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**FULL RESEARCH PAPER**
*Cardiac Rehabilitation*

# Impact of activity trackers on secondary prevention in patients with coronary artery disease: a systematic review and meta-analysis

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**Aims** Coronary artery disease (CAD) is related to high rates of morbidity and mortality among cardiovascular diseases (CVDs). Activity trackers have been used in cardiac rehabilitation (CR) in the last years. However, their effectiveness to influence outcomes after CAD is debated. This review summarizes the latest data of impact of activity trackers on CVD risk and outcomes: peak oxygen consumption ($VO_2$), major adverse cardiovascular events (MACE), quality of life (QoL), and low-density lipoprotein-cholesterol (LDL-C).

**Methods and results** Articles from 1986 to 2020 in English were searched by electronic databases (PubMed, Cochrane Library, and Embase). Inclusion criteria were: randomized controlled trials of CAD secondary prevention using an activity tracker which include at least peak $VO_2$, MACE, QoL, or LDL-C as outcomes. Meta-analysis was performed. After removing duplicates, 604 articles were included and the screening identified a total of 11 articles. Compared to control groups, intervention groups with activity trackers significantly increased peak $VO_2$ [mean difference 1.54; 95% confidence interval (CI) (0.50–2.57); $P = 0.004$] and decreased MACE [risk ratio 0.51; 95% CI (0.31–0.86); $P = 0.01$]. Heterogeneity was low ($I^2$ = 0%) for MACE and high ($I^2$ = 51%) for peak $VO_2$. Intervention with an activity tracker also has positive impact on QoL. There was no between-group difference in LDL-C.

**Conclusion** CR using activity trackers has a positive and multi-faceted effect on peak $VO_2$, MACE, and QoL in patients with CAD.

**Keywords** Activity tracker • Secondary prevention • Coronary artery disease

## Introduction

Cardiovascular disease (CVD) has the highest rate of mortality of all non-communicable diseases.[1] Cardiac rehabilitation (CR) is defined as a structured multidisciplinary intervention for cardiovascular risk assessment and management, advice on physical activity, psychosocial support, and the appropriate prescription and adherence to cardioprotective drugs.[2] CR, one of the secondary prevention, is essential to reduce the burden of recurrent coronary artery disease (CAD),[3] but are underused. Recent developments of mobile technologies in CR and secondary prevention have led to new opportunities to provide home-based and long-term care. One of the advantage of the high-tech accelerometers are their non-invasiveness and its convenient use which makes them suitable not only for patients but for healthy subjects as well.[4] Saner *et al.*[5] stated that wearable devices can help the activity tracking and personal data collection, which has the potential for maintaining and stimulating patients' interest in prevention and management of chronic diseases including CVD. Reid *et al.*[6] also reported that tracking CVD patients' objective parameters may enhance their self-management skills and improve their long-term behavioural

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change towards a healthier lifestyle. In addition, as the usual CR in the rehabilitation centre became less accessible due to the COVID-19 pandemic, the benefit of using an activity tracker has become even more a topic of interest to perform an adequate self-monitoring.[7]

The number of reviews about the topic has increased rapidly since 2017.[8–10] However, according to a review from the American Heart Association (AHA), there is still a lack of scientific evidence of mobile health technologies' efficacy for reducing CVD's risk factors.[11] Moreover, a comprehensive and exhaustive review of the effectiveness of CR with activity trackers for the prognostic outcomes after acute coronary syndrome has not yet been recently published.

The first systematic review and meta-analysis of the effectiveness of a pedometer were published in 2007.[12] New devices are emerging every day. The purpose of this systematic review and meta-analysis is to summarize the latest available data on efficacy of CR using activity trackers on CVD risk, exercise capacity, quality of life (QoL), and cardiovascular outcomes.

# Methods

## Data sources and search

The search was conducted in adherence to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) reporting guideline.[13] No study protocol was registered. PubMed, Cochrane Library, and Embase databases were searched for studies published between 1986 and October 2020. The search was performed iteratively for synonyms of 'coronary artery disease', 'physical activity', and 'activity tracker' by controlled vocabulary (like MeSH or Emtree) and free text words (Supplementary material online, *Figure S1*). Only randomized controlled trials (RCTs) with an adult study population, which is more than 20 years old, were included. The reference lists and referred articles of the identified relevant papers including reviews were cross-checked for additional references.

## Study selection

This review included full-length research papers published in peer-reviewed journals. Inclusion criteria for studies were as follows: (a) describing an RCT written in English; (b) subjects were diagnosed with CAD [myocardial infarction, stable/unstable angina pectoris, undergone Percutaneous coronary intervention (PCI) and/or coronary artery bypass grafting (CABG)]; (c) comparing an activity tracker device (which has an accelerometer and/or pedometer function and included smartphones and watches) with usual care during and/or after CR; and (d) describing at least one of the following outcomes comparing before and after the intervention: peak oxygen consumption ($VO_2$), major adverse cardiovascular events (MACE), QoL, or low-density lipoprotein-cholesterol (LDL-C). At first papers were included following the inclusion criteria (a)–(c). After checking each outcome of the papers, these four outcomes were chosen because more papers set them as outcomes and related to the secondary prevention of CAD. Regarding (c), a structured exercise programme was at least needed in all of the CR components defined above.

