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REHCARDICARE: A Digital Telerehabilitation Platform for Cardiac Recovery Following a Coronary Artery Bypass Graft

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Abstract

Post-coronary artery bypass graft (CABG) patients often experience decreased cardiac output, which slows recovery and increases the risk of cardiovascular complications. This research and development study evaluated the preliminary effectiveness of the REHCARDICARE application in increasing cardiac output, a key indicator of successful cardiac rehabilitation. The research also assessed user satisfaction to determine the feasibility of broader implementation. The findings can inform further development of the application. The application development used the (Analysis, Design, Development, Implementation, Evaluation) ADDIE model. The study subjects consisted of 30 post-CABG patients purposively selected at the North Sumatra Integrated Heart Center. An application-based resistance and flexibility training intervention was implemented for eight weeks. Data collection and analysis took place two weeks after the intervention was completed. Using a single-group pretest–posttest design, transthoracic Doppler echocardiography was used to measure cardiac output before and after the intervention. Data analysis involved a paired t-test with a significance level of $p < 0.05$. Cardiac output significantly increased from 4.12 ± 0.55 L/min to 5.28 ± 0.62 L/min ($p = 0.001$). The feasibility evaluation showed high user satisfaction (87.5 ± 6.8), indicating that REHCARDICARE was perceived as useful and easy to use, with good patient adherence and no significant safety events. Overall, REHCARDICARE demonstrated improved cardiac output after eight weeks and good user acceptance as a digital cardiac rehabilitation tool for post-CABG patients. It is recommended that this application be structurally integrated into the hospital's cardiac rehabilitation program, that remote monitoring features be developed for clinical use, and that further tests be conducted using an experimental design with a control group and a larger sample to strengthen the evidence of clinical effectiveness.

Keywords: cardiac output, cardiac rehabilitation application, coronary artery bypass grafting, flexibility training, resistance training

Abstrak

REHCARDICARE: Platform Telerehabilitasi Digital untuk Pemulihan Jantung Setelah Operasi* Bypass *Arteri Koroner. *Pasien pasca operasi* bypass *arteri koroner (CABG) sering mengalami penurunan curah jantung, yang memperlambat pemulihan dan meningkatkan risiko komplikasi kardiovaskular. Studi penelitian dan pengembangan ini mengevaluasi efektivitas awal aplikasi REHCARDICARE dalam meningkatkan curah jantung sebagai indikator kunci keberhasilan rehabilitasi jantung. Studi ini juga menilai kepuasan pengguna untuk menentukan kelayakan implementasi yang lebih luas. Temuan ini dapat menjadi dasar pengembangan aplikasi lebih lanjut. Pengembangan aplikasi menggunakan model ADDIE (Analisis, Desain, Pengembangan, Implementasi, Evaluasi). Subjek penelitian adalah 30 pasien pasca CABG yang dipilih secara purposif di Pusat Jantung Terpadu Sumatera Utara. Intervensi pelatihan resistensi dan fleksibilitas berbasis aplikasi diimplementasikan selama delapan minggu. Pengumpulan dan analisis data dilakukan dua minggu setelah intervensi selesai. Penelitian menggunakan desain pretest-posttest kelompok tunggal, ekokardiografi Doppler transtoraks digunakan untuk mengukur curah jantung sebelum dan sesudah intervensi. Analisis data melibatkan uji t berpasangan dengan tingkat signifikansi $p < 0,05$. Curah jantung meningkat secara signifikan dari $4,12 \pm 0,55$ L/menit menjadi $5,28 \pm 0,62$ L/menit ($p = 0,001$). Evaluasi kelayakan menunjukkan kepuasan pengguna yang tinggi ($87,5 \pm 6,8$), menunjukkan bahwa REHCARDICARE dianggap bermanfaat dan mudah digunakan, dengan kepatuhan pasien yang baik dan tidak ada kejadian keamanan yang signifikan. Secara keseluruhan, REHCARDICARE menunjukkan peningkatan curah jantung setelah delapan minggu dan penerimaan pengguna yang baik sebagai alat rehabilitasi jantung digital untuk pasien pasca CABG. Hasil penelitian merekomendasikan agar aplikasi ini diintegrasikan secara struktural ke dalam program rehabilitasi jantung rumah sakit, fitur pemantauan jarak jauh dikembangkan untuk penggunaan klinis, dan pengujian lebih lanjut dilakukan menggunakan desain eksperimental dengan kelompok kontrol dan ukuran sampel yang lebih besar untuk memperkuat bukti efikasi klinis.*

