Effectiveness of home-based cardiac rehabilitation interventions delivered via mHealth technologies: a systematic review and meta-analysis

Leah Li, Mickaël Ringeval, Gerit Wagner, Guy Paré, Cemal Ozemek, Spyros Kitsiou

Summary

Background Centre-based cardiac rehabilitation (CBCR) is underused due to low referral rates, accessibility barriers, and socioeconomic constraints. mHealth technologies have the potential to address some of these challenges through remote delivery of home-based cardiac rehabilitation (HBCR). This study aims to assess the effects of mHealth HBCR interventions compared with usual care and CBCR in patients with heart disease.

Methods We conducted a systematic review and meta-analysis of randomised controlled trials of mHealth HBCR interventions. Four electronic databases (MEDLINE, CENTRAL, CINAHL, and Embase) were searched from inception to March 31, 2023, with no restrictions on language or publication type. Eligible studies were randomised controlled trials of adult patients (age ≥18 years) with heart disease, comparing mHealth interventions with usual care or CBCR. The primary outcome of interest was aerobic exercise capacity, assessed with VO_2 peak or 6-min walk test (6MWT). Quality of evidence was assessed using the GRADE system. This review was registered with PROSPERO, CRD42024544087.

Findings Our search yielded 9164 references, of which 135 were retained for full-text review. 13 randomised controlled trials met eligibility criteria and were included in the systematic review, involving 1508 adults with myocardial infarction, angina pectoris, or heart failure, or who had undergone revascularisation. Intervention duration ranged from 6 weeks to 24 weeks. Random-effects meta-analysis showed that, compared with usual care, mHealth HBCR significantly improved 6MWT (mean difference 24·74, 95% CI 9·88–39·60; 532 patients) and VO_2 peak (1·77, 1·19–2·35; 359 patients). No significant differences were found between mHealth HBCR and CBCR. Quality of evidence ranged from low to very low across outcomes due to risk of bias and imprecision (small sample size).

Interpretation mHealth HBCR could improve access and health outcomes in patients who are unable to attend CBCR. Further research is needed to build a robust evidence base on the clinical effectiveness and cost-effectiveness of mHealth HBCR, particularly in comparison with CBCR, to inform clinical practice and policy.

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Department of Biomedical and Health Information Sciences (L Li MSN, S Kitsiou PhD) **and Department of Physical Therapy** (C Ozemek PhD), **College of Applied Health Sciences, University of Illinois at Chicago, Chicago, IL, USA; Department of Information Technologies, HEC Montréal, Montréal, QC, Canada** (M Ringeval PhD, Prof G Paré PhD); **Faculty of Information Systems and Applied Computer Science, Otto-Friedrich-Universität Bamberg, Bamberg, Germany** (G Wagner PhD)

Correspondence to: Dr Spyros Kitsiou, Department of Biomedical and Health Information Sciences, College of Applied Health Sciences, University of Illinois at Chicago, Chicago, IL 60612, USA **skitsiou@uic.edu**

Introduction

Coronary heart disease is the leading cause of death and disability globally.[1,2] Secondary prevention strategies, such as cardiac rehabilitation, are essential to managing and reducing the impact of coronary heart disease. Cardiac rehabilitation is a guideline-recommended programme aimed at stabilising, slowing, or even reversing cardiovascular disease progression.[3] The core components of cardiac rehabilitation are well recognised[4,5] and include patient assessment, exercise training, physical activity promotion, health education, nutritional counselling, psychological support, and cardiovascular disease risk factor management, personalised to the individual needs and condition of the patients diagnosed with heart disease. Cardiac rehabilitation programmes are delivered by a multidisciplinary clinical team that could include physicians (eg, cardiologists), nurses, clinical exercise physiologists, behavioural health experts, physical and respiratory therapists, dietitians, and others, who collaborate to deliver these services.[4,5]

Cardiac rehabilitation consists of three phases.[6] Phase I (clinical phase) begins in the inpatient setting soon after a cardiovascular event or procedure (eg, revascularisation or heart transplantation). Phase II cardiac rehabilitation (outpatient phase), known as centre-based cardiac rehabilitation (CBCR), is provided at outpatient settings after discharge from the hospital and typically includes up to 36 supervised, in-person sessions that take place over 12 or more weeks (about two to three 1-h sessions per week).[4] Phase III (post cardiac rehabilitation) is an extension of phase II cardiac rehabilitation, but involves more independence and self-monitoring, and seeks to help patients maintain healthy lifestyle behaviours.[6–8]

A considerable body of evidence supports cardiac rehabilitation as a clinically effective and cost-effective

Research in context

Evidence before this study

Cardiac rehabilitation is an evidence-based programme recommended for patients across a wide range of cardiac conditions, including acute coronary syndrome, heart failure, and coronary revascularisation. Cardiac rehabilitation programmes, predominantly delivered in outpatient settings known as centre-based cardiac rehabilitation (CBCR), are widely underutilised, prompting the development of alternative models such as home-based cardiac rehabilitation (HBCR), supported by telehealth technologies. Among the different types of telehealth modalities, the potential of mobile health technology-based interventions (mHealth) has been highlighted as a promising approach for the delivery of HBCR due to the increasing adoption of smartphones, mobile applications, and wearable sensor devices. We searched four electronic databases (MEDLINE, CENTRAL, CINAHL, and Embase) from inception to March 31, 2023, for studies and systematic reviews on the effects of mHealth HBCR, using a combination of keywords and Medical Subject Heading terms related to "cardiac rehabilitation", "telehealth", "mHealth", and "cardiovascular disease". We did not apply any language or publication type restrictions to the search. We found several clinical trials evaluating the effects of phase II mHealth HBCR in patients with coronary heart disease and heart failure. However, to our knowledge, no previous systematic review has synthesised this body of evidence to determine the effectiveness of mHealth HBCR compared with traditional CBCR or usual care. Previous systematic reviews and meta-analyses have used a broad scope of inquiry, treating technology interventions as one large category. Specifically, they combined findings from HBCR trials that used various and quite heterogeneous digital health or telehealth technologies (eg, videoconferencing, telephones, computers or laptops, smartphones, mobile applications, websites, and home telemonitoring equipment), without making a distinction between mHealth and other types of interventions. Some of these reviews also combined results from different cardiac rehabilitation phases (eg, phase II and phase III) or focused on one condition only (eg, percutaneous coronary intervention or heart failure), which further confounds or limits the generalisability of their results. Given the increased adoption of smartphones and unique opportunities that mHealth technologies create for expanding cardiac rehabilitation, particularly among hard-to-reach populations, it is important to investigate the effectiveness of phase II mHealth HBCR across a wider range of cardiac diagnoses to inform clinical practice, policy, and research.

Added value of this study

To our knowledge, this is the first systematic review and meta-analysis to assess the effect of phase II exercise-based cardiac rehabilitation delivered via mHealth technologies in patients with heart disease. We synthesised results from 13 randomised controlled trials encompassing 1508 patients with one or more of acute coronary syndrome, stable angina, revascularisation, and heart failure. Most studies (n=9) tested the effects of mHealth HBCR compared with usual care (standard outpatient visits without cardiac rehabilitation). Fewer studies compared mHealth HBCR with CBCR. By pooling results into meta-analyses, we found that, compared with usual care, mHealth HBCR interventions involving exercise training alone or in combination with other cardiac rehabilitation components could significantly improve functional and exercise capacity, blood pressure, resting heart rate, health-related quality of life, and depression in patients who are clinically stable after myocardial infarction or heart revascularisation, or who have angina or chronic heart failure. We found no significant differences between mHealth HBCR and CBCR interventions. The quality of evidence ranged from low to very low across outcomes due to insufficient information size (ie, small number of studies and small sample sizes) and potential risk of bias in the included studies, mainly due to lack of masking of health-care providers and patients, or outcome assessors.

