Cardiorespiratory Responses During High-Intensity Interval Training Prescribed by Rating of Perceived Exertion in Patients After Myocardial Infarction Enrolled in Early Outpatient Cardiac Rehabilitation

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Objective: We aimed to determine the cardiorespiratory responses during, and adaptations to, high-intensity interval training (HIIT) prescribed using ratings of perceived exertion (RPE) in patients after myocardial infarction (MI) during early outpatient cardiac rehabilitation (CR).

Methods: We prospectively recruited 29 MI patients after percutaneous coronary intervention who began CR within 2 weeks after hospital discharge. Eleven patients (seven men; four women; age: 61 ± 11 yrs) who completed ≥24 supervised HIIT sessions with metabolic gas exchange measured during HIIT once weekly for 8 weeks and performed pre- and post- CR cardiopulmonary exercise tests were included in the study. Each HIIT session consisted of 5–8 high-intensity intervals [HIIs, 1-min RPE 14–17 (Borg 6–20 scale)] and low-intensity intervals (LIIs, 4-min RPE < 12). Metabolic gas exchange, heart rate (HR), and blood pressure during HIIT were measured.

Results: The mean oxygen uptake (\(\dot{V}O_2\)) during HIIs across 88 sessions of HIITs [91 (14)% of \(\dot{V}O_{2peak}\), median (interquartile range, IQR)] was significantly higher than the lower limit of target \(\dot{V}O_2\) zone (75% of \(\dot{V}O_{2peak}\) recommended for the HIIT \(p < 0.001\)). Exercise intensity during RPE-prescribed HIITs, determined as %\(\dot{V}O_{2peak}\), was highly repeatable with intra-class correlations of 0.95 (95% CI 0.86–0.99, \(p < 0.001\)). For cardiorespiratory adaptations from the first to the last session of HIIT, treadmill speed, treadmill grade, treadmill power, \(\dot{V}O_{2HIIT}\), %\(\dot{V}O_{2peak}\), and \(V_E\) during HIIs were increased (all \(p < 0.05\)), while no difference was found for HR, %HR\(\dot{V}O_{2peak}\) and systolic blood pressure (all \(p > 0.05\)). \(\dot{V}O_{2peak}\) increased by an average of 9% from pre-CR to post-CR. No adverse events occurred.

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**INTRODUCTION**

Exercise-based cardiac rehabilitation (CR) is a secondary prevention tool used worldwide to improve physical function and prognosis in patients after myocardial infarction (MI) (1, 2). High-intensity interval training (HIIT) has recently emerged as an alternative or adjunct strategy to traditional moderate-intensity continuous training (3). HIIT involves alternating periods ranging from a few seconds to 4 min of higher intensity exercise [high-intensity intervals, HIIs: 85 to 95% of peak heart rate (HR) corresponding to 75 to 85% of peak oxygen uptake (\(\dot{V}O_2\))] with 1 to 4 min of lower intensity exercise (low-intensity intervals, LIIs: <60% of peak HR) during an exercise session (4). HIIT has been shown to result in similar or greater improvements in aerobic capacity and other health outcomes compared to moderate-intensity continuous training (4). However, the relationships between patient safety, perception of effort, and cardiorespiratory responses and adaptations during HIIT sessions in patients after MI have not been reported. Gaps in our understanding of the relationship between effort perception and cardiorespiratory responses limit our ability to provide optimal guidance for prescription, implementation, and safety of HIIT in CR.

The most common metrics to prescribe aerobic exercise intensity during CR include \(\dot{V}O_2\), HR, and their derivative indicators such as percentages of predicted/peak HR and \(\dot{V}O_2\); reserves of HR and \(\dot{V}O_2\); and metabolic equivalents (METs) (5). During outpatient CR, continuous monitoring of \(\dot{V}O_2\) is impractical and, while continuous HR monitoring is feasible, the high number of MI patients prescribed rate modulating pharmacotherapy (e.g., beta-blockers) makes HR a highly variable metric for exercise prescription (6). Furthermore, many patients who begin CR have not performed a graded exercise test, and peak HR has not been determined (7). For these patients, prescribing exercise intensity using predicted peak HR as a guide is imprecise.