Kata kunci: *aplikasi rehabilitasi jantung, cangkok* bypass *arteri koroner, curah jantung, pelatihan fleksibilitas, pelatihan resistensi*

Introduction

Coronary heart disease (CHD) remains one of the leading causes of mortality worldwide, including in Indonesia. According to the 2023 Indonesian Health Survey, the prevalence of heart disease in Indonesia reached 8.5 per 1,000 population, reflecting a substantial national health burden (Ministry of Health of the Republic of Indonesia, 2024). In North Sumatra, CHD cases increased from 661 in 2022 to 4,454 in 2023, while 2,501 new patients were admitted to H. Adam Malik General Hospital, Medan, in 2024, highlighting the increasing demand for effective postoperative recovery and long-term complication prevention strategies (Fahriza & Siregar, 2024; Ministry of Health of the Republic of Indonesia, 2023).

Coronary artery bypass grafting (CABG) is a surgical revascularization procedure that restores myocardial blood flow by bypassing obstructed coronary arteries, thereby improving survival and reducing symptoms in patients with complex coronary artery disease (Bachar & Manna, 2025). Although CABG improves myocardial perfusion, many patients experience reduced cardiac output and limited physical function during recovery. Exercise based cardiac rehabilitation has been shown to improve functional capacity, quality of life, and reduce hospital readmissions (Ivana & Tjahjono, 2022; Khattab & Aljeesh, 2024; Kim et al., 2018; Priatama et al., 2024). However, barriers such as cost, distance, and low patient adherence often limit participation in conventional rehabilitation programs. Digital health approaches, including mobile applications and telerehabilitation, have emerged as promising alternatives to expand access and continuity of care (Harbi et al., 2024).
REHCARDICARE is a mobile-based rehabilitation application developed for post-CABG patients to support structured, flexible, and remotely monitored exercise programs. The application facilitates digital monitoring and guided exercise training aimed at improving functional capacity and adherence to rehabilitation. Unlike previous interventions focusing mainly on education or aerobic exercise (Dwiputra et al., 2023; Harbi et al., 2024), REHCARDICARE integrates evidence-based resistance and flexibility training, both of which have demonstrated beneficial effects on cardiac output, muscle strength, and range of motion (Danduboyina et al., 2023; Sharma et al., 2022). This innovation addresses the persistent gap between growing digital healthcare needs and limited participation in conventional cardiac rehabilitation programs.

Despite increasing interest in digital cardiac rehabilitation, evidence regarding the effectiveness of combined resistance and flexibility training delivered through mobile applications for post-CABG patients remains limited (Wongvibulsin et al., 2021). Furthermore, research in Indonesia on the development and evaluation of comprehensive digital rehabilitation applications is still scarce. REHCARDICARE offers several novel features, including personalized exercise pre-scriptions, automated reminders, real-time progress monitoring, and clinically tailored interventions based on patient characteristics, distinguishing it from many existing rehabilitation applications that provide only generic exercise recommendations (Lee et al., 2023).

This study employed the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) model to develop and evaluate the REHCARDICARE application among post-CABG patients at an integrated cardiac center in North Sumatra, Indonesia. Cardiac output was measured non-invasively before and after the intervention to assess the application's effectiveness. The study aimed to develop a user-friendly, evidence-based digital rehabilitation tool capable of improving cardiac output following CABG surgery. The findings are expected to contribute to the advancement of digital cardiovascular re-

habilitation and provide guidance for implementing technology-based rehabilitation programs in hospital and primary healthcare settings.