Two investigators (T.K. and V.I.-G.) checked all identified articles on their titles and abstracts. All duplicates were excluded. If there was doubt about eligibility, articles were read in full. A third investigator (M.S.) resolved differences in decision-making. The selection procedure was conducted according to the PRISMA guideline.[13]

## Data extraction

For each selected RCT, the first physician (T.K.) completed the data extraction. It included authors, year of publication, country of trial, number of patients including their characteristics (e.g. the diagnosis), their achievement rate of RCT and details of drop-out. Moreover, the kind of devices used, study duration from randomization to the end of follow-up periods, intervention duration of activity trackers, and the type of intervention were extracted. Eventually, the outcome data regarding changes in peak $VO_2$, MACE, QoL, and LDL-C was gathered. The corresponding authors of selected papers were contacted for completion of missing information. Two authors (Dr Bernocchi and Dr Izawa) gave additional information. The selection process is shown in *Figure 1*.

## Study quality

Two investigators (T.K. and V.I.-G.) separately assessed the risk of bias of included articles and a third investigator (M.S.) compared the results. The methodological risk of bias of these studies was checked according to the Cochrane Handbook for Systematic Reviews of Interventions[14] which includes the following seven parameters (random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other sources of bias). Each parameter is scored as high, low, or unclear risk of bias. Studies were considered to be at high risk of bias if that random sequence generation or allocation concealment showed a high or unclear risk.

## Data synthesis and statistical analyses

As shown in *Figure 1*, a total of 11 articles were identified. Peak $VO_2$ and MACE were suitable for meta-analysis. A narrative synthesis was carried out for QoL and LDL-C because of heterogeneity and lack of the data in measurement of outcomes.

Moreover, Review Manager Version 5.4 for Windows (The Cochrane Collaboration, Oxford, UK) was used to carry out a meta-analysis to explore the effect of an activity tracker for CAD secondary prevention on peak $VO_2$ and MACE. Differences were investigated for two comparative groups (with vs. without an activity tracker). Effect sizes for relative risks and 95% confidence interval (CI) were calculated for peak $VO_2$ and MACE. Random effects modelling was performed because of the variability of duration, delivery and assessment across studies. Heterogeneity was assessed by Q statistics with $I^2 > 75\%$ being consistent with a high level of heterogeneity.[15] All tests were done at a 5% significance level. For peak $VO_2$, mean changes and standard deviations (SDs) from baseline were used if available. For the trials which did not report the SD of the change in the outcome, values were imputed by a validated strategy.[16] These values were calculated by specific pre- and post-intervention SD with the formula: $SD_{pre-post} = (SDpre)2 + (SDpost)2 - 2 \times R \times SDpre \times SDpost$ and a conservative estimation of within-patient correlation (R) = 0.7 was assumed followed by Rosenthal's recommendation.[17]

# Results

## Study characteristics

Thirty-nine full-text articles were assessed for eligibility and eleven RCTs that met the inclusion criteria were selected[18–28] (*Table 1*). A total of 1356 patients was included in the 11 RCTs. Four studies were from Europe (the Netherlands,[19] Italy,[23] and Belgium[24,26]), one

