Digitally enabled cardiac rehabilitation following coronary revascularization: results from a single centre feasibility study

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Wearable activity monitors, together with smartphone-based health and fitness applications (apps), are becoming more accessible and their widespread use provides an additional opportunity for the recording of cardiovascular metrics in patients with cardiovascular disease. The use of selected metrics by cardiac rehabilitation (CR) programmes allows the facilitation of individualized and tailored positive lifestyle changes to patients and places the patient at the centre of their recovery programme. To investigate the role of such devices on outcomes with patients on a CR programme, a cohort/case-control study was conducted. Patients post-myocardial infarction who were treated with either percutaneous coronary intervention or surgical coronary revascularisation at a single centre were invited to use a physical activity monitor linked to a customized app at their initial assessment for the rehabilitation programme. Those who accepted were allocated to the treatment group. The control group was selected from a larger pool of 400 historical and concurrent patients. Propensity matching was used to associate each case with their closest control. The changes in self-reported physical activity were similar for both groups at the end of the CR programme (EOP). The digitally monitored group tended to achieve greater METS (metabolic equivalent of task - a measure of exercise intensity) at 12 weeks ($P < 0.059$); however, no difference was observed in the overall change in METS at EOP ($P < 0.333$). Although no difference was noted in diastolic blood pressure, a statistically significant drop in the systolic blood pressure in the digitally monitored group ($P < 0.004$) was detected. In this study, the innovative combination of technology and face-to-face CR showed promising results and assisted the individualization of delivered content. This intervention could easily be replicated and expanded. Challenges are the recruitment of the elderly population, those who may be less engaged with or have less access to technology, and the underrepresentation of women in the study sample.

Introduction

Increasing physical activity and reducing sedentary behaviour can extend disease-free survival, improve quality of life, and help prevent comorbid chronic disease among patients following a cardiac event or coronary revascularization. We studied the effect of individualized cardiac rehabilitation (CR) on a patient cohort following either a cardiac event, or coronary artery revascularization in a tertiary cardiothoracic centre. Over 2200, percutaneous coronary intervention (PCI) procedures are performed at the hospital each year, with 96.7% involving insertion of a stent (2020/21 data). Similar numbers of patients undergo cardiac surgery. CR is offered to all post-PCI patients, those post-cardiac surgery, following a medically managed myocardial infarction (MI) and those with a new diagnosis of cardiac failure.
Cardiac rehabilitation is a comprehensive intervention providing education, physical activity, and cardiovascular risk factor information together with medication advice and psychological support. Consistent data, including meta-analyses and several Cochrane reviews, have shown that CR reduces a patient’s risk of further cardiovascular disease events over the following year, improves exercise performance, enhances medication compliance, reduces symptoms such as angina, dyspnoea, and fatigue and reduces all-cause mortality by 25%.1 Furthermore, hospital- and home-based CRs have proved equally effective in decreasing morbidity and mortality,2–4 with home-based programmes being able to reach those patients who may find accessing CR difficult due to increased age, lower socioeconomic status, travel distance, and other co-morbidities.2–12 The need for home-based CR has increased in the pandemic period to reduce both the risk of community acquired and nosocomial infection.

Our CR department consists of a multi-disciplinary team including cardiac specialist nurses, physiotherapists, exercise specialists, and a dietician. Patients are invited for an initial assessment (IA) including a functional exercise test and are then encouraged to complete a 12-week programme via a home-based plan (the ‘Road to Recovery’ programme) or by attending hospital-based exercise and education sessions.

For patients starting either the hospital-based or Road to Recovery programme, our institutional CR programme has a 90% completion rate, which considerably above the UK mean figure of 77%.13 We used a propensity matched cohort study to determine the impact of using physical activity monitors and a tailored app on the outcomes of patients enrolled in the home-based or hospital-based CR programme.

Methods
The study comprised 31 patients post PCI, surgical revascularization, or medically managed MI, together with 71 historical and concurrent controls. The control group underwent our standard CR protocol but did not have access to the digitally enhanced data record and follow-up afforded to the group using the app. Available baseline data included: sex, age, type of intervention, ethnicity, work status, blood pressure, comorbidities, medication, and in-hospital CR or home-based allocations. In the digitally monitored arm, the patients used a wrist worn physical activity monitor (Fitbit charge2: Fitbit Inc., San Francisco, CA, USA) in conjunction with a bespoke smartphone app (uMotif: uMotif Limited, London, UK).

Patients entered exercise and activity data into the app manually as well as linking their activity monitors with the app to capture heart rate data, step data, exercise type, and frequency. The graded exercise programme used a CR exercise DVD developed and provided by the CR centre, which was digitized and made available through the app. In addition, the app was tailored to allow patients to record other symptoms using a unique flower-like ‘motif’ data capture interface, e.g. chest symptoms.
Digitally enabled cardiac rehabilitation following CR

pain, energy levels, sleep, and stress. Furthermore, smokers had the ability to record details of smoking and quit attempts in the diary section and could be offered automated reminders to do this (Figures 1 and 2). Patients were made aware that the app was for recording only and any new or worsening symptoms should be reported to a relevant healthcare professional in a timely fashion. Data downloaded to the app were used to inform the weekly interactions that the team had scheduled with both cohorts of patients either face to face or via telephone consultations. Patients received a welcome email and app confirmation when registering for uMotif (Figure 3).