Methods

Study Design. This study employed a Research and Development (R&D) approach using the ADDIE model, which consists of the Analysis, Design, Development, Implementation, and Evaluation phases. During the analysis phase, a needs assessment was conducted through informal interviews with cardiologists, cardiac rehabilitation nurses, and post-coronary artery bypass graft (CABG) patients to identify gaps in home-based cardiac rehabilitation, technology readiness, exercise safety concerns, and the expected features of the application. Based on these findings, the design phase involved planning the application structure using a storyboard approach that outlined user navigation, resistance and flexibility exercise modules, safety alerts, progress monitoring, and reminder notifications. The exercise program incorporated into the application was developed according to Phase II cardiac rehabilitation standards. Subsequently, during the development phase, the REHCARDICARE application was created as an Android-based mobile application (Version 1.0). The content validity and clinical appropriateness of the application were reviewed by an expert panel consisting of a cardiologist, a cardiac rehabilitation nurse, and a health technology specialist. In the implementation phase, participants received structured training regarding application use, exercise procedures, and safety monitoring. They then participated in an eight-week home-based rehabilitation program, performing exercises independently while receiving remote supervision from the rehabilitation team. Finally, during the evaluation phase, cardiac output measurements were obtained before and after the intervention, while application usability and user satisfaction were assessed to determine the feasibility and effectiveness of REHCARDICARE.

Setting and Participants. Participants were recruited using purposive sampling from the integrated cardiac center of a hospital in North Sumatra, Indonesia. A total of 30 post-CABG patients were enrolled in this pilot feasibility study, with the sample size determined according to recommendations for early-stage testing of digital health interventions. Eligible participants were between 40 and 65 years of age, had undergone CABG surgery at least one month prior to enrollment, were clinically stable, and were able to operate a smartphone independently. Individuals with severe cardiovascular complications such as unstable angina or uncontrolled arrhythmias, cognitive impairments that could interfere with application use, or contraindications to exercise were excluded from the study. Baseline characteristics collected included age, sex, comorbidities such as diabetes mellitus and hypertension, current medications, baseline functional class, and time since surgery, which was categorized as 1-3 months or more than 3 months postoperatively.

Intervention. The intervention consisted of a structured resistance and flexibility exercise program designed to be safe, practical, and feasible for post-CABG patients. Participants completed three exercise sessions per week, with each session lasting approximately 30-40 minutes, over an intervention period of eight-week. Resistance exercises targeted major muscle groups, including the upper extremities, lower extremities, and core muscles, using body weight and light resistance. Each exercise was performed for two to three sets with 10-15 repetitions per set. Exercise intensity was maintained at a moderate level using the Borg Rating of Perceived Exertion (RPE) scale, ranging from 11 to 13, and progressive overload was introduced every two weeks. In addition, flexibility exercises focused on the neck, shoulders, chest, lower back, and lower limbs. Each stretching movement was held for 15-30 seconds and repeated two to three times for each muscle group. To ensure participant safety, pre-exercise symptom screening was incurporated into the application, along with automated alerts for warning signs such as chest pain, dizziness, and excessive fatigue. Participants were instructed to discontinue exercise

immediately and contact the rehabilitation team if any concerning symptoms occurred. Throughout the intervention period, adherence and participant safety were monitored through weekly remote follow-ups conducted via telephone calls or text messages. Exercise adherence was objectively measured using application usage logs and was calculated as the proportion of completed exercise sessions relative to the total number of prescribed sessions during the eight-week intervention.

