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ORIGINAL RESEARCH

Digital Health Programs to Reduce Readmissions in Coronary Artery Disease

A Systematic Review and Meta-Analysis



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ABSTRACT

BACKGROUND The use of mobile health (mHealth, wireless communication devices, and/or software technologies) in health care delivery has increased rapidly in recent years. Their integration into disease management programs (DMPs) has tremendous potential to improve outcomes for patients with coronary artery disease (CAD), yet a more robust evaluation of the evidence is required.

OBJECTIVES The purpose of this study was to undertake a systematic review and meta-analysis of mHealth-enabled DMPs to determine their effectiveness in reducing readmissions and mortality in patients with CAD.

METHODS We systematically searched English language studies from January 1, 2007, to August 3, 2021, in multiple databases. Studies comparing mHealth-enabled DMPs with standard DMPs without mHealth were included if they had a minimum 30-day follow-up for at least one of all-cause or cardiovascular-related mortality, readmissions, or major adverse cardiovascular events.

RESULTS Of the 3,411 references from our search, 155 full-text studies were assessed for eligibility, and data were extracted from 18 publications. Pooled findings for all-cause readmissions (10 studies, $n = 1,514$) and cardiac-related readmissions (9 studies, $n = 1,009$) indicated that mHealth-enabled DMPs reduced all-cause (RR: 0.68; 95% CI: 0.50-0.91) and cardiac-related hospitalizations (RR: 0.55; 95% CI: 0.44-0.68) and emergency department visits (RR: 0.37; 95% CI: 0.26-0.54) compared to DMPs without mHealth. There was no significant reduction for mortality outcomes (RR: 1.72; 95% CI: 0.64-4.64) or major adverse cardiovascular events (RR: 0.68; 95% CI: 0.40-1.15).

CONCLUSIONS DMPs integrated with mHealth should be considered an effective intervention for better outcomes in patients with CAD. (JACC Adv 2023;2:100591) © 2023 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

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The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the [Author Center](#).

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**ABBREVIATIONS
AND ACRONYMS****AMI** = acute myocardial infarction**CAD** = coronary artery disease**CR** = cardiac rehabilitation**CVD** = cardiovascular disease**DMP** = disease management program**ED** = emergency department**MACE** = major adverse cardiovascular events**mHealth** = mobile health**ICT** = information communication technology

A concerning proportion of patients with coronary artery disease (CAD) have major risk factors,¹ such that the residual lifetime risk for cardiovascular events and death could decrease if risk factor control and treatment improved.² Optimal management following a cardiac event via secondary prevention cardiac rehabilitation (CR), and disease management programs (DMPs) is paramount to improve risk factors, enhance the prescription of cardio-protective medications, and reduce hospitalizations and mortality.³⁻⁹ However, despite unequivocal evidence for their effectiveness, CR programs are still underutilized with <50% of eligible patients referred worldwide.^{1,10} Conse-

quently, cardiac readmission rates remain high and result in substantial costs. A major driver of these costs is hospitalization expenditure^{11,12} with the average cost of a 30-day readmission postacute myocardial infarction (AMI) costing approximately USD \$15,000, with a cumulative cost of over USD \$1 billion per year.¹³

The rapid use of mobile health (mHealth) technologies has produced strategies and modalities to overcome the historical challenges associated with traditional delivery of CR and DMPs. mHealth-delivered DMP interventions are newly recommended in guidelines,¹⁴ albeit based on lower-level quality evidence derived from a limited number of studies. An in-depth synthesis of the literature is required to keep abreast with the rapid boom in mHealth delivered secondary prevention cardiovascular disease (CVD) care.¹⁵ While previous systematic reviews in this field have shown improvements in clinical, behavioral, and lifestyle risk factors¹⁶⁻¹⁹ (Supplemental Table 1), most prior systematic reviews, that investigated impact outcomes, involved mHealth interventions delivered via telephone.²⁰⁻²² Telephone delivery is resource-intensive, time-consuming, and limits scalability. Less attention has been paid to the most up-to-date digital technologies, which enable a scalable and personalized service to numerous individuals. Further, the few systematic reviews that have attempted to address newer technologies^{23,24} included only a limited number of studies in their meta-analyses with mixed results. Therefore, the aim of this systematic review and meta-analysis was to develop evidence for the effectiveness of mHealth-enabled DMPs, excluding telephone only, on hospital readmissions and mortality in patients diagnosed with CAD.

METHODS

We conducted this systematic review in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines²⁵ and registered it with International Prospective Register of Systematic Reviews (PROSPERO) (registration number [CRD42022306749](#)).

DATA SOURCES AND SEARCHES. MEDLINE, Embase database, the Cochrane Central Register of Controlled Trials, CINAHL, the Web of Science, and Scopus electronic databases were systematically searched for English language studies from January 1, 2007, to August 3, 2021. Grey literature was searched for additional papers. This start date was selected to coincide with the release of the Apple iPhone (the first internet-accessible smartphone with apps). The specific keywords, Medical Subject Heading terms, and search strategy are provided in Supplemental Table 2.

STUDY SELECTION. We used Covidence software for this systematic review.²⁶ Two independent reviewers scanned the titles and abstracts of publications while a third reviewer adjudicated discrepancies. The full texts of selected studies were read in detail, and reasons for exclusion were recorded.

Inclusion criteria. Studies of patients who were discharged from hospital with CAD with a minimum of 30-days follow-up and at least 50 patients in the total sample that evaluated a DMP using mHealth compared with a standard DMP without mHealth were included. mHealth was defined as the use of wireless communication devices (mobile phones, smartphones, electronic tablets, and laptops) and/or software technology (apps, video and teleconferencing, email, telemonitoring, social media, and SMS communication), excluding telephone-only interventions. A DMP is defined as a coordinated health care plan to help people manage their disease better. A DMP is the sum of activities that include some if not all of the following: health professional/nurse consultations, care coordination, regular follow-up, optimization of efficacious medications, education, psychological support, physical activity prescription, self-monitoring strategies (eg, blood pressure measurement), goal setting, and lifestyle/behavioral self-management strategies (eg, medication adherence and dietary intake). Studies were included if they contained at least one DMP component and reported outcomes for at least one of all-cause or cardiovascular mortality, all-cause or

cardiovascular readmissions, or major adverse cardiovascular events (MACE).

Exclusion criteria. Studies were excluded if participants were not diagnosed with CAD or if they had heart failure. Interventions that did not involve mHealth, used the telephone only, or focused on a single behavior (eg, smoking cessation) were excluded.

DATA EXTRACTION AND MANAGEMENT. One reviewer extracted information about the study population, intervention and control/comparison group characteristics, and outcome data from each study using a predeveloped data extraction form. Ambiguities were resolved by discussion and consensus. Multiple publications of the same study were assessed for the provision of endpoint data and the most recent publication was chosen for inclusion.

