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Review

Effectiveness of mobile health applications on clinical outcomes and health behaviors in patients with coronary heart disease: A systematic review and meta-analysis

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ABSTRACT

Objective: Mobile health applications (apps) have gained significant popularity and widespread utilization among patients with coronary heart disease (CHD). The objective of this study is to evaluate the effects of mHealth apps on clinical outcomes and health behaviors in patients with CHD.
Methods: Databases were searched from inception until December 2023, including Cochrane Library, PubMed, EMBASE, Web of Science, CINAHL, China National Knowledge Infrastructure (CNKI), Chinese BioMedical Literature Service System (SinoMed), Wanfang Data, China Science and Technology Journal Database (VIP), for randomized controlled trials (RCTs) regarding the effectiveness of mHealth apps in patients with CHD. Two researchers conducted a comprehensive review of the literature, extracting relevant data and evaluating each study's methodological quality separately. The meta-analysis was performed utilizing Review Manager v5.4 software.
Results: A total of 34 RCTs were included, with 5,319 participants. The findings demonstrated that using mHealth apps could decrease the incidence of major adverse cardiac events ($RR = 0.68$, $P = 0.03$), readmission rate ($RR = 0.56$, $P < 0.001$), total cholesterol ($WMD = -0.19$, $P = 0.03$), total triglycerides ($WMD = -0.24$, $P < 0.001$), waist circumference ($WMD = -1.92$, $P = 0.01$), Self-Rating Anxiety Scale score ($WMD = -6.70$, $P < 0.001$), and Self-Rating Depression Scale score ($WMD = -7.87$, $P < 0.001$). They can also increase the LVEF ($WMD = 6.50$, $P < 0.001$), VO_2 max ($WMD = 1.89$, $P < 0.001$), 6-min walk distance (6MWD) ($WMD = 19.43$, $P = 0.004$), Morisky Medication Adherence Scale-8 score ($WMD = 0.96$, $P = 0.004$), and medication adherence rate ($RR = 1.24$, $P = 0.03$). Nevertheless, there is no proof that mHealth apps can lower low-density lipoprote in cholesterol, blood pressure, BMI, or other indicator ($P > 0.05$).
Conclusion: Mobile health apps have the potential to lower the incidence of major adverse cardiac events (MACEs), readmission rates, and blood lipids in patients with CHD. They can also help enhance cardiac function, promote medication adherence, and alleviate symptoms of anxiety and depression. To further corroborate these results, larger-scale, multi-center RCTs with longer follow-up periods are needed.

What is known?

- Mobile health applications have become increasingly popular among patients with coronary heart disease (CHD), particularly for improving their health behaviors.
- Studies on mobile health interventions have shown inconsistent outcomes due to variations in implementers, intervention contents, and formats.

What is new?

- This systematic review provides a comprehensive overview of the theoretical basis, necessary materials, procedures, frequency and follow-up, customization and modification, fidelity maintenance and improvement of mobile health applications.
- Studies have demonstrated the efficacy of utilizing mobile health applications for patients with CHD to improve medication adherence and cardiac function, resulting in better clinical outcomes.

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1. Introduction

Coronary heart disease (CHD) continues to be the leading cause of mortality despite significant advancements in diagnostic and therapeutic technologies. It accounts for 16.6% of all fatalities worldwide, resulting in an estimated 8.9 million deaths each year. In China, over 11 million individuals have CHD, and on average, 1.7 million people die from it each year [1–4].

According to previous studies [5–7], the lack of effective interventions in controlling CHD risk factors, such as hypertension, diabetes, hyperlipidemia, obesity, and unhealthy behaviors like smoking, low medication adherence, and insufficient physical activity, are the most critical factors contributing to the rising prevalence and mortality of CHD. It has been proven that modifying these risk factors can reduce the incidence of major adverse cardiac events (MACEs), cardiac-related mortality, and overall mortality in CHD patients by 47%, 57%, and 58%, respectively [8,9].

The most commonly used and have been proven to be effective in controlling CHD risk factors by researchers are public health promotion [10], face-to-face health education [11,12], and telephone consultations [13]. However, the sustainability of those measures, as evidenced by certain studies [14,15], is compromised due to being time-consuming and labor-intensive and requiring large amounts of medical resources. This situation starkly contrasts the declining labor force population in subsequent periods.

Over the past few years, mobile health (mHealth) has rapidly emerged due to advancements in mobile communication technology, the extensive use of mobile devices, and the implementation of supportive regulations [16]. Mobile health, new technical support aimed at managing the health of patients with CHD, is a field of medicine and public health facilitated by portable electronics such as mobile phones, personal digital assistants (PDAs), and portable monitoring devices [17]. The principal mHealth strategies encompass short message service (SMS)-based reminders, mHealth application (apps)-based services, and collaborative wearable devices [18]. According to the National Institutes of Health (NIH) Consensus Panel on Health, mHealth apps are characterized as using mobile and wireless devices to improve health outcomes, healthcare delivery, and health research [19].

Nevertheless, the effectiveness of mHealth in managing patients with CHD, particularly in reducing the incidence of MACEs and risk of relevant diseases, changing unhealthy behaviors, and improving medication adherence, remains inconclusive [20–26]. Some clinical trials have demonstrated that, compared to control groups, mHealth apps significantly reduced blood lipids and glucose and improved medication adherence and exercise capacity [20–22]. However, other studies have failed to yield significant effects [23,24].

A systematic review [25] published in 2022 was conducted to assess the effects of various mHealth programs on lifestyle and risk factors, which found an improvement in medication adherence and exercise capacity but no significance in the reduction of blood lipids and glucose. Jin et al. [26] synthesized relevant randomized controlled trials (RCTs) evaluating telehealth interventions for cardiac patients with a follow-up period of at least three months. The study observed reduced incidence of MACEs and long-term decreases in blood lipid levels. However, there was no significant effect on blood pressure, anxiety, and depression scores in both studies. Notably, the intervention components examined in these two systematic reviews encompassed diverse mHealth interventions, predominantly emphasizing SMS-based reminders rather than mHealth apps; the population was also not limited to patients with CHD. Consequently, conducting a comprehensive assessment and integration of existing research on mHealth apps regarding these specific outcomes is imperative.

As far as we know, few systematic reviews or meta-analyses specifically summarize the details of the critical elements of mHealth app implementers, intervention content and format, and evaluation of the effectiveness of app interventions. Notably, the assessment of prognostic indicators and clinical outcomes is absent. Thus, the present study conducted a systematic review and meta-analysis of pertinent RCTs to investigate the combined impact of mHealth apps on clinical outcomes and health behaviors in patients with CHD.

2. Methods

The meta-analysis was performed and documented using the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines [27]. The current study was a retrospective analysis exclusively on published research material, with no involvement of human subjects. Hence, the Institution Review Board approval was deemed unnecessary based on the institutional policies. The study protocol was prospectively registered at PROSPERO (CRD42023452666).

2.1. Search strategy

A comprehensive review of the existing literature from 1 January 2000 to 31 December 2023 was conducted, as the adoption of mHealth apps was limited prior to this time period. The databases we searched were PubMed, Embase, Cochrane Library, Web of Science, CINAHL, China National Knowledge Infrastructure (CNKI), Chinese BioMedical Literature Service System (SinoMed), Wanfang Data, China Science and Technology Journal Database (VIP), ClinicalTrials.gov, and hand-searching of relevant literature (more details in Appendix A). The search terms comprised a combination of Medical Subject Headings and the keywords, included *mobile health, mHealth, eHealth, telehealth, telemedicine**, *mobile application**, *smartphone app**, *mobile app, portable software apps, and coronary disease**, *coronary heart disease, coronary artery disease**, *myocardial ischemia**, *myocardial revascularization**, *acute coronary syndrome**, *coronary artery bypass**, *percutaneous coronary intervention**. To ascertain the inclusion of all eligible studies in this review, we investigated published reviews, reference lists of included studies, and meta-analyses to identify any further pertinent articles. Additionally, we reached out to the primary authors of the study to obtain any missing data, which was then incorporated into the final analysis.

2.2. Inclusion and exclusion criteria

The PICOS (population, intervention, comparison, outcome, and study design) was used to determine the inclusion criteria for articles [28]. The inclusion criteria were as follows: 1) population: adult (age>18 years) patients with CHD; 2) intervention: interventions were delivered through mHealth apps, and the apps could be web or mobile-based programs; 3) comparison: including but not limited to the usual care, standard cardiac rehabilitation therapy, routine health education, and follow-up; 4) primary outcomes: the incidence of MACEs and readmission rate, 5) secondary outcomes: physiological outcomes (blood pressure, lipids, glucose, body composition, cardiac function, and exercise capacity), psychological outcome (anxiety and depression scores), and health behaviors (medication adherence, exercise time, smoking, and alcohol consumption); and 6) study design: RCTs, published in peer-reviewed journals in English and Chinese language.

The exclusion criteria were as follows: 1) abstract-only articles and protocols without full-text even after contacting the author; 2) duplicate record literature; 3) the study did not furnish a detailed description of the mHealth app interventions; and 4) no transparent reporting of included outcomes or incomplete data.

2.3. Data extraction

The eligibility of the retrieved studies was evaluated and assessed by two researchers (Y. Zhu and Y. Zhao) using the inclusion and exclusion criteria. Two researchers used a pre-designed standardized data collection form to extract data. Information about each study, such as authors, publication year, country, sample size, app-based intervention details, settings, outcome measures, and main results were extracted from the records. During the procedures, any differences between the two researchers were resolved through dialogue or by consulting a third researcher. We reached out to the primary study authors for additional details as needed.

2.4. Quality assessment of included studies

The risk of bias and methodological quality of the included RCTs were evaluated independently by two researchers (Y. Zhu and Y. Zhao). This assessment was conducted using the guidelines in the Cochrane Handbook for Systematic Reviews of Intervention [29]. The study evaluated seven factors related to the potential for bias: randomization sequence generation, allocation concealment, participant blinding, outcome assessment blinding, insufficient outcome data, selective reporting, and other sources of bias.

2.5. Statistical analysis

The meta-analysis was performed utilizing Review Manager (RevMan) Version 5.4. Dichotomous outcomes are typically expressed in risk ratio (*RR*) accompanied by a 95% confidence interval (CI). On the other hand, continuous outcomes are commonly reported as weighted mean difference *(WMD)* together with a 95% confidential interval. The chi-square test, I^2, and *P* value were utilized as measures of statistical heterogeneity. A fixed-effects model was implemented, assuming $P > 0.1$ and $I^2 < 50\%$. A random-effects model was used in cases where $P < 0.1$ and $I^2 \geq 50\%$ unless the articles were clinically similar. Sensitivity analysis was carried out to investigate the provenance of heterogeneity by methodically eliminating each study from the analysis. Funnel plots were employed to detect potential publication bias using the Begg and Egger tests in Stata software (version 18.0; StataCorp LP, College Station, TX) when the number of integrated studies exceeded 10.

