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Guidelines for the delivery and monitoring of high intensity interval training in clinical populations☆

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ABSTRACT

High intensity interval training (HIIT) is now recognized in international clinical-based exercise guidelines as an appropriate and beneficial adjunct to moderate intensity continuous training. HIIT involves alternating periods of high intensity aerobic exercise with light recovery exercise or no exercise, allowing for greater physiological stimulus and adaptation than moderate intensity continuous training (MICT) for cardiorespiratory fitness and other cardiometabolic processes. However, there is no universal criteria or framework for the prescription and monitoring of HIIT in clinical populations, and safety concerns remain a common barrier for implementing HIIT as standard care. Historically, exercise intensity has been prescribed using heart rate (HR) targets derived from either a predicted maximal HR (HR_{max}) or from an attempt to objectively measure HR_{max}. However, using this approach alone has a number of limitations. Here we provide guidelines to improve the delivery of HIIT in cardiometabolic populations using 1) a framework for HIIT prescription using a combination of objective and subjective measures of exercise intensity, and 2) clinical considerations for assessment and monitoring to maximize patient safety. The framework involves an individualized step-by-step process to calculate, validate, and calibrate HR target zones for HIIT training to allow for appropriate workload prescription and progression. We strongly recommend this framework be used in future clinical trials investigating HIIT.

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Abbreviations and acronyms: AACVPR, American Association of Cardiovascular and Pulmonary Rehabilitation; ACSM, American College of Sports Medicine; BP, blood pressure; CACPR, Canadian Association of Cardiac Rehabilitation; CHD, coronary heart disease; COPD, chronic obstructive pulmonary disease; CR, cardiac rehabilitation; CRF, cardiorespiratory fitness; EACPR, European Association for Cardiovascular Prevention and Rehabilitation; HIIT, high intensity interval training; HF, heart failure; HR, heart rate; HR_{max}, maximal heart rate; HTN, hypertension; ICD, implantable cardioverter defibrillator; MI, myocardial infarction; MICT, moderate intensity continuous training; RPE, rating of perceived exertion; SPO_2, peripheral capillary oxygen saturation.

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High intensity interval training (HIIT) involves alternating periods of high intensity aerobic exercise at or below maximal oxygen uptake with light recovery exercise or no exercise between intervals.[1] Completing bouts of higher intensity exercise allows for greater physiological stimulus and adaptation than moderate intensity continuous training (MICT). This produces larger benefits for cardiorespiratory fitness (CRF), vascular function, skeletal muscle metabolism, and other metabolic processes[1,2] that are important for primary and secondary prevention of cardiometabolic diseases. HIIT has also been shown to be more enjoyable than MICT, which may encourage long-term exercise adherence.[3] For home-based training (following a supervised period), HIIT compared with MICT, has resulted in greater exercise adherence in the short-term (1 month) in patients with pre-diabetes[4] and in the long-term (30 months) following cardiac rehabilitation (CR).[5]

High volume vs low volume HIIT

HIIT was recognized as an appropriate and beneficial adjunct to MICT in the 2013 joint position statement on aerobic exercise intensity assessment and prescription in CR by the European Association for Cardiovascular Prevention and Rehabilitation (EACPR), the American Association of Cardiovascular and Pulmonary Rehabilitation (AACVPR) and the Canadian Association of Cardiac Rehabilitation (CACPR).[6] However, there is no universal criteria or framework for delivery of HIIT in clinical populations. Furthermore, safety concerns remain a common barrier for implementing HIIT as standard care. While it is still unclear what the optimal dose of HIIT is for maximizing health outcomes, the majority of evidence for improving CRF in clinical populations has used the high volume 4 × 4 minute HIIT protocol developed by a Norwegian research group.[1,2,6] This approach has also demonstrated safety in patients with stable coronary heart disease (CHD).[7,8] High volume HIIT protocols have been defined as those that accumulate ≥15 min of time spent during the high intensity intervals, with all other HIIT protocols being defined as low volume HIIT.[9] Low volume HIIT protocols with long duration intervals (e.g. 1 × 4 min) have shown comparable improvements in CRF to high volume HIIT[10,11] and superior to MICT.[10] Conversely low volume HIIT with multiple short duration intervals ≤1 min (e.g. 10 × 1 min) have shown similar but not superior improvements in CRF compared with MICT.[12–14]

