

Clinical and cost-effectiveness of home-based cardiac rehabilitation compared to conventional, centre-based cardiac rehabilitation: Results of the FIT@Home study

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Abstract

Aim: Although cardiac rehabilitation improves physical fitness after a cardiac event, many eligible patients do not participate in cardiac rehabilitation and the beneficial effects of cardiac rehabilitation are often not maintained over time. Home-based training with telemonitoring guidance could improve participation rates and enhance long-term effectiveness.

Methods and results: We randomised 90 low-to-moderate cardiac risk patients entering cardiac rehabilitation to three months of either home-based training with telemonitoring guidance or centre-based training. Although training adherence was similar between groups, satisfaction was higher in the home-based group ($p = 0.02$). Physical fitness improved at discharge ($p < 0.01$) and at one-year follow-up ($p < 0.01$) in both groups, without differences between groups (home-based $p = 0.31$ and centre-based $p = 0.87$). Physical activity levels did not change during the one-year study period (centre-based $p = 0.38$, home-based $p = 0.80$). Healthcare costs were statistically non-significantly lower in the home-based group (€437 per patient, 95% confidence interval –562 to 1436, $p = 0.39$). From a societal perspective, a statistically non-significant difference of €3160 per patient in favour of the home-based group was found (95% confidence interval –460 to 6780, $p = 0.09$) and the probability that it was more cost-effective varied between 97% and 75% (willingness-to-pay of €0 and €100,000 per quality-adjusted life-years, respectively).

Conclusion: We found no differences between home-based training with telemonitoring guidance and centre-based training on physical fitness, physical activity level or health-related quality of life. However, home-based training was associated with a higher patient satisfaction and appears to be more cost-effective than centre-based training. We conclude that home-based training with telemonitoring guidance can be used as an alternative to centre-based training for low-to-moderate cardiac risk patients entering cardiac rehabilitation.

Keywords

Cardiac rehabilitation, home-based training, telemonitoring, physical fitness, physical activity

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Introduction

Although cardiovascular disease remains a major cause of mortality and results in approximately 17 million annual deaths worldwide, the number of deaths decreases each year.¹ This is caused, among others, by high quality cardiac rehabilitation after an initial cardiac event.^{2,3} Cardiac rehabilitation (CR) is a

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multidisciplinary treatment aiming at physical and psychosocial recovery after an acute coronary syndrome or cardiac intervention and prevention of future events.⁴ Exercise-based CR has been shown to reduce mortality, prevent hospital readmission and improve quality of life.^{3,5,6} Nonetheless, two persistent barriers limit the effectiveness of CR. First, participation in centre-based CR is low because a substantial number of patients do not participate or drop out at a later stage. This is partly due to health system barriers such as a lack of referral to CR.⁷ But there are also important practical barriers such as travelling time to the outpatient CR clinic and limited availability due to work resumption. In addition, personal barriers such as reluctance to participate in group-based therapy and individual training preferences that deviate from what is offered in centre-based CR can limit participation rates.^{8,9} Second, the long-term effectiveness of CR is low.¹⁰ Although it is well established that low physical activity levels (i.e. physical inactivity) are a major health risk,¹¹ health systems struggle to incorporate physical activity enhancement in (secondary) prevention and intervention programmes. Exercise-based CR is often aimed at short-term improvement of physical fitness rather than inducing long-term lifestyle changes. In fact, patients in centre-based CR are often not sufficiently prepared for independent exercise in the home environment. Therefore, the beneficial effects of CR tend to decrease after supervised training in the outpatient clinic has completed.^{10,12,13}

