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FULL RESEARCH PAPER
Cost-effectiveness

Cost-effectiveness of a digitally enabled cardiac rehabilitation programme for patients with coronary heart disease

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Aims This study aimed to explore the long-term cost-effectiveness of a nationally implemented, digitally enabled cardiac rehabilitation (DeCR) programme for patients admitted for coronary heart disease (CHD).

Methods and results We conducted a cost-effectiveness analysis, using a Markov model to compare DeCR with usual care. Coronary heart disease patients were recruited nationally post-hospitalization into an 8-week DeCR programme comprising telehealth consultations and a mobile app. Index hospitalization and rehospitalization costs were sourced from private hospital administrative insurance claims, and intervention delivery was micro-costed. Quality-adjusted life years (QALYs) were derived from EQ-5D-5L utility scores collected in the DeCR group and literature-based estimates for usual care. Costs and QALYS were modelled over a 5-year time horizon and discounted at 3% annually. Costs and QALYs were based on average values per patient, rather than being driven by sample sizes. Uncertainty was assessed using one-way and probabilistic sensitivity analyses, with a willingness-to-pay (WTP) threshold of AUD$50 000 per QALY. Of the 337 patients (DeCR: 88; usual care: 249), most were male (73%), aged ≥65 years (70%) with multimorbidity (Charlson Comorbidity Index ≥ 1: 61%). Digitally enabled cardiac rehabilitation yielded 4.677 QALYs at a cost of AUD$121,235, compared with 3.244 QALYs at AUD$100 733 for usual care. The incremental cost of AUD$20 503 resulted in an incremental cost-effectiveness ratio (ICER) of AUD$14 302 (€9082) per QALY gained, well below the WTP threshold. Key ICER drivers included mortality risk, proportion of usual care attending cardiac rehabilitation, and DeCR utility gained. Digitally enabled cardiac rehabilitation was cost-effective in 87% of simulations.

Conclusion Digitally enabled cardiac rehabilitation is a cost-effective alternative to usual care, offering improved health outcomes at an acceptable cost.

Lay summary This study assessed the long-term cost-effectiveness of a digitally enabled cardiac rehabilitation (DeCR) programme, delivered over 8 weeks via telehealth and a mobile app, for people recovering from a hospitalization for coronary heart disease.

- The DeCR programme improved patients' quality of life at a cost that offers good value for money, making it a cost-effective alternative to usual care. Digitally enabled cardiac rehabilitation is an efficient prevention alternative to usual care, as it provides additional health benefit at an acceptable additional cost.
- These findings support offering DeCR more broadly in clinical practice. Expanding DeCR may help more people access cardiac rehabilitation, especially those who find it challenging to attend in-person programmes, such as people who live in regional or remote areas, while also providing long-term health and economic benefits. Further research is needed to confirm these benefits in public healthcare settings.

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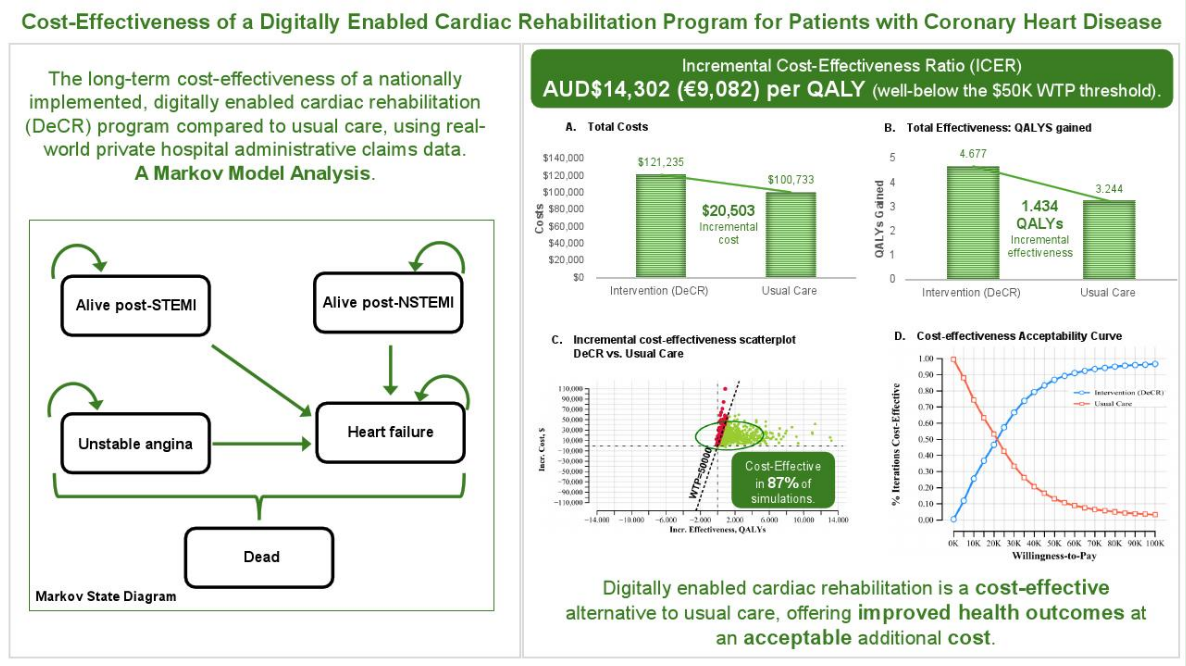
Graphical Abstract



Cost-Effectiveness of a Digitally Enabled Cardiac Rehabilitation Program for Patients with Coronary Heart Disease

The long-term cost-effectiveness of a nationally implemented, digitally enabled cardiac rehabilitation (DeCR) program compared to usual care, using real-world private hospital administrative claims data. **A Markov Model Analysis.**

Incremental Cost-Effectiveness Ratio (ICER)
AUD$14,302 (€9,082) per QALY (well-below the $50K WTP threshold).

Digitally enabled cardiac rehabilitation is a **cost-effective** alternative to usual care, offering **improved health outcomes** at an **acceptable** additional **cost**.