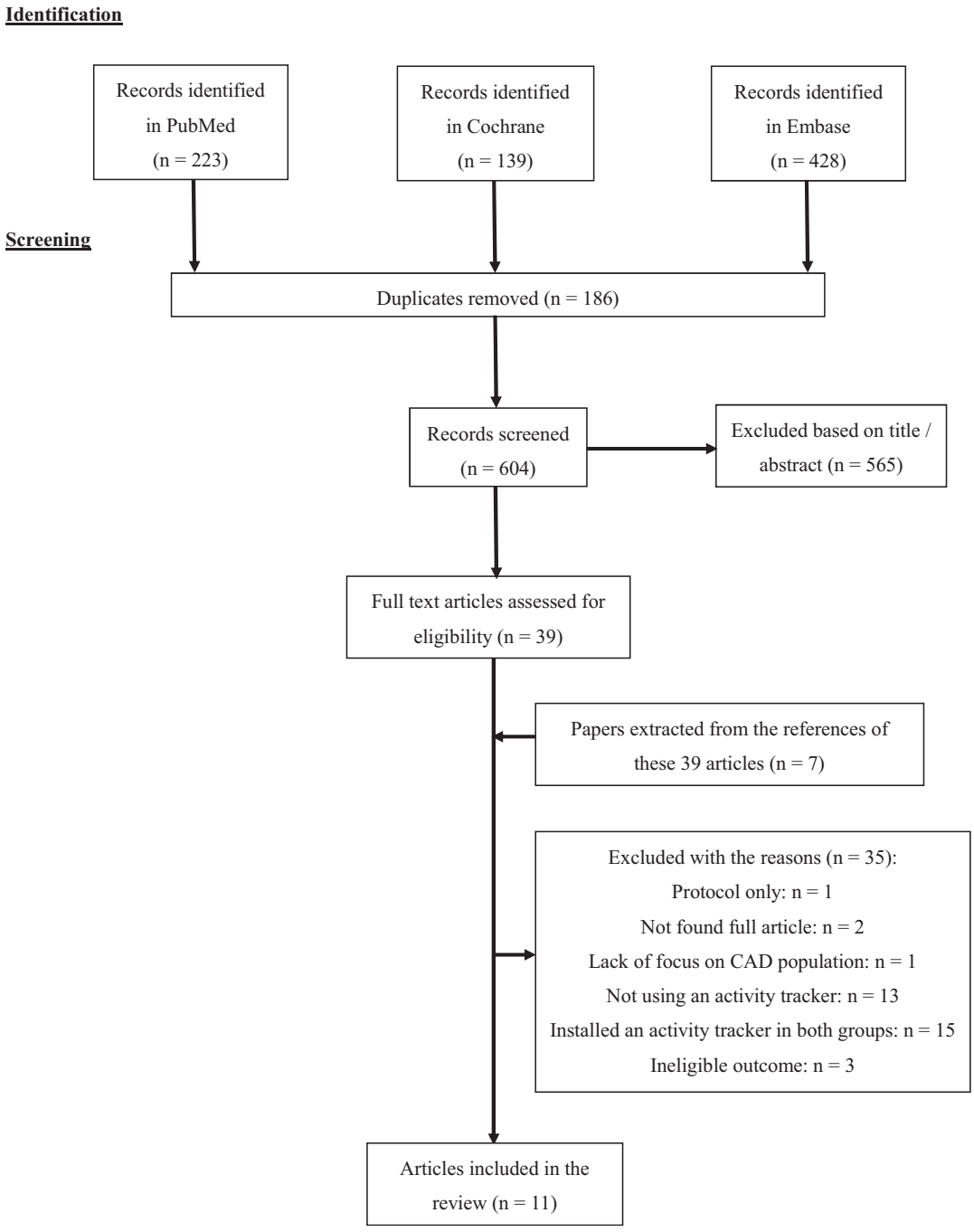



**Figure 1** PRISMA diagram of the study selection strategy.

was from the USA,[27] three were from Asia (China[18,22] and Japan[20]), and three were from Oceania (Australia[21,28] and New Zealand[25]). The rate of male and mean ages of participants ranged respectively from 62.7% to 87.5% and 54–71 years. The sample size ranged from 32 to 312. One study[26] demonstrated significant younger mean ages in the intervention group compared to the control group. Diagnosis of patients included in the studies were acute myocardial infarction or unstable angina ($n = 7$), CAD ($n = 5$), PCI ($n = 3$), chronic heart failure ($n = 3$), and CABG ($n = 2$). Only one study[23] includes CVD patients other than CAD (65 CAD patients out of a total of 112 patients). The details of patient characteristics are shown in *Table 1*.

**Table 1 Study and participant characteristics**

| Articles (year), country | Patients' diagnosis | No. of randomized patients | Male, % | Mean or median age, years | Patients who complete the study, % |
|---|---|---|---|---|---|
| Song (2020),[18] China | Stable CHD by coronary angiography | 106 | 86.5 | 54 | 90.6 (96/106) |
| Treskes (2020),[19] Netherland | AMI | 200 | 78.0 | 60 | 85.5 (171/200) |
| Dorje (2019),[21] Australia | CHD (including MI and unstable or stable angina) treated with PCI during their index admission | 312 | 81.4 | 61 | 84.9 (265/312) |
| Fang (2019),[22] China | Patients with low risk after PCI | 80 | 62.7 | 61 | 83.8 (67/80) |
| Bernocchi (2018),[23] Italy | CHF (NYHA class II–IV) and COPD (GOLD class B, C, and D) | 112 (in which 65 were diagnosed CAD) | 82.1 | 71 | 71.4 (80/112) |
| Duscha (2018),[27] Unites States of America | MI with PCI or CABG, PCI without MI, CABG with MI, valve repair with CABG, HF, and stable angina/MI only | 32 | 76.0 | 62 | 78.1 (25/32) |
| Frederix (2015),[24] Belgium | CAD and treated conservatively with a PCI or with CABG, CHF with reduced EF, or CHF with preserved EF | 140 | 81.4 | 61 | 90.0 (126/140) |
| Maddison (2015),[25] New Zealand | IHD, defined as angina, MI, revascularization, including angioplasty, stent, or CABG within the previous 3–24 months | 171 | 81.3 | 60 | 89.5 (153/171) |
| Frederix (2015),[26] Belgium | ACS for which a PCI or CABG was performed | 80 | 83.0 | 61 | 82.5 (66/80) |
| Varnfield (2014),[28] Australia | MI | 120 | 87.5 | 55 | 60.0 (72/120) |
| Izawa (2005),[20] Japan | MI | 50 | 84.4 | 64 | 90.0 (45/50) |

ACS, acute coronary syndrome; AMI, acute myocardial infarction; CABG, coronary artery bypass grafting; CAD, coronary artery disease; CHD, coronary heart disease; CHF, chronic heart failure; EF, ejection fraction; GOLD, Global Initiative for Chronic Obstructive Lung Disease; IHD, ischaemic heart disease; NYHA, New York Heart Association; PCI, percutaneous coronary intervention.