Importance of intensity

The efficacy of high volume HIIT compared to MICT was recently questioned by two medium-sized multi-center randomized controlled trials (SAINTEX-CAD[15] and SMARTEX-HF[16]) that found no statistical differences between groups for CRF and other cardiometabolic parameters. However, compared to earlier trials demonstrating greater efficacy of high volume HIIT compared to MICT,[1,17,18] the recent trials reported issues with adherence to the prescribed HIIT using percentage of maximal heart rate (HR_{max}).[2] Specifically the SAINTEX CAD study[15] reported a lower average training heart rate (HR) of 88%HR_{max} for HIIT (target = 90–95%HR_{max}) and higher average training HR of 80%HR_{max} for MICT (target = 65–75%HR_{max}), resulting in less difference for training intensities between groups than previous studies. Further, the SMARTEX HF study reported that 51% of HIIT participants were training below their target HR, despite an average training HR of 90%HR_{max} (target = 90–95% HR_{max}). Additionally, 80% of MICT participants were training above the HR target range with an average training HR of 77%HR_{max} (target = 60–70%HR_{max}).[16]

For the SAINTEX-CAD study,[15] average training HR for HIIT was determined by averaging four HRs from each training session (recorded at the end of each 4-minute interval) and then calculating the mean training HR for the entire study period expressed as %HR_{max}. The reported mean training HR for weeks 1–6 (88%HR_{max}) was based on HR_{max} at the initial exercise test, and for weeks 7–12 (84%HR_{max}) was based on the 12-week (follow-up) exercise test.[15] As mean HR_{max} was significantly higher at the 6-week exercise test, compared to initial exercise test, mean training %HR_{max} during the first 6 weeks could have been overestimated.

Limitations of using 'HR_{max}'

Several limitations exist for using percentage of HR_{max} for exercise intensity prescription. Firstly, it may not be an accurate measure of intensity if the true maximal HR was not achieved during the maximal exercise test (e.g. due to peripheral fatigue). Secondly, for patients taking beta blockade medication, dose adjustment can have a significant effect on HR_{max}. For example, up-titration of beta blockade dose is common for optimizing heart function post myocardial infarction (MI), in heart failure (HF) management, and for rate control for atrial fibrillation. In addition, timing of beta blockade (although to a lesser effect than dose) may also affect HR_{max}, particularly if exercise training times vary throughout the day.[19] For example, if maximal exercise testing was conducted in the morning just after taking the beta blockade (i.e. when the drug effect is highest), and training sessions occurred in the evening (i.e. when there is less dampening of exercise HR) the HR response to exercise is likely to be different. Finally, while an incremental cardiopulmonary exercise test to voluntary exhaustion with respiratory gas analysis is the gold standard for determining exercise intensity descriptors (such as HR_{max} and then HR target zones), it is not routinely performed as part of a clinical assessment.[6] Historically, maximal exercise testing was an important screening tool for patients with residual ischemia and instability before initiating CR.[20] However, now with more aggressive revascularization interventions, advancement in medical therapies, and patients with uncomplicated MI, there is an increasing trend for patients being referred to CR without an exercise test.[6,20] Barriers for conducting maximal exercise testing within CR programs often include additional expense for staffing and equipment (such as metabolic systems), as well as availability of medical personnel for test supervision.[20]