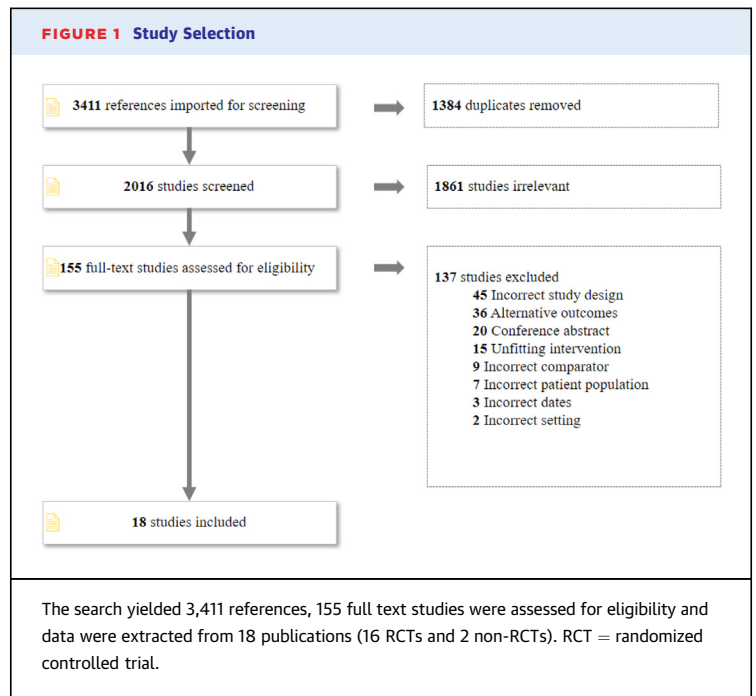
ASSESSMENT OF RISK BIAS AND QUALITY OF THE EVIDENCE. Risk of bias was assessed using the Cochrane Collaboration’s tool²⁷ for randomized controlled trials and the ROBINS-I assessment tool²⁸ for observational studies. Risk of bias plots were generated using ROBIS.²⁹ GRADEpro GDT software³⁰ was used to assess the quality of evidence for each outcome reported.

DATA SYNTHESIS AND ANALYSIS. Analysis was performed using Review Manager (RevMan) version 5.3 software. We measured heterogeneity for each outcome across studies qualitatively by comparing study characteristics and quantitatively using the I^2 test statistic. A meta-regression was performed to account for baseline differences between comparator groups for each outcome. Dichotomous variables were converted to log odds differences between comparator groups. Mean differences were used for continuous variables. We undertook subgroup analysis of: duration of DMP, length of follow-up, year of publication, patient characteristics, and intervention components (outlined in *Inclusion criteria*) to assess the effect of benefit from mHealth DMPs compared to standard DMPs.

We generated estimates of treatment effect using pooled RR with 95% CIs and random-effects models utilizing Mantel-Haenszel methods for combining results across studies. Data were pooled and displayed in forest plots. Hypothesis testing was set at the 2-tailed 0.05 level. The funnel plot and Egger test were used to examine publication bias (Supplemental Figure 1).³¹

RESULTS

As shown in Figure 1, our initial search yielded 3,411 references. After the removal of 1,384 duplicates,



2,016 were reviewed for title and abstract eligibility. Of these, we assessed 155 full-text studies to include a total of 18 publications in the systematic review.

PUBLICATION CHARACTERISTICS. Table 1, Figure 2, and Supplemental Table 3 outline details of the study and intervention characteristics. In summary, included studies were published between 2008 and 2021, and the majority were RCTs (89%). Most studies were conducted in Europe,^{32-34,44,45} North America and Canada,^{35,46-49} and Australasia.³⁶⁻³⁹ Most studies (13 publications) reported follow-up within 6 months,^{32,34-43,46,48} 4 reported 12-month follow-up,^{44,45,47,49} and one study reported 24-month follow-up.³³

The intervention duration of most DMPs lasted 12 to 24 weeks.^{32,33,35-38,40,41,43-45,47-49} All mHealth-enabled DMPs were delivered remotely, yet in 9 studies, some aspects of the model of care were undertaken in a face-to-face setting.^{32-34,37-39,43,44,48} The most common digital component reported in 12 studies were text messages (SMS).³²⁻⁴³ Ten studies reported web applications and/or provider dashboards entailing online portals for reviewing patient-generated data from remote monitoring.^{34,37,38,41,42,44-48} Mobile apps were used in one-third of studies.^{34,35,37,39,43,48} Mobile phones were the most common hardware component used in 14 studies.^{32-43,45,48} Within the mHealth-enabled DMP group, all studies included self-management strategies and education; 13 included health professional coaching^{32-34,37-39,43-49}

TABLE 1 Publication and mHealth Intervention Characteristics

First Author	Year of Publication	Study Country	Study Design	Length of Follow-Up	Duration of DMP	Setting	Software(s)	Digital Hardware(s)	DMP Components
Bae	2021	Korea	RCT	6 mo	24 wk	Home & center based	1-way sms (delivered via message-sending program) & supporting info website	Mobile phone & computer	Education; meds mgmt; exercise prescription; self-management; psychosocial support; behavior change; goal setting
Chow	2015	Australia	RCT	6 mo	24 wk	Home	1-way sms delivered via automated computerized message management system	Mobile phone	Education; meds mgmt; exercise prescription; self-management; psychosocial support; behavior change
Frederix	2015	Belgium	RCT	4.5 mo	18 wk	Home & hybrid	1-way sms; email & web application/web portal; telemonitoring	Mobile phone; motion sensor/wearable device & computer	Health professional consultations; education; meds mgmt; exercise prescription; metrics monitoring; self-management; psychosocial support; behavior change
Frederix	2017	Belgium	RCT	24 mo	24 wk	Home, center based & hybrid	1-way sms; email & web application/secure webpage (telemonitoring)	Mobile phone; motion sensor/wearable device (Yorbody accelerometer) & computer	Health professional consultations; education; exercise prescription; metrics monitoring; self-management; goal setting; multidisciplinary team
Khonsari	2015	Malaysia	RCT	2 mo	8 wk	Home	1-way sms; automated sms-based reminder system & telephone calls	Mobile phone & computer	Education; meds mgmt; self-management; behavior change
Khonsari	2020	Iran	Feasibility RCT	3 mo	12 wk	Home	1-way sms & automated sms-based reminder system	Mobile phone & computer	Education; meds mgmt; self-management; behavior change
Kraal	2017	the Netherlands	RCT	12 mo	12 wk	Home, center based & hybrid	Telemonitoring with web application (Garmin Connect); patient facing + provider facing web application & telephone calls;	Heart rate monitor with a chest strap (Garmin FR70); computer & telephone	Health professional consultations; education; exercise prescription; metrics monitoring; self-management; behavior change; multidisciplinary team
Maddison	2019	New Zealand	RCT	6 mo	12 wk	Home, center based & hybrid	Mobile application; 1- & 2-way sms; web application (provider facing); telemonitoring; & teleconferencing	Mobile phone (smartphone) & smartphone and chest-worn wearable sensor	Health professional consultations; education; exercise prescription; metrics monitoring; self-management; psychosocial support; behavior change; goal setting; multidisciplinary team
Mcelroy	2016	USA	Non-randomized Prospective study	1 mo	4 wk	Home & center based	Telemonitoring; web application; digital questionnaires; video conferencing; telephone	Digital health kits: tablet linked to a Bluetooth-enabled pulse oximeter, heart rate monitor, blood pressure cuff, and weight scale & telephone	Health professional consultations; education; meds mgmt; exercise prescription; metrics monitoring; self-management; multidisciplinary team
Pakrad	2021	Iran	RCT	6 mo	16 wk	Home, center based & hybrid	Mobile application & 2-way communication	Mobile phone	Health professional consultations; education; meds mgmt; exercise prescription; metrics monitoring; self-management; behavior change; goal setting

