine practice for stable CHD patients. For example, HIIT could be a good modality when patients are transferred home and/or to community-based programs because of its superior benefits for VO_{2peak} , time efficiency, equivalent adherence and patient preference. HIIT should now become systematically integrated in cardiac rehabilitation programs for all cardiac patients, while reinforcing existing evidence on long-term safety and efficacy of this training modality.

Disclosure of interest

The authors declare that they have no competing interest.

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