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REVIEW

Virtual healthcare solutions for cardiac rehabilitation: a literature review

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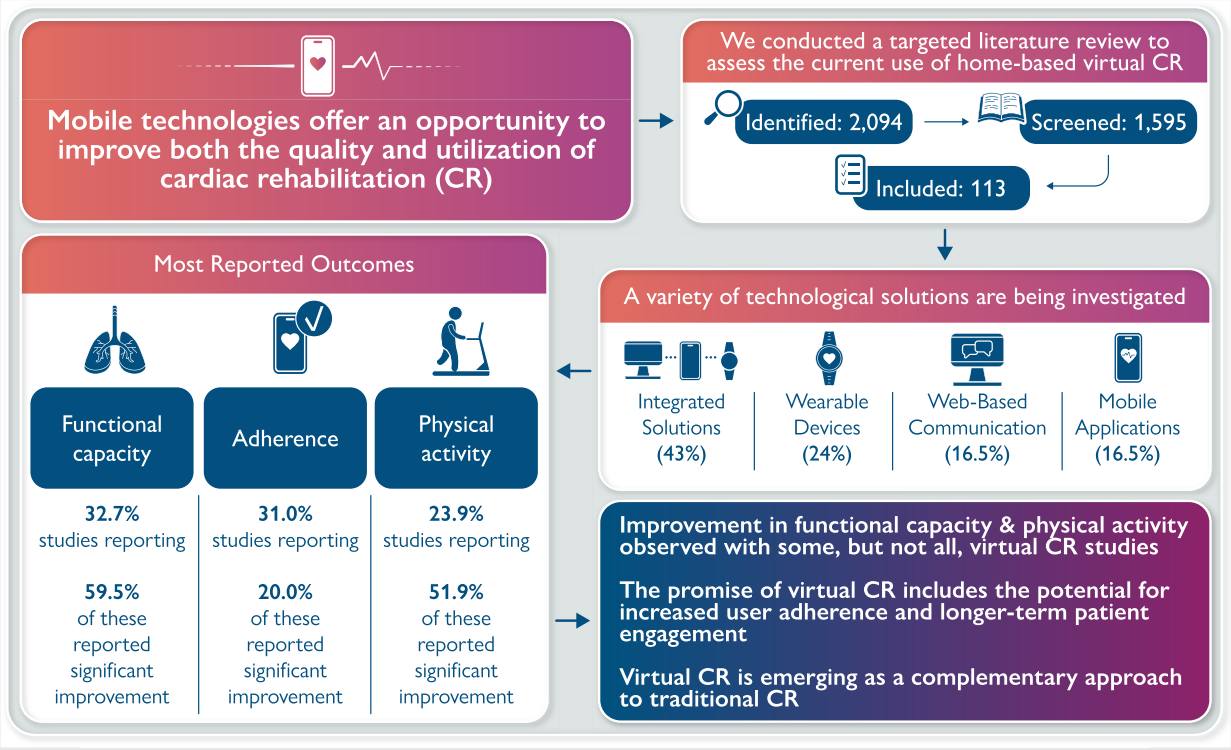
Graphical Abstract



Adherence to cardiac rehabilitation following a primary event has been demonstrated to improve quality of life, increase functional capacity, and decrease hospitalizations and mortality. Mobile technologies offer an opportunity to improve both the quality and utilization of cardiac rehabilitation, and recent clinical studies investigated this technology. This literature review summarizes the current use of mobile health, wearable activity monitors (WAMs), and other multi-component technologies deployed to support home-based virtual cardiac rehabilitation. The methodology was adapted from the *Cochrane Handbook for Systematic Reviews of*

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Interventions. We identified 2094 records, of which 113 were eligible for qualitative analysis. Different virtual cardiac rehabilitation solutions were implemented in the studies: (i) multi-component interventions in 48 studies (42.5%), (ii) WAMs in 27 studies (23.9%), (iii) web-based communications solutions, and (iv) mobile apps, both in 19 studies (16.4%). Functional capacity was the most frequently reported primary outcome ($k = 37$, 32.7%), followed by user adherence/compliance ($k = 35$, 31.0%), physical activity ($k = 27$, 23.9%), and quality of life ($k = 14$, 12.4%). Studies provided a mixed assessment of the efficacy of virtual cardiac rehabilitation in attaining either significant improvements over baseline or significant improvements in outcomes compared with conventional rehabilitation. Efficacy outcomes with virtual cardiac rehabilitation sometimes improve on the centre-based outcomes; however, superior clinical efficacy may not necessarily be the only outcome of interest. The promise of virtual cardiac rehabilitation includes the potential for increased user adherence and longer-term patient engagement. If these outcomes can be improved, that would be a significant justification for using this technology.

Keywords Cardiac rehabilitation • Virtual healthcare • Telemedicine • eHealth • patient empowerment • Self-care

Introduction

Cardiovascular disease (CVD) is the leading cause of death globally, and the increasing incidence of CVD constitutes a pandemic that affects populations worldwide.[1] Following a primary CVD event [e.g. myocardial infarction (MI), heart failure (HF)], cardiac rehabilitation (CR) programmes may be offered to patients to provide support aimed at secondary prevention.[2,3] Many studies have demonstrated the benefits of adherence to CR programmes, leading to improvements in health and quality of life, increased functional capacity, decreased hospitalizations, and mortality (see[4,5] for recent reviews). However, one of the more challenging aspects of CR concerns the significant underutilization among eligible patients. In the USA, only 16.3% of Medicare patients and 10.3% of veterans hospitalized for MI, percutaneous coronary intervention, or coronary artery bypass graft surgery between 2007 and 2011 participated in CR.[6] In other countries, 20–33% of eligible patients have been reported to enrol in CR.[7–10] Despite proven benefits and strong guideline recommendations, less than half of eligible patients with CVD within European Union (EU) countries participate in CR, due to both insufficient referral by medical professionals and suboptimal enrolment of patients who are referred.[11]

The underutilization of CR is even more pronounced in certain populations, who already have poorer health outcomes across a wide range of indicators. These disparities are evident in CR participation rates among women, individuals from rural communities, and racial and ethnic minorities when compared with the general population.[12–14]

With the advent of new technologies, smartphones and wearable devices, healthcare professionals and researchers have looked at incorporating these into novel CR programmes in an effort to improve uptake and participation.[15] The use of stand-alone devices such as wearable activity monitors (WAMs) or mobile apps running on smartphones and tablets (mHealth) allows the capture of patient performance and exercise information. These interventions allow medical staff to provide regular feedback and guidance to patients.[16,17] More sophisticated multi-component interventions with multiple technologies integrated into a comprehensive CR solution are also being investigated.[18]

Remote home-based virtual CR may provide advantages in removing certain barriers preventing patients from participating in CR, such as transportation issues, time spent travelling, and associated costs.[19] In addition to traditional barriers to participation, the COVID-19 pandemic introduced new urgency to remote CR as the lockdowns severely limited access to in-person CR.[20] However, given the relative novelty of mobile technologies in CR, most published studies are limited to research settings, usually within academic research centres and funded by external grants. To date, the use of home-based virtual CR has often been in the context of small pilot studies.

