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Original article

Effect of self-tailored high-intensity interval training versus moderate-intensity continuous exercise on cardiorespiratory fitness after myocardial infarction: A randomised controlled trial

Thimo Marcin [a], Lukas D. Trachsel [a], Michelle Dysli [a], Jean Paul Schmid [b], Prisca Eser [a], Matthias Wilhelm [a,*]

[a] *Department of cardiology, Centre for preventive cardiology, Inselspital, Bern University Hospital, University of Bern, Freiburgstrasse 46, 3010 Bern, Switzerland*
[b] *Department of cardiology, Clinic Barmelweid, Barmelweid, Switzerland, Klinik Barmelweid, 5017 Barmelweid, Switzerland*

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ABSTRACT

Background: Whether high-intensity interval training (HIIT) is more efficient than moderate-intensity continuous exercise (MICE) to increase cardiorespiratory fitness in patients with acute coronary syndrome at moderate-to-high cardiovascular risk is controversial. The best approach to guide training intensity remains to be determined.
Objective: We aimed to assess intensities achieved with self-tailored HIIT and MICE according to perceived exertion and to compare the effect on cardiorespiratory fitness in patients early after ST-elevation myocardial infarction (STEMI).
Methods: We included 69 males starting cardiac rehabilitation within 4 weeks after STEMI. After a 3-week run-in phase with MICE, 35 patients were randomised to 9 weeks of HIIT (2 × HIIT and 1 × MICE per week) and 34 patients to MICE (3 × MICE). Training workload for MICE was initially set at the patients' first ventilatory threshold (VT). HIIT consisted of 4 × 4-min intervals with a workload above the second VT in high intervals. Training intensity was adjusted weekly to maintain the perceived exertion (Borg score 13–14 for MICE, ≥ 15 for HIIT). Session duration was 38 min in both groups. Peak oxygen consumption (VO_2) was measured by cardiopulmonary exercise testing pre- and post-intervention.
Results: Both groups improved peak VO_2 (ml/kg/min) (HIIT +1.9, $P < 0.001$; MICE +3.2, $P < 0.001$, Cohen's d -0.4), but changes in VO_2 were not significantly different between groups ($P = 0.104$). Exercise regimes did not differ between groups in terms of energy expenditure or training time, but perceived exertion was higher with HIIT.
Conclusions: Self-tailored HIIT was feasible in patients early after STEMI. It was more strenuous but not superior nor more time-efficient than MICE in improving peak VO_2.

The trial was registered at ClinicalTrial.gov (NCT02627586).

1. Introduction

Peak oxygen consumption (VO_2) as a measure of cardiorespiratory fitness (CRF) is a well-established and valid surrogate for cardiovascular risk in healthy people and in patients with cardiovascular disease [1,2]. Structured supervised exercise training to improve patients' CRF is one of the core components of modern cardiac rehabilitation (CR) [3], and improved peak VO_2 is related to better prognosis [4].

Multiple studies and meta-analyses of coronary artery disease from the last decades indicate that high-intensity interval training (HIIT) is superior to moderate-intensity continuous exercise (MICE) to improve peak VO_2 [5–7]. However, studies comparing isocaloric training modalities did not find greater peak VO_2 improvements with HIIT than MICE [7].

Despite the growing evidence supporting HIIT, the European Association of Preventive Cardiology endorsed HIIT for only stable low-risk patients [8]. A concern may be the safety and feasibility of HIIT in moderate- to high-risk patients with acute coronary syndrome. Only a few studies comparing HIIT and MICE reported the inclusion of patients within 2 months after myocardial infarction (MI), and their results in terms of improvements in

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* Corresponding author.
E-mail address: matthias.wilhelm@insel.ch (M. Wilhelm).

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peak VO_2 were controversial [9–12]. Few studies have investigated the feasibility and effectiveness of HIIT in MI patients at moderate to high risk, namely patients early after ST-elevation MI (STEMI) who are undergoing primary percutaneous coronary intervention (PCI). Moreover, the authors of the recent position paper stressed the need for further studies on the utility and best protocols of aerobic HIIT [8].

