

High-intensity interval training in patients with lifestyle-induced cardiometabolic disease: a systematic review and meta-analysis

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ABSTRACT

Background/Aim Cardiorespiratory fitness (CRF) is a strong determinant of morbidity and mortality. In athletes and the general population, it is established that high-intensity interval training (HIIT) is superior to moderate-intensity continuous training (MICT) in improving CRF. This is a systematic review and meta-analysis to quantify the efficacy and safety of HIIT compared to MICT in individuals with chronic cardiometabolic lifestyle diseases.

Methods The included studies were required to have a population sample of chronic disease, where poor lifestyle is considered as a main contributor to the disease. The procedural quality of the studies was assessed by use of a modified Physiotherapy Evidence Base Database (PEDro) scale. A meta-analysis compared the mean difference (MD) of preintervention versus postintervention CRF (VO₂peak) between HIIT and MICT.

Results 10 studies with 273 patients were included in the meta-analysis. Participants had coronary artery disease, heart failure, hypertension, metabolic syndrome and obesity. There was a significantly higher increase in the VO₂peak after HIIT compared to MICT (MD 3.03 mL/kg/min, 95% CI 2.00 to 4.07), equivalent to 9.1%.

Conclusions HIIT significantly increases CRF by almost double that of MICT in patients with lifestyle-induced chronic diseases.

INTRODUCTION

Lifestyle-induced chronic diseases significantly alter the quality of life of sufferers. In many cases, the disease itself can be potentially avoided or successfully managed with appropriate lifestyle modifications.¹ Diseases such as type II diabetes, atherosclerotic cardiovascular disease and the metabolic syndrome are closely related and often stem from the same preventable risk factors. Therapy for most chronic diseases involves exercise training to slow or reverse disease progression. Despite the known benefits of regular moderate-intensity exercise in regulating risk factors in chronic disease, the majority of patients are still physically inactive.²

Rehabilitation for cardiac patients prior to the 1950s comprised abstention from all forms of physical activity. This was thought to diminish the cardiac load and assist in the reparative process of the healing myocardial scar.³ Levine and Lown⁴ appear to be the first to document challenging the idea of complete immobilisation by introducing the then controversial 'armchair treatment' where patients were encouraged to sit in an armchair as much as possible during hospitalisation postmyocardial infarction. When the weight of evidence

suggesting the benefits of light-to-moderate activity in patients with chronic disease became irrefutable, exercise guidelines were created for this population.⁵ Interval training appears to have been first studied in cardiac rehabilitation in 1972, when patients were asked to cycle at high workloads for 60 s with a 30 s rest between intervals. Using the intervals, the patients were able to exercise for at least twice as long as what they were able to do when cycling continuously.⁶ In 1977, a study on healthy participants examined the effects of a 10-week programme which included a combination of interval and moderate continuous training. Interestingly, the authors found a linear increase in augmenting maximal oxygen uptake (VO₂max) over 10 weeks, contrary to the study's hypothesis that VO₂ would plateau over time.⁷ In 1979, it was suggested that high-intensity exercise was required to provoke the necessary training adaptations needed to improve exercise capacity in patients with recent myocardial infarctions.⁸ One of the first studies to investigate intense exercise in patients with cardiovascular disease found that if the exercise is intense and prolonged enough, then it can instigate a reduction in myocardial ischaemia.⁹ These findings were revolutionary, as they were established before widespread percutaneous coronary interventions were performed. From there, differing study protocols in the 1980 s and 1990 s in cardiac patients led to conflicting findings that appear to have decreased the interest in this approach.^{10–12} Forty years after the first reported use of interval training in cardiac patients, the interest in high-intensity interval training (HIIT) in higher risk patients has now led to a number of studies in this area.

HIIT involves alternating short bursts of high-intensity exercise with recovery periods or light exercise. Studies in athletes and the general population have shown that increasing the intensity of exercise amplifies the training stimulus and associated adaptations, such as VO₂max, anaerobic threshold, stroke volume and performance.^{13 14} A commonly cited barrier to physical activity is lack of time. Including HIIT in a training programme implies that greater health-enhancing benefits could be gained in less time, making HIIT a more time efficient and attractive option. Moreover, short bursts of activity may address another common limiting factor, lack of motivation, as it may be a more enticing option than the prospect of continuously exercising for an extended period of time. Short work periods at a higher intensity also result in a reduction in the ventilatory

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response and resultant dyspnoea, which in many patients with chronic disease are limiting factors to continuous exercise.¹⁵

VO₂max is a strong predictor of mortality.¹⁶ Indeed, a 1-metabolic equivalent task (MET) increase is associated with a 10–25% improvement in survival.¹⁷ Furthermore, it is established that cardiorespiratory fitness is more cardioprotective than the overall physical activity levels.¹⁸ This provides further evidence regarding the benefits of higher intensity exercise compared with lower intensity general physical activity. It seems likely that improving VO₂max will improve the prognosis of patients with chronic disease.

The aim of this systematic review is to compare and quantify the effects of HIIT against moderate-intensity continuous training (MICT) in improving VO₂max in patients with lifestyle-induced chronic diseases. Furthermore, safety of HIIT will be discussed along with the feasibility of this approach with suggestions to standardise terminology and protocol recommendations.

METHODS

Electronic searching of the MEDLINE, PubMed, EMBASE and Cinahl databases were conducted from the earliest available date to April 2013, limited to the English language. The Medical Subject Heading (MeSH) database was employed to establish all related articles on HIIT and chronic disease. The MeSH terms used were 'cardiovascular diseases' OR 'metabolic diseases' OR 'chronic diseases' and their related terms. Text words used in conjunction with the MeSH terms were 'high intensity training/exercise', OR 'interval training/exercise', OR 'intermittent training/exercise', OR 'low volume training/exercise' OR 'aerobic

interval training/exercise'. Reference lists of retrieved articles were also searched for in other appropriate studies.

Inclusion criteria

Only full text, randomised control trials were considered for inclusion. The studies were required to have a cardiometabolic chronic disease population, where poor lifestyle is considered to be the main contributor. The main characteristics of such diseases, such as coronary artery disease, heart failure, diabetes, hypertension, obesity and metabolic syndrome, are recognisable by the common presence of cardiovascular risk factors. Other systematic reviews on the effects of HIIT have been conducted with specific conditions: pulmonary disease¹⁵ and coronary artery disease.¹⁹ Inclusion criteria were: exercise protocols using cardiorespiratory exercise training; a comparator group that completed MICT (matched to HIIT); an accepted measure of intensity (ie, heart rate or rating of perceived exertion); intervention of 4 weeks; appropriate intensities for both groups (eg, 60–75% peak heart rate (PHR) for MICT, 85–95% PHR for the high-intensity intervals or 80–100% peak work rate (PWR)) and a direct measure of the VO₂peak/max. Owing to the difficulty patients with chronic disease have in reaching a plateau in the VO₂max, the VO₂peak was reported in nine of the studies.^{20–28} Studies including other activities (eg, resistance training) on top of the prescribed aerobic intervention were also included, provided the same volume and modality of resistance exercises were given to the MICT and HIIT groups.