3. Results

3.1. Description of included studies

Thirty-four studies [30–63] were included in the systematic review, 20 in English and 14 in Chinese. The search process outcomes are shown in Fig. 1. The studies primarily focused on patients with coronary artery disease, including those after percutaneous coronary intervention (PCI). Studies targeted various age groups, including middle-aged and young individuals, as well as older patients. Patient recruitment and implementation took place in settings primarily in cardiology departments, medical centers, community centers, and cardiac rehabilitation centers. Characteristics and outcomes of included studies are provided in Table 1.

3.2. Details of interventions of included studies

Only a few studies reported the theory basis of app development, including social cognitive theory, goal-setting theory, cognition and behavior theory, self-efficacy, and self-determination theories, all focusing on behavior change. The educational materials provided during the intervention are mainly derived from guidelines on official websites or written by experts, and some specialized wearable monitoring devices are also used. The more common procedures are health education and sessions, SMS services push and reminders, and real-time interactions.

The implementor is typically a team of healthcare professionals, including physicians/cardiologists, dietitians, psychological counselors, specialized nurses, and technicians. The effectiveness of the intervention depends on the specific and corresponding setting of the program, as well as how frequently and intensely it is applied. In various studies, patients are typically followed up for a period of 1.5–12 months, with 6 and 12 months being the most commonly used time frames. Many apps offer customization and personalization through goal setting, prescriptions, reminders, and feedback. To ensure that the intervention is correctly and consistently implemented, appropriate strategies such as upfront training, in-process supervision, problem-solving, and reminders were utilized. Most studies have evaluated patient completion rates and adherence, and the majority of patients who failed do so due to technology barriers or illness. The details of the mHealth app interventions in the included studies are provided in Table 2.

3.3. Risk of bias assessment

The risk of bias in the included studies was presented in Figs. 2 and 3. Of the 34 studies, while randomization was stated in every study, only 24 provided a complete description of the random sequence generation process, and 4 studies showed sufficient allocation concealments. The majority of studies on mHealth app interventions did not implement participant blinding due to the impossibility of concealing the intervention from patients. Ten studies reported blinding of outcome assessment. Additionally, 34 studies exhibited a low risk of bias attributed to selective reporting and other biases.

3.4. Meta-analysis results

3.4.1. Effect of mHealth app interventions on the incidence of MACEs and readmission rate

Eleven studies [31,35,38,44,49,51,54,55,57,58,60] reported the effect of mHealth app interventions on the incidence of MACEs in patients with CHD. The fixed-effects model indicated that, compared with control groups, mHealth apps lowered the incidence of MACEs by 32% ($RR = 0.68$, 95% CI 0.48 to 0.97, $P = 0.03$; $I^2 = 30\%$). Four studies [38,53,55,56] reported the effect of mHealth app interventions on the readmission rate in patients with CHD. The fixed-effects model showed that, compared with control groups, mHealth apps lowered the readmission rate by 44% ($RR = 0.56$, 95% CI 0.41 to 0.76, $P < 0.001$; $I^2 = 0\%$) (Table 3, Figs. 4 and 5).

3.4.2. Effects of mHealth apps on physiological outcomes

For blood pressure, 17 studies [30,31,34,35,37–39,42,44–46,50,53–56,58] reported the effect of mHealth app interventions on systolic blood pressure (SBP), and the random-effects model revealed no significant difference in SBP between two groups ($WMD = 0.43$, 95%CI −1.97 to 2.82, $P = 0.73$; $I^2 = 75\%$). Fifteen studies [30,31,34,35,37,42,44–46,50,53–56,58] reported the effect of mHealth app interventions on diastolic blood pressure (DBP), and the fixed-effects model demonstrated that there was no difference identified in DBP between two groups ($WMD = -0.44$, 95%CI −1.14 to 0.26, $P = 0.22$; $I^2 = 46\%$) (Table 3, Supplementary Fig. 1).

For blood lipids, 10 studies [31,35,41,44,46,53,54,56,58,59]

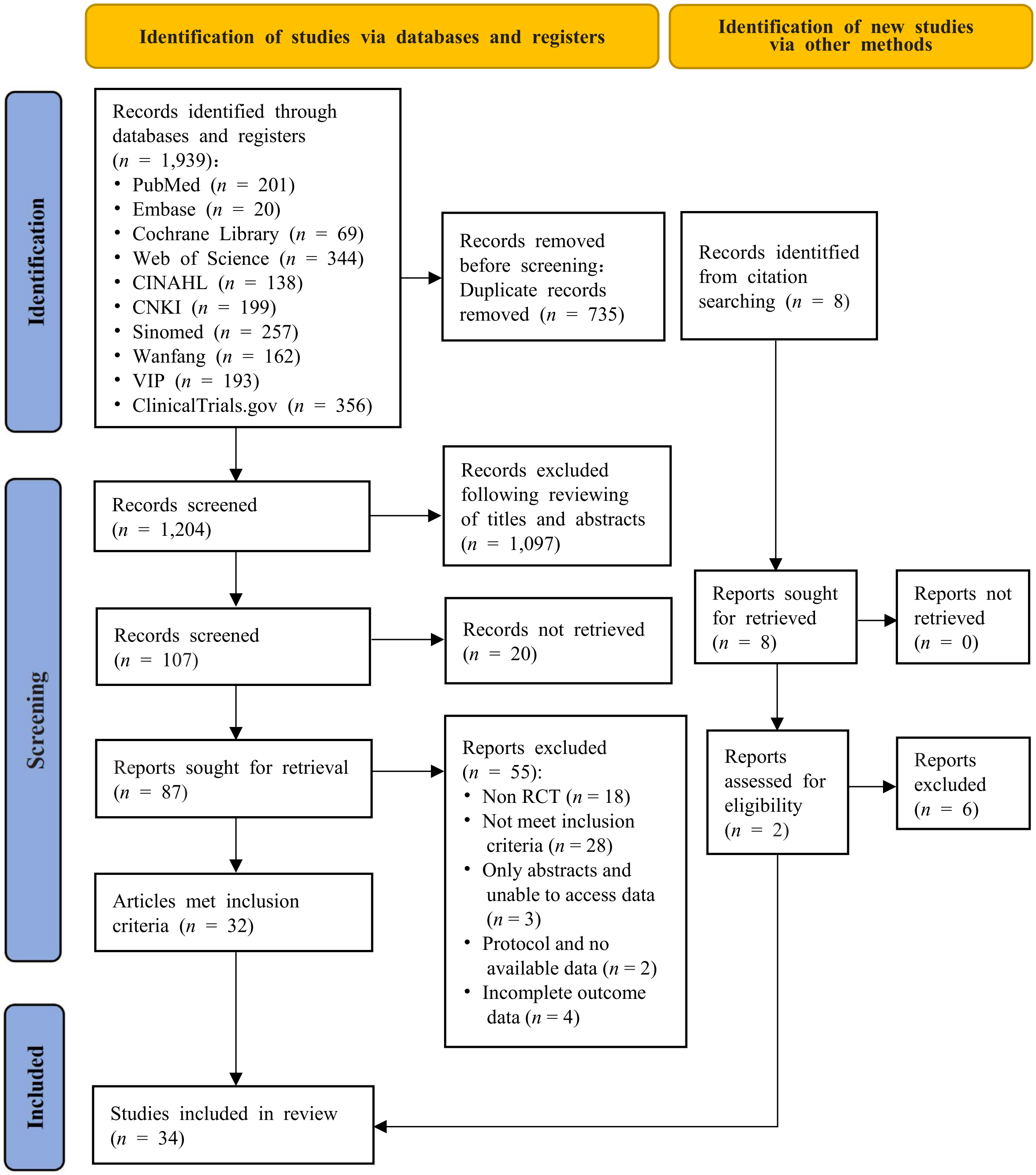

Fig. 1. Flowchart of study selection process.

reported the effect of mHealth app interventions on TC. The random-effects model indicated that, compared with control groups, mHealth app interventions decreased TC (*WMD* = −0.19, 95%CI −0.37 to −0.02, P = 0.03; I^2 = 68%). Nine studies [31,35,41,44,53,54,56,58,59] reported the effect on TG; the fixed-effects model revealed that, compared with control groups, mHealth app interventions decreased TG of patients (*WMD* = −0.24, 95%CI −0.29 to −0.18, $P < 0.001$; $I^2 = 0\%$). Thirteen studies [31,35,38,39,41,42,44,46,53,54,56,58,59] reported the effect of mHealth app interventions on LDL-C, and 7 studies [31,44,53,54,56,58,59] reported the effect on HDL-C. The random-effects models demonstrated that there were no differences with significance in LDL-C (*WMD* = −0.09, 95%CI −0.28 to 0.09, P = 0.32; I^2 = 89%) and HDL-C (*WMD* = 0.12, 95%CI −0.00 to 0.23, P = 0.05; I^2 = 89%) between two goups (Table 3, Supplementary Fig. 2).

For blood glucose, 4 studies [31,44,53,54] reported the effect of mHealth app interventions on fasting blood sugar (FBS), and the random-effects model revealed no difference with significance between two groups (*WMD* = 0.11, 95%CI −0.44 to 0.66, P = 0.70; I^2 = 70%). Three studies [31,53,58] reported the effect of mHealth app interventions on Hb1Ac, and the random-effects model indicated no discernible difference in the Hb1Ac between two groups (*WMD* = 0.60, 95%CI −0.25 to 1.45, P = 0.22; I^2 = 81%) (Table 3, Supplementary Fig. 3).

For cardiac function, 5 studies [35,42,45,50,58] reported the effect of mHealth app interventions on heart rate, and the fixed-

Table 1
Characteristic and outcomes of included studies.