With the trend toward precision medicine in the last decade, close monitoring and guidance of training intensity according to heart rate (HR) and workload is important in the CR setting. However, patients' perception of objectively measured training intensity during CR must be gauged [8]. Monitoring and prescription of training intensity according to continuously monitored parameters may be feasible during centre-based CR, but is less feasible for long-term maintenance of exercise training at home. Consequently, studies have investigated the feasibility of using self-rated perceived exertion to guide training and found comparable CRF benefits as compared with training guided by HR and workload monitoring [13–15].

We believe that training intensities for HIIT and MICE complying with the recommendations of current guidelines is feasible by using a self-tailored approach, namely, guiding patients initially by objectively measured parameters from exercise testing and then by self-rated perceived exertion. We aimed to assess the training intensity achieved with self-tailored HIIT and MICE and to compare the effect between the 2 training modalities on changes in peak VO_2 in patients undergoing CR early (within 4 weeks) after STEMI.

The reporting of the study follows the CONSORT guidelines for non-pharmacological interventions.

2. Methods

2.1. Study population

Patients with a first STEMI or equivalent (i.e., left bundle branch block) undergoing primary PCI within 4 weeks before inclusion and who participated in the ambulant CR programme of the University Hospital Bern, Switzerland, were recruited for the HIIT-Early study between November 30, 2015 and November 30, 2019. Exclusion criteria were known chronic heart failure with left ventricular ejection fraction $\leq 45\%$ before the acute MI, recent valve surgery, musculoskeletal limitations, thrombus formation, and permanent atrial fibrillation. The study was approved by the ethics committee of the Canton of Bern and registered at ClinicalTrial.gov (NCT02627586). Written informed consent was obtained from all patients.

2.2. Study design

The present study was a sub-study of the HIIT-Early study, a prospective, randomised controlled trial whose primary outcome was left ventricular remodelling with HIIT as compared with MICE in patients undergoing CR early after STEMI. The 9-week intervention was integrated into a 12-week multidisciplinary ambulant CR programme that consisted of 36 supervised 90-min exercise training sessions (3 per week) as well as nutrition counselling, psychotherapy and smoking cessation according to individual needs. The exercise sessions usually included 38-min endurance training on a cycling ergometer, followed by 45 min of coordination training, resistance training, water therapy, stretching or relaxation.

The study design is illustrated in appendix Fig. A.1. Patients underwent a baseline examination followed by a 3-week run-in phase with up-titration of guideline-directed medical therapy before group allocation. After the run-in phase, the pre-intervention testing was performed, and patients were randomised (1/1, block size 2) to the HIIT or MICE group, stratified by left ventricular function (global longitudinal strain, cut-off ≤ -12) by research staff not involved in the intervention delivery who used sealed envelopes. Post-intervention testing was performed after another 9 weeks (corresponding to the CR completion visit).

2.3. Exercise intervention

2.3.1. Run-in phase: MICE

During the run-in phase, all patients underwent the same exercise regime, namely 3 MICE sessions per week on a cycle ergometer in order to familiarise patients to exercise training before applying high-intensity sessions (safety reasons). For the first training, exercise intensity was set at the workload of patients' individual first ventilatory threshold (VT) measured during the cardiopulmonary exercise testing (CPET) at baseline visit. The training sessions lasted 38 min in total and included a 5-min warm-up and 3-min cool-down at 50% of the training workload. Training intensity was monitored by an experienced exercise therapist and adapted weekly based on patients' perceived exertion, with a target score of 12–13 on the Borg scale of perceived exertion, ranging from 6 to 20.

During this run-in period, pharmacological therapy was optimised, in particular regarding beta-blockers and inhibitors of the renin–angiotensin–aldosterone system.

2.3.2. Intervention phase: HIIT or MICE

Patients allocated to the MICE group continued to perform 3 MICE training sessions per week. MICE training was continued with the same protocols as in the run-in phase.

Patients allocated to the HIIT group performed 2 HIIT training sessions and one MICE training session per week. HIIT consisted of 4×4-min intervals with a workload above the second VT (corresponding to approximately 90–95% of peak HR), with each interval separated by 3 min of active recovery with a workload below the first VT. The total duration of a HIIT session was 38 min, including a 10-min warm-up and 3-min cool-down.

