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Systematic Review

Exercise-based cardiac rehabilitation after myocardial revascularization: a systematic review and meta-analysis

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Abstract

Background: The present study aimed to analyze the effects of exercise-based cardiac rehabilitation (CR) on physical performance after myocardial revascularization. In addition, we compared the type and duration of exercise-based CR protocols to determine which ones produced the best performance improvements. **Methods**: This systematic review and meta-analysis was conducted and reported in accordance with PRISMA statement. A systematic search of PubMed, Web of Science, SPORTDiscus and ProQuest, was performed in July 2020. Studies that met the following criteria were included: (i) participants submitted to myocardial revascularization (i.e., coronary artery bypass grafting (CABG) and percutaneous coronary intervention (PCI)), (ii) participants submitted to exercise-based CR, and (iii) participants submitted to protocols for assessing physical performance before and after the exercise-based CR. **Results**: Thirteen and eleven studies evaluating the effects of exercise-based CR after myocardial revascularization were included in the systematic review and meta-analysis, respectively. Exercise-based CR increased physical performance after myocardial revascularization (mean effect size (ES) 0.75; 95% confidence interval (CI) 0.62, 0.88), particularly when aerobic (ES 0.85; 95% CI 0.68, 1.01) and combined training (ES 1.04; 95% CI 0.70, 1.38) lasting 8–12 weeks (ES 1.20; 95% CI 0.87, 1.53) was prescribed. **Conclusions**: The present systematic review and meta-analysis indicates that exercise-based CR increases physical performance after myocardial revascularization. The prescription of physical training for these patients should emphasize aerobic and combined training lasting at least 8–12 weeks, which is more effective in improving physical performance. **Impact**: Our findings demonstrate the effectiveness of physical training in improving physical performance after myocardial revascularization.

Keywords: myocardial revascularization; exercise-based cardiac rehabilitation; physical training

1. Introduction

Ischemic heart disease is a major cause of morbidity and mortality worldwide. Manifested by unstable angina pectoris and acute myocardial infarction, this syndrome is caused by a decreased blood supply to the heart muscle due to either narrowing of the vessels that supply the heart or blood clot. Chest pain during rest is the primary symptom that initiates diagnosis and treatment of this syndrome [1–3].

The initial approach should address pain relief and early risk stratification and include a haemodynamic assessment, antithrombotic and anticoagulant therapy, monitoring and early treatment of arrhythmias, and a decision on whether to use invasive or conservative strategies [4]. The main invasive methods for treating ischemic heart disease include coronary artery bypass grafting (CABG) and percutaneous coronary intervention (PCI) [5–8]. These procedures can be performed in the context of acute or chronic ischemic heart disease, and the choice of the appropriate procedure depends on predicted surgical mortality, complexity of the coronary anatomy, and comorbidities [8].

CABG is a technique based on revascularization that involves diverting blood flow to other arteries to increase the blood supply to the heart muscle [9], while PCI, commonly known as coronary angioplasty, is performed by inflating a balloon to allow blood to flow through the vessel again, followed by the insertion of coronary stents into the vessel to ensure it remains open [10].

Cardiac rehabilitation (CR) programs are helpful for patients undergoing cardiac surgeries, including CABG and PCI. These programs may include a variety of therapies, with exercise training being a central and strongly indicated element [11–14]. CR promotes several benefits, such as increased cardiovascular function and physical performance, decreased cardiovascular symptoms and cardiovascular morbidity and mortality, and improved quality of life [14–16].

Among the different physical training protocols available, it is worth mentioning, at this point, aerobic training, resistance training, combined training and high intensity interval training (HIIT). Aerobic training is designed to increase endurance, the term aerobic training generally refers to training in oxidative metabolism as opposed to glycolytic metabolism [17]. Resistance training consists of exercise designed to improve muscular fitness (strength, power, hypertrophy, and/or endurance) through exercise against external resistance [18]. Finally, combined training corresponds to protocols involving a combination of aerobic and resistance exercises, whereas HIIT involves repeated bouts of high-intensity effort followed by various recovery times [19].

Recent systematic reviews assessed the effect of CR in different cardiovascular conditions, such as coronary heart disease, heart valve surgery, and cardiac surgery [14,20,21]. However, the benefits of exercise-based CR, including the best exercise training protocol, specifically after myocardial revascularization, are still not well established. Therefore, this systematic review and meta-analysis aimed to analyze the effects of exercise-based CR on physical performance after myocardial revascularization (i.e., CABG and PCI). In addition, we compared the type and duration of exercise-based CR protocols to determine which ones produce the best performance improvements.

2. Materials and methods

2.1 Search strategy

This systematic review and meta-analysis were conducted and reported according to the guidelines outlined in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) statement [22,23]. A systematic search of electronic databases, including PubMed, Web of Science, SPORTDiscus and ProQuest, was performed in July 2020 without any date restrictions. The search strategy used combinations of the following keywords: myocardial revascularization, exercise-based cardiac rehabilitation, exercise, exercise-based rehabilitation, cardiac rehabilitation, physical training, physical exercise, exercise rehabilitation, physical activity and cardiorespiratory fitness.

2.2 Study selection

Studies that met the following criteria were included in this systematic review and meta-analysis: (i) participants submitted to myocardial revascularization (i.e., CABG and PCI), (ii) participants submitted to exercise-based CR and (iii) participants submitted to protocols for assessing physical performance before and after the exercise-based CR. Reviews, abstracts, case studies, and letters were not included, although this bibliography was consulted. Studies involving experimental research models were excluded. Based on the search and inclusion/exclusion criteria, 13 and 11 studies were selected for inclusion in the systematic review and meta-analysis, respectively (Fig. 1). Two studies were not included in the meta-analysis. The first did not present data as mean and standard deviation [24], whereas the second did not assess physical performance before and after the exercise-based CR [25]. Notably, several studies measured more than one physical performance variable or performed more than one physical training protocol. Thus, each performance variable or physical training analyzed in a given study will be presented as a trial, and therefore the number of trials reported will be greater than the number of studies.

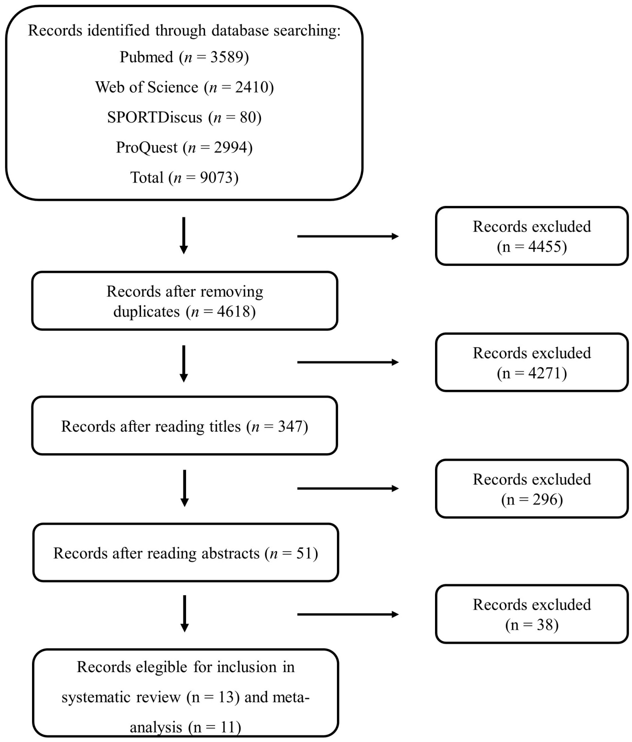

Fig. 1. Summary of the study selection process. The stages of the study selection process are highlighted with the number of studies selected and the number of studies excluded at each stage.