These limitations and recent studies (SAINTEX-CAD and SMARTEX-HF) highlight the necessity in clinical practice to use additional approaches to adjust objectively defined HR targets and workloads.[6,15] Rating of perceived exertion (RPE) is a subjective measure of exercise intensity commonly prescribed in CR programs as the primary prescription for exercise intensity or as an adjunct to HR monitoring.[6] It is valuable for reasons outlined above, particularly when there is difficultly obtaining a reliable or meaningful exercise-related HR.[6] Using RPE has been shown to be an effective approach to prescribe and monitor exercise intensity in cardiometabolic patients with or without beta blockade, particularly after a period of familiarisation.[6,21–23] An observer RPE, reported by the person supervising the exercise, may also be useful if a patient has difficulty reporting an accurate RPE.

The aim of this article is to provide clinicians and researchers with a framework to guide delivery of HIIT in cardiometabolic populations. We outline: 1) a framework for HIIT prescription using a combination of objective and subjective measures of exercise intensity, and 2) clinical considerations for assessment and monitoring to maximize patient safety. Importantly, we recommend this framework be used in future clinical trials investigating HIIT.

Guidelines for HIIT Prescription and Monitoring

The Guidelines for HIIT Prescription and Monitoring (Fig 1) encourages the use of participant and observer RPE to validate and adjust HR target zones for HIIT. It is essential that the participant and observer are educated on the correct use of the RPE scale. Top and bottom values should be anchored to sensations of *extremely hard*/*maximal* and *no exertion at all*, representing an integrated rating of muscular and cardiovascular sensations.[24] Indeed, the original article describing use of the RPE scale explicitly states this is a requirement to accurately use RPE to measure exercise intensity.[25] Additionally, using RPE and HR monitoring in combination during HIIT has been shown to elicit higher adherence to exercise intensity targets than RPE alone.[26] Therefore we have employed this approach to help patients appreciate their RPE at levels we expect them to be operating at physiologically.

The framework has been adapted from the Norwegian 4 × 4 minute HIIT model (total time 33–38 min)[17,18] to a 30-minute session with a shorter warm-up (usually 5–10 min) and cool-down (usually 3 min) to enhance time efficiency. However for cardiac patients or patients taking anti-hypertensive medication it is recommended to extend cool-down periods to 3–5 min to reduce the post-exercise hypotensive response,[2] as well as increase the warm-up period to 10 min in patients with known exercise-induced angina.[2]

Our framework involves a step-by-step process to calculate, validate, and calibrate HR target zones for HIIT training.

Step 1 involves measuring or estimating HR_{max}. While maximal exercise testing is the ideal method for determining HR_{max} and HR target zones, prediction equations can be utilised (e.g. $HR_{max} = 211 - (0.64 \times \text{age})$).[27] While predictive equations can be adapted for patients taking beta blockade medication (e.g. $HR_{max} = 164 - (0.7 \times \text{age})$),[28] the magnitude of beta blockade effect on HR_{max} can be highly variable between patients, which would best be defined by an exercise test.

Step 2 involves calculating the HR target zone corresponding to 85–95%HR_{max}.

Step 3 involves validation of the HR target zone using RPE. For this process, we recommend starting the high intensity interval at a workload corresponding to a participant/observer RPE 15 (hard) on the Borg 6–20 scale,[25] and finishing the interval at an RPE 17–18 (very hard).[2,6] Patients should display heavy breathing but still be able to talk in short sentences. They should feel ready to stop at the end of the high intensity interval, but not be completely exhausted. If the patient needs to stop before the end of 4 min, the exercise intensity is most likely too hard and should be reduced for the next interval. Observer RPE (using the guidance above) may over-ride participant RPE if it appears that the patient is having difficultly reporting an accurate RPE. The skill and experience of the observer and their experience with the patient should all be taken into account during this step.