Training workload was adjusted weekly in order to maintain or increase the patient's perceived exertion (Borg score 13–14 for MICE, ≥ 15 for HIIT) and to achieve isocaloric exercise regimes between HIIT and MICE groups.

2.4. Blinding

Because of the nature of the intervention, patients were not blinded. Pre- and post-intervention CPET was conducted according to clinical routine practice by medical staff, who were not involved in the study. Therefore, outcome assessors were considered blinded.

2.5. Outcomes

Training HR and workload were monitored in each training session to assess the average training intensity. Pre- and post-intervention examination included a CPET to assess changes in peak VO_2. Because the present study investigated secondary study outcomes of the HIIT-Early study, no sample size was calculated a priori.

2.6. Data collection

2.6.1. Cardiopulmonary exercise testing

CPET was performed with the participant on a cycle ergometer with an individualised ramp protocol aiming to achieve exhaustion within 8 to 12 min of ramp duration. The protocol consisted of a 3-

min warm-up at a workload of 20 W followed by an increase of 10, 15, or 20 W/min until voluntary exhaustion and a 2-min active cool-down period. Throughout the CPET, patients were monitored by a cardiologist with continuous assessment of 12-channel electrocardiography. Gas exchange was measured by using the spirometry system Jaeger Oxycon Pro (Masterscreen CPX, PanGas Healthcare GmbH).

Peak VO_2 was determined as the highest value of a moving average over 8 breathing cycles. As a measure of exhaustion, the peak respiratory exchange ratio was determined by dividing VCO_2 by VO_2. We aimed to achieve a respiratory exchange ratio ≥ 1.1 during CPET. The first and secondary ventilatory thresholds (VT_1 and VT_2) were visually determined by experienced physicians with the Wassermann's 9-Panel plot [16]. In addition, the ventilation (VE) to CO_2 output slope from start to VT_2 and VO_2 to workload slope were derived [17].

2.7. Training monitoring

Only endurance training sessions on cycle ergometers were monitored for study purposes. Resistance, coordination or other endurance sessions from the regular CR programme were the same for both intervention groups and were not monitored. Training workload was monitored by using the Ers2 system (ergoline GmbH, 72575 Bitz, Germany, Version 1.01). In addition, HR and rhythm were continuously recorded with 3-lead electrocardiography. After every training session, patients were asked about the perceived exertion by using the established Borg scale [18].

2.8. Data analysis

We used R v3.6.1 for all statistical analyses. Patient characteristics were compared between groups by using Wilcoxon rank-sum tests. CRF parameters at pre- and post-intervention were compared between HIIT and MICE groups by using Wilcoxon rank-sum tests. Student *t*-test and Cohen's *d* were used to compare observed changes in CRF parameters from pre- to post-intervention between groups (group × time interaction) according to intention-to-treat analysis. In addition to intention-to-treat analysis, we used a per-protocol analysis for change in peak VO_2 (group × time interaction). Patients from the HIIT group who performed < 12 of the 18 prescribed HIIT sessions or more MICE than HIIT sessions were re-allocated to the MICE group for the per-protocol analysis.

Training characteristics were compared between HIIT and MICE groups by Wilcoxon rank-sum tests. The increase in training intensity (Borg scale, HR and watts in percentage of peak at pre-intervention CPET) during the intervention period was compared between groups by linear mixed models for repeated measures. Group × training-number interaction was included as a fixed effect with patients as random intercepts and slopes. For linear mixed models, MICE sessions performed by the HIIT group were excluded. Training intensity was averaged over the entire training session for both HIIT and MICE groups. Therefore, the reported training intensity for HIIT sessions includes both high- and low-intensity intervals.

An additional explorative analysis was performed to assess the association of training characteristics and change in peak VO_2 by using a linear regression model with change in peak VO_2 as a response variable and age, number of session, percentage of HIIT sessions, average training workload and pre-intervention peak VO_2 as explanatory variables.

3. Results

3.1. Patients

A total of 75 patients were enrolled in the HIIT-Early study, and 69 patients (mean [SD] age 56 [10]) were finally included in the intention-to-treat analysis (35 HIIT, 34 MICE). The flow of patients is presented in appendix Fig. A.2. Patient characteristics at pre-intervention are in Table 1. Patients allocated to the HIIT group did not significantly differ from those allocated to the MICE group.