## Types of the activity tracker and characteristics of intervention for physical activity

Included studies used devices with a function of an accelerometer or a pedometer in the intervention group continuously during the study period. They included a software installed on a smartphone (MEMRS-CRS developed by Medicus,[18] SMART-CR/SP system delivered via the social media platform WeChat,[21] and StepCounter by Nokia Research[28]), a belt strap with sensor (Ucare RG10[22]), a wearable pedometer (Pulse Ox; Withings[19]) (Kenz Lifecorder; Suzuken[20]) (not shown[23,25]), and a wearable accelerometer (Yorbody accelerometer[24,26]) (Fitbit Charge; Fitbit[27]).

There were various kinds of interventions in the studies (Supplementary material online, *Table S1*). In the intervention group, feedback of an activity tracker was performed by medical staffs,[18,24,27,28] nurse practitioner,[19] nurse,[23,25] doctor,[21,25] and physical therapist.[20,22,23,25] The studies used health application,[27] email or text messaging,[18,21,24–26] telephone call,[18,22,23,28] a virtual meeting room via internet,[19] website,[25] home visits,[22] or written feedback[20] as a method of communication. Other than an activity tracking also blood pressure and heart rate,[18–21,23,28] pulse oximetry,[23] weight,[19,20,28] single-lead electrocardiogram,[19,23] and health diary preinstalled with a smartphone[28] were measured in the included studies. Education about lifestyle behaviour was given through an online platform, phone-call, or in-person in the intervention groups in almost all the studies.[18,21–28]

The control group also received regular outpatient follow-up and usual community-based CR. In a selection of studies, patients received the education with paper-based CAD educational booklets[22] including psychological support.[24–26]

## Reasons for dropout

The study periods ranged from 1.5 to 12 months and the mean periods were 6.7 months. The mean completion rates among the included trials were 83.1% (range 60.0%[28] to 90.6%[18]). Common causes for drop-out included loss of interest or motivation,[18,24,26–28] family reasons,[18,28] work reasons,[18,28] medical reasons,[19,24–27] lack of time,[28] change in personal circumstances,[28] and technical problems about the device or application.[18,24,26,28] Not all articles reported precise reasons for dropout.[21–23]

## Study quality

The risk of bias was assessed in each study. All 11 studies demonstrated a low risk of bias for random sequence generation, all studies showed a low-risk bias for allocation concealment. However, one study[26] showed mean ages in the intervention group was younger than the control group, which showed the randomization approach was insufficient or has failed as known confounders have not been balanced. Blinding of participants and personnel was not possible due to the nature of the intervention. Blinding of outcome assessment was not demonstrated in most studies. Both attrition and reporting bias were low. Overall, 10 out of 11 studies were thought to be of high quality (Supplementary material online, *Figure S2*).

## Outcomes

### Peak oxygen consumption

Six studies reported peak $VO_2$ as one of the cardiopulmonary exercise test (CPET) parameters of exercise tolerance (*Table 2*). *Figure 2* showed the meta-analysis and forest plot results performed between two groups. Peak $VO_2$ was significantly increased in the intervention group compared to the control group in overall effect [mean difference 1.54; 95% CI (0.50–2.57); $P = 0.004$] with substantial heterogeneity found ($I^2$ = 51%, $P = 0.07$). Further subgroup analysis was performed on studies that used just a pedometer[20,25] (*Figure 2*, *middle panel*) and a device without a pedometer[18,24,26,27] (*Figure 2*, *lower panel*). There was a non-significant increase in peak $VO_2$ [mean difference 0.32; 95% CI (−0.52 to 1.15); $P = 0.46$] across studies using a pedometer. A significant increase was observed in peak $VO_2$ [mean difference 2.23; 95% CI (1.26–3.20); $P < 0.001$] across studies using a device with an accelerometer (without a pedometer). No significant heterogeneity was found in both subgroups ($I^2 = 0\%$).

### Major adverse cardiovascular events

Three studies[19,23,26] described MACE (*Table 2*). Treskes *et al.*[19] defined MACE as the composite outcomes of death, recurrent myocardial infarction, hospitalization for heart failure, elective revascularization, and out-of-hospital cardiac arrest. Bernocchi *et al.*[23] defined it as the composite outcomes of death, recurrent hospitalization for CVD. Frederix *et al.*[26] showed its definition as the composite outcomes of death, recurrent cardiovascular events, and recurrent hospitalization for CVD. *Figure 3* illustrated the meta-analysis and forest plot results performed for MACE between two groups. There was no significant heterogeneity in the studies and two out of three studies showed decreased MACE in the intervention group. MACE was significantly decreased in the intervention group compared to the control group in overall effect [risk ratio 0.51; 95% CI (0.31–0.86); $P = 0.01$; $I^2 = 0\%$].

