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Review

Comparison of Different Forms of Exercise Training in Patients With Cardiac Disease: Where Does High-Intensity Interval Training Fit?

Mathieu Gayda, PhD,[a,b,c] Paula A.B. Ribeiro, PhD,[a,b,c] Martin Juneau, MD,[a,b,c] and Anil Nigam, MD[a,b,c]

[a] Cardiovascular Prevention and Rehabilitation Center (ÉPIC), Montreal Heart Institute and University of Montréal, Québec, Canada

[b] Research Center, Montréal Heart Institute and University of Montréal, Montréal, Québec, Canada

[c] Department of Medicine, University of Montréal, Montréal, Québec, Canada

ABSTRACT

In this review, we discuss the most recent forms of exercise training available to patients with cardiac disease and their comparison or their combination (or both) during short- and long-term (phase II and III) cardiac rehabilitation programs. Exercise training modalities to be discussed include inspiratory muscle training (IMT), resistance training (RT), continuous aerobic exercise training (CAET), and high-intensity interval training (HIIT). Particular emphasis is placed on HIIT compared or combined (or both) with other forms such as CAET or RT. For example, IMT combined with CAET was shown to be superior to CAET alone for improving functional capacity, ventilatory function, and quality of life in patients with chronic heart failure. Similarly, RT combined with CAET was shown to optimize benefits with respect to functional capacity, muscle function, and quality of life. Furthermore, in recent years, HIIT has emerged as an alternative or complementary (or both) exercise modality to CAET, providing equivalent if not superior benefits to conventional continuous aerobic training with respect to aerobic fitness, cardiovascular function, quality of life, efficiency,

RÉSUMÉ

Dans le cadre de cet article, nous discuterons des plus récents types d'exercice physique offerts aux patients atteints d'une maladie cardiaque de même que de leur comparaison ou de leur combinaison, ou encore des deux, dans le cadre de programmes de réadaptation cardiaque à court et à long terme (programmes de phases II et III). Parmi les types d'exercices abordés, on retrouve notamment l'entraînement des muscles inspiratoires, l'entraînement contre résistance, l'entraînement aérobique en continu et l'entraînement par intervalles à haute intensité. Un accent particulier a été mis sur l'entraînement par intervalles à haute intensité comparé ou combiné (ou les deux) à d'autres types d'exercices, notamment l'entraînement aérobique en continu et l'entraînement contre résistance. Par exemple, il a été démontré que l'entraînement des muscles inspiratoires combiné à l'entraînement aérobique en continu était supérieur à l'entraînement aérobique en continu seul pour améliorer la capacité fonctionnelle, la fonction ventilatoire et la qualité de vie des patients souffrant d'insuffisance cardiaque chronique. De même, il a été démontré que

Peak oxygen uptake ($\dot{V}O_2$peak) is closely associated with morbidity and mortality in patients with cardiac disease.[1-3] Also, cardiac rehabilitation that includes an exercise training component was shown to be safe and to improve prognosis both in individuals with coronary heart disease (CHD) and in those with chronic heart failure (CHF).[4-9] Numerous other clinical benefits of exercise training in patients with cardiac disease are well documented and include improvements in cardiovascular, lung, and skeletal muscle functions; endurance; quality of life; inflammation; depressive symptoms; stress; and cognitive functions.[10-12] Therefore, exercise training is now a cornerstone of the nonpharmacologic treatment of patients with CHD and CHF and is well integrated into North American and European cardiology guidelines.[10,13,14] However, there is still a need to understand which components of exercise training prescription—including frequency, intensity, time (duration), type (modality),[11] and their combination—are the most efficient at improving cardiovascular adaptations to exercise training. The purpose of this article is to review the different forms of exercise training in an effort to optimize exercise training adaptations both in individuals with CHD and in those with CHF. We have chosen to focus on 3 different forms of exercise training that may represent complementary approaches, including inspiratory muscle training (IMT), resistance training (RT), and

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Corresponding author: Dr Mathieu Gayda, Cardiovascular Prevention and Rehabilitation Centre (Centre ÉPIC), Montreal Heart Institute and Université de Montréal, 5055 St-Zotique St E, Montreal, Québec H1T 1N6, Canada. Tel.: +1-514-374-1480 ×268; fax: +1-514-374-2445.

E-mail: mathieu.gayda@icm-mhi.org

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safety, tolerance, and exercise adherence in both short- and long-term training studies. Finally, short-interval HIIT was shown to be useful in the initiation and improvement phases of cardiac rehabilitation, whereas moderate- or longer-interval (or both) HIIT protocols appear to be more appropriate for the improvement and maintenance phases because of their high physiological stimulus. We now propose progressive models of exercise training (phases II-III) for patients with cardiac disease, including a more appropriate application of HIIT based on the scientific literature in the context of a multimodal cardiac rehabilitation program.

l'entraînement contre résistance combiné à l'entraînement aérobique en continu optimisait les bienfaits obtenus relativement à la capacité fonctionnelle, à la fonction musculaire et à la qualité de vie. De plus, au cours des dernières années, l'entraînement par intervalles à haute intensité s'est révélé une modalité d'exercice pouvant remplacer ou compléter (ou les deux) l'entraînement aérobique en continu puisqu'il a donné lieu à des bienfaits équivalents sinon supérieurs à l'entraînement aérobique en continu traditionnel en ce qui a trait à la capacité aérobique, à la fonction cardiovasculaire, à la qualité de vie, à l'efficacité, à l'innocuité, à la tolérance et à l'observance du traitement dans le cadre d'études sur les programmes d'exercice à court et à long terme. Enfin, il a été démontré que l'entraînement par intervalles courts à haute intensité était utile lors des phases d'amorce et d'amélioration en réadaptation cardiaque, tandis que l'entraînement par intervalles moyens ou longs, ou les deux, à haute intensité paraissait plus adapté aux phases d'amélioration et de maintien en raison de l'important stimulus physiologique qu'il offrait. En nous basant sur des données scientifiques appliquées dans le cadre d'un programme de réadaptation cardiaque combiné, nous sommes désormais en mesure de proposer aux patients atteints d'une maladie cardiaque des modalités d'entraînement progressif (phases II et III) de même qu'une utilisation plus appropriée des divers types d'entraînement par intervalles à haute intensité.

aerobic exercise training (both continuous and high-intensity interval training [HIIT]). Only phases II (short-term) and III (long-term/maintenance) of cardiac rehabilitation are discussed. Finally, we propose how HIIT may be incorporated appropriately into progressive phase II and phase III exercise training models (phase II/III), based on current scientific evidence.