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TABLE 1 Continued

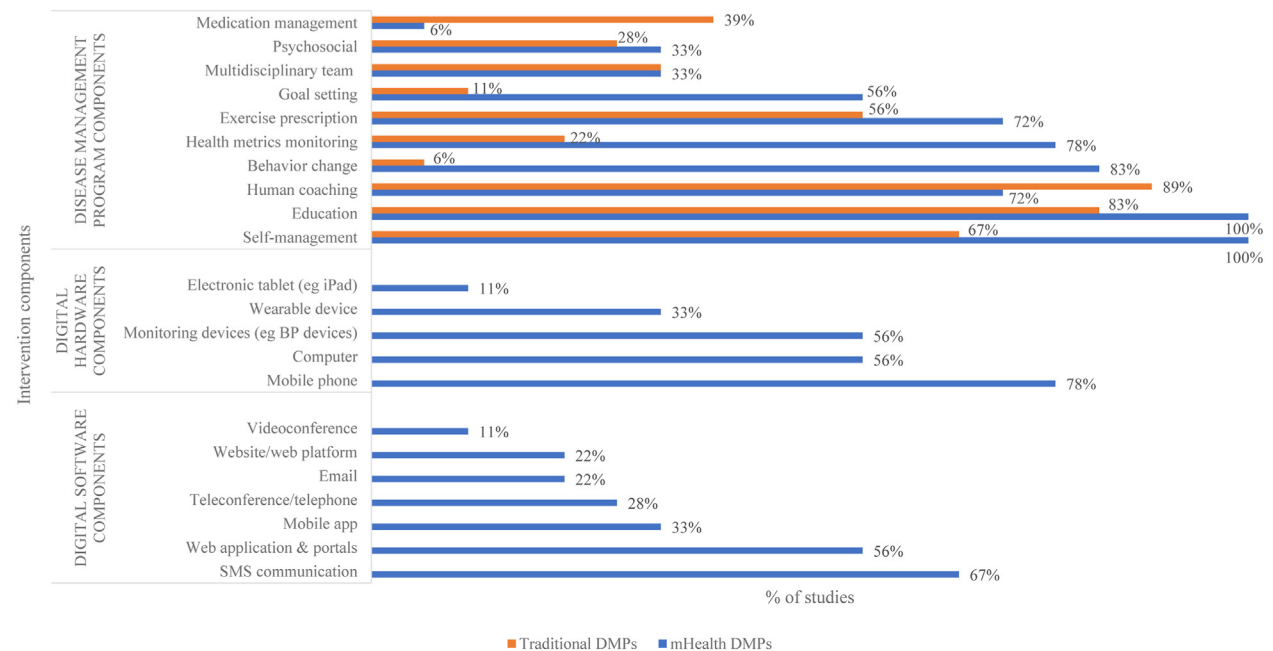
First Author	Year of Publication	Study Country	Study Design	Length of Follow-Up	Duration of DMP	Setting	Software(s)	Digital Hardware(s)	DMP Components
Pfaeffli	2015	New Zealand	RCT	6 mo	24 wk	Home & center based	2-way sms; supporting website/web portal; telemonitoring; participant blog	Mobile phone; computer & pedometer	Health professional consultations; education; meds mgmt; exercise prescription; metrics monitoring; self-management; psychosocial support; behavior change; goal setting
Reid	2012	Canada	RCT	12 mo	24 wk	Home	Web portal/secure website; email & online tutorials	Computer & Pedometer	Health professional consultations; education; exercise prescription; metrics monitoring; self-management; behavior change; goal setting
Riegel	2020	USA	RCT	3 mo	12 wk	Home	Mobile application & electronic messages	Mobile phone & electronic pill device	Education; meds mgmt; metrics monitoring; self-management; behavior change
Snoek	2019	the Netherlands	RCT	12 mo	24 wk	Home & center based	Telemonitoring; web application/web portal & telephone	Mobile phone (Samsung Galaxy); Bluetooth-connected heart rate belt & computer	Health professional consultations; education; exercise prescription; metrics monitoring; self-management; behavior change; goal setting; multidisciplinary team
Widmer	2017	USA	RCT	6 mo	12 wk	Home, center based & hybrid	Mobile application; email; web-based portal; telemonitoring; online messaging;	Mobile phone & computer	Health professional consultations; education; meds mgmt; exercise prescription; metrics monitoring; self-management; behavior change; goal setting
Wolf	2016	Sweden	Sub study of a RCT	6 mo	8 wk-6 mo	Home & hybrid	Mobile application; web application/webpage & 2-way messaging/chat function	Mobile phone & computer	Health professional consultations; education; metrics monitoring; self-management; behavior change; goal setting; multidisciplinary team
Woodend	2008	Canada	RCT	12 mo	12 wk	Home	Video conferencing & telemonitoring	Home monitoring equipment; electronic weigh scales; blood pressure, and electrocardiogram machines	Health professional consultations; education; metrics monitoring; self-management
Yudi	2021	Australia	RCT	2 mo	8 wk	Home, center based & hybrid	Mobile application & personalized feedback	Mobile phone	Health professional consultations; education; meds mgmt; exercise prescription; metrics monitoring; self-management; psychosocial support; behavior change; goal setting; multidisciplinary team

DMP = disease management program; RCT = randomized controlled trial.

and exercise prescription^{32,33,36-40,43-48} and 14 studies incorporated monitoring of health metrics.^{32-35,37-39,43-49}

CAD subvariants could be delineated in 9 studies.^{34,37-40,42,44,47,49} Of these, patients were hospitalized with acute CAD after an AMI (58%

intervention and 61% control) or unstable angina (42% intervention and 39% control), and the most common treatment was with percutaneous coronary intervention (84% intervention and 85% control) compared with coronary artery bypass graft (32% intervention and 38% control). AMI type was reported

FIGURE 2 Intervention Characteristics mHealth DMPs vs Traditional DMPs

Text messages (SMS) were the most common mHealth component³²⁻⁴³ followed by web applications^{34,37,38,41,42,44-48} and mobile apps.^{34,35,37,39,43,48} Mobile phones were the most common hardware component.^{32-43,45,48} DMP = disease management program; mHealth = mobile health.

in 3 papers^{34,39,42} as ST-elevation myocardial infarction (34% intervention and 28% control) and non-ST-elevation myocardial infarction (mean 34% intervention and 46% control). Overall, 3,818 patients were included ranging from 62 to 879 patients per study. The weighted average age of the intervention and control groups was 60.3 ± 1.3 years and 62.6 ± 1.15 years, respectively, and the majority were men (82% intervention and 80% control). Pooled baseline characteristics were similar for the mHealth DMP group and the DMP group alone, aside from a higher proportion of current smokers (24% vs 19%) and family history of CVD (53% vs 33%) in the mHealth DMP group (Supplemental Table 4).