We hypothesised that if CR were tailored to the patients' preferences and CR programmes were aimed at preparing patients for independent exercise and physical activity, then uptake could be improved, drop-out rates reduced and beneficial effects of exercise-based CR sustained. Wearable sensor technologies and ubiquitous connectivity have introduced new possibilities of delivering physical fitness and physical activity interventions in the home environment at low cost.¹⁴ Previous studies have demonstrated that home-based CR is a safe alternative to centre-based CR and short-term effectiveness is similar.¹⁵ However, home-based CR has the potential to improve participation in CR programmes, especially for patients who are unable to participate in the conventional centre-based CR due to work resumption or other scheduling problems.^{8,16} In addition, exercise training in the home environment with remote support may aid patients in developing self management skills for improving and maintaining their physical fitness levels after completion of CR, thereby enhancing long-term effectiveness of CR.¹⁷ Previous studies showed beneficial effects of telerehabilitation interventions after completion of centre-based CR¹⁸ or in combination with centre-based CR.¹⁹ However, those interventions were an

addition to usual care, and therefore require additional costs. If a telerehabilitation intervention replaces usual care, then these beneficial effects may be achieved without additional costs. Unfortunately, data on cost-effectiveness of telerehabilitation interventions are scarce.¹⁵ Furthermore, when the intervention uses telemonitoring guidance to provide patients with the opportunity to develop self-management skills for maintaining an active lifestyle after CR, beneficial effects can be sustained over time.²⁰ If the telemonitoring guidance is focused on behavioural change using coaching strategies (i.e. motivational interviewing and cognitive behaviour therapy) and objective feedback, patients will be sufficiently prepared for independent exercise in the home environment.^{21,22}

To study the long-term effects and costs of home-based CR, we developed a home-based exercise training intervention with telemonitoring guidance for low-to-moderate cardiac risk patients entering CR. The telemonitoring guidance was aimed at improving exercise behaviour by providing feedback on exercise data using motivational interviewing principles. We addressed the following research questions:

- What is the effect of home-based exercise training with telemonitoring guidance compared to regular centre-based exercise training on physical fitness and physical activity levels in low-to-moderate cardiac risk patients entering CR?
- How does home-based exercise training compare to regular centre-based exercise training regarding training adherence, health-related quality of life, and psychological status?
- Finally, is it a cost-effective alternative compared to centre-based exercise training?

We hypothesised that the home-based CR intervention would result in improved physical activity levels and physical fitness compared to the centre-based CR, at one-year follow up.

Methods

Study design

We performed a prospective randomised controlled trial among cardiac patients entering CR at the Máxima Medical Centre. All subjects provided informed consent before enrolment in the study. The study protocol was approved by the Institutional Review Board of Máxima Medical Centre, and is registered at ClinicalTrials.gov with registration number NCT01732419. The study was conducted in accordance with the principles stated in the Declaration of Helsinki. The study protocol is described in detail elsewhere.²³

Population and randomisation

We included patients that entered CR at Máxima Medical Centre after an acute coronary syndrome (ACS; myocardial infarction or unstable angina) or a revascularisation procedure (percutaneous coronary intervention (PCI) or coronary artery bypass grafting (CABG)). Patients were eligible for participation when they were classified as low to moderate risk for further events by a cardiologist, based on the criteria described in the Dutch CR practice guideline.²⁴ In addition, patients were required to have Internet access and a personal computer (PC) at home. After baseline measurements patients were randomised to either centre-based training or home-based training groups. Allocation was performed with dedicated computer software and numbered and sealed opaque envelopes were used to conceal the allocation of patients. Exclusion criteria were: (a) ventricular arrhythmias or myocardial ischaemia during the maximal exercise test at baseline; (b) left ventricular ejection fraction below 45%; and (c) psychological, physical or cognitive impairments that prevented participation in exercise-based CR.

Intervention

In both groups, all treatment components of CR other than exercise training were performed in the outpatient clinic as usual. Exercise training was prescribed according to the current national and international guidelines.^{25,26} Both groups participated a training programme of 12 weeks with at least two training sessions a week. Session duration was 45–60 min and all sessions were based on continuous training with an intensity of 70–85% of the maximal heart rate (HR_{max}) assessed during the cardiopulmonary exercise test at baseline.

Patients in the centre-based group received group-based training in the outpatient clinic, supervised by two physical therapists specialised in CR. All patients received an individually tailored training programme on a cycle ergometer and treadmill. During the final sessions of the training programme, the physical therapist encouraged the participants to continue their physical activities in their home environment.