This narrative literature review summarizes the current state of the art of mHealth, with WAMs, and other multi-component technologies deployed in support of home-based virtual CR. The main objective is to evaluate the efficacy of home-based CR as compared to traditional centre-based CR and consider the strengths and weaknesses of this new approach. Given that the main challenges of CR are recruitment, participation, and long-term adherence, this review will also explore the potential of the new technologies to address these issues.

The mobile and healthcare solutions are also commonly referred to in the literature as 'virtual healthcare' and are especially relevant with COVID-19-associated restrictions and limits on direct human-to-human interactions.[21] This review generally uses the term virtual cardiac rehabilitation (virtual CR), broadly defined as the remote delivery of cardiac rehabilitation interventions via connected devices, mobile phones or tablets, and related internet technologies. It is recognized that the terms 'virtual' and 'remote' may be used differently in other CR literature or contexts. Although the methodology of this review follows the recommendations of the *Cochrane Handbook*, a targeted literature review form was chosen due to significant heterogeneity in the evidence base. This heterogeneity makes it difficult to conduct a systematic review, since both the diverse methodologies of the included trials and the variety of the interventions do not allow for a systematic comparison of the treatment outcomes across the studies. The adopted methodology of targeted literature review is based on a clearly formulated question using explicit methods to identify, select, qualitatively analyse, and interpret key relevant research. As such, it allows us to understand the salient issues relevant to the research question.

Methods

The methodology for this literature review was adapted from published guidance on methods for systematic literature reviews by Cochrane (*Cochrane Handbook for Systematic Reviews of Interventions*).[22] Results were reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline.[23]

Sources of data

The searches were conducted on 24 September 2020, in MEDLINE® and Embase via the Ovid platform. Grey literature searching included manual screening of leading cardiac medical body websites for conference abstracts (2018–20), including the European Society of Cardiology, the American Heart Association, and the American College of Cardiology.

Search strategies

Keywords included the MeSH heading 'cardiac rehabilitation' and 'heart rehabilitation'. For the virtual healthcare solutions, keywords included 'telehealth', 'telecommunications', and 'telemedicine'; wearable* or device* or gadget* or sensor* or smart*, among others. No limits on language were set for the search, although titles and abstracts in English only were screened. Details of search strategies are provided in Supplementary material online, *Tables S1* and *S2*.

Table 1 PICOS eligibility criteria

PICO item	Inclusion criteria	Exclusion criteria
Population	Patient engaged in rehabilitation due to underlying cardiovascular disease, including but not limited to myocardial infarction, percutaneous coronary intervention, coronary artery bypass, stable angina, ischaemic heart disease, ischaemic stroke, haemorrhagic stroke, atrial fibrillation, peripheral arterial disease, aortic aneurysm, cardiomyopathy and myocarditis, hypertensive heart disease endocarditis, rheumatic heart disease	N/A
Interventions	Virtual or mobile (mHealth) healthcare solutions [defined as a care team + connected devices + a digital solution (e.g. smartphone app) or a platform], which can also include telephonic interventions or infrastructures such as an health care practitioner/nurse call centres	Self-contained devices or apps
Comparators	Any or none	N/A
Outcomes	Efficacy/effectiveness outcomes: • Improvements in risk factors, exercise capacity, cardiovascular symptoms, blood pressure, metabolic panel, body-mass index (BMI), anxiety/depression, and medication adherence to secondary preventive therapies • Survival after an initial cardiac event • User adherence/compliance Safety outcomes (including but not limited to): • Total adverse events, device-related adverse events, serious adverse events, adverse events leading to discontinuation of study, major adverse cardiac events including not limited to: cardiovascular death, myocardial infarction, stroke, hospitalization (all reasons), • Increase of existing diuretic dose or addition of a new diuretic due to fluid retention, hyperkalaemia, heart failure measures (heart failure progression, B-type natriuretic peptide biomarker change) Health-related quality-of-life outcomes • Patient reported and health related quality of life (including but not limited to EuroQol-5D, EuroQol-Visual Analogue Scale, Heart Quality of Life, MacNew Heart Disease Health-Related Quality of Life Questionnaire, Quality of Life after Myocardial Infarction, The Minnesota Living with Heart Failure Questionnaire)	N/A
Study design	• Randomized Controlled Trials (RCTs) • Non-randomized clinical trials • Observational studies • Cohort studies (retrospective and prospective) • Case-control studies • Cross-sectional studies • Systematic literature reviews	• Notes • Letters • Editorials • Comments • Case reports/series
Additional criteria (limits)		
Timing	None	
Setting	None	
Publication date limit	None	
Language	No limit on language was set for the search. Title and abstracts in English were screened.	

Study selection

Study selection was carried out by one senior (PhD level) trained methodologist and study eligibility criteria were defined using a PICOS (Population, Intervention, Comparator, Outcomes, Study design) framework as presented in *Table 1*. Following duplicate removal, all titles and abstracts were screened for potential eligibility according to the prespecified PICOS criteria (*Table 1*). All studies identified as eligible during abstract screening were then screened at a full-text stage by two investigators. Reasons for inclusion/exclusion were documented.

Data extraction

A standardized data extraction table was generated to define study, patient, and intervention characteristics, and outcomes to be extracted from eligible studies. All relevant data from the final list of included studies were extracted by the same reviewer that carried out the study selection. The following data were extracted where available: (i) study design, study settings, intervention category (mobile application, wearable device, web-based, multiple interventions), country, study duration, and sample size; (ii) mean patient age, cardiac condition; medical history (comorbidities), cardiac procedure; (iii) primary outcome(s), secondary outcome(s), statistical significance of primary outcome(s) (i.e. yes, no, not applicable), primary outcome(s) effect size, and dispersion and aggregate category of primary outcome.