Author, year, and country	Patient characteristics	Sample size (EG/CG)	Settings	Outcome measures	Main results
Blasco et al. [30] (2012) Spain	ACS patients with at least one CRF, such as smoking, LDL-C≥100 mg/dL, hypertension, or diabetes mellitus	102/101	Tertiary referral hospital in Madrid, Spain	SBP, DBP, BMI, smoking status, medication adherence rate, LDL-C, and HbA1c	More patients in EG achieved goals for BP (62.1% vs. 42.9%, $P = 0.012$) and HbA1c (86.4% vs. 54.2%, $P = 0.018$), with no differences in smoking cessation or LDL-C. BMI was significantly lower in EG ($P = 0.005$).
Bravo et al. [31] (2017) Spain	Patients with stable ischaemic cardiomyopathy, at moderate risk, met at least one criterion: ventricular dysfunction using ejection fraction 40%−55%, functional capacity 5−7 METS and/or raised blood pressure with exertion	14/14	Cardiac rehabilitation unit of the Hospital Virgen de la Victoria in Malaga, Spain	SBP, DBP, TC, TG, LDL-C, HDL-C, FBS, Hb1Ac, BMI, the incidence of MACEs, SF-36 overall	The only difference between the two groups was for quality of life scores (10.93 [95%CI 3.33 to 17.25, $P = 0.007$] vs. −4.31 [95%CI −11.41 to 2.79, $P = 0.206$]).
Brouwers et al. [32] (2021) Netherlands	CHD patients entering phase II outpatient CR	150/150	Máxima Medical Center	VO_2 max, BMI, waist, EQ-5D index	No significant between-group difference in the response over time ($P = 0.731$). 16 patients in EG showed a relapse in PAL after 3 months.
Chen et al. [33] (2018) China	Middle-aged and young ACS patients, no acardiac, lung, brain and other serious organic lesions	48/52	Patients self-manage after discharge	Medication adherence rate	The compliance rate, self-management and quality of life in EG were significantly higher than those in CG ($P < 0.01$).
Fang et al. [34] (2019) China	Patients with low risk after PCI, living with at least one other person	40/40	First Affiliated Hospital of Shantou University Medical College in China	SBP, DBP, 6MWD	The improvements in SF-36, FTND scores, and 6MWT distance in EG were significantly better than those in CG ($P < 0.05$).
Gallagher et al. [35] (2023) Australia	CHD patients with no lack of English proficiency or neurocognitive impairment or visual impairment	128/122	Three major tertiary referral teaching hospitals and one tertiary referral private hospital in Sydney, Australia.	SBP, DBP, TC, TG, LDL-C, HR, BMI, waist, the incidence of MACEs, smoking status	EG achieved more physical activity than CG, which was not statistically significant (95% CI −37.4 to 696, $P = 0.064$). No differences occurred between groups on secondary outcomes except for LDL-C [mean difference −0.3 (95% CI −0.5 to −0.1, $P = 0.004$)].
He [36] (2021) China	PCI patients	37/37	The Sixth People's Hospital of Huizhou	LVEF, SAS and SDS score	There were significant differences in LVEF, SAS and SDS scores between EG and CG ($P < 0.05$).
Hong et al. [37] (2021) Taiwan, China	≥20 years patients with CHD	30/30	A medical center	SBP, DBP	SBP ($P = 0.02$), self-management behavior ($P = 0.004$) and QoL ($P = 0.03$) significantly improved in EG.
Indraratna et al. [38] (2022) Australia	Either HF or ACS patients, aged ≥18 years, and owned a compatible smartphone	78/78	2 hospitals in Sydney, New South Wales, Australia (Prince of Wales Hospital and The Sutherland Hospital).	SBP, LDL-C, 6MWD, weight, waist, medication adherence rate, the incidence of MACEs, readmission rate, EQ-5D index	The intervention was associated with a significant reduction in unplanned hospital readmissions (21 in EG vs. 41 in CG, $P = 0.02$), including cardiac readmissions (11 in EG vs. 25 in CG, $P = 0.03$), and medication adherence (57/76, 75% vs. 37/74, 50%, $P = 0.002$).
Johnston et al. [39] (2016) Sweden	> 18 years patients with ST-elevation myocardial infarction or a non−ST-elevation myocardial infarction	85/77	16 cardiology departments in Sweden	SBP, LDL-C, BMI, smoking status, exercise time	EG was associated with higher degree of smoking cessation, increased physical activity, and change in quality of life; but no statistical significance ($P > 0.05$).
Kraal et al. [40] (2014) Netherlands	Patients entered CR and had a low to moderate risk of future cardiac events	25/25	Maxima Medical Centre, Veldhoven, The Netherlands.	VO_2 max	EG and CG both showed a significant improvement in VO_2 max (10% and 14% respectively), without significant between group differences ($P > 0.05$).
Li et al. [41] (2021) China	Resident patients undergoing PCI for the first time and at least one family member with long-term companionship	41/41	Department of Cardiology, Affiliated Hospital of North Anhui Health Vocational College	TC, TG, LDL-C, SAS score, MMAS-8 score	The medication adherence of EG was significantly higher, and the SAS score and lipid level were significantly lower than CG ($P < 0.05$).
Li et al. [42] (2022) China	≥18 years CHD patients, with basic reading skills in Chinese	143/147	Peking University First Hospital, China	SBP, DBP, LDL-C, HR, medication adherence rate	EG had a significant improvement in the percentage of medications, higher proportion of achieving BP under control and LDL-C < 1.8 mmol/L with CG (*RR* 1.34, 95% CI 1.12 to 1.61, $P = 0.001$; *RR* 1.45, 95% CI 1.22 to 1.72, $P < 0.001$, and *RR* 1.40, 95% CI 1.11 to 1.75, $P = 0.004$).
Lu [43] (2022) China	Patients with stable CHD	60/60	Zhumadian City Center Hospital	Smoking status, drinking status	The proportion of BP in EG was higher than CG ($P < 0.05$), but there was no statistical difference in BMI, smoking and drinking ($P > 0.05$).
Maddison et al. [44]	clinically stable, English-speaking adults (≥18 years) with a documented diagnosis of CHD within 6 months	82/80	Metropolitan hospitals, outpatient clinics and community-based CR	SBP, DBP, FBS, TC, TG, LDL-C, HDL-C, VO_2 max, weight,	VO_2 max was comparable in both EG and CG, EG was non-inferior to CG, mean

Table 1 (*continued*)

Author, year, and country	Patient characteristics	Sample size (EG/CG)	Settings	Outcome measures	Main results
(2019) Australia			seminars in Auckland and Tauranga (New Zealand)	BMI, waist, the incidence of MACEs, EQ-5D index	difference = 0.51 mL/(kg·min) (95% CI −0.97 to 1.98, P = 0.48).
Ni et al. [45] (2022) China	≥18 years CHD patients with an antihypertensive medication regimen lasting at least 90 days	103/93	West China Hospital, Chengdu	SBP, DBP, HR	The mean decrease in medication nonadherence score and DBP was statistically significant at both 60 days (P = 0.04) and 90 days (P < 0.001).
Santo et al. [46] (2019) Australia	≥18 years CHD patients	50/51	A large urban tertiary hospital in Sydney, Australia	SBP, DBP, TC, LDL-C, MMAS-8 score, medication adherence rate	EG had higher adherence (mean MMAS-8 score 7.11) compared with the CG (mean MMAS-8 score 6.63) with a mean difference between groups of 0.47 (95% CI 0.12 to 0.82, P = 0.008).
Si [47] (2020) Henan, China	PCI patients	51/50	Department of Cardiology, Hebi People's Hospital, Henan Province	SAS and SDS score	The medication compliance of CG was lower than that of EG, and the scores of SAS and SDS were higher than that EG (P < 0.05)
Song et al. [48] (2020) China	Stable CHD patients, age ≤75 years old and without physical or mental disorders affecting exercise	48/48	Department of Cardiology, Peking University Third Hospital	VO_2 max	The subjects in EG performed significantly better in VO_2 max (P = 0.007), main effect of time (P = 0.033) and exercise compliance (P = 0.02) than CG.
Treskes et al. [49] (2020) Netherlands	≥18 years patients with AMI	100/100	Department of Cardiology of the Leiden University Medical Center	The incidence of MACEs	BP control in EG and CG was 79% and 76%, without significant between group differences (P = 0.64). The all-cause mortality rate was 2% in both groups (P > 0.99).
Varnfield et al. [50] (2014) Australia	post-MI patients referred to CR	46/26	Four CR centers in Brisbane, Australia	SBP, DBP, HR, 6MWD, weight, waist, SF-36 overall, EQ-5D index	Both CG and EG showed significant improvements in 6MWD after 6 months: CG: (537 ± 86) m vs. (584 ± 99) m; EG: (510 ± 77) m vs. (570 ± 80) m.
Wang [51] (2018) China	PCI patients	50/50	Zhengzhou Seventh People's Hospital	The incidence of MACEs	The self-management scores and SF-36 of EG were significantly higher than CG, and the incidence of MACEs was lower (8% vs. 26%, P < 0.05).
Wang [52] (2019) China	PCI patients, age 18−59 years old, with no cognitive dysfunction and Killip grade I and II	50/50	Department of cardiology, third class A hospital, Zunyi City	BMI, smoking status	The scores of self-management behavior and return visit rate of EG were higher, the current smoking rate was lower (P < 0.05), compared with CG, and no statistical difference in BMI between the two groups.
Widmer et al. [53] (2017) America	Patients with ACS, willing to participate in CR, as well as access to the Internet	37/34	Mayo Clinic	SBP, DBP, FBS, Hb1Ac, TC, TG, LDL-C, HDL-C, weight, BMI, readmission rate, exercise time	EG had improved weight loss ([−5.1 ± 6.5] kg vs. [−0.8 ± 3.8] kg, P = 0.02), a non-significant reduction in emergencyd epartment visits and rehospitalizations (8.1% vs. 26.6%; *RR* 0.30, 95% CI 0.08 to 1.10, P = 0.054).
Wong et al. [54] (2022) Hongkong, China	Patients with at least 2 CRF, such as current smoker, > 50 years, diabetes or hypertension, family history of IHD or hyperlipidemia, hyperlipidemia or regular medication, BMI >25, PCI and stable angina and on nitroglycerin medication	30/30	Community centers or in a university research laboratory	SBP, DBP, FBS,TC, TG, LDL-C, HDL-C, weight, BMI, the incidence of MACEs, exercise time	EG showed a moderate effect (Cohen's d = 0.43) in significant increase in exercise amount, and reduction of lipid concentration (TG d = −0.43, TC d = −0.39).
Yu et al. [55] (2020) China	> 18 years patients who underwent an isolated CABG and had been prescribed at least one secondary preventive oral medication within 2 weeks after surgery	493/494	Four hospitals in different regions across China	SBP, DBP, BMI, the incidence of MACEs, readmission rate, medication adherence rate, smoking status	The proportion of low-adherence participants, categorized by MMAS-8 scores, was 11.8% in EG and 11.7% in CG (*RR* 1.01, 95% CI 0.68 to 1.48, P = 1.000).
Yuan et al. [56] (2020) China	PCI patients, with no serious complications or cognitive or psychiatric disorders	60/60	Department of Cardiology, Zhengzhou Cardiovascular Hospital	SBP, DBP, HDL-C, LVEF, SAS and SDS score, readmission rate, MMAS-8 score	LVEF, HDL-C and medication adherence in EG were higher than those in CG; SBP, DBP, TC, TG, LDL-C and readmission rates were lower than those in CG (P < 0.05).
Yuan et al. [57] (2022) Jiangsu, China	PCI patients, aged 60−75 years	50/50	Jiangsu Provincial People's Hospital	TC, TG, LDL-C, the incidence of MACEs, MMAS-8 score	The MMAS-8 score in EG were higher than CG (P < 0.05). There was no significant difference in the incidence of MACEs between the two groups (P > 0.05).
Yudi et al. [58] (2021) Australia	> 18 years patients with ACS and documented coronary artery disease on angiography (coronary artery stenosis >50%)	83/85	Six tertiary Australian hospitals	SBP, DBP, Hb1Ac, TC, TG, LDL-C, HDL-C, HR, 6MWD, weight, BMI, the incidence of MACEs, smoking status, SF-36 overall	EG had a significant improvement in 6MWD (Δ117 ± 76 vs. Δ91 ± 110 m, P = 0.02), similar smoking cessation rates, LDL-C, BP reduction, and quality of life compared to UC (all P > 0.05).
Zhang et al. [59] (2017) China	Patients who received PCI for the first time, aged 16−75 years	63/61	Henan Provincial People's Hospital	TC, TG, LDL-C, HDL-C, MMAS-8 score	The medication adherence and HDL-C in EG were significantly higher while TG, TC and LDL-C were significantly lower compared to CG (P < 0.05). Intervention