2.3 Data grouping

The characteristics of the exercise-based CR protocols included in the systematic review and meta-analysis are shown in Table 1 (13 studies, 16 trials), while the studies selected for the systematic review are shown in Table 2 (13 studies, 42 trials). The studies selected for inclusion in the meta-analysis (11 studies, 39 trials) were initially divided to analyze the effect of exercise-based CR on patients undergoing CABG (6 studies, 15 trials) or PCI (5 studies, 10 trials). Then they were grouped according to the characteristic of the exercise-based CR performed: combined training (aerobic and resistance exercises) (6 studies, 17 trials), aerobic training (3 studies, 15 trials), and HIIT (2 studies, 6 trials). The studies were then divided according to the duration of the exercise-based CR as follows: less than 8 weeks (3 studies, 8 trials) or 8–12 weeks (5 studies, 22 trials). Once the physical performance was assessed using different protocols (i.e., 6-minute walk test, cardiopulmonary exercise testing on a cycle ergometer, Bruce protocol on a treadmill), we divided the reported variables into four categories: maximum oxygen consumption (6 studies, 11 trials), distance travelled (3 studies, 5 trials), exercise duration (3 studies, 6 trials) or workload (3 studies, 5 trials). This categorisation allowed us to analyze and compare performance measured in different studies. Thus, increased distance travelled, maximal oxygen consumption, exercise duration, and workload indicate improved physical performance.

2.4 Risk of bias assessment

The risk of bias was assessed by two independent reviewers using an adapted Assessment, Development and Assessment Rating of Recommendations (GRADE) instrument [26,27]. When there was disagreement between the two evaluators, a third evaluator was consulted for resolution. This approach allowed us to evaluate the risk of bias in each study included in the present systematic review. Domains reflecting allocation concealment, blinding of participants and personnel, incomplete outcome data, selective outcome reporting, and other sources of bias were evaluated. Inadequacy in one of these domains reduced the methodological quality of each study according to the following sequence: high, moderate, low and very low.

2.5 Statistical analysis

The mean and standard deviation values of the physical performance indexes in both the exercise rehabilitation and control trials were obtained from data provided in the consulted research papers. Heterogeneity was evaluated using the χ^2 test for homogeneity and the I^2 statistic. The effect size (Cohen's d or Hedges' g) was calculated for the physical performance indexes in each study. A weighted-mean estimate of the effect size (ES) was calculated to account for differences in the sample sizes, along with the mean unweighted ES and associated 95% confidence interval (CI). When CI included zero, ES was considered not significant. Threshold values for ES were defined as negligible ($<$0.2); small (0.20–0.49); moderate (0.50–0.79); and large ($>$0.8) [28].

3. Results

3.1 Systematic review

In total, 9073 studies were identified through the database and reference searches. After the selection process based on eligibility criteria, 13 and 11 studies were included in the systematic review and meta-analysis, respectively (Fig. 1).

Exercise-based CR protocols of all 13 studies included in the systematic review and meta-analysis are summarized in Table 1, including the type of exercise, duration of the training protocol, weekly frequency, intensity and duration of the exercise sessions. The studies mainly investigated aerobic and combined training, with a duration varying from 3 to 24 weeks and a frequency of 2 to 6 times per week (Table 1, Ref. [24,25,29–39]). It is noteworthy to mention that the intensity of aerobic training was controlled in several different ways, including peak oxygen consumption, anaerobic threshold, percentage of maximum heart rate, percentage of reserve heart rate, and perceived exertion scale. Meanwhile, when reported, resistance training was controlled by the percentage of one-repetition maximum (1RM), ranging from 30 to 60%. Most studies started exercise-based cardiac rehabilitation within one month after myocardial revascularization. However, two studies included patients up to 1 year after coronary artery bypass graft surgery.

Table 2 (Ref. [24,25,29–39]) characterizes the studies included in the systematic review, including groups, sample size, age, type of surgery, training protocol, training duration, protocol, analyzed variables and results. The main variables used to assess physical performance were maximum oxygen consumption, exercise duration, distance travelled and workload obtained through cardiopulmonary exercise test (on a cycle ergometer or treadmill) and the 6-minute walk test. Overall, the results demonstrate that patients undergoing myocardial revascularization (either CABG or PCI) have increased physical performance after exercise-based CR.

3.2 Meta-analysis

3.2.1 Exercise-based cardiac rehabilitation

In total, 11 studies (39 trials and 3865 individuals) were included in the meta-analysis. The mean effect size was 0.75 (95% CI 0.62, 0.88), which indicates that exercise-based CR had a moderate and significant effect on physical performance after CABG and PCI ($p < 0.05$; Fig. 2). According to a fixed-effects analysis, heterogeneity was observed among these studies (I^2 = 72.5%; Q = 138.1, df = 38, p = 0.000).

3.2.2 PCI

After pooling the data from ten trials (5 studies, 3358 individuals), the mean effect size 0.64 (95% CI 0.59, 0.69), which indicates that exercise-based CR had a moderate and significant effect on physical performance after PCI ($p <$ 0.05; Fig. 3). According to a fixed-effects analysis, no heterogeneity was observed among these studies (I^2 = 7.7%; Q = 9.7, df = 9, p = 0.371).