Implications of all the available evidence

Our findings suggest that mHealth technologies hold promise for expanding cardiac rehabilitation outside of traditional in-person outpatient settings to offer remote intervention to patients, particularly those who are unable to attend CBCR in person, potentially improving health outcomes and overcoming barriers such as transportation, accessibility, and competing responsibilities (eg, work, childcare, or caring for older people). However, there is a crucial need for additional, well designed, and adequately powered randomised controlled trials to build a more robust evidence base on the effectiveness of phase II mHealth HBCR to inform clinical practice and policy.

intervention.[9] As such, clinical guidelines[5,10–16] consistently provide a strong recommendation for referral to cardiac rehabilitation for patients across a range of cardiac diagnoses, including acute coronary syndrome (eg, myocardial infarction and unstable angina), heart failure, and coronary revascularisation (percutaneous coronary intervention and coronary artery bypass graft surgery). Cardiac rehabilitation is also indicated for patients after heart valve surgery or heart-lung transplantation. Despite its benefits, referral to and participation in CBCR remain low,[17–19] particularly among women, minority racial and ethnic populations, and rural populations, and those with socioeconomic challenges.[19–23] In the USA, participation in CBCR ranges from 19% to 34%, with substantial geographical variation.[24–26] Similarly, referral and uptake of CBCR in Europe,[27,28] Canada,[29] and other countries is less than 50%.[30] Barriers to participation include low physician referrals, lack of programme availability, individual challenges such as time constraints, lack of

transportation, and social support, and socioeconomic factors.[21–23,31,32]

To overcome these challenges, alternative models, such as home-based cardiac rehabilitation (HBCR), have emerged, particularly those supported by telehealth technologies.[33–36] Telehealth is a broad term used to describe the use of health information and communication technologies for delivering care services at a distance.[37] The European guidelines on cardiovascular disease prevention in clinical practice state that the use of digital health tools supporting HBCR holds promise for increasing participation and supporting healthy lifestyle changes.[34] Similarly, a 2019 scientific statement from the American Heart Association, American College of Cardiology, and the American Association of Cardiovascular and Pulmonary Rehabilitation advocated for more research to assess whether technology-aided HBCR has a lasting favourable impact on programme enrolment, adherence, and clinical outcomes.[35] The COVID-19 pandemic and interruption of CBCR programmes as non-essential health services underscored the need for alternative cardiac rehabilitation models and revolutionised attitudes toward HBCR.[38,39]

One form of telehealth-supported HBCR that has gained significant popularity in recent years, due to the large increase in smartphone ownership[40] and advances in consumer-grade mobile sensor technology,[41,42] is mHealth HBCR.[36,43] The term mHealth refers to the use of mobile technologies to support health-care delivery and healthy lifestyle changes.[44] mHealth technologies include smartphones, mobile telephones, tablets, mobile health applications, text messaging, and wearable activity tracking and sensor devices, as well as digital health platforms[45] that enable individuals and health-care providers to communicate and track health-related data during activities of daily living. In contrast to traditional telehealth tools that are physically bound to the patient's home due to predominant reliance on desktop or laptop computers, landline telephones, or broadband internet service, mHealth technologies can make cardiac rehabilitation more accessible, efficient, and tailored to individual needs.[36] Smartphone applications can offer personalised, evidence-based exercise training plans, guide patients through each session, track their performance, and provide feedback in various formats (eg, text, graphs, or voice).[46] They can also provide patient education, counselling, medication reminders, and several other self-monitoring and cardiovascular disease risk management tools to engage participants in healthy lifestyle behaviours.[46] Wearable activity trackers and sensor devices can help patients self-monitor their exercise, physical activity, and physiological measures, and communicate these data to health-care providers to receive feedback.[41]

In recent years, several clinical trials have evaluated the effects of phase II mHealth HBCR in patients with heart disease. However, so far, no systematic review has synthesised this body of evidence to determine their effectiveness. A 2023 Cochrane review by McDonagh and colleagues[47] compared the effect of different types of HBCR interventions with supervised CBCR in patients with heart disease. Other systematic reviews[48–51] combined findings from HBCR trials using various telerehabilitation technologies (eg, videoconferencing stations and computer-based, smartphone-based, or web-based home telemonitoring stations), thus confounding the true effects of mHealth-supported interventions. Some of these reviews also mixed studies of phase II and phase III cardiac rehabilitation interventions or focused on one condition only (eg, percutaneous coronary intervention or heart failure).[48,50] Given the ubiquity of smartphones and the unique opportunities that mHealth technologies create for cardiac rehabilitation, it is important to investigate the effectiveness of phase II mHealth HBCR across a range of qualifying cardiac diagnoses (eg, acute coronary syndrome, heart revascularisation, and heart failure) to inform clinical practice, policy, and research.

This systematic review aims to identify and synthesise evidence from randomised clinical trials comparing the effects of phase II mHealth HBCR with usual care (without exercise prescription) or supervised CBCR in patients with heart disease.

Methods

Search strategy and selection criteria

This systematic review and meta-analysis was conducted and reported in accordance with the Cochrane Collaboration methodology[52] and the PRISMA statement (appendix pp 2–4).[53] The protocol was registered in PROSPERO, CRD42024544087.

See Online for appendix

Eligible studies were randomised controlled trials of adult patients (age ≥18 years) who were post myocardial infarction, had angina pectoris, or had undergone revascularisation (coronary artery bypass graft or percutaneous coronary intervention), or who had heart valve repair or replacement, or who had stable chronic heart failure, irrespective of left ventricular ejection fraction (LVEF) given that LVEF cutoffs for cardiac rehabilitation referral differ across countries, or who had coronary heart disease defined by standard non-invasive or invasive methods. Eligible interventions included phase II mHealth HBCR, defined as the use of non-invasive portable and wireless technologies (eg, one or more of smartphones, personal digital assistants, mobile applications, text messages, wearable activity trackers, wearable sensor devices, and other connected health technologies) to support exercise training alone or in combination with other established cardiac rehabilitation components. The comparison group was usual care or CBCR.

Four databases (MEDLINE, CENTRAL, CINAHL, and Embase) were searched from inception up to March 31, 2023, with no restrictions on language or

publication type. We excluded trials of phase I and phase III cardiac rehabilitation interventions, trials published as abstracts only, and non-English articles if translation was not possible and sufficient details regarding the participants, intervention, usual care, or outcomes could not be obtained through published reports or email contact with the authors. Electronic searches (appendix pp 5–18), developed by SK in consultation with the rest of the coauthors, were supplemented with manual searches of the reference lists of relevant studies and reviews. All references retrieved from the searches were imported into Covidence software and duplicates were removed. Two authors (LL and MR) independently screened all references for inclusion. Disagreements were resolved through discussion, adjudicated by SK.

For more on **Covidence** see https://www.covidence.org

Data analysis

Two reviewers (LL and SK) independently extracted data using a standardised data extraction form implemented in Microsoft Excel. Data included information about the study design, patient population, intervention components, control group, and outcomes. Disagreements were resolved through discussion. When the required study information or data were missing in the publication, we contacted the corresponding authors for details via email. Where necessary, we used RevMan 5.4.1 (Cochrane Collaboration, Copenhagen, Denmark) to calculate missing standard deviations using other data from the trial, such as confidence intervals.[52]

Risk of bias was assessed independently by two reviewers (LL and SK) using the Cochrane Collaboration risk of bias tool.[54] The following domains were assessed: random sequence generation, allocation concealment, masking of participants and personnel, masking of outcome assessment, incomplete outcome data, selective outcome reporting, and other bias. Each domain was assessed as having a low, high, or unclear risk of bias. Disagreements were resolved through discussion, and adjudication by MR.

The primary outcome of interest was aerobic exercise capacity, assessed with VO_2 peak or 6-min walk test (6MWT). Secondary outcomes were BMI, systolic and diastolic blood pressure, resting heart rate, lipid profile, and self-reported health outcomes (anxiety, depression, and quality of life). We performed random-effects meta-analyses with 95% CIs when the underlying clinical question, population, and treatments were similar enough for pooling to make sense. We used the random-effects model due to the clinical heterogeneity of the included studies (types of mHealth interventions and population characteristics). The rationale to pool studies into a meta-analysis irrespective of whether they focused on one condition (eg, heart failure) or a mix of conditions (coronary heart disease and heart failure) was based on the scope and research question of our review as well as the fact that contemporary guidelines on the management of coronary heart disease and heart failure consistently recommend CBCR as an effective and safe intervention for the conditions included in our review.[9] Our approach is similar to that of McDonagh and colleagues.[47]

Data analysis was performed separately for the two comparisons: mHealth HBCR versus usual care, and mHealth HBCR versus CBCR. All outcomes in the included studies were reported as continuous data. Therefore, we used the mean difference (MD) as the main effect measure when outcomes were measured across studies with the same scale or instrument, and standardised MD (SMD; Hedges' adjusted *g*) when different scales or versions of the same scale were used across studies to measure the same outcome. We interpreted an SMD of 0·2, 0·5, and 0·8 as representing a small, medium, and large effect size, respectively. When combining data on the (unstandardised) MD scale, we used change-from-baseline measurements (wherever available) or post-intervention measurements (alternative option) for each study. By contrast, when combining data using SMD, we used post-intervention data only.[52] Statistical heterogeneity was quantified using the χ^2 and I^2 statistical tests. We considered statistical heterogeneity to be important when I^2 was greater than 50%, the p value of the χ^2 test was less than 0·05, and studies differed in both magnitude and direction of effects. Per our protocol, we planned to conduct subgroup analyses to explore any significant heterogeneity in study results and examine potential treatment effect modifiers (eg, population case mix, exercise dose, or length of follow-up). We also planned to assess publication bias using funnel plots and Egger's test. However, the small number of studies (<10) included in the meta-analyses precluded such investigations. All meta-analyses were conducted using RevMan 5.4.1. using the intention-to-treat principle (ie, all participants and their outcomes were analysed according to the group to which they were allocated).