(*continued on next page*)

Table 1 (*continued*)

Author, year, and country	Patient characteristics	Sample size (EG/CG)	Settings	Outcome measures	Main results
					effect, time effect and interaction effect were significant (all $P < 0.01$).
Zhang et al. [60] (2020) China	PCI patients, who skilled use of WeChat and other tools	50/50	Shanghai Xuhui District Central Hospital	The incidence of MACEs	The self-management scores of patients in EG were significantly higher, and the incidence of MACEs was lower (12.8% vs. 34.1%, $P < 0.05$).
Zhang et al. [61] (2021) China	AMI patients, who met at least two criteria for "typical chest pain, characteristic electrocardiogram changes, and elevated serum necrotic markers"	48/48	Shenzhen Second People's Hospital	LVEF, SF-36 overall	LVEF and QoL in EG was higher than CG ($P < 0.05$).
Zheng et al. [62] (2019) China	≥18 years patients with CHD	143/147	Department of Cardiovascular Medicine, Peking University First Hospital	SBP, DBP, TC, TG, LDL-C, HDL-C, FBS, Hb1Ac, BMI, the incidence of MACEs, SF-36 overall	The CHD self-management behavior and BP control of patients in EG were better than CG ($P < 0.05$).
Zhou et al. [63] (2018) China	patients with CHD	60/60	Huangshi Central Hospital of East Hubei Medical Group	VO_2 max, BMI, waist, EQ-5D index	Compared with CG, the medication adherence in EG was significantly increased ($P < 0.05$)

Note: ACS = acute coronary syndrome. AMI = acute myocardial infarction. BMI = body mass index. BP = blood pressure. CABG = coronary artery bypass graft. CG = control group. CHD = coronary heart disease. CR = cardiac rehabilitation. CRF = chronic renal failure. DBP = diastolic blood pressure. DHI = digital health interventions. EG = experimental group. EQ-5D = European Quality of Life-5 Dimensions. FBS = fasting blood sugar. FTND = Fagerström Test for Nicotine Dependence. Hb1Ac = glycosylated hemoglobin. HDL-C = high-density lipoprote in cholesterol. HF = heart failure. HR = heart rate. IHD = ischemic heart disease. LDL-C = low-density lipoprote in cholesterol. LVEF = left ventricular ejection fraction. MACEs = major adverse cardiac events. METS = metabolic equivalent of task. MMAS-8 = Morisky Medication Adherence Scale-8. PAL = physical activity level. PCI = percutaneous coronary intervention. QoL = Quality of Life. SAS = Self-Rating Anxiety Scale. SBP = systolic blood pressure. SDS = Self-Rating Depression Scale. SF-36 = the MOS 36-item short-form health survey. TC = total cholesterol. TG = total triglycerides. VO_2 max = maximum oxygen consumption. 6MWD = 6-min walk distance.

effects model indicated there was no difference identified in heart rate changes between two groups ($WMD = -0.85$, 95%CI -2.25 to 0.56, $P = 0.24$; $I^2 = 0\%$). Three studies [36,56,61] reported the effect of mHealth app interventions on LVEF, and the random-effects model demonstrated that, compared with control groups, the LVEF increased in experimental groups ($WMD = 6.50$, 95%CI 2.19 to 10.81, $P < 0.001$; $I^2 = 89\%$) (Table 3, Supplementary Fig. 4).

For exercise capacity, 4 studies [32,40,44,48] reported the effect of mHealth app interventions on VO_2 max, and 4 studies [34,38,50,58] reported the effect on 6MWD. The fixed-effects models demonstrated that, compared with control groups, the VO_2 max ($WMD = 1.89$, 95%CI 0.73 to 3.05, $P = 0.001$; $I^2 = 3\%$) and 6MWD increased in experimental groups ($WMD = 19.43$, 95%CI 6.25 to 32.61, $P = 0.004$; $I^2 = 14\%$) (Table 3, Supplementary Fig. 4).

For body composition, 6 studies [38,44,50,53,54,58] reported the effect of mHealth app interventions on patient weight, 11 studies [30–32,35,39,44,52–55,58] reported the effect of on BMI, and 5 studies [32,35,38,44,50] reported the effect on waist circumference. The fixed-effects models revealed that, compared to control groups, waist circumference reduced in experimental groups ($WMD = -1.92$, 95%CI -3.41 to -0.42, $P = 0.01$; $I^2 = 47\%$). However, no differences were found between two goups in the weight ($WMD = -1.06$, 95%CI -2.88 to 0.75, $P = 0.25$; $I^2 = 44\%$) and BMI ($WMD = -0.36$, 95%CI -3.41 to -0.42, $P = 0.06$; $I^2 = 6\%$) (Table 3, Supplementary Fig. 5).

3.4.3. Effects of mHealth apps on psychological outcomes

Four studies [36,41,47,56] reported the effect of mHealth app interventions on SAS score, the random-effects model revealed that mHealth app interventions led to a significant reduction in the SAS score ($WMD = -6.70$, 95%CI -7.78 to -5.62, $P < 0.001$; $I^2 = 89\%$). Three studies [36,47,56] reported the effect of mHealth app interventions on SDS score, the fixed-effects model indicated that the interventions resulted in a notable decrease in the SDS scores in experimental groups ($WMD = -7.87$, 95%CI -8.97 to -6.76, $P < 0.001$; $I^2 = 43\%$) (Table 3, Supplementary Fig. 6).

3.4.4. Effects of mHealth apps on health behaviors

For medication adherence, 5 studies [41,46,56,57,59] reported the effect of mHealth app interventions on MMAS-8 score, and 7 studies [30,33,38,42,46,55,63] reported the effect on medication adherence rate. The random-effects models indicated that, compared with control groups, the MMAS-8 score ($WMD = 0.96$, 95%CI 0.30 to 1.62, $P = 0.004$; $I^2 = 94\%$) and medication adherence rate increased in experimental groups ($RR = 1.24$, 95%CI 1.03 to 1.49, $P = 0.02$; $I^2 = 96\%$) (Table 4, Supplementary Fig. 7).

Three studies [39,53,54] reported the effect of mHealth app interventions on exercise time of patients. The fixed-effects models demonstrated a trend that mHealth apps might increase the exercise time in experimental groups ($WMD = 24.41$, 95%CI -9.39 to 58.21, $P = 0.16$; $I^2 = 18\%$), but not statistically significant (Table 4, Supplementary Fig. 7).

Eight studies [30,35,39,43,52,55,58,62] reported the effect of mHealth app interventions on smoking rate, and 2 studies [43,62] reported the effect on drinking rate. The fixed-effects models showed that there were no differences with statistical significance in smoking and drinking rate changes between experimental groups and control groups (Table 4, Supplementary Fig. 7).

3.5. Sensitivity analysis

Sensitivity analysis was conducted on studies that exhibited considerable heterogeneity ($P < 0.01$, $I^2 > 50\%$). The remaining studies' heterogeneity was less than previously ($I^2 < 50\%$) following leave-one-out analysis. However, the results of HDL-C changed ($P < 0.05$) (Table 5). Sensitivity analyses revealed higher heterogeneity due to differences in sample size and literature quality, mainly focused on these studies [41,56,59]. Further analysis showed that these studies did not use specific strategies to improve patient adherence during the intermediate process, and overall completion was not reported in the results. Additionally, the frequency and duration of interventions varied in other studies, which could potentially increase heterogeneity (Table 5).

Table 2a
App intervention details of included studies.