Results

Study selection

The search identified 2094 records. Title/abstract screening and duplicate removal resulted in the exclusion of 1743 records. Full-text review of the remaining 351 records resulted in the exclusion of 217 records. In total, 134 studies were included comprising of 113 original clinical

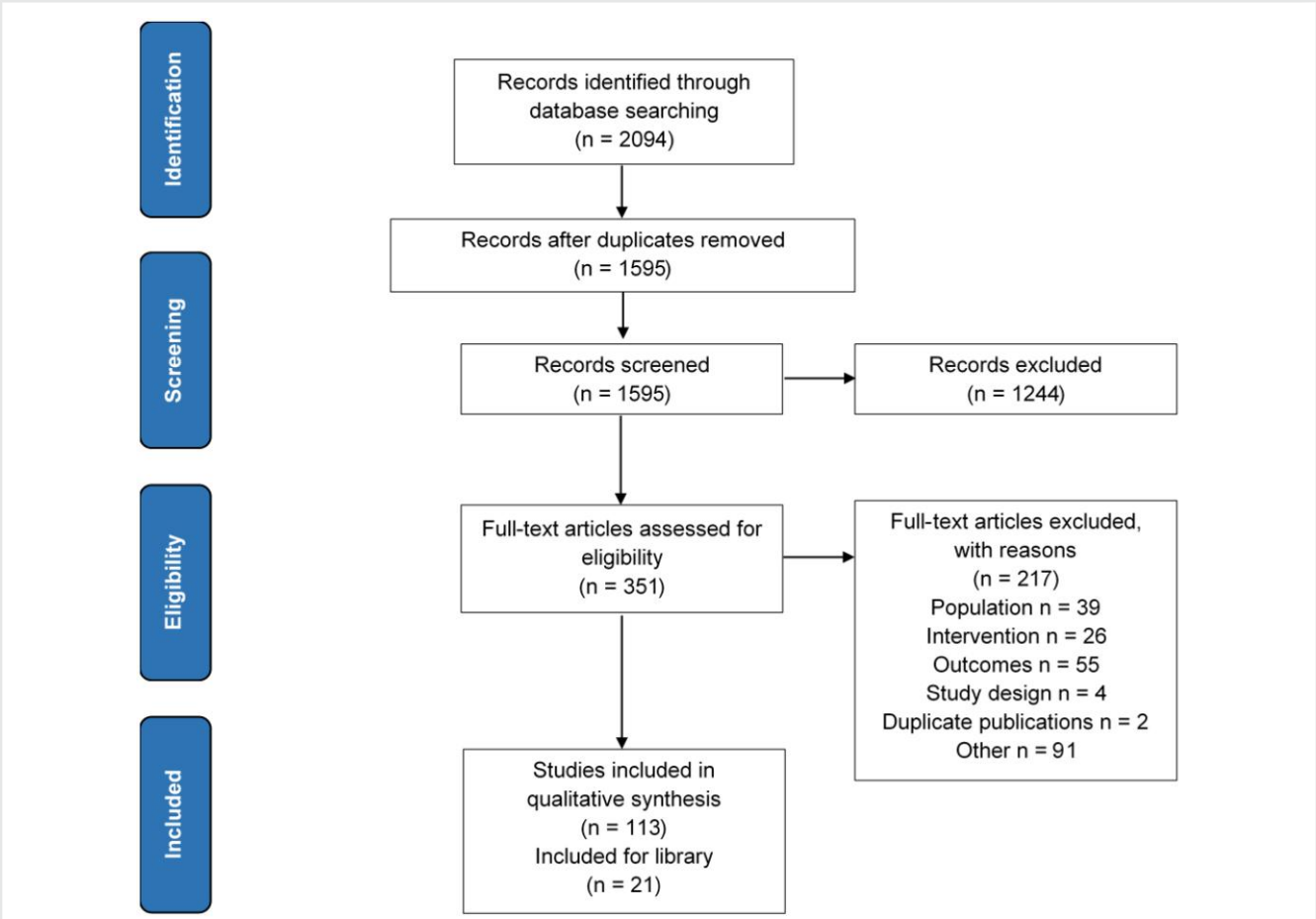

Figure 1 Study selection (PRISMA) diagram.

Table 2 Number of studies classified by study type and the proportion reporting a significant primary outcome

Study type	Number of studies (%)	Number of studies with a significant* primary outcome (%)
Randomized controlled trials (RCT)	64 (56.6)	31 (48.4)
Observational studies	19 (16.8)	4 (21.0)
Cross-sectional	12 (10.6)	3 (25.0)
Single-arm trials	8 (7.1)	6 (75)
Comparative, non-randomized trials	5 (4.4)	2 (40.0)
Retrospective	4 (3.5)	0
Prospective cohort	1 (0.88)	1 (100)
Total	113	47 (41.6)

*$P < 0.05$.

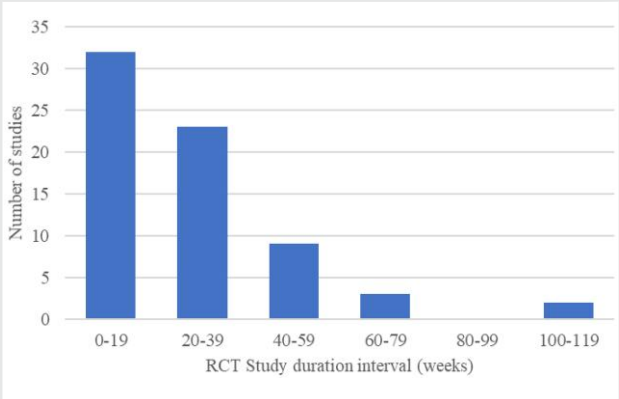

Figure 2 Study distribution of RCT duration. RCT, randomized controlled trial.

studies and 21 review articles included for the library. The PRISMA diagram is shown in *Figure 1*.