Ratings of perceived exertion (RPE) are a practical alternative for prescribing exercise intensity and facilitates relative patient autonomy and progression of exercise intensity during CR (4, 8). Our CR program has used RPE, accompanied by continuous HR and periodic blood pressure monitoring, to prescribe exercise intensity for several decades (9, 10). Our CR staff are experienced in instructing patients on the proper use of the 6–20 Borg RPE scale. Patients are carefully instructed on the use of RPE as part of their baseline graded exercise test and during their first supervised exercise session in CR (10). We have previously demonstrated that RPE-prescribed HIIT improves body composition, characteristics of metabolic syndrome, and cardiorespiratory fitness in patients after MI (11, 12). However, the cardiorespiratory responses directly measured with metabolic gas exchange during, and adaptations to HIIT across several exercise sessions in MI patients have not been previously reported.

Therefore, this study aimed to determine the cardiorespiratory responses and adaptations during HIIT exercise sessions prescribed using RPE in patients with MI who participate in early outpatient CR. We hypothesized that: (1) Using RPE to prescribe exercise intensity will effectively elicit a desired HIIT cardiorespiratory response, and (2) RPE-based HIIT will result in an increasing \(\dot{V}O_2\) during exercise training across exercise sessions without increased perception of effort or excessive increases in heart rate and blood pressure.

**METHODS**

Participants and Study Design

This prospective observational study initially recruited 29 consecutive MI patients with percutaneous coronary intervention who were referred to outpatient CR within 2 weeks of discharge from inpatient care (our traditional time to begin CR) at Mayo Clinic, Rochester, MN, USA from February 1st, 2017, to September 30th, 2018. Thirteen patients who did not perform a post-CR cardiopulmonary exercise test (CPET), two who refused to wear a metabolic gas collector/mask during exercise training, and three who changed their exercise type from treadmill to recumbent stationary cycle were excluded. Eleven patients [seven men, four women; age: 62 [11] yrs, median (interquartile range, IQR); BMI: 33.0 (7.2) kg/m\(^2\); the interval between hospital dismissal and the start of CR: 14 [4] days] who completed ≥24 sessions of supervised HIIT on a treadmill with metabolic gas exchange measured during HIIT once per week for eight consecutive weeks and who performed pre and post CR CPET were included. Cardiovascular medications were unchanged during the study period. Participants were free of angina at low exercise intensities, symptomatic arrhythmias, symptomatic heart valve disease, musculoskeletal limitations to exercise training, and significant frailty or weakness (i.e., inability to engage in HIIT). Study procedures were approved by the Institutional Review Board for Research at Mayo Clinic (Rochester, MN, USA; 15-007977) and conformed to the standards set forth by the Declaration of Helsinki. Patients were informed regarding testing procedures and potential risks of participation before providing written, informed consent.
High-Intensity Interval Training Intervention

Our protocol for HIIT has been routinely applied in CR for more than a decade and was described previously (4, 13). It was designed for routine use by patients who begin CR within 2 weeks of hospital dismissal and start HIIT after 1 week of moderate intensity aerobic exercise. Components of the exercise prescription were Frequency: set as three sessions per week for eight consecutive weeks. Intensity: HIIs lasting 1 min at an RPE 14–17 [Borg 6–20 RPE scale] followed by 4-min LIIs at RPE < 12, treadmill speed and grade were self-selected by patients themselves to achieve the target RPEs, and the RPE scores were obtained at the end of each interval. Time: a treadmill was used under continuous observation by clinical exercise physiologists. Type: HIIT was used in accordance with observation by clinical exercise physiologists. Energy expenditure was calculated as the product of VO₂ and breathing frequency (f brisk). The respiratory exchange ratio (RER) was calculated as the ratio of VCO₂ to VO₂. VO₂HIIT and VO₂LII were calculated as the highest average VO₂ of three consecutive breaths during the HIIs and LIIs (i.e., the highest single-breath VO₂ value and the preceding and following breaths), respectively. Other metabolic gas exchange values (i.e., RER, VCO₂, V E, V E/VCO₂) were determined by averaging values of the final 15-s of HIIT and LIIT, respectively, of each HIIT session.