Study	App name and theory basis	Aim of the study	Necessary materials	Main procedures
Blasco et al. [30]	TMG (the Airmed -Cardio platform)	Efficacy evaluation	• An automatic sphygmomanometer (Omron M4-I; Omron Corporation, Kyoto, Japan), a glucose and lipid meter (Cardiochek, Polymer Technology System, Inc, Indianapolis, IN) and a cellular phone (Nokia 3510i, Nokia Corporation, Espoo, Finland). • A “rapid learning guide”	Physiological measurements; short message service; follow-up
Bravo et al. [31]	The NUUBO® system	Efficacy and safety evaluation	• Bluetooth wireless technology and biometric vests using textile electrodes developed and patented by Nuubo, blendfix Sensor Electrode Technology. • Exercise at home according to the European Society of Cardiology guidelines (https://doi.org/10.1093/eurheartj/eht296).	Cardiac rehabilitation unit review; supervised physical exercise session; follow-up
Brouwers et al. [32]	Web app; motivational Interviewing	Efficacy evaluation	• A heart rate monitor (Mio Alpha, Physical En-terprises Inc., Vancouver, British Columbia, Canada) and accelerometer (actigraph wgt3x-BT, Actigraph LLC, Pensacola, Florida, USA) • Use recent Dutch and European CR guidelines and position statement	Supervised group-based sessions; exercise training at home; video consultations; follow-up
Chen et al. [33]	Tongxin Butler	Efficacy evaluation	• Physician summarizes and collects information on issues with high patient feedback	Formation of PCI extended care team; enrollment and care guidance; postoperative WeChat group; regular reminders and pushes
Fang et al. [34]	HBCTR remote monitoring system	Efficacy evaluation	• A paper-based and self-study CHD booklet	Supervised outdoor walking or jogging; home visits
Gallagher et al. [35]	MyHeartMate; social cognitive theory	Efficacy evaluation	• All content was developed by an expert multidisciplinary panel with reference to the Australian Heart Foundation	Receive text and email reminders and instructions; tracking, challenges, and quizze
He [36]	Smartphone app	Efficacy evaluation	• Set up a push of music and movie content, with a focus on light music and upbeat movies	Managed by healthcare professionals; daily push; patient communication
Hong et al. [37]	Health IT system; self-efficacy theory	Efficacy evaluation	• The Health IT system (Chunghwa Telecom Personal Health Record, CHT PHR, Taipei, China); an automatic sphygmomanometer (BP 3MX1; watchbp home, Microlife, Taipei, China); a wristband-wearable device (The Xiaomi Mi Smart Band 4, Beijing, China)	Health IT equipment; study contact details; a reminder prior to the follow-up appointment
Indraratna et al. [38]	TeleClinical Care (TCC)	Feasibility, efficacy, and costs evaluation	• A pamphlet that described the correct technique for using the devices and basic troubleshooting advice. • The notifications was based on the National Heart Foundation of Australias managing my heart health consumer resource	Physiological measurements; activity data automatically transmitted; educational push notifications
Johnston et al. [39]	Web app	Efficacy evaluation	• Include 4 main modules: extended drug adherencee-diary, exercise, weight, and smoking modules. All modules included referenced medical information	Extended drug adherence e-diary; secondary prevention educational modules; short message service; follow-up
Kraal et al. [40]	Garmin Connect; goal-setting theory	Efficacy evaluation	• Exercise training was prescribed according to the current recommendations of the European Society of Cardiology • A wearable heart rate monitor (Garmin Forerunner 70)	Supervised training sessions; telephonic feedback; follow-up
Li et al. [41]	Tongxin Butler	Efficacy evaluation	• Including “postoperative daily knowledge”, “rehabilitation encyclopedia”, “rehabilitation management”, “family sharing”, “medication reminders” and so on	Set up continuous nursing group; perioperative nursing; discharge nursing
Li et al. [42]	Smartphone app	Efficacy evaluation	• Provide educational materials and instructions on medication • An automatic omrondevice (Omron Healthcare, inc)	Discharge medication and lifestyle intervention plan; home management; follow-up
Lu [43]	Cardiovascular Home Care	Efficacy evaluation	• Regular dissemination of CHD health knowledge	Targeted health management programs; self-monitoring; push regularly; health report summary
Maddison et al. [44]	Web app; self-efficacy and self-determination theories	Efficacy and costs evaluation	• The sensor provides information on heart and respiratory rates, single lead ECG and accelerometry, smartphones with a mobile data subscription (NZD1.50/GBP0.76 per week) at no cost • Consistent with clinical exercise prescription guidelines	Exercise prescription; real-time exercise monitoring/coaching; behavioural strategies; follow-up
Ni et al. [45]	Tencent Inc and Message Express	Efficacy evaluation	• Educational materials were retrieved from the website of the World Health Organization and were screened by a cardiologist and a nurse to ensure their accuracy	Educational materials and reminders; follow-up
Santo et al. [46]	MedApp-CHD	Feasibilityand efficacy evaluation	• Apps were freely available in the Australian itunes and Google app stores, which were selected through a previously reported systematic review and stepwise process	Interactive/customizable daily reminders; feedback questionnaires
Si [47]	Tongxin Butler	Efficacy evaluation	• Everyday delivery of text, pictures, voice, and videos along with timely information on diseases and physiological outcomes	Set up collaborative intervention teams; app use and targeted rehabilitation guidance; daily push; WeChat group interaction
Song et al. [48]	MEMRS-CRS; cognition and behavior theory	Efficacy evaluation	• Telemonitoring software (MEMRS-CRS, developed by Medicus), distributed heart rate belts (Suunto, provided by Medicus)	Exercise monitoring; text message and feedback; follow-up
Treskes et al. [49]	The box	Feasibility and efficacy evaluation	• A BP monitor (Wireless Blood Pressure Monitor; Withings), a step counter (Pulse Ox; Withings), a weight scale (Smart Body Scale Analyzer; Withings), and a single-lead ECG device (Kardia; alivecor Inc)	BP and rhythm monitor; step counter; electronic visits; follow-up
Varnfield et al. [50]	WellnessDiary and StepCounter	Efficacy evaluation	• Components of a comprehensive CR programme developed according to national guidelines • A smartphone (Nokia N96, Nokia Inc) with health diary (wellnessdiary, Nokia Research) and activity monitoring (stepcounter, Nokia Research) applications; BP monitor (AXIS	Exercise monitoring; delivery of motivational and educational materials; self-management phase; follow-up

(*continued on next page*)

Table 2a (*continued*)

Study	App name and theory basis	Aim of the study	Necessary materials	Main procedures
			Pacific C/-Delmond flexibles Pty Ltd); and weight scale (Glass Body Analysis scale, Propert)	
Wang [51]	Smartphone app	Efficacy evaluation	• Everyday delivery of text, pictures, voice, and videos along with timely information on diseases and physiological outcomes	Set up collaborative intervention teams; app use and targeted rehabilitation guidance; daily push; WeChat group interaction
Wang [52]	Tongxin Butler	Efficacy evaluation	• Lecture given by experts from the cardiovascular departments of major hospitals; e-books written by professors and concentric butler • Refer to the Chinese expert consensus on coronary heart disease rehabilitation and secondary prevention	Set up health management programmes and a health management team; health education and information distribution; follow-up
Widmer et al. [53]	Personal health assistant (PHA)	Efficacy evaluation	• Construct a set of guideline and evidence-based, user-friendly tasks and educational material	Daily tasks and reminders; guideline-based recommendations; update the risk factors
Wong et al. [54]	Smartphone app	Efficacy evaluation	• The educational area, which defines CHD and provides tips on a healthy diet, exercise, and medications	E-educational contents; health and exercise records; alert/feedback messages; follow-up
Yu et al. [55]	Heart Health	Feasibility and efficacy evaluation	• Many educational readings on secondary preventive cardiac care that originated from scientific guidelines	Medication reminders, cardiac health education, health questionnaire and feedback; follow up
Yuan et al. [56]	PCI Butler	Efficacy evaluation	• Consult relevant books and literature, compile medication guidance, etc., and push videos via WeChat public account platform	App download and registration; remote supervision method; follow-up
Yuan et al. [57]	Smartphone app	Efficacy evaluation	• Watch health education knowledge and videos after intervention, such as diet and exercise rehabilitation exercise teaching videos	Drug administration; measurement and task reminders; lifestyle and emotional management; interactive communication
Yudi et al. [58]	SMART-REHAB	Efficacy evaluation	• A multi-faceted intervention with particular emphasis on early physical activity	Exercise prescription; dynamic tracking; health education; interactive communication
Zhang et al. [59]	Smartphone app	Efficacy evaluation	• The *PCI Rehabilitation Manual* and follow-up care contact card were distributed, and the Health Information app pushed the knowledge of cardiac rehabilitation	Set up a medical support team; follow-up management; health education; real-time feedback
Zhang et al. [60]	Cloud Hospital	Efficacy evaluation	• Push related knowledge of PCI self-management of coronary heart disease compiled under the guidance of specialist nurses	Set up a continuing care team; app management; peer and family support; follow-up visit
Zhang et al. [61]	Personal digital assistant (PDA)	Efficacy evaluation	• A health education list with pictures and video materials uploaded to the unified platform	PDA cardiac rehabilitation assessment; in-hospital rehabilitation; re-evaluate before discharge
Zheng et al. [62]	Cardiovascular Home Care	Efficacy evaluation	• Regular dissemination of CHD health knowledge and precautions	Physiological monitoring; medication reminder and record; health education information push; telephone follow-up
Zhou et al. [63]	Famous Medical Clinic	Efficacy evaluation	• Interventions prepared by team members and reviewed by attending physicians and head nurses	Set up a continuing care group; electronic health records; health education and guidance; interactive communication

Note: BP = blood pressure. CHD = coronary heart disease. CR = cardiac rehabilitation. ECG = electrocardiogram. PCI = percutaneous coronary intervention.

3.6. Analysis of publication bias

In this study, we created funnel plots of the incidence of MACEs, SBP, DBP, TC, LDL-C, and BMI. A low probability of publishing bias is shown by the relatively symmetric distribution of most outcomes on both sides of the funnel (Supplementary Figs. 8–12). The Begg and Egger tests also showed $P > 0.05$ for BMI, TC, LDL-C, DBP, and SBP.

However, publication bias was only present for the incidence of MACEs, which should be interpreted cautiously ($P = 0.038$) (Supplementary Fig. 13). As a result, we did an extra investigation to assess the credibility of the trim-and-fill approach results. Our findings show no reversal of the results before and after, indicating the stability of the combined results (Supplementary Fig. 14, Supplementary Table 1).

4. Discussion

In our meta-analysis, we included 34 RCTs with 5,319 individuals to evaluate the effect of mHealth app interventions on patients with CHD. Through quality evaluation, we found that most of the studies could not achieve strict double-blindness due to the app's intervention characteristics. However, the overall quality is fair and has particular clinical reference value. Our main findings were that, with comparison to control groups, mHealth app interventions lowered the incidence of MACEs and readmission rate; decreased TC, TG, and waist circumference; reduced SAS and SDS scores; increased the cardiac function (LVEF, VO_2 max, and 6MWD); and increased MMAS-8 score and medication adherence rate. To the best of our knowledge, this meta-analysis concludes the preliminary investigation into the effects of mHealth apps on clinical outcomes and health behaviors in patients with CHD. It also incorporates a rich array of extensively referenced English and Chinese literature from diverse regions.

The accumulation of lipids and cholesterol in arterial walls is the primary cause of atherosclerotic plaques. Evidence indicates that reducing blood lipids by one mmol/L can decrease the risk of CHD by 21% [64]. In line with Kavradim et al.'s [65] findings, our research also observed significant improvements in TC and TG, but no noteworthy changes were observed in HDL-C and LDL-C. However,

Table 2b
App intervention details of included studies.