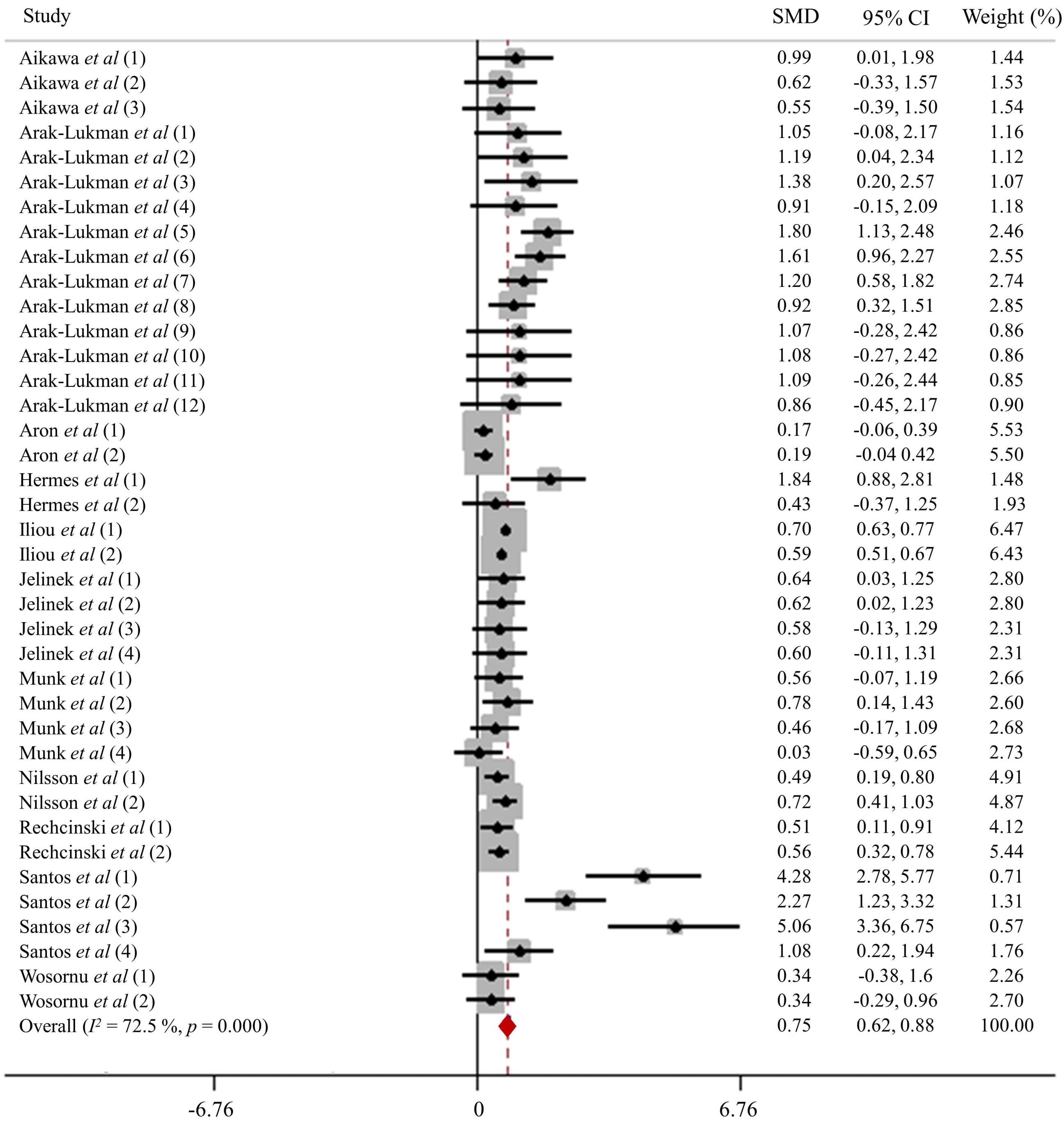

Fig. 2. Forest plot of physical performance following physical training in patients undergoing myocardial revascularization (CABG and PCI). SMD, standardized mean difference.

Table 1. Exercise-based cardiac rehabilitation protocol of the studies included in systematic review and meta-analysis.

References	Exercise-based cardiac rehabilitation				
	Exercise	Training duration (weeks)	Frequency (x/week)	Session duration (min)	Intensity
Aikawa *et al.* [29]	Aerobic and resistance training - 5 min warm up - 30 min treadmill and cycloergometer - 20 min free weights - 5 min relaxation	24	3	90	Aerobic exercise: 30–60% HR_{rest} Resistance exercise: 30–60% 1RM
Arak-Lukman *et al.* [30]	Aerobic training (bicycle) - 10 min warm-up - 30 min aerobic exercise - 10 min cool-down	12	3	50	80% of anaerobic threshold
Aron *et al.* [31]	Aerobic and resistance training - 10 min warm-up calisthenics and stretching - 30–45 min aerobic exercise - 5–10 min resistance exercise - 5–10 min cool-down	12	3	45–60	11–14 on the Borg (6 to 20 scale)
Hermes *et al.* (1) [32]	Aerobic and resistance training - 30 min aerobic exercise on a treadmill and bike - 20 min resistance exercise - 10 min stretching and relaxation	12	2	60	Aerobic exercise: 55–65% $HR_{reserve}$ and 4–6 on the Borg scale Resistance exercise: 50% 1RM
Hermes *et al.* (2) [32]	Aerobic and resistance training with inspiratory muscle training - Inspiratory muscle training - 30 min aerobic exercise on a treadmill and bike - 20 min resistance exercise - 10 min stretching and relaxation	12	2	60	Aerobic exercise: 55–65% of $HR_{reserve}$ and 4–6 on the Borg scale Resistance exercise: 50% 1RM
Iliou *et al.* [33]	Aerobic training - Callisthenics and bike or treadmill	4–7	3–5	60	70–80% $HR_{reserve}$
Jelinek *et al.* [34]	Aerobic training (cycle ergometer, treadmill and rowing) - 5–10 min warm-up - 15–20 min endurance training - 10–15 min strength/resistance training - 5–10 min cool-down/relaxation	6	3	45–70	55–70% VO_{2peak} and 11–13 on the Borg scale

Table 1. Continued.

References	Exercise-based cardiac rehabilitation				
	Exercise	Training duration (weeks)	Frequency (x/week)	Session duration (min)	Intensity
Munk *et al*. [35]	High-intensity interval training - 10 min warm-up - High-intensity interval training (4 min: cycle ergometer or running and 3 min: active recovery) - 5 min cool-down - 10 min abdominal and spine resistance exercises - 5 min stretching and relaxation	24	3	60	60–70% HR_{max} or 80–90% HR_{max}
Nilsson *et al*. [36]	High-intensity interval training - Warm-up - Aerobic exercise: low, moderate and high intensity - Flexibility - Strength exercise - Cold down and stretching	12	2	50	50–90% HR_{max}
Rechciński *et al*. [37]	Cardiac rehabilitation program - Warm-up - 10–30 min cycling - 30–45 min walking - Resistance exercise	3	6	-	Cycling: Workload 10W–100W
Santos *et al*. (1) [38]	Moderate-to-high intensity inspiratory muscle training Aerobic and resistance exercises	12	2	60	Aerobic exercise: 4–6 on the Borg scale. Resistance exercise: 50% 1RM
Santos *et al*. (2) [38]	Low intensity inspiratory muscle training Aerobic and resistance exercises	12	2	60	Aerobic exercise: 4–6 on the Borg scale. Resistance exercise: 50% 1RM
Szmigielska *et al*. [24]	Cycle ergometer interval training	8	3	45	60–80% $HR_{reserve}$ and 11–16 on the Borg scale
Chuang *et al*. [25]	Submaximal endurance training exercise (Virtual Reality)	12	2	30	85% HR_{max} or 75% VO_{2peak}
Wosornu *et al*. (1) [39]	Aerobic training	24	3	12–60	Not reported
Wosornu *et al*. (2) [39]	Resistance training	24	3	12–60	Not reported

1RM, one-repetition maximum; HR_{rest}, resting heart rate; HR_{max}, maximal heart rate; $HR_{reserve}$, heart rate reserve; VO_{2peak}, peak oxygen consumption.