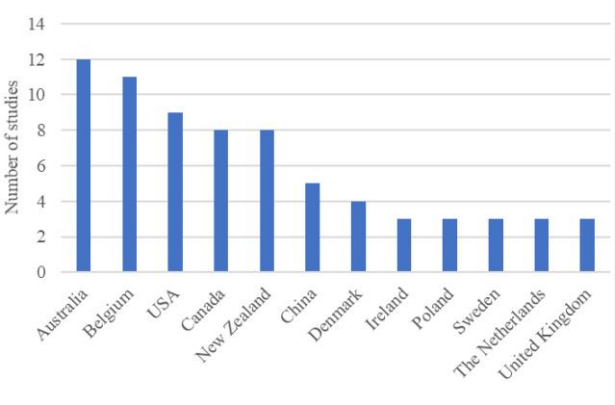

Figure 3 Number of studies in different countries (Top 12).

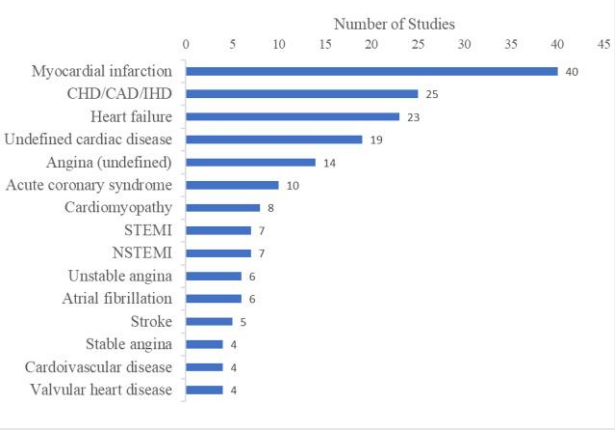

Figure 4 Number of studies reporting on disease/condition (Top 15). CAD, coronary artery disease; CHD, coronary heart disease; IHD, ischaemic heart disease; NSTEMI, non-ST-Elevation Myocardial Infarction; STEMI, ST-Elevation Myocardial Infarction.

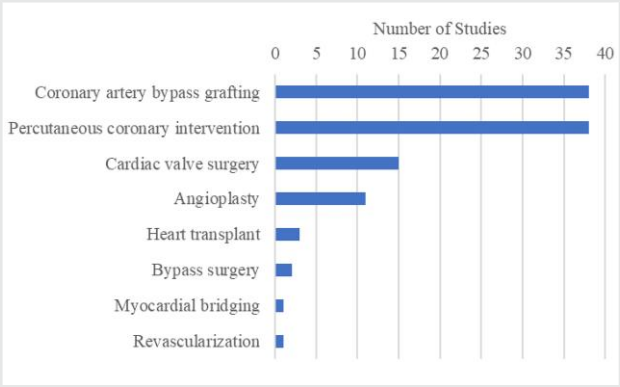

Figure 5 Number of studies reporting on invasive cardiac procedures. Myocardial bridging refers to myocardial bridge unroofing surgery.

Study characteristics

Out of 113 included studies, 64 were randomized controlled trials (RCTs), 19 were observational studies, 12 were cross-sectional studies, 8 were single-arm studies, 5 were comparative non-randomized trials, 4 were retrospective studies, and 1 was a prospective cohort study (*Table 2*). Most study settings included home-based CR (68 out of 113 studies, 60%), followed by studies conducted in academic centres (20/113, 18%) and real-world centres (11/113, 10%). Fourteen studies (12%) were conducted in mixed settings where some of the interventions were home based, and some were centre based. The CR services for the home-based studies in case of interventional studies (57 out of 68 home-based studies were interventional and 11 were observational/retrospective) were provided by the academic centre supervising the study. The intervention group would usually receive additional care in some form of virtual healthcare, whereas the control group (if applicable) would receive the standard level of CR according to usual practice within each institution. For the remaining 11 observational/retrospective studies in home-based settings, the patients were recruited through existing CR programmes.

Studies included in this review provided an overall mixed assessment of the efficacy of virtual CR either in attaining significant improvements over baseline or in attaining significant improvements in outcomes compared with conventional hospital-based cardiac rehabilitation. Less than half of the included studies—47 out of 113 (41.6%)—reported a significant result for a primary outcome (*Table 2*). It should be noted that this ratio refers to the significance of the result for any primary outcome, combining both within-group differences (i.e. baseline vs. elapsed time interval) and between-group differences [i.e. baseline vs. elapsed time interval but comparing usual centre-based CR (CBCR) vs. virtual CR]. The latter comparative outcome was reported in 16 studies, and these results will be described in a subsequent section.

The distribution of study duration in the RCTs included is shown in *Figure 2*. The study duration of RCTs ranged between 2 weeks and 104 weeks, with mean and median durations of 26.5 weeks and 24 weeks, respectively. Patient populations in included RCTs ranged between 15 and 731, with total, mean, and median populations of 8446, 120, and 102, respectively. The follow-up duration of the majority of RCTs was <39 weeks (*Figure 2*), corresponding to Phases II and III of a CR programme. The studies were conducted in 23 different countries shown in *Figure 3*.

Patient characteristics

The baseline demographics of the patients were typical for patients enrolled in CR programmes. The mean age of patients across the 101 studies reporting this information ranged from 49.2[24] to 80.2[25] with a median reported mean age of 60.9 and a weighted (by sample size) mean average age of 61.4 years. A total of 11 541 patients were included among the studies reporting mean age and sample size. In terms of sex, among 105 studies reporting the breakdown, the proportion of female participants ranged from 0 to 68.8%, with a mean of 23.4% and a median of 19%. Among 18 studies reporting the racial composition of the patient populations, the proportion of white participants ranged from 55.4 to 98.8%, with a mean of 80.4% and a median of 85%.

A total of 70 studies reported on the urban/rural divide: 54 studies enrolled participants from urban centres, 8 studies enrolled participants from both urban and rural settings, and the remaining 8 studies included participants from rural areas only.

A wide variety of cardiovascular conditions were represented. There were 34 distinct conditions identified and the 15 most frequently noted are shown in *Figure 4* (some studies included mixed patient populations with multiple conditions). The most commonly reported invasive cardiac procedures are listed in *Figure 5*.

Enrolment in virtual CR was restricted to patients recovering after the procedure without excessive cardiac risk (patients in Phase II—IV of CR).

