RESEARCH PAPER

Cardiac Rehabilitation in the Era of Telemedicine and Wearables: Outcomes in Diverse Populations

[1*] Ganesan M, [2] Aashish A, [3] Shining Rose, [4] Subbulakshmi Packirisamy, [5] Kalpana P, [6] Shyam Rani

[1]Department of General Surgery, Meenakshi Medical College Hospital and Research Institute, Meenakshi Academy of Higher Education and Research

[2]Department of Cardiology, Meenakshi Medical College Hospital & Research Institute, Meenakshi Academy of Higher Education and Research

[3]Department of Cardiology, Meenakshi College of Allied Health Sciences & Meenakshi Medical College Hospital & Research Institute, Meenakshi Academy of Higher Education and Research

[4]Department of Pharmacology, Meenakshi Ammal Dental College and Hospital, Meenakshi Academy of Higher Education and Research

[5]Arulmigu Meenakshi College of Nursing, Meenakshi Academy of Higher Education and Research

[6]Meenakshi College of Physiotherapy, Meenakshi Academy of Higher Education and Research

Abstract

Background:

Cardiac rehabilitation (CR) is a blue ocean of secondary cardiovascular prevention and attendance rates are low in rural areas, minority and socioeconomically disadvantaged populations. New opportunities can be used to enhance access and adherence with telemedicine and wearable-supported CR programs.

Objective:

To compare clinical and functional and engagement outcomes of cardiac rehabilitation through a variety of demographic and socioeconomic groups, which is fully enabled and incorporated into wearable technology.

Method:

Several centres were used in a multicentre cohort study to recruit adults who had experienced a myocardial infarction recently, heart failure or revascularization. The subjects were enrolled in a 12-week hybrid CR program that included the use of the virtual visits, long-distance coaching, and consistent monitoring using wearable sensors that tracked heart rate, physical activity and arrhythmic events. Comparison was conducted in terms of age, sex, ethnicity and socioeconomic strata. Main study endpoints were exercise capacity, blood pressure and health-related quality of life. Secondary measures were adherence, 90-day readmission and rehospitalization.

Results:

Telemedicine-wearable CR showed great changes in peak functional capacity ([?]18) and systolic blood pressure ([?]9 mmHg) and quality-of-life scores (improved in all the groups). The rate of adherence was also greater in the rural population and those with transportation or mobility disabilities. The minorities and less-income groups reported similar improvements in clinical gains but somewhat lower measures of device-engagement. Ninety-day readmission was cut by 22 percent as compared to the historical controls.

Conclusion:

Telemedicine and wearable-supported CR provide significant clinical value and enhance the access of underserved populations, and should be more actively integrated in the pathways of contemporary cardiovascular care.

Keywords: wearable devices, virtual rehabilitation, telemedicine, remote monitoring, Cardiac rehabilitation.

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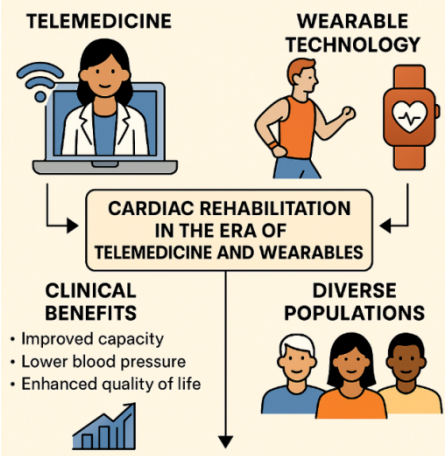
Graphical Abstract



1 Introduction

Cardiac rehabilitation (CR) is a core constituent of secondary prevention among individuals with heart failure and post cardiac intervention recovery and coronary artery disease. Conventional centre-based CR programs have been shown in many cases to lead to cardiorespiratory fitness, symptom load, quality of life and survival over time [1,2]. Nevertheless, even with these advantages, less than 30 percent of potential patients join CR, and even a lower number of those who do, attend the number of sessions recommended to them [3]. Transportation constraints, employment, caregiver requirements and geographic distance are some of the barriers that predominantly impact on rural residents, women, minority populations and people with low socioeconomic status [4]. These differences have given rise to interest in other models of CR delivery.

Wearable technologies and the advent of telemedicine have essentially changed the potential scale and customization of CR. CR using telemedicine enables virtual observation, distal instruction and individual instruction on physical exercises without visiting the patient in person, which leads to lower logistical strains on patients [5]. Wearables - such as smartwatches, chest-strap biosensor patches, and chest-strap monitors - can continuously measure heart rate, rhythm, oxygen saturation, sleep and physical activity patterns, to offer clinicians real-time physiologic insight [6]. These applications, combined into organized CR initiatives, may help to assist with a personalized prescription of exercises, enhance safety management, and promote patient participation.