Table 2. Characteristics of the studies included in the systematic review.

References	Groups	N (♂/♀)	Age	Surgery	Outcomes: Test protocol	Outcomes: Variables	Outcomes: Results
Aikawa *et al.* (1) [29]	-	9 (5/4)	66	CABG	6-min walk test	Distance (m)	Pre: 459 ± 94 Post: 547 ± 83*
Aikawa *et al.* (2) [29]	-	9 (5/4)	66	CABG	1RM - Biceps	Muscle strength (kg)	Pre: 9.7 ± 4.1 Post: 12.5 ± 4.9
Aikawa *et al.* (3) [29]	-	9 (5/4)	66	CABG	1RM - Quadriceps	Muscle strength (kg)	Pre: 19.3 ± 9.3 Post: 24.4 ± 9.1*
Arak-Lukman *et al.* (1) [30]	GI: VO_{2peak} >19	7	55.1 ± 10.1	CABG PCI	Bicycle cardiopulmonary testing	Exercise duration (min)	Pre :11.8 ± 3.3 Post: 15.1 ± 3.0*
Arak-Lukman *et al.* (2) [30]	GI: VO_{2peak} >19	7	55.1 ± 10.1	CABG PCI	Bicycle cardiopulmonary testing	Maximal load (W)	Pre: 151.4 ± 32.9 Post: 184.3 ± 21.1*
Arak-Lukman *et al.* (3) [30]	GI: VO_{2peak} >19	7	55.1 ± 10.1	CABG PCI	Bicycle cardiopulmonary testing	VO_2 at maximal load ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	Pre: 20.5 ± 1.1 Post: 23.9 ± 3.3*
Arak-Lukman *et al.* (4) [30]	GI: VO_{2peak} >19	7	55.1 ± 10.1	CABG PCI	Bicycle cardiopulmonary testing	Heart rate at maximal load (beats.min^{-1})	Pre: 134.8 ± 14.3 Post: 147.7 ± 12.2*
Arak-Lukman *et al.* (5) [30]	GII: VO_{2peak} 11–19	24	61.1 ± 7.8	CABG PCI	Bicycle cardiopulmonary testing	Exercise duration (min)	Pre: 7.5 ± 2.4 Post: 11.4 ± 1.9*
Arak-Lukman *et al.* (6) [30]	GII: VO_{2peak} 11–19	24	61.1 ± 7.8	CABG PCI	Bicycle cardiopulmonary testing	Maximal load (W)	Pre: 106.5 ± 26.7 Post: 145.4 ± 21. 2*
Arak-Lukman *et al.* (7) [30]	GII: VO_{2peak} 11–19	24	61.1 ± 7.8	CABG PCI	Bicycle cardiopulmonary testing	VO_2 at maximal load ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	Pre: 15.5 ± 2.4 Post: 18.9 ± 3.2*
Arak-Lukman *et al.* (8) [30]	GII: VO_{2peak} 11–19	24	61.1 ± 7.8	CABG PCI	Bicycle cardiopulmonary testing	Heart rate at maximal load (beats.min^{-1})	Pre: 126.2 ± 10.1 Post: 138.5 ± 16.0*
Arak-Lukman *et al.* (9) [30]	GIII: VO_{2peak} <11	5	64.6 ± 8.9	CABG PCI	Bicycle cardiopulmonary testing	Exercise duration (min)	Pre: 3.5 ± 2.7 Post: 7.8 ± 5.0*
Arak-Lukman *et al.* (10) [30]	GIII: VO_{2peak} <11	5	64.6 ± 8.9	CABG PCI	Bicycle cardiopulmonary testing	Maximal load (W)	Pre: 70.0 ± 25.5 Post: 114.0 ± 51.8*
Arak-Lukman *et al.* (11) [30]	GIII: VO_{2peak} <11	5	64.6 ± 8.9	CABG PCI	Bicycle cardiopulmonary testing	VO_2 at maximal load ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	Pre: 8.7 ± 2.1 Post: 12.8 ± 4.9*
Arak-Lukman *et al.* (12) [30]	GIII: VO_{2peak} <11	5	64.6 ± 8.9	CABG PCI	Bicycle cardiopulmonary testing	Heart rate at maximal load (beats.min^{-1})	Pre: 107.4 ± 20.1 Post: 121.6 ± 11.8*

Table 2. Continued.

References	Groups	N (♂/♀)	Age	Surgery	Outcomes: Test protocol	Outcomes: Variables	Outcomes: Results
Aron *et al.* (1) [31]	Off pump	150 (110/40)	65.3 ± 10.3	CABG	-	Grip strength	Pre: 37.0 ± 11.0 Post: 38.9 ± 11.6*
Aron *et al.* (2) [31]	On pump	145 (113/32)	64.9 ± 9.5	CABG	-	Grip strength	Pre: 36.0 ± 11.1 Post: 38.2 ± 12.0*
Hermes *et al.* (1) [32]	CR	12 (10/2)	59.5 ± 8.7	CABG	Treadmill exercise test - Bruce protocol	VO_{2peak} (mL·kg^{-1}·min^{-1})	Pre: 26.0 ± 5.6 Post: 35.7 ± 4.9*
Hermes *et al.* (2) [32]	CR + inspiratory muscle training	12 (7/5)	55.2 ± 7.9	CABG	Treadmill exercise test - Bruce protocol	VO_{2peak} (mL·kg^{-1}·min^{-1})	Pre: 25.5 ± 3.7 Post: 27.2 ± 4.1
Iliou *et al.* (1) [33]	Early rehabilitation	1821 (1578/243)	56.1 ± 11.5	PCI	Exercise stress test	Workload (W)	Pre: 105 ± 35.5 Post: 133 ± 44
Iliou *et al.* (2) [33]	Late rehabilitation	1311 (1076/235)	57.3 ± 11.2	PCI	Exercise stress test	Workload (W)	Pre: 105 ± 38 Post: 130 ± 46
Jelinek *et al.* (1) [34]	CABG	22 (18/4)	62.5 ± 9.9	CABG	6-min walk test	Distance (m)	Pre: 504.3 ± 93.5 Post: 565.8 ± 98.8*
Jelinek *et al.* (2) [34]	CABG	22 (18/4)	62.5 ± 9.9	CABG	6-min walk test	VO_{2peak} (mL·kg^{-1}·min^{-1})	Pre: 11.9 ± 1.6 Post: 12.9 ± 1.6*
Jelinek *et al.* (3) [34]	PCI	16 (13/3)	64.9 ± 8.8	PCI	6-min walk test	Distance (m)	Pre: 548.1 ± 62.0 Post: 589.0 ± 78.1*
Jelinek *et al.* (4) [34]	PCI	16 (13/3)	64.9 ± 8.8	PCI	6-min walk test	VO_{2peak} (mL·kg^{-1}·min^{-1})	Pre: 12.6 ± 1.0 Post: 13.3 ± 1,3*
Munk *et al.* (1) [35]	-	20 (17/3)	57 ± 14	PCI	Ergospirometry - 20 W/min ramp protocol	VO_{2peak} (mL·kg^{-1}·min^{-1})	Pre: 23.2 ± 5.7 Post: 27.1 ± 8.0*
Munk *et al.* (2) [35]	-	20 (17/3)	57 ± 14	PCI	Ergospirometry - 20 W/min ramp protocol	Ventilatory threshold (mL·kg^{-1}·min^{-1})	Pre: 15.6 ± 5.0 Post: 20.4 ± 7.1*
Munk *et al.* (3) [35]	-	20 (17/3)	57 ± 14	PCI	Ergospirometry - 20 W/min ramp protocol	Workload (W)	Pre: 180 ± 49 Post: 202 ± 46
Munk *et al.* (4) [35]	-	20 (17/3)	57 ± 14	PCI	Ergospirometry - 20 W/min ramp protocol	HR_{peak} (beats.min^{-1})	Pre: 153 ± 26 Post: 154 ± 34
Nilsson *et al.* (1) [36]	-	86	57 ± 9	PCI CABG	Running protocol	VO_{2peak} (mL·Kg^{-1}·min^{-1})	Pre: 31.9 ± 7.6 Post: 35.9 ± 8.6*