IMT in Patients With Cardiac Disease

Respiratory muscle training (especially inspiratory muscles) has been prescribed in patients with cardiac disease, essentially in patients with CHF but also in patients with CHD.[15-17] Inspiratory muscle weakness (IMW) is highly prevalent in CHF; this muscle dysfunction occurs in approximately 30%-50% of patients.[18] This condition is defined as a maximal inspiratory pressure (PImax) < 70% of predicted values and is an independent predictor of mortality in patients with CHF, even those treated with β-blockers.[19,20] The benefits of IMT alone in patients with cardiac disease are well described, especially in those with CHF and IMW.[16,18,21-23] They include improvements in $\dot{V}O_2$peak, $\dot{V}O_2$ kinetics during recovery, ventilatory efficiency ($\dot{V}E/\dot{V}CO_2$ slope), dyspnea, and functional capacity (6-minute walk test distance).[16,18,21,22] Inspiratory muscle training is prescribed using a percentage of PImax,[24] starting at 30%, with adjustment of the intensity every 7-10 days (up to 60% of PImax), depending on symptoms and response to treatment. The total session time may vary between 20 and 90 min/d (continuous or not) and the frequencies between 3 and 7 times/wk.[17,19,22-24] Furthermore, total session time can be divided into 2-3 sessions during the day. With respect to duration of IMT, some benefits were observed after only 4 weeks,[16,25] and the duration reported across IMT studies was from 4-12 weeks in patients with cardiac disease.[15] In general, IMT can be performed at home with hand-held devices that are very affordable.[15] In theory, this training modality should be prescribed to patients with cardiac disease who present with IMW, in addition to conventional aerobic training to optimize cardiopulmonary benefits (see next section). Considered an easy self-administrated training method (in most studies, patients have trained at home), IMT is an additional possibility for rehabilitation prescribers.

IMT Combined With Continuous Aerobic Exercise Training

The effects of IMT combined with continuous aerobic exercise training (CAET) vs CAET alone have also been studied in patients with CHF.[21,26] Combined training was found to have superior effects (from 9%-38%) on several end points, including $\dot{V}O_2$peak, endurance, PImax, ventilatory efficiency, muscle function, and quality of life.[21,26] In summary, given its benefits, IMT should not be overlooked in the context of a complete cardiac rehabilitation program and would appear to be particularly useful in patients with CHF, who are more likely to suffer from IMW, although this training modality is also indicated for debilitated patients with CHD. A practical guide to the application of IMT (progressive training model) is given in Supplemental Tables S1 and S2.

RT in Patients With Cardiac Disease

RT is recommended as a complement to aerobic training, providing additional benefits with respect to glucose metabolism, body composition, bone density, and muscle composition strength and endurance in patients with cardiac disease.[10,11,27] In particular, patients with CHF often demonstrate altered skeletal muscle function and muscle wasting, which are important determinants of exercise intolerance and can severely impact activities of daily living.[10,11,27] An RT program should be initiated under the supervision of an exercise specialist for maximal safety, with medical supervision recommended for high-risk individuals with very low functional capacity. Potential safety concerns include musculoskeletal strain (soreness) or injuries and excessive blood pressure response, which could expose the patients to cardiovascular events.[10,11,27] For these reasons, RT programs generally start with a pretraining or initial phase that is individually adapted to the patient's clinical status (age, heart disease, cause, comorbidities). During this phase, resistance exercise at a low intensity (< 30% of maximal dynamic strength [1-RM]) is prescribed, with a low number of repetitions (5-10) and sets (1-3), a low frequency (2-3 sessions/wk), and a modest rate of perceived exertion (RPE; < 11-12). Initial goals are to teach the patient to perform the correct movements, how to report to evaluate one's subjective rating of perceived exertion, and to become familiar with different RT equipment (machines, free weights, elastic bands).[10,11,27] The second phase aims at improving muscle endurance and coordination. The recommended prescription is an intensity of 30%-50 % of 1-RM (RPE, 12-13), with 1-3 sets, each set having 10-25 repetitions, at a frequency of 2-3 sessions/wk.[10,11,27] The third phase aims at improving muscle mass (hypertrophy) and muscle coordination. For this purpose, it is recommended to increase RT intensity to 40%-60% of 1-RM (RPE, 13-15), while continuing 1-3 sets with 8-15 repetitions per set, at a frequency of 2-3 sessions/wk.[10,11,27] The fourth and final phase aims at improving muscle strength. Upper level intensities should not exceed 60%-80% of 1-RM (RPE ≈ 15), with 1-3 sets and 8-10 repetitions per set, 1-3 sets, 2-3 times/wk. Supervision with an exercise specialist (and medical specialist if deemed necessary) is recommended at the start of each new phase. Furthermore, RT modalities (machines, free weights, elastic bands) should be performed as interval bouts with single or dual (or both) limb movements interspaced with sufficient recovery periods adjusted to each patient's physiological responses.[10,11,27] Finally, excessive abdominal straining (Valsalva manoeuvre) should be avoided because this may cause an exaggerated blood pressure response during RT sets.[10,11,27] The effects of RT on functional capacity and cardiovascular risk factors are presented in Supplemental Table S3.