### Quality of life

Five studies demonstrated QoL compared with vs. without an activity tracker for the secondary prevention of CAD (*Table 2*). Dorje *et al.*[21] used the 12-Item Short Form Health Survey (SF-12) mental and physical health score[29] as indicator for QoL. No adjusted mean difference between intervention and control groups was found at either 2 or 6 months [SF-12 mental health score, −0.93 (−3.34 to 1.49) at 2 months ($P = 0.45$) and −1.44 (−4.05 to 1.18) at 6 months ($P = 0.28$); SF-12 physical health score, 0.61 (−1.23 to 2.46) at 2 months ($P = 0.52$) and 1.26 (−0.74 to 3.26) at 6 months ($P = 0.22$)]. Fang *et al.*[22] used the 36-Item Short Form Survey (SF-36) version 2 score.[30] After the 6-week intervention, the improvement in SF-36 score was significantly greater for the intervention group than that in the control group [SF-36 mental component summary scale, 11.39 vs.4.27 ($P = 0.021$); SF-36 physical component summary scale, 14.18 vs. 6.75 ($P = 0.015$)]. Bernocchi *et al.*[23] adopted Minnesota Living with Heart Failure Questionnaire (MLHFQ)[31] as a parameter of QoL. It was significantly improved in the intervention group compared with the control group [−10.5 (−14.2 to −6.8) vs. −0.44 (−4.9 to 4.0) at 4 months ($P = 0.0007$)], intervention group maintained the benefits acquired at 6 months ($P = 0.0001$). Frederix *et al.*[24] used 14-item offline HeartQol questionnaire[32] in the study. Between-group analysis confirmed that HeartQoL in the intervention group improved more than the control group ($P = 0.01$). Maddison *et al.*[25] showed the EuroQol five-dimensional questionnaire (EQ-5D)[33] and SF-36 version 2 scores to evaluate QoL. There were significant improvements in the general health domain of the SF-36 [difference 2.1 (0.1 to 4.1) at 24 weeks ($P = 0.03$)] for interventional groups, but no statistically significant differences were observed in EQ-5D between the two groups [difference 0.03 (−0.02 to 0.08) at 24 weeks ($P = 0.03$)]. Varnfield *et al.*[28] adopted EQ-5D as a parameter of QoL. Statistical significance was observed for the difference in the means in EQ-5D-Index for interventional groups [difference −0.08 (−0.14 to −0.02) at 6 weeks ($P = 0.01$)].

### Low-density lipoprotein-cholesterol

Three out of four studies, which compared LDL-C with and without an activity tracker, showed negative results (*Table 2*). Song *et al.*[18] reported that there was no significant change in the control rate of LDL-C after 6 months of follow-up between the intervention and control group. Frederix *et al.*[24] also reported that LDL-C did not change during the study period (24 weeks) in the intervention group ($P = 0.20$) nor the control group ($P = 0.31$). Varnfield *et al.*[28] showed no statistical significance was observed for the difference in the means in LDL-C [−0.11 (−0.42 to 0.20) at 6 months ($P = 0.50$)] between the intervention and the control group.

# Discussion

## Main findings

A systematic review was conducted which shows the utility of CR with an activity tracker for patients with CAD. The outcomes of the study are summarized as the following main findings. (i) Wearing an activity tracker continuously in CR has a positive impact in reducing MACE and improving peak $VO_2$ in CPET and QoL in secondary prevention of CAD. (ii) However, the intervention did not show a decrease in LDL-C. These observations suggest that wearing an activity tracker constantly during CR has a multi-faceted impact on outcomes related to CVD.

## Study characteristics

There are several types of not only interventions based on activity trackers but also CR programmes including education for exercise, diet, and behaviour. The use of activity trackers and feedback in combination with classical CR are summarized in this review. There are