The outcomes measures following intervention were: to be able to achieve either 150 min of moderate activity or 75 min of vigorous activity per week, to compare Total Activity Measure in Metabolic Equivalent of Task in minutes (TAM-MET min) between cases and controls at the end of the programme (EOP) and the changes from baseline, to record functional capacity in METS [exercise tolerance test (ETT) on treadmill] at EOP and as change from baseline and to compare systolic blood pressure (SBP) and diastolic blood pressure (DBP) between cases and controls at EOP and their changes from baseline.

Baseline data were collected at IA prior to the start of the CR programme and at EOP. The total programme duration was 12 weeks. Data regarding physical activity were gathered via self-report by means of the National Audit of Cardiac Rehabilitation questionnaire (Chief Medical Officer Physical Activity Questionnaire and Total Activity Measure) together with an ETT using Bruce, Modified Bruce, or Naughton protocol.

All continuous variables were summarized using mean and standard deviation with a probability comparison of \( P < 0.05 \) considered significant. The independent sample t-test was used for significance between the study and propensity matched groups. Categorical measures were reported using frequency and percentage. The \( \chi^2 \) test enabled comparison between the two mode groups.

**Results**

Our cardiac rehab programme enrols any patient who has undergone either percutaneous or surgical coronary revascularization, as well as patients with a new diagnosis of cardiac failure. Baseline demographics were recorded between the two separate cohorts (Table 1). Statistically significant differences between cohorts were difficult to achieve due to the low number of participants in the digitally enhanced rehab group (Table 2). However, there were several trends of interest and the subjective feedback measures were notable for their positive impact on the patient experience. There were no significant differences in most of the baseline demographic and cardiovascular measures between the two groups. However, there were a higher percentage of males in the digitally monitored group (95.5 vs. 86%).

Regarding progress during the CR course, there was a trend for the digitally monitored group to achieve more METS at EOP (\( P < 0.059 \)), although there was no difference in the overall change in METS between usual care and the digitally monitored group at EOP (\( P < 0.333 \)). There was a statistically significant drop in SBP in the digitally

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**Figure 2** Example screenshots of summary screens available to the app end user to map progress.
The results showed no difference in DBP at EOP (P < 0.130). The changes in self-reported physical activity were similar in both groups at EOP, for those achieving 150 min moderate activity per week and/or 75 min vigorous activity per week (P < 0.994 and P < 0.694, respectively). In addition, no significant difference was seen in TAM-MET mins at EOP (P < 0.255).

During the study, patients recorded over 150,000 symptom scores in the app (including diary notes and exercise results) and 1200 scores using the simple flower-like motif interface. Feedback from patients included positive comments regarding ease of use of the uMotif app, with 47% of patients using the app at least weekly, and enjoying recording information and finding out more detailed data about themselves. Furthermore, the information supplied via the app and accessed by the CR team via a secure web dashboard and data spreadsheet enabled more data-based and patient-centred interactions during scheduled face-to-face or telephone consultations.

**Discussion**

In this study, the uMotif app was tailored and deployed to enhance delivery of the core components of an existing, effective CR programme. The low mean age of our study population represents the usual demographic seen during follow-up of our patient cohort. The results and patient feedback indicate that the app was well received and utilized by patients and may be of benefit in
improving patient outcomes and information exchange between patients and their healthcare teams. By tailoring the app further, it may also be useful in addressing other challenges in CR delivery.

Increasing uptake of cardiac rehabilitation
As reported in EUROASPIRE IV (the European Society of Cardiology survey on the therapeutic management of ischaemic heart disease patients from 24 European countries), 14 <50% of eligible patients attend CR. Patients choose not to attend for a variety of reasons, e.g. increased age, gender, lower socioeconomic status, travel distance, other comorbidities, lack of motivation, and lack of time (sometimes related to return to work). 2-14 However, a cross-sectional study of 200 adult cardiac patients in Israel suggested that CR delivered remotely via digital means was acceptable to most cardiac patients, including the elderly population. 15 In addition, although women have multiple barriers to attending CR programmes, 16 a recent narrative review suggests that their participation in CR programmes can be enhanced by understanding their specific needs including offering convenient times, settings, and a variety of modes of activity. 17

An innovative delivery strategy such as that used in this study, utilizing an app and a physical activity monitor, is an effective way of facilitating more individualized CR, including choice of time, place and mode of physical activity, empowering self-directed recovery, and therefore optimizing engagement and outcomes.