Keywords Digital health • Telerehabilitation • Cardiac rehabilitation • Cost-effectiveness analysis • Health economics • Coronary heart disease

Introduction

Cardiac rehabilitation (CR) is a well-established secondary prevention strategy, with strong evidence demonstrating it improves quality of life and reduces unplanned hospitalizations,[1] leading to associated cost savings through decreasing healthcare utilization.[2] Given these advantages, CR is endorsed by international guidelines for the secondary prevention of various cardiac conditions.[3]

Despite its well-established benefits, most eligible patients do not participate in CR.[4] Access is hindered by patient-level factors such as time and transport constraints,[5] as well as system-level issues such as limited funding and programme availability.[4] The underutilization of CR contributes to high rehospitalization rates, premature death, and perpetuates a cycle of rising healthcare costs.[6,7] Even modest increases in CR participation could prevent a significant number of premature deaths and acute hospital admissions,[6] thereby optimizing the cost-effective potential of secondary prevention. To improve participation in CR and enhance accessibility, digitally enabled cardiac rehabilitation (DeCR) has emerged as an alternative approach, delivering care virtually through digital technologies such as the internet, wearable devices, and mobile applications.[8] It is associated with improved clinical outcomes,[9 ,10] and it facilitates remote monitoring, metric tracking, and communication, enabling clinicians to oversee patient care remotely beyond traditional healthcare delivery methods.[8]

Despite the potential of DeCR to enhance secondary prevention strategies,[9,10] its adoption remains limited, with programmes neither routinely implemented nor sustainably funded without cost-effectiveness evidence.[11] To date, most existing evidence comes from controlled trial settings rather than real-world contexts[8] and economic evaluations are typically embedded within short-duration randomized controlled trials.[12] As the integration of DeCR into routine practice becomes the next frontier in secondary prevention, robust cost-effectiveness analyses, conducted across diverse settings and supported by modelling to extrapolate long-term costs and outcomes beyond the trial time horizon,[12] are essential to determine value and inform real-world implementation and scale-up.[11 ,13]

Building on prior research,[14] this study used real-world hospital administrative claims data, supplemented with existing literature, to evaluate the cost-effectiveness of a nationally implemented DeCR programme delivered to patients discharged from hospital following treatment for coronary heart disease (CHD).

Methods

Study design

We conducted this cost-effectiveness analysis, alongside a broader real-world observational propensity matched cohort study, called *Heart Health at Home* (ClinicalTrials.gov: NCT06813482).[14,15] This study followed the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) reporting guideline for economic evaluations of healthcare interventions.[16]

Study population and selection procedures

The study cohort selection, including eligibility criteria and propensity score matching, has been detailed previously.[14] Briefly, for both groups, eligible patients were identified using hospital administrative claims data that captured all procedures performed as per the Australian Classification of Health Intervention (ACHI procedure codes) and primary diagnoses recorded according to the International Classification of Diseases 10th revision-Australian Modification (ICD-10) from all private hospitals across

Australia. For inclusion in the Markov model, we selected only patients with an index admission for CHD from the wider observational study cohort (see Supplementary material online, *S1*). Participants were excluded if they had heart failure (HF).

Digitally enabled cardiac rehabilitation intervention cohort

In short, private health insurance patients discharged between October 2019 and November 2020 with a cardiovascular diagnosis and/or procedure eligible for CR and living in any Australian State or Territory were eligible to participate. Participants were excluded if they were enrolled in another CR programme for the same index event or did not have access to a smartphone and internet connection. Potentially eligible patients were recruited into the DeCR programme through direct telephone outreach by the insurer within 30 days of discharge from their index cardiac hospitalization.

The DeCR programme has been described in detail previously.[14] In brief, it was an 8-week remotely delivered telerehabilitation programme, whereby participants received weekly one-on-one telehealth sessions (30 min each) and were supported by a mobile app designed for risk factor self-management and personalized education, reminders, and support.

Comparison group

The usual care group was constructed retrospectively from private hospital administrative insurance claims data. Patients were included if they were discharged from hospital during the same time period and with a diagnosis and/or procedure qualifying for CR, consistent with the inclusion criteria applied to the intervention group. This group reflected routine clinical practice, typically being medical management with advice on lifestyle behaviours. Usual care comprised two subgroups: those who received face-to-face CR (F2F-CR) and those who did not attend CR (No-CR). Patients in the F2F-CR subgroup were identified through linkage with specific CR-related insurance claims, representing individuals who attended traditional, in-person programmes delivered in hospital or community-based settings. The No-CR subgroup included patients with an eligible index cardiac hospitalization with no linked record of a CR claim, indicating they likely did not participate in any formal rehabilitation.

For modelling purposes, we assumed a distribution of 30% F2F-CR and 70% No-CR, consistent with reported CR participation rates in Australia.[17] This was to account for the possibility that a small proportion of the No-CR subgroup may have participated in CR through publicly funded services not captured in the private claims data, thereby better reflecting real-world CR uptake. Notably, the observed distribution in our dataset was 34% F2F-CR and 66% No-CR, closely aligned with these national estimates.

Propensity score matching procedures were used to construct the comparison group, which has been described in detail previously.[14] Briefly, each DeCR patient was matched with one F2F-CR patient and two No-CR patients. Patients were matched on the following covariates: index diagnosis or procedure, Charlson Comorbidity Index, PEGASUS-TIMI readmission risk score, gender, year of hospital admission, and a gender × year interaction term. Age was not included separately, as it is incorporated within the PEGASUS-TIMI risk score and did not improve model performance when added. Variable selection was informed by data availability and expert clinical input.

Markov model structure and data

We developed a Markov model from the perspective of the Australian private health insurance sector to evaluate the cost-effectiveness of DeCR compared with usual care following hospitalization for CHD. We chose a Markov model to account for the progressive nature of CHD, allowing for the long-term evaluation of costs and health outcomes by simulating transitions between health states over time. The model estimated quality-adjusted life years (QALYs) and healthcare costs over a 5-year time horizon, with monthly cycles to reflect disease progression and intervention effects. Costs to deliver the intervention, acute index hospital costs, rehospitalization costs, and EQ-5D-5L derived quality of life (QoL) utility scores informed the incremental cost-effectiveness ratio (ICER). Costs and QALYs were based on average values, rather than being driven by sample sizes, and index hospitalization conditions and procedures were assigned based on the observed distribution within the study cohort; thus, results are independent of group sample sizes. The 5-year modelled costs accounted for multiple readmissions per patient. The model was structured according to the post-acute coronary artery syndrome (ACS) care pathway.[18] *Figure 1* provides an overview of the Markov decision tree, and Supplementary material online, *Table S2* summarizes the index hospitalization conditions and procedures.

Transition probabilities

Probabilities were obtained from external literature to reflect risks of hospital readmission, HF development, and mortality (see Supplementary material online, *Table S3*). The probabilities were transformed to monthly transition probabilities, reflecting clinical progression over time.

Quality of life

Health-related QoL (HR-QoL), represented by EQ-5D-5L health states,[19] was sourced from study data for the DeCR intervention group and from the published literature for the usual care group.[20,21] Australian preference weights were used to calculate HR-QoL values and QALYs for each health state.[22] The HR-QoL values (utility weights) are on a scale where 1 = full health and 0 = dead; it is possible to have negative HR-QoL scores for health states worse than dead. All values were converted to monthly estimates to allow for consistent comparison across health states (see Supplementary material online, *Table S4*).

Mortality

Mortality data for all groups were sourced from national private hospital administrative claims. Adjusted mortality relative risks (RRs) were estimated using Firth logistic regression, which allows for estimation in the presence of zero events by applying a penalized likelihood approach.