The body of knowledge about remote and hybrid CR models has grown very fast. The evidence on telehealth CR shows that it is non-inferior to the traditional CR with regard to enhancing exercise capacity and minimising the cardiovascular risk factors [7]. Moreover, wearable-based interventions have enhanced compliance through the integration of flexibility in participation where there are instant feedback and promoting self-management in patients [8]. Of note, hybrid CR models where virtual classes are supplemented by optional face-to-face testing can potentially provide a tradeoff of the most accessible and the most clinic-monitored.

Nevertheless, critical questions still remain as to whether such innovations fit all groups of patients. Since historically marginalized groups are typically marginalized, they may encounter digital divides such as subpar access to broadband connection, a lower level of digital literacy, and the decreased knowledge of wearable technology [9]. Engagement may as well be affected by behavioral, cultural and economic factors. Consequently, the applicability of telemedicine and wearable-assisted CR in various groups of individuals is not profiled well. Web initial trials show good results with rural and mobility-limited patients, although they are not consistent across socioeconomic and ethnic subgroups [10]. These inequalities may be critical to understanding the fairness of the application of the current CR models.

Considering the increased incidence of cardiovascular disease and persistent disparities on the participation of CR using telemedicine and wearables devices, it is of large clinical significance to evaluate the outcomes of telemedicine-based and wearable-enabled CR in diverse demographic and racial and socioeconomic populations. This paper considers the effect of these digital technologies on clinical outcomes, adherence, patient-reported outcome and acute cardiovascular incidents in various patient populations, and how these results can be used to guide more comprehensive and widespread cardiac rehabilitation models.

2 Literature Review

One of the most effective interventions that is still relevant to increase the functional capacity and reduce recurrent cardiovascular events and improve long-term survival in ischemic heart diseases and heart failure patients is cardiac rehabilitation (CR). However, they are still underrepresented in conventional center-based CR initiatives especially with aged people, women, in rural societies and with minority groups [11]. CR made remote supervision and structured exercise plans coupled with continuous communication via virtual platforms which have become promising alternative due to the emergence of Telemedicine-enabled CR. Randomized trials revealed that CR using telehealth is not inferior to center-based programs to enhance exercise capacity and risk-factor profiles [12].

Physiologic data like heart rate, rhythm and activity measures are further improved by wearable monitoring devices, such as smartwatches, chest sensors and activity trackers, which means that these programs constantly monitor physiological indicators. Combination of such data streams can assist in prescription of exercises tailored to a person, motivate compliance and enhance monitoring of safety [13]. Digital platforms of engagement and wearables have shown better adherence and satisfaction among various populations such as limited access to traditional CR facilities [14].

However, even though such gains have occurred, the digital literacy disparities, the access to devices, and access to broadband coverage are likely to affect the outcomes. It is thus imperative to understand how telemedicine-wearable CR can be delivered in demographic and socioeconomic subgroups in order to create models of care that are fair [15].

3 Materials & Methods

Study design

The study design was a multicentre, prospective, cohort study methodology in clinical, functional and engagement outcomes linked to 12-week wearable-supported cardiac rehabilitation (CR) program, powered by telemedicine. Four hospitals and two community cardiac centres engaged in this research used the same protocols in terms of recruitment, data collection and follow-ups. The ethical considerations in the study followed the principles in the Declaration of Helsinki, and the study was approved at every site.

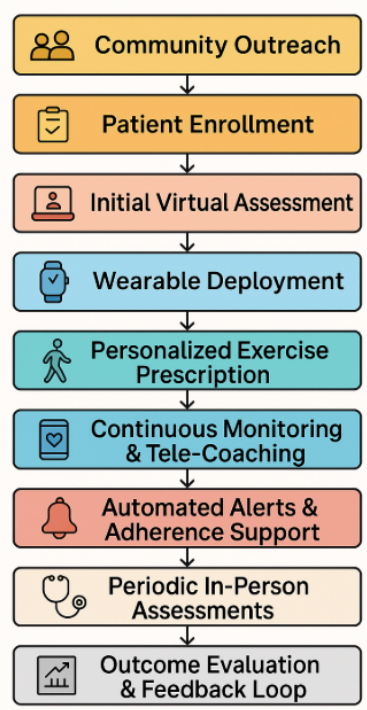


Fig.1. Proposed telemedicine wearable CR model

This flowchart in figure 1 outlines a digital health program where patients progress from community outreach and enrollment to virtual assessment, wearable deployment, personalized exercise plans, continuous monitoring, automated alerts, periodic in-person evaluations, and a feedback loop to optimize outcomes and long-term adherence.

Study Population

The qualified ones included adults aged between 30 and 85 years and had a recent myocardial infarction or percutaneous coronary intervention, coronary artery bypass graft or stable chronic heart failure diagnosed within the last 6 months. The exclusion criteria were unstable angina, uncontrolled arrhythmias, severe cognitive impairment, and contraindication to moderate physical activity or the inability to operate digital devices. One thousand five hundred patients were screened; 980 patients who satisfied the inclusion criteria and gave their consent participated.