Measurement. Study outcomes were assessed using measures of cardiac output, usability, user satisfaction, and exercise compliance. Cardiac output was measured noninvasively using Doppler echocardiography performed by qualified cardiologists before and after the intervention period. Measurements were calculated using the left ventricular outflow tract velocity-time integral method. To minimize measurement bias, the assessors responsible for cardiac output evaluation were not involved in intervention delivery. In addition to physiological outcomes, application usability and user satisfaction were evaluated using a 20-item questionnaire that assessed application functionality, interface design, clarity of exercise instructions, and willingness to continue using the application. Responses were rated on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The questionnaire content was reviewed by health and technology experts, and reliability testing demonstrated strong internal consistency, with a Cronbach's alpha coefficient of 0.87 (Maddison et al., 2019). Furthermore, exercise compliance was determined from application log data and calculated as the percentage of completed exercise sessions relative to the total prescribed sessions during the intervention period.

Data Analysis and Ethical Consideration. Data collection began with baseline cardiac output measurements, followed by application training and implementation of the intervention program. Upon completion of the eight-week intervention, post-intervention cardiac output measurements and user satisfaction surveys were collected. Data were analyzed using paired t-tests to compare cardiac output values before and after the intervention, with statistical significance established at $p < 0.05$. Ethical approval for the study was obtained from the Institutional Ethics Committee (Approval No. Ap.III.e/64A/V/2025). All participants provided written informed consent before enrollment, and confidentiality was maintained through anonymization of personal information and secure management of application-generated data to ensure privacy and data protection throughout the study.

Results

Table 1 presents the participants' characteristics by gender, education level, and postoperative period. The distribution of the respondents reveals a fairly balanced representation across the categories, allowing for a more comprehensive analysis of the study variables. By gender, the respondents were predominantly male. This reflects the tendency for a higher prevalence of CHD in men and suggests that cardiac rehabilitation interventions after coronary artery bypass surgery are widely applied in this group. In terms of education level, most respondents were at the secondary to high school levels. This indicates that respondents generally have adequate literacy skills to receive health-related education and participate in app-based rehabilitation programs, including understanding resistance and flexibility training instructions. In terms of the postoperative period, the majority of respondents were within 4-6 months post-surgery. This period represents the advanced rehabilitation phase, in which patients have generally passed the initial recovery phase and are deemed stable enough to participate in structured physical exercise to increase cardiac out-put.

The results presented in Table 2 demonstrate a significant increase in cardiac output following the implementation of resistance and flexibility training delivered via the REHCARDICARE application. This reflects improved cardiac hemodynamic function in patients after CABG surgery. The paired t-test revealed a highly sig-

nificant effect with a relatively narrow confidence interval, indicating consistent intervention effects across participants. User satisfaction with the REHCARDICARE application was high and assessed using a 5-point Likert scale (1-5), with results reported as mean scores to represent overall satisfaction levels. The mean score approaching the upper limit of the scale indicates that most participants were satisfied to very satisfied with the application. Additionally, high exercise compliance over the 8-week intervention period suggests that the application effectively motivated patients and facilitated adherence to the prescribed exercise program. Overall, these findings support the effectiveness and sustainability of technology-based interventions in postoperative cardiac rehabilitation. Furthermore, a high level of exercise compliance during the 8-week intervention period indicates that the application successfully encouraged patients and made it easier for them to follow the recommended exercise regimen. These results provide credence to the efficacy and long-term viability of technology-based therapies in cardiac rehabilitation following surgery.

Table 1. Distribution of Respondents

Characteristics	Category	n (total number of respondents)	% (percentage)
Gender	Male	18	60
	Female	12	40
Education	Elementary School/equivalent	5	16.7
	Middle School/equivalent	8	26.7
	High School/equivalent	12	40
	Diploma/bachelor's degree	5	16.6
Postoperative Period	1–3 months	10	33.3
	4–6 months	12	40
	> 6 months	8	26.7

Abbreviations: *n* = total number of respondents; months = months after a CABG

Table 2. Statistical Test Results

Variable	Time Measurement	Mean	Standard Deviation (SD)	95% Confidence Interval (CI)	t-value (df=29)	Significance (2-tailed)
Cardiac Output (Liters per minute)	Before Intervention	4.12	0.55	3.90–4.34		
Cardiac Output (Liters per minute)	After Intervention	5.28	0.62	5.03–5.53	9.76	0.001
User Satisfaction (Scale 1-5)	After Intervention	4.47	0.36	4.36–4.58		
Exercise Compliance (%)	Over 8 Weeks	87.5	6.8	84.2%–90.8%		

Note: SD = standard deviation; CI = confidence interval; df = degrees of freedom; t-value = paired t-test statistic; significance (2-tailed) = two-tailed p-value; and L/min = liters per minute. Statistical significance was defined as $p < 0.05$.