Interventions

A wide variety of virtual CR solutions were implemented in the 113 included studies to engage with patients and facilitate behaviour modification to promote cardiac rehabilitation. These technological interventions were classified into four categories for the purposes of this review:

(1) Multi-component interventions with multiple technologies integrated into a comprehensive CR solution in 48 studies (42.5%). An example of this approach is shown in a paper by Avila *et al.*[26] on the results of the TeleRehabilitation in Coronary Heart disease (TRiCH) study. The virtual intervention consisted of an individualised exercise prescription for home-based exercise for 3 months. Patients were asked to log all exercise data and to upload the data on the online web application for review by the investigators. Based on these data, an individualised exercise prescription was created, recommending patients exercise for at least 150 min a week at a target heart rate of 70–80% of heart rate reserve (HRR) at home for 3 months. Once a week, patients received feedback by phone or e-mail.

(2) WAMs (e.g. Fitbit, Actigraph, Apple Watch) in 27 studies (23.9%). An example of this category is a study by Batalik *et al.*[27] which enrolled 56 cardiac rehabilitation patients and randomized them into a 12-week regular outpatient training group and interventional home-based telerehabilitation group. For both groups, the intensity of the training was prescribed to be performed at 70–80% of heart rate reserve for 60 min, three times a week. The interventional home-based patients started their training with a wrist-worn heart rate monitor in their home environment. These patients received feedback once a week, reflecting data uploaded on the internet application. Training adherence in both groups was determined and compared. The results showed similar outcomes for both groups, suggesting that telerehabilitation via wrist-worn heart rate monitor could become an alternative kind of cardiac rehabilitation which deserves attention and further analysis.

(3) Web-based communications solutions: This category was selected to separate the studies where the only means of communication between the patient and the healthcare professional was a personal computer with internet access. An example is a study by Duan *et al.*[24] aiming to evaluate the effect of an 8-week Web-based intervention in terms of physical activity (PA), fruit and vegetable consumption (FVC), lifestyle changes, social-cognitive outcomes, and health outcomes compared with a waiting control group in Chinese cardiac patients. The web intervention content was designed based on the Health Action Process Approach theory. Based on the collected data, two types of feedback were provided: (i) individualized feedback on patient self-reported behaviour performance 4 weeks ago, 3 weeks ago, 2 weeks ago, and 1 week ago, and (ii) criterion-based feedback (e.g. accumulated at least 150 min with moderate intensity of PA per week and five portions of FVC per day).

(4) Mobile apps running on smartphones and tablets (mHealth), in 19 studies (16.4%) for each device. An example is a paper by Rosario *et al.*[28] showing the results of a pilot study aiming to determine if a smartphone-based adjunct to standard care could increase the completion rate of a cardiac rehabilitation programme (CRP). Sixty-six participants who were about to commence a hospital-based CRP were randomized so that half received three devices embedded with near-field communication, namely a smartphone [pre-installed with an application (app) designed specifically for cardiac rehabilitation], portable blood pressure monitor, and weight scale whilst completing the CRP. All patient measurements (i.e. activity, questionnaire responses, blood pressure, and weight) were stored securely on the smartphone before being re-transmitted to centre's remote telehealth platform. During the intervention, patients continued their CRP programme as scheduled.

A summary of the overall results separated by the four categories is presented in *Table 3*. A majority of multi-component intervention studies were RCTs ($k = 36$, 75.0%) and just over half of multi-component studies reported a significant result for improvement in the primary outcome ($k = 27$, 56.3%) (*Table 3*). Over half of mHealth studies were also RCTs ($k = 11$, 57.9%); however, just under half of mHealth studies reported significant improvements in primary outcomes ($k = 9$, 47.4%) (*Table 3*). The proportion of RCTs and significant improvements in primary outcomes in studies utilizing WAMs and web-based communications were all <50% (*Table 3*).

A total of 16 studies reported significant between-group improvements in primary outcomes of virtual CR vs. usual hospital-based CR; 9 of these were studies utilizing multi-component interventions, 6 used mHealth, and 1 reported on the use of WAMs (*Tables 3* and *4*). These are described in more detail in the next sections on specific interventions.

Table 3 Number of studies utilizing different technologies, number of corresponding RCTs, and studies with significant primary outcomes

Technology Number of studies (% of total)	Number of RCTs (% of technology studies)	Studies with a significant* primary outcome (% of technology studies)	Studies with significant* improvements in virtual CR vs. usual CR patient groups[a]
Multi-component interventions 48 (42.5)	36 (75.0)	27 (56.3)	9
WAMs 27 (23.9)	9 (33.3)	10 (37.0)	1
Web-based communication 19 (16.8)	8 (42.1)	1 (5.3)	0
mHealth 19 (16.8)	11 (57.9)	9 (47.4)	6
Total: 113	64 (56.6)	47 (41.6)	16

RCT, randomized controlled trial; mHealth, mobile apps; WAM, wearable activity monitor.
[a]Note that comparative studies were limited to virtual cardiac rehabilitation vs. control groups with hospital-based cardiac rehabilitation.
*$P < 0.05$.

Table 4 Studies reporting significant differences in primary outcomes between virtual cardiac rehabilitation and routine hospital-based cardiac rehabilitation

Short reference	Technology	Primary aggregate outcome	Study design	Patient cardiac conditions	Country
Avila 2018[26]	Multiple interventions (web-based communication; WAM)	Functional capacity	RCT	CABG, PCI	Belgium
Bernocchi 2018[29]	Multiple interventions (web-based communication; WAM)	Functional capacity	RCT	CHF + COPD	NR[a]
Frederix 2015[30]	Multiple interventions (web-based communication; WAM)	Functional capacity	RCT	CABG, PCI	Belgium
Frederix 2017[31]	Multiple interventions (web-based communication; WAM)	Functional capacity	RCT	STEMI, NSTEMI, unstable angina, stable angina	Belgium
Skobel 2017[32]	Multiple interventions (web-based communication; WAM)	Functional capacity	RCT	CAD	Germany; UK; Spain
Pfaeffli Dale 2015[33]	Multiple interventions (mobile application; web-based communication)	Patient adherence/ compliance	RCT	MI, unstable angina, angina	New Zealand
Rosario 2018[28]	Multiple interventions (NR)	Patient adherence/ compliance	RCT	Undefined cardiac disease	Australia
Varnfield 2014[34]	Multiple interventions (WAM; mHealth; web-based Communication)	Patient adherence/ compliance	RCT	STEMI, NSTEMI, HF, angina, stroke, bypass surgery, angioplasty/stent, heart valve problems	Australia
Claes 2020[35]	Multiple Interventions (Web-based communication; WAM)	Physical activity	RCT	PCI, CABG, valve repair	Belgium; Ireland
Eyles 2017[36]	mHealth	Quality of Life	RCT	Cardiovascular disease	New Zealand
Sjolin 2019[37]	mHealth	Quality of Life	RCT	AMI	NR[b]
Widmer 2014[38]	mHealth	Quality of Life	Observational	ACS	USA
Cai 2019[39]	mHealth	Functional capacity	RCT	AF	NR[c]
Yudi 2021[40]	mHealth	Functional capacity	RCT	STEMI, NSTEMI, unstable angina	Australia
Ding 2012[41]	mHealth	Patient adherence/ compliance	RCT	Undefined cardiac disease	Australia
Izawa 2012[42]	WAM	Physical activity	RCT	Undefined cardiac disease	Japan