An important part of the protocol is the time taken during the high intensity interval to reach the HR target zone. Based on the Norwegian approach we recommend that the patient is given the first 4 minute high intensity interval to reach the HR target zone.[2] Therefore during the validation process if RPE is <17 after 4 min (first interval) the

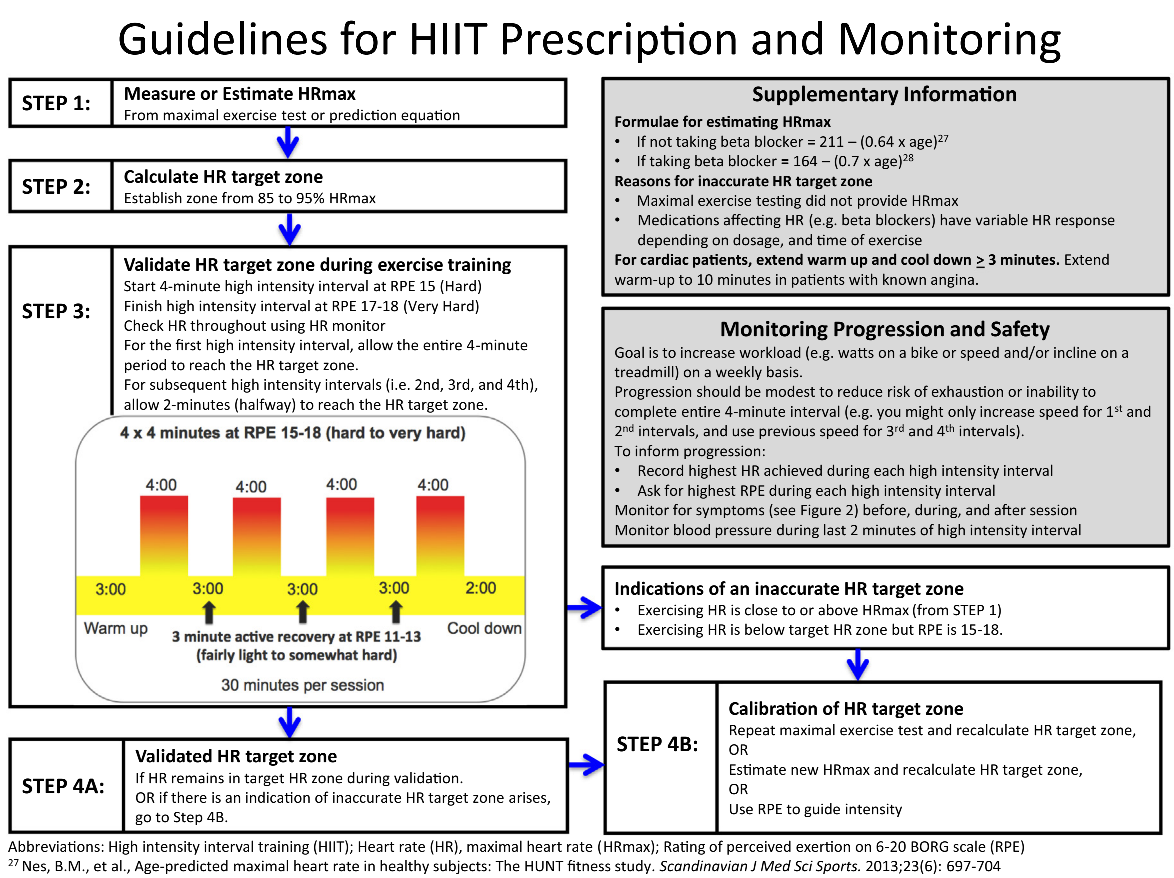

Fig 1. Guidelines for HIIT Prescription and Monitoring. Abbreviations: High intensity interval training (HIIT); heart rate (HR), maximal heart rate (HR_{max}); rating of perceived exertion on 6–20 Borg scale (RPE).

workload should be increased at the start of the second interval. For subsequent high intensity intervals (i.e. 2nd, 3rd, and 4th) it is recommended to reach the target HR zone by the halfway point at 2 min. Therefore if RPE <17 after 2 min, workload should be increased. It must be emphasized that the first HIIT session should be used to find the correct workload and that increases in workload (speed, inclination, or watts) should be very modest if RPE is not correct. If workload adjustments are too large, this increases the risk of exhaustion and inability to complete the full protocol.