PRIMARY OUTCOME ANALYSIS. The results for dichotomous primary outcome data are shown in separate forest plots for hospital encounters (Figure 3), MACE (Figure 4), and mortality (Figure 5).

Readmissions. Ten studies assessed all-cause readmissions,^{32,34,35,37-39,43,46,48,49} and 9 studies assessed cardiovascular readmissions.^{32,33,39,42-45,47,48} Pooled analysis showed that risk for all-cause readmission ($n = 1,514$) (Figure 3A) was reduced by 32% (RR: 0.68; 95% CI: 0.50-0.91) and cardiovascular readmissions ($n = 1,009$) (Figure 3B) by 45% (RR: 0.55; 95% CI: 0.44-0.68) in the mHealth-enabled DMP group compared

to the DMP alone group. There was no evidence of competing risk analysis whereby mortality may lead to a reduction in readmission given there were a total of 4 deaths from 1,514 patients included in all-cause readmission analysis and 5 deaths from 1,009 patients included in cardiac-related readmission analysis.

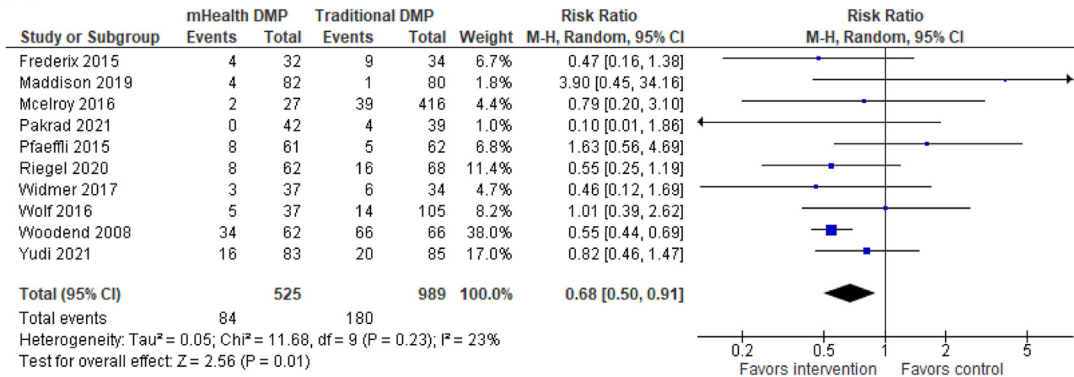
ED visits and MACE. From 2 studies^{48,49} ($n = 199$) reporting emergency department (ED) visits (Figure 3C), risk was reduced by 63% in favor of the mHealth-enabled DMP group (RR: 0.37; 95% CI: 0.26-0.54) compared with the traditional DMP control group. Four studies^{39,41,45,47} ($n = 588$) (Figure 4) assessed MACE, and there was no significant effect of a mHealth DMP relative to a standard DMP (RR: 0.68; 95% CI: 0.40-1.15).

Mortality. Eight studies^{34,36,37,40,42,44,46,47} ($n = 2,711$) assessed all-cause mortality. As shown in Figure 5, there was no risk reduction for all-cause mortality (RR: 1.72; 95% CI: 0.64-4.64) in the mHealth-enabled DMP group compared with the traditional DMP alone group. There were no included studies reporting cardiac-related deaths.

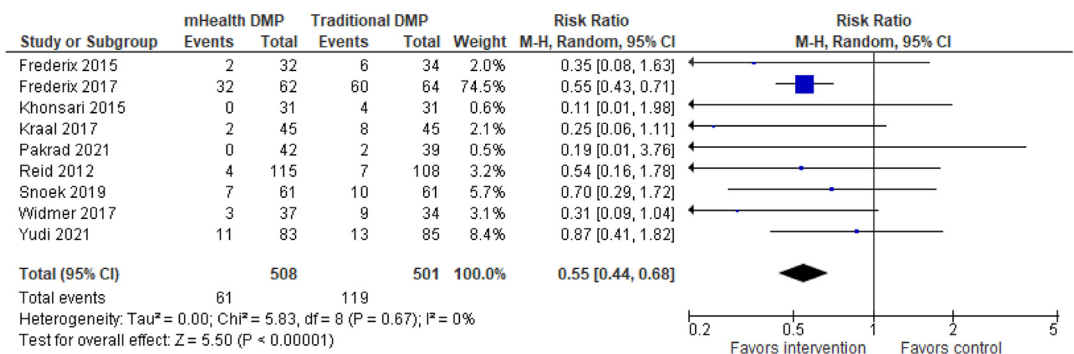
There was no evidence of statistical heterogeneity in the sets of studies for all primary outcomes aside from a small amount for all-cause readmissions

FIGURE 3 Primary Outcome Analysis

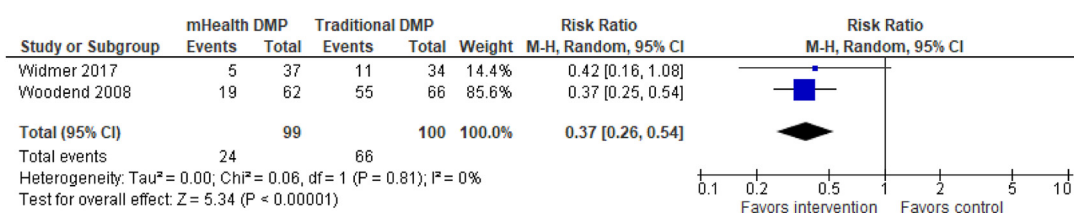
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B