Patients in the home-based group received three supervised training sessions in the outpatient clinic, before they continued their training programme in their home environment. During these sessions, patients were familiarised with training duration and intensity and their preferred training modality was discussed with a physical therapist and exercise specialist. In addition, they were instructed how to use a heart rate monitor with a chest strap (Garmin FR70) and how to

upload recorded heart rate data to a web application (Garmin Connect) through the Internet. After the three training sessions, patients started their training programme in the home environment. The heart rate monitor was used to record the exercise data and to evaluate training duration and intensity during the training. The web application was used by the patient, the physical therapist and the exercise specialist to review the data. Once a week the patient received feedback on training frequency, duration and intensity via telephone by the physical therapist. Motivational interviewing principles were used to enhance patients' motivation and encourage the development of self-management skills. After 12 weeks, the feedback was terminated, but the patients were encouraged to continue their training programme with the heart rate monitor and web application.

Outcome measures

Primary outcome measures were physical fitness and physical activity levels. Secondary outcome measures were health related quality of life, psychosocial status, patient satisfaction, training adherence and cost-effectiveness.

Physical fitness was determined as peak oxygen consumption ($peakVO_2$) assessed during a maximal exercise test with respiratory gas analysis on a cycle ergometer (Lode Corral, Groningen). During the assessment a 12-lead electrocardiogram was monitored continuously. $PeakVO_2$ was defined as the average oxygen uptake during the final 30 s of the individualised ramp protocol. Ventilatory anaerobic threshold (VAT) was assessed using the V-slope method²⁷ by two independent physicians who were blinded for patient allocation. When the VAT of an exercise test deviated over 10% between the two physicians, a third physician was asked for an additional assessment of the VAT. An average of the two nearest values was selected.

Physical activity was determined as physical activity energy expenditure (PAEE) and physical activity level (PAL), estimated from data of a tri-axial accelerometer worn at the hip (ActiGraph wGT3X+ monitor) and heart rate monitor with chest strap (Garmin FR70) with a chest strap. Patients were instructed to wear both sensors continuously during daytime for a period of five subsequent days. Accelerometry (ACC) data was recorded with a sample frequency of 40 Hz and was time-aligned with the heart rate monitor (beats per minute). For analysis, ACC data was resampled into 20 Hz epochs and filtered using a band pass filter (0.5–3 Hz) and a median filter (window size 5) before counts per minute were calculated. In order to determine the PAL, physical activity energy expenditure was divided by resting metabolic rate, calculated by the

Harris-Benedict equation.²⁸ Physical activity energy expenditure was calculated from ACC, heart-rate data and patient characteristics using a multivariate regression model for beta-blocker medicated cardiac patients. To develop the model, the heart-rate and ACC data of 16 CR patients were measured during a resting metabolic rate assessment and activity protocol. Simultaneously, energy expenditure was measured using breath-by-breath pulmonary gas exchange measurement (Cosmed K4, b2 portable system). Results of the model development and validation are published elsewhere.²⁹ A physical activity assessment was considered successful when at least one day with at least eight hours of useful ACC and heart-rate data was recorded. When the physical activity assessment was considered successful, we used all useful heart-rate and ACC data available for the calculation of PAEE. We calculated PAL to allow comparing physical activity measurements for subjects with different body size and composition. PAL is an accepted parameter to express a person's daily energy expenditure. When PAL is used to classify the intensity of an activity, $PAL < 3$, $3 \leq PAL < 6$, and $PAL \geq 6$ are characterised as light, moderate, and vigorous intensity activities, respectively.³⁰ An average daily PAL of 1.2 represents the activity level of a bed-bound subject, while the average PAL for the adult population is 1.7.³¹

Health-related quality of life (HRQoL) was assessed using the 36-Item Short Form Survey (SF-36) and the MacNew questionnaire.^{32,33} Results of the SF-36 questionnaire were used to calculate the health utility scores for the cost-utility analyses. The total score and scores within three separate domains of the MacNew questionnaire were used to calculate the health-related quality of life (physical, emotional and social score). The MacNew score ranges from 1–7, where a high score indicates better quality of life. Patient satisfaction was measured directly after completion of CR (either home-based or centre-based) using the Consumer Quality index. The Consumer Quality index is a standardised patient survey method developed by the Dutch Center for Consumer Experience in Health Care, combining the inventory of patient experiences with an assessment of their priority.³⁴ Psychological status was assessed using the Hospital Anxiety and Depression Scale (HADS) and patient health questionnaire (PHQ).³⁵

Outcome measures were assessed at baseline, after CR and one year after the start of CR. SF-36 questionnaires were also sent three months after completion of CR (six months after inclusion).