During validation, the highest HR should be recorded during each interval. The HR target zone is then validated (**Step 4a**) if HR remains within the HR target zone (calculated in Step 2) during the validation process. If HR increases above HR_{max} (calculated in Step 1) or remains below the HR target zone (calculated in Step 2), this indicates the HR target zone is inaccurate.

Step 4b involves calibration of HR target zone if deemed inaccurate by the validation process. Options for calibration include: repeating maximal exercise test or estimating a new HR_{max} from a prediction equation. Another option is to recalculate the HR target zone (Step 2) using percentage of heart rate reserve (%HRR) corresponding to 80–90%HRR. Although %HRR is primarily used in research settings, it is another method of quantifying exercise intensity that may be more appropriate for individuals with a high/low resting HR. If an accurate HR target zone is not able to be determined, patients can continue using RPE alone as this has been shown to elicit similar HR responses to patients given a HR target zone of 85% HRR,[23] which is equivalent to 90% of HR_{max}.

Translating to a real world environment

While much of the research has been conducted in supervised clinical settings, applying HIIT to the real world is critical for optimizing long-term patient outcomes. For gym-based exercise training, the protocol can be adapted to various exercise machines such as rowing ergometers, cross-trainers, or arm ergometry depending on preference or musculoskeletal limitations. Home-based alternatives to treadmills or cycle ergometers may include walking steep hills, jogging, stair climbing, step-ups, high knee marching, or dancing. Interval duration can be timed by 3–4 minute music tracks or using specific hills or street light poles as a reference when exercising outside. Educating patients on principles of progressive overload to maintain desired intensity is imperative.

Monitoring training progression

To ensure appropriate progression, we recommend frequently monitoring absolute training workload and ensuring it increases overtime.[29] The goal should be to increase workload (e.g. speed/incline on a treadmill or watts on a bike) on a regular (e.g. weekly) basis. Regarding progression of treadmill speed, adjusting the speed for first 2 high intensity bouts only (i.e. keeping previous speed for last 2 high intensity bouts) may allow for a more gradual progression and maintaining the desired RPE level. For stationary cycling, previous studies showing efficacy for HIIT over MICT have observed an increase in power output of ~2 watts per training session.[29] Striving to keep RPE and HR within the recommended and validated target zones should also be used to inform HIIT progression.

Recording and reporting exercise training intensities

Keeping records of exercise training intensity is important for clinicians and researchers to monitor and report exercise training adherence. We recommend recording the highest HR and final RPE for each high intensity interval, which can then be used to calculate the four following exercise training intensity indicators for each session:

1) Peak training HR (i.e. highest HR during the entire HIIT session),
2) Average training HR (i.e. averaging highest HR from each interval),
3) Peak training RPE (i.e. highest RPE during the entire HIIT session), and
4) Average training RPE (i.e. averaging final RPE from each interval).

Patients can be educated to assist clinicians and researchers by keeping track of their highest HR and final RPE during each high intensity interval for patient data sheets or self-report exercise logs. If reporting on HR and RPE intensities for research or clinical reports, we recommend reporting mean data (from all sessions) for these four exercise training intensity indicators. HR values should be expressed as $\%HR_{max}$ with HR_{max} derived from an exercise test (if available).

To avoid overestimation of the reported training intensity, if an individual has a maximal exercise test before and then after a training period then the highest HR_{max} value from these tests should be used to report training intensity (expressed as $\%HR_{max}$). However, factors such as medication (e.g. beta blockade) adjustment during the training phase should be considered during this process.