Table 2. Continued.

References	Groups	N (♂/♀)	Age	Surgery	Outcomes: Test protocol	Outcomes: Variables	Outcomes: Results
Nilsson *et al.* (2) [36]	-	86	57 ± 9	PCI CABG	Running protocol	Exercise duration (s)	Pre: 569 ± 104 Post: 645 ± 107*
Rechciński *et al.* (1) [37]	Imcomplete revascularization	49 (36/13)	58 ± 10	PCI	Treadmill exercise test - Bruce protocol	Workload (MET)	Pre: 7.3 ± 3.0 Post: 8.8 ± 2.9*
Rechciński *et al.* (2) [37]	Complete revascularization	141 (89/52)	58 ± 9	PCI	Treadmill exercise test - Bruce protocol	Workload (MET)	Pre: 7.6 ± 2.8 Post: 9.2 ± 2.9*
Santos *et al.* (1) [38]	IMT + CT	12 (8/4)	55.0 ± 7.0	CABG	Treadmill cardiopulmonary exercise test	VO_{2peak} (mL·kg^{-1}·min^{-1})	Pre:19.3 ± 0.9 Post: 23.6 ± 1.1*
Santos *et al.* (2) [38]	IMT + CT	12 (8/4)	55.0 ± 7.0	CABG	6-min walk test	Distance (m)	Pre: 412.9 ± 53.1 Post: 537.9 ± 56.8*
Santos *et al.* (3) [38]	Sham-IMT + CT	12 (9/3)	56.6 ± 5.5	CABG	Treadmill cardiopulmonary exercise test	VO_{2peak} (mL·kg^{-1}·min^{-1})	Pre:19.1 ± 0.8 Post: 22.3 ± 0.4*
Santos *et al.* (4) [38]	Sham IMT + CT	12 (9/3)	56.6 ± 5.5	CABG	6-min walk test	Distance (m)	Pre: 403.1 ± 50.9 Post: 459.1 ± 53.0*
Szmigielska *et al.* (1) [24]	PCI	72 (72/0)	55.7 ± 8.5	PCI	Exercise test (cycle ergometer)	Workload (W)	Pre: 90 Post: 120*
Szmigielska *et al.* (2) [24]	CABG	59 (59/0)	56.4 ± 8.9	CABG	Exercise test (cycle ergometer)	Workload (W)	Pre: 90 Post: 120*
Chuang *et al.* [25]	Trained	20	65.7 ± 14.4	CABG	Endurance training sessions	Speed (mph)	Non-VR: 3.7 ± 0.8 VR: 4.6 ± 1.4*
Wosornu *et al.* (1) [39]	Aerobic	15 (15/0)	57 ± 9	CABG	Treadmill exercise test - Balke II protocol	Exercise duration (min)	Pre: 791.2 ± 306.5 Post: 891.4 ± 287.9*
Wosornu *et al.* (2) [39]	Power	20 (20/0)	60 ± 6	CABG	Treadmill exercise test - Balke II protocol	Exercise duration (min)	Pre: 800.4 ± 290.5 Post: 900.3 ± 300.8*

1RM, one-repetition maximum; VO_2, oxygen consumption; VO_{2peak}, peak oxygen consumption; HR_{peak}, heart rate peak; IMT + CT, inspiratory muscle training + combined; Non-VR, no virtual reality; VR, virtual reality. * indicates statistical difference between groups.

3.2.3 CABG

After pooling the data from 15 trials (6 studies, 428 individuals), the mean effect size was 1.01 (95% CI 0.61, 1.41), which indicates that exercise-based CR had a large and significant effect on physical performance after CABG ($p < 0.05$; Fig. 3). According to a random-effects analysis, heterogeneity was observed among these studies (I^2 = 84.1%; Q = 88.1, df = 14, p = 0.000).

3.2.4 Combined training

After pooling the data from 17 trials (6 studies, 556 individuals), the mean effect size was 1.04 (95% CI 0.70, 1.38), which indicates that combined training had a large and significant effect on physical performance after CABG and PCI ($p < 0.05$; Fig. 4). According to a random-effects analysis, heterogeneity was observed among these studies (I^2 = 85.9%; Q = 113.5, df = 16, p = 0.000).

3.2.5 Aerobic training

After pooling the data from 15 trials (3 studies, 3183 individuals), the mean effect size was 0.85 (95% CI 0.68, 1.01), which indicates that aerobic training had also a large and significant effect on physical performance after CABG and PCI ($p < 0.05$; Fig. 4). According to a random-effects analysis, heterogeneity was observed among these studies (I^2 = 56.0%; Q = 31.85, df = 14, p = 0.004).

3.2.6 High intensity interval training

After pooling the data from six trials (2 studies, 106 individuals), the mean effect size was 0.55 (95% CI 0.37, 0.73), which indicates that HIIT had a moderate and significant effect on physical performance after CABG and PCI ($p < 0.05$; Fig. 4). According to a fixed-effects analysis, no heterogeneity was observed among these studies (I^2 = 0.0%; Q = 4.47, df = 5, p = 0.483).