Data collection and analysis

After full text analysis of the retrieved articles, 10 articles were identified to have met the inclusion criteria for the purpose of meta-analysis (table S1—web file only). These trials involved 273 patients consisting of men and women. This included 137 in HIIT groups and 136 in the MICT groups. The corresponding authors of two eligible studies were contacted for VO₂ data, but no information was provided.^{29 30}

The procedural quality of the studies was assessed by use of the modified Physiotherapy Evidence Base Database (PEDro) scale. Table 1 illustrates that one point was awarded for each of the 10 criteria. Review Manager statistical software V5.0 (Nordic Cochrane Centre, Copenhagen, Denmark) was used to determine the mean difference and 95% CI. A forest plot is used to portray the treatment effects of each study (figure 1).

RESULTS

Seven of the 10 studies included in this review studied cardiovascular disease; Rognmo *et al*²¹ and Moholdt *et al*²² investigated coronary artery disease and Wisloff *et al*,²⁰ Roditis *et al*,²³ Freysson *et al*,²⁴ Fu *et al*²⁸ and Iellamo *et al*²⁷ recruited heart failure patients. Molmen-Hansen *et al*²⁵ studied participants with hypertension, Schjerve *et al*²⁶ looked at participants with obesity and Tjonna *et al*³¹ investigated the metabolic syndrome. Six of the 10 studies were conducted at the same institute, the Norwegian University of Science and Technology.^{20–22 25 26 31}

The quality assessment of the studies was determined by two reviewers. Where there was a discrepancy, the average was taken. The studies achieved a mean PEDro score of 7.35/10. There was no blinding of all assessors in any of the studies reviewed. A between-group statistical comparison was provided by all studies with measures of variability given for the VO₂peak.

Table 1 Methodology quality of the high-intensity interval training (HIIT) studies conducted in patients with chronic disease

	1	2	3	4	5	6	7	8	9	10	Total
Rognmo <i>et al</i> ²¹	+	+	+	+	–	+	+	+	+	–	8
Roditis <i>et al</i> ²³	–	+	–	+	–	+	+	+	+	–	6
Wisloff <i>et al</i> ²⁰	+	+	–	+	–	+	+	+	+	–	7
Schjerve <i>et al</i> ²⁶	+	+	–	+	+	–	+	+	+	–	7
Tjonna <i>et al</i> ³¹	±	+	–	+	–	+	+	+	+	+	7.5
Moholdt <i>et al</i> ²²	+	+	+	+	–	±	±	+	+	+	8
Fu <i>et al</i> ²⁸	+	+	–	+	–	+	+	+	+	–	7
Freysson <i>et al</i> ²⁴	+	+	–	+	–	–	+	+	+	+	7
Iellamo <i>et al</i> ²⁷	+	+	–	+	–	+	+	+	+	–	7
Molmen-Hansen <i>et al</i> ²⁵	+	+	–	+	+	+	+	+	+	+	9

+ Represents criteria achieved and one point is given.

– Represents criteria not achieved.

± Represents whether or not the criteria met were viewed differently by two different reviewers and therefore half a point is given.

PEDro criteria:

1. Eligibility criteria were specified.

2. Participants were randomly allocated to groups.

3. Allocation was concealed.

4. The groups were similar at baseline regarding the most important prognostic indicators.

5. There was blinding of all assessors who measured the primary outcome.

6. Measures of at least one key outcome were obtained from more than 70% of the participants initially allocated to groups.

7. All participants for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome were analysed by 'intention to treat'.

8. The results of between-group statistical comparisons are reported for the primary outcome.

9. The study provides the point measures and measures of variability for at least one key outcome.

10. Sample size calculations were explained.

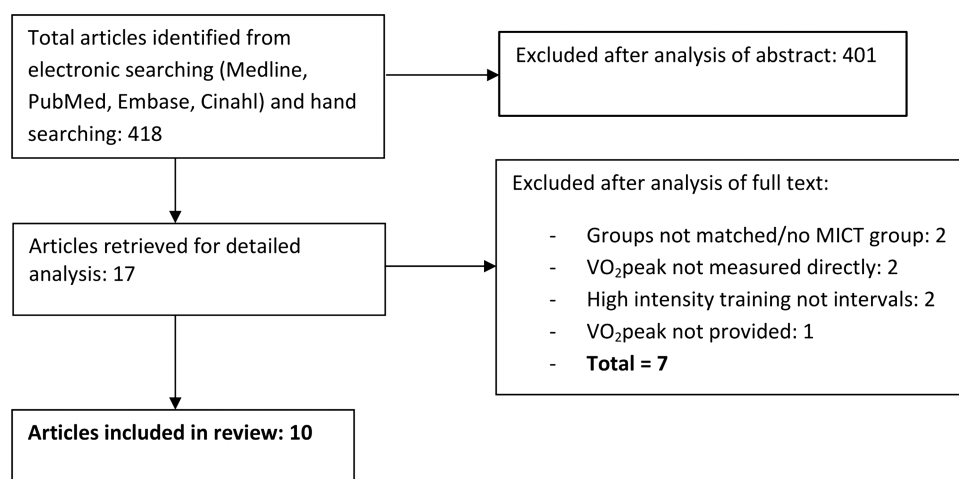


Figure 1 Systematic review process.

Meta-analysis

Nine studies included means and SDs of the VO_2peak to allow the calculation of an overall mean difference.^{20–27 31} One study provided means \pm SE of mean, allowing the SDs to be calculated.²⁸ Homogeneity between the studies was displayed with $I^2=9\%$, $p=0.36$. The mean difference in the VO_2peak from the 10 studies was 3.03 mL/kg/min (95% CI 2.00 to 4.07), significantly ($p<0.001$) favouring HIIT (figure 2).