**Table 2 Details of the included studies in terms of the outcomes**

| Articles | Outcomes |
|---|---|
| Song (2020)[18] | [Peak $VO_2$] Main effect of intervention was statistically significant in peak $VO_2$ between the two groups regardless of the time factor ($P = 0.007$).<br>[MACE] No serious complications or adverse events occurred during follow-up.<br>[QoL] NA<br>[LDL-C] There were no statistically significant differences in LDL-C between the two groups. |
| Treskes (2020)[19] | [Peak $VO_2$] NA<br>[MACE] In total, 20 hospitalizations for nonfatal adverse cardiac events occurred. Eight occurred (2 recurrent AMIs, 2 out-of-hospital cardiac arrests, and 4 elective revascularizations) in the intervention group and 12 (1 heart failure admission, 2 recurrent AMIs, and 9 elective revascularizations) in the control group. These differences were not statistically significant.<br>[QoL] NA<br>[LDL-C] NA |
| Dorje (2019)[21] | [Peak $VO_2$] NA<br>[MACE] No adverse events or SMART-CR/SP programme-related safety issues were recorded during the study.<br>[QoL] No difference between groups was found at either 2 months or 6 months for quality of life.<br>[LDL-C] No differences in LDL-C were observed between groups at 2 months and 6 months. However, at the 12-month follow-up, LDL-C was significantly lower in the intervention group than in the control group ($P = 0.016$). |
| Fang (2019)[22] | [Peak $VO_2$] NA<br>[MACE] NA<br>[QoL] Patients in the intervention group had significantly greater improvement in QoL evaluated by SF-36 Health Survey than those in the control group ($P = 0.015$ for SF-36 PCS, $P = 0.021$ for SF-36 MCS).<br>[LDL-C] NA |
| Bernocchi (2018)[23] | [Peak $VO_2$] NA<br>[MACE] In the intervention group, the media time to hospitalization/death was longer than the control group ($P = 0.048$, log-rank test). Hospitalizations were 21 in the intervention group (11 for CVDs, 6 for respiratory diseases, and 5 for other causes) and 37 in the control group (25 for CVDs, 11 for respiratory diseases, and 1 for other causes).<br>[QoL] ΔMLHFQ was significantly improved in the intervention group compared with the control group ($P < 0.001$) at 4 months<br>[LDL-C] NA |
| Duscha (2018)[27] | [Peak $VO_2$] The combination of an increase in the intervention group and a decrease in the control group resulted in a significant difference for absolute peak $VO_2$ between groups ($P \leq 0.05$).<br>[MACE] NA<br>[QoL] NA<br>[LDL-C] NA |
| Frederix (2015)[24] | [Peak $VO_2$] Between-group analysis of aerobic capacity was significant after 24 weeks ($P < 0.001$) in favour for the intervention group.<br>[MACE] NA<br>[QoL] The intervention group patients showed a significant improvement in perceived HRQoL for the physical subscale from baseline to the end of study period ($P < 0.001$). Their global HRQoL score also improved significantly ($P < 0.001$). Between-group analysis confirmed that globally the intervention group's HRQoL improved more than the control group ($P = 0.01$).<br>[LDL-C] LDL-C did not change during the study period in the intervention group ($P = 0.20$) nor in the control group ($P = 0.31$). |
| Maddison (2015)[25] | [Peak $VO_2$] Both groups showed a small increase in peak $VO_2$ from baseline to 24 weeks; however, there were no differences between the intervention group and the control group ($P = 0.65$) at 24 weeks.<br>[MACE] NA<br>[QoL] There was significant improvements in the general health domain of the SF-36 ($P = 0.03$) at 24 weeks in the intervention group. No statistically significant differences were observed in EQ-5D between the two groups.<br>[LDL-C] NA |
| Frederix (2015)[26] | [Peak $VO_2$] In the intervention group, peak $VO_2$ increased significantly during follow-up ($P = 0.001$), whereas in the control group it did not ($P = 0.273$). Between-group analysis yielded significant results ($P = 0.013$).<br>[MACE] The Kaplan–Meier curve showed a trend towards fewer re-hospitalizations in the intervention group, compared to the control group ($P = 0.09$).<br>[QoL] NA<br>[LDL-C] In the both groups LDL-C exhibited no significant change during follow-up ($P = 0.099$, $P = 0.514$). Between-group analysis showed no significant result ($P = 0.065$). |

*Continued*

**Table 2** *Continued*

| Articles | Outcomes |
|---|---|
| Varnfield (2014)[28] | [Peak $VO_2$] NA<br>[MACE] NA<br>[QoL] EQ-5D-Index improved significantly in the intervention group compared with the control group ($P < 0.001$) at 6 weeks. Statistical significance was observed for the difference in the means in EQ-5D-Index for the intervention group at 6 weeks. Between-group differences for changes in EQ-5D-Index or K10 were not significant at 6 months.<br>[LDL-C] Between-group differences for changes in LDL-C was not significant both at 6 weeks and 6 months. |
| Izawa (2005)[20] | [Peak $VO_2$] Peak $VO_2$ was significantly different from initial values within each group ($P < 0.001$), but there were no statistically significant interaction periods by group ($P = 0.561$).<br>[MACE] NA<br>[QoL] NA<br>[LDL-C] NA |

AMI, acute myocardial infarction; CVD, cardiovascular disease; EQ-5D, the EuroQol five-dimensional questionnaire; HRQoL, the 14-item offline HeartQol questionnaire; K10, Kessler 10 Psychological Distress Scale; LDL-C, LDL-cholesterol; MACE, major adverse cardiovascular events; MCS, mental component summary scale; mHealth, mobile health; MLHFQ, Minnesota Living with Heart Failure Questionnaire; NA, not described in the paper; PCS, physical component summary scale; QoL, quality of life; SF-36, the 36-Item Short Form Survey; SMART-CR/SP, smartphone and social media-based cardiac rehabilitation and secondary prevention; $VO_2$, oxygen consumption.

also various types of feedback, most of the included articles adopting email or text message, in more recent articles also telephone calls. Therefore, we do not have enough evidence to decide which methods and programmes we should choose.