Study	Who and how to deliver the service	Frequence and follow up	Tailoring and modification	Fidelity maintaining and improvement
Blasco et al. [30]	Cardiologists; app	• Measure weight (weekly), glucose and lipids (monthly) • 3 clinical visits during 12 months	• Personal identification, personalized questionnaire, and short message service	• Seventeen patients left the study (8.4%), 12 in EG (11.8%) and 5 in CG (4.9%). Reasons were stress, personal reasons, and inability to handle the equipment
Bravo et al. [31]	Investigator and physician; home-based mixed surveillance	• Walking for 1 h in duration at 70% of the reserve heart rate during the first month and 80% during the second; prescribed training session once a week • 2 months with weekly visits	_	• Supervised physical exercise session; received information about the methods • Only one patient withdrew due to personal reasons
Brouwers et al. [32]	Psychologistor dietician, nurse specialist, CR cardiologits, and thephysicaltherapist; supervised sessions and video consultations	• Attended a median of 14 60-min supervised sessions in the first 3 months, a median of 6 video consultations afterward • 3, 6, 9, and 12 months	• Personalized diagnosis, training goals and physical fitness level; evidence-based clinical algorithms • 98 patients (64%) had ≥1 on-demand consultations, mostly because of reduced training volume	• Attend a median of 6 supervised training sessions (range, 2–23 sessions), mostly because of anxiety, chest pain, and technical issues
Chen et al. [33]	The team consists of 1 attending physician and 4 nurses; app and WeChat	• 3 months	• Complete personal information and provide targeted guidance	• If the patient has not interacted in the WeChat group for a long time, take the initiative to ask the patient's situation
Fang et al. [34]	Physical therapist and clinicians; a belt strap, app, computer servers, and a web portal	• Walking or jogging no less than thrice/week, two home visits, weekly telephone calls • 6 weeks		• A weekly telephone call to resolve any questions the patients might have • 33 patients completed (1 excluded, 4 withdraw, and 1 lost)
Gallagher et al. [35]	Ward staff, GP follow up, researchers; gamified app	• Range from those achievable within-the-day to those requiring behaviour "streaks" of 5 days and 4 weeks, 2–3 weeks post-discharge • 6 months	• Using participant's preferred name in messages and greetings, personal health data as starting points for tracking and social circle • Attempts to reduce travel was not as successful as anticipated as appointments were highly variable and converted to virtual only during covid-19 pandemic restrictions	• All participants received 5 min training and access to a facebook page providing the same training in video, staff provided a single call to participants who had not logged-in within 5 days • 76 were unable to be contacted, 34 withdrew/declined, 5 had died or were too unwell
He [36]	Health professionals; app	_	_	_
Hong et al. [37]	Health professionals; app with telephone interviews and education	• 3-month health it program and a health education telephone call every 2 weeks • 3 and 6 months	• Patients and caregivers could read the blood pressure data every day, an alert was automatically triggered if it was abnormal	• Nobody in either group was lost to follow-up
Indraratna et al. [38]	Investigators, monitoring team (a cardiologist and a cardiac nurse practitioner); app and Bluetooth devices	• Provided 3 weekly educational push notifications • 6 months	• Customizable limits for bp, pulse rate, and weight gain in consultation with the treating cardiologist • Telephone follow-up after covid-19, blood tests were not mandated	• Participants were shown how to use the devices and performed 1 measurement with each device under the supervision • 2 patients did not operate the app (2/164, 1.2%), another patient did not use the app because of a new diagnosis of lung cancer, 8 patients (4.9%) were lost to follow-up
Johnston et al. [39]	Research personnels; app and e-diary	• Recall registration of drug intake within a 48-h span, evening dose could not be registered before 3 p.m. • 2 study visits for 6 months (6–10 weeks; 6 months)	• Personalized and automatized feedback, 15 different but similar predefined messages in the drug adherence e-diary module for individualization	• Education on how to use the e-diary and interactive tool, new message was displayed by a blue colored symbol, and the patient received an sms notification. • Protocol violations in 8 patients
Kraal et al. [40]	Physical therapist and exercise specialist; app and telephone feedback	• 12-week exercise programme with at least two training sessions per week, exercise for 45–60 min per session at 70%–85% of maximal heart rate • 3 and 12 months	• Personalized goal setting, barriers and facilitative factors, motivational interviewing and feedback	• Patients received instructions on how to use a wearable monitor and upload the recorded data • 2 patients dropped out due to technical difficulties and 1 due to a change in health status
Li et al. [41]	1 physician and 7 nurses form a team, and the members have been carefully trained to clarify the division of labor; app and group activity	• The 4 nurses followed up by telephone every two weeks, and the group leader followed up in the first and third months	_	• Nurses specialize in helping patients install, register, and learn the software, train them 2–3 times, emphasize the importance, and proactively contact patients who have not reported it
Li et al. [42]	Physicians, nurses, certified cardiologists; app	• Every 3 months in 12 months	• Personalized medication, lifestyle intervention plan, follow-up protocol, and patient education materials based on hospital informatics system	• Education materials were given at the beginning and during each visit, education on how to use the portal

(continued on next page)

Table 2b (*continued*)

Study	Who and how to deliver the service	Frequence and follow up	Tailoring and modification	Fidelity maintaining and improvement
				• 2% (6/300) of the patients withdrew consent, and 1.3% (4/300) were lost to follow-up
Lu [43]	1 director, 1 physician, 6 nurses, and 2 network technicians were all trained before intervention; app	• Daily medication guidance, self-monitoring and health management values, summarize health report weekly • 6 months	• Discharge summary and basic information of patients are associated with app to set personalized health management and medication plans	• Health managers explain the app operation process to patients and their families
Maddison et al. [44]	The research team and exCR specialist; app and chest-worn wearable sensor	• Three sessions per week and encouraged to be active ≥5 days per week, prescribed session duration and intensity ranged from 30 to 60 min and 40%–65% heart rate reserve • 3 and 6 months	• Personalized goal setting, real-time interaction, audio coaching, feedback and social support	• Patients and specialists operate from any location with an internet connection • 26 patients dropped out (4 patients did not complete VO_2 max, 8 for personal reasons, 6 lost to follow-up, and so on)
Ni et al. [45]	Cardiologist and nurses; app	• Receive medication reminders • Every morning at a random time between 7 and 8 a.m. • Intervention lasted 60 days, followed up for 30 and 90 days	_	• Materials were specifically related to medication adherence and included information on medications function, negative consequences, and so on • 6 patients dropped out of the study and 9 were lost during the follow-up period
Santo et al. [46]	Researchers; app	• Reminders occurred up to three times at 10 min intervals • 3 months	• Personalized daily reminders, refill reminders and information share	• Researcher provide an nitial training sessionon how to use the basic app; adherence statistics feature; alert family members if patients missed a dose • 11 patients did not complete (5 could not contacted, 5 withdrew, and 1 died)
Si [47]	Team leader, doctor in charge, head nurse, medical staff; app and WeChat group	• Push educational materials daily; WeChat group daily interaction and reminders • 3 months	• Complete personal information and provide targeted guidance	• Head nurse and supervisor guide app use; WeChat group daily interaction, questions and reminders, take the initiative to understand the reasons for not participating
Song et al. [48]	Researchers; app	• Prescription and intensity based on anaerobic threshold and hr, frequency was 3–5 times per week, with each duration of 30 min and 5–10 min of warm-up and relaxation • 6 months	• Personalized exercise prescription and feedback	• Instruct patients to wear belts and use the app, medical staff monitor exercise frequency and condition, and answer patients' questions in time • 5 patient dropouts (1 failed to master the app; 1 withdrew due to work reasons; 3 failed to continuously wear belts)
Treskes et al. [49]	Physician, cardiologist, nurse practitioner, and a clinical end point committee; smartphone-compatible devices	• 1, 6, and 12 months (laboratory testing); 3 months (stressechocardiogram); 3 and 6 months (24-h holter); 6 and 12 months (transthoracic echocardiogram)	_	• Patients could log in from anywhere with a stable internet connection; reviewed daily by professionals • 24 fail the 1-year follow-up; four patients died (3 had a cardiac cause, 1 died of alcohol intoxication) and 20 patients were lost to follow-up
Varnfield et al. [50]	The Australian Cardiovascular Health and Rehabilitation Association provided upfront training for mentors; app	• Daily use of stepcounter, wellnessdiary, moderate activity at least 30 min; text message 2/4 per day and video clips 1 to 2 per week; weekly consultation each last 15 min • 6 weeks and 6 months	• Mentors reviewed participants updated data and provide personalized feedback according to goals set	• All patients received detailed programme information and 1 h of face-to-face training on technology use and technical phone support during the trial if required
Wang [51]	Team leader, doctor in charge, head nurse, medical staff; app and WeChat group	• Push educational materials daily; WeChat group daily interaction and reminders • 3 months	• Complete personal information and provide targeted guidance	• Head nurse and supervisor guide app download and use; WeChat group daily interaction, questions and reminders, take the initiative to understand the reasons for lost
Wang [52]	The team included 2 cardiologists, 2 nurses, 1 graduate student, and 2 professionals; app and WeChat group	• Push health knowledge every monday, wednesday and saturday, and answer questions in real time • Telephone follow-up one week after discharge and monthly from 1 to 6 months	• Through telephone follow-up to provide personalized knowledge guidance for different patients	• Record the telephone numbers of regular residents, and register the appropriate time to answer; WeChat group announcements in the form of reading reminders; monthly phone follow-up of patients' app learning • Two cases were lost to follow-up in EG and five cases in CG
Widmer et al. [53]	Mayo Clinic investigators; app	• Patients only received automated reminders to complete educational or recalltasks once logged into the system • 3 months	• Personalized guidance, and the progress can be individually tracked and trended	• Instruct the patients on the program use in a 30-min session; contact the study team or obtain technical support, and inquiries were answered within 24 h • 6 patients (16%) continued to use, 6 complaints, 7 logistical questions

Table 2b (*continued*)