Exercise protocols

Mode

Seven studies used uphill walking/running on a treadmill as the primary exercise modality.^{20–22 25–27 31} One study described the exercise undertaken as ‘treadmill walking’; therefore, the differences in heart rate between intervals could have been achieved either through a change in speed or a change in incline.²² In three studies, cycle ergometers were used for the duration of the programme.^{23 24 28} Freyssin *et al*²⁴ used strengthening,

stretching and relaxing exercises in addition to the treadmill and cycle programme.

Intensity

Intensities were set based on baseline maximal/peak testing data. Six studies used a percentage of PHR or maximal heart rate (MHR), two studies used a percentage of PWR or peak power and a further two studies used the VO_2peak /heart rate reserve ($\text{VO}_{2\text{peak}}/\text{HRR}$). The Norwegian studies used a heart rate of between 85% and 95% for the high-intensity interval with a recovery of 50–75% MHR.^{20–22 25 26 31} Two studies on the cycle ergometer were set at an intensity of 80% and 120% PWR for the high-intensity interval with a passive recovery.^{23 24} The two studies using the HRR/ VO_2peak to determine intensity used 75–80% for the interval and 40–50% for an active recovery.^{27 28}

Total duration

A common approach to compare the HIIT and MICT sessions is to match the energy expenditure, resulting in the HIIT session

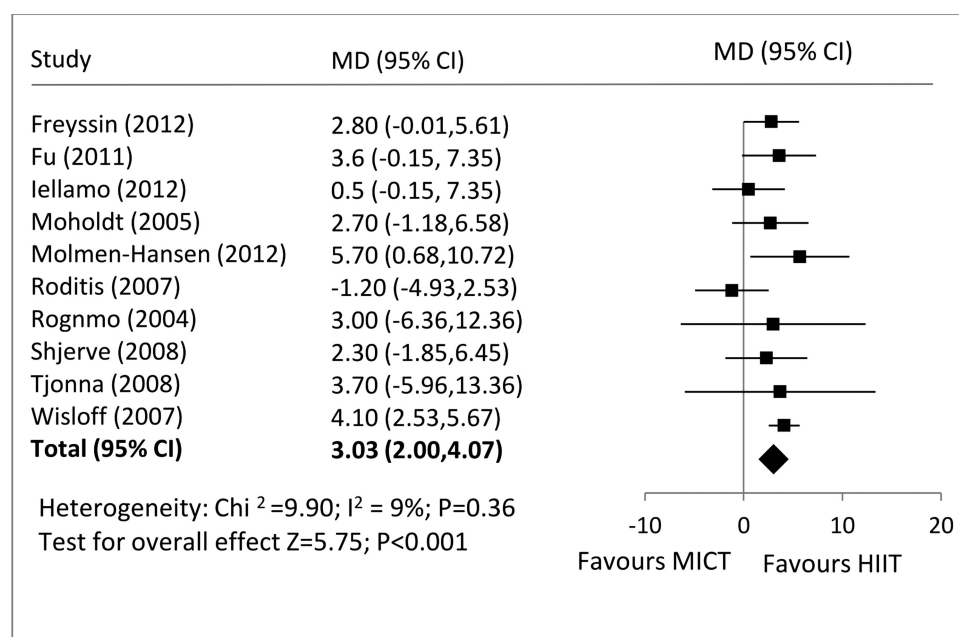


Figure 2 Forest plot of included studies.

being shorter. Seven of the studies differed the duration of the HIIT and MICT sessions so that the training sessions were isocaloric.^{20–22 25 26 28 31} The median duration of exercise times was 38 min for the HIIT group and 46 min for the MICT group. One study kept the duration identical between both groups but altered the mean intensity between the groups.²³ Another study used a different method (training impulse method) to alter the duration of each session based on the average change in heart rate.²⁷

Interval duration

Seven of the studies included high-intensity intervals of 4 min with 3 min of active recovery.^{20–22 25–27 31} One study included 5×3 min intervals with 3 min recoveries.²⁸ Two studies included shorter interval and recovery periods, with 30 s used for interval as well as recovery,²³ and 30 s used for interval and 60 s for recovery.²⁴

Supervision

Three studies included a supervised training component as well as a self-administered home programme,^{20 22 26} whereas the remaining were purely supervised sessions. Direct supervision allows the instructor to adjust the intensity, monitor the patient and provide motivation. The length of supervised HIIT or MICT within the studies varied from 4 to 16 weeks. One study was supervised for the first 4 weeks, and thereafter the participants were advised to continue the training programme at home for the following 6 months.²² The studies prescribed 3–6 training sessions/week, with two studies including one home session/week out of the three for the HIIT and MICT groups.^{20 26}

Owing to the constant changes in the heart rate response to exercise, supervision allows for a closer monitoring to ensure that the rates are within the desired zones. Therefore, the presence of a supervisor is quite likely to improve the accuracy of the intensity.

Outcomes

Adaptations occurring significantly more with HIIT compared with MICT are shown in box 1.

Box 1 Adaptations occurring significantly more with HIIT compared to MICT

- ▶ ↑VO₂peak
 - ▶ ↓Systolic and diastolic blood pressure
 - ▶ ↑High density lipoproteins
 - ▶ ↓Triglycerides and fasting glucose
 - ▶ ↓Oxidative stress and inflammation
 - ▶ ↓FATP-1 and FAS
 - ▶ ↑Adiponectin, insulin sensitivity and β-cell function
 - ▶ ↑PGC-1α
 - ▶ ↑Maximal rate of Ca²⁺ reuptake
 - ▶ ↑Availability of nitric oxide
 - ▶ ↑Cardiac function
 - ▶ ↑Enjoyment of exercise
 - ▶ ↑Quality of life
- FATP-1, fatty acid transport protein 1; FAS, fatty acid synthase; HIIT, high-intensity interval training; MICT, moderate-intensity continuous training

Cardiorespiratory fitness

There were improvements in the VO₂peak from HIIT as well as MICT in nine of the ten studies.^{20–22 24–28 31} The average of the pretraining values was 22.5 and increased to 27.9 mL/kg/min after HIIT (a 19.4% increase). MICT had baseline values of 22.6 that increased to 25.2 mL/kg/min after the intervention (10.3% increase). The mean difference in the change in the VO₂peak between HIIT and MICT was 3.03 mL/kg/min. A measure of exercise capacity (6 min walk test), as well as the VO₂peak, was assessed in one study. It was found that the distance walked improved in the HIIT and MICT groups.²⁴

Cardiometabolic risk factors

The study by Tjonna *et al*³¹ found that MICT and HIIT both reduced blood pressure, approximately 10 mm Hg systolic and 6 mm Hg diastolic. Molmen-Hansen *et al*²⁵ also showed a significant reduction of 12 mm Hg for systolic blood pressure in the HIIT group. Other studies showed no change in systolic blood pressure after the interventions. Significant reductions in oxidised low-density lipoproteins were found in HIIT but not MICT.^{20 31} However, in one study, the opposite was found.²⁶ Furthermore, it was established that high-density lipoprotein was increased by 25% in the HIIT group.³¹ These changes were supported by Wisloff *et al*²⁰ who also found an increase in high-density lipoprotein, lower triglycerides and improved fasting glucose in the HIIT group. An improvement in triglycerides was identified by Moholdt *et al*²² for the HIIT and MICT groups. Iellamo *et al*²⁷ found no significant differences in the metabolic profile (lipids, homeostasis model assessment-insulin resistance (HOMA-IR)), with the exception of an improvement in fasting glucose with HIIT. Fu *et al*²⁸ found improvements in oxidative stress/inflammatory markers plasma brain natriuretic peptides, myeloperoxidase and interleukin-6.