Quality of evidence by outcome of interest was assessed independently by two reviewers (LL and SK) using the GRADE system via GRADEpro software.[55] GRADE is an internationally recognised and widely used framework that offers a transparent, reproducible, and systematic approach to rating the quality of evidence (ie, confidence that the estimate of the effect is close to the true effect) at the outcome level by considering five domains: risk of bias,[56] inconsistency,[57,58] indirectness,[59] imprecision,[60,61] and publication bias.[62] Assessing and combining the results of the five domains determine the quality of evidence for each outcome of interest as high, moderate, low, or very low (appendix p 19).[63]

Role of the funding source

There was no funding source for this study.

Results

Our search yielded 9164 references. After removal of duplicates, we screened the title and abstract of

5983 references and retained 135 references for full-text review. Overall, 13 unique randomised controlled trials (18 references in total) were included in this systematic review (figure 1). The 117 articles that were excluded based on full-text review are listed in the appendix (pp 19–30).

The 13 included studies (table) were published between 2010 and 2022. Seven studies were conducted in Asia,[64–70] four in Europe,[71–74] one in Oceania,[75] and one in North America.[76] All studies were prospective, parallel-group randomised controlled trials examining the effects of phase II exercise-based cardiac rehabilitation delivered at home via the use of mHealth technologies. 1508 patients (18% female) were included in the 13 trials. Sample sizes ranged from 30 to 312 patients. The mean age of study participants ranged from 54·5 years to 73·0 years. The mix of participants' conditions varied, with five studies including a mixed population of coronary heart disease,[69–71,74,76] two studies including patients post myocardial infarction who received revascularisation,[66,75] one study including a mixed population with acute coronary syndrome having undergone percutaneous coronary intervention,[65] one study of patients with coronary heart disease who were treated with percutaneous coronary intervention during their index admission,[64] and four studies focusing exclusively on adults with heart failure.[67,68,72,73] A detailed overview of the included studies is provided in the appendix (pp 31–34). The duration of the intervention period in the included studies ranged from 6 weeks to 24 weeks, with exercise frequencies ranging from three sessions per week to daily. The main exercise type was aerobic exercise, with walking as the predominant mode (12 of 13 studies).[64,65–69,71–76] One study also offered resistance training.[67]

Two studies provided comprehensive cardiac rehabilitation with all core components,[65,71] whereas three studies used standalone exercise training.[69,73,74] 11 studies incorporated additional components, such as health education,[64,65,67,68,71,75] nutritional advice,[64,67,70,76] medication adherence support,[64,76] psychosocial well-being,[64,70,76] and smoking cessation.[64,70,71,76] Exercise intensity in the included studies was guided mainly by one or both of Borg scale[66,67,69,70,72–76] and heart rate reserve.[65,66,68,71–73,75]

All studies used smartphones (nine studies)[64,66–70,74–76] or mobile telephones (four studies)[65,71–73] in the HBCR interventions. Other monitored devices used in the intervention group included heart rate monitors,[65,66,69,71,74] electrocardiograph (ECG) monitors,[65,72,73] and blood pressure monitors.[64] The primary mHealth tools used for intervention delivery were mobile applications.[64,66–70,74–76] Monitored measures included heart rate, ECG, blood pressure, steps, Borg score, and others. In nine of the included studies, interventions were augmented with weekly or daily telephone calls.[65,67–69,71–75]

In four of the included studies, the comparison group was CBCR, whereas in the remaining nine studies the comparison group was usual care. CBCR comprised traditional, in-person sessions conducted in an outpatient setting. Training intensity was measured by Borg scale[72,75] or heart rate reserve.[71,72] Training frequency was three times per week in two studies[71,72] and twice per week in one study,[75] and in another study it was not reported.[66] Usual care involved standard outpatient care without exercise prescription or training.

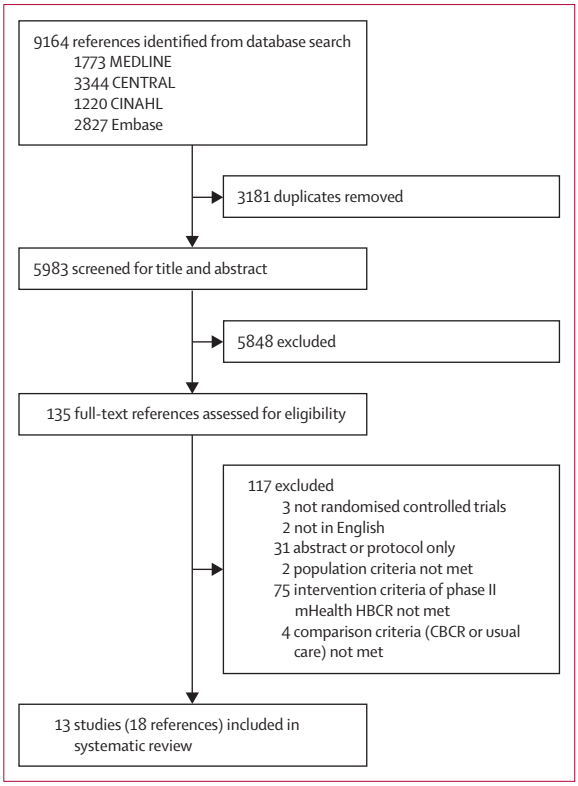


Figure 1: **Study selection**
No references were added by manual searching of reference lists. CBCR=centre-based cardiac rehabilitation. HBCR=home-based cardiac rehabilitation.

Results of the risk-of-bias assessment are presented in the appendix (pp 35–36). Random sequence generation and allocation concealment were found to be at low risk of bias in eight (62%) studies and unclear risk of bias in five (38%) studies. Masking of participants and cardiac rehabilitation personnel to group allocation is not feasible. Therefore, all studies were assessed as having a high risk of performance bias. For example, knowledge of group allocation might have affected the way interventions were provided, which, in turn, might have affected the study outcomes. Performance bias could operate in either direction and could be due to deviations from the protocol-specified intervention delivery or non-adherence to the assigned intervention by study participants due to knowledge of group assignment. Masking of outcome assessment was judged to be at low risk of bias in five (38%) studies, unclear risk of bias in five (38%) studies, and high risk of bias in three (23%)