RT Combined With CAET (Combined Training)

In the most recent guidelines,[11,13,12] it is recommended that RT be performed in combination with aerobic exercise training. In this section, we briefly review the existing literature comparing the benefits of combined training (RT + CAET) vs aerobic training alone in cardiac populations. In a recent meta-analysis consisting of 12 randomized trials in 504 patients with CHD,[28] combined training was shown to be safe and more effective than CAET alone on certain cardiometabolic, fitness, and psychological parameters.[28] In particular, combined training was superior for improving body composition parameters, muscle strength, peak work capacity, and quality of life, with similar exercise adherence and benefits on $\dot{V}O_2$peak.[28] In patients with CHF, some studies (but not all) have demonstrated superior effects (from 8%-33%) of combined training vs CAET alone on $\dot{V}O_2$peak,[29] left ventricular function,[29] submaximal capacity, and quality of life.[30] However, other studies reported similar effects for both training modes on $\dot{V}O_2$peak,[31,32] leg muscle strength,[31] left ventricular ejection fraction,[30] and quality of life.[31] Most studies in patients with CHF found that combined training was superior to CAET for improving skeletal muscle strength and endurance.[29,30,32-34] Finally, a recent meta-analysis suggested that combined training does not improve or worsen cardiac function (left ventricular ejection fraction and end-systolic and diastolic volumes) in patients with CHF, but only 2 studies evaluating combined training were included,[35] indicating the need for larger studies on the effects of combined training on cardiac remodelling in this patient population.

CAET in Patients With Cardiac Disease

CAET remains the cornerstone of cardiac rehabilitation programs, being widely recommended by national society guidelines across the globe.[10,11,13,14,36] Basic exercise prescription of CAET is generally at a frequency of 2-5 times/wk, an intensity of 50%-75% of $\dot{V}O_2$peak, with a duration of 20-60 minutes per session, depending on the phase. It has proved to be safe, easily feasible, and almost free of contraindications for most patients with cardiac disease while also improving prognosis.[10,11,13,14,36] There is consensus in the literature regarding the beneficial effects of CAET in patients with cardiac disease, as demonstrated by many clinical trials and meta-analyses.[13,14,16,17] In particular, CAET results in improvements in morbidity and mortality,[4-9,37-41] $\dot{V}O_2$peak and ventilatory function, clinical symptoms (dyspnea, sleep disorders, and depressive symptoms), control of risk factors, and endothelial and muscle function.[13,14,16,17,40] The effects of CAET on functional capacity and cardiovascular risks factors are presented in Supplemental Table S3. However, despite its beneficial effects, the optimal dose-response and its impact on prognosis in different patients with cardiac disease are still under investigation.

What is the Optimal Dose of CAET?

The establishment of an "optimal dose" of CAET provides a major challenge and must take into account several factors with respect to the training program and the individual. Factors to consider include the exercise prescription itself (duration, intensity, frequency, total volume, and rehabilitation program stage), psychobehavioural factors (ie, patient preferences, motivation and adherence, depressive symptoms, and quality of life) and the setting (centre and community or home based). The main goal of CAET is to perform longer exercise periods in steady-state metabolism, which favours oxidative metabolism. For beginners, walking programs remain the most prescribed modality in cardiac rehabilitation because of their numerous advantages. Walking is safe, appropriate as an initiation to exercising training for "exercise-naive" individuals, needs no supervision, and can be performed anywhere (both indoors and outdoors). Other CAET modalities include Nordic walking, running, cycling, rowing, swimming, stepping and stair climbing.[13,14,16,17,40] In general, CAET permits higher fat oxidation and longer exercise bouts at intensities that vary from 40%-50% of $\dot{V}O_2$peak for beginners and those with low functional capacity (eg, patients in New York Heart Association [NYHA] class III) to 50%-75% of $\dot{V}O_2$peak for individuals with a higher fitness level.[13,14,16,17,40] Traditionally, prescription of exercise intensity during CAET has been made with the use of percentage of maximal heart rate (%HRmax), percentage of heart rate reserve, percentage of peak power output, or the individual's RPE (Borg scale, 6-20) (or a combination of these measurements) with considerable success.[13,14,16,17,40] Exercise intensity zones for CAET are usually classified as follows: a light-to moderate-intensity zone (40%-50 % of $\dot{V}O_2$peak; RPE, 11-12) and a moderate-to high-intensity zone (50%-75% of $\dot{V}O_2$peak; RPE, 12-15).[42] The latter zone should be used principally in phase II (initial improvement) and phase III (maintenance) of cardiac rehabilitation programs (see progression models in Supplemental Table S2 and Fig. 1). Corresponding values or equivalencies between clinical status (NYHA, Weber class), $\dot{V}O_2$peak, metabolic equivalents (METs), and power (W) are provided in Supplemental Table S4.