## Dropout rate

The dropout rate for the included studies in our review was less than 30% in most studies, which is consistent with dropout rates described in literature.[34,35] Especially, loss of motivation and technical problems of the devices are shown in several studies. For such a patient-related barriers, support from patients' family or friends and healthcare providers' endorsement is helpful.[36] Not only depending on patient individual effort but also involving society surrounding a patient may be a countermeasure for the dropout.

## Outcomes

### Peak oxygen consumption

This review indicated a significant increase in peak $VO_2$ in the intervention group (*Figure 2*). The review of Franssen *et al.*[37] indicated that utilizing a consumer wearable activity tracker has a significant impact on physical activity and other cardiometabolic parameters. Another recent review[38] mentioned wearable monitoring devices with exercise prescription or advice significantly improves cardiorespiratory fitness in a CVD population as compared to a group where no devices were used. Subgroup analysis showed a larger effect size in the studies using a device involving an accelerometer than using a pedometer. It may indicate that more information about patients' exercise help them improve their physical activity.

On the other hand, there is some concern. The positive studies[18,24,26,27] compared outpatient CR followed by home-based CR with wearable devices vs. outpatient CR alone. The recent review[39] reported mobile technologies for outpatient CR did not improve exercise capacity compared with outpatient CR alone. It also reported that there are no studies comparing home-based CR with and without mobile technologies directly. The fact that the content of the home-based CR itself is a confounding factor cannot be eliminated.

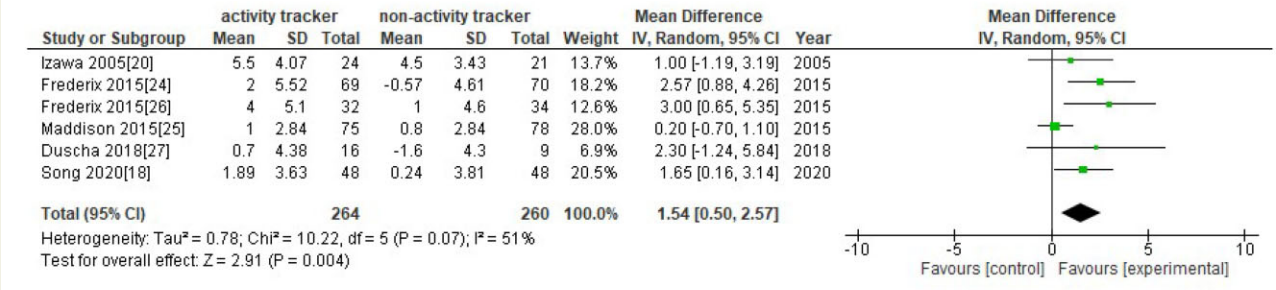
### Major adverse cardiovascular events

This review showed a significant decrease in MACE in the intervention group (*Figure 3*). There are lots of studies which report the positive effect of CR on MACE of the CAD patients, and 2017 European Society of Cardiology (ESC) Guidelines showed that participation in a CR programme is recommended.[40] A large meta-analysis demonstrated that CR is related to a reduction in cardiac mortality rate in CAD patients.[41] However, few meta-analyses analysing the effect of activity trackers on MACE were found.

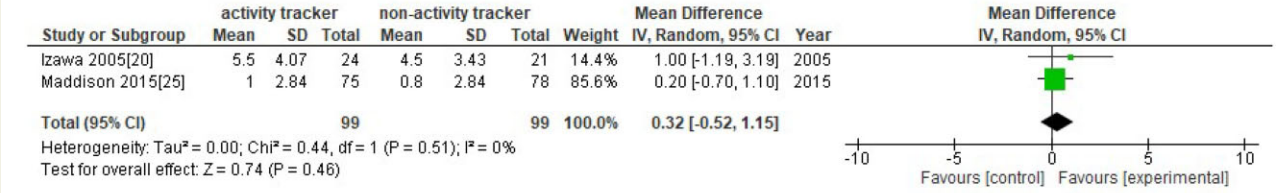
Peak $VO_2$ has been shown to be a powerful predictor of both non-fatal and fatal cardiac events among subjects with or without common cardiovascular risk factors.[42] The efficacy of CR with activity trackers for peak $VO_2$ is one of the mechanisms of improving MACE. Another study using education with a secure website as the intervention for preventing CVD showed a positive effect on reducing cardiovascular events.[43] As these articles illustrate, CR with the use of information and communication technology or wearable devices may affect MACE. The activity tracker may influence the cardiovascular prognosis separately from the mechanism of CR itself.