Heart Rate and Blood Pressure Measurements

During each HIIT session, HR and rhythm were continuously measured via electrocardiogram (ECG) telemetry (Q-Tel RMS, Welch Allyn, New York, USA). The HRs at the end of HIIs and LIIs were recorded. Systolic (SBP) and diastolic (DBP) blood pressures were measured via manual sphygmomanometer by clinical exercise physiologists at rest and during the final 15-s of HIIT and LIIT, respectively, of each HIIT session.

Cardiopulmonary Exercise Testing

CPETs were conducted by clinical exercise physiologists with cardiologist oversight at the beginning and end of CR. The exercise modality and end-test criteria were consistent between pre-and post-CR tests for all patients. Our operation and interpretation procedures for CPET have been described previously (13).

Metabolic Gas Exchange Measurements During HIIT

Breath-by-breath VO₂, carbon dioxide production (VCO₂), breathing frequency (f brisk), and tidal volume (V T) were measured continuously using a standard cardiorespiratory diagnostic system (Ultima Series 6 CPX™, MGC Diagnostics Corporation, Minnesota, USA) during an RPE-prescribed HIIT session once each week. Continuous cardiorespiratory measurements were performed during a total of 88 HIIT exercise sessions. The cardiorespiratory diagnostic system was calibrated for flow and gas concentrations before each session according to the manufacturer’s recommendations using a 3-liter syringe and calibration gases of known concentration. To minimize the influence of subsidiary work, and therefore VO₂ and VCO₂, patients were instructed to refrain from excessive stabilization (i.e., using handrails) during all exercise sessions. Minute V E was calculated as the product of V T and breathing frequency (f brisk). The respiratory exchange ratio (RER) was calculated as
 Patients' demographic and clinical characteristics are shown in Table 1. Among the 11 patients, four suffered ST-segment elevation MI, and seven suffered non-ST-segment elevation MI; two patients underwent double-vessel PCI, and nine performed single-vessel PCI. The interval between the hospital dismissal and the start of outpatient CR was 14 [4] (median [IQR]) days. Pre CR echocardiograms demonstrated normal left ventricular systolic function with left ventricular ejection fractions of 56% [6%] [median [IQR]]. Echocardiography was not repeated after CR.

Exercise workload and cardiorespiratory responses to RPE-prescribed HIIT are presented in Figure 1 and Table 2. The highest mean \( \dot{V}O_2 \) during HIIs of 88 sessions of HIITs [91 (14)% of \( \dot{V}O_2^{peak} \), median (IQR)] was significantly higher than for the target \( \dot{V}O_2 \) (75% of \( \dot{V}O_2^{peak} \)) recommended for HIIs (\( p < 0.001 \)). The ICC of exercise intensity, \( %\dot{V}O_2^{peak} \), between the RPE-prescribed HIIT sessions was 0.95 (95% CI, 0.86 to 0.99, \( p < 0.001 \)). The values of treadmill speed, treadmill grade, power, \( \dot{V}O_2 \), \( %\dot{V}O_2^{peak} \), HR, \( %HR^{peak} \), SBP, VE, VT and \( f_B \) in the HIIs were significantly greater than those in the LIIs during each exercise session (all \( p < 0.01 \)), which was consistent with the values of RPE during the HIIs vs. during the LIIs [15 (2) vs. 11 (2), median (IQR), \( p < 0.001 \)]. A difference of 9–11% between \( %HR^{peak} \) and \( %\dot{V}O_2^{peak} \) was present for the LIIs and is consistent with conventional wisdom as reported in the literature (16) that \( %HR^{peak} \) is greater than \( %\dot{V}O_2^{peak} \) at a constant workrate. However, for the HIIs, \( %HR^{peak} \) was not higher than \( %\dot{V}O_2^{peak} \). For the HIIs of the first HIIT session, median \( %HR^{peak} \) and \( %\dot{V}O_2^{peak} \) were identical (88%), while for the final session \( %\dot{V}O_2^{peak} \) was greater than \( %HR^{peak} \) (97% vs. 90%) during HIIs. No differences were found in DBP and RER between HIIs and LIIs (all \( p > 0.05 \)).