Long-Term CAET and the Maintenance Phase in Patients With Cardiac Disease

Long-term CAET has a major role to play in maintaining the health and well-being of individuals with cardiovascular conditions, including the potential to allow individuals to remain autonomous during their aging process and to sustain acquired clinical benefits.[4,13,14,16,17,37,40,43-49] Studies of long-term/maintenance programs (maintenance phase or phase III for cardiac rehabilitation) have been conducted in home-based, community-based, or specialized-centre settings (or a combination).[40,44-50] Overall, these studies have demonstrated the beneficial effects of long-term CAET on prognosis, cardiometabolic risk factors, quality of life, and maintaining or improving (or both) fitness.[44,47-53] In the CHF population, most studies, despite varying duration (6 months-10 years), demonstrated the safety of long-term CAET while also providing both physiological (fitness, cardiac, and vascular function) and psychological benefits (quality of life).[7,51-57] With respect to prognosis, 1 observational study and 2 small randomized controlled trials (RCTs) demonstrated a reduction in mortality, cardiovascular events, and rehospitalization in patients with CHF.[51,52,56] However, in the **H**eart Failure: **A** **C**ontrolled **T**rial **I**nvestigating **O**utcomes of Exercise Trai**n**ing (HF-ACTION) trial, in which 2231 patients with systolic HF were randomized to exercise training or usual care,[7] long-term CAET was not associated with a reduction of

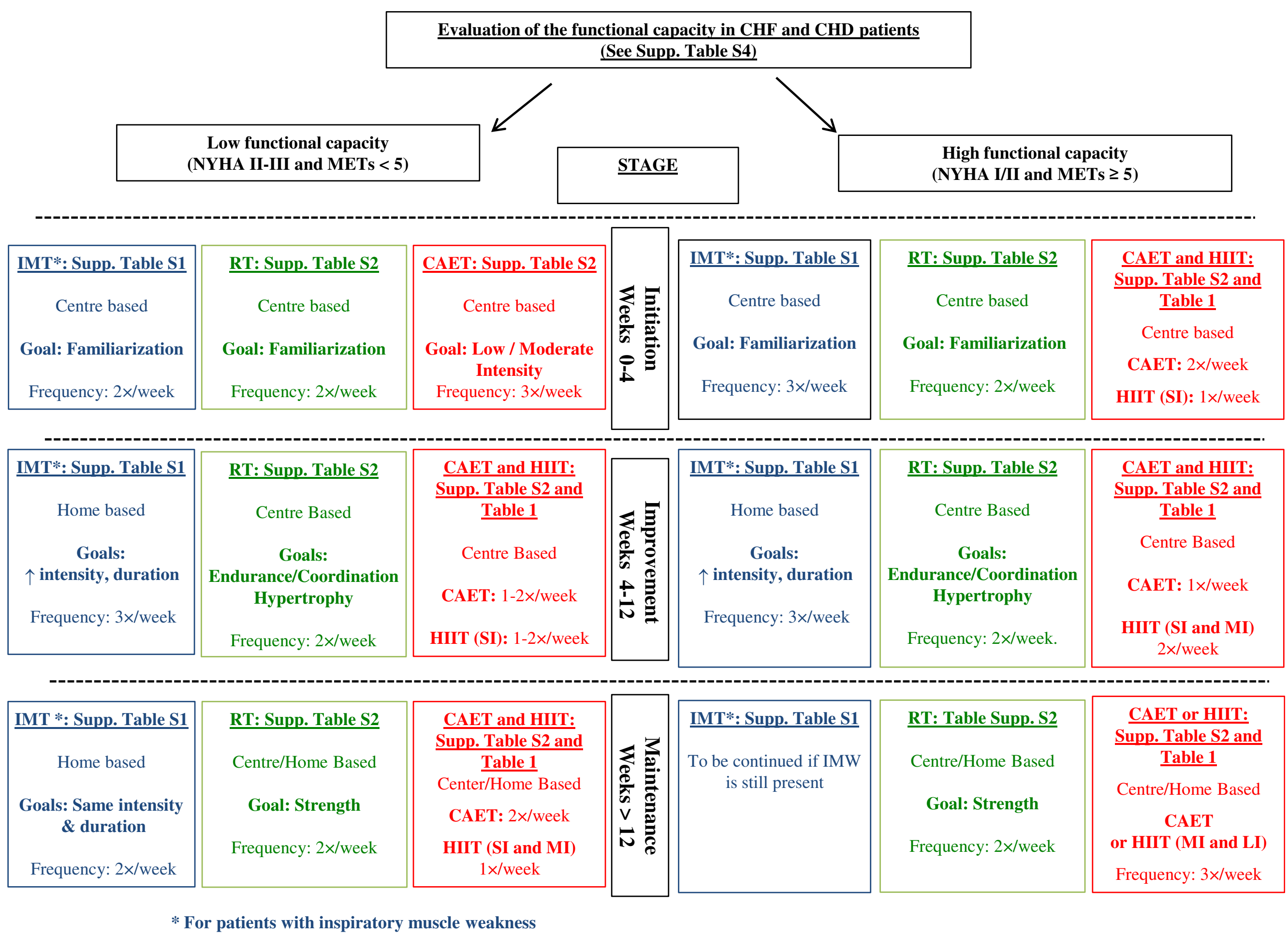

Figure 1. Flow diagram summarizing the basis for choosing among the different training modalities (inspiratory muscle training [IMT], resistance training [RT], continuous aerobic exercise training [CAET], and high-intensity interval training [HIIT]) according to patient's functional capacity and stage of the exercise training program. All patients should ideally perform combined RT with CAET/HIIT. If inspiratory muscle weakness (IMW) is present, IMT will be prescribed in addition. LI, long intervals (> 3 minutes); METs, metabolic equivalents; MI, moderate interval (1-3 minutes); NYHA, New York Heart Association; SI, short interval (15-30 seconds).

the primary end point (all-cause mortality or hospitalization) over a median follow-up period of 30 months. A major problem was that only 40% of the patients in the exercise group performed the recommended exercise training volume.[58] Among this group, even modest exercise volumes (3-7 MET hours per week) were associated with a significant improvement in outcomes, and the longest event-free survival was observed among patients with the highest $\dot{V}O_2$peak improvement.[59,60]

HITT in Patients With Cardiac Disease

HITT has garnered significant interest as an exercise training modality in individuals with cardiovascular disease and has been incorporated into many society position papers and guidelines.[10-14] In this section, we review the general principles of HIIT prescription adapted to patients with cardiac disease and its place in the context of implementing an exercise training program. Furthermore, we review the available studies comparing HIIT with CAET, which has become a very important topic in cardiac rehabilitation in recent years. Finally, we propose a guide for HIIT prescription and implementation for patients with cardiac disease.