Costs

Costs to deliver the DeCR intervention were estimated from bottom-up, micro-costing methods, capturing real-world delivery costs and included the costs of using the digital software, staff resources, intangible costs, and other administrative costs. The app development and design costs were not included, as the mobile app had already been developed prior to this evaluation (see Supplementary material online, *Table S5*). Within the usual care group, cost to deliver No-CR was $0, while costs related to delivering F2F-CR were obtained from the literature.[23] Acute index hospitalization costs and 12-month rehospitalization costs (*Tables 2* and *3*), for the groups, were obtained from national private hospital administrative claims data. The cost of HF hospitalization was sourced from the literature,[24] as HF claims were not captured within the study cohort due to HF being an exclusion criterion. The estimated mean annual cost of HF was AUD\$32 417 (±AUD\$51 684), equating to a monthly cost of AUD \$2701 (±AUD\$4307).

All costs were adjusted for inflation and converted to 2021 Australian dollars (AUD) (\$1 AUD ≈ \$0.71 USD) using the OECD purchasing power parity source dataset.[25]

Statistical analysis

Cost-effectiveness was assessed using the ICER, and uncertainty was explored through probabilistic sensitivity analysis via 10 000 Monte Carlo simulations to assess the uncertainty in cost-effectiveness across all parameters in the model; deterministic one-way sensitivity analyses was used to identify key cost-effectiveness drivers by applying a ±25% adjustment to define low and high values and visualized using a tornado diagram.

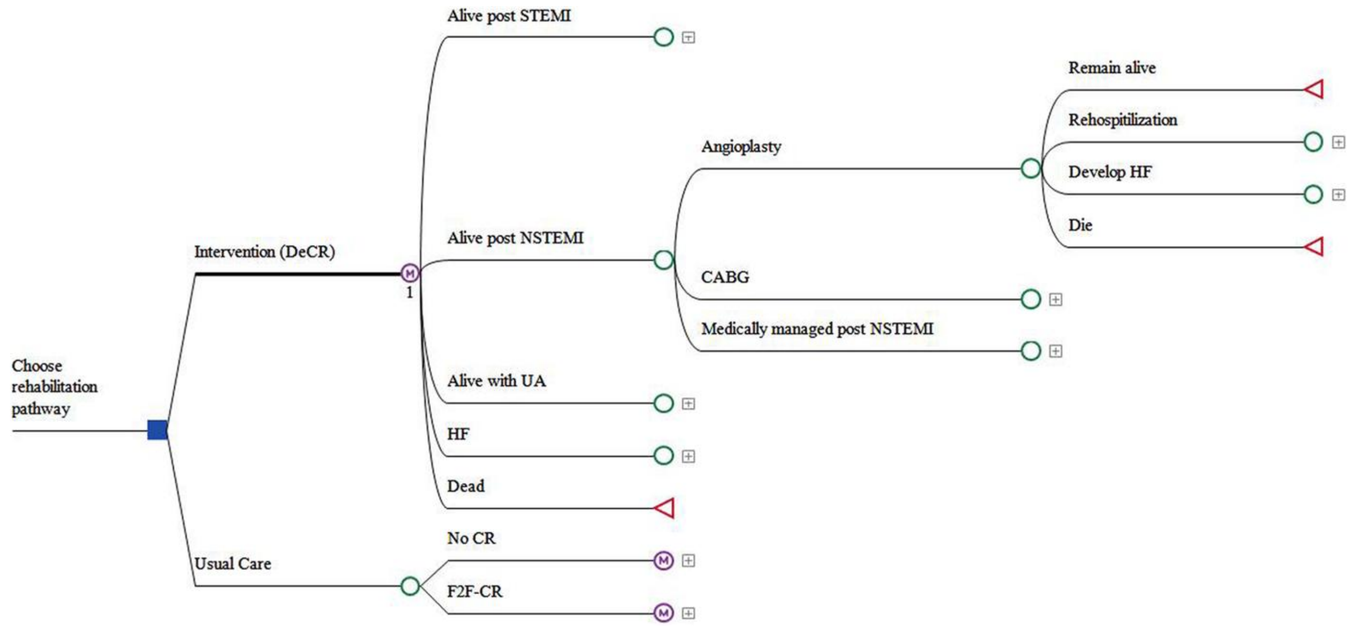


Figure 1 Simplified structure of the Markov model showing, intervention groups, index hospitalization conditions, index hospitalization procedures, and transition states. Visual overview of the initial branches of the Markov tree used in the analysis, displaying the structure for each intervention group (digitally enabled cardiac rehabilitation and usual care), the base-state index health conditions (e.g. post-STEMI, post-NSTEMI, unstable angina, heart failure), and corresponding index procedures (e.g. angioplasty, coronary artery bypass graft, medical management). This view highlights how simulated patients enter the model based on their index condition and subsequent management strategy. The intervention costs and utilities for digitally enabled cardiac rehabilitation and usual care were applied after the index hospitalization procedures, reflecting real-world post-discharge pathways. Following the index hospitalization procedure, patients either remained alive and stable or they experienced a rehospitalization, which may have led to subsequent angioplasty, coronary artery bypass graft, or medical management, or they progressed to heart failure or death. Patients with heart failure remained in that health state unless they died. The dead state is an absorbing state with no further transitions. For clarity, only a portion of the tree is shown; unopened branches follow the same structural logic as those displayed. The full tree contains multiple additional layers reflecting transition states and long-term outcomes, which have been simplified here due to size constraints.

We estimated the ICER for the interventions with a willingness-to-pay (WTP) threshold of AUD$50 000 per QALY, commonly used in Australia.[26] Costs were expressed in 2021 Australian dollars ($1 AUD ≈ $0.71 USD in 2021) to align with the follow-up period for hospital admission claims, and both costs and outcomes were discounted at 3% annually. This discount rate is consistent with international conventions, as a 3% rate is commonly used in health economic evaluations worldwide.[27] We conducted statistical analyses using RStudio (version 2024.12.0; R Foundation for Statistical Computing, Vienna, Austria) and built the Markov model using TreeAge Pro (version 25.1.1, TreeAge Software, LLC, Williamstown, MA, USA).

Results

Overall, 337 CHD patients from the original matched cohort were included in this cost-effectiveness analysis. Of these, 88 were in the DeCR intervention group and 249 in the usual care group, comprising 164 patients who did not attend CR (No-CR) and 85 who received F2F-CR (see Supplementary material online, *S1*).

Patient characteristics at baseline

Baseline demographic, index hospital admission conditions, and clinical characteristics are shown in *Table 1*. Patients were predominantly male (73%) and 70% were aged ≥65 years. Patients were from across the country; the majority lived in Victoria (41%), NSW/ACT (26%), or Queensland (18%). More than one in four patients were from regional or rural locations (26%) and located in lower socio-economic areas (bottom 50th percentile) (27.3%).