Comparisons of the first vs. the last exercise sessions to assess cardiorespiratory adaptations during RPE-prescribed HIIT are presented in Table 2 and Figure 2. No differences were found for RPE, HR, \( %HR^{peak} \), \( VT \), \( f_B \), VE/\( CO_2 \), SBP and DBP (all \( p > 0.05 \)) between the first and last session for both HIIs and LIIs. However, treadmill speed, treadmill grade, power, \( \dot{V}O_2 \), \( %\dot{V}O_2^{peak} \), EE per minute and per session and VE increased significantly from the first to the last session for the HIIs (all \( p < 0.05 \)), while no changes were detected for the LIIs (all \( p > 0.05 \)). No adverse events related to exercise training occurred during the study.

Body mass significantly decreased [98.1 (22.6) kg vs. 95.0 (11.0) kg, median (IQR)] with a mean decrease of 3.1 [95% CI, 0.5 to 5.7] kg (\( p = 0.02 \)). Peak cardiorespiratory variables were determined via CPETs at the beginning and end of CR. \( \dot{V}O_2^{peak} \) independent of body mass was not significantly different from pre- to post-CR [2.4 (0.6) L min\(^{-1}\) vs. 2.5 (0.7) L min\(^{-1}\),...
FIGURE 1 | Cardiorespiratory responses and treadmill workload during RPE-prescribed HIIT. (A), a representative patient’s oxygen uptake (\(\dot{V}O_2\)), heart rate (HR), systolic (SBP), and diastolic (DBP) blood pressure responses during a HIIT session. The average \(\dot{V}O_2\) (B), %\(\dot{V}O_2\)peak (C), HR (D), %HRpeak (E), treadmill speed (F), and treadmill grade (G) responses to the high- and low-intensity intervals over time. FS is the first exercise session, LS is the last exercise session. Repeated-measures ANOVA was used for all assessments. Data were expressed as mean ± upper limit of 95% confidence interval for high-intensity intervals and mean–low limit of 95% confidence interval for low-intensity intervals in (B–G). *Significantly higher than low-intensity interval, \(p < 0.001\).
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TABLE 2 | Treadmill workload and cardiorespiratory variables during high- and low-intensity intervals.