Clinical considerations

When assessing a patient's suitability for participation in HIIT, an initial assessment should be conducted to help identify any absolute contraindications to participation (Fig 2). An exercise screening tool is recommended to identify risk factors to HIIT participation and minimize risk of adverse events.[30] As HIIT results in near-maximal exercise intensities, absolute contraindications have been adapted from the American Heart Association's scientific statement on exercise testing[31] with additional criteria for MI, coronary artery bypass surgery, and percutaneous coronary intervention.

While HIIT has been shown to be low risk in patients with CHD,[7,8] these individuals are usually medically evaluated before participation. Additionally, in studies demonstrating the safety of HIIT,[7,8] patients were screened via cardiopulmonary exercise testing with 12-lead electrocardiogram prior to participation in cardiac rehabilitation, excluding patients with evidence of recurrent ischemia or chest pain. It should be emphasized that while exercise is usually supervised by trained allied health professionals, patients often have multiple comorbidities that require consideration. Medical clearance from the patient's general practitioner or physician should be sought prior to initiating vigorous exercise in patients with known cardiometabolic disease.[30] Furthermore, for patients who have recently undergone surgery or percutaneous coronary intervention, medical clearance from the respective surgeon or interventionalist is recommended. However, it is important to note that HIIT involves intensities below peak workload, and differs from sprint interval training involving supramaximal efforts at or above peak workload. For many deconditioned individuals the intensity of HIIT is similar to what they encounter during their activities of daily living.[32] Questions around safety must take this into consideration.

Following medical clearance, patients should receive regular monitoring (Fig 2) to identify any changes to medical status or medications that may preclude HIIT participation or affect HR response. Resting HR and blood pressure (BP) should be taken in all patients. Use of electrocardiogram is recommended to identify the presence of arrhythmias. If electrocardiogram is unavailable, manual pulse palpation can be used but is less sensitive and may only detect overt arrhythmias. Additionally, patients should be asked if they are feeling unwell, or experiencing symptoms of angina, light-headedness, palpitations or dyspnea, and encouraged to report any symptoms during/after the session. BP, RPE, HR, and symptoms should be monitored throughout the HIIT session (Fig 1) to identify any reasons to cease HIIT. If new symptoms or adverse events arise during training, HIIT should be suspended and patients referred for medical review and clearance. The following paragraphs address clinical considerations for specific cardiometabolic conditions and potential co-morbidities.

Clinical Considerations for HIIT

Initial Assessment
- Presenting medical condition
- Medical history (check for exclusions)
- Co-morbidities (e.g. diabetes, hypertension)
- Medication regimen (including dose and timing)
- Relevant clinical data (e.g. resting blood pressure and heart rate, fasting blood glucose, oxygen saturation)
- Treating physicians and general practitioner
- Current or previous physical activity level
- Factors that may impact exercise participation (e.g. injury)

Screening tool may be useful (ACSM Preparticipation screening algorithm[30])

Monitoring Checklist
- How is the patient feeling today
- Medical updates or changes to health status
- Recent symptoms (e.g. angina, light-headedness)
- Prescribed medications taken within the past 24 hours
- Medication regimen changes (dose / timing)
- Resting blood pressure and heart rate
- Resting and post-exercise blood glucose in patients taking insulin or other oral hypoglycemic agents
- Monitor fluid overload in patients with HF (for >2kg change in 1-3 days) and signs/symptoms of hypovolemia (e.g. dizziness, weakness, fatigue)

Absolute Contraindications (adapted from Fletcher et al[31] and ACSM[34])
- Obstructive left main artery disease
- Unstable angina
- Uncontrolled cardiac arrhythmia
- Acute endocarditis, myocarditis or pericarditis
- Moderate to severe aortic stenosis
- Decompensated heart failure
- Acute pulmonary embolism, or deep vein thrombosis
- Aortic dissection
- Higher degree heart block
- Hypertrophic obstructive cardiomyopathy
- Recent stroke or transient ischemic attack
- Uncontrolled diabetes
- Retinopathy
- Severe autonomic or peripheral neuropathy
- Acute systemic illness or fever
- Acute or chronic renal failure
- Pulmonary fibrosis or interstitial disease
- Recent myocardial infarction (<4 weeks), coronary artery bypass surgery (<4 weeks), or percutaneous intervention (<3 weeks).