3.2. Cardiorespiratory response

Improvements in peak VO_2 for each patient are shown in Fig. 1 and illustrate the trend toward greater improvements in MICE than HIIT patients. Peak VO_2 improved significantly from pre- to post-intervention, by 12% with MICE and by 8% with HIIT but with no significant group × time interaction (Table 2). Likewise, both groups showed comparable improvements in VE to CO_2 slope and VT_1 (Table 2).

Table 1
Characteristics of patients with moderate-intensity continuous exercise (MICE) and high-intensity interval training (HIIT) at pre-intervention.

	MICE *n* = 34	HIIT *n* = 35	*P*-value[a]
Age (years)	59 (50–62)	55 (50–66)	0.75
BMI (kg/m^2)	27.3 (26.1–28.9)	26.6 (24.4–28.3)	0.16
Systolic BP (mmHg)	122 (115–136)	125 (110–132)	0.77
Diastolic BP (mmHg)	76 (70–81)	72 (68–78)	0.22
LVEF (%)	61 (53–66)	57 (49–64)	0.22
Time between MI and pre-intervention (days)	42 (40–48)	46 (40–52)	0.51
Culprit lesion, *n* (%)			0.99
LAD	17 (50)	17 (49)	
LCX	6 (18)	6 (17)	
RCA	11 (32)	12 (34)	
Number of vessels with hemodynamic relevant stenosis, *n* (%)			0.99
1	12 (35)	13 (37)	
2	9 (26)	9 (26)	
3	13 (38)	13 (37)	
Peak VO_2 predicted (%)[b]	100 (86–112)	96 (88–112)	0.77
Beta blockers, *n* (%)	33 (97)	34 (97)	> 0.99
RAAS inhibitors, *n* (%)	33 (97)	32 (91)	0.61
Statins, *n* (%)	34 (100)	35 (100)	

BMI: body mass index; BP: blood pressure; LAD: left anterior descending; LCX: left circumflex; LVEF: left ventricular ejection fraction; MI: myocardial infarction; RAAS: blockers of the renin–angiotensin–aldosterone system; RCA: right coronary artery; VO_2: oxygen consumption. Data are median (interquartile range) unless indicated.

[a] *P*-values from Wilcoxon rank-sum test; Chi^2 test of independence; Fisher's exact test.

[b] According to Wassermann formulae.

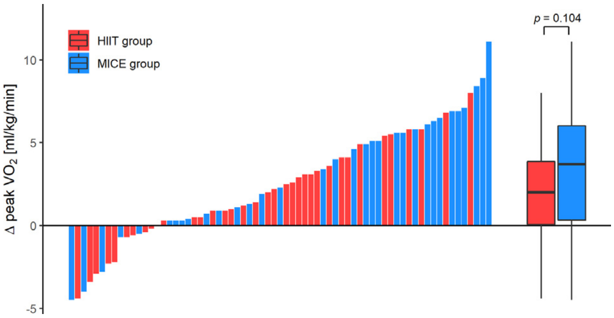

Fig. 1. Changes in peak oxygen consumption (VO_2) (mL/kg/min) from pre- to post-intervention. Bars represent individual patient data, and the box plot represents group data. The *P*-value is obtained from unpaired *t*-test comparing changes in peak VO_2 between high-intensity interval training (HIIT) and moderate-intensity continuous exercise (MICE).

One patient from the HIIT group showed signs of adverse cardiac remodelling after randomisation, and hence was prescribed only MICE. Correspondingly, this patient was re-allocated to the MICE group for the per-protocol analysis. All other patients in the HIIT group performed at least as many HIIT sessions as MICE sessions during the intervention period. Per-protocol analysis did not differ from intention-to-treat analysis in terms of change in peak VO_2.

We found no sustained ventricular tachycardia or ventricular fibrillation in either group during the intervention period.