3.2.7 Exercise-based CR duration: ≤8 weeks

After pooling the data from eight trials (3 studies, 3360 individuals), the mean effect size was 0.65 (95% CI 0.60, 0.69), which indicates that exercise-based CR lasting ≤8 weeks had a moderate and significant effect on physical performance after CABG and PCI ($p < 0.05$; Fig. 5). According to a random-effects analysis, heterogeneity was observed among these studies (I^2 = 58.7%; Q = 5.53, df = 7, p = 0.033).

3.2.8 Exercise-based CR duration: >8 and ≤12 weeks

After pooling the data from 22 trials (5 studies, 441 individuals), the mean effect size was 1.20 (95% CI 0.87, 1.53), which indicates that exercise-based CR lasting >8 and ≤12 weeks had a large and significant effect on physical performance after CABG and PCI ($p < 0.05$, Fig. 5). According to a random-effects analysis, heterogeneity was observed among these studies (I^2 = 83.3%; Q = 125.9, df = 21, p = 0.000).

3.2.9 Physical performance variables: maximum oxygen consumption

After pooling the data from 11 trials (6 studies, 204 individuals), the mean effect size was 1.33 (95% CI 0.78, 1.88), which indicates that exercise-based CR had a large and significant effect on oxygen consumption after CABG and PCI ($p < 0.05$; **Supplementary Fig. 1**). According to a random-effects analysis, heterogeneity was observed among these studies (I^2 = 82.8%; Q = 58.0, df = 10, p = 0.000).

3.2.10 Physical performance variables: distance travelled

After pooling the data from five trials (3 studies, 59 individuals), the mean effect size was 0.98 (95% CI 0.47, 1.48), which indicates that exercise-based CR had a large and significant effect on distance travelled after CABG and PCI ($p < 0.05$; **Supplementary Fig. 1**). According to a fixed-effects analysis, no heterogeneity was observed among these studies (I^2 = 47.3%; Q = 7.59, df = 4, p = 0.108).

3.2.11 Physical performance variables: exercise duration

After pooling the data from six trials (3 studies, 157 individuals), the mean effect size was 0.81 (95% CI 0.37, 1.25), which indicates that exercise-based CR had a large and significant effect on exercise duration after CABG and PCI ($p < 0.05$; **Supplementary Fig. 1**). According to a random-effects analysis, heterogeneity was observed among these studies (I^2 = 58.7%; Q = 12.11, df = 5, p = 0.033).

3.2.12 Physical performance variables: workload

After pooling the data from five trials (3 studies, 3342 individuals), the mean effect size was 0.63 (95% CI 0.56, 0.71), which indicates that exercise-based CR had a moderate and significant effect on workload after CABG and PCI ($p < 0.05$; **Supplementary Fig. 1**). According to a fixed-effects analysis, no heterogeneity was observed among these studies (I^2 = 31.0%; Q = 5.80, df = 4, p = 0.215).

3.3 Risk of bias

The risk of bias was assessed in the 13 included studies. Twelve studies did not present any major risk of bias. Only one study showed the absence of allocation. Thus, 92.3% of the studies showed consistent control of the risk of bias and were classified as good quality studies (**Supplementary Table 1**).

4. Discussion

The present study confirms that exercise-based CR significantly affected physical performance after myocardial revascularization. More specifically, aerobic and combined training were the most efficient exercise-based CR protocols for improving performance in patients who un-

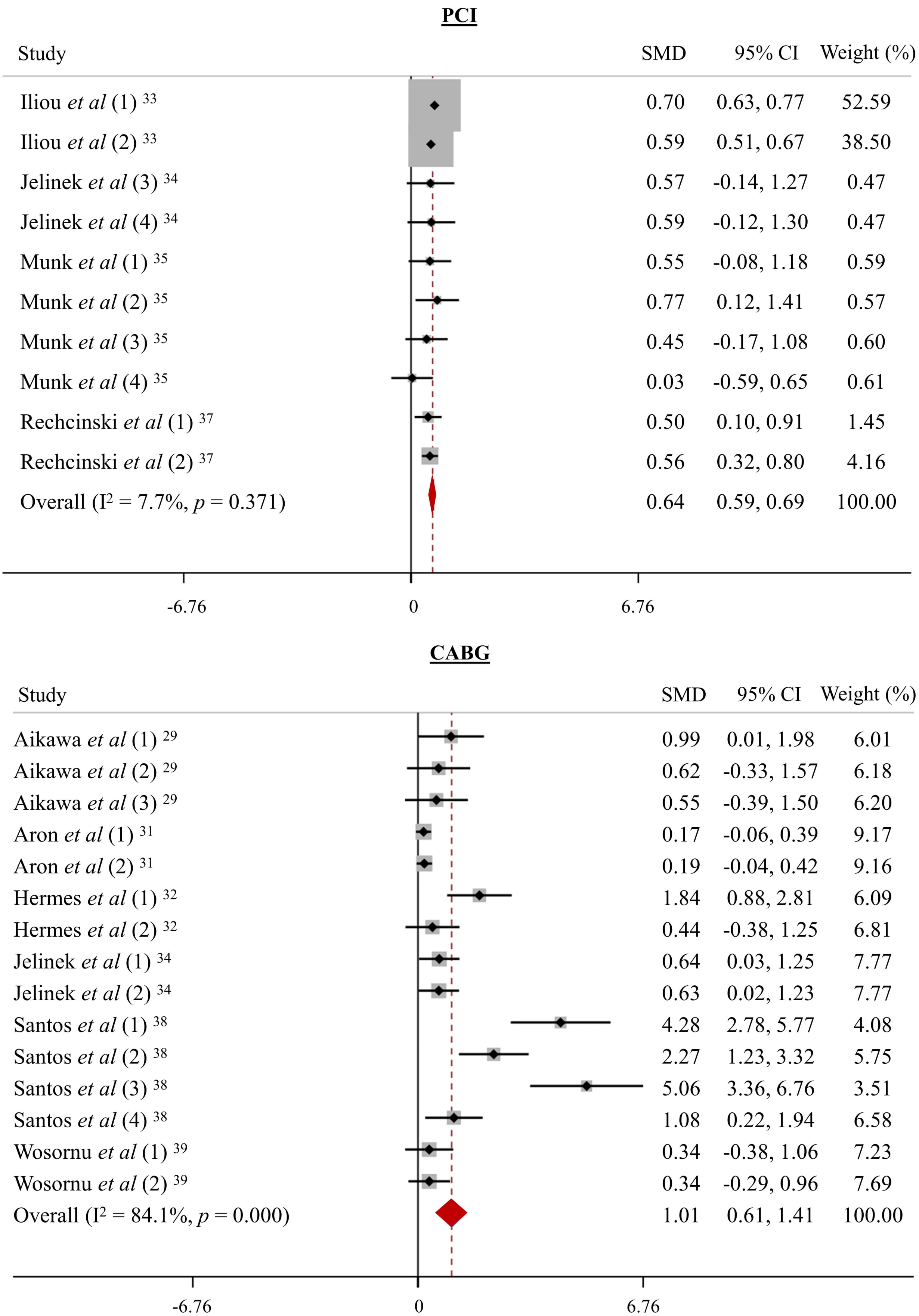

Fig. 3. Forest plot of physical performance following physical training in patients undergoing CABG or PCI. SMD, standardized mean difference.