|                      | High-intensity intervals | Low-intensity intervals |
|----------------------|--------------------------|-------------------------|
|                      | First session            | Last session            | First session            | Last session            |
| Treadmill speed (km per hour) | 5.9 [2.4] | 6.2 [2.1]† | 4.9 [1.1] | 4.9 [1.5] |
| Treadmill grade (%)     | 8.4 [2.7] | 10.3 [5.8]† | 4.9 [3.2] | 5.1 [2.9]† |
| Treadmill power (Watts) | 807 [573] | 1039 [707]† | 390 [211] | 407 [196] |
| RPE                   | 14 [2]* | 15 [2]* | 11 [1] | 11 [2] |
| VO₂ (ml·kg⁻¹·min⁻¹)   | 21.1 [2.8]* | 23.3 [3.0]† | 14.6 [4.6] | 14.8 [2.5] |
| %VO₂peak             | 88 [11]* | 97 [17]† | 61 [15] | 61 [11] |
| EE per minute (kcal·min⁻¹) | 10.4 [1.5]* | 11.4 [2.0]† | 7.1 [2.0] | 7.2 [1.3] |
| EE per 30-min session (kcal)‡ | 62.0 [8.8]* | 68.5 [11.3]† | 170.4 [45.8] | 171.7 [28.6] |
| RER                   | 0.95 [0.06] | 0.98 [0.07] | 0.94 [0.07] | 0.93 [0.08] |
| HR (bpm)              | 124 [23]* | 126 [26]* | 99 [17] | 101 [23] |
| %HRpeak               | 88 [8]*  | 90 [14]* | 70 [8]  | 72 [11]  |
| SBP (mmHg)            | 156 [18]* | 148 [26]* | 136 [16] | 137 [16] |
| DBP (mmHg)            | 66 [8]  | 61 [7]  | 64 [14] | 61 [6]  |
| Vₑ (L·min⁻¹)          | 59 [22]* | 65 [24]† | 40 [12] | 42 [16] |
| Vₒ (L)                | 1.8 [0.6]* | 1.9 [0.3]* | 1.4 [0.7] | 1.4 [0.8] |
| fᵣ (breaths·min⁻¹)    | 34 [8]* | 36 [6]* | 30 [5] | 30 [6] |
| Vₑ/VO₂                | 32 [5] | 33 [6]* | 30 [3] | 31 [4] |

Data presented as median [interquartile range, IQR]. RPE, rating of perceived exertion; HR, heart rate; VO₂, oxygen uptake; EE, energy expenditure; VCO₂, carbon dioxide production; RER, respiratory exchange ratio; SBP, systolic blood pressure; DBP, diastolic blood pressure; Vₑ, ventilation; Vₒ, tidal volume; fᵣ, breathing frequency; VCO₂, carbon dioxide output.

*Significantly greater than the low-intensity interval (p < 0.05). †Significantly different compared to first session (p < 0.05). Repeated-measures ANOVA was used for all evaluations.

median (IQR) with a mean difference of 0.1 [95% CI, −0.1 to 0.3] L·min⁻¹ (p = 0.21). However, VO₂peak dependent on body mass increased in nine of 11 subjects. VO₂peak relative to body mass increased [24.0 (6.5) ml·kg⁻¹·min⁻¹ vs. 26.1 (8.0) ml·kg⁻¹·min⁻¹, median (IQR)] with a mean increase of 1.9 [95% CI, 1.0 to 3.8] ml·kg⁻¹·min⁻¹. In addition, VO₂peak as a percentage of age, sex, and anthropometrically predicted values significantly increased from pre- to post-CR [95 (28)% vs. 100 (25%), median (IQR)] with a mean difference of 5 [95% CI, 1 to 10] % (p = 0.04). No additional significant differences were detected in peak exercise cardiorespiratory variables pre- and post-CR.

DISCUSSION

Our study provided unique metabolic gas exchange data obtained during HIIT sessions and established the efficacy of using self-selected exercise intensity based on a target RPE range as a safe and practical method of prescribing HIIT for patients after MI during early outpatient CR. Our method of prescribing 5–8 one minute HIIs with RPE 14–17 interspersed with 4-min LIIs (RPE <12) during a 40-min session of training was effective in eliciting a VO₂ of >95% of pre-training VO₂peak during the final HIIT session.

We demonstrated that over 8 weeks of HIIT, patients were able to exercise at a higher VO₂ without a concurrent increase in RPE or excessive HR and blood pressure response. Patients were able to increase the rate of energy expenditure during the HIIT sessions without an increased perception of effort which is potentially clinically important for decreasing body fat stores with the attendant metabolic health benefits.

Aamot et al. (17) reported that using RPE to prescribe exercise intensity during HIIT resulted in a lower than expected intensity based on %HRpeak (detected 82% HRpeak vs expected 85% HRpeak) during HIIs (18) in patients with coronary artery disease in which 80% patients regularly used beta-blockers. In our study, we utilized both %VO₂peak (gold standard to reflect exercise intensity) and %HRpeak to assess the validity of RPE-prescribed HIIT. Both %VO₂peak and %HRpeak achieved during HIIs were more than the required levels to meet the designation of high-intensity (75% VO₂peak and 85% HRpeak) for all sessions. VO₂HII increased from 88% of VO₂peak in the first HIIT session to 97% of VO₂peak in the last session.