ACS, acute coronary syndrome; AF, atrial fibrillation; AMI, acute myocardial infarction; CABG, coronary artery bypass graft; CAD, coronary artery disease; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; HF, heart failure; MI, myocardial infarction; mHealth, mobile health apps; NSTEMI, ST-Elevation Myocardial Infarction; PCI, percutaneous intervention; STEMI, non-ST-Elevation Myocardial Infarction.
[a]First author affiliation is located in Italy.
[b]First author affiliation is located in Sweden.
[c]First author affiliation is located in China.

Wearable activity monitors

In studies with WAMs as the only virtual CR intervention used ($k = 27$), 10 (37.0%) reported significant effects on a primary outcome associated with cardiac rehabilitation.[42–51] All primary patient outcomes in these studies concerned either the amount and intensity of physical activity and/or heart rate monitoring. Two randomized controlled trials provided evidence supporting the direct positive impact and improvement in physical activity for patients fitted with an accelerometer to monitor physical activity[42] and a wireless electrocardiogram (ECG) device to monitor heart rate[49] compared with their respective control groups; however, the latter study did not provide CR to the control group, whereas the former study did (*Tables 3* and *4*).

Mobile apps (mHealth)

Nineteen studies used a mobile app as the only virtual CR intervention. The studies included in this category are distinct from the studies using mobile apps integrated into a comprehensive CR solution, which are reported under the 'Multi-component interventions' category. Six studies utilizing mobile app-based virtual CR reported significantly improved outcomes in the intervention arm compared with control CR, five of these were RCTs[36,37,39–41] with one observational study (*Tables 3* and *4*).[38] Specific primary outcomes in these RCTs included VO_2 peak,[39] 6MWT,[40] diet (specifically reduced salt intake),[36] cardiac risk profile,[37] and patient adherence/compliance.[41] The observational study compared reductions in blood pressure.[38]

Table 5 Number of studies reporting on aggregate primary outcomes and proportions of RCTs and studies with a significant primary outcome

Aggregate primary outcome category (APOC) number of studies (% of total)	Specific primary outcomes	Number of RCTs (% of APOC)	Studies with a significant primary outcome* (% of APOC)
Functional capacity 37 (32.7)	• VO_2 peak	28 (75.7)	22 (59.5)
	• 6MWT		
	• Exercise capacity		
	• Functional capacity		
	• Heart rate		
Patient adherence/compliance 35 (31.0)	• User adherence	13 (37.1)	7 (20.0)
	• User compliance		
	• Patient engagement		
	• User experience		
	• Device utilization		
Physical activity 27 (23.9)	• Number of steps	13 (48.1)	14 (51.9)
	• Daily step count		
	• Exercise time		
	• Sedentary time		
Quality of life 14 (12.4)	• Quality of life	10 (71.4)	4 (28.6)
	• Blood pressure		
	• Weight loss		
	• Salt intake		
	• Cardiac risk profile change		
	• Anxiety/depression		
Total: 113		64 (56.6)	47 (41.6)

6MWT, 6-minute walk test; APOC, aggregate primary outcome category; RCT, randomized clinical trial; VO_2, oxygen uptake.
*$P < 0.05$.

Web-based interventions

This literature review identified 19 studies where a web-based intervention was the only virtual CR intervention. Eight studies were RCTs and one of these reported significant improvements in physical activity and FVC; however, this result is tempered by the lack of CR in the control arm (*Table 3*).[24]

Multi-component interventions

By far, the largest number of included studies used a combination of technologies to achieve the CR goals. Forty-eight studies used multi-component interventions for providing virtual CR solutions. Out of those, 28 (54.9%) reported significant effects in the primary outcome (*Tables 3* and *4*).[26,28–35,52–68] Nine of these studies reported significant improvements in the virtual CR arm compared with usual CR, and all nine were RCTs (*Tables 3* and *4*).[26,28–31,33–35,69] The primary outcome was VO_2 peak in four studies,[26,30–32] patient adherence/compliance in three,[28,33,34] and one each with 6MWT[29] and physical activity.[35]

Outcomes

Specific primary outcomes in included studies were grouped together in aggregate categories as presented in *Table 5*. Functional capacity was the most frequently reported aggregate primary outcome category ($k = 37$, 32.7%), followed by user adherence/compliance ($k = 35$, 31.0%), physical activity ($k = 27$, 23.9%), and quality of life ($k = 14$, 12.4%). RCTs comprised the majority of study types in the functional capacity category ($k = 28$, 75.7%) and over half of the functional capacity studies reported significant results for improvements in primary outcomes (both within-group and between-group comparisons) ($k = 22$, 59.5%). Almost half of the studies in the physical activity outcomes category comprised RCTs ($k = 13$, 48.1%) and just over half reported significant improvements in outcomes ($k = 14$, 51.9%).