Two studies demonstrated no positive improvements in weight loss, body mass index or body composition between the HIIT and MICT groups postintervention.^{27 31} Furthermore, one study on obese patients reported a greater decrease in body weight with MICT than with HIIT.²⁶ However, reduced fatty acid transport protein 1 (FATP-1) and fatty acid synthase (FAS) levels (markers of fatty acid uptake and lipogenesis) were identified, which was associated with improvements in anti-insulin receptor activation in HIIT but not MICT.³¹

The findings from Tjonna *et al*³¹ showed increased circulating adiponectin and improved insulin sensitivity and β-cell function in the HIIT group. No changes in adiponectin were found by Moholdt *et al*²² at 4 weeks; however, after the 6-month intervention, HIIT and MICT increased the circulating levels.

Skeletal muscle

Three studies identified significant increases in PGC-1α, indicating improved mitochondrial biogenesis in the HIIT group.^{20 26 31} These studies also significantly increased the maximal rate of Ca²⁺ reuptake into the sarcoplasmic reticulum by 50–73%. Changes in the total myoglobin concentration and tissue oxygenation in the vastus lateralis were observed in HIIT but not MICT both acutely and after the 12 week intervention.²⁸

Myocardium and vasculature

Flow-mediated dilation was improved after HIIT and MICT in studies that assessed endothelial function.^{20 25 26 31} An increased availability of nitric oxide was found with HIIT but not MICT.³¹ Furthermore, a greater increase in antioxidant status, found in HIIT rather than MICT, supports the finding of

increased production and availability of nitric oxide.²⁰ An improvement in antioxidant status was not supported by the findings of Schjerve *et al.*²⁶ Patients with heart failure demonstrated improved left ventricular ejection fraction by 10% and a positive reversal of left ventricular remodelling.²⁰ An improvement in left ventricular ejection fraction was also demonstrated by Fu *et al.*,²⁸ alongside increases in cardiac output and total peripheral resistance. In contrast, Iellamo *et al.*²⁷ found no difference in cardiac output, stroke volume and left ventricular ejection fraction in their patients with heart failure. Patients with hypertension also had significantly improved ejection fraction, stroke volume, systolic flow velocity, end-diastolic volume, early diastolic mitral annulus tissue velocity and isovolumic relaxation rate.²⁵

Adherence

A minimum attendance of 70% and 90% of training sessions was an inclusion criterion for four of the studies.^{21 22 25 26} Only one participant was excluded from the analysis from one of these studies based on this criterion.²¹ For the first 4-week supervised period of Moholdt *et al.*'s study, the HIIT group attended 82% of sessions and the MICT group attended 84%. The attendance rate during the remainder of the 6-month home programme was not identified.²² Both groups in six of the other studies reported attendance rates above 85%.^{20 21 24 27 28 31} One study did not mention adherence to the protocol for either group.²³

Enjoyment and quality of life

HIIT was reported to be more enjoyable than MICT.³¹ Three studies demonstrated that HIIT improved the quality of life more than MICT,^{20 25 28} whereas another study showed similar increases between the two groups.²² Anxiety and depression also had similar improvements with HIIT and MICT.²⁴

Adverse events

Reporting of adverse events is important in determining the safety of applying this type of training to high-risk populations. No studies described their adverse event monitoring protocol. However, four reported no adverse events due to the exercise training^{20–22 24} and six did not mention adverse events.^{23 25–28 31}

DISCUSSION

The main finding from this meta-analysis is that HIIT is superior to MICT in improving CRF in patients with lifestyle-induced chronic diseases. Indeed, the increase in the $\text{VO}_{2\text{peak}}$ with HIIT was almost twice the increase gained from MICT. In addition, although there are limited data, HIIT appears to be well tolerated and safe.

Efficacy

HIIT increased the $\text{VO}_{2\text{peak}}$ by 5.4(19.4%) compared with 2.6 mL/kg/min (10.3%) with MICT. It has been shown that a 1-MET (3.5 mL/kg/min) increase is associated with 10–25% improvement in survival.¹⁷ Indeed, the protective role of fitness occurs even in the presence of established cardiovascular disease risk factors.³² CRF is an easily modifiable risk factor; therefore, identifying the most effective way to improve $\text{VO}_{2\text{peak}}$ should be a health priority.

Some of the studies investigated mechanisms explaining the greater improvement of the $\text{VO}_{2\text{peak}}$ with HIIT. Peripheral adaptations leading to improvements in CRF were investigated by measuring PGC-1 α and Ca^{2+} reuptake into sarcoplasmic reticulum in the skeletal muscles. Mitochondrial dysfunction is

central to most chronic diseases and could play a vital role in the reduced CRF that is experienced by these populations. Improvements in mitochondrial biogenesis have been demonstrated by increases in PGC-1 α after a single bout of low volume HIIT.³³ Studies by Tjonna *et al.*³¹ and Wisloff *et al.*²⁰ identified significant increases in PGC-1 α (138% and 47%, respectively), indicating mitochondrial biogenesis in the HIIT group. Wisloff *et al.*²⁰ found the increase in PGC-1 α to be strongly correlated with the improved $\text{VO}_{2\text{peak}}$ ($r=0.72$, $p<0.01$), supporting the influence of mitochondrial function on exercise capacity. Mitochondrial biogenesis is essential to maintain the structural integrity of skeletal muscle. Daussin *et al.*³⁴ concluded that a fluctuation in ATP turnover in interval training, which is different from the usual steady-state conditions of ATP production, activates the signalling pathways, which lead to increases in PGC-1 α . The increase in PGC-1 α identified by Wisloff *et al.* and Tjonna *et al.* may translate into improvements in aerobic and functional capacity. Both studies also significantly increased the maximal rate of Ca^{2+} reuptake into the sarcoplasmic reticulum by 50–60%.^{20 31} The increase in calcium cycling reduces skeletal muscle fatigue and would contribute to improvements in muscle function and therefore CRF. The findings by Fu *et al.*²⁸ demonstrate repeated bouts of deoxygenation in HIIT but not MICT, which may contribute to the observed adaptations to the muscles' oxidative capacity.