3.3. Training characteristics

The average training workload (predicted population value of the linear mixed model) was lower with MICE than HIIT at the beginning of the intervention phase but increased significantly more during the intervention phase ($P < 0.001$ for interaction), from 48% to 69%. In comparison, average workload of HIIT sessions increased from 55% to 61% (Fig. 2a). Relative HR intensity increased from 80% to 86% in the MICE group but decreased slightly, from 86% to 84%, in HIIT sessions ($P < 0.001$ for interaction) (Fig. 2b). The perceived exertion in HIIT sessions decreased slightly, from Borg score 14.8 to 14.4, but increased in the MICE group, from Borg score 12.7 to 13.6, during the intervention phase (Fig. 2c). Training characteristics summarised over the whole intervention phase are in Table 3. The average training session duration as well as energy expenditure (metabolic equivalents of task) did not differ between HIIT and MICE groups.

3.4. Association of training characteristics and cardiorespiratory response

Greater improvement in peak VO_2 (mL/kg/min) was associated with higher training workload [log(watt/kg)] (β = 5.79, 95% confidence interval 0.78–10.8) and greater number of training sessions (β = 0.21, 95% confidence interval 0.03–0.39) independent of training modality (HIIT sessions as a percentage of total training sessions) or baseline peak VO_2 (appendix Table A.1).

4. Discussion

In the present randomised controlled trial including 69 patients starting CR early after STEMI, HIIT was feasible but not superior to MICE in improving peak VO_2 or any other exercise testing parameters, such as VE/VCO_2 slope or VT_1. Self-tailored exercise guidance according to patients' perceived exertion was feasible in HIIT and MICE groups and resulted in exercise regimes of comparable energy expenditure. Because of the chosen same session duration, HIIT was not more time efficient than MICE in these patients. Therefore, HIIT differed from MICE only in that it was more strenuous.

4.1. Cardiorespiratory response

Our study agrees with results of previous studies comparing isocaloric HIIT and MICE protocols [19–22], as classified by the meta-analysis of Gomes-Neto et al. [7]. We did not find any significant differences between HIIT and MICE in terms of change in peak VO_2. In fact, we even observed a trend toward greater improvement with MICE than HIIT (+3.2 vs. +1.9 mL/kg/min, $P = 0.104$; Cohen's d −0.4). Similar results were found with the per-protocol analysis. The trend toward greater improvement in peak VO_2 with MICE is illustrated in Fig. 1. Different arbitrary cut-offs have been suggested (+1 mL/kg/min, +2.5 mL/kg/min, +6%, technical error) to classify patients as responders or non-responders to exercise training [23]. Fig. 1 shows a tendency of more responders in the MICE than HIIT group; depending on the cut-off, this difference became significant. Comparable results were reported by Trachsel et al. [12], who found a greater proportion of peak VO_2 responders with MICE than HIIT.

The largest study to date comparing HIIT with MICE in patients with coronary artery disease (58% after acute myocardial infarction) was the SAINTEX-CAD study, including 200 patients [9,24]. The authors found comparable peak VO_2 improvements in patients performing MICE or HIIT (both +20.3%) over an intervention period of 12 weeks (36 sessions). In comparison, we

Table 2
Cardiorespiratory response to HIIT versus MICE.

	HIIT $n = 35$			MICE $n = 34$			Delta (post–pre-intervention)			
	Pre-intervention	Post-intervention	P[a]	Pre-intervention	Post-intervention	P[a]	HIIT	MICE	P[b]	Cohen's d
Peak VO_2 (mL/kg/min)	26.5 (24.4–31.1)	29.6 (25.2–32.2)	< 0.001	27.6 (23.9–31.6)	29.9 (26.1–34.9)	< 0.001	1.9 (3.0)	3.2 (3.8)	0.104	−0.4
RER	1.1 (1.1–1.2)	1.2 (1.1–1.2)	0.884	1.1 (1.1–1.2)	1.1 (1.1–1.2)	0.983	0.0 (0.0)	0.0 (0.1)	0.956	0.0
VE/VCO_2 slope	32.9 (29.7–35.1)	30 (29–33.9)	0.001	31.5 (27.9–33.9)	30 (27.2–32)	0.090	−1.9 (3.0)	−1.0 (3.3)	0.219	−0.3
$\Delta VO_2/\Delta W$ trajectory	8.9 (8.2–9.6)	9.1 (8.5–10)	0.243	9.4 (8.8–9.9)	9.7 (9.1–10.4)	0.244	0.2 (1.0)	0.2 (0.9)	0.980	0.0
VT_1 (W)	72 (58–99)	78 (65–105)	0.038	84 (64–112)	88.5 (69–116)	0.034	6.6 (20.8)	7.4 (22.5)	0.881	0.0
VT_2 (W)	150 (127–183)	167 (151–210)	< 0.001	165 (136–194)	182.5 (145–223)	< 0.001	19.1 (25.6)	16.6 (26.9)	0.703	0.1
Peak HR (bpm)	139 (127–154)	147 (137–158)	< 0.001	142 (128–152)	151.5 (133–161)	< 0.001	6.0 (9.1)	8.1 (9.4)	0.352	−0.2