Patient progression in exercise training dose without the sacrifice of safety is a core tenet of cardiac rehabilitation. We observed that despite an increased VO₂HII across exercise sessions, no significant increases in HR, DBP, SBP, or perception of effort were found during RPE-prescribed HIIT. The underlying reasons for this remain unclear. VO₂ is an integrated indicator of the systems that transport and utilize oxygen, including the respiratory (oxygen uptake from the atmosphere), heart (oxygen transport), peripheral vasculature (oxygen transport, tissue perfusion, tissue diffusion), and skeletal muscle (oxygen extraction and utilization) (19, 20). In the present study, HR, O₂ pulse [a surrogate for stroke volume (21)],
FIGURE 2 | Cardiorespiratory and treadmill workload adaptations to RPE-prescribed HIIT. (A,B) Present comparisons of treadmill speed, treadmill grade, and power output between the first and last HIIT sessions during high- and low-intensity intervals, respectively. (C,D) Present comparisons of heart rate (HR), systolic (SBP), and diastolic (DBP) blood pressure between the first and last HIIT sessions. (E,F) Present comparisons of oxygen uptake (\(\dot{V}O_2\)), energy expenditure (EE) per minute, and per session. (G,F) Present the changes in the relationship of %\(\dot{V}O_2\)peak and %HRpeak between the first and last HIIT sessions during high- and low-intensity intervals, respectively. HIIT is high-intensity interval. LII is low-intensity interval. Repeated-measures ANOVA was used for all assessments. Data were expressed as mean difference [95% confidence interval].
V̇E/V̇CO₂ [an indicator of ventilatory efficiency (22)], RER (a variable to reflect degree of exertion) were not significantly changed during 8 weeks of RPE-prescribed HIIT sessions, which suggests that peripheral vasculature and skeletal muscle adaptations may have contributed to the increase in VO₂HIIT across sessions. This hypothesis is supported by our pre-clinical studies in mice that demonstrated regular exercise improved the structure and function of the aortic endothelium (23) and mitochondria in skeletal muscle (24, 25). However, additional research on the mechanisms responsible for these observations is needed.

In order to evaluate the cardiopulmonary adaptations during 8 weeks of HIIT sessions, we studied the relationship between %VO₂peak and %HRpeak during the HIIT sessions. During LIIs, the values for %VO₂peak were 61% for both first and last sessions, and the corresponding %HRpeak values were 70 and 72%, respectively. This is consistent with previous reports, where %HRpeak was ∼10% higher than %VO₂peak (26). However, during HIIs, the %VO₂peak was 88% for the first session and 97% for the last session, while the corresponding %HRpeak remained ∼90% for both sessions. This is a clear disconnect from the assumed relationship of %VO₂peak and %HRpeak. Though it has been assumed that the %HRpeak-%VO₂peak relationship holds during HIIT, the expected linear relationship between %VO₂peak and %HRpeak was established during graded exercise testing with cardiopulmonary measurements and may differ during HIIT. Further studies are needed to elucidate the mechanisms responsible for these observations.