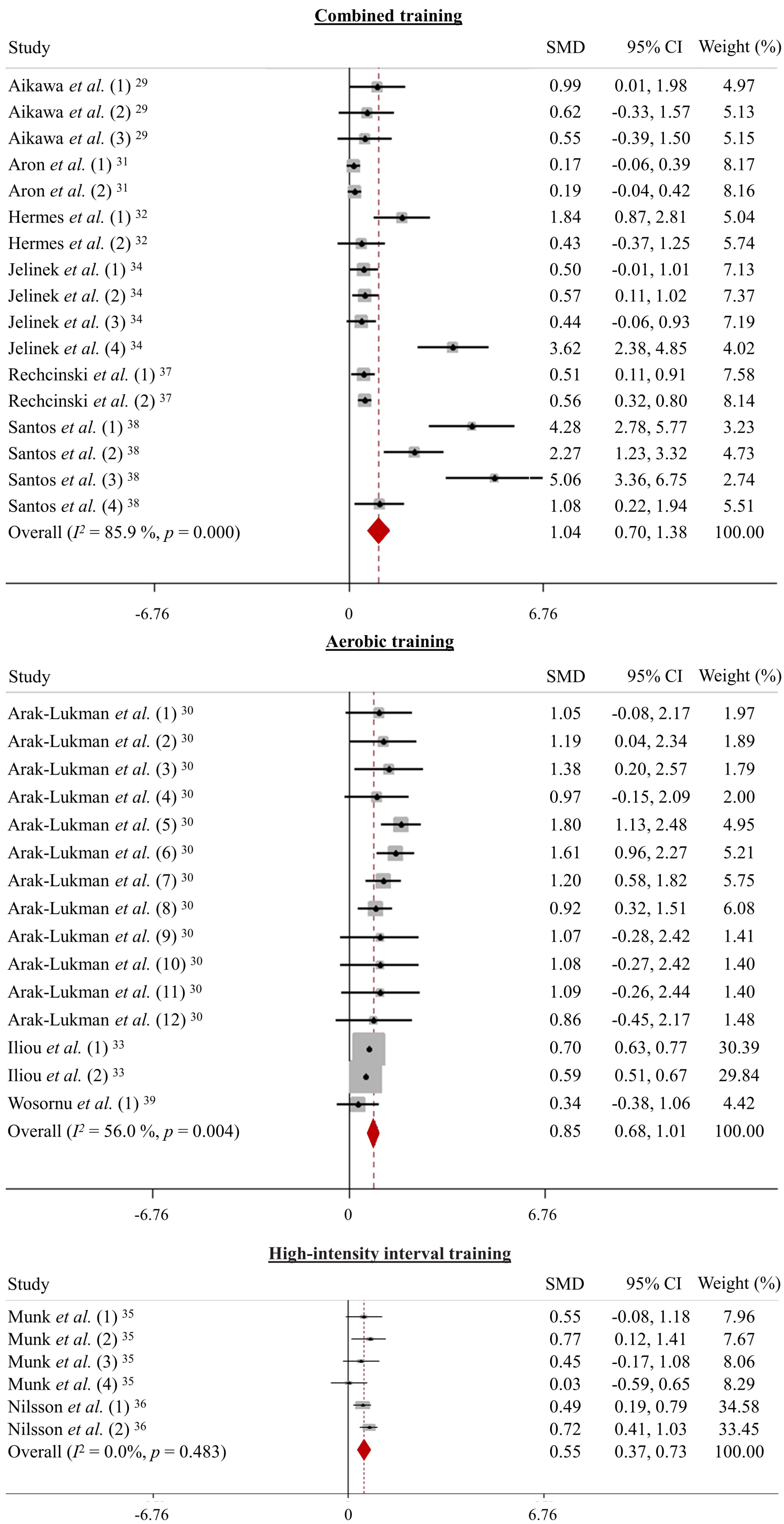

Fig. 4. Forest plot of physical performance following combined, aerobic and HIIT training in patients undergoing myocardial revascularization (CABG and PCI). SMD, standardized mean difference.