CR: cardiac rehabilitation; VO_2: oxygen consumption; RER: respiratory exchange ratio; VE: ventilation; CO_2: carbon dioxide output; W: Watt; VT: ventilatory threshold; HR: heart rate. Data are median (interquartile range) or mean (SD).

[a] Wilcoxon signed rank test for within-group differences.

[b] Unpaired *t*-test for between-group differences.

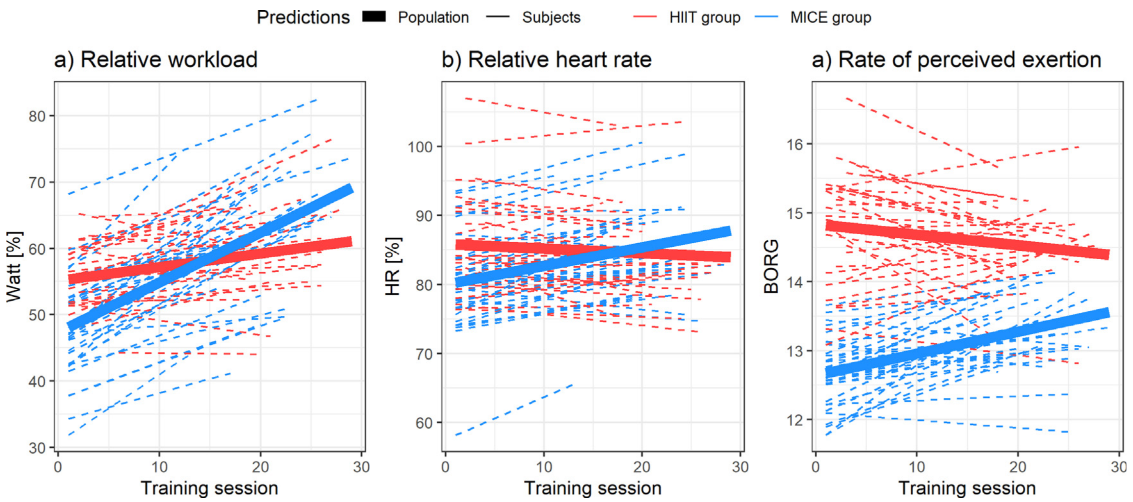

Fig. 2. Training intensity over the intervention period. The interaction plot shows the predicted value of the training intensity over intervention period averaged by group (Population HIIT versus MICE) as well as the predicted value of each patient individually (Subjects) based on the linear mixed model. Training heart rate and workload are shown relatively to peak values achieved at pre-intervention exercise testing and were averaged over the entire training session. Therefore, HIIT intensity includes high- and low-intensity intervals. HIIT: high intensity interval training; MICE: moderate continuous intensity exercise; HR: heart rate.

Table 3
Training characteristics of HIIT and MICE groups according to intention-to-treat analysis.