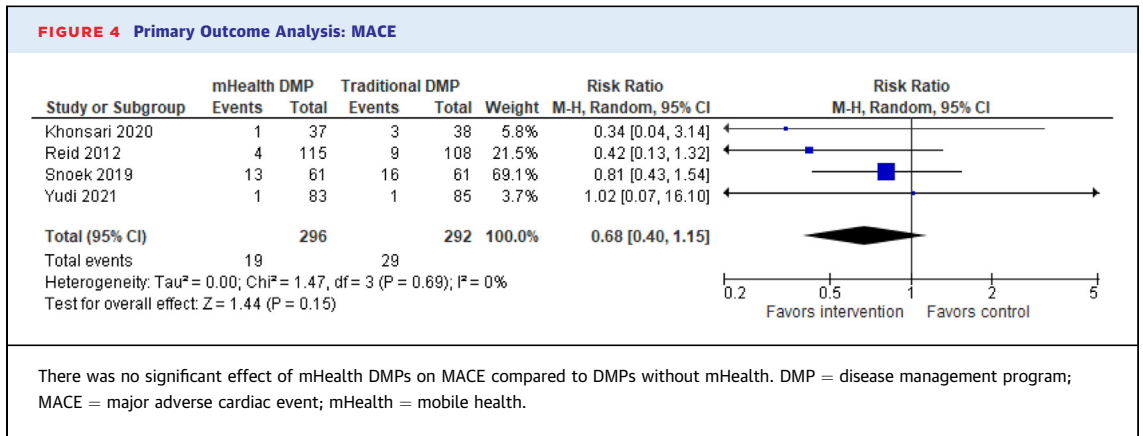
C



(A) All-cause readmissions. Risk for all-cause readmission (n = 1,514) is reduced by 32% in the mHealth DMP group compared to DMPs without mHealth. **(B)** Cardiac-related readmissions. Risk for cardiovascular related readmission is reduced by 45% in the mHealth DMP group compared to DMPs without mHealth. **(C)** ED visits. The risk for emergency department visits is reduced by 63% in favor of the mHealth-enabled DMP group compared to DMPs without mHealth. DMP = disease management program; ED = emergency department.

(I² = 23%). Stratified meta-regression revealed no baseline differences between comparator groups for any primary outcome (Supplemental Table 5). Sub-group analysis using pooled data revealed no significant group differences (Supplemental Table 6). There were no group differences after removing the 2 observational studies.

RISK OF BIAS AND GRADE ASSESSMENT. The overall risk of bias across domains for each study was judged to be low or unclear (Supplemental Figure 2). The GRADE quality of evidence for each outcome was assessed as moderate for all-cause readmissions, high for cardiac-related readmissions and ED visits, low for MACE and very low for all-cause mortality (Table 2,



Supplemental Table 7). There was no evidence of funnel plot asymmetry or significant Egger tests (Supplemental Figure 1), and thus no evidence of publication bias.

DISCUSSION

In this systematic review and meta-analysis, mHealth-enabled DMPs for patients with CAD were effective interventions for reducing hospital readmissions and visits to ED. However, there was no greater benefit for mHealth-enabled DMPs on mortality or MACE outcomes (Central Illustration). Findings did not vary across any patient, intervention, or study characteristics. Our results update the evidence for the effectiveness of mHealth-enabled secondary prevention DMPs by including more studies that assessed impact outcomes

(hospitalizations, ED visits, MACE, and mortality) and using only the latest digital technologies over and above telephone communication.

Our findings indicated a 32% reduction in the relative risk of rehospitalization for any cause and a 45% relative risk reduction in cardiovascular-related rehospitalizations in mHealth-enabled DMP patients compared with patients who undertook a traditional DMP. This contrasts with a prior systematic review that used text messaging or mobile phone app interventions²³ but aligns with others incorporating telephone call interventions, which showed a reduction of between 38% and 44% in all-cause rehospitalizations compared with standard postdischarge secondary prevention care.^{20,22} Overall, mHealth DMPs are effective and complement existing telephone-based interventions. mHealth-enabled DMPs support the scalability of existing models of

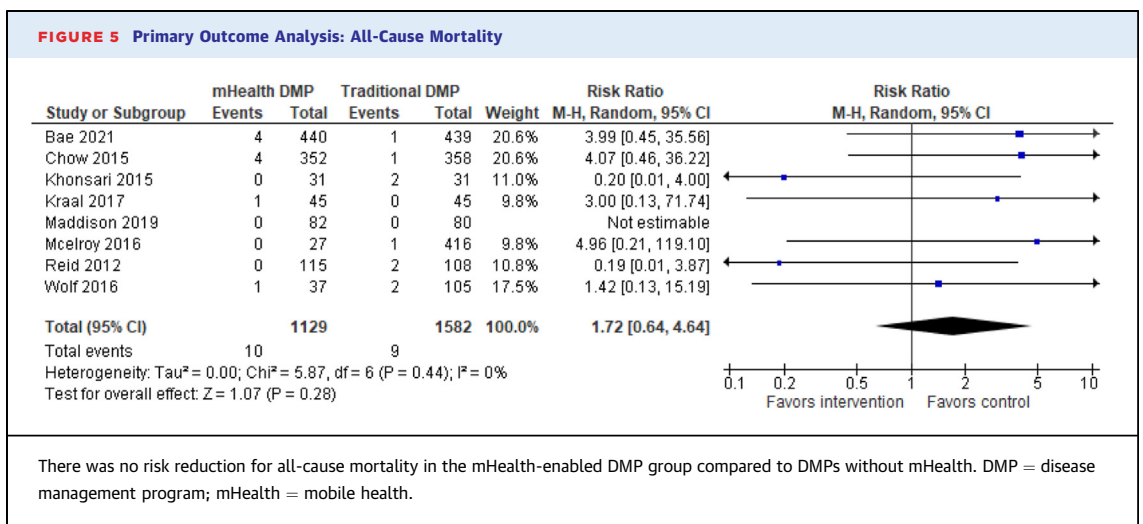


TABLE 2 Summary Findings of Grade Quality Assessment

	Anticipated Absolute Effects* (95% CI)		Relative Effect (95% CI)	No. of Participants (Studies)	Certainty of the Evidence (GRADE)
	Risk With Traditional DMPs Alone	Risk With mHealth DMPs			
All-cause readmissions	18 per 100	12 per 100 (9-17)	RR: 0.68 (0.50-0.91)	1,514 (8 RCTs and 2 non-RCTs)	⊕⊕⊕○ Moderate
Cardiac-related readmissions	24 per 100	13 per 100 (10-16)	RR: 0.55 (0.44-0.68)	1,009 (9 RCTs)	⊕⊕⊕⊕ High
ED visits	66 per 100	24 per 100 (17-36)	RR: 0.37 (0.26-0.54)	199 (2 RCTs)	⊕⊕⊕⊕ High
MACE	10 per 100	7 per 100 (4-11)	RR: 0.68 (0.40-1.15)	588 (4 RCTs)	⊕⊕○○ Low
All-cause mortality	1 per 100	1 per 100 (0-3)	RR: 1.72 (0.64-4.64)	2,711 (6 RCTs and 2 non-RCTs)	⊕○○○ Very low

GRADE Working Group grades of evidence. High certainty: we are very confident that the true effect lies close to that of the estimate of the effect. Moderate certainty: we are moderately confident in the effect estimate; the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different. Low certainty: our confidence in the effect estimate is limited; the true effect may be substantially different from the estimate of the effect. Very low certainty: we have very little confidence in the effect estimate; the true effect is likely to be substantially different from the estimate of effect. GRADEpro GDT software³⁰ was used to assess the quality of evidence for each outcome reported. The GRADE quality of evidence for each outcome was assessed as moderate for all-cause readmissions and ED visits, low for MACE, and very low for all-cause mortality. *The risk in the intervention group (and its 95% CI) is based on the assumed risk in the comparison group and the relative effect of the intervention (and its 95% CI).
 ED = emergency department; MACE = major adverse cardiac event; RR = risk ratio.