The main principle of HIIT is to perform brief periods of high-intensity exercise (eg, > 85% of $\dot{V}O_2$peak or PPO) interspersed with periods of low-intensity exercise or rest, allowing patients with cardiac disease to accumulate greater time at a higher intensity than they would otherwise with continuous exercise.[58,61,62] In patients with cardiac disease, who often report a lack of time as a reason for not exercising,[63] HIIT can be considered a time-efficient substitute or alternative (or both) to traditional CAET.[58,61,62] Different HIIT protocols (intensity, stage duration, nature of recovery, number of intervals) have been tested and used in patients with cardiac disease.[58,61,62] Based on these studies, HIIT can generally be divided into 3 categories according to interval duration: (1) long intervals: 3 to 15 minutes at 85%-90 % of $\dot{V}O_2$peak; (2) moderate intervals: 1-3 minutes at 95%-100% of $\dot{V}O_2$peak; and (3) short intervals: 10 seconds-1 minute at 100%-120% of $\dot{V}O_2$peak (Table 1).[58,61-63] Furthermore, HIIT can be performed with different exercise modalities, including cycling, running, walking, rowing, swimming, or other activities. For long- and moderate-interval HIIT, exercise intensity may be determined using percentage of $\dot{V}O_2$peak, percentage of HRmax, percentage of PPO, percentage of maximal short exercise capacity, or subjective RPE (Borg scale).[58,61,62] For short-interval HIIT, the percentage of PPO and RPE are the most reliable parameters to control intensity given that heart rate never reaches steady state or has sufficient time to reach the percentage of targeted intensity.[58,61,62] The choice of HIIT protocol with respect to exercise intensity, interval duration, and the use of active or passive recovery has a profound influence on acute physiological responses, exercise tolerance, and RPE.[58,61,62]

HIIT With Short Intervals

The acute physiological responses to different short-interval HIIT protocols have been studied in patients with CHD and CHF.[64-71] In patients with CHD, our group sought to identify the optimal protocol that allowed patients to spend more time near $\dot{V}O_2$peak values and to exercise for a longer total time with a lower subjective feeling of fatigue and dyspnea.[58,67,68,72] Comparing the acute cardiovascular physiological responses to 4 protocols (short, 15 seconds vs short-moderate, 1 minute), the optimal protocol was found to be the 1 using 15-second exercise intervals at peak power, interspersed with passive recovery intervals of the same duration.[58,67] Compared with moderate-intensity continuous exercise training (MICET), this optimized HIIT protocol was associated with a slightly but significantly lower mean $\dot{V}O_2$, lower ventilation, lower RPE, and longer total exercise duration and was preferred by patients.[58,72] In patients with CHF, Meyer et al.[64] compared 3 short-interval HIIT protocols that provided similar results with respect to rate-pressure product, gas exchange, catecholamine levels, and RPE, such that all 3 were recommended by the authors.[58] Similarly, our group compared 4 different HIIT protocols in CHF,[58,65] including short (30 seconds) vs moderate intervals (90 seconds). The optimal mode (30-second exercise intervals at peak power

Table 1. High-intensity interval training progressive models according to functional status of patients with cardiac disease[64-91]

Patients with cardiac disease	Stage	Aims/intensity	Active/recovery ratio	Borg (range)	HIIT duration	Frequency (weekly)	Site/location
Low functional class CHF (NHYA class III) CHD	Initiation (wk 0-4)	SI: 80%-100% PPO	15-30 s/15-30 s P	15	10-20 min	2-3	Centre based
	Improvement (wk 4-12)	SI: 80%-100% PPO	1 min/1 min P + A	15-18	15-20 min	3	Centre based
	Maintenance (wk > 12)	SI + MI SI: 80%-120% PPO MI: 80% PPO or 80%-90% HRmax	1-3 min/1-3 min P + A	15-18	15-20 min	3	Community/home based
High functional class CHF (NYHA I/II) CHD	Initiation (wk 0-4)	SI: 80-100% PPO	15-30 s/15-30 s P	15	15-20 min	2-3	Centre based
	Improvement (wk 4-12)	SI + MI SI: 80-120% PPO MI: 80% PPO or 80-90% HRmax	1-3 min/1-3 min P + A	15-18	20-25 min	3	Centre based/community/ home-based
	Maintenance (wk > 12)	MI to LI: 80%-90% PPO or 80%-95% HRmax	1-4 min/1-4 min A	15-18	25 min	3	Community/home-based

HIIT proposal (SI, MI, and LI) was based on references.[64-91]

A, active recovery; CHD, coronary heart disease; CHF, congestive heart failure; HIIT, high-intensity interval training; LI, long interval (> 3 minutes); MI, moderate interval (1-3 minutes); HRmax, maximal heart rate; NYHA, New York Heart Association; P, passive recovery; PPO, peak power output; SI, short interval (15-30 seconds).

with passive recovery intervals of the same duration) was associated with a longer total exercise time, a similar time spent near $\dot{V}O_2$peak, a lower RPE, greater patient comfort, and a greater likelihood of completing the prescribed exercise session.[58,65] Compared with an isocaloric MICET session, our optimized HIIT session was associated with (1) similar time spent near $\dot{V}O_2$peak, (2) a trend toward a lower RPE, (3) a higher exercise session completion rate, and (4) higher external power work performed during exercise.[58,66] Finally, compared with MICET, our optimized HIIT protocol also elicited similar central hemodynamics (cardiac output) and muscle substrate oxidation in patients with CHF.[58,70,71] Taken together, these results indicate that HIIT with short intervals is safe, very well tolerated by patients with cardiac disease, and produces physiological responses very similar to those of MICET,[58,61,62] thus potentially resulting in improved adherence to exercise training. This form of HIIT appears to be best suited for the improvement and maintenance stages (Table 1) as an efficient alternative or substitute for CAET in patients with cardiac disease.[58,61,62]