	HIIT $n = 35$	MICE $n = 34$	*P*-value[a]
Number of sessions	20 (18–24)	22 (18–25)	0.55
HIIT modality in %	76 (68–83)	0 (0–0)	< 0.001
Intervention period (weeks)	5.7 (3.0–7.6)	7.3 (3.1–8.9)	0.26
Session duration	38.0 (37.6–38.0)	38.0 (38.0–38.0)	0.19
Workload (W/kg)	1.2 (1.1–1.5) 1.2 (1.1–1.6)[b]	1.2 (1.0–1.4)	0.93
Workload (% of peak)	56 (52–60) 58 (53–62)[b]	56 (52–59)	0.86
Peak training workload (W/kg)	1.53 (1.38–1.88) 1.66 (1.54–2.11)[b]	1.24 (1.03–1.45)	< 0.001
METs	5.1 (4.6–5.9) 5.3 (4.8–6.2)[b]	5.2 (4.4–5.9)	0.93
HR	115 (108–128) 119 (109–130)[b]	114 (106–127)	0.79
HR (% of peak)	82 (79–88) 84 (81–90)[b]	81 (79–86)	0.86
Peak training HR	139 (127–149) 146 (131–156)[b]	130 (119–140)	0.038
RPE (Borg score)	14.3 (13.7–14.6) 14.7 (14.2–15.2)[b]	12.9 (12.8–13.2)	< 0.001

W: watt; HIIT: high-intensity interval training; MICE: moderate intensity continuous exercise; METs: metabolic equivalents of task; HR: heart rate; RPE: rate of perceived exertion (Borg scale 6–20). Data are median (interquartile range).

[a] *P*-value from Wilcoxon rank-sum test.

[b] Summary including only HIIT sessions.

observed improvements of only 12% with MICE and 8% with HIIT. The greater improvements observed in the SAINTEX-CAD study compared to our improvements may be explained in part by the shorter intervention period in our study. When we calculate the change in peak VO_2 over the course of CR (12 weeks) including the 3-week run-in phase, the overall improvements equalled a mean (SD) of 17% [16]. In addition, the SAINTEX-CAD study included 60 patients after coronary artery bypass graft (CABG), whereas our patients received only primary PCI. CABG patients exhibited greater CRF improvements than patients after PCI as shown by the SAINTEX-CAD study [25] and other studies [26,27].

A recent meta-analysis compared the effect of HIIT and MICE on secondary exercise testing parameters, such as the first VT_1 or the VE/VCO_2 slope or peak HR in patients with coronary artery disease and chronic heart failure [28]. The authors found a significantly greater increase in VT_1 (mL/kg/min) with HIIT than MICE in heart failure patients but only a small and non-significant trend for coronary artery disease patients (mean effect size 0.73, $P = 0.14$). In addition, they found a significantly greater increase in peak HR (bpm) with HIIT for coronary artery disease patients (mean effect size 5.11, $P = 002$), but VE to VCO_2 slope improvements were comparable between training modalities (mean effect size 0.5, $P = 0.27$) [28]. In comparison, we found comparable changes in VT1, peak HR or VE to VCO_2 slope between our HIIT and MICE groups (Table 2).

4.2. Training characteristics

Most previous studies prescribed MICE sessions with longer exercise duration than the HIIT sessions to achieve isocaloric exercise regimes. The SAINTEX-CAD study planned to use the same protocols as in the study by Wisloff et al. [29], namely a 47-min

MICE protocol at 70% to 75% peak HR and a 4 × 4-min HIIT at 90% to 95% peak HR in high intervals. Wisloff et al. [9] did not adjust the initial exercise intensity over the course of the intervention, but the SAINTEX-CAD study added an additional exercise test after 6 weeks of intervention to re-assess peak HR and re-tune the training workload correspondingly.

In contrast, we investigated a clinically more feasible procedure of using only CPET parameters for the initial setting of exercise intensity, but adjusted these intensities weekly based on perceived exertion. Close monitoring of the training intensity in the SAINTEX-CAD study showed that MICE can be performed at higher intensities than 70% to 75% peak HR. From these findings and again clinical feasibility, we chose the same session duration for HIIT and MICE in order to achieve isocaloric exercise regimes and to validly compare efficiency between modalities.

MICE intensity increased in our study, from Borg score 12.7 to 13.6, accompanied by an increase in workload (48–69% peak watts) and HR (80–86% peak HR) (Fig. 2). Therefore, we achieved similar exercise MICE intensities as the SAINTEX-CAD study (66–72% peak watts) by simply guiding patients upon perceived exertion.