Improvement in the $\text{VO}_{2\text{peak}}$ with HIIT can also be explained mechanistically by central factors. Findings from one of the studies indicate that HIIT improved ejection fraction in patients with heart failure to the same degree as treating with ACE inhibitors and β -blockers, outlining the potential for further left ventricular remodelling with HIIT (Wisloff²⁰). Improvements in cardiac remodelling are supported by the findings of Fu *et al.*,²⁸ with significant reductions in brain plasma natriuretic peptide levels. HIIT may also contest modern medical treatments in improving systolic and diastolic blood pressure, with significant decreases of 12 and 8 mm Hg, respectively, found in patients with hypertension.²⁵ It was also found that the myocardial contractile function was improved with HIIT in terms of stroke volume, mitral annular excursion, ejection velocity and systolic mitral annular velocity. Besides a small reduction in the left ventricular filling pressure with MICT, the aforementioned improvements in systolic and diastolic function with HIIT were not found with MICT.

Conversely, Roditis *et al.*²³ demonstrated similar improvements in the $\text{VO}_{2\text{peak}}$ for the HIIT and MICT groups. Furthermore, the findings suggest that phase II of oxygen kinetics (indirect measurement of muscle oxidative capacity), showed superior improvements after MICT. The use of 30 s Wingate sprint intervals in this study may highlight the need for a longer duration of intervals, such as those used in four of the other studies reviewed.^{20–22 31} Although 30 s intervals are a more time efficient option than endurance training (similar improvements shown with ~90% less volume), 30 s may not be long enough to induce superior health-enhancing benefits.¹⁴ It appears from the studies reviewed that HIIT elicits many superior benefits to MICT in a slightly shorter time period (median 38 vs 46 min, respectively). It seems reasonable to suggest that gaining similar benefits would require either a longer period of MICT or an even shorter period of HIIT, supporting the ideology of HIIT being a more time efficient option. Future studies should identify the minimum amount of HIIT needed to elicit adaptations similar to MICT. There was another study that did not find a greater benefit of HIIT over MICT, which may be due to the method of establishing intensity by assessing blood lactate levels.²⁷

The HERITAGE study has established the influence genetic components have on the trainability of the $\text{VO}_{2\text{max}}$ in certain individuals, resulting in 'non-responders' to exercise training.³⁵ The consistently large improvements in the $\text{VO}_{2\text{max}}$ seen in a variety of cohorts in the HIIT studies questions whether this type of training can ameliorate the familial dampening of VO_2 in these 'non-responders'. Only one study in 1986 has examined the relationship between HIIT and hereditary trainability.³⁶ Although aerobic capacity was not assessed in this study, it was found that genotype *was* associated with anaerobic capacity after a HIIT training intervention, suggesting that the effectiveness of HIIT is affected by hereditary factors.³⁶ Indeed, in the studies reviewed in the meta-analysis, the SD of the change in the $\text{VO}_{2\text{peak}}$ in the HIIT group was 26% (relative to the mean change), whereas the MICT group had only an 8% variance. Future studies are needed to further compare the effects of HIIT and MICT on the $\text{VO}_{2\text{peak}}$ trainability.

In addition to CRF, efficacy can also be assessed by the effect on cardiometabolic risk factors. The studies reviewed found reductions in risk factors in HIIT notwithstanding the differences in body mass, body mass index or weight loss between HIIT and MICT. These findings are supportive of the theory of 'fitness over fatness'—in that it is more beneficial to health to improve physical fitness than to focus solely on weight loss. This is supported by Terada *et al*³⁷ who found similar reductions in body fat percentage in the HIIT and MICT groups after a 5 day/week, 12 week programme. Although weight loss was not different between groups, one study found a reduction in the FATP-1 and FAS levels in the HIIT group, suggesting a suppression of fatty acid uptake and lipogenesis. No studies measured visceral adiposity; however, the existence of increased circulating adiponectin levels found with HIIT but not MICT is suggestive of decreased intra-abdominal obesity.

Owing to the augmented PHR and cardiac output that is experienced in HIIT, it is quite likely that pulsatile and shear stress influence vasculature during periods of intense exercise.³⁸ Interval exercise has been shown to reduce arterial stiffness through increased distensibility of the vessels.^{38–39} A recent study by Smart and Steele⁴⁰ demonstrated no difference in fitness and cardiac function between moderate training and intermittent training groups matched by the volume of work. However, the intervals were not high intensity, suggesting that to elicit changes, intervals need to increase the heart rate to a

certain level. Arterial stiffness is a key contributor to a number of cardiovascular conditions that influence mortality through cardiovascular disease.⁴¹ Two studies demonstrated higher endothelial derived nitric oxide production in the HIIT group.^{20–31} It is suggested that shear stress through an increase in pulse and frequency pressure promotes vasodilatory nitric oxide release, thereby increasing arterial compliance.⁴² This is further supported by Wisloff *et al*²⁰ and Tjonna *et al*³¹ who found greater increases in flow-mediated dilation in HIIT than in MICT. The improvements in endothelial function are supported by the findings from Fu *et al*.²⁸ The study's findings demonstrate an increase in perfusion and oxygen utilisation between cerebral and muscular tissues, which occurs through increases in shear flow and metabolic stress. The increased perfusion to the vastus lateralis and frontal cortex would promote increased flow and shear stress and therefore the release of NO.

Safety

The reporting of adverse events enables the safety of the intervention to be inferred to the population being studied. Four of the 10 reviewed studies reported no adverse events as a result of the exercise training.^{20–22, 24} One study that did not mention adverse events did explain that follow-up testing was not performed on five patients either due to orthopaedic-related problems or the inconvenient programme timetable.²³ Other reasons cited for loss of patient follow-up were comorbidities (the group was not cited),²² ankle fracture in the HIIT group and knee injury in the MICT group.²¹ One participant in the MICT group died from cardiac causes; however, it was stated that this was unrelated to exercise training.²⁰

A recent study by Rognmo *et al*⁴³ aimed to assess the safety of HIIT compared to MICT, during and after exercise, in patients with coronary heart disease in cardiac rehabilitation. The study of 4846 participants indicated that the risk of a cardiovascular event occurring is low in MICT and HIIT. During this study, there was one fatal cardiac event during MICT and two non-fatal cardiac events during HIIT. The calculated event rates were 1/129 456 h of moderate-intensity exercise and 1/23 182 h of high-intensity exercise. Moreover, when vigorous intensity exercise was energy matched with moderate-intensity exercise, greater cardioprotective benefits were elicited. To accurately assess a cardiac event occurring during training, the study required a sample size of >20 500 patients. Despite the study being underpowered,⁴⁴ the results explore the beneficial dose-response relationship associated with HIIT and the negligible risk that is involved.