The index hospitalization conditions included unstable/progressive angina (75%), non-ST-segment elevated myocardial infarction (NSTEMI) (18%), and ST-elevation myocardial infarction (STEMI) (7%). The majority of these conditions were managed with a revascularization procedure by either angioplasty (46%) or coronary artery bypass grafting (27%), and the rest were treated with medical management (27%). Of those treated with medical management, the majority had unstable/progressive angina (66%), NSTEMI (32%), and 2% had STEMI. Approximately, one-third (30%) of patients were deemed high risk for hospital readmission as per PEGASUS-TIMI 54 criteria (≥5),[28] and two-thirds had a Charlson Comorbidity Index ≥ 1 (61%), while only a few had a chronic kidney disease comorbidity (3%) or had received a previous AMI (1.8%). Over one-third of patients had multi-vessel coronary artery disease (36%), less than one in five had diabetes (17%), and 43% of patients smoked cigarettes in the last 5 years.

Costs

Observed costs associated with the index admissions and 12-month rehospitalization costs are presented in *Tables 2* and *3*. The costs to deliver the DeCR intervention were estimated at AUD$2750 per patient (see Supplementary material online, *Table S5*). Within the usual care group, cost to deliver No-CR was AUD$0, while cost to deliver F2F-CR was estimated at AUD$1525 per person.[23] To account for uncertainty, we increased the DeCR intervention cost to AUD$5500, and separately, we increased the F2F-CR cost to AUD$2,288, in one-way sensitivity analyses to assess their independent impact on the ICER (*Figure 2*; Supplementary material online, *Table S6*). Overall, DeCR incurred higher total costs (AUD$121 235), compared with usual care (AUD$100 733), with an incremental cost of AUD$20 503 (over the 5-year time horizon).

Health-related quality of life

HR-QoL scores are summarized in Supplementary material online, *Table S4*. In the DeCR intervention group, EQ-5D-5L scores significantly improved from baseline to 8-week follow-up ($P < 0.001$), with a mean utility gain of 0.045 (95% CI: 0.029–0.061). This equated to a monthly utility gain of 0.022 (95% CI: 0.014–0.031). Within the usual care group, the overall mean monthly utility gained in F2F-CR was found to be 0.004 ± 0.006[20] and -0.005 ± 0.004 for patients who did not attend CR (No-CR).[21]

Mortality

Mortality outcomes varied across the groups. At 12-month follow-up, no deaths were recorded in the DeCR group, while seven deaths (4.3%) occurred in the usual care group. After adjustment, patients in the usual care group who undertook F2F-CR had a RR of 0.70 (95% CI: 0.08–6.05; $P = 0.860$) for mortality compared with the DeCR group. Patients in the usual care group who did not attend CR (No-CR) had a higher RR of mortality (RR = 2.85; 95% CI: 0.61–13.44; $P = 0.381$) compared with the DeCR group. The Markov state transition traces, including survival curves, for the DeCR intervention and usual care groups over the 5-year model horizon are displayed in Supplementary material online, *Figure S7*.

Cost effectiveness

Table 4 compares the 5-year base-case cost-effectiveness of DeCR with usual care in terms of costs and QALYs. Usual care was associated with a total cost of AUD$100 733 and an effectiveness of 3.244 QALYs over the 5-year time horizon. Digitally enabled cardiac rehabilitation had a higher cost of AUD$121 235 but yielded 4.677 QALYs, an increase of 1.434 QALYs. The incremental cost of DeCR compared with usual care was AUD$20 503, resulting in an ICER of AUD$14 302 per QALY gained, which falls well below the WTP threshold of AUD$50 000 per QALY. The base-case analysis suggests that DeCR is an efficient secondary prevention alternative to usual care, as it provides additional health benefit at an acceptable cost.

One-way sensitivity analysis

The one-way sensitivity analysis tornado diagram (*Figure 2*) illustrates the impact of key model parameters on the ICER. We selected the variables for inclusion in the tornado diagram based on their impact on the model's outcomes, with only those contributing more than 0.1% to the results being included. All other variables had a negligible effect (less than 0.1%) and were excluded from the tornado diagram.

To account for greater uncertainty in some parameters of interest, we increased the cost of delivering the DeCR intervention by 100% for the high entry and increased the cost of F2F-CR subgroup (within the usual care group) by 50%. Furthermore, for prudence, we reduced the RR of mortality in the usual care group, specifically for those who did not attend CR (No-CR), by 100% for the low entry value, minimizing the assumed mortality risk in this cohort. We also varied the model time horizon from 12 months to 5 years and separately the discount rate from 2 to 10%.

The largest drivers of ICER variability were (i) RR of mortality in the usual care group (ICER: $1583 to $18 738), (ii) usual care pathway proportions, F2F-CR vs. No-CR (ICER: $9525 to $15 595), and (iii) the utility gained in the DeCR group (ICER: $12 317 to $17 050), indicating that changes in these parameters had the greatest influence on the cost-effectiveness outcome. Additional influential parameters included the total cost of delivering the DeCR intervention (ICER: $12 884 to $17

Table 1 **Patient characteristics at baseline**

Variable	Overall $N = 337^a$	DeCR $N = 88^a$	Usual Care $N = 249^a$
Age 65+ years old	236 (70%)	57 (65%)	179 (72%)
Age category			
≤44 years	6 (1.8%)	0 (0%)	6 (2.4%)
45–54 years	15 (4.5%)	5 (5.7%)	10 (4.0%)
55–64 years	80 (24%)	26 (30%)	54 (22%)
65–74 years	125 (37%)	31 (35%)	94 (38%)
75–84 years	94 (28%)	24 (27%)	70 (28%)
≥85 years	17 (5.0%)	2 (2.3%)	15 (6.0%)
Gender			
Male	247 (73%)	65 (74%)	182 (73%)
Region[b]			
Metro	247 (74%)	62 (70%)	185 (75%)
Regional	34 (10%)	7 (8.0%)	27 (11%)
Rural	54 (16%)	19 (22%)	35 (14%)
State			
ACT	8 (2.4%)	4 (4.5%)	4 (1.6%)
NSW	87 (26%)	20 (23%)	67 (27%)
VIC	138 (41%)	31 (35%)	107 (43%)
QLD	62 (18%)	21 (24%)	41 (16%)
SA	12 (3.6%)	3 (3.4%)	9 (3.6%)
WA	21 (6.2%)	6 (6.8%)	15 (6.0%)
TAS	6 (1.8%)	3 (3.4%)	3 (1.2%)
NT	3 (0.9%)	0 (0%)	3 (1.2%)
Socio-economic condition			
IRSD, lowest 50th percentile[b]	92 (27.3%)	29 (33.0%)	63 (25.3%)
Index hospitalization conditions			
NSTEMI	60 (18%)	15 (17%)	45 (18%)
STEMI	23 (6.8%)	6 (6.8%)	17 (6.8%)
Unstable/progressive angina	254 (75%)	67 (76%)	187 (75%)
Index hospitalization procedures			
Angioplasty	154 (46%)	41 (47%)	113 (45%)
CABG	91 (27%)	25 (28%)	66 (27%)
Medically managed	92 (27%)	22 (25%)	70 (28%)
Clinical risk (*n*, %)			
Chronic kidney disease, stages 3–5	10 (3.0%)	2 (2.3%)	8 (3.2%)
Previous AMI	6 (1.8%)	1 (1.1%)	5 (2.0%)
Multi-vessel coronary artery disease	120 (36%)	32 (36%)	88 (35%)
Diabetes	58 (17%)	21 (24%)	37 (15%)
Smoking, last 5 years	146 (43%)	39 (44%)	107 (43%)
Re-admission risk, PEGASUS-TIMI 54			
High (≥5)	102 (30.3%)	27 (31.0%)	75 (30.1%)
Charlson Comorbidity Index			
No comorbidities (CCI 0)	132 (39%)	33 (38%)	99 (40%)
Low comorbidity (CCI 1–2)	141 (42%)	37 (42%)	104 (42%)
Moderate comorbidity (CCI 3–4)	48 (14%)	14 (16%)	34 (14%)
High comorbidity (CCI ≥ 5)	16 (4.7%)	4 (4.5%)	12 (4.8%)