HIIT With Moderate to Long Intervals

Moderate to long protocols have also been previously used in patients with cardiac disease, with interval duration ranging from 1-4 minutes (80%-145% of PPO). Such protocols typically use a compensatory low-intensity active recovery with a close work/recovery ratio.[58,73-76] As noted previously, although they are as effective or even superior to CAET, they present some limitations and most importantly were developed arbitrarily.[61,62,77] Indeed, our previous work demonstrated that longer-stage HIIT protocols with active recovery resulted in a higher mean exercise intensity (percentage of $\dot{V}O_2$peak) but were less well tolerated (higher RPE) and associated with a lower ability to complete exercise sessions because of fatigue and exhaustion.[65,67] Therefore, we recommend limiting their use to lower-risk, higher-fitness patients if clinicians wish to use them very soon in the exercise training phase program (improvement phase). For less fit or higher-risk (or both) patients with cardiac disease, and particularly for those who are exercise-naive, we recommend beginning a training program with CAET with the gradual inclusion of short-interval HIIT sessions using passive recovery.[58,61,62] Finally, moderate to long HIIT protocols may be particularly useful during the maintenance phase of cardiac rehabilitation, eg, twice a week, because of their high physiological stimulus and their feasibility in the home-based setting (see next section).[78-80]

Home-Based HIIT

Although long-term CAET has been widely studied in the home-based setting,[10,11] only a few studies used HIIT for this purpose. Previous studies in patients with CHD have reported similar or improved adherence after a cardiac rehabilitation program with HIIT compared with CAET, with comparable or greater long-term effects on $\dot{V}O_2$peak and self-reported physical activity.[79,81] More recently, 1 study compared 3 different 12-week HIIT programs, 1 being home-based: (1) treadmill HIIT (hospital based), (2) multimodality HIIT (hospital based), and (3) home-based HIIT.[80] The latter was as efficient with respect to targeted exercise intensity, attendance, and $\dot{V}O_2$peak increase as hospital-based cardiac rehabilitation.[80] The same authors reported the long-term effects (1 year) of home-based HIIT vs hospital-based HIIT in patients with CHD. Home-based HIIT provided similar benefits with respect to improvements in long-term exercise adherence and $\dot{V}O_2$peak.[78] Taken together, these studies suggest that home-based HIIT is as efficient as or even superior to hospital-based CAET or HIIT (or both) programs in patients with CHD. Whether home-based HIIT is suitable for patients with CHF requires further study. The effects of HIIT on functional capacity and cardiovascular risks factors are provided in Supplemental Table S3.

HIIT vs Continuous Aerobic Exercise Training

Recently, 4 meta-analyses were published in patients with cardiac disease (2 in patients with CHD and 2 in patients with CHF) comparing HIIT to CAET.[82-85] One compared the effect of different exercise training intensities on $\dot{V}O_2$peak in patients with CHF and demonstrated a superior effect of HIIT (3 studies; n = 58) over CAET (18 studies; n = 423) in the absence of any increase in study withdrawals or major adverse events, including hospitalization or death.[84] Similarly, Haykowsky et al.[83] showed that HIIT was superior to CAET for improving $\dot{V}O_2$peak (2.14 mL/min/kg) in patients with CHF, with similar effects on left ventricular function and exercise compliance. In patients with CHD, 2 meta-analyses demonstrated the superior effects of HIIT on ventilatory threshold and $\dot{V}O_2$peak (from 1.53 to 1.60 mL/min/kg) relative to CAET, with similar effects on blood pressure.[82,85] They also confirmed the safety of HIIT.[82,85] However, 2 recent RCTs in patients with CHD demonstrated similar effects of HIIT and CAET with respect to $\dot{V}O_2$peak, workload,[86,87] cardiometabolic risk factors, and quality of life.[86] The effects of HIIT vs CAET on functional capacity and cardiovascular risks factors are summarized in Supplemental Table S3. Taken together, these studies show that HIIT is comparable if not superior to CAET for improving $\dot{V}O_2$peak, with similar effects on safety and adherence. Ideally, an RCT with a substantial sample size and a greater number of women would be important to confirm the beneficial effects of HIIT in patients with cardiac disease and to ensure that results are generalizable. The absolute contraindications for HIIT are shown in Table 2.[10,36,42]

Conclusions and Future Perspectives

Since 2009, we have incorporated short-interval HIIT into our phase II and phase III cardiac rehabilitation programs; this training modality is used annually in approximately 1000 patients with cardiac disease undergoing phase III/IV cardiac rehabilitation at our institution.[58] Beyond this clinical experience, more research is needed on HIIT, particularly with respect to its combination with other training methods (IMT, RT, and CAET). For example, short-interval HIIT has not been assessed in home-based or community-based (or both) settings. In addition, no previous studies have compared different HIIT protocols (ie, short vs long interval) with respect to cardiovascular physiological responses, safety, adherence, and tolerance/preferences in patients with cardiac disease. The use of HIIT would not

Table 2. Absolute contraindications to HIIT for patients with coronary heart disease and those with chronic heart failure[10,36,42]

Absolute contraindications
Unstable angina
Recent MI or coronary revascularization (< 4 wk)
Decompensated heart failure
NYHA functional class IV
Recent transplantation or hospitalization (< 6 mo)
Left ventricular assist device
Fixed-rate pacemaker
Uncontrolled cardiac arrhythmias causing symptoms of hemodynamic compromise
Symptomatic aortic stenosis
Uncontrolled hypertension > 180/100 mm Hg
Uncontrolled diabetes
Symptomatic cerebrovascular disease (< 6 mo)
Severe dyspnea at rest or severe exercise intolerance, or both
Thrombophlebitis
Recent embolism
Acute pulmonary embolism or pulmonary infarction
Acute myocarditis or pericarditis, active endocarditis
Acute noncardiac disorder that may affect exercise performance or be aggravated by exercise (eg, infection, renal failure, thyrotoxicosis)