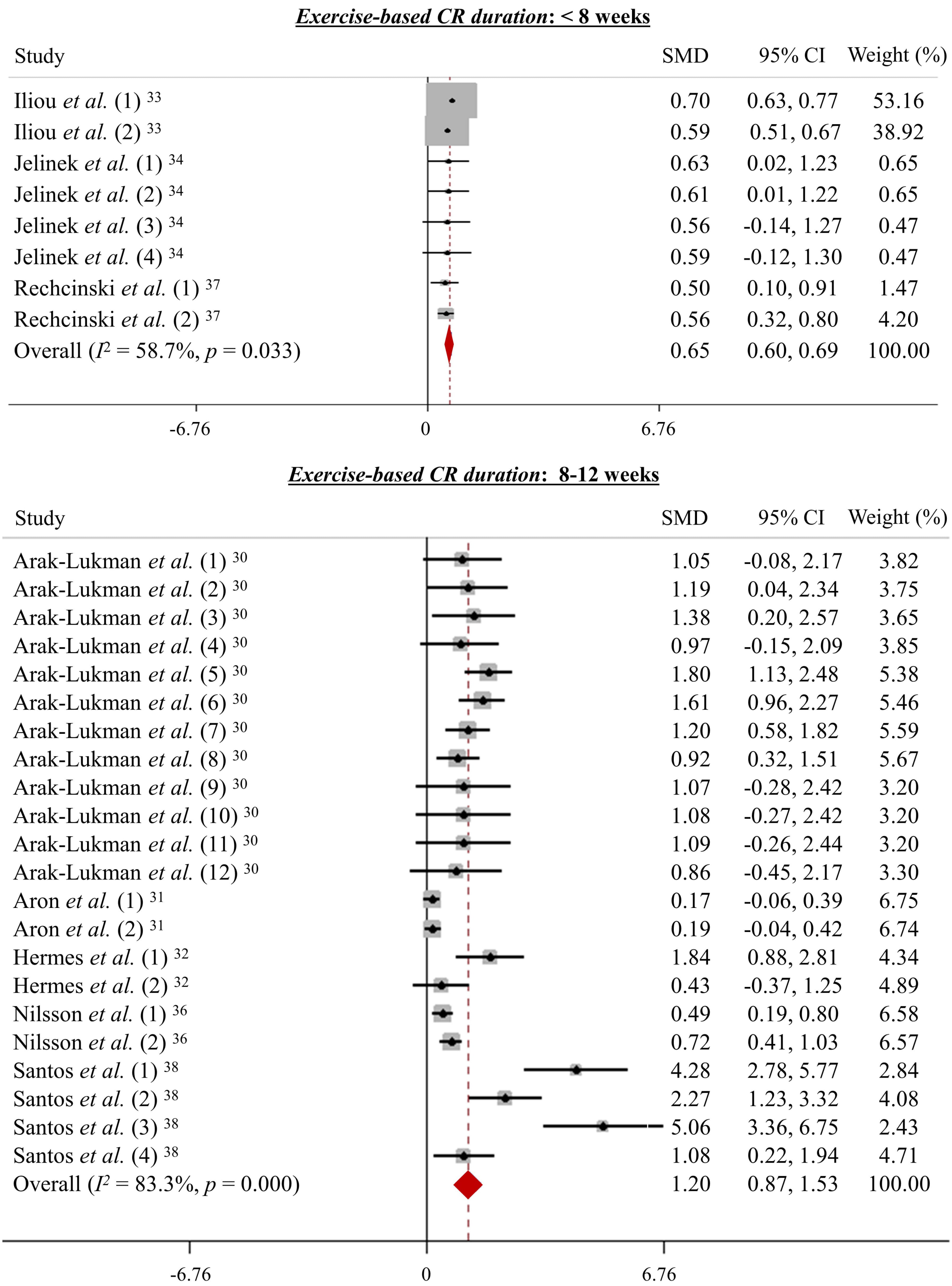

Fig. 5. Forest plot of physical performance following physical training with duration <8 weeks and between 8–12 weeks in patients undergoing myocardial revascularization (CABG and PCI). SMD, standardized mean difference; CR, cardiac rehabilitation.

derwent myocardial revascularization (i.e., CABG or PCI). In addition, the duration of the exercise-based CR was also an issue in these patients, as the results show that more effective improvements require at least 8 to 12 weeks.

Although international guidelines emphasize exercise prescription for CR [16], it is unclear which training program is the safest or whether there is any training protocol that could negatively affect CR patients. Thus, this study evaluated, for the first time, the differences between three programs of exercise (i.e., combined training, aerobic training, and HIIT) on physical performance in patients submitted to myocardial revascularization.

The American Heart Association and the American Association of Cardiovascular and Pulmonary Rehabilitation have recommended that aerobic training (e.g., walking, treadmill, cycling, stair climbing, rowing) should be performed for 20–60 minutes per session, 3–5 sessions per week, and at an intensity of 40–80% VO_{2peak} (peak oxygen uptake) or HR_{max} (maximum heart rate), based on a maximal exercise test. For resistance training (calisthenics, hand weights, pulleys, dumb-bells, free weights, machine weights), the recommendation is 1–3 sets or 10–15 repetitions for 8–10 different exercises, 3 sessions per week (on non-consecutive days) at 50% of the one-repetition maximum (1RM) progressing to 60–70% 1RM [40,41]. Our findings support these recommendations and indicate that aerobic or combined training may be more effective for CR patients.

After a careful selection and quality assessment, three guidelines on CR were included in a recent systematic review: the International Council of Cardiovascular Prevention and Rehabilitation (2016), National Institute for Health and Care Excellence (2013) and Scottish Intercollegiate Guideline Network (2017). By consensus, the three guidelines indicated that the CR should focus on exercise training, nutritional counseling, risk factor modification, psychological management, and patient education. Specifically for regular physical activity, the counseling is to perform physical exercise 20–30 minutes a day, choosing the exercise modality of your preference and gradually progressing the duration and intensity of sessions to increase physical performance [42].

The meta-analysis demonstrated that two exercise training protocols (aerobic and combined) effectively promoted improvements in the physical performance of patients undergoing myocardial revascularization. In a comparative analysis of effect sizes, the combined training showed the greatest effect size (1.06), followed by aerobic training (0.79). Moreover, as expected, it was found that physical performance increases proportionally to the training duration, since a period of 8–12 weeks had a greater effect than training lasting up to 8 weeks (ES = 1.33 and 0.64, respectively).

Scientific evidence indicates that physical training results in improvements in physical performance, being a key component of CR. Countless reasons explain the improvements in physical performance induced by exercise training, such as the positive effect of training on muscle strength and mobility in elderly patients [43], the restoration of sensitivity to autonomic modulation in recently heart-transplanted subjects [44], and the improvements in cardiopulmonary fitness [45], and utilization of energetic substrates [46].

Aerobic training is an intervention recommended in all international guidelines; however, differences are evident in the intensity and duration of exercise and frequency of training sessions that are recommended. The most contentious issue in cardiac patients is related to exercise intensity, as the lower and upper safe and effective limits are still debated in several guidelines worldwide [16]. Studies indicate that higher intensity exercise generally results in more evident increases in cardiorespiratory fitness [47], but it may be associated with an increased risk of cardiac events [48] or not be personally acceptable and/or sustainable for some patients. Thus, the individualized prescription of physical exercise must take into account the optimal intensity, acceptability, and safety [49].

It is important to note that the population evaluated in this review consists of patients who have already undergone an invasive cardiac remodeling procedure; they are in a group with higher cardiac risk and are less susceptible to adaptation to HIIT than other individuals. One of the reasons that corroborate this statement is the small number of studies that used HIIT (2 studies, 6 trials), probably due to the individual assessments of the patients' ability to adhere to the training or to caution being used in prescribing this type of training to these patients.

The meta-analysis showed that combined training effectively improved physical performance in patients after myocardial revascularization, even though resistance training is not routinely included in exercise-based CR guidelines to the same level as aerobic exercise prescription [16]. In this sense, dynamic resistance training is also beneficial for patients participating in CR, leading to an increase in physical strength and improved independence in activities of daily living and positively influencing quality of life [50]. Evidence indicates that combined training results in a greater increase in muscle mass and a reduction in body fat compared to aerobic training alone [51]. Thus, the prescription of resistance training to an exercise-based CR programme may also optimize responses to aerobic training as a result of increased muscle strength, leading to more favorable effects on exercise performance [51].

In general, exercise-based CR can be part of the multidisciplinary approach during the late postoperative period since exercise is part of the prevention and treatment of chronic diseases that are risk factors for coronary syndromes. The exercise prescription must respect patient wellness and limitations and authorities' recommendations and be evidence-based to optimize adherence and, consequently, the training results.

The present systematic review and meta-analysis indicates that exercise-based cardiac rehabilitation increases physical performance after myocardial revascularization. The prescription of physical training for these patients should emphasize aerobic and combined training lasting 8–12 weeks, which are more effective in improving physical performance.

Author contributions

All authors have contributed to the development of the research question and study design. HOC, QTR, LRD and MdCM developed the literature search. HOC, LRD, QTR, PMAL and MdCM performed the study selection. HOC, QTR and LRD analysed the data. HOC, QTR, LRD, PMAL, MdCM, SPW and CCC interpret the results and wrote the manuscript. All authors reviewed and approved the manuscript.

Ethics approval and consent to participate

Not applicable.

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Not applicable.

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Conflict of interest

The authors declare no conflict of interest.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at https://www.imrpress.com/journal/RCM/23/2/10.31083/j.rcm2302074.

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