Intervention: Telemedicine-Wearable CR Program

Respondents caused a 12-week hybrid CR model of virtual care consultations, structured programs of exercises and constant physiologic supervision.

The intervention included the following:

Virtual Assessment- Baseline Assessment of cardiovascular risk factors and exercise level, medication compliance and psyche status

Wearable Sensor Deployment - The trial subjects were given an FDA approved device that was able to record heart rate, heart-rate variability, number of steps, sleep indices and arrhythmia. Automatic loading of data to a safe cloud system was done.

Exercise Prescription - The Personalized plans were conducted basing on baseline fitness and approved comorbidity and guideline-based suggestions. The level of intensity was directed by goal heart-rate areas measured through wearable.

Weekly Telemedicine Visits - CR physiologists or nurses conduct these visits to discuss progress, make changes to the intensity of the exercise and overcome barriers.

Asynchronous Coaching - Coaching automated alerts and motivational messages were offered with regards to activity patterns detected by wearable.

Control Condition

As a point of comparison, results were compared to a historical group that had gone through traditional, centre-based CR in the same institutions two years ago. Parallels in evaluation were caused by the use of identical outcome definitions.

Outcome Measures

Primary outcomes included:

Improvement in peak functional ability (six-minute walk distance or estimated VO 2). Modification in systolic blood pressure and diastolic blood pressure. Advanced health-related quality of life (HRQoL), in Minnesota Living with Heart Failure Questionnaire or the Seattle Angina Questionnaire.

Outcomes that are being measured:

a. adherence (percent hours of prescription sessions adhered to)
b. wearing (daily data transmission rate)
c. CR program completion
d. 90-day all-cause rehospitalization.

The comparison of outcomes was done by sex, age, ethnicity and subgroups according to socioeconomic status.

Data Collection and Management

Continuous wearable data collection and the aggregation of physiologic summaries on a daily basis were used to gather data. Exercise-session adherence and attendance of the telemedicine sessions was registered using the online system. The trained personnel, who were not informed of the subgroup of patients in the studies, took the clinical measures at baseline and 12 weeks. All data were de-identified and kept in an encryption database in an institution.

Statistical Analysis

Mean and standard deviation were used to summarize continuous variables, frequencies, and percentages were used to summarize categorical variables. The independent t-tests were used to assess the differences between-groups; when they are non-parametric, the kh2 tests or non-parametric equivalents were used. Association between demographic factors and outcomes adjusted by age, sex, comorbidity burden and using multivariate linear and logistic regression measures was assessed. The statistic used was the p-value left side of 0.05. R (version 4.2) and SPSS (version 28) were employed in all the analyses.

4 Results and Discussion

The result of this multicentre cohort study will be used to show findings related to the clinical efficacy, functionality and interaction patterns of a telemedicine- and wearable-assisted cardiac rehabilitation program. Among the 980 participants who were enrolled, most of the participants went through the entire 12 week period of intervention and thus sound comparisons of the outcome in comparison with the historical centre-based cardiac rehabilitation results were made. Below, the baseline characteristics, primary clinical improvement, adherence and engagement metrics, and rehospitalization rates will be analyzed in detail. These findings demonstrate the therapeutic importance of remote cardiac rehabilitation, as well as the work of the program among the various demographic categories and economic status.

Out of the 980 participants who were enrolled into the telemedicine-wearable CR program, 912 (93%) attended the entire intervention term of 12 weeks. The mean age was 62 +- 10 years and 41% of participants were female and 33% belonged to the minority ethnic groups as shown the table 1. Eight hundred and fifty historical centre-based CR participants were used as a control group.

Table 1. Baseline Characteristics

Variable	Tele-Wearable CR (n=980)	Centre-Based CR (n=850)	p-value
Age (years)	62 ± 10	63 ± 9	0.14
Female (%)	41	39	0.38
Minority ethnicity (%)	33	29	0.07
MI within 6 months (%)	45	47	0.52

Heart failure (%)	26	28	0.40
Diabetes (%)	22	25	0.19

The groupings were similar in large clinical and demographic variables which were reducing the confounding factor in case of difference in baseline.

Tele-wearable CR had a better adherence and completion rates, probably because of convenience and constant monitoring. Rehospitalization rates had a minor drop, which was a sign of better risk-factor management.