MI, myocardial infarction; NYHA, New York Heart Association.

appear to be associated with lower adherence or to an increase in cardiovascular risk (when properly prescribed). Furthermore, it is generally well tolerated and appreciated by patients.[58,61,62] One important contribution to the cardiac rehabilitation literature would be to test different individualized progressive models combining RT, CAET, and HIIT to optimize training adaptations in patients with cardiac disease. Nevertheless, we do believe, in accordance with other groups,[88,89] that HIIT should now be more fully and systematically integrated into cardiac rehabilitation programs while reinforcing existing evidence on long-term safety and efficacy of this training modality.[78-80,86,90,91]

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Supplementary Material

To access the supplementary material accompanying this article, visit the online version of the *Canadian Journal of Cardiology* at www.onlinecjc.ca and at http://dx.doi.org/10.1016/j.cjca.2016.01.017.

SUPPLEMENTARY MATERIAL

Supplemental Table S1: Progressive model for inspiratory muscle training (IMT) in cardiac patients

Cardiac patients	Stage	Aims/Intensity	Session duration	Frequency	Site/Location
CHF (NHYA III-IV) Low function CHD	Initiation Week 0-4	30 % of PImax	2 × 5 min	2-3 sessions/week	1x/week supervised for load adjustments
	Maintenance Week >4	30 -60% of PImax	20-30 min/day	>3 sessions/week*	Home-based sessions
CHF (NYHA I-II) CHD	Initiation Week 0-4	30 % of PImax	3 × 5 min	3 sessions/week	1x/week supervised for load adjustments
	Maintenance Week >4	30-60 % of PImax	20-30 min/day	>3 sessions/week*	Home-based sessions

* Depending on training combination with CAET, HIIT and/or RT.

Supplemental Table S2: Progression model for combined exercise training in cardiac patients

Patient profile	Stage of training	IMT	RT	CAET and/or HIIT
CHF (NHYA III) Low function CHD	Initiation (Week 0-4)	2 sessions/week 30 % of PImax	2x week when combined with AT: <30 % of 1RM, 5-10 repetitions, 1-3 sets (RPE<11-12)	**3xweek CAET** 50-70% of PPO (RPE: 11-15)
	Improvement (Week 4-12)	3 sessions/week 30 - 60% of PImax	<u>For endurance/coordination</u>: 2x week when combined with AT: 30-50 % of 1-RM, 10-25 repetitions, sets of 1-3 (RPE 12-13); <u>For hypertrophy</u>: 40-60% of 1-RM 8-15 repetitions, 1-3 sets (RPE 13-15).	**2x CAET and 1x HIIT (SI)/week** **Then 2/HIIT and 1/CAET** <u>CAET</u>: 50-70% of PPO (RPE:11-15) <u>HIIT-SI</u>: 15 seconds to 1 min at 70-100 % of PPO (RPE: 15 -18):
	Maintenance (Week >12)	2 sessions/week 30 - 60% of PImax	<u>Strength training</u>: 2x week when combined with AT 60-80% of 1-RM 8-10 repetitions, 1-3 sets (RPE ≈15)	**2x CAET and 1x HIIT (SI + MI)/week** <u>HIIT-MI</u>: 1 to 3 min at 90–110 % of PPO (RPE > 15) <u>HIIT-SI</u>: 15 seconds to 1 min at 100–120 % of PPO (RPE: 15-18).
CHF (NYHA I-II) CHD	Initiation (Week 0-4)	3 sessions/week 30 % of PImax	2x week when combined with AT: <30 % of 1RM, 5-10 repetitions, 1-3 sets (RPE<11-12).	**2x CAET and 1x HIIT (SI)/week** <u>HIIT-SI</u>: 15 seconds to 1 min at 80-100% of PPO (RPE: 15-18).
	Improvement	3 sessions/week	<u>For endurance/coordination</u>: 2x	**1x CAET and 2x HIIT**

	(Week 4-12)	30 - 60% of PImax	week when combined with AT: 30-50 % of 1-RM, 10-25 repetitions, sets of 1-3 (RPE 12-13); For hypertrophy: 40-60% of 1-RM 8-15 repetitions, 1-3 sets (RPE 13-15).	**(SI+MI)/week** CAET: 50-70% of PPO (RPE: 11-15) HIIT-MI: 1 to 3 min at 95–100 % of VO_2peak (RPE > 15) HIIT-SI: 10 seconds to 1 min at 100–120 % of VO_2peak (RPE: 15-18).
	Maintenance (Week >12)	2 sessions/week* 30 - 60% of PImax	Strength training: 2x week when combined with AT 60-80% of 1-RM 8-10 repetitions, 1-3 sets (RPE ≈15)	**CAET or HIIT (MI+LI) – 3x week** CAET: 50-70% of PPO (RPE 14-16) HIIT-MI: 1 to 3 min at 95–100 % of VO_2peak (RPE > 15) HIIT-LI: 3 to 4 min at 80–85 % of VO_2peak (RPE > 15)

PImax – maximal inspiratory pressure; IMT – inspiratory muscle training; RT- resistance training; CAET: continuous aerobic exercise training; HIIT: high intensity interval training; HRR – heart rate reserve; RPE – rate of perceived exertion; SI: short intervals; MI: moderate intervals; AT-aerobic training. *Evaluate the necessity to be continued (IMP <70% age and gender predicted).