Decreasing sedentary time
A particular focus for cardiovascular health is the reduction of sedentary time, especially for high-risk patients, those who are extremely deconditioned, or with mobility restrictions for whom structured exercise may initially be inappropriate. A systematic review and meta-analysis showed that increased sedentary time is significantly associated with an increased risk of diabetes, cardiovascular disease, and cardiovascular and all-cause mortality. 18 Using a digitally monitored programme to track activity and offer regular reminders to move could be a useful addition to self-management of activity and facilitate positive behaviour change.

More recent perspectives
The COVID-19 pandemic necessitated CR programmes having to adopt more remote methods of delivery to maintain their service, with up to 12% increase in web-based CR during COVID-19. 19 The new and emerging NHS infection control and prevention strategies and CR service delivery having to place greater emphasis on patient vulnerability and the effective use of hospital space has led to significant challenges. Thus, the inclusion of remote technology may be valuable in providing agility to move between face-to-face and remote delivery options without compromising the resilience to maintain

| Outcome | Usual care cohort | Digitally monitored cohort | P-value |
|---------|------------------|----------------------------|---------|
| 150 min moderate activity WK 1 (%) | 44 (62.9) | 21 (67.7) | 0.805 |
| 150 min moderate activity WK 12 (%) | 65 (92.9) | 30 (96.8) | 0.755 |
| 150 min change | 22 (31.4) | 9 (29.0) | 0.994 |
| 75 min vigorous activity WK 1 (%) | 4 (5.6) | 3 (9.7) | 0.751 |
| 75 min vigorous activity WK 12 (%) | 34 (47.9) | 19 (61.3) | 0.303 |
| 75 min change | 32 (45.1) | 16 (51.6) | 0.694 |
| TAM2 WK1 [mean (SD)] | 1636.12 (1427.44) | 2352.72 (2634.49) | 0.099 |
| TAM2 WK12 [mean (SD)] | 4162.34 (3393.83) | 6084.42 (6955.86) | 0.108 |
| TAM change [mean (SD)] | 2612.93 (3628.41) | 3959.61 (6262.73) | 0.255 |
| METS WK1 [mean (SD)] | 7.60 (2.45) | 8.39 (3.18) | 0.177 |
| METS WK12 [mean (SD)] | 10.58 (3.03) | 11.76 (2.50) | 0.059 |
| METS change [mean (SD)] | 3.00 (1.79) | 3.39 (2.08) | 0.333 |
| SBP WK1 [mean (SD)] | 135.97 (19.57) | 133.35 (14.44) | 0.593 |
| DBP WK1 [mean (SD)] | 84.29 (9.42) | 82.68 (10.35) | 0.523 |
| SBP WK12 [mean (SD)] | 138.49 (20.24) | 124.86 (13.58) | 0.004 |
| DBP WK12 [mean (SD)] | 84.49 (11.38) | 80.32 (10.35) | 0.130 |
quality of patient care and outcomes, while helping to reduce hospital footfall and minimizing the potential for nosocomial infection.

**Atrial fibrillation**

Current management of patients with atrial fibrillation (AF) is often limited by low levels of detection, non-adherence to guidelines, and lack of individualization for patient needs and preferences. This, therefore, indicates the need for an integrated and individualized approach to AF management. Recent studies have shown that for those patients with AF who engaged with technology for ongoing monitoring and care for >1 year, there was a reduction in adverse clinical outcomes. Smartwatch photoplethysmography coupled with a multi-layered computer system (‘deep neural network’) can passively detect AF. Patients with AF using an on-demand photoplethysmography-based heart rate and rhythm monitoring found the app easy to use, easy to install, and 58% suggesting they would like to use the app longer term. Thus, the use of wearable sensors and a tailored, intelligent, app offers the potential for effective, economical detection, and condition management.

Limitations of our current study include the potential low accuracy of activity trackers in estimating energy expenditure in cardiac patients and their poor performance to detect within-patient changes in the low-to-moderate exercise intensity domain.

Initially, we were concerned that the smartphone-based app would exclude our older patients from participation. Studies that assessed the determinants of intention of older patients to use technology in healthcare found that, in general, the majority perceived it easy to learn and use. In addition, use is increased by education about the benefits and giving opportunities to practice using the technology. A recent systematic review identified several studies supporting home telehealth and suggested that overall, home telehealth was feasible, acceptable, and effective across several populations of older adults. Results from a study during the COVID-19 pandemic reinforced these findings. However, effective use of technology in healthcare by older adults is complicated by cognition, motivation, physical ability, and perceptual barriers. Moreover, there may be specific medical conditions that influence the useability and usefulness of technology.

The ongoing support and contact offered by CR programme teams make this an ideal setting in which to provide the education, motivation, and practical help to overcome individual barriers and engage successfully with technology. Although our study population was trending towards a younger mean age than the controls, age did not appear to be a barrier to implementation of the app. A wider cohort would enable us to test this potential limitation more thoroughly. Our sample size is also small in this pilot study with the intention being to confirm our finding in a larger prospective study going forward having shown proof of concept and feasibility.

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**Data availability**

The date underlying this article will be shared on reasonable request to the corresponding author.

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