Indications for avoiding HIIT (adapted from ACSM[34])
- Feeling unwell
- Current angina, light-headedness, or dyspnea
- Resting heart rate >120bpm (or >100bpm supine in patients with HF)
- Presence of any atypical arrhythmia (detected via telemetry or pulse)
- Resting blood pressure > 180/110mmHg
- Hypoglycemic event in the past 24hours that required assistance from another individual to treat the event
- Blood glucose <4.0mmol/L
- Blood glucose >15.0mmol/L with symptoms of hyperglycemia

Indications for ceasing HIIT (adapted from ACSM[34])
- Symptoms such as angina, dyspnea, light-headedness, confusion, or signs of poor perfusion.
- Oxygen saturation < 88%
- Rise in blood pressure > 220/105mmHg
- Drop in systolic blood pressure >10mmHg from baseline during high intensity interval.
- Slowing heart rate with higher workload or development of any atypical arrhythmia

Medical Clearance
- Medical clearance (from medical specialist or general practitioner) should be sought for all patients with clinical condition s prior to commencing HIIT.
- For patients post surgery or percutaneous intervention, clearance should be sought from the respective surgeon or interventionalist.

Abbreviations: High intensity interval training (HIIT); Heart failure (HF)
[30] Riebe D, et al. Updating ACSM's Recommendations for Exercise Preparticipation Health Screening. *Med Sci Sports Exercise.* 2015;47(11):2473-9. doi:10.1249.
[31] Fletcher GF, et al. Exercise standards for testing and training: a scientific statement from the American Heart Association. *Circulation.* 2013;28(8): 873-934. doi:10.1161.
[34] American College of Sports Medicine. *ACSM's guidelines for exercise testing and prescription*. 9th ed.. ed.: Philadelphia, PA : Lippincott Williams & Wilkins, 2014

Fig 2. Clinical considerations for HIIT. Abbreviations: High intensity interval training (HIIT).

Heart failure

Exercise training, and particularly HIIT, should only be undertaken by patients with stable HF determined by their treating physician. Exercise training is also contraindicated for patients who have progressive worsening of exercise tolerance or dyspnea at rest over the previous 3–5 days.[33] Additional exercise considerations for commencing exercise in patients with HF include a resting HR below 100 bpm in a supine position[33] and ensuring the patient is euvolaemic (normal fluid volume). HF patients, and particularly those with renal impairment, are at increased risk of fluid volume changes that can cause electrolyte imbalances and cardiac arrhythmias. Bodyweight prior to exercise should be used to assess if a patient is fluid overloaded (≥2 kg increase in previous 1–3 days),[33] as well as checking for signs and symptoms of hypovolemia (from diuretic therapy) such as dizziness, weakness, or fatigue. As patients with HF are also more prone to orthostatic or post-exercise hypotension, an extended and carefully monitored cool-down period (i.e. with measurement of BP during exercise recovery) is another important consideration for these patients,[33] particularly for initial sessions of a HIIT program. As beta blockade and diuretic medications can affect thermoregulatory function, signs and symptoms of hypoglycemia (in patients with diabetes) and heat intolerance, should be monitored in these patients.[34] For further information on hypoglycemia, see section on diabetes below. For patients with an implantable cardioverter defibrillator (ICD), exercising HR should be maintained at least 10 bpm below the ICD tachycardia threshold.[34] For patients who are limited by dyspnea during exercise, see section on chronic obstructive pulmonary disease (COPD) below for further recommendations. For patients with HF, maintaining peripheral capillary oxygen saturation (SpO_2) >92% is optimal during exercise.