The safety of HIIT has been controversial among health professionals treating high-risk populations. This has perhaps been created through a common avoidance of anginal episodes, which can sometimes be triggered by high-intensity exercise. Although commonly thought to be a dangerous byproduct of exercise, episodes of controlled ischaemia may actually be beneficial in preventing secondary conditions in coronary artery disease through ischaemic preconditioning.⁴⁵ Exercise-induced coronary collateral formation is based on the vascular endothelial growth factor, and this adaptation is correlated with exercise intensity. Lu *et al*⁴⁶ found that exercise-induced intermittent ischaemia promoted coronary angiogenesis by the vascular endothelial growth factor. The favourable effects of intermittent exercise on angiogenesis is further supported in a meta-analysis on peripheral arterial disease.⁴⁷ In a study by Lu *et al*, a normal cardiac troponin I indicated that no myocardial damage occurred when ischaemia was applied. Lu *et al* state that HIIT is safe even for patients with high-risk chronic disease with stable

Box 2 Suggested contraindications to high-intensity interval training (HIIT)

- ▶ Unstable angina pectoris
- ▶ Uncompensated heart failure
- ▶ Recent myocardial infarction (<4 weeks)
- ▶ Recent coronary artery bypass graft or percutaneous coronary intervention (<12 months)
- ▶ Heart disease that limits exercise (valvular, congenital, ischaemic and hypertrophic cardiomyopathy)
- ▶ Complex ventricular arrhythmias or heart block
- ▶ Severe chronic obstructive pulmonary, cerebrovascular disease or uncontrolled peripheral vascular disease
- ▶ Uncontrolled diabetes mellitus
- ▶ Hypertensive patients with blood pressure >180/110 (or uncontrolled)
- ▶ Severe neuropathy

angina. Rather than promoting the instigation of angina in HIIT, this information is intended to highlight the safety of HIIT in high-risk populations. Caution should be exercised on a case-by-case basis depending on the participant's cardiac history. Indeed, despite the patients in the studies reviewed being a high-risk cohort, they were only included if their diseases were relatively well controlled or stable. Therefore, these findings may not be applicable to some patients in these disease groups. Box 2 provides a suggested guide of contraindications for participation in HIIT in high-risk patients. In summary, when used with appropriate screening and communication with the patient's doctor, HIIT can be a safe option for patients with high risk.

Limitations

Although this review provides the basis for further clinical trials testing of HIIT in rehabilitation of patients with chronic disease, all the studies analysed experienced methodological limitations. Although three of the studies used a different training protocol to the other seven, the heterogeneity of the VO_2peak measure was low ($\chi^2=9.90$, $I^2=9\%$, $p=0.36$).^{23 24 28} Owing to the relatively recent interest with HIIT in chronic disease, HIIT training guidelines have not yet been created. Consequently, current research consists of a variety of intervals, intensities and programme durations. Furthermore, comparison of studies proves difficult when volumes of HIIT and MICT are equated in different ways. There are also discrepancies in the percentage of heart rate used. Some of the studies used a higher definition of moderate intensity (75%) to the general intensity of moderate exercise suggested by Norton *et al* (55–70% MHR) and the American College of Sports medicine (ACSM; 60–70% MHR).^{2 20 21 48} Not all studies included assessor blinding of the VO_2peak , which may have influenced the testing results. Also, studies in cardiac rehabilitation programmes may have been guided by other confounding factors such as dietary advice or smoking status. A limitation of this review is that 6 of the 10 studies reviewed are from the same research group. It is important that these findings are replicated in future studies at other institutions.

The studies reviewed consisted of small sample sizes, with one study including an unequal male-to-female ratio.²⁰ The current literature is lacking in HIIT studies on all the chronic diseases. This systematic review on the cardiometabolic lifestyle-induced chronic diseases would have benefited from studies with other lifestyle diseases such as type II diabetes and chronic kidney disease. Owing to the limited research in this area, a variety of diverse diseases were included under the title cardiometabolic disease for this meta-analysis. However, the pathophysiology of the varied diseases may mean that HIIT will have different influences on the parameters being compared among different studies. Research on more chronic diseases will allow specific prescription guidelines to be recommended.

Protocol recommendations

Future research is needed to establish the optimal protocol of HIIT. However, based on the findings from this review, recommendations in table 2 are provided. It is important to note that the effectiveness and adherence to different HIIT protocols will always be highly individualised.

Mode and intensity

The duration of intervals can differ greatly in various HIIT protocols. Two studies which used shorter duration intervals of 30 s showed no improvements and smaller improvements in the

Table 2 Protocol recommendations for HIIT

Frequency	3x/Week
Duration	40 min
Modality	Treadmill/hill, cycle ergometer. Increasing speed or incline
Intensity	Interval=85–95% PHR Rest=passive–70% PHR
Interval times	4x4 min intervals 3x3 min recovery
Warm-up	10 min at 60% PHR
Cool-down	5 min at 50% PHR

HIIT, homeostasis model assessment-insulin resistance; PHR, peak heart rate.

VO_2peak , respectively.^{23 24} Studies which demonstrated the biggest changes in the VO_2peak after a HIIT intervention used the 4x4 approach (4 intervals at 4 min each between 90% and 95% PHR).^{20–22 25 26 31} The recommendation of the 4x4 approach (~40 min duration) in table 2 does not preclude shorter duration HIIT protocols being potentially more appropriate. However, more research is needed to compare a shorter duration of HIIT with the current recommendation. Furthermore, future research comparing HIIT and MICT should ensure that MICT is kept consistent with current definitions of moderate exercise.