NSTEMI, non-ST-segment elevated myocardial infarction; STEMI, ST-elevation myocardial infarction; AMI, acute myocardial infarction; IRSD, Index of Relative Socio-economic Disadvantage; CABG, coronary artery bypass graft.

[a] *n* (%); mean (SD).

[b] Missing cases: region (*n* = 2); IRSD (*n* = 3).

Table 2 **Observed mean (and standard deviation) costs of the index hospitalization admissions (model input parameters)**

Index condition	Index procedure	Index admission cost[a]	Standard deviation[a]
STEMI	Angioplasty	$12 273	$6547
	CABG	$29 477	$28 453
	Medical management	$5596	$4989
NSTEMI	Angioplasty	$14 685	$7169
	CABG	$59 238	$9972
	Medical management	$16 137	$19 413
Unstable/progressive angina	Angioplasty	$13 764	$3504
	CABG	$58 078	$16 412
	Medical management	$12 197	$22 490

NSTEMI, non-ST-segment elevated myocardial infarction; STEMI, ST-elevation myocardial infarction; AMI, acute myocardial infarction; CABG, coronary artery bypass graft.

[a] 2021, Australian dollars.

Table 3 **Observed mean (and standard deviation) 12-month readmission costs (model input parameters)**

		DeCR	Usual care	
Index condition	Index procedure	Mean (SD) cost[a]	F2F-CR Mean (SD) cost[a]	No-CR Mean (SD) cost[a]
STEMI	Angioplasty	$22 791 (23 018)	$6450 (5609)	$10 781 (17 309)
	CABG	$17 581 (15 821)	$10 715 (12 701)	$8317 (11 897)
	Medical management	$84 547 (90 772)	$51 528 (72 871)	$51 528 (72 871)
NSTEMI	Angioplasty	$8187 (12 079)	$7383 (8898)	$321 (540)
	CABG	$2200 (3112)	$961 (1359)	$763 (1526)
	Medical management	$29 709 (32 900)	$3612 (5108)	$15 593 (24 180)
Unstable/progressive angina	Angioplasty	$4160 (10 544)	$6176 (14 906)	$7661 (15 113)
	CABG	$6073 (11 432)	$6560 (10 394)	$5097 (8441)
	Medical management	$9169 (19 475)	$3603 (6333)	$10 567 (21 809)

NSTEMI, non-ST-segment elevated myocardial infarction; STEMI, ST-elevation myocardial infarction; AMI, acute myocardial infarction; CABG, coronary artery bypass graft; SD, standard deviation.

[a] 2021, Australian dollars.

139), the model time horizon (ICER: $13 135 to $15 603), and the index procedure cost for CABG to treat unstable angina (ICER: $12 943 to $15 661). Despite these conservative adjustments, the base-case ICER remained well below the AUD$50 000 per QALY WTP threshold, reinforcing the cost-effectiveness of the intervention under a range of input values. A summary of low and high entry values for all parameters is provided in Supplementary material online, *Table S6*.

Probabilistic sensitivity analysis

The optimal strategy selection based on probabilistic sensitivity analyses revealed that DeCR was the preferred cost-effective option in 86.9% of simulations, while usual care was optimal in 13.1% of simulations. In the incremental cost-effectiveness scatterplot (*Figure 3A*), the majority of the 10 000 simulations fall within the northeast quadrant, indicating that DeCR is both more costly and more effective than usual care. Most points sit below the WTP line, suggesting that DeCR is a cost-effective strategy under the AUD$50 000 per QALY WTP threshold. The cost-effectiveness acceptability curve (*Figure 3B*) illustrates the probability that DeCR and usual care are cost-effective across a range of WTP thresholds (AUD$0-$100 000). At lower WTP values (≤AUD $20 000 per QALY), usual care has a higher probability of being cost-effective. As the WTP threshold increases, the probability of DeCR being the cost-effective option rises. At approximately AUD$22 000 per QALY, the probability of cost-effectiveness for DeCR and usual care is equal. Beyond AUD$50 000 per QALY, DeCR has a ≥87% probability of being cost-effective.

Additional sensitivity analyses

To enhance interpretability, we conducted additional sensitivity analyses comparing DeCR with each of the usual care subgroups, F2F-CR and No-CR, individually. As shown in Supplementary material online, *Table S8*, No-CR was associated with the lowest cost (AUD $94 627) but also the least effectiveness (2.955 QALYs). Both DeCR (AUD$121 235; 4.677 QALYs) and F2F-CR (AUD$114 978; 3.824 QALYs) yielded higher QALYs at increased cost. Compared with No-CR, the ICER was AUD$15 816 for DeCR and AUD$24 537 for F2F-CR, both well below the WTP threshold of AUD$50 000 per QALY. Digitally enabled cardiac rehabilitation was also cost-effective compared with F2F-CR, with an ICER of AUD$7336 per QALY gained.