care, enhance patient motivation and adherence, and achieve effective results.⁵⁰ They also create cost efficiencies for health care delivery by reducing clinician and health system burden.^{51,52} Hence, rather than replacing the entire traditional model of care with a digital solution, digitally integrated models may provide disease management strategies in a more engaging, accessible, and scalable manner.⁵³

It appears that the beneficial effects of novel mHealth DMPs are due to the sum of their parts. The evidence suggests that there is no one specific component that is the key but rather a combination of factors working together to improve provider-patient communication and enhance patient-centered care. These factors combined enhance engagement, adherence, and subsequent outcomes.^{24,50,54}

Our study provides evidence for the effectiveness of mHealth interventions (incorporating digital technologies) for reducing readmissions and ED visits in patients with CAD. These tech-integrated models of DMPs provide unique opportunities for providers and health systems to interact directly with patients' contemporary lifestyles, delivering more personalized patient-centered care. Rapid technological advancement, improved user experience, and positive consumer acceptance and adoption (from patients and providers)^{55,56} have enhanced engagement and adherence^{16,57} to prevention programs and may explain the added benefit of mHealth-enabled DMPs over and above traditional DMPs without mHealth.











Despite almost all earlier systemic reviews showing significant improvements in clinical, behavioral and lifestyle risk factors when comparing digital technology interventions with traditional DMPs or usual

care,¹⁶⁻¹⁹ previous studies have not investigated the impact of mHealth interventions on readmission and mortality outcomes using emerging digital technologies and devoid of telephone only interventions (Supplemental Table 1). There is heterogeneity between DMP interventions such that more tangible benefits might be realized from improved self-care/behavior change strategies and symptom awareness. These patient-focused behaviors may result in effective risk factor reduction and minimize exacerbation of CVD (including the onset of other events) rather than reduce mortality.

While our results provide evidence for mHealth interventions in lowering readmission risk, a consistent finding is that there is no evidence for reducing mortality.^{17,20,23,24} This may be due to comparator groups²⁰ (either standard care, traditional DMP or cardiac rehabilitation) receiving close to optimal care (Supplemental Tables 8 and 9) or study populations being at low risk of mortality.¹⁷ Given the large heterogeneity between DMP interventions, there is also difficulty in assessing the overall impact on survival rates and health outcomes. Importantly, many studies include relatively short follow-up periods, which may be too short to detect longer-term impacts on mortality.

The results of this systematic review support wider implementation of mHealth-enabled DMPs in secondary prevention settings and should be made accessible to all CAD patients to choose their preferred DMP type and setting. In doing so, one needs to consider the implication for vulnerable or disadvantaged patients. We must ensure to continue to innovate and drive rapid translational research in

CENTRAL ILLUSTRATION mHealth-Enabled DMPs Reduced All-Cause and Cardiac-Related Hospitalizations and Emergency Department Visits Compared to DMPs Without mHealth

	Outcomes following the DMP intervention		Absolute reduction	Relative risk reduction
	mHealth-enabled DMPs	Traditional DMPs without mHealth	mHealth-enabled DMP vs. traditional DMP without an mHealth component For every 50 patients, there are ...	mHealth-enabled DMP vs. traditional DMP without an mHealth component
All-cause readmissions 10 studies n = 1,514			3 fewer readmissions	One-third reduction in all-cause readmissions*
Cardiac-related readmissions 9 studies n = 1,009			5-6 fewer cardiac-related readmissions	Cardiac-related readmissions almost halved*
ED visits 2 studies n = 199			21 fewer patients have an ED visit	Nearly two-thirds reduction in ED visits*
MACE 4 studies n = 588			1-2 fewer MACE events	No difference
Mortality 8 studies n = 2,711			No mortality differences	No difference

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There was no significant reduction for mortality outcomes or MACE. DMP = disease management program; MACE = major adverse cardiac event; mHealth = mobile health.

digital health, but at the same time, consideration must be placed not to exacerbate health inequalities.⁵⁸ Referral to CVD DMPs is often inequitable, with lower referral rates for older adults, women, under-represented minority groups, lower socioeconomic status populations, and those living in remote and regional areas.⁵⁹⁻⁶¹ This is notable because many of these populations have greater rates of CVD compounded by less access to care.⁶² Additional research is needed to strengthen equitable

access to digital health-based DMPs for these key populations⁵⁸ and investigate the factors that are important for implementation of mHealth-enabled DMPs in real-world settings, particularly in low- and middle-income countries.

STRENGTHS AND LIMITATIONS. This systematic review and meta-analysis provides evidence for the effectiveness of the most contemporary mHealth-enabled DMPs on readmission outcomes. There are a few limitations to our study. Firstly, the limited

availability of mortality outcomes with a relatively short follow-up period made it challenging to assess the intervention's effect on mortality. Secondly, while we extracted all available data in each publication, adjudication of cardiovascular events that constitute a cardiovascular readmission may vary between studies, and similarly, noncardiovascular-related readmissions may not have been included among all studies. Finally, most studies included were conducted in high-income countries, yet more than 75% of CVD deaths take place in low- and middle-income countries.⁶³ Hence, caution is required with regards to generalizability of the findings in these less represented populations.

CONCLUSIONS

In this contemporary systematic review and meta-analysis, mHealth-integration into DMPs was an effective intervention for reducing hospital readmissions and visits to ED. DMPs supported by mHealth should be considered for improving outcomes in patients with CAD.

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PERSPECTIVES

COMPETENCY IN PATIENT CARE: Traditional secondary prevention DMPs improve risk factors and reduce hospitalizations. However, they are underutilized worldwide. Telephone delivered DMPs are also effective in improving health outcomes, but they are less scalable and increase clinician burden. The results of this study provide updated evidence for the effectiveness of mHealth interventions for reducing readmissions and ED visits in patients with CAD. Providing patients with the choice, access, and control of their care via mHealth-enabled DMPs should be considered when offering secondary prevention care to patients.

TRANSLATIONAL OUTLOOK: Alternative and cost-effective models of DMPs are required to increase access and engagement to care and reduce preventable and costly readmissions. Further research is required to understand the factors that are important for implementation of mHealth-enabled DMPs, particularly in disadvantaged populations that are at higher risk for CAD.