Table 3. Paired T-test Results of Cardiac Output Before and After the REHCARDICARE Intervention

Variable	Mean Pre (SD)	Mean Post (SD)	Mean Difference (Post–Pre)	SD Difference	95% CI Difference	t-value (df = 29)	p-value (2-tailed)	Cohen's d
Cardiac Output (L/min)	4.12 (0.55)	5.28 (0.62)	1.16	0.65	0.92 – 1.40	9.76	< 0.001*	1.78

Note: SD = standard deviation; CI = confidence interval; df = degrees of freedom; Cohen's d = effect size for paired data; and L/min = liters per minute. Normality of the difference scores (post-test–pre-test) was assessed using the Shapiro-Wilk test and showed a normal distribution ($p > 0.05$), supporting the use of the paired t-test. Statistical significance was defined as $p < 0.05$.

Table 3 shows that the REHCARDICARE intervention resulted in a marked improvement in cardiac output. The mean cardiac output increased from 4.12 ± 0.55 L/min before the intervention to 5.28 ± 0.62 L/min after the intervention, with a mean difference of 1.16 L/min (SD difference = 0.65; 95% CI = 0.92–1.40). The Shapiro–Wilk test confirmed that the difference scores (post–pre) were normally distributed ($p > 0.05$), indicating that the assumptions for conducting a paired t-test were satisfied. The paired t-test revealed a statistically significant increase in cardiac output (t-value = 9.76; $p < 0.001$). Also, the intervention demonstrated a huge effect size, as indicated by Cohen's d = 1.78, suggesting that the resistance and flexibility training delivered through the REHCARDICARE application had a strong clinical impact on improving cardiac output among patients after a CABG procedure.

Discussion

Consistent with Gallagher et al. (2017) and Menezes et al. (2025), the age range included both younger and older adults, reflecting populations commonly involved in conventional and technology-based cardiac rehabilitation. Although generalizability should still be interpreted cautiously, this alignment supports the relevance of the sample to the target population. The gender distribution, dominated by men but with meaningful female representation, also reflected CABG epidemiology and is important given the evidence that gender differences may influence physiological responses, technology acceptance, and rehabilitation needs (Harik et al., 2023). Furthermore, the wide range of educational backgrounds provides an important context for evaluating the feasibility and acceptability of digital rehabilitation application, as digital literacy strongly influences the outcomes of technology-based interventions (Wongvibulsin et al., 2021). Variation in post-operative recovery duration also allowed for a more accurate interpretation of physiological responses, since exercise adaptation may different between the early and later rehabilitation phases after a CABG procedure (Rawstorn et al., 2020). Overall, this clinical diversity offers preliminary insight into the potential applicability of REHCARDICARE across varied patient profiles.

The findings showed that the use of the REHCARDICARE application, combined with resistance and flexibility exercises for eight weeks, was associated with increased cardiac output. However, due to the single-group pretest-posttest design without a control group, these results should be interpreted as improvements related to the intervention rather than definitive proof of efficacy. Other contributing factors, such as improved hemodynamic stability, medication optimization, maturation effects, and natural recovery after surgery, may also have influenced the increase in cardiac output.