Training adherence in the centre-based training group was determined as the number of attended training sessions at the outpatient clinic. Patients in the home-based group recorded their training sessions in the web application using the heart rate monitor.

These data were used to determine training adherence, training frequency, training intensity and time spent in the prescribed training zone. Other healthcare resource use, medication use and productivity losses from paid and unpaid work were recorded by means of a cost questionnaire at three, six and 12 months after inclusion. When the questionnaire was completed, but answers concerning hospital resource use or medication use were missing or unclear, validation was performed via the electronic patient record.

Cost analysis

Healthcare costs were obtained by multiplying health care resource use by the unit costs obtained from the Dutch manual for costing in economic evaluations³⁶ and converted to 2015 price levels with the general Dutch consumer price index.³⁷ Estimated costs of the CR intervention were based on adherence data. For the centre-based group, the total training duration (session frequency \times session duration) supervised by a physical therapist was divided by the average number of patients participating in group-based CR (four patients per physical therapist). This was multiplied by the hourly cost of a physical therapist (€66.08, which includes overhead). For the home-based group, costs for the supervised sessions were calculated similarly. Additional costs were incurred for the heart rate monitor (€75) and the additional time spent to introduce home-based training (30 min, €33), the preparation and conduction of the ten weekly telephone calls (5 min preparation and 9 min calling, €55 and €99 respectively). Medication costs were based on actual Dutch standard costs.³⁸ Costs of absenteeism were calculated with the friction cost method³⁹ using standard salary costs based on the age of the patient. Presenteeism costs, the costs for productivity loss due to health issues while at work, were calculated by weighing the number of working days impaired by the efficiency score on these days as indicated by the patients. Cost of unpaid labour were obtained by multiplying the number of hours carers and other people performed household tasks that would normally be performed by the patient with the hourly rate of unpaid labour (€14).³⁶

Sample size analysis

Sample size calculation was performed for primary outcome measure PAEE after one year, using data from Bonomi et al.⁴⁰ They found a PAEE in healthy subjects of 4.0 ± 1.2 MJ/day. If the difference in improvement in PAEE between the control group and intervention group in this study was 20%, 36 participants in both groups were required to test the null hypothesis that the

population means were equal (power = 0.8 and $\alpha = 0.05$). To account for a loss of 20% follow-up after one year, 45 patients were included in both groups.

Statistical analysis

We compared physical fitness, physical activity levels, HRQoL, and patient satisfaction between groups at discharge from CR and after one year using independent Student *t*-tests. The Shapiro-Wilk test was used to assess normality. Differences within groups over time were assessed with paired *t*-tests. Differences in baseline characteristics between participants and dropouts were compared using independent Student *t*-tests. We calculated effect sizes (Cohen's *d*) for the primary outcome measures. We imputed missing cost and effect data using the Multivariate Imputation by Chained Equations (MICE) algorithm with 20 iterations.⁴¹ The primary analysis was conducted on an intention-to-treat basis, while a sensitivity analysis compared primary outcomes between 'as treated' groups. Data are presented by mean \pm standard deviation (SD) unless stated otherwise, with a *p*-value < 0.05 considered as significant. Analyses were carried out using the statistical programming language R (version 3.0.3) and SPSS for Windows (version 22.0). For the analysis of sensor data we used the Lisa Compute Cluster (www.surfsara.nl) to parallelise computation. Specifically, we used the Portable Batch System (PBS) to submit a compute job requiring two Lisa compute nodes, each with 16 cores. We hence obtain a 32 \times speed-up in computation.

In the economic evaluation, the effects of both interventions were compared to their difference in costs. Although the cost data appeared skewed, differences in costs between groups were analysed using *t*-tests, as recommended by previous literature.⁴² A cost-