REFERENCES

1. Kotseva K, De Backer G, De Bacquer D, et al. Lifestyle and impact on cardiovascular risk factor control in coronary patients across 27 countries: results from the European Society of Cardiology ESC-EORP EUROASPIRE V Registry. *EJPC*. 2020;26:824-835.
2. Van Trier TJ, Snatser M, Ter Hoeve N, et al. Modifiable lifetime risk for recurrent major cardiovascular events: observations in a contemporary pooled cohort. *Eur Heart J*. 2021;42(Supplement_1):ehab724.2553.
3. McAlister FA, Lawson FME, Teo KK, Armstrong PW. Randomised trials of secondary prevention programmes in coronary heart disease: systematic review. *BMJ*. 2001;323:957-962.
4. Taylor RS, Brown A, Ebrahim S, et al. Exercise-based rehabilitation for patients with coronary heart disease: systematic review and meta-analysis of randomized controlled trials. *Am J Med*. 2004;116:682-692.
5. Jorstad HT, von Birgelen C, Alings AMW, et al. Effect of a nurse-coordinated prevention programme on cardiovascular risk after an acute coronary syndrome: main results of the RESPONSE randomised trial. *Heart*. 2013;99:1421-1430.
6. de Vries H, Kemps HM, van Engen-Verheul MM, Kraaijenhagen RA, Peek N. Cardiac rehabilitation and survival in a large representative community cohort of Dutch patients. *Eur Heart J*. 2015;36:1519-1528.
7. Maroto Montero JM, Artigao Ramírez R, Morales Durán MD, de Pablo Zarzosa C, Abreira V. [Cardiac rehabilitation in patients with myocardial infarction: a 10-year follow-up study]. *Rev Esp Cardiol*. 2005;58:1181-1187.
8. Hermann M, Witassek F, Erne P, Rickli H, Radovanovic D. Impact of cardiac rehabilitation referral on one-year outcome after discharge of patients with acute myocardial infarction. *Eur J Prev Cardiol*. 2020;26:138-144.
9. Astley CM, Chew DP, Keech W, et al. The impact of cardiac rehabilitation and secondary prevention programs on 12-month clinical outcomes: a linked data analysis. *Heart Lung Circ*. 2020;29:475-482.
10. Turk-Adawi K, Sarrafzadegan N, Grace SL. Global availability of cardiac rehabilitation. *Nat Rev Cardiol*. 2014;11:586-596.
11. Allen KB, Alexander JE, Liberman JN, Gabriel S. Implications of payment for acute myocardial infarctions as a 90-day bundled single episode of care: a cost of illness analysis. *Pharmacoecost*. 2022;6:799-809.
12. Smith LN, Makam AN, Darden D, et al. Acute myocardial infarction readmission risk prediction models: a systematic review of model performance. *Circ Cardiovasc Qual Outcomes*. 2018;11:e003885.

13. Khera R, Jain S, Pandey A, et al. Comparison of readmission rates after acute myocardial infarction in 3 patient age groups (18 to 44, 45 to 64, and ≥ 65 years) in the United States. *Am J Cardiol*. 2017;120:1761-1767.
14. Visseren FLJ, Mach F, Smulders YM, et al. 2021 ESC guidelines on cardiovascular disease prevention in clinical practice. *Eur Heart J*. 2021;42:3227-3337.
15. Day S, Shah V, Kaganoff S, Powelson S, Mathews SC. Assessing the clinical robustness of digital health startups: cross-sectional observational analysis. *J Med Internet Res*. 2022;24:e37677.
16. Wongvibulsin S, Habeos EE, Huynh PP, et al. Digital health interventions for cardiac rehabilitation: systematic literature review. *JMIR*. 2021;23:e18773.
17. Huang K, Liu W, He D, et al. Telehealth interventions versus center-based cardiac rehabilitation of coronary artery disease: a systematic review and meta-analysis. *EJPC*. 2015;22:959-971.
18. Akinosun AS, Polson R, Diaz-Skeete Y, et al. Digital technology interventions for risk factor modification in patients with cardiovascular disease: systematic review and meta-analysis. *JMIR Mhealth Uhealth*. 2021;9:e21061.
19. Deng L, Wu Q, Ding F, et al. The effect of telemedicine on secondary prevention of atherosclerotic cardiovascular disease: a systematic review and meta-analysis. *Front Cardiovasc Med*. 2022;9:1020744.
20. Jin K, Khonsari S, Gallagher R, et al. Telehealth interventions for the secondary prevention of coronary heart disease: a systematic review and meta-analysis. *Eur J Cardiovasc Nurs*. 2019;18:260-271.
21. Neubeck L, Redfern JU, Fernandez R, Briffa T, Bauman A, Freedman SB. Telehealth interventions for the secondary prevention of coronary heart disease: a systematic review. *Eur J Cardiovasc Prev Rehabil*. 2009;16:281-289.
22. Kotb A, Hsieh S, Wells GA. The effect of telephone support interventions on coronary artery disease (CAD) patient outcomes during cardiac rehabilitation: a systematic review and meta-analysis. *PLoS One*. 2014;9:e96581.
23. Gandhi S, Chen S, Hong L, et al. Effect of mobile health interventions on the secondary prevention of cardiovascular disease: systematic review and meta-analysis. *Can J Cardiol*. 2017;33:219-231.
24. Su JJ, Yu DSF, Paguio JT. Effect of eHealth cardiac rehabilitation on health outcomes of coronary heart disease patients: a systematic review and meta-analysis. *J Adv Nurs*. 2020;76:754-772.
25. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71.
26. Covidence Systematic Review Software VHI, Melbourne, Australia. Covidence systematic review software. Veritas Health Innovation. Accessed August 1, 2021. www.covidence.org
27. Higgins JPT, Altman DG, Gotzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ*. 2011;343:d5928.
28. Sterne JAC, Hernán MA, Reeves BC, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. *BMJ*. 2016;355:i4919.
29. McGuinness LA, Higgins JPT. Risk-of-bias VISualization (robvis): an R package and Shiny web app for visualizing risk-of-bias assessments. *Res Synth Methods*. 2021;12(1):55-61.
30. GRADEpro GDT: GRADEpro Guideline Development Tool [Software]. McMaster University and Evidence Prime. 2022. Accessed September 15, 2022. <https://www.gradepro.org>
31. Egger MDSG, Schneider M. Bias in meta-analysis detected by a simple, graphical test. *BMJ*. 1997;315(7109):629-634.
32. Frederix I, Driessche NV, Hansen D, et al. Increasing the medium-term clinical benefits of hospital-based cardiac rehabilitation by physical activity telemonitoring in coronary artery disease patients. *Eur J Prev Cardiol*. 2015;22:150-158.
33. Frederix I, Solmi F, Piepoli MF, Dendale P. Cardiac telerehabilitation: a novel cost-efficient care delivery strategy that can induce long-term health benefits. *Eur J Prev Cardiol*. 2017;24:1708-1717.
34. Wolf A, Fors A, Ulin K, Thorn J, Swedberg K, Ekman I. An eHealth diary and symptom-tracking tool combined with person-centered care for improving self-efficacy after a diagnosis of acute coronary syndrome: a substudy of a randomized controlled trial. *J Med Internet Res*. 2016;18:e40.
35. Riegel B, Stephens-Shields A, Jaskowiak-Barr A, Daus M, Kimmel SE. A behavioral economics-based telehealth intervention to improve aspirin adherence following hospitalization for acute coronary syndrome. *Pharmacoepidemiol Drug Saf*. 2020;29:513-517.
36. Chow CK, Redfern J, Hillis GS, et al. Effect of lifestyle-focused text messaging on risk factor modification in patients with coronary heart disease: a randomized clinical trial. *JAMA*. 2015;314:1255-1263.
37. Maddison R, Rawstorn JC, Stewart RAH, et al. Effects and costs of real-time cardiac tele-rehabilitation: randomised controlled non-inferiority trial. *Heart*. 2019;105:122-129.
38. Pfaeffli Dale L, Whittaker R, Jiang Y, Stewart R, Rolleston A, Maddison R. Text message and internet support for coronary heart disease self-management: results from the Text4Heart randomized controlled trial. *J Med Internet Res*. 2015;17:e237.
39. Yudi M, Clark D, Tsang D, et al. SMARTphone-based, early cardiac REHAbilitation in patients with acute coronary syndromes: a randomized controlled trial. *Coron Artery Dis*. 2021;32(5):432-440. <https://doi.org/10.1097/MCA.0000000000000938>
40. Bae J-W, Woo S-I, Lee J, et al. mHealth interventions for lifestyle and risk factor modification in coronary heart disease: randomized controlled trial. *JMIR Mhealth Uhealth*. 2021;9:e29928.
41. Khonsari S, Chandler C, Parker R, Holloway A. Increasing cardiovascular medication adherence: a medical research council complex mhealth intervention mixed-methods feasibility study to inform global practice. *J Adv Nurs*. 2020;76:2670-2684.
42. Khonsari S, Subramanian P, Chinna K, Latif LA, Ling LW, Gholami O. Effect of a reminder system using an automated short message service on medication adherence following acute coronary syndrome. *Eur J Cardiovasc Nurs*. 2015;14:170-179.
43. Pakrad F, Ahmadi F, Grace SL, Oshvandi K, Kazemnejad A. Traditional vs extended hybrid cardiac rehabilitation based on the continuous care model for patients who have undergone coronary artery bypass surgery in a middle-income country: a randomized controlled trial. *Arch Phys Med Rehabil*. 2021;102:2091-2101.e3.
44. Kraal JJ, Van den Akker-Van Marle ME, Abu-Hanna A, Stut W, Peek N, Kemps HM. Clinical and cost-effectiveness of home-based cardiac rehabilitation compared to conventional, centre-based cardiac rehabilitation: results of the FIT@Home study. *Eur J Prev Cardiol*. 2017;24:1260-1273.
45. Snoek JA, Meindersma EP, Prins LF, et al. The sustained effects of extending cardiac rehabilitation with a six-month telemonitoring and tele-coaching programme on fitness, quality of life, cardiovascular risk factors and care utilisation in CAD patients: the TeleCaRe study. *J Telemed Telecare*. 2019;27:473-483.
46. McElroy I, Sareh S, Zhu A, et al. Use of digital health kits to reduce readmission after cardiac surgery. *J Surg Res*. 2016;204:1-7.
47. Reid RD, Morrin LI, Beaton LJ, et al. Randomized trial of an internet-based computer-tailored expert system for physical activity in patients with heart disease. *Eur J Prev Cardiol*. 2012;19:1357-1364.
48. Widmer RJ, Allison TG, Lennon R, Lopez-Jimenez F, Lerman LO, Lerman A. Digital health intervention during cardiac rehabilitation: a randomized controlled trial. *Am Heart J*. 2017;188:65-72.
49. Woodend AK, Sherrard H, Fraser M, Stuewe L, Cheung T, Struthers C. Telehome monitoring in patients with cardiac disease who are at high risk of readmission. *Heart Lung*. 2008;37:36-45.
50. Turakhia MP, Desai SA, Harrington RA. The outlook of digital health for cardiovascular medicine: challenges but also extraordinary opportunities. *JAMA Cardiol*. 2016;1:743-744.
51. Willems SH, Rao J, Bhambers S, Patel D, Biggins Y, Guite JW. Digital solutions to alleviate the burden on health systems during a public health care crisis: COVID-19 as an opportunity. *JMIR Mhealth Uhealth*. 2021;9:e25021.
52. Iribarren SJ, Cato K, Falzon L, Stone PW. What is the economic evidence for mHealth? A systematic review of economic evaluations of