	Country	Total sample size (intervention: control), n	Mean age (SD), years	Female participants, n (%) or n/N (%)*	Heart conditions	Intervention duration	CR session frequency	Type of mHealth intervention	Control group	Primary and secondary outcomes
mHealth HBCR *vs* usual care										
Dorje et al (2019)	China	312 (156:156)	60·5 (9·2)	58 (19%)	MI, angina, PCI	24 weeks	Four sessions per week in first 8 weeks, then two per week for 16 weeks	Smartphone-based home CR programme delivered via WeChat; the system included features such as social media communication, online education about cardiovascular health, physical activity tracking and prescription, nutritional advice, BP and HR monitoring (linked to an external monitor), wireless data transfer, and multimedia to support the delivery of comprehensive CR	Standard care, as provided by community doctors and cardiologists after hospital discharge, which included health education, medication management, and ad-hoc follow-up visits	Primary: 6MWT; secondary: SBP, RHR, BMI, TC, LDL cholesterol, HDL cholesterol, depression, HRQoL, and anxiety
Lee et al (2013)	South Korea	55 (26:29)	56·14 (8·3)	11 (20%)	MI, UA, PCI	12 weeks	Four to five sessions per week	Participants instructed to perform home-based gait exercise training while wearing a wireless monitor (HeartCall) and check their HR through their mobile telephones; ECG data sent to a server via mobile telephone; weekly telephone calls by study team for counselling	Standard medical therapy, diet control, and exercise at home on their own without participating in a CR programme	SBP, DBP, RHR, and HRQoL†
Nagatomi et al (2022)	Japan	30 (15:15)	63·7 (10·1)	14 (47%)	HF	12 weeks	Three to five sessions per week of aerobic exercise or two to three per week of resistance training	Comprehensive, individualised HBCR with exercise and nutrition guidance facilitated by patient's smartphone, a paired Fitbit device, and a text messaging tool or telephone	Standard medical care, including pharmacological and non-pharmacological therapy but not HBCR	Primary: 6MWT; secondary: TC and HRQoL
Olivier et al (2021)	USA	63 (31:32)	NR	13 (21%)	MI, revascular-isation, HF	12 weeks (90 days)	Four sessions per week	Comprehensive CR programme delivered via smartphone application (BrightHeart) and a CR coach; data such as medication adherence, lifestyle, and vitals entered by the participant or passively collected (eg, step count) through smartphone sensors; platform generated insights on performance and engagement and the coach modified the action plan as needed	Usual care without participating in CR programme	Primary: proportion of days covered by medications (NR); secondary: LDL cholesterol
Peng et al (2018)	China	98 (49:49)	66·3 (10·5)	40 (41%)	HF	8 weeks	Three sessions per week in weeks 1–4 and five per week in weeks 5–8	Telehealth exercise training and education programme (32 sessions) delivered via online webcam communication and supervision using QQ and WeChat software on smartphones	Usual care without any type of instruction regarding exercise	Primary: HRQoL; secondary: 6MWT, RHR, depression, and anxiety
Piotrowicz et al (2015)	Poland	111 (77:34)	56·7 (11·9)	12 (11%)	HF	8 weeks	Five sessions per week	Home-based telemonitored Nordic Walking training programme, consisting of EHO-MINI device, BP monitor, and weighing machine transmitting patient data to a monitoring centre via patient's mobile telephone; the device had training sessions pre-programmed for each patient	Usual care without formal exercise training prescription or supervised rehabilitation; recommendations for lifestyle changes and self-management according to clinical guidelines	Primary: VO_2 peak; secondary: SBP, DBP, RHR, depression, and HRQoL
Snoek et al (2021)	Netherlands, Denmark, France, Switzerland, Spain	179 (89:90)	73·0 (5·5)	34 (19%)	PCI, CABG	24 weeks	Five sessions per week	Home-based mobile guided CR with telemonitoring supported by smartphone application and heart belt, and coaching based on motivational interviewing to help reach exercise goals; patients were instructed to exercise at moderate intensity for at least 30 min per day, 5 days per week; motivational interviewing provided by telephone (weekly in month 1, biweekly in month 2, and monthly thereafter)	Locally defined standard care without any form of CR	Primary: VO_2 peak; secondary: SBP, DBP, BMI, TC, LDL cholesterol, HDL cholesterol, depression, HRQoL, and anxiety

(Table continues on next page)

	Country	Total sample size (intervention: control), n	Mean age (SD), years	Female participants, n (%) or n/N (%)*	Heart conditions	Intervention duration	CR session frequency	Type of mHealth intervention	Control group	Primary and secondary outcomes
(Continued from previous page)										
Song et al (2020)	China	106 (53:53)	54·5 (8·1)	13/96 (14%)	MI	24 weeks	Three to five sessions per week	Smartphone-based telemonitored CR software paired with a heart rate belt for monitoring patients' exercise, BP, and HR before and after exercise; WeChat used for communicating weekly with patients via text messages	Standard treatment consisting of routine discharge education and outpatient follow-up, which included advice to exercise regularly	Primary: VO_2 peak; secondary: exercise habits, blood lipid, blood glucose, and adverse events
Su and Yu (2021)	China	146 (73:73)	55·8 (7·1)	24 (16%)	PCI	12 weeks	150 min per week	Patients invited to a web platform and telehealth platform (WeChat) and provided with a pedometer; patients received goals from the platform and were encouraged to upload their data into it	Usual care, which was a 10-min didactic session on medication usage and lifestyle changes (physical activity, diet, and smoking cessation) delivered by staff nurses of the study hospital; for data collection, researcher taught control group participants how to use a pedometer	Primary: daily steps; secondary: SBP, DBP, BMI, depression, HRQoL, and anxiety
mHealth HBCR vs CBCR										
Batalik et al (2020)	Czech Republic	56 (28:28)	57·1 (7·2)	9/51 (18%)	MI, angina, PCI, CABG, HF	12 weeks	Three sessions per week	Home-based telerehabilitation programme involving use of a Polar wrist HR monitor and transfer of data to Polar Flow web application via mobile telephone; physiotherapists checked data and contacted patients via telephone once a week to give feedback in the form of recommendations, advice, and training motivation	Regular outpatient training (60 min per session, three sessions a week for 12 weeks), under direct supervision of a physiotherapist specialising in CR	Primary: VO_2 peak; secondary: HRQoL
Li et al (2022)	China	80 (40:40)	55·5 (8·5)	28 (35%)	MI with PCI	24 weeks	Seven sessions per week	HBCR delivered via remote ECG technology (Checkup app and exercise bracelet) for monitoring of exercise and HR, and WeChat for communication between patients and nurses via text messages; patients taught to monitor their HR using Checkup app or exercise bracelet and nurses collected patients' medication, exercise completion, and HR data	Traditional outpatient rehabilitation and weekly telephone calls to ask patients whether they took their medicines on time, exercised, and had any discomfort	Primary: 6MWT; secondary: LDL cholesterol and HRQoL
Piotrowicz et al (2010)	Poland	152 (77:75)	58·1 (10·2)	14/131 (11%)	HF	8 weeks	Three sessions per week	Home-based telemonitored CR programme using walking training; patients received an EHO 3 device, and a mobile telephone used to monitor and control training in any place where the patient elected to exercise; the EHO 3 enabled recording of ECG data and transmission via mobile telephone to the monitoring centre; the device had training sessions pre-programmed individually for each patient; the mobile telephone was also used for voice communication	Outpatient-based standard CR programme based on supervised interval training on a cycle ergometer for 8 weeks; ECG, HR, and BP were monitored during training sessions; Other CR components included education and psychological support	VO_2 peak, 6MWT, and HRQoL†

(Table continues on next page)

	Country	Total sample size (intervention: control), n	Mean age (SD), years	Female participants, n (%) or n/N (%)*	Heart conditions	Intervention duration	CR session frequency	Type of mHealth intervention	Control group	Primary and secondary outcomes
(Continued from previous page)										
Varnfield et al (2014)	Australia	120 (60:60)	55·6 (9·8)	12/94 (13%)	MI, angina	6 weeks	Most days	Comprehensive CR programme delivered via a CR platform which used a smartphone application for health and exercise monitoring, and delivery of motivational and educational materials via text messages and pre-installed audio and video files; participants given a smartphone pre-installed with a health diary and activity monitoring application, BP monitor, and weight scale. Activity monitoring (steps, duration, and intensity) was automatic through the telephone's built-in accelerometer	Traditional CBCR comprising two supervised moderate-intensity exercise sessions and 1-h educational sessions per week for 6 weeks; programme included cardiovascular and strengthening routines involving treadmill, rower, resistance bands, weights, squats, and modified push-ups	Primary: uptake, adherence, and completion of a CR programme; secondary: 6MWT, SBP, DBP, RHR, TC, LDL cholesterol, HDL cholesterol, depression, HRQoL, and anxiety

6MWT=6-min walking test. BP=blood pressure. CABG=coronary artery bypass grafting. CBCR=centre-based cardiac rehabilitation. CR=cardiac rehabilitation. DBP=diastolic blood pressure. ECG=electrocardiogram. HBCR=home-based cardiac rehabilitation. HF=heart failure. HR=heart rate. HRQoL=health-related quality of life. MI=myocardial infarction. NR=not reported. PCI=percutaneous coronary intervention. RHR=resting heart rate. SBP=systolic blood pressure. TC=total cholesterol. UA=unstable angina. *Some studies reported the number of female participants based on those who completed the study and were analysed rather than all randomly assigned participants; in these cases, the denominator has also been given in the format n/N (%). †The study did not report which of these was the primary outcome.

Table: Characteristics of the included randomised controlled trials

studies. Incomplete outcome data was found to be at low risk of bias in eight (62%) studies, unclear risk of bias in two (15%) studies, and high risk of bias in three (23%) studies. Selective reporting and other biases were found to be at low risk of bias in most studies (>85%).