Recovery

The intensity and duration of the recovery period in HIIT may play just as integral role as the interval period. Past research has suggested that an active recovery is recommended in order to effectively aid the process of lactate removal.⁴⁹ However, a study by Dupont *et al*⁵⁰ indicated that during the active rest period there was less replenishment of oxygen in myoglobin and haemoglobin and a reduced rate of resynthesis of phosphocreatine from the previous work phase. Meyer *et al*'s study⁵¹ on patients with chronic heart failure found that short intervals (30 s) with passive recovery provided the most benefit (longest time to exhaustion in an exercise test). This study also determined that including a passive recovery instigated a lower rating of perceived exertion as indicated on the BORG scale, despite having a higher oxygen pulse, which is dependent on the stroke volume and arteriovenous difference.⁵¹ Logistically, it may be more practical and convenient to include an active recovery for the purpose of timing and equipment control, albeit at as low an intensity as possible. To successfully employ HIIT, recovery intensities need to be achieved. If the heart rate is not reducing to the required intensity by the end of the recovery period, the interval work rate should be adjusted accordingly.

Feasibility

Indisputably, the success of an exercise intervention and maximising long-term benefits relies directly on adherence to the exercise programme. Central to adherence is the enjoyment of the activity being prescribed. Bartlett *et al*⁵² found that the ratings of perceived enjoyment after HIIT were higher when compared to MICT. It was identified in this study that the rating of perceived exertion had a positive correlation with enjoyment, through a likely combination of stimulation and accomplishment.

Wisloff *et al*'s²⁰ study addresses the feasibility of HIIT being performed independently. During home sessions, participants were provided with heart rate monitors that recorded heart rate data. These monitors were placed so that they could not be seen

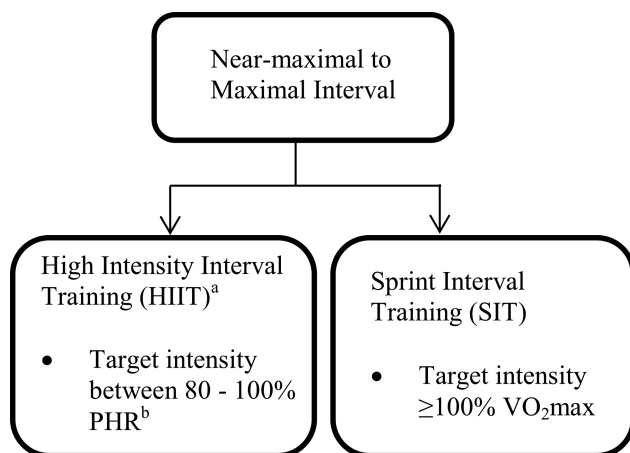
by the participant. The patients achieved the correct heart rate zones without feedback from the heart rate monitor. The design of this study supports the feasibility of incorporating HIIT into a real-world situation, where a home HIIT programme can be successfully prescribed after a familiarisation period. This is further supported by Moholdt *et al.*⁵³ who demonstrated that adherence to a home programme of HIIT was as suitable as the usual cardiac residential care.

Future directions

Given the small number of studies conducted thus far, there are still important questions that need to be addressed. Similar to current issues with the dose response of less intensive exercise, much more work is needed to determine if the recommendations provided here provide the optimal approach for future studies. Furthermore, it is realistic that most people will combine HIIT with MICT; therefore, determining the optimal ratio of *both* types of training over longer periods of time is also important. Similarly, current guidelines for all populations recommend the inclusion of resistance training in an exercise programme; yet the interaction between HIIT and resistance training is unknown. As it is likely that most people will include HIIT and resistance training in the same session, future studies should identify the ratio of HIIT and resistance training needed for optimal benefits.

Analogous to the clinical trial phases in the development of a new pharmaceutical product, the evaluation of HIIT training for patients with cardiometabolic diseases would be in phase 2 (assessing efficacy). Indeed, the guidelines for clinical populations should use the same approach and criteria as other therapies (eg, drugs), with eventual recommendations based on large randomised control trials and not on small feasibility and efficacy studies alone.

Another important question is regarding adherence after the supervised programme. Future studies should determine whether this approach is sustainable in a non-supervised, home-based environment.



^aHas been referred to as Aerobic Interval Training (AIT) in a number of studies ([1-6])

^b PHR is used to prescribe the intensities (refer to text)

Figure 3 Suggested classification scheme for interval training based on exercise intensity.

Consistency of terminology

The terminology used to describe HIIT varies across research groups. The Norwegian research group that has conducted the majority of studies in this area has preferred the term 'aerobic interval training (AIT)'. Other prominent groups have used 'SIT' to describe all-out supramaximal (>100% VO₂max) intervals in studies with healthy individuals^{14 54} or low-volume HIIT when short intervals (~30 s) with an intensity <95% are used.^{55 56} We suggest that the classification scheme shown in figure 3 is used to standardise terminology in future studies. This approach is based on (1) the widespread media use of the term 'HIIT' rather than 'AIT' for nearmaximal intensity (80–100% PHR) intervals, (2) the additional information regarding the intensity of the interval provided by HIIT compared to AIT and (3) the need to separate all-out supramaximal sprint interval training from HIIT as there are concerns for the safety of this all-out approach in clinical populations. Furthermore, it is suggested that, in comparative studies, the term 'moderate-intensity continuous training' (MICT) should be used, where appropriate.

CONCLUSIONS

This meta-analysis has identified that HIIT has more physiological benefits than MICT in patients with lifestyle-induced cardiometabolic disease. HIIT significantly improved CRF by almost double that of MICT (19.4% vs 10.3%). This should translate into greater decreases in risks of morbidity and all-cause mortality. Incorporation of HIIT into a rehabilitation programme may be a more achievable way for people with chronic disease to reach a level of exercise that promotes health enhancing benefits. These findings suggest that future exercise guidelines for lifestyle-induced cardiometabolic disease should incorporate HIIT. There are various logistical considerations that contribute to the feasibility of a HIIT programme; however, if participants are adequately screened and the programme is prescribed and supervised by appropriately trained and qualified individuals, then it should be an achievable training option.

What are the new findings?

- ▶ High-intensity interval training (HIIT) is superior to moderate-intensity continuous training in improving cardiorespiratory fitness in lifestyle-induced cardiometabolic diseases.
- ▶ HIIT is well-tolerated, safe and improves the quality of life.
- ▶ Central and peripheral adaptations are responsible for the superior benefits of HIIT.