The effect of HIIT on cardiopulmonary fitness in patients with coronary artery disease has been reported, with mean VO₂peak increases ranging from 11 to 25% (4). A recent study from our group demonstrated that RPE-prescribed HIIT during early outpatient CR significantly improved VO₂peak by 18% (pre-CR vs. post-CR, 23.0 ± 6.3 vs. 28.0 ± 5.9; mean change 5.0 ± 2.5 ml·kg⁻¹·min⁻¹) in 42 MI patients (12). In the present study, HIIT improved cardiopulmonary fitness (i.e., VO₂peak) in 9 of 11 (82%) patients, with a mean improvement of only 9%. Possibly related to the small sample size in the current study, statistically significant changes were found in VO₂peak related to body mass and % predicted VO₂peak, but not in VO₂peak independent of body mass. The percentage of non-improvement (non-responder: failure to improve VO₂peak) in CR was 18% in the present study, which is consistent with the data reported in the study by Savage et al. (27) in which 81 out of 385 patients (21%) failed to improve VO₂peak during outpatient CR using moderate-intensity continuous training. Our finding of non-improvement in VO₂peak with HIIT in some patients is a novel finding. Non-improvement in CR may be associated with exercise intensity, comorbidity score, self-reported physical function, diabetes, and baseline VO₂peak (27). In the present study, mean baseline VO₂peak was normal and may be a factor in our findings of a less than typical increase in VO₂peak and identification of non-responders with HIIT.

The present study did not assess change in left ventricular systolic or diastolic function resulting from HIIT. The literature suggested that HIIT is an effective strategy to attenuate left ventricular remodeling in clinically stable heart failure patients with reduced ejection fraction (28). The effect of HIIT on left ventricular function in heart failure with preserved ejection fraction is controversial (29), while the positive effects of HIIT on exercise capacity and quality of life in patients with MI and heart failure have been reported (4). The patients in the present study were not diagnosed with HFrEF. Further studies are warranted to investigate the effects of HIIT on cardiac function in patients after MI and heart failure with preserved ejection fraction.

**LIMITATIONS**

Our study examined a single, unique HIIT protocol in MI patients and may not be generalizable to other methods of prescribing HIIT or to other clinical populations. Because measuring metabolic gas exchange data during multiple 30–40 min CR exercise sessions is technically and logistically challenging, we studied only a limited number of patients. Our patients’ average baseline VO₂peak was in the normal range for healthy individuals and our subjects are not representative of typical post-MI patients. In addition, we did not compare RPE vs. HR-based prescriptions for HIIT. While RPE certainly appears to be an effective prescriptive tool for HIIT, it remains unknown if RPE is the optimal prescription method despite its previously discussed advantages. Additionally, the cardiorespiratory assessments made during HIIT did not include direct measures of cardiac function (e.g., echocardiogram) and relied on an indirect method for cardiac adaptations (i.e., VO₂ and V̇E/V̇CO₂). As such, future studies should consider performing more comprehensive and direct measurements to identify the specific central and peripheral mechanisms responsible for the cardiorespiratory adaptations to RPE-prescribed HIIT in patients after MI.

**CONCLUSIONS**

RPE is an effective and safe method for prescribing HIIT for patients enrolled in early outpatient CR after uncomplicated MI. Using RPE eliminates reliance on heart rate for exercise intensity prescription and may be advantageous for patients who do not perform a pre-CR exercise test and for individuals receiving heart rate modulating medications. Using an RPE target of 14–17 during 1-min of high-intensity exercise elicits a robust VO₂HIIT of >90% of VO₂peak. The expected relationship between %HRpeak and %VO₂peak (%HRpeak > %VO₂peak) is not present during the HIIs of the HIIT. Patients are comfortable performing 5–8 one-minute intervals at >90% of VO₂peak during a 40-minute aerobic exercise session. Over the course of eight weeks of HIIT-based CR, patients increased treadmill speed and grade, and VO₂HIIT without an increase in perception of effort or excessive increases in heart rate and blood pressure.

**DATA AVAILABILITY STATEMENT**

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.
ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Mayo Clinic Institutional Review Board. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

YD, RS, and TO are responsible for the conception and design of the work. YD, JS, and MM contributed to the acquisition or interpretation of the work. YD, SH, JS, BS, RS, SL, and TO critically revised the manuscript. YD, SH, JS, MM, BS, RS, SL, and TO gave final approval and agree to be accountable for all aspects of the work ensuring integrity and accuracy. All authors have read and approved the final manuscript.

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