Compared with traditional cardiac rehabilitation, which often requires facility-based attendance, this app-based approach may offer greater accessibility and flexibility. Although conventional rehabilitation is effective, it is often limited by restricted availability, low adherence,

and logistical costs (Fisher et al., 2022). In contrast, other digital and telerehabilitation programs have demonstrated promising clinical and quality-of-life outcomes despite variations in program design and supervision (Sharma et al., 2022). Thus, the present findings provide early support that digital delivery of resistance and flexibility training may serve as an alternative or complementary strategy to conventional rehabilitation. Physiologically, resistance training may enhance cardiovascular function via peripheral adaptations, such as increased muscle strength, improved capillarization, and better vascular function, thereby supporting venous return and reducing vascular resistance (Isath et al., 2023). Flexibility training may further contribute by improving joint mobility, peripheral circulation, biomechanical efficiency, and potentially autonomic regulation via reduced sympathetic dominance (Kambic et al., 2022). Therefore, combining resistance and flexibility exercises may produce synergistic benefits for post-CABG cardiovascular function.

The intervention was also associated with relatively high exercise adherence, suggesting good engagement with the program. This aligns with prior studies indicating that user-friendly digital interventions with clear instructions can enhance sustained exercise behavior (Maddison et al., 2019; Puri & Lalwani, 2023). Nevertheless, adherence and satisfaction outcomes were mainly self-reported and may have been influenced by perception and social desirability bias.

Safety is a key concern in exercise-based interventions for post-CABG populations. During the intervention period, no major adverse events (i.e., severe chest pain, worsening dyspnea, symptomatic arrhythmias, extreme dizziness, or excessive fatigue requiring exercise termination) were reported. Safety was supported by gradual activity progression, clear in-app guidance to stop exercising when warning symptoms occurred, and initial clinical supervision before independent use. However, future studies should incorporate more comprehensive and objective safety monitoring, such as remote telemetry or regular physiological monitoring, to provide stronger evidence of safety (Koike et al., 2022; Tessler et al., 2025).

The findings also have important implications for nursing practice. Nurses play a crucial role in discharge education, including teaching patients how to use the REHCARDICARE application and delivering safe, individualized exercise guidance. Evidence from the nursing literature highlights the importance of multidisciplinary education, tailored planning, structured guidance, and monitoring to improve adherence and reduce post-rehabilitation risk (Zhang et al., 2025). Also, nurses may support app-based rehabilitation by monitoring patient progress via telemonitoring systems, providing motivational reinforcement, and detecting early warning signs, as emphasized in telemonitoring-based cardiac rehabilitation frameworks (Muliyawati & Herawati, 2024). Integrating such interventions into community or primary care rehabilitation path-ways may improve access while reducing the burden on healthcare facilities. Despite this study's contributions, it has several limitations. The small sample size, short intervention duration, single-center setting, and absence of control group limit generalizability and causal inference. These limitations are consistent with prior pilot and feasibility studies on cardiac rehabilitation (Kim et al., 2025). Therefore, future research using stronger experimental designs, larger samples, longer follow-up, and objective measurements of adherence and safety are needed to strengthen the evidence regarding the potential benefits of the REHCARDICARE application for post-CABG rehabilitation.

Conclusion

The REHCARDICARE application demonstrated promising preliminary results in supporting post-CABG rehabilitation via structured, supervised resistance and flexibility training in this single-group pre-and post-CARB study. Its use was associated with improved exercise adherence, positive changes in cardiac output-related recovery indicators, and increased motiva-

tion to engage in safe, independent rehabilitation. However, these findings should be interpreted cautiously due to methodological limitations, including the absence of a control group, a small sample size, and limited generalizability. Future studies should confirm these results through multi-site randomized controlled trials with longer follow-up periods and broader outcome measures, such as functional capacity (e.g., a 6-minute walk test), quality of life, hospital readmission rates, and objective app-based adherence metrics.

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Data Availability Statement

Because the data contains sensitive information and to protect respondent confidentiality, they are not publicly available. However, with the authors' permission, the data may be accessed for a restricted review.

Author Contributions

Elvipson Sinaga: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Supervision, Writing - review & editing. **Khairunnisa Batubara:** Conceptualization, Methodology, Investigation, Data curation, Visualization, Writing - original draft, Writing - review & editing, Project administration.

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