In contrast, perceived exertion and relative HR decreased slightly after HIIT sessions, despite an increase in relative training workload (based on the peak watts achieved at pre-intervention exercise testing). This finding suggests that the increase in HIIT workload was not sufficient in relation to the increase in CRF level and peak HR during the intervention; probably because some patients did not tolerate a high level of perceived exertion (Borg score > 15). This finding agrees with the SAINTEX-CAD study, which reported that many patients did not tolerate high intensities or were not able to reach the target of 90% to 95% peak HR. The variance in relative HR intensity was relatively large as compared with the variance in relative workload and Borg score (Fig. 2). This finding may be due to adaptions in chronotropic response to exercise during the intervention phase. Given the low variance in relative workload and perceived exertion and because we achieved appropriate training intensities in our study, we recommend guiding patients by Borg score and relative workload rather than relative HR.

4.3. Association of training characteristics and cardiorespiratory response

We found a greater improvement in peak VO_2 with increasing training intensity, independent of training modality, number of sessions and CRF level at pre-intervention. A 10% higher training workload was related to a 0.55-mL/kg/min greater increase in peak VO_2 (appendix Table A.1). Our results agree with a recent meta-analysis finding significant but clinically irrelevant greater improvements of peak VO_2 in studies using exercise interventions of vigorous intensities than studies using moderate to vigorous exercise intensities [30].

4.4. Clinical perspective

Given the results of our study, we support the recommendations of Conraads et al. [9] that if a higher intensity can be sustained with MICE (i.e., greater than 70–75% peak HR, Borg score 12), the workload should be adjusted to achieve the most optimal improvements. In clinical practice, we recommend increasing the workload of MICE sessions toward a Borg score 13–14 already at an early stage of CR (i.e., after the first week) if tolerated by patients.

Not all patients tolerated the high level of exertion with HIIT, as shown by the rather low mean Borg score (14.7 instead of the target ≥ 15). However, self-tailored intensity guidance was well accepted by patients as indicated by the low dropout rate (only one patient) and the high compliance (median of attended sessions during intervention phase 81% with MICE, 75% with HIIT). One of the main purposes of CR supervised exercise training should be to restore patients' confidence in performing exercise on their own to improve long-term adherence [31]. Therefore, patients should be allowed to choose their preferred training modality as they wish because we did not find MICE or HIIT superior or more efficient. Self-chosen training modality and intensity may increase patients' intrinsic motivation to exercise and hence may help them maintain a physically active lifestyle [32].

4.5. Strengths

The randomised study design with a run-in period, which facilitated the optimisation of guideline-directed medical therapy and provided a familiarisation test (baseline testing), was an obvious strength of our study. Another strength was the complete monitoring of workload, HR and heart rhythm during all training sessions. This monitoring permitted a detailed and reliable evaluation of the training progression. Furthermore, the choice of equal-duration HIIT and MICE sessions allowed a valid comparison of training modality effectiveness in terms of energy consumption and improvement in peak VO_2. The training was implemented in a clinical setting and purposely designed with the intention of clinical feasibility, so our conclusions can directly be applied to exercise training in CR.

4.6. Limitations

We intended to achieve comparable training intensity increases in both groups by encouraging all patients to train at the maximal load possible over the respective training duration (four 4-min bouts or one 30-min bout). As compared with previous studies, MICE training intensity was relatively low at the beginning of our intervention period. However, we set the initial workload at patients' individual first VTs according to guidelines and achieved at the end, isocaloric exercise regimes for both groups because of weekly adjustments in intensity. Isocaloricity between training modalities was assessed by HR and workload analyses, but not gas analyses (i.e., measuring VO_2).

5. Conclusions

We present 2 clinically feasible training protocols with HIIT and MICE, with the same session duration and energy expenditure, guided by patients' perceived exertion. HIIT was perceived as more strenuous, but was not superior to MICE in improving peak VO_2 or any other parameter of cardiorespiratory response in patients undergoing CR early after STEMI. The average training intensity did not differ between the 2 training modalities. Independent of training modality, higher average training intensity was related to greater improvements in peak VO_2. Therefore, the training modality can be according to patient preference; however, the training intensity should regularly be adjusted to maintain patients' perceived exertion during the CR.

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Disclosure of interest

The authors declare that they have no competing interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.rehab.2021.101490.

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