Details of extracted outcomes can be found in the appendix (pp 37–42). A summary of findings tables and funnel plots by outcome of interest are also available in the appendix (pp 43–55). Ten (77%) studies[64,66–69,71–75] reported data on aerobic exercise capacity. Of these, six studies[64,67–69,73,74] compared mHealth HBCR with usual care and four studies[66,71,72,75] with CBCR. Pooled results showed that mHealth HBCR significantly improved VO_2 peak (MD 1·77, 95% CI 1·19–2·35; 359 participants in three studies; I^2=0%; figure 2A) and 6MWT (24·74, 95% CI 9·88–39·60; 532 participants in four studies; I^2=71%; figure 2B) compared with usual care. However, quality of evidence was low for both outcomes due to risk of bias and imprecision (optimal information size [OIS] not met).

Statistical heterogeneity in 6MWT results was high, but this was due to differences in magnitude of effects (all studies showed a consistent trend towards positive effect). Removing the study by Nagatomi and colleagues,[67] in which the intervention group was significantly younger than the control group (mean age 59·8 years [SD 10·0] in HBCR group *vs* 67·7 years [8·9] in control group; p=0·030) and the overall effect size appeared to be large compared with the other studies (outlying study), significantly reduced statistical heterogeneity (χ^2=2·52, p=0·28; I^2=21%). The summary effect size was smaller but remained statistically significant in favour of the intervention (MD 15·35, 95% CI 8·21–22·50; p<0·0001; I^2=0%).

Compared with CBCR, mHealth HBCR tended to improve VO_2 peak (MD 0·67, 95% CI –0·76 to 2·11; 182 participants in two studies; I^2=0%; figure 2A) and 6MWT (23·08, –36·91 to 83·06; 283 participants in three studies; I^2=96%; figure 2B). However, group differences were not statistically significant. There was substantial heterogeneity among studies in 6MWT results, which could not be explained by our post-hoc investigations. Quality of evidence was downgraded to low for VO_2 peak due to risk of bias and imprecision, and to very low for 6MWT due to risk of bias, substantial heterogeneity (inconsistency), and imprecision (OIS not met and wide 95% CI).

Six (46%) studies[64,65,70,73–75] reported data on blood pressure. Five studies[64,65,70,73,74] compared mHealth HBCR with usual care and one study[75] with CBCR. mHealth HBCR significantly reduced systolic blood pressure (MD –7·78, 95% CI –10·15 to –5·41; 741 participants in five studies; I^2=0%; figure 3A) and diastolic blood pressure (–2·33, –4·39 to –0·27; 429 participants in four studies; I^2=20%; figure 3B) compared with usual care. There was no evidence of important heterogeneity among study results. The quality of evidence was ranked

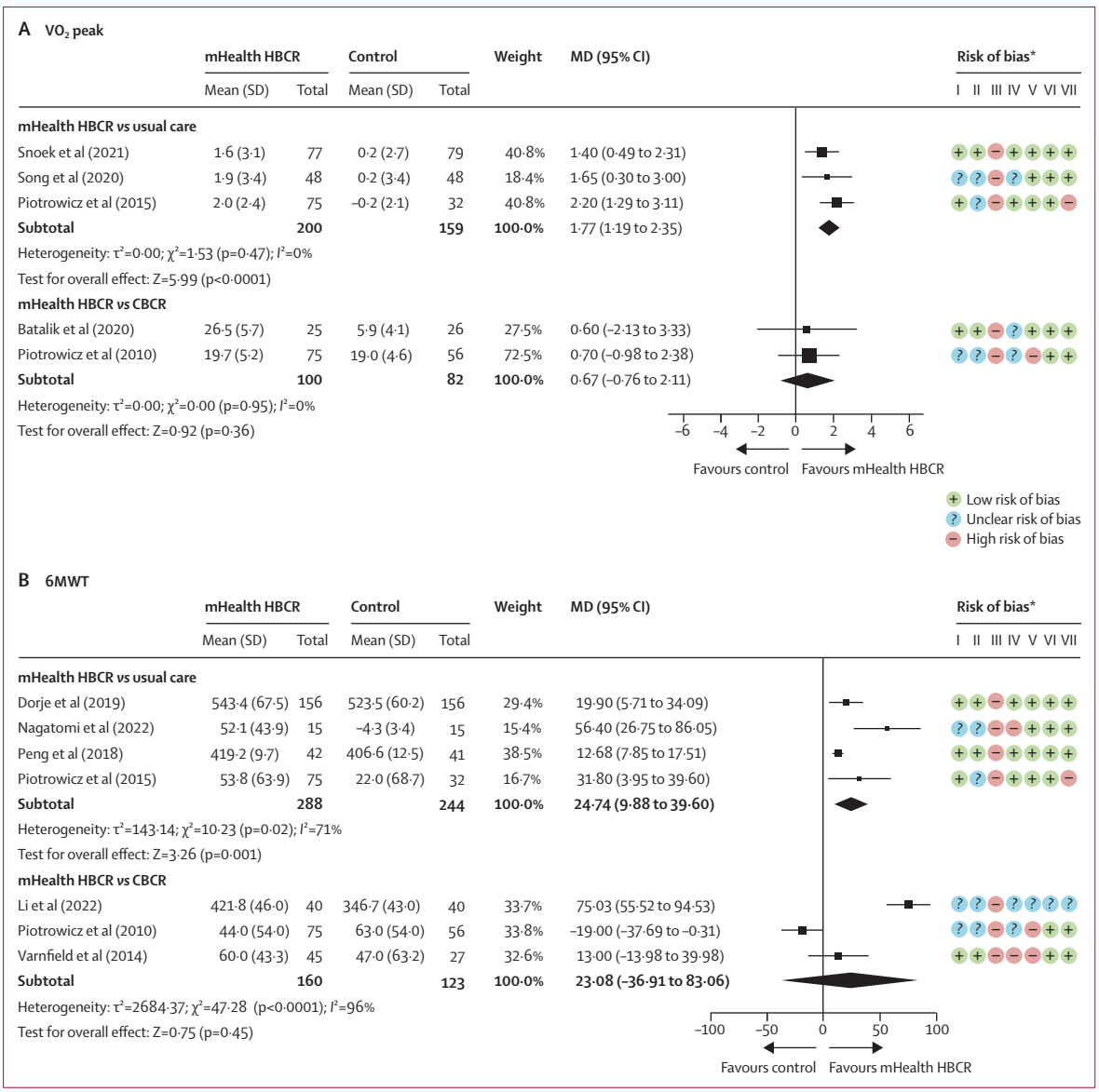


Figure 2: **Forest plots of VO_2 peak (mL/kg per min) and 6MWT (m)**
6MWT=6-min walk test. CBCR=centre-based cardiac rehabilitation. HBCR=home-based cardiac rehabilitation. MD=mean difference. *Risk of bias was assessed in seven domains, as shown in the columns below: (I) random sequence generation; (II) allocation concealment; (III) masking of participants and personnel; (IV) masking of outcome assessment; (V) incomplete outcome data; (VI) selective reporting; and (VII) other bias.

as low for both systolic and diastolic blood pressure due to risk of bias and imprecision (OIS not met). In the single study[75] (n=72) that compared mHealth HBCR with CBCR, there was a positive trend towards improvement in both systolic blood pressure (MD −3·14, 95% CI −13·82 to 7·54; figure 3A) and diastolic blood pressure (3·80, −8·71 to 1·11; figure 3B), but results were inconclusive due to lack of power. Confidence in the evidence was downgraded to very low due to risk of bias and imprecision (OIS not met and wide 95% CI).