IMT proposal was based on the following studies : references 15,16, 21, 22, 24 and 25.
RT proposal was based on the following studies : references 10-12, and 27.
Combined methods proposal was based on the following studies : references 8, 9, 13, 21 and 29-34.
HIIT proposal (SI, MI and LI) was based on the following studies: references 64-91.

Supplemental Table S3: Expected effects of exercise modalities on functional capacity and cardiovascular risks factors in cardiac patients.

Parameters	IMT	RT	CAET	HIIT	CAET vs. HIIT
VO_2peak	+ 2.59 [0.90, 4.28] ml/min/kg (CHF) [1] + 52 sec. (exercise time) (CHD) [2]	+ 9.3 % (CHF) [3]	+ 15 % [4] + 2.61±2.12 ml/min/kg (CHD) [5] + 2.17 [1.34, 2.99] ml/min/kg (CHF) [6]	+ 4.26±2.47 ml/min/kg (CHD) [5] + 3.33 [0.53, 6.13] ml/min/kg (CHF) [6]	Favours HIIT: 1.60 [0.18, 3.02](CHD) [5] Favours HIIT: 1.04 [0.42, 1.66](CHF) [7]
Muscle strength	IMP: + 22.62 [3.7, 41.5] cmH_2O (CHF) [1] PFR: +25.6 l/min (CHD) [2]	MS: + 27 % * (CHF) [8-12] MS: +22.6 % (CHD) [13]	MS: + 14 % * (CHD) [13-19] MS: + 8 % * (CHF) [11, 20]		
BMI or BM		BMI: +1.7% (CHF) [11] BM: +1.4 % (CHF) [11] BM: +0.2% (CHD)[13]	Δ BMI: -0.3±0.64 kg/m^2 [21] (CHD) BMI: -1.5 % [4] (CHD) Δ BM : -0.5 kg±2.05 [21] (CHD)	Δ BMI: + 0.1±0.61 kg/m^2 [21] (CHD) Δ BM: + 0.5±2.20 kg [21] (CHD) BM: -0.3% (CHF) [22]	Trends in favours of CAET for BM: 0.78 [-0.01, 1.58] (CHD) [5]
Resting BP			Δ SBP : -3.2 (-5.4 to 0.9) mmHg [23] Δ DBP: -1.2 (-2.7 to 0.3) mmHg [23]	Δ SBP : 0.0±2.19 mmHg [21] (CHD) Δ DBP: - 1.1±1.29 mmHg [21] (CHD) Δ SBP : - 2 ±0.95 mmHg [22] (CHF) Δ DBP : -2 ±1.19 mmHg [22] (CHF)	Trends in favours of CAET: -3.44 [-7.25, 0.36] (CHD) [24]
Total chol.			Δ:+0.16±0.12 mmol/l [21] (CHD) -5 % [4] (CHD)	Δ:+ 0.17±0.11 mmol/l [21] (CHD) -1.5% [22, 25] * (CHF)	
HDL-chol.			Δ:+0.09 ±0.04 mmol/l [21]	Δ :+ 0.08±0.04 mmol/l [21]	

			(CHD) + 6% [4] (CHD)	(CHD) +0.8% * (CHF) [22, 25]	
LDL-chol.			+0.07 ±0.10 mmol/l [21] (CHD) -2% [4] (CHD)	Δ : +0.09±0.08 mmol/l [21] (CHD) - 3.8% * (CHF) [22, 25]	
TG			- 0.03±0.07 mmol/l [21] (CHD) -15% [4] (CHD)	Δ : - 0.02±0.15 mmol/l [21] (CHD) - 3.8% * (CHF) [22, 25]	

IMT: inspiratory muscle training, RT: resistance training, CAET : continuous aerobic exercise training, HIIT: high-intensity interval training, IMP: inspiratory muscle pressure, MS: muscle strength, PFR: peak flow rate, BMI: body mass index, BM: body mass, BP: blood pressure, chol. : cholesterol, TG: triglycerides. *= mean of the cited references.

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Supplemental Table S4: Functional status, Weber Class and correspondence with VO_2, Metabolic Equivalent and power.

<table>
<tr><th>Functional Status</th><th>Weber Class</th><th>VO_2 (ml/min/kg)</th><th>Metabolic Equivalent</th><th>Power (Watts)</th></tr>
<tr><td rowspan="9">High</td><td rowspan="14">A</td><td>Higher</td><td rowspan="2">≥ 16</td><td rowspan="5">245</td></tr>
<tr><td>56.0</td></tr>
<tr><td>52.5</td><td rowspan="7">8-15</td></tr>
<tr><td>49.0</td></tr>
<tr><td>45.5</td></tr>
<tr><td>42.0</td><td>220</td></tr>
<tr><td>38.5</td><td>200</td></tr>
<tr><td>35.0</td><td>170</td></tr>
<tr><td>31.5</td><td rowspan="2">150</td></tr>
<tr><td rowspan="5">Normal</td><td>28.0</td><td rowspan="5">5-8</td></tr>
<tr><td>25</td><td rowspan="2">120</td></tr>
<tr><td>24.5</td></tr>
<tr><td>21.0</td><td rowspan="2">100</td></tr>
<tr><td>20.0</td></tr>
<tr><td rowspan="7">Low</td><td rowspan="2">B</td><td>17.5</td><td rowspan="6">2-5</td><td>75</td></tr>
<tr><td>15.0</td><td rowspan="2">50</td></tr>
<tr><td rowspan="2">C</td><td>14.0</td></tr>
<tr><td>10.5</td><td rowspan="2">25</td></tr>
<tr><td rowspan="2">D</td><td>7.0</td></tr>
<tr><td>5.0</td><td></td></tr>
<tr><td>E</td><td>3.5</td><td>1</td><td></td></tr>
</table>

Data source from references [1,36].