Hypertension (HTN)

Uncontrolled HTN >180 mm Hg resting systolic BP and/or resting diastolic BP >110 mm Hg is a contraindication to commencing exercise training.[34] It is also recommended during exercise to maintain systolic BP ≤220 mm Hg and/or diastolic BP ≤105mm Hg[34]. If patients have not undergone maximal exercise testing, we recommend for the initial HIIT session to monitor BP during the final 2 min of the first high intensity interval to assess the HTN response to exercise. As anti-hypertensive medication can lead to sudden excessive reductions in post exercise BP, an extended and carefully monitored cool-down period is also an important consideration for these patients.[34] For patients taking beta blockade or diuretics, refer to previous section on HF regarding effect on thermoregulatory function.

Diabetes

In patients with diabetes, only those with well-controlled blood glucose levels should engage in high intensity exercise. Additionally, high intensity exercise is contraindicated for individuals with retinopathy due to increased risk of retinal detachment.[34] Hypoglycemia (<70 mg/dL or <4 mmol/L) is an important consideration for patients with diabetes who are taking insulin or oral hypoglycemics that increase insulin secretion (e.g. sulfonylureas).[34] Symptoms of hypoglycemia may include shakiness, weakness, abnormal sweating, hunger, confusion, visual disturbances, or tingling of the mouth and fingers. To prevent hypoglycemia with exercise, blood glucose levels and symptoms should be monitored pre and post exercise session, and even several hours after exercise in patients beginning a new exercise program such as HIIT. Exercise should be avoided if blood glucose is <4 mmol/L, or >15 mmol/L with symptoms of hyperglycemia such as polyuria, fatigue, weakness, increased thirst, or acetone breath.[34] Autonomic and/or peripheral neuropathy is another important consideration for patients with diabetes. As this can reduce neural sensations, extra monitoring of appropriate footwear and foot care should occur to prevent foot ulcers and blisters,[34] particularly in patients performing high-impact activities (e.g. walking or running). Cycle ergometry may be a safer alternative to prevent falls in patients with limited sensation. Also symptoms of hypoglycemia and silent ischemia (e.g. shortness of breath and back pain) should be carefully monitored as individuals with autonomic neuropathy are less likely to recognize them.[34]

Chronic obstructive pulmonary disease

Interval training has also been recommended by the American Association of Cardiovascular and Pulmonary Rehabilitation (AACVPR) as an appropriate training modality for patients with COPD, particularly when patients are unable to maintain continuous exercise training at a high intensity.[35] For these patients, the Borg Dyspnea scale should be used in combination with the BORG RPE scale, aiming for a dyspnea rating of up to 6 (severe) during high intensity intervals.[35] For this patient group, poor exercise tolerance and oxygen desaturation are usually limiting factors during exercise. For patients with COPD, The American College of Sports Medicine (ACSM) recommends that SpO_2 be maintained >88% during exercise, which may be aided by supplemental oxygen if prescribed by the patient's physician.[34]

Conclusion

This framework provides clinicians and researchers with a framework to guide the delivery of HIIT in clinical populations. At optimal HR target zones (85–95%HR_{max}), high volume HIIT provides larger benefits for CRF and other cardiometabolic processes, compared to moderate intensity exercise. This framework for HIIT prescription using objective and subjective measures of exercise intensity, involves a step-by-step process to calculate, validate, and calibrate HR target zones for HIIT training, to allow for optimal training targets and appropriate progression of workload. To maximize safety in clinical populations the framework also provides recommendations for appropriate pre-exercise screening and regular monitoring.

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Authors' contributions

JLT, DJH, JGS, KSB, UW, SEK, and JSC contributed to conceptualization of article. JT drafted the manuscript. JT, DJH, JGS, KSB, UW, SEK, and JSC provided critical revision of the manuscript. All authors approved the final version of the manuscript and agree to be accountable for all aspects of work ensuring integrity and accuracy.

Statement of conflict of interest

The authors declare that there is no conflict of interest.

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