mHealth solutions. *PLoS One*. 2017;12:e0170581.

53. Oldenburg B, Taylor CB, O'Neil A, Cocker F, Cameron LD. Using new technologies to improve the prevention and management of chronic conditions in populations. *Annu Rev Public Health*. 2015;36:483-505.

54. Subedi N, Rawstorn JC, Gao L, Koorts H, Maddison R. Implementation of telerehabilitation interventions for the self-management of cardiovascular disease: systematic review. *JMIR Mhealth Uhealth*. 2020;8:e17957.

55. Association AAM. AMA digital health research: physicians' motivations and key requirements for adopting digital health adoption and attitudinal shifts from 2016 to 2022. AMA American Medical Association. 2022. Accessed July 15, 2022. <https://www.ama-assn.org/system/files/ama-digital-health-study.pdf>

56. Deloitte. Australia's Health Reimagined. Deloitte, Digital Health Cooperative Research Centre, Consumers Health Forum of Australia and Curtin University. March 2022. 2022. Accessed

June 20, 2022. <https://www2.deloitte.com/au/en/pages/life-sciences-and-healthcare/articles/australias-health-reimagined.html>

57. Hamilton SJ, Mills B, Birch EM, Thompson SC. Smartphones in the secondary prevention of cardiovascular disease: a systematic review. *BMC Cardiovasc Disord*. 2018;18(1):25.

58. Arcaya MC, Figueroa JF. Emerging trends could exacerbate health inequities in the United States. *Health Aff*. 2017;36:992-998.

59. Li S, Fonarow GC, Mukamal K, et al. Sex and racial disparities in cardiac rehabilitation referral at hospital discharge and gaps in long-term mortality. *JAHA*. 2018;7:e008088.

60. Kotseva K, Wood D, De Bacquer D, EUROASPIRE Investigators. Determinants of participation and risk factor control according to attendance in cardiac rehabilitation programmes in coronary patients in Europe: EUROASPIRE IV survey. *Eur J Prev Cardiol*. 2020;25:1242-1251.

61. Chindhy S, Taub PR, Lavie CJ, Shen J. Current challenges in cardiac rehabilitation:

strategies to overcome social factors and attendance barriers. *Expert Rev Cardiovasc Ther*. 2020;18:777-789.

62. Troy A, Xu J, Wadhera R. Abstract 10423: US counties with low broadband internet access have a high burden of cardiovascular risk factors, disease, and mortality. *Circulation*. 2022;146:A10423.

63. WHO. Cardiovascular diseases (CVDs) fact sheets. In: Organisation WH, editor. 2021. Accessed March 10, 2022. [https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-\(cvds\)](https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds))

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APPENDIX For supplemental tables and figures, please see the online version of this paper.