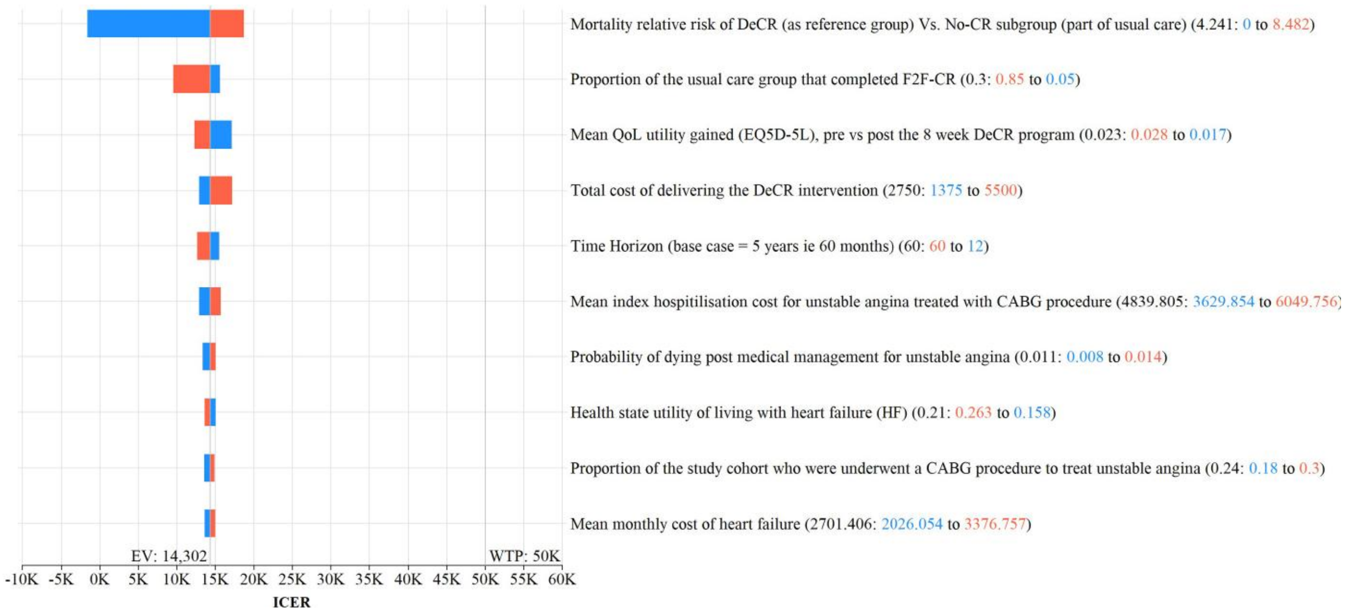


Figure 2 **Tornado diagram:** incremental cost-effectiveness ratio—intervention (digitally enabled cardiac rehabilitation) vs. usual care (willingness-to-pay: 50 000). One-way sensitivity analysis tornado diagram showing the impact of key model parameters on the incremental cost-effectiveness ratio of digitally enabled cardiac rehabilitation vs. usual care (over a 5-year time horizon), with wider bars indicating greater influence on the incremental cost-effectiveness ratio, and the base-case incremental cost-effectiveness ratio remaining below the willingness-to-pay threshold of AUD$50 000 per quality-adjusted life year. Bars are coloured according to the adjusted parameter range. The top 10 variables with the biggest impact on the incremental cost-effectiveness ratio are displayed in the tornado diagram; all other variables were included in the one-way sensitivity analysis but are not displayed because their impact on the incremental cost-effectiveness ratio was negligible.

Table 4 **Modelled cost-effectiveness outcomes at 5 years of digitally enabled cardiac rehabilitation compared with usual care**

Strategy	Cost	Incr. cost	Effectiveness	Incr. effectiveness	ICER (IC/IE)
Usual care	AUD$100 733		3.244 QALYs		
Intervention (DeCR)	AUD$121 235	AUD$20 503	4.677 QALYs	1.434 QALYs	AUD$14 302

ICER, incremental cost-effectiveness ratio; IC, incremental cost; IE, incremental effectiveness; AUD, Australian dollars.

Discussion

We evaluated the cost-effectiveness of a DeCR programme compared with usual care for post hospitalized CHD patients, using a Markov model over a 5-year time horizon. The results of our study support DeCR as a cost-effective alternative to usual care in a real-world setting. The base-case analysis indicates that DeCR is cost-effective, as it provides additional health benefit at an acceptable additional cost, with an ICER of AUD$14 302 per QALY gained, which is below the WTP threshold of AUD$50 000 per QALY. These findings were supported by probabilistic sensitivity analysis, whereby when we combined the uncertainty of multiple model parameters, the analysis indicated that DeCR was cost-effective in 87% of the 10 000 simulations, providing confidence in the base-case analysis results. Our findings support the economic viability of DeCR, advocating for its broader real-world implementation within the Australian healthcare system and potential expansion to enhance secondary prevention options for CHD patients after hospital discharge.

Most DeCR cost-effectiveness analyses over the past decade have been conducted within RCTs.[12] These studies are typically limited by short time horizons (6–12 months),[21,29–31] small sample sizes (ranging from 90 to 171 participants),[21 ,29–32] and reliance solely on clinical and resource-usage data captured from within the trial.[21]

As a result, trial-based analyses often underestimate long-term costs and outcomes and fail to reflect real-world practice, potentially misguiding resource allocation.[33] While decision-analytic modelling can address these limitations,[11 ,33] few studies have applied it to CHD populations over extended time horizons.[11,12] Our study advances previous cost-effectiveness analyses by (i) applying modelling to capture long-term outcomes and make use of broader data parameters; (ii) using real-world observed data; (iii) including a larger sample size; and (iv) incorporating a comparator group that reflects routine clinical practice.

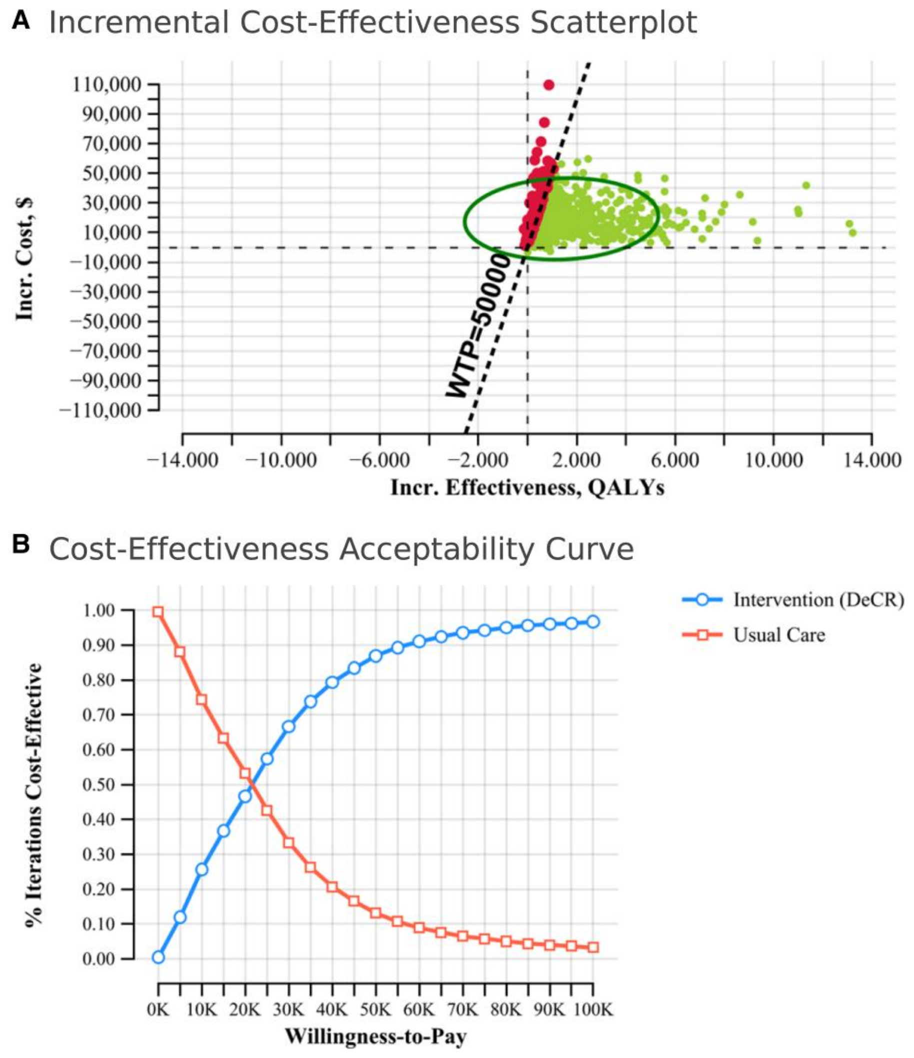
We built a Markov model to extrapolate costs and QALYs over a 5-year horizon, beyond the typical RCT period, using observed real-world private hospital administrative claims data supplemented with literature-based inputs. This approach incorporated relevant parameters beyond a clinical trial setting and likely provided a realistic and policy-relevant estimate of DeCR's value. Our cohort was also larger ($n = 337$) than most prior studies ($n = 90$–171),[21,29–32] which may enhance confidence in the results, albeit, primarily related to our larger usual care group. Furthermore, previous cost-effectiveness studies have typically compared DeCR only with centre-based CR,[12,13] overlooking that many patients do not attend CR at all. This limits real-world relevance.[33] Our study used a usual care comparator reflecting both F2F-CR and patients who did not attend CR, providing a more realistic basis for evaluating DeCR in routine practice.