Study	Who and how to deliver the service	Frequence and follow up	Tailoring and modification	Fidelity maintaining and improvement
				about the program, 5 suggestions, and 2 compliments
Wong et al. [54]	Trained research nurses, who were experienced in cardiac nursing; app and telephone advice	• Three monthly 20-min telephone follow-ups twice weekly, text messages were provided by a trained research nurse for up to 3 months • 1 and 3 months	• Personalized health and exercise record, and alerts of risk factors	• The patients are encouraged to input own daily exercise time and type of exercise to arouse interest • Attrition rates of 3.3% ($n = 1$) and 0% at 1 month, and 3.3% ($n = 1$) and 0% at 3 months in EG and CG
Yu et al. [55]	All researchers received uniform training before intervention; app	• 3 and 6 months	• Personalized feedback, encouragement, and advice about secondary prevention status and performance	• Researchers adopted a user-centered design process; help patients install and use the app • 3 patients could not be contacted, and 3 died within 3 months; 5 patients could not be contacted, and 2 died within 6 months
Yuan et al. [56]	2 attending physicians and 3 nurses; app with WeChat and phone	• Push at least 2 messages per week for 1 year • 1 month home follow-up 30 min/times, 3 and 6 months outpatient review	• Patients can feedback questions in real time, and follow-up personnel can analyze and answer them one-on-one	• The head nurse communicated over the phone with the patients who did not appear or withdrew from the group for 10 consecutive days, and suggested family members to participate
Yuan et al. [57]	Doctor in charge and nurse in charge; app	• 1 month walk (65–75 m/min, 30 min/time, 3 times/week), 1–2 months alternating fast walking (65–85 m/min, 30 min/times, 3 times/week), 2–3 months recovery exercise • 6 months	• The app monitors the patient's abnormality, and the medical staff will contact the patient and provide targeted guidance upon receiving the reminder	• Remind the patient to measure blood pressure and heart rate daily and record it in the app
Yudi et al. [58]	Researchers, cardiologist or general practitioner; app	• 30 min of walking a day for at least 5 days per week, 5 messages per week; progress to moderate intensity activity • 2 months	• Personalized goal setting, messaging service, feedback and support	• Every patient receive education on how to use the app • 3 people unable to download app; 17 people lost to follow-up (3 people moved interstate and 14 missed the follow-up appointment)
Zhang et al. [59]	The team included 2 cardiologists and 3 nurses, trained uniformly before intervention; app and telephone, home and outpatient visits	• Adjust the form and frequency of information push content according to their reading preferences and habits • 3 and 6 months	• Push personalized health information based on rehabilitation stage, and adjust the form and frequency of push content according to preferences and habits	• The nurse assisted the patient to download and register the app, and explained the use method and precautions
Zhang et al. [60]	4 physicians, 6 nurses, and 6 peer support educators to learn about relevant knowledge and evidence-based evidence; app and telephone	• The app sends 1–2 messages a day, and carries out peer support education outside the hospital around 15 themes (1–2 times, 60–90 min/time) • 12 months	_	• Guide the patient to download the app and log in to the patient terminal • There were 3 cases in EG and 6 cases in CG
Zhang et al. [61]	CCU nurses receive unified training in the department; app	_	• Personalized education and discharge guidance based on assessment	• The nurse explained the incomprehensible content in detail, guided the patient to do while learning and carried out bedside monitoring
Zheng et al. [62]	3 physicians, 6 nurses, and 2 technical personnel were unified before intervention; app and telephone	• Daily medication plan, self-monitoring plan and follow-up plan, set alarm clock to remind patients to complete on time • 6 and 12 months	• Complete personal information and provide targeted guidance	• Increase telephone follow-up for patients with poor compliance, solve roblems, assess the causes of abnormalities, and conduct health education according to actual needs • EG withdrew 5 cases, CG withdrew 1 case and 4 cases were lost to follow-up
Zhou et al. [63]	The team included the head nurse of the department of Cardiology, attending physicians and senior nursing staff; app	• 6 months	• View patient information and understand individual cognitive needs for personalized health guidance	• The nurse instructed the patient to download and use the app

Note: CCU = coronary care unit. CG = control group. CR = cardiac rehabilitation. DHI = digital health interventions. EG = experimental group. GP = general practitioner. PDA = personal digital assistant. SMS = short message service. VO_2 max = maximum oxygen consumption.

further investigation is required for the findings of three studies conducted by Huang et al. [66], Cruz-Cobo et al. [25], and Al-Arkee et al. [67], which suggest that changes in TC, TG, LDL-C, and HDL-C may lack meaningful distinctions. Moreover, Xu et al. [68] and Akinosunet et al. [69] similarly documented an increase in HDL and TC but no increase in LDL-C and TG. Our study suggests that some individuals may improve their condition through behavior changes, while others may require more rigorous medication. Further investigation is needed to understand these findings.

Abdominal obesity significantly increases the risk of developing hyperlipidemia and diabetes by 3–4 times more than the general population, as stated in Ref. [70]. Reducing waist circumference is a

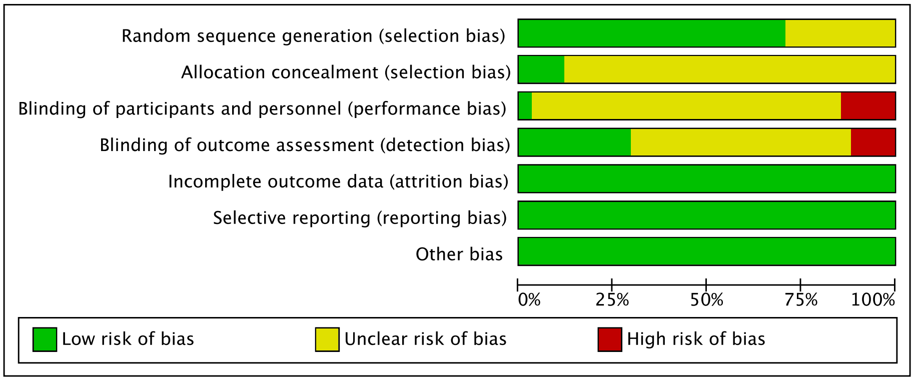

Fig. 2. Risk of bias graph. Assessments of each bias risk category, expressed as percentages for all included studies.

crucial lifestyle goal to prevent CHD. In our meta-analysis, we found that mHealth app interventions were effective in reducing waist circumference, which is consistent with the findings of Xu et al.'s study [68]. Our study included the RCTs to enhance the reliability of the results. Regular physical activity has been shown to lower blood lipid levels and reduce waist circumference. Mobile health apps are useful in motivating patients to increase their activity levels by setting goals, self-tracking, and receiving feedback. Consistent exercise can also lead to changes in lipid metabolism.

Over the past few decades, VO_2 max and 6MWD have been recognized as autonomous prognosticators of cardiovascular risk, cardiovascular mortality, and overall mortality in patients with CHD [58,71]. A noteworthy correlation exists between VO_2 max and individual exercise tolerance and disease prognosis. As noted by Beatty et al. [72], there is a dose-response relationship between the 6MWD and the incidence of MACEs, and even minor adjustments in exercise capacity can yield substantial effects on long-term clinical outcomes. Furthermore, an increased LVEF effectively improves coronary perfusion, reducing the incidence of MACEs and readmission rates.

Interestingly, our findings also revealed substantial alterations in these outcomes, alongside enduring effects on the incidence of MACEs within the subgroup study. However, our results differ from the systematic reviews of Huang et al. [66] and Cruz-Cobo et al. [25]. While Cruz-Cobo's study also observed an increase in 6MWD with mHealth apps, the outcomes for VO_2 max recorded by both Huang and Cruz-Cobo differ from our study. Many mHealth apps, compared to traditional interventions, can achieve the function of remote monitoring, enabling real-time alerts and prevention when there is an urgent change in a patient's vital signs. In addition, timely feedback and guidance from healthcare providers can significantly improve patients' exercise capacity and adherence. Notably, individuals who had established an exercise routine before the intervention are more inclined to sustain it.

Psychopathological conditions frequently manifest in patients with CHD, where elevated levels of anxiety and depression serve as indicators of an unfavorable prognosis. Research by Zhou et al. [73] indicates that nearly 80% of patients with CHD experience symptoms of anxiety and depression. Recent research [20,74] has suggested that the use of mHealth apps can improve symptoms related to anxiety and depression. Our study found that the mHealth groups experienced a decrease in SAS and SDS scores compared to the control groups. Conversely, studies by Huang [66] and Cruz-Cobo et al. [25] both showed no effect on anxiety and depression. While few RCTs investigate psychosocial variables, such as SAS and SDS scores, as we did in our analysis, it is essential to note that we reviewed all psychologically focused studies conducted in China. The results also showed increased patients' medication adherence, similar to a recent systematic review [67]. This improvement could be attributed to system-generated app features, such as customizable notifications and motivational messages. Notably, most studies assessed medication adherence through self-report questionnaires; therefore, future research should consider employing more objective measures.

However, our meta-analysis did not reveal appreciable SBP, DBP, FBS, or Hb1Ac variations. The findings were similar to Semper et al.'s [75] systematic review and Pfaeffli et al.'s [22] clinical study. Some studies [31,58] did not restrict their recruitment to patients with poor BP and glycemic control, which could partly explain the results. Evidence suggests that poor patient acceptance and engagement with mHealth apps were associated with changes in physiological indicators [76]. The lack of emphasis on motivation and willpower to change behavior is also a significant contributing factor. This aspect was rarely underscored during clinical design and implementation, necessitating consideration in the development of apps.

Results from the meta-analysis also indicated a nonsignificant effect on weight and BMI. The negative results for weight and BMI are consistent with those of Akinosum et al. [69], Huang et al. [66], and Cruz-Cobo et al. [25]. Several studies [28,35,38,48,58] offered dietary advice and exercise prescriptions but needed to have targeted weight loss strategies. Weight loss is a complex cognitive process that involves attention, anticipation, memory, and inhibition [77].

Nevertheless, despite the absence of statistical significance in the overall effects on SBP, DBP, LDL-C, HDL-C, BMI, and waist circumference, we identified their gradual reductions in the long-term intervention. Research [78] has highlighted the importance of managing BP and lipid levels in cardiovascular patients to mitigate the readmission rate. Hypertension, diabetes mellitus, uncontrolled SBP, elevated LDL-C, and a lower BMI were significantly associated with the incidence of MACEs at one year. This observation stems from a comprehensive long-term follow-up study [79] involving 6,242 patients who underwent PCI in Korea. Moreover, in an extensive Chinese study [80] with a large sample size of 1,325 and a 9.5-year follow-up period, LDL-C and hypertension were also identified as significant risk factors for the incidence of MACEs. The current study provides evidence concerning the cumulative and enduring effects of mHealth apps on the incidence of MACEs and readmission rates, which could be attributed to managing these

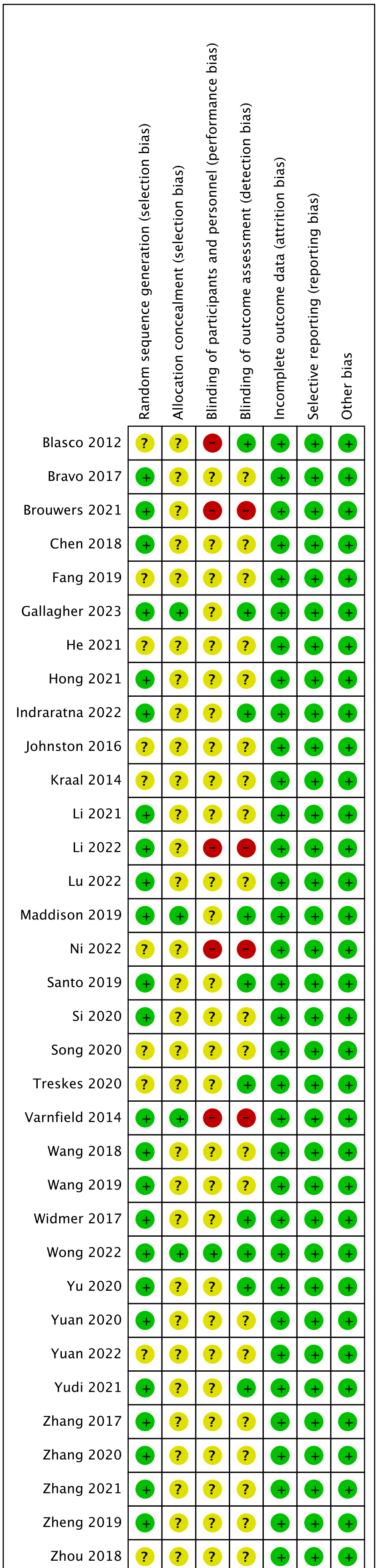

Fig. 3. Risk of bias summary. Assessments of each bias risk category for each study. ("+" means low risk; "-" means high risk; "?" means unclear risk).

risk factors over an extended period.