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Table 1. Summary of studies comparing the effects of HIIT vs MICT

Study	Population	Intervention	Interval Parameters	Program	Outcomes of HIIT compared to MICT
Rognmo et al., (2004)[21]	21 stable coronary artery disease patients HIIT (n=8), MICT (n=9)	Uphill treadmill walking HIIT- 4 x 4 min intervals (85- 95% PHR), 3 min recovery (65- 75% PHR), 33 mins MICT- 65-75% PHR, 41 mins	Ratio:4/3 MI:80% Amplitude: 25%	Supervised 3x/week 10 weeks	↑ VO ₂ peak
Roditis et al., (2007)[23]	21 stable CHF patients HIIT (n=11), MICT (n=10)	Electromagnetically braked cycle ergometer HIIT – 30 sec intervals (120% pWR), 30 sec recovery (0% pWR), 40 mins	Ratio:1/1 MI:60% Amplitude: 72%	Supervised 3x/week 12 weeks	⇔ VO ₂ peak

MICT – 60% pWR, 40 mins

Wisloff et al., (2007)[20]	27 stable	Uphill treadmill walking	Ratio: 4/3	2x/week supervised,	↑↑ VO ₂ peak
	postinfarction heart	HIIT- 4 x 4 min intervals (90-	MI: 76%	1x/week unsupervised	↑↑ LVEF
	failure patients	95% PHR), 3 min recovery (50-	Amplitude: 43%	for 12 weeks HIIT and	↑↑ LV remodelling
	HIIT (n=9), MICT	70%), 38 mins		MICT groups	↑↑ EF
	(n=9), C (n=9)	MICT- 70-75% PHR, 47 mins			↑↑ mitochondrial
		C- standard PA advice			function
					↑↑ QOL
Schjerve et al., (2008)[26]	40 obese patients,	Treadmill walking or running	Ratio: 4/3	2x/week supervised	↑↑ VO ₂ peak
	BMI >30 kg/m ²	HIIT- 4 x 4 min intervals (85-	MI: 80%	1x/week unsupervised	↑↑ peak O ₂ pulse
	HIIT (n=14), MICT	95% PHR), 3 min recovery (50-	Amplitude: 25%	12 weeks all groups	↑↑ PGC-1α
	(n=13), strength	60% PHR), 38 mins			↑↑ sarcoplasmic
	training (n=13)	MICT- 60-70% PHR, 47 mins			reticulum Ca ²⁺
		Strength- abdominal, back leg			uptake

strength programme

↑↑ FMD

↔ artery diameter,

shear rate

↓↓ LDL and body

weight in MICT

Tjonna et al., (2008)[31]	32 patients with metabolic syndrome	Uphill treadmill walking/running	Ratio:4/3 MI:80%	Supervised 3x/week 16 weeks	↑↑ VO ₂ max
	HIIT (n=12), MICT (n=10), C (n=10)	HIIT- 4 x 4 min intervals (90% PHR), 3 min recovery (70%), 40 mins MICT- 70% PHR, 47 mins C- followed advice from family physician	Amplitude: 25%		↑↑ PGC-1α ↑↑ sarcoplasmic reticulum Ca ²⁺ uptake ↑↑ EF ↑↑ insulin action ↑↑ lipogenesis

Moholdt et al., (2009)[22]	59 CABG HIIT (n=23), MICT (n=25)	Treadmill walking HIIT- 4 x 4 min intervals (90% PHR), 3 min recovery (70%), 37 min MICT- 70% PHR, 46 min	Ratio:4/3 MI:80% Amplitude: 25%	Supervised 5x/week 4 weeks. Unsupervised until 6mth time point	After 4 weeks: \Leftrightarrow VO ₂ peak After 6 months: \Uparrow VO ₂ peak \Uparrow HR recovery after 6 months. \Leftrightarrow QOL
Fu et al. (2011)[28]	45 CHF HIIT (n=15), MICT (n=15), control (n=15)	Cycle ergometer HIIT- 5 x 3 min intervals (80% VO ₂ peak), 3 min recovery (40% VO ₂ peak), 33 min MICT- 60% VO ₂ peak, 36 min	Ratio: 1 MI: 60% Amplitude: 67%	Supervised 3x/week 12 weeks.	\Uparrow VO ₂ peak \Uparrow CO \Uparrow TPR \Uparrow LVEF \Downarrow BNP, MPO, IL-6 \Uparrow QOL

Freyssin et al., (2012)[24]	26 stable CHF patients	Uphill treadmill walking and cycle ergometer	Ratio:1/2	Supervised 6x/week	↑↑ VO ₂ peak
			MI:	8 weeks	↑↑ exercise test
	HIIT (n=12), MICT (n=14)	HIIT – 3 x (12 x 30 sec intervals, 60 sec complete rest), 80% pWR, 5 mins rest between sets, 54 mins	Amplitude:		duration
		MICT – 45 mins, intensity at 1 st ventilator threshold			↑↑ oxygen pulse
Iellamo et al., (2012)[27]	16 post-infarction HF	Uphill treadmill walking	Ratio: 4/3	Supervised 2x/week	⇔ VO ₂ peak
		HIIT – 4 x 4 min intervals (75-80% HRR), 3 min recovery (45-50% HRR), 20-34	MI: 62.5%	progressing to	⇔ CO, SV, LVEF
	HIIT (n=8), MICT (n=8)	MICT – 45-60% HRR, 30-45 min, 30-45	Amplitude: 48%	5x/week	⇔ lipids, HOMA-
				12 weeks	IR

Molmen-	88 patients with	Treadmill walking	Ratio: 4/3	Supervised 3x/week,	↑↑ VO ₂ peak
Hansen et al.,	essential	HIIT – 4 x 4 min intervals (90-	MI: 75.25%	12 weeks	↑↑ heart rate
(2012)[25]	hypertension stage	95% PHR), 3 min recovery (60-	Amplitude:		recovery
	1-2, SBP 140-170	70%), 38 mins	40.5%		↑↑ endothelial
	mmHg and DBP 90-	MICT – 70% PHR, 47 mins			function
	109 mmHg	C – standard recommendations			↑↑ EF, SV
	HIIT (n=25), MICT	for hypertension, including			↓↓ 24 hour SBP
	(n=23), C (n=25)	light-moderate exercise without			↔ LV mass, TPR
		supervision			↑↑ QOL

Ratio = relationship between duration of interval and recovery. MI = Mean intensity between high intensity interval and recovery. Amplitude = difference between interval and recovery intensities, divided by the mean intensity. 1-RM = 1 repetition maximum for plantar flexion, SaO₂ = oxygen saturation, ABI = ankle brachial index, FMD = flow mediated dilatation, LV = left ventricular, EF = ejection fraction, QOL = quality of life, SV = stroke volume, TPR = total peripheral resistance * No within group differences, BNP = brain natriuretic peptide, MPO = myeloperoxidase, IL-6 = interleukin-