Broadly, our findings are consistent with systematic review evidence demonstrating the cost-effectiveness of DeCR programmes.[12,13] Our ICER was lower than that reported in a similar New Zealand RCT-based study ($28 768 NZD per QALY),[21] likely due to our longer time horizon and broader cost inputs. While some comprehensive DeCR interventions have shown dominant effects (demonstrating both cost savings and improved utility),[30] others with highly technology-intensive interventions have reported poor cost-effectiveness,[34] highlighting that duration, data sources and parameters, and intervention design are key drivers of value.

When we varied the model duration in our study, between 12 months to 5 years, the ICER was highest at 12 months (AUD$15 450 per QALY) and declined to a minimum of AUD$12 641 per QALY after 2 years, then gradually increased to AUD$14 302 per QALY after 5 years. Given that most previous studies used short time horizons (6–12 months),[10 ,12,13] longer-term modelling studies are needed to capture DeCR's full economic impact.[11]

An influential parameter on the ICER in our study was the RR of mortality among patients who did not attend CR. Although these no-CR patients had a higher estimated mortality risk, the association was not significant, with wide confidence intervals, particularly when compared with other studies.[35] To account for this, we conducted a sensitivity analysis, setting the RR to zero difference. Surprisingly, this lowered the ICER, as more usual care patients survived and accumulated long-term costs without corresponding QALY gains. This also explains the higher costs observed for DeCR in the base-case analysis, where the incremental cost was AUD$20 503 compared with usual care. As DeCR patients lived longer, they accrued more healthcare costs over time. Furthermore, the higher 12-month rehospitalization costs observed in the intervention group reflect a higher average number of readmissions compared with the usual care groups. We have previously speculated[14] that while the number of readmissions was higher, the average length of stay was shorter, suggesting that patients may have presented to hospital earlier and at a lower acuity than if they had delayed care. This pattern may be attributed to easier access to nurse support and health education provided through the DeCR programme, prompting timely and warranted admission to hospital. However, more detailed information on the severity of rehospitalizations is needed to confirm this hypothesis. Importantly, despite higher readmission costs, the DeCR intervention remained cost-effective. While increased patient contact may raise short-term costs through early diagnosis and treatment, it can also improve outcomes and thus may not negatively impact the overall cost-effectiveness.

Moreover, the estimated DeCR delivery cost of AUD$2750 per patient, based on micro-costing, was higher than F2F-CR (AUD$1525), likely due to the one-on-one telehealth model requiring more staff time and fewer cost-sharing efficiencies. Still, our estimate aligns with other DeCR and intensive CR programmes.[23,30,31] When we doubled the DeCR delivery cost in sensitivity analysis to AUD$5500 per patient, DeCR remained cost-effective, with ICERs staying below the AUD$50 000 threshold. Digitally enabled cardiac rehabilitation interventions that include personalized clinician consultations have been shown to enhance patient engagement.[15] These programmes typically use technology to strengthen, rather than replace, communication between


A Incremental Cost-Effectiveness Scatterplot

B Cost-Effectiveness Acceptability Curve

Figure 3 (*A*) Incremental cost-effectiveness scatterplot intervention (digitally enabled cardiac rehabilitation) vs. usual care. The distribution of incremental costs and effectiveness (quality-adjusted life years) for digitally enabled cardiac rehabilitation compared with usual care, based on 10 000 Monte Carlo simulations. Each point represents an iteration from the probabilistic sensitivity analysis, with green dots indicating cost-effective iterations and red dots representing iterations where digitally enabled cardiac rehabilitation is not cost-effective at a willingness-to-pay threshold of AUD$50 000 per quality-adjusted life year. The dashed line represents the willingness-to-pay threshold of AUD$50 000 per quality-adjusted life year, with most points lying below this line, suggesting that digitally enabled cardiac rehabilitation is a cost-effective strategy under this threshold. The elliptical confidence region further supports that the majority of probabilistic estimates favour digitally enabled cardiac rehabilitation as a cost-effective intervention over a 5-year time horizon. (*B*) The cost-effectiveness acceptability curve. The cost-effectiveness acceptability curve illustrates the probability that digitally enabled cardiac rehabilitation and usual care are cost-effective across a range of willingness-to-pay thresholds (AUD$0-$100 000) over a 5-year time horizon.

clinicians and patients. However, this emphasis on one-on-one interaction can limit scalability compared with traditional F2F-CR models, which are commonly delivered in group formats. Future research should explore alternative models that retain the benefits of personalized communication while leveraging digital tools, such as artificial intelligence, to support clinician triage, prioritization, and monitoring. Such innovations may improve efficiency, reduce costs, and expand reach without compromising patient outcomes.

Our findings demonstrate that DeCR is not only effective[9,14] but also a cost-effective alternative to usual care, supporting its broader implementation. Scaling up DeCR could provide additional QALYs at a reasonable cost, whereas failing to expand access incurs an opportunity cost, missed potential to reduce hospital utilization and long-term expenditures. In our study, we conducted a sensitivity analysis varying the proportion of the usual care group receiving F2F-CR from 30 to 85% (UK's National Health Service (NHS) target),[6] the ICER for DeCR improved from AUD$14 302 to AUD$9525 per QALY (see Supplementary material online, *Table S9*). Although this change increased the average effectiveness of usual care, it also increased cumulative costs, driven by F2F-CR's improved survival. Thus, it reduced the incremental cost of DeCR relative to usual care. These results demonstrate a dual benefit, increasing overall CR uptake, including F2F-CR, enhances DeCR's cost-effectiveness, highlighting DeCR as a complementary, cost-effective strategy to expand CR reach.