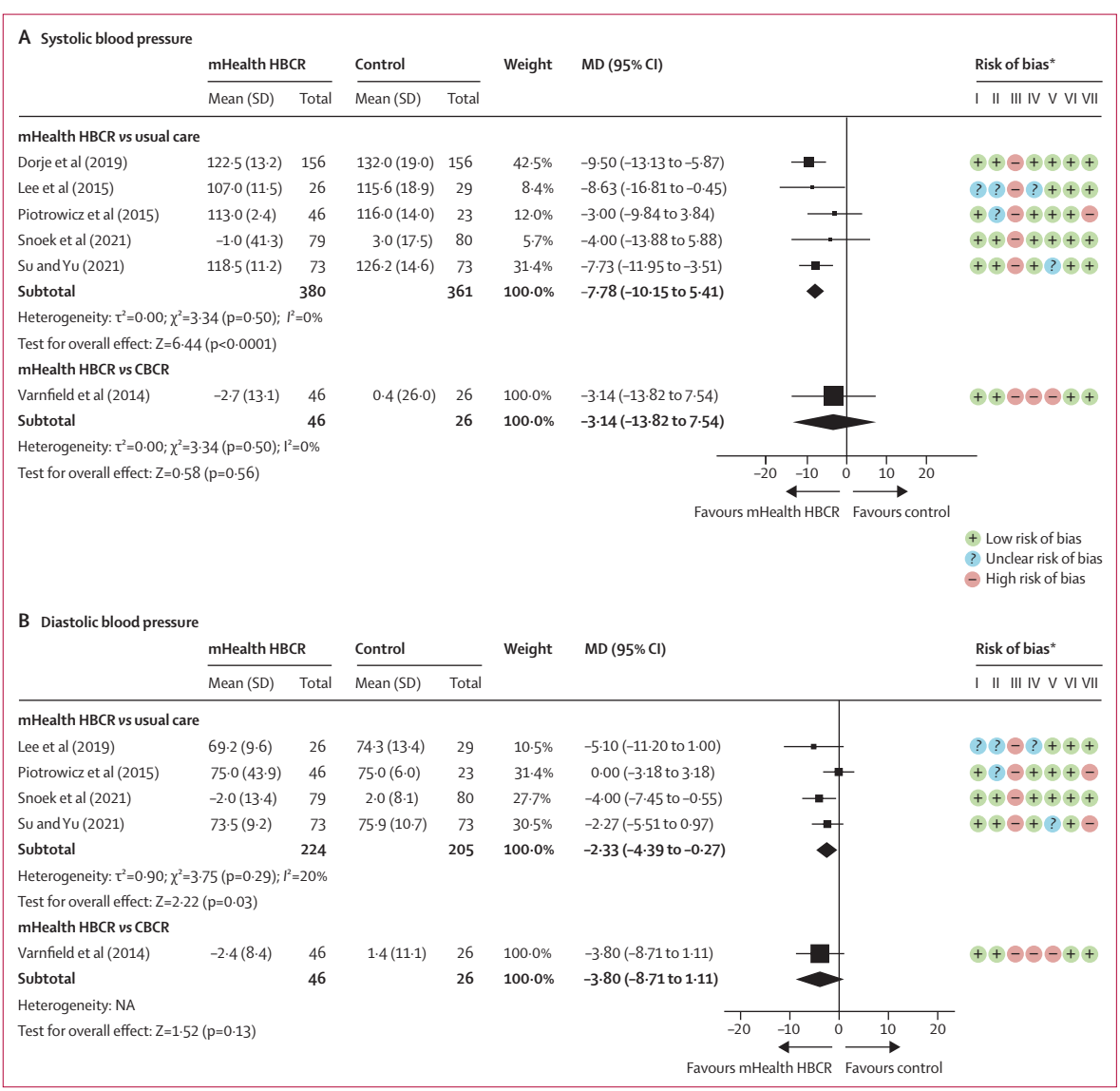
Five (38%) studies[64,65,68,73,75] investigated the effect of mHealth HBCR on resting heart rate. Of these studies, four compared the intervention with usual care and one with CBCR. Pooled results showed that mHealth HBCR significantly reduced resting heart rate compared with usual care (MD −2·12, 95% CI −3·65 to −0·59; 557 participants in four studies; I^2=0%; figure 3C). There was no evidence of statistical heterogeneity. The one study[75] (n=72) that compared mHealth HBCR with CBCR found no significant differences between the two groups (−2·03, −5·81 to 1·75; figure 3C).

Change in BMI was assessed by four (31%) studies,[64,70,71,74] all of which compared mHealth HBCR with usual care. Pooled results showed no difference in BMI between the two groups (MD 0·25, 95% CI −0·25 to 0·75; 617 participants in three studies; I^2=0%; figure 3D). The

quality of evidence was ranked as low due to risk of bias and imprecision (OIS not met).

Four (31%) studies[64,67,74,75] assessed the effect of mHealth HBCR on total cholesterol, five (38%)[64,66,74–76] on LDL cholesterol, and three (23%)[64,74,75] on HDL cholesterol. When comparing mHealth HBCR with usual care, there were no significant differences in total cholesterol (MD 0·06, 95% CI –0·08 to 0·20; 501 participants in three studies; I^2=0%; figure 3E), LDL cholesterol (0·01, –0·20 to 0·21; 497 participants in three studies; I^2=40%; figure 3F), or HDL cholesterol (0·03, –0·06 to 0·12; 471 participants in two studies; I^2=37%; figure 3G). There was no evidence of significant statistical heterogeneity in these results. The quality of evidence was ranked as low due to risk of bias and imprecision (OIS not met). Similarly, when comparing mHealth HBCR with CBCR, there were no differences in total cholesterol (0·37, –0·21 to 0·95; 46 participants in one study; figure 3E), LDL cholesterol (–1·62, –5·41 to 2·17; 124 participants in two studies; figure 3F), or HDL cholesterol (0·04, –0·05 to 0·13; 46 participants in one study; figure 3G).

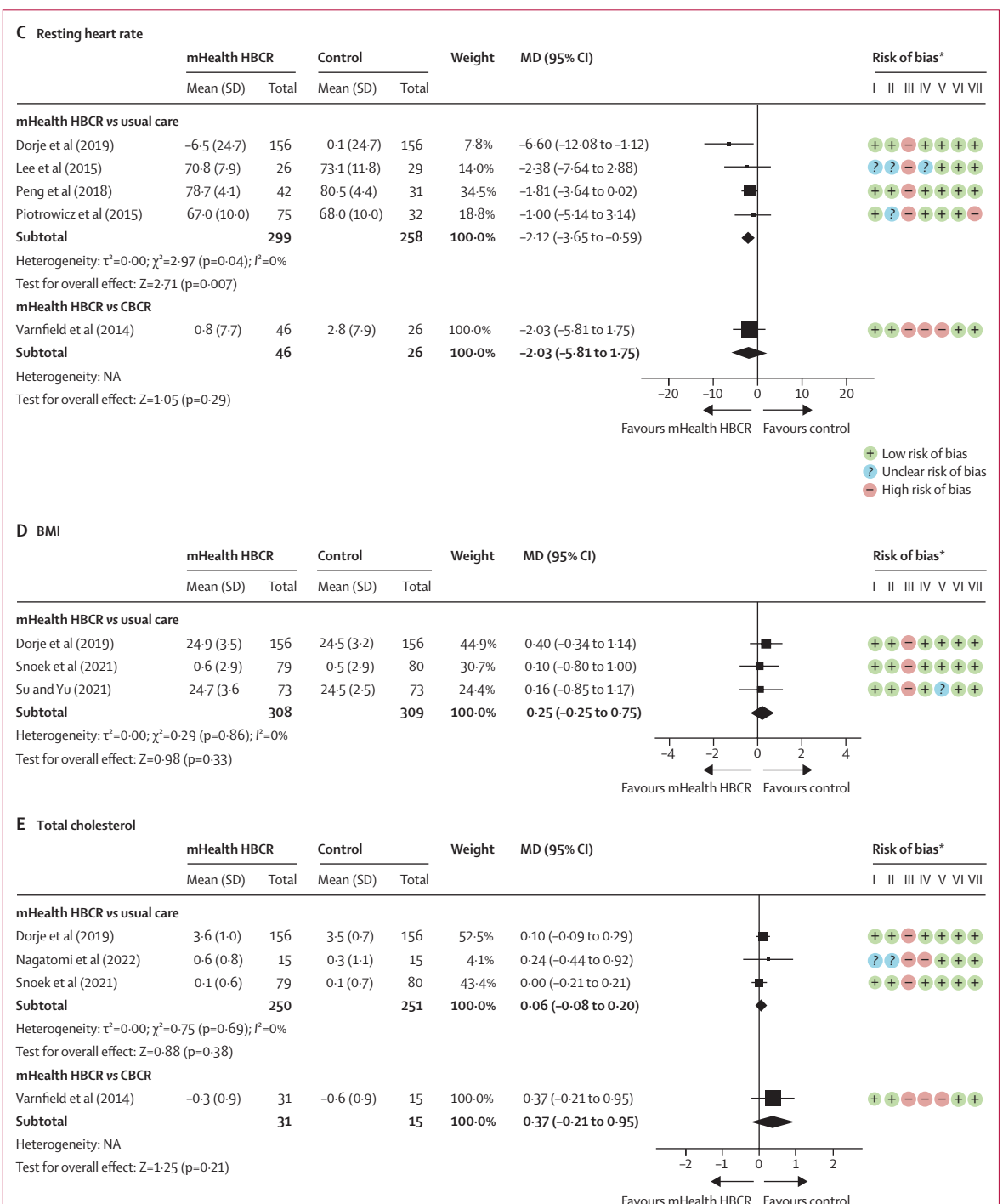
Six (46%) studies reported data on depression[64,68,70,73–75] and five (38%) on anxiety.[64,68,70,74,75] Pooled results from studies comparing mHealth HBCR with usual care showed an almost significant reduction in depression scores (SMD –0·24, 95% CI –0·38 to –0·09; 769 participants in five studies; I^2=0%; figure 4A) and anxiety scores (–0·14, –0·29 to 0·01; 715 participants in four studies; I^2=0%; figure 4B), favouring the intervention. The quality of evidence was ranked as low due to risk of bias and imprecision (OIS not met). The



(Figure 3 continues on next page)

one study[75] that assessed the effects of mHealth HBCR versus CBCR on depression and anxiety found no significant difference.