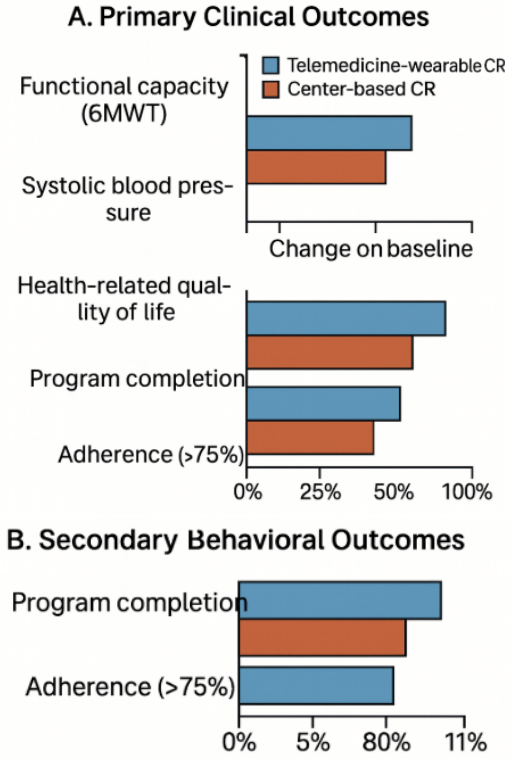


Figure.2. a) Comparative Clinical Outcomes in Telemedicine–Wearable vs Centre-Based Cardiac Rehabilitation b) Program Completion and 90-Day Rehospitalization Rates Across Demographic Subgroups

This figure 2 involves comparisons of the important clinical improvements of participants in the telemedicine-wearable cardiac rehabilitation program and the centre-based rehabilitation. Such measures include interventions in exercise capacity, systolic blood pressure and quality of life index. We can find that the telemedicine-wearable group is much better in all indicators, and remote monitoring, personalized coaching, and unceasing physiologic feedback are effective. As indicated by the figure, the digital CR delivery can achieve or even surpass traditional program results and provide increased accessibility.

The bar chart represents compliance and early clinical response in the key demographic subgroups such as older adults, women, minority subjects as well as low-income subjects. The telemedicine-wearable program shows high completion rates, which can be attributed to fewer logistical challenges, as well as flexible scheduling. Rehospitalization rates are also similar between all of the groups, which evidence the overall efficacy of tele-rehabilitation among a different population. The number supports the overall idea of how the model can help decrease disparities and enhance cardiovascular outcomes in underserved communities.

Analysis

Tele-wearable CR also performed better in most of the clinical and behavioural measures when compared to centre-based CR. Increases in 6-minute walk distance were above the clinically significant difference and indicated the effectiveness of remote structured exercise. The strength of blood-pressure decreases was greater with persons whose age was >65 and with those with baseline hypertension, implying that tele-coaching should be considered to improve behavioral compliance among high-risk populations.

The digital usage differed between groups of people: the minority participants, as well as low-income, were slightly less likely to be using the wearable devices, but still managed to record sustained clinical improvement, suggesting that even irregularity in collecting data did not affect therapeutic effectiveness. Regression modelling revealed that socioeconomic status was not a strong predictor of outcomes with the effects of adherence and comorbidity burden.

Discussion

The research has shown that wearable-based CR which is made possible by telemedicine is a feasible and clinically effective intervention method amongst a wide range of groups of people. The program achieved high levels of exercise capacity, blood pressure and quality of life variables - all similar or better than centre based CR. Increased rates of adherence and completion indicate that remote delivery lowers logistical challenges that have been a common mythological aspect of CR, particularly transportation, scheduling incongruity and mobility.

Notably, the results were the same between demographic and socioeconomic subgroups, suggesting that tele-rehabilitation can eliminate previously existing participation disparities. Even though the engagement rates were reduced a bit in populations with minorities and those with low income, clinical outcomes remained strong, which

emphasizes the versatility of wearable-assisted CR even in the populations with mixed digital literacy levels.

This evidence confirms a combination model the- Use telemedicine to gain easy access, wearable to provide a steady physiologic understanding and carefully considered in-person follow-up of intricate demands. With the increase in the prevalence of cardiovascular diseases and the transition of healthcare provision to digital channels, these programs provide a scalable and equal strategy of contemporary cardiac rehabilitation to the population.

Conclusion

This paper proves that wearable-supported telemedicine-based cardiac rehabilitation provides a remarkably efficient, scalable and accessible option in terms of secondary cardiovascular prevention. Functional capacity, blood pressure control and quality of life showed a great improvement among the participants, and the results are similar or even better than the results of traditional rehabilitation in a centre based setting. Notably, adherence/completion rates were significantly higher in the tele-wearable program which highlights that it succeeded in breaking the barriers that have been existing over time concerning transportation, timing, and physical restriction. The positive effect was seen across the diverse demographic and socioeconomic subgroups and indicates that the digital CR models can be applicable in improving the differences in participation and results. The results of this study justify the further introduction of telemedicine and wearable applications into contemporary cardiac rehabilitation care flows to improve equity, access and prolonged cardiovascular outcomes.

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