We illustrated critical factors that influence the outcomes of mHealth app-based interventions in the studies we included. These factors include theoretical basis, necessary materials, procedures, frequency of use, follow-up, customization and modification, fidelity maintenance, and strategies for improvement. However, the need persists for superior RCTs with multi-center, comprehensive, and prolonged follow-up periods to pinpoint the fundamental elements that influence patients' inclination to use mHealth apps. This understanding is crucial for encouraging adherence to usage and enhancing therapeutic outcomes.

5. Limitations

The current review has some limitations that must be taken into account. First, not all studies were involved in each outcome analysis, potentially impacting the combined results and increasing heterogeneity. However, we carefully analyzed the entire text and reached out to the authors via email to obtain additional valid data. Second, although we comprehensively analyzed and summarized the intervention details of mHealth apps from all studies, these differences may inevitably lead to increased heterogeneity in results, so further in-depth analysis is needed. Third, the impact on the incidence of MACEs should be interpreted with caution because of publication bias. Nevertheless, we discovered that the trim-and-fill approach produced stable results. Last, among the 34 studies included, many were single-center and small-scale. Therefore, further large-scale, multi-center RCTs may be necessary to validate the findings.

6. Conclusion

Our meta-analysis indicates that mHealth apps can contribute to reducing the incidence of MACEs and readmission rates among patients with CHD. Additionally, they show promise in enhancing exercise capacity, medication adherence, lipid levels, and alleviating symptoms of anxiety and depression. However, the absence of recommended guidelines results in diverse intervention components of mHealth apps, and these interventions' optimal frequency and duration remain undetermined. Future assessments of the effects of mHealth apps on patients in various settings and phases of recovery are recommended. To validate these effects, rigorous RCTs encompassing multi-center, extensive, and prolonged follow-up periods are necessary.

CRediT authorship contribution statement

Yining Zhu: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Software, Formal analysis, Writing - original draft, Writing - review & editing, Project administration. **Yuhan Zhao:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Software, Formal analysis. **Ying Wu:** Conceptualization, Methodology, Writing-review & editing, Supervision, Funding acquisition, Project administration.

All authors have read and agreed to the published version of the manuscript.

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Table 3
Effects of mHealth apps on clinical outcomes in patient with CHD.

Outcomes	Number of studies	Number of patients	Statistical Method	Effect Estimate	I^2 value (%)	*P*
The incidence of MACEs	11	2,455	Mantel-Haenszel, fixed	0.68 [0.48, 0.97]	30	0.03
Readmission rate	4	1,347	Mantel-Haenszel, fixed	0.56 [0.41, 0.76]	0	< 0.001
Physiological outcomes						
Blood pressure						
SBP	17	3,080	Inverse variance, random	0.43 [−1.97, 2.82]	75	0.73
DBP	15	2,825	Inverse variance, fixed	−0.44 [−1.14, 0.26]	46	0.22
Blood lipids						
TC	10	1,195	Inverse variance, random	−0.19 [−0.37, −0.02]	68	0.03
TG	9	1,043	Inverse variance, fixed	−0.24 [−0.29, −0.18]	0	< 0.001
LDL-C	13	1,717	Inverse variance, random	−0.09 [−0.28, 0.09]	89	0.32
HDL-C	7	711	Inverse variance, random	0.12 [−0.00, 0.23]	89	0.05
Blood glucose						
FBS	4	299	Inverse variance, random	0.11 [−0.44, 0.66]	70	0.70
Hb1Ac	3	267	Inverse variance, random	0.60 [−0.25, 1.45]	81	0.17
Cardiac function						
HR	5	976	Inverse variance, fixed	−0.85 [−2.25, 0.56]	0	0.24
LVEF	3	290	Inverse variance, random	6.50 [2.19, 10.81]	89	< 0.001
VO_2 max	4	583	Inverse variance, fixed	1.89 [0.73, 3.05]	3	0.001
6MWD	4	473	Inverse variance, fixed	19.43 [6.25, 32.61]	14	0.004
Body composition						
Weight	6	599	Inverse variance, fixed	−1.06 [−2.88, 0.75]	44	0.25
BMI	11	2,306	Inverse variance, fixed	−0.30[−0.67, 0.08]	0	0.12
Waist circumference	5	800	Inverse variance, fixed	−1.92 [−3.41, −0.42]	47	0.01
Psychological outcomes						
SAS score	4	377	Inverse variance, random	−7.67 [−12.19, −3.15]	89	< 0.001
SDS score	3	295	Inverse variance, fixed	−7.87 [−8.97, −6.76]	43	< 0.001

Note: BMI = body mass index. DBP = diastolic blood pressure. FBS = fasting blood sugar. Hb1Ac = glycosylated hemoglobin. HDL-C = high-density lipoprote in cholesterol. HR = heart rate. LDL-C = low-density lipoprote in cholesterol. LVEF = left ventricular ejection fraction. MACEs = major adverse cardiac events. SAS = Self-Rating Anxiety Scale. SBP = systolic blood pressure. SDS = Self-Rating Depression Scale. TC = total cholesterol. TG = total triglycerides. VO_2 max = maximum oxygen consumption. 6MWD = 6-min walk distance.

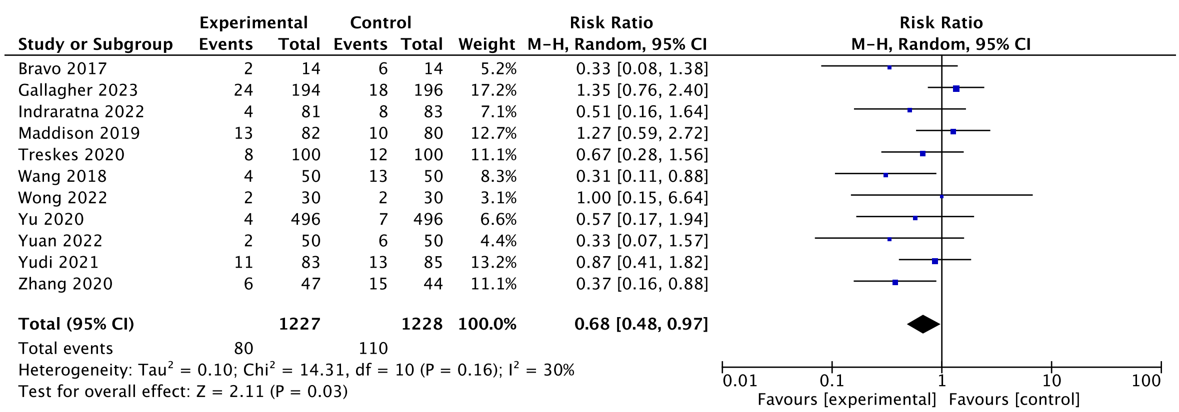

Fig. 4. Effect of mHealth app interventions on the incidence of MACEs in patients with CHD.

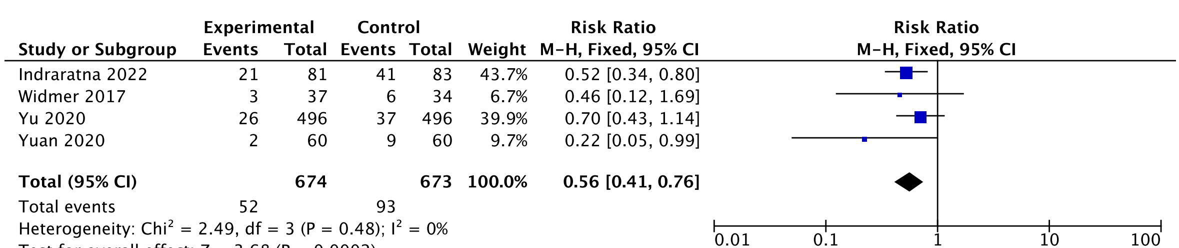

Fig. 5. Effect of mHealth app interventions on readmission rate in patients with CHD.

Table 4
Effects of mHealth apps on health behaviors in patients with CHD.

Outcomes	Number of studies	Number of patients	Statistical Method	Effect Estimate	I^2 value (%)	*P*
Medication adherence						
MMAS-8 score	5	578	Inverse variance, random	0.96 [0.30, 1.62]	94	0.004
Medication adherence rate	7	2,292	Mantel-Haenszel, random	1.23 [1.01, 1.48]	96	0.030
Exercise time (min/week)	3	282	Inverse variance, fixed	24.41 [−9.39, 58.21]	18	0.160
Smoking rate	8	2,607	Mantel-Haenszel, fixed	0.97 [0.85, 1.11]	0	0.670
Drinking rate	2	410	Mantel-Haenszel, fixed	0.79 [0.60, 1.04]	0	0.100

Note: MMAS-8 = Morisky Medication Adherence Scale-8.

Table 5
Sensitivity analysis of included studies.

Outcomes	I^2 value (%) before	Number of excluded studies	Statistical Method	Effect Estimate	I^2 value (%) after	*P*
SBP	75	1 [42]	Inverse variance, fixed	1.45 [−0.50, 3.40]	56	0.140
TC	68	1 [41]	Inverse variance, fixed	−0.18 [−0.27, −0.09]	49	< 0.001
LDL-C	89	4 [39,41,56,59]	Inverse variance, fixed	−0.06 [−0.13, 0.01]	47	0.110
HDL-C	89	2 [31,59]	Inverse variance, fixed	0.06 [0.02, 0.10]	50	0.003
Hb1AC	81	1 [53]	Inverse variance, fixed	0.12 [−0.14, 0.38]	0	0.370
LVEF	89	1 [56]	Inverse variance, fixed	4.02 [2.58, 5.45]	0	< 0.001
SAS score	89	1 [36]	Inverse variance, fixed	−5.65 [−6.78, −4.53]	0	< 0.001
MMAS-8 score	94	2 [41,59]	Inverse variance, fixed	0.33 [0.15, 0.51]	32	< 0.001
Medication adherence rate	96	1 [30]	Mantel-Haenszel, fixed	1.21 [1.14, 1.27]	34	< 0.001

Note: Hb1Ac = glycosylated hemoglobin. HDL-C = high-density lipoprote in cholesterol. LDL-C = low-density lipoprote in cholesterol. LVEF = left ventricular ejection fraction. MMAS-8 = Morisky Medication Adherence Scale-8. SAS = Self-Rating Anxiety Scale. SBP = systolic blood pressure. TC = total cholesterol.

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Not applicable.

Appendices. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijnss.2024.03.012.

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