Ten (77%) studies[64–66,68,70–75] reported the effect of mHealth HBCR on health-related quality of life using generic health-related quality of life scales (eg, Short-Form 36 or EQ-5D), disease-specific scales (eg, the Minnesota Living With Heart Failure Questionnaire or MacNew Heart Disease Health-related Quality of Life questionnaire), or other unspecified questionnaires. Due to the heterogeneity of reported health-related quality of life instruments in terms of subscales and direction of benefit



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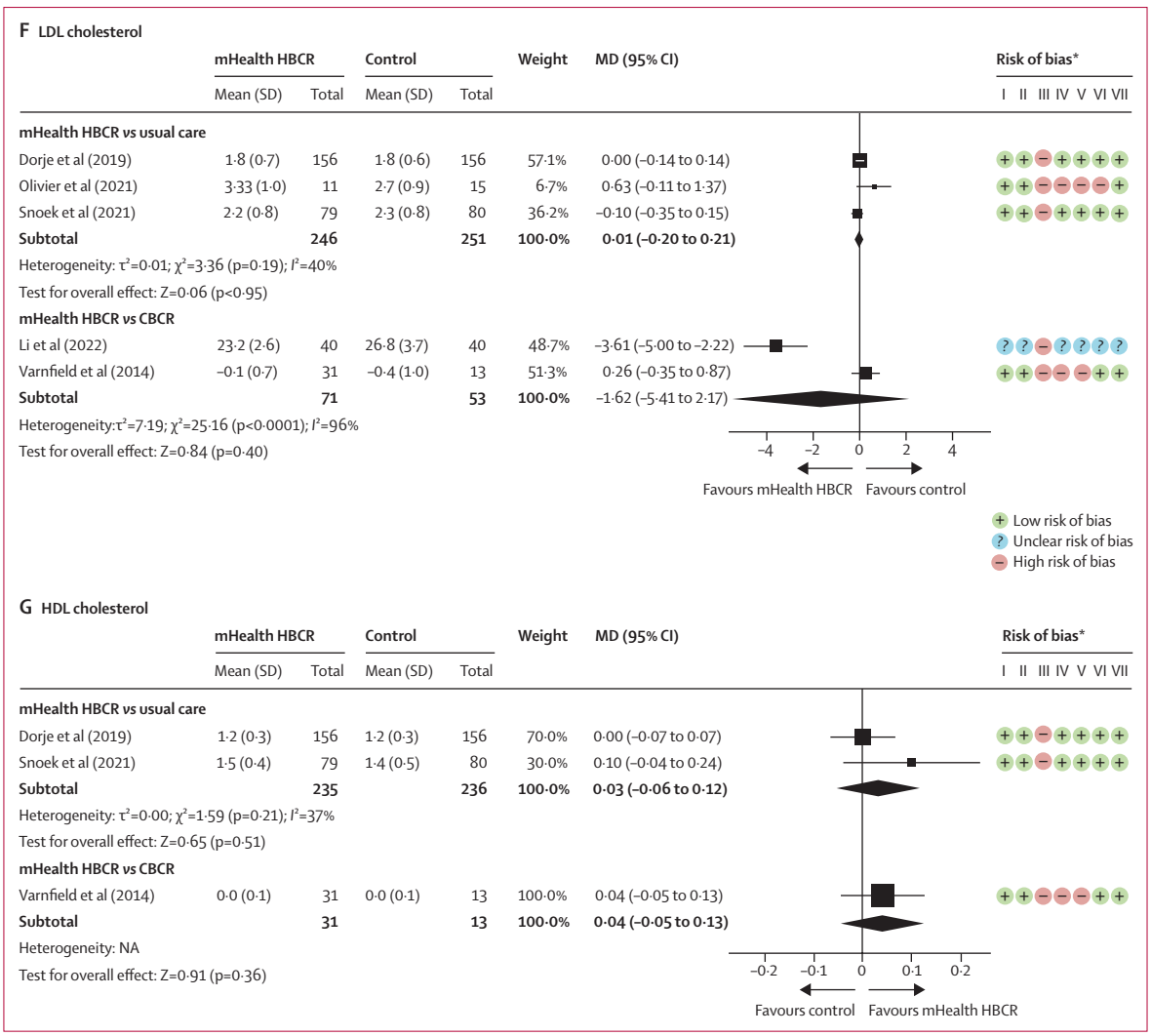

Figure 3: **Forest plots of systolic and diastolic blood pressure (mm Hg), resting heart rate (beats per min), BMI (kg/m²), and lipid profile (total, LDL, and HDL cholesterol, mmol/L)**

CBCR=centre-based cardiac rehabilitation. HBCR=home-based cardiac rehabilitation. MD=mean difference. NA=not applicable. *Risk of bias was assessed in seven domains, as shown in the columns below: (I) random sequence generation; (II) allocation concealment; (III) masking of participants and personnel; (IV) masking of outcome assessment; (V) incomplete outcome data; (VI) selective reporting; and (VII) other bias.

versus harm (eg, a higher score indicates worse outcomes in the Polish version of Short-Form 36 but improved outcomes in other versions), meta-analysis was deemed inappropriate. Therefore, we used vote-counting to summarise results (appendix pp 41–42).

11 health-related quality of life domain comparisons were made in mHealth HBCR groups versus usual care groups,[64,65,68,70,73,74] and 22 were made in mHealth HBCR groups versus CBCR groups.[66,71,72,75] Compared with usual care, most studies (ten of 11) consistently showed improvement in health-related quality of life domains with mHealth HBCR (six were statistically significant and four were not statistically significant). The evidence was mixed regarding mHealth HBCR versus CBCR. Most comparisons (18 of 22) found non-significant improvement, with ten favouring CBCR and eight favouring mHealth HBCR. A small proportion of evidence (four of 22 comparisons) showed significant improvement, with two favouring mHealth HBCR and two favouring CBCR.

Discussion

To our knowledge, this is the first systematic review and meta-analysis to examine the effects of mHealth HBCR interventions in patients with heart disease. Compared with usual care, mHealth HBCR improved functional capacity, blood pressure, resting heart rate, depression, and health-related quality of life in patients who were clinically stable after myocardial infarction or heart revascularisation, or who had angina or chronic heart failure. Compared with usual care, improvements in VO_2 peak (1·77 mL/kg per min) and systolic blood pressure (–7·78 mm Hg) were clinically and statistically