However, DeCR is not appropriate or suitable for all patients. Some individuals may prefer F2F-CR, while others may encounter barriers to participating in remotely delivered programmes, including low digital literacy, limited access to technology, or discomfort with home-based exercise.[36] In our study, we excluded patients with limited access to internet or digital devices, or low technology competence, recognizing these as common barriers to DeCR.[36] Our findings suggest that DeCR should be considered a complementary option rather than a replacement for F2F-CR. Increasing the availability of diverse CR delivery models is important to enhance equitable access and ensure that programmes are tailored to meet the needs and preferences of different patient populations.

While our study was conducted within the private healthcare system, the findings have broader relevance. Given that over half of Australians hold private health insurance[37] and are often navigating both public and private care, our findings are likely to offer relevant learnings for the wider healthcare system. These learnings are important in the context of an ageing population and rising chronic disease burden, which continue to strain acute hospital services across both public and private settings.[38] As health systems seek to strengthen prevention and reduce avoidable hospitalizations,[38] digitally enabled models of care, such as the one evaluated in our study, can inform secondary prevention strategies not only within the public healthcare system in Australia but also in comparable health systems globally.

Strengths and limitations

This study builds upon previous research[9] by implementing the programme at a national level for private health insurance patients[14] and extending the evidence base through a cost-effectiveness analysis using real-world hospital claims data. While this real-world implementation offers valuable insights, certain limitations related to generalisability must be acknowledged. Recruitment was conducted nationally, with approximately one-quarter of participants residing in regional or rural areas. The sample was predominantly male, which reflects the known sex distribution of CHD patients in Australia.[17] However, a notable limitation is the exclusion of patients from the public healthcare system, all patients held private health insurance, which may limit the generalisability of the findings. However, a large proportion of Australians (55%) hold private health insurance,[37] so the findings remain relevant, with potential for broader applicability across the health system, as both sectors face shared challenges. The model incorporated a combination of study data and existing literature, introducing some uncertainty around the precise treatment effect and cost-effectiveness of this specific model of care. Although QoL utility data for the control group were not collected directly, values were sourced from existing literature, which may introduce uncertainty in the QALY estimation. However, the selected studies closely aligned with our population and intervention contexts (see Supplementary material online, *Table S4B*). Additionally, due to the commercial nature of the study, the cost of delivering the intervention was estimated using micro-costing methods and literature sources. Both estimated parameters may have contributed to uncertainty in the cost-effectiveness results. To account for this, we conducted probabilistic sensitivity and one-way sensitivity analyses, stress-testing the base-case parameters and cost-effectiveness results under varying conservative assumptions. Additionally, key drivers of uncertainty in the model included mortality estimates and care pathway proportions. Uncertainty existed around the mortality estimates, because the RRs reflected model-based estimates which accounted for penalization, rather than direct observed proportions. Consequently, mortality differences had wide confidence intervals. To mitigate this, we conducted a conservative sensitivity analysis, nullifying mortality differences between groups to test the robustness of the ICER. Similarly, we varied the proportion of usual care patients attending F2F-CR up to 85%, reflecting real-world targets.[6] While we attempted to mitigate uncertainty, variation may still exist given that these parameters were informed by study design and observational data. Moreover, our study data lacked long-term follow-up beyond 12 months, yet we modelled a 5-year horizon. Sensitivity analyses indicated that the ICER was highest at 12 months and lowest at 2 years, gradually increasing beyond that time point, suggesting that our base-case results may be overestimated.

Finally, this study was conducted alongside a real-world cohort study employing propensity score matching, a method frequently utilized in CR research to approximate randomization and minimize confounding bias. While this approach enhances comparability between groups, causal inference may still be influenced by unmeasured confounders. Therefore, although our findings build on prior evidence of the intervention's efficacy, well-designed randomized controlled trials remain essential to validate treatment effects observed in real-world DeCR settings and across diverse populations.

Nevertheless, this study provides valuable insights into the cost-effectiveness of DeCR in routine clinical practice, capturing real-world complexities that may not be observed in controlled trial settings. The findings contribute to the growing evidence supporting the economic viability of DeCR,[13] underscoring the need for further long-term cost-effectiveness evaluations to confirm its sustained benefits.

Policy and clinical implications

Despite over half a century of evidence supporting the effectiveness of CR, uptake remains low.[4] Digitally enabled cardiac rehabilitation is a promising option, yet its integration into routine clinical practice has been limited. We speculate that one reason for this is that many DeCR studies have been conducted in controlled research settings, with slow translation into real-world care.[8 ,11] Additionally, funding models remain a key barrier to broader adoption. Reimbursement pathways for DeCR are still in early development. Progress has been hindered by a lack of robust cost-effectiveness data, modelled over longer time horizons, to appropriately inform resource allocation and funding mechanisms.[39] In the USA, legislative efforts are underway to permanently secure Medicare reimbursement for telehealth-based CR,[40] reflecting growing international recognition of the need for scalable, virtual models of care.

The findings from our study support the case for funding DeCR programmes as part of standard care, particularly within private health systems, and lay the groundwork for other similar evaluations. Future research should focus on assessing the cost-effectiveness of DeCR, using real-world data, in the public system, and evaluate its long-term clinical and economic impact across diverse patient groups. Additionally, future research should capture broader perspectives, including indirect patient and productivity costs, which are particularly relevant when comparing virtual and centre-based models.

Conclusion

Digitally enabled cardiac rehabilitation is a cost-effective strategy for CHD patients, offering better health outcomes at an acceptable additional cost. These findings can be used to inform decisions on implementing DeCR in clinical practice to expand access to CR. Digitally enabled cardiac rehabilitation may hold promise beyond the private sector, enabling more flexible and geographically accessible care for eligible patients. Further research is needed to confirm its real-world long-term economic benefits in the public system.

Supplementary material

Supplementary material is available at *European Journal of Preventive Cardiology*.

Author contribution

J.B. and C.K. contributed to the conception of the *Heart Health at Home* project. J.B., M.J.C. and C.K. contributed to the study design. J.B., M.J.C., and T.H.M. contributed to the data planning and data acquisition. J.B. was the study project manager and contributed the overall study implementation. J.B., M.J.C., and P.S. contributed to the data readiness and data analysis. J.B., T.H.M., and P.S. designed the Markov model and J.B. built the Markov model. J.B. drafted the manuscript, and all authors revised the manuscript critically. All the authors gave approval and agree to be accountable for all aspects of the work.

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Conflict of interest: J.B. and C.K. are employed by Medibank. There are no conflicts of interest from any other authors.

Data availability

The data underlying this article may be shared on reasonable request to the corresponding author.

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