Out of 35 studies reporting on patient adherence/compliance, only 7 (20.0%) reported a significant improvement in primary outcomes; 6 used multiple interventions,[28,33,34,54,58,61] while 1 used a mobile application.[41] Many of the studies reporting on patient adherence/compliance were non-comparative and, therefore, not designed to capture relative adherence rates between virtual and traditional CR. However, of the seven studies reporting a significant primary outcome under the category of user adherence/compliance, four were RCTs showing significantly better outcomes in the intervention arm[28,33,34,41] and one was a non-randomized controlled trial similarly reporting significantly better patient adherence/compliance in the intervention arm.[61] The two other studies were single-arm, reporting significantly improved user adherence/compliance at 4 weeks over baseline in heart-healthy eating,[54] and higher adherence to exercise recommendations at 12 weeks compared with baseline.[58]

Most studies did not report results separated by sex. The studies generally balanced the male/female ratio across the intervention groups and reported only the overall results per group. There were three studies that did stratify by sex but only one found statistically significant differences in the outcomes.[70] In a study investigating correlates of objectively measured physical activity, sex was a significant factor in moderate-to-vigorous physical activity.[70] Similarly, the studies did not tend to stratify results by age. Out of the six studies that considered age as a factor, two reported significant differences in outcomes across the age groups. A study investigating mobile technology use across age

groups found significant differences in the overall use and confidence in the technology.[71] A study examining attitudes, perceptions, and behavioural intentions towards remote digital CR found differences both in attitudes towards healthy lifestyles through mobile phones and in acceptance rates of virtual CR classes.[72]

No intervention-related adverse events were reported in the included studies. The adverse events reported were related to the medical condition of the patients and, when compared, the frequency of adverse events did not differ between the intervention and comparator groups.

Discussion

The aim of this literature review was to provide a 'state of the art' update on the growing body of evidence relating the use of different virtual CR solutions available to address the significant underutilization of cardiac rehabilitation. The virtual CR solutions described are available for clinicians and healthcare practitioners to monitor patient progress, intervene when necessary, and to reinforce desirable healthy habits and lifestyle choices. As with any new intervention modality, the question of comparative efficacy is at the forefront of clinical investigations. In this respect, the results for virtual CR compared to traditional centre-based CR are mixed at best (see *Table 2*). This is not a surprise; other recently published reviews found a similar result.[18] This may not be a major drawback, however. The main challenge for CR in general is to engage as many patients needing this intervention as possible and keep them engaged over an extended period. Virtual CR may be the tool that can help accomplish those goals.

When it comes to efficacy, this review attempted to find the intervention domains in which virtual CR is most efficacious based on the comparative results of the included studies. Given the variety of interventions and methodologies, the goal was to identify the underlying efficacy patterns by grouping the interventions into functionally similar categories. In addition to the efficacy, patient enrolment and adherence to the treatment regimen are the main challenges facing CR. Studies reporting on adherence and patient satisfaction reported encouraging results, albeit the potential of virtual CR seems to be still unfulfilled. One limitation of the published studies is a relatively restricted demographic pool from which the studies are recruiting patients. Increasing diversity and extending virtual CR into the real-world settings are important challenges that are yet to be addressed. Finally, COVID-19 lockdowns and restrictions brought the importance of virtual healthcare to a broader audience. CR patients were one of the most vulnerable populations with respect to this virus and the lessons from the pandemic are still being debated.

Virtual cardiac rehabilitation efficacy

In the current evidence base, the most investigated outcomes were related to exercise and physical activity, cardiac risk factors, user adherence, as well as patient experience and preferences. Overall, this review shows that virtual and mobile technologies can help to enable effective home-based cardiac rehabilitation (HBCR), providing a viable complement to the traditional centre-based CR (CBCR). Outcomes with virtual CR from the studies surveyed were comparable to those with CBCR. In some cases, outcomes with virtual CR were statistically significantly better than those using the traditional approach, notably in nine RCTs using multiple interventions to assess: functional capacity,[26,29–32] patient adherence/compliance,[28,33,34] and physical activity.[35] Significant outcomes were also observed in six studies using mHealth interventions: two of these were RCTs assessing outcomes in quality of life (QoL),[36,37] one was an observational study of QoL,[38] two were RCTs assessing functional capacity,[39,40] and one was an RCT assessing patient adherence/compliance.[41] One study using WAM technology reported significantly better physical activity outcomes compared with traditional CR.[42]

Review of the most effective virtual healthcare intervention shows a few common features. First, most successful interventions used multicomponent models, where the patients used multiple devices and apps both for monitoring their activities and for communications with the healthcare team. Devices such as home-based ECG, pedometers, connected scales, and blood-pressure monitors were connected either to a smartphone or to the internet. Data were available to both the patients and the healthcare staff. For the patient, the availability of the data provided objective feedback on their status; for the healthcare staff, the data allowed personalized patient recommendations. Second, given the novelty of the technology provided to the patients, the researchers spent a significant amount of time and effort on individualized training and education, particularly at the beginning of the study. The training included direct instruction on the correct use of the technology and on the data upload and management. Given that a significant part of the CR population is older adults, the training was adopted towards a basic level of technology understanding among the patients. Third, the successful studies placed emphasis on the continuous feedback tailored to individual patients. For example, studies targeting physical fitness created individualized exercise prescriptions based on average steps per day as measured by an accelerometer. The last two points show the importance of personalization of the intervention which was often aided by questionnaires distributed to the patients.

In searching for reasons for the relatively high efficacy of the virtual interventions targeting physical fitness, one can notice the 'omnipresence' of the monitoring devices. The continuous feedback received from WAMs can serve as a constant reminder that the devices are 'watching'. Although the technology does present some 'big brother' privacy concerns, when handled properly, the ever-present monitoring seems to encourage a more active lifestyle. This makes intuitive sense, as the awareness of a monitoring device or app that logs exercise or physical activity data may motivate the patient simply through its presence. In various instances of clinical research, this is referred to as a trial, or 'Hawthorne' effect,[73–75] an effect known in psychology where some individuals tend to alter their behaviour when observed or monitored. Regardless of the contribution of this effect to observed outcomes, physical activity and exercise training are core components of recommendations from the American Association of Cardiovascular and Pulmonary Rehabilitation, the American Heart Association, and the American College of Cardiology, provided in their joint Scientific Statement.[76] The European Society of Cardiology also provide similar recommendations on the use of exercise training and increased physical activity to improve aerobic fitness, prognosis, and quality of life and reduce the overall risk of disease progression or recurrence.[77]

Patient enrolment and adherence to cardiac rehabilitation

The main challenge of the traditional CBCR concerns patient enrolment and patient adherence to the CR regimen. Lack of referral has been cited as a barrier to enrolment in CR; however, patients regularly choose not to attend CBCR sessions due to a lack of access to transport, ill health, scheduling commitments associated with returning to work, and reimbursement issues.[8,10] Patient adherence was one of the primary reported outcomes in 35 studies; however, the success in boosting adherence was rather limited. Only 20% of studies targeting improvement in patient adherence reported significant results. This statistic is somehow misleading though, because many of the studies were non-comparative and, therefore, the contextual significance of the outcomes was difficult to assess. The successful interventions used some form of feedback, usually in the form of regular text messages that were targeted at specific aspects of CR, such as monitoring

symptoms, medication taking, exercising, and dietary recommendations. More advanced interventions also used personalized feedback based on the data uploaded from monitoring devices (such as accelerometers or digital blood-pressure devices). In contrast to active messaging, the availability of passive information (in the form of a dedicated website) did not seem effective in engaging patients. Overall, the effect of persistent, yet unobtrusive reminders, either as targeted text messages or as direct communication from the nursing staff, was both acceptable by the patients and effective in encouraging patient adherence to the CR regimen.