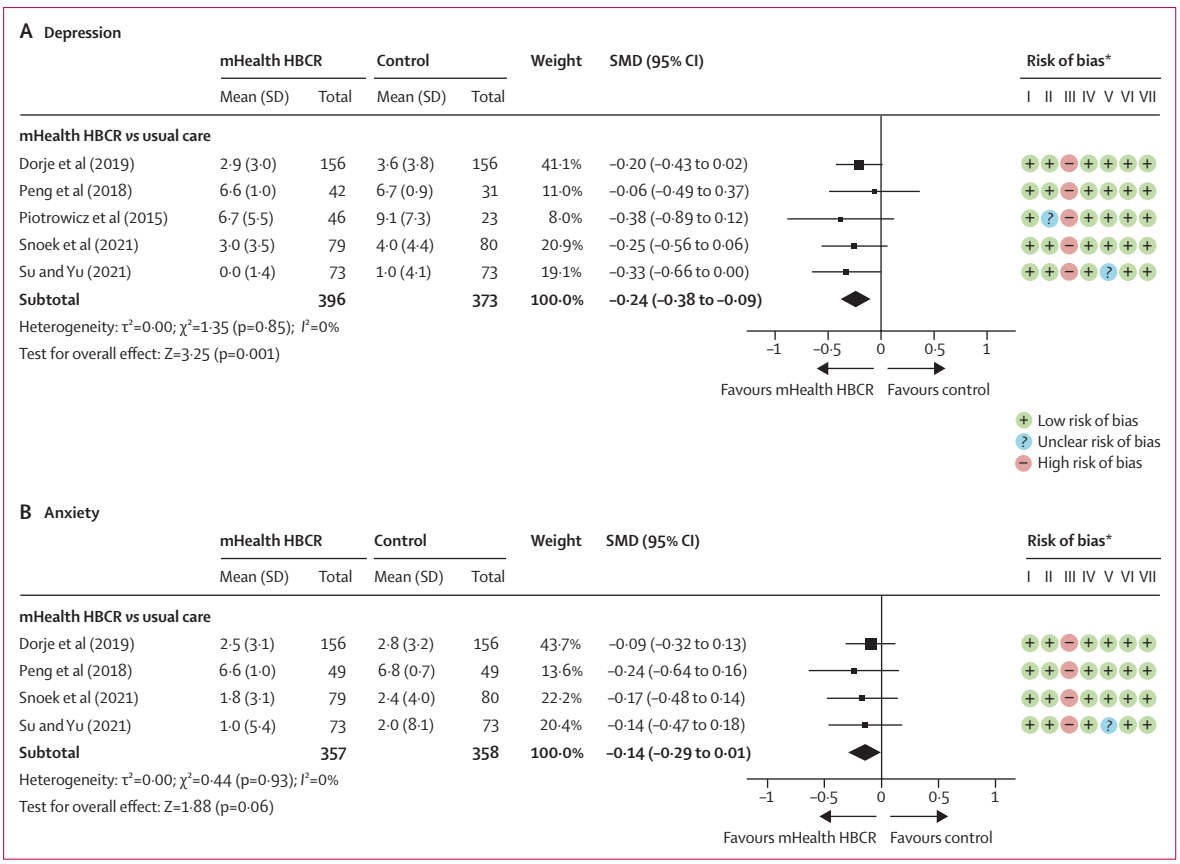

Figure 4: **Forest plots of depression and anxiety**
HBCR=home-based cardiac rehabilitation. SMD=standardised mean difference. *Risk of bias was assessed in seven domains, as shown in the columns below: (I) random sequence generation; (II) allocation concealment; (III) masking of participants and personnel; (IV) masking of outcome assessment; (V) incomplete outcome data; (VI) selective reporting; and (VII) other bias.

significant, whereas for 6MWT (24·74 m), they approached clinical significance. The minimal clinically important differences for 6MWT, VO_2 peak, and systolic blood pressure have previously been estimated to be 25 m,[77] 1·5 mL/kg per min,[78] and 4 mm Hg,[79] respectively. With respect to the effectiveness of mHealth HBCR compared with CBCR, the evidence was inconclusive. We found no statistically significant differences between the two cardiac rehabilitation models on exercise capacity and cardiovascular risk factors in participants who were clinically stable with coronary heart disease or heart failure. The number of included studies was small, and the quality of evidence ranged from low to very low.

Smartphone adoption has substantially increased over the past decade across all age groups, including older adults and minority racial and ethnic groups who traditionally have lower participation in CBCR.[80,81] Many people without home broadband internet access rely on their smartphones to access the internet. Hence, the findings of our review have important implications. They show that mHealth holds promise for expanding cardiac rehabilitation outside of traditional in-person outpatient settings to offer remote intervention to patients who are unable to attend CBCR in person, potentially improving health outcomes and overcoming barriers such as transportation, accessibility, and competing responsibilities. However, further research is needed to improve certainty in the estimates of effect and to elucidate which patients would be optimal candidates. Trials of mHealth HBCR have mainly been conducted in high-income countries, on male participants, and have included people with a history of myocardial infarction, stable chronic angina, revascularisation, and chronic heart failure. Hence, results might not be generalisable to the wider community of patients with heart disease or patients in low-income and middle-income countries. Questions remain regarding which participants are more likely to benefit from mHealth HBCR, how and where such programmes should be delivered, and their effect on outcomes in diverse populations. Given that studies did not report data on clinical events, the effect of mHealth HBCR on mortality, cardiovascular events, and hospitalisations remains unknown. Also, because the equipment for mHealth HBCR interventions was, in most cases, provided as part of the study, the implications for the purchase, implementation, and maintenance of

such equipment, including training of participants on how to use the technology, need to be considered because these could be barriers to the expansion of CBCR using mHealth technologies. Technology can further exacerbate health disparities and social isolation when there is a lack of sufficient support and training. Individual characteristics and social determinants of health, such as age, education, digital literacy, insurance, acuity of illness, comorbidities, cognitive or physical impairments, and access to the required technology and broadband connectivity, need to be considered because they could affect participation and adherence to mHealth HBCR.

Several other systematic reviews and meta-analyses have been published on this topic.[47–49,51,82–89] Although, superficially, these reviews appear similar, there are important differences in inclusion criteria from our review, particularly in the inclusion and pooling of studies involving heterogeneous types of telehealth technologies (eg, videoconferencing units, home telemonitoring stations, desktop computers, laptops, websites, web-based platforms, and mHealth) and cardiac rehabilitation phases (appendix pp 56–59). Differences in the inclusion criteria and classification of studies impair the possibility of directly comparing effect sizes between our review and previous systematic reviews. Nonetheless, overall findings suggest that, compared with usual care, telehealth-supported HBCR interventions significantly improve functional capacity, health-related quality of life, and depression, whereas compared with CBCR, there are no significant differences across outcomes.

Our review has some limitations. First, given the small number of studies, we were unable to conduct subgroup or meta-regression analyses to explore heterogeneity and potential treatment effect modifiers. Second, due to poor reporting of exercise adherence, we were unable to consider the actual amount of exercise that participants received or performed and assess potential exercise-related changes. Third, although masking of participants and personnel to group allocation is not possible in studies of mHealth HBCR, we opted to include this domain in the risk-of-bias assessment and rank down our confidence in the evidence due to possible performance bias. Also, we used a conservative OIS threshold (400 per group for a total of 800 sample size) in assessing imprecision of summary effects, following the 2022 GRADE guidelines.[61] These two choices could have led to more conservative quality of evidence assessments.

Notwithstanding these limitations, our review is novel in that we sought to determine the effects of mHealth HBCR, one of the most popular and promising types of telehealth intervention given the exponential growth and capabilities of smartphone technology, while excluding other types of technology interventions that might confound the effects of mHealth. Also, we focused explicitly on phase II cardiac rehabilitation interventions and used broad inclusion criteria for the population to reflect current clinical guidelines,[5,10–16] where an increasingly diverse patient population with coronary heart disease, including heart failure, are accessing cardiac rehabilitation services. Employing a systematic and transparent method,[90] our review implemented a comprehensive search strategy and independent review and data extraction by two evaluators to minimise errors and biases. The diversity of conditions included in the studies enhances the generalisability of our findings, making them more applicable to the broader set of approved conditions for cardiac rehabilitation and more relevant to clinical practice.

Overall, there is a crucial need for additional, well designed, and adequately powered randomised controlled trials to build a more robust evidence base on the effectiveness of phase II mHealth HBCR to inform clinical practice and policy. These trials need to include adequate numbers of women and people with coronary heart disease more representative of usual clinical practice, including hard-to-reach groups (eg, older people, minority ethnic groups, and disadvantaged populations), to increase generalisability of results. Also, future trials need to assess the impact of mHealth HBCR on mortality and hospital admissions, including cost-effectiveness.

Contributors

SK conceived the idea for this review. SK and LL designed and wrote the review protocol with critical input from MR, GP, GW, and CO. LL and SK developed the search strategy and conducted the searches in all databases. LL and MR independently screened all references and determined eligibility. SK oversaw and adjudicated the study selection process. LL and SK independently extracted data, assessed risk of bias, conducted the meta-analyses, and assessed quality of evidence by outcome of interest. LL and SK drafted the manuscript. MR, GP, GW, and CO were involved in the writing and revision of the manuscript. All authors critically reviewed and approved the content of the manuscript. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Declaration of interests

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Data sharing

The datasets generated from this review are available from the corresponding author upon request.

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