### Quality of life

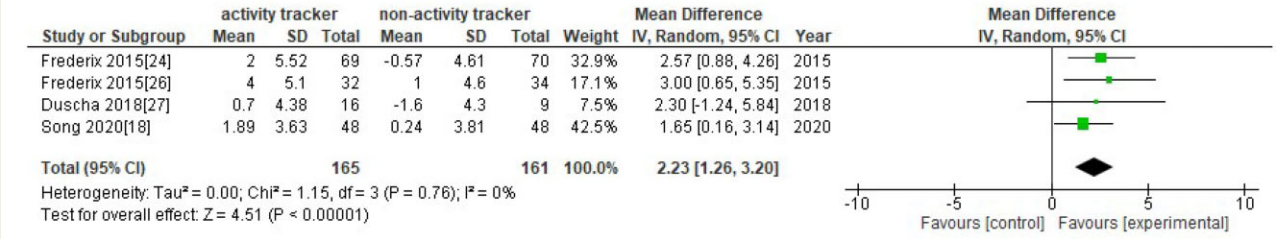
Five out of six articles showed QoL was improved in the intervention group. Many studies have shown the positive influence of CR on QoL. Regarding an activity tracker, the recent RCT[44] showed smart wearable devices have potential benefits of enhancing the QoL. Cowdery *et al.*[45] mentioned that wearable devices enhance the exercise motivation, perceived fitness, and pleasure of exercise. As can be concluded from these recent articles, there is evidence that CR with wearable devices can improve QoL, and the result of our review can be considered as consistent. Our review shows an additional effect of activity tracking and feedback on QoL in CR.




SD, standard deviation; IV, weighed mean difference; CI, confidence interval

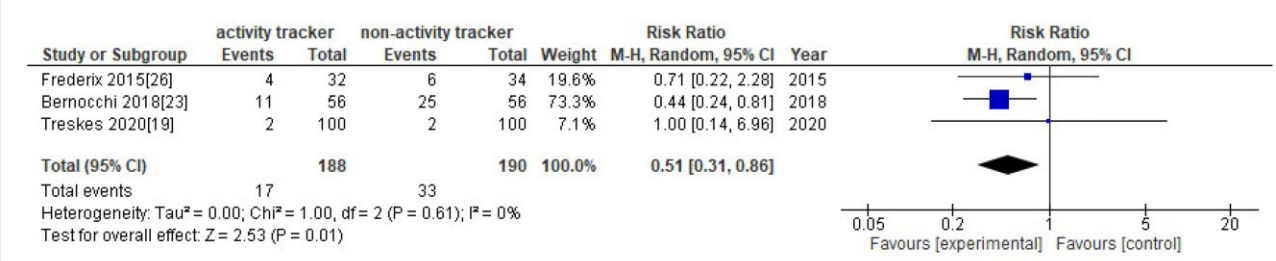



SD, standard deviation; IV, weighed mean difference; CI, confidence interval




SD, standard deviation; IV, weighed mean difference; CI, confidence interval

**Figure 2** Forest plot of peak $VO_2$ (upper panel, all six studies; middle panel, two studies with a pedometer intervention; lower panel, four studies without a pedometer intervention). CI, confidence interval; IV, weighed mean difference; SD, standard deviation.




M-H, Mantel-Haenszel test; CI, confidence interval

**Figure 3** Forest plot of MACE. CI, confidence interval; M-H, Mantel–Haenszel test.

### Low-density lipoprotein-cholesterol

Three out of four included studies did not show a significant decrease in LDL-C. Yu *et al.*[46] reported that most data about physical activity and blood lipids conclude that regular physical activity or exercise training does not decrease LDL-C concentration. Another review[47] mentioned that pharmacological intervention might have more beneficial effects for LDL-C decrease compared to increasing physical activity. These studies support the negative data in this review. The study periods of these studies[18,24,28] were less than 6 months and just one study[21] demonstrated a significant decrease in LDL-C at 12 months. Chiauzzi *et al.*[48] indicate that there is a lack of evidence supporting persistent effects on health outcomes, as studies are highlighted establishing the feasibility of monitoring activity with short-term benefits. The long-term result may be a subject for further study.

Finally, the recent review mentioned that CR using activity tracker, etc. (cardiac telerehabilitation) may be an alternative for hospital-based CR for stable CVD patients.[49] These devices enable patients to stay at home while taking part in CR in the COVID-era. This fact accelerates the need for using digital devices like activity trackers.

## Limitations

This review has some limitations. Firstly, only English language articles were included and no attempt was made to include the grey literature. Secondly, due to the heterogeneity of the outcomes, only three to six articles were included for each outcome's analysis despite the 11 articles totally included in the review. The insufficient numbers of the studies decreased the power of this review. Funnel plots could not be used because there were less than 10 studies included in each meta-analysis.[14] Thirdly, the variations in activity trackers themselves could not be avoided in this review. Not only an activity tracker, but the entire field of digital health is progressing rapidly and all studies use their own specific devices. However, articles which differentiate groups clearly between with and without activity trackers were selected and as such this review can measure the effect of CR with activity trackers as an intervention for secondary prevention of CAD. Lastly, one study[26] showed the potential selection bias which could not be ignored.

# Conclusion

This systematic review and meta-analysis demonstrate that using activity trackers with feedback in combination with CR has a positive and multi-faceted effect on peak $VO_2$, QoL, and major adverse cardiac and cerebrovascular events in patients with CAD.

# Supplementary material

Supplementary material is available at *European Journal of Preventive Cardiology* online.

**Conflict of interest:** The Authors declare that there is no conflict of interest.

## Data availability

All dataset analysed are included in this manuscript and supplementary materials.

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