In studies exploring patient acceptance, the results were presented in a qualitative form as patient feedback on the likelihood of adherence and usability of the virtual interventions. Patients expressed positive attitudes towards the technology, with the emphasis on the ease of use, user-friendliness, flexibility, and self-efficacy. The main advantage was seen in overcoming traditional participation barriers while preserving the oversight from healthcare professionals. One caveat to the applicability of the results is the fact that most studies enrolled the patients by recruitment through existing CR programmes. Therefore, there is a certain degree of selection bias towards patients positively inclined towards the virtual CR in the sampling of participants.

Patient diversity

One caveat associated with the published research is the limited diversity of included patient population. Since most of the studies are run by academic hospitals, the included patient populations tend to be more urban and middle class. The included populations also skew to more males than females, which reflects the underrepresentation of female patients in CR programmes in general.[78] Recruitment for the studies was mostly through CR programmes at major research universities, and the patients were broadly familiar with the use of cell phones, internet, and personal technology in general. To extend the benefits of CR outside the technologically advanced segment of the population (the 'digital divide'), additional barriers need to be overcome. Particularly rural populations and less affluent populations face not only limited access to high-speed internet but also limited access to technology education often resulting in reluctance to engage in the advanced programmes such as virtual CR. In the future expansion of the reach of virtual CR into the real-world settings, those imbalances will provide additional challenges.

Real-world applicability of virtual cardiac rehabilitation

Duration of intervention is important as sustained physical activity is a key to improving outcomes. Relatively fewer studies have investigated the longer-term benefits of CR.[79] One of the advantages of virtual CR is the potential extended duration beyond the limit of 36 weeks typically seen in centre-based CR. In our selection, 22 out of 113 (19.5%) studies extended CR beyond 36 weeks and of these, 19 studies lasted 1 year or more. Although it is reasonable to presume virtual CR interventions (in case they were effective) lead to improving clinical outcomes, further studies are needed to understand the long-term impacts of these interventions. However, promising results from individual studies suggest that virtual CR is at least as effective in maintaining multiple intervention outcomes as centre-based programmes.[27,80] A cost-utility analysis based on the TELEREH-HF trial in patients with HF confirmed the cost-effectiveness of the hybrid telerehabilitation programme compared with standard care, from the perspective of the Polish National Health Fund.[81] Additional studies are needed to assess the economic viability of virtual CR in other aetiologies such as post MI. Future research efforts should focus on the key health behaviour change techniques in technology-based interventions that enable full persistence of long-term behaviour change in large and diverse populations of affected patients.

One of the main challenges facing the widespread implementation of virtual CR may not be necessarily a lack of efficacy but rather an acceptance of these technologies and their continuous use by CR patients. This issue was investigated in a recently published study on the CR barriers scale in the Czech Republic.[82] The study highlighted the most relevant real-world barriers from patients' point of view and can serve as a starting point for further explorations. The focus should be on the issues such as seamless integration of the mobile technologies into the daily routines, simplification of the interactions between the patient and the device, and complementary role of technology and care personnel in the CR programme. This review clearly established the superiority of the integrated approach using both the technology and human interaction in patient care. Future studies should focus on making the technology transparent to both patients and healthcare professionals, allowing both to focus on the ultimate goal of improving the lives of cardiac patients.[83]

Finally, COVID-19 has exacerbated the constraints on healthcare sector resources. For patients requiring CR, COVID-19 is a dual-edged sword since pre-existing CVD poses a higher risk for worse COVID-linked outcomes, including death.[84,85] CR centres worldwide were closed, with notably a two-third decrease in centre-based CR from the pre-COVID period (4969 patients; May 2019—January 2020) to the COVID period (1474 patients; February 2020—August 2020).[86] However, the proportion of patients receiving home-based CR increased substantially over the same time interval, from 22.2 to 72.4%. Additionally, the mobilization of virtual CR resources from research settings to more routine care to make up for the loss of CBCR has been suggested.[87]

Limitations

This is not a systematic review capturing all published studies within this domain. Rather, the review is focused on the recent technological advancements in monitoring programme adherence and providing guidance and means of communication for CR patients. Many technologies reviewed here are in an early stage of development. The reviewed trials are often pilot studies with small sample populations. This review does not address the potential challenges facing the technologies in larger and more diverse populations. Also, this review does not attempt to evaluate the feasibility of using these technologies in routine clinical practice across a variety of clinical settings. The nature of this review is qualitative with the intention to provide a narrative summary of the most relevant findings related to the stated objectives of the study. The quantitative information provided here is selected based on the representativeness of the data without providing additional statistical analyses.

Conclusions

Although efficacy outcomes with virtual CR sometimes, but not always, improve on the centre-based CR outcomes, superior clinical efficacy may not necessarily be the most relevant aspect of the virtual CR. This is particularly the case considering that many patients are likely to have a hybrid approach combining different doses of centre based and virtual CR. The overall results suggest that the promise of this technology is in its potential for increased user adherence, longer-term patient engagement, and broader availability. Given the relatively low risk and cost of such interventions, they should be considered as an adjunctive therapy in the management of patients in need of CR. The main challenge of the traditional CR is patient access and patient adherence to the CR regimen. If the virtual CR solutions can improve adherence/compliance of cardiac patients, that would be a significant justification for using this technology.

Supplementary material

Supplementary material is available at *European Heart Journal – Digital Health*.

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Data availability

No new data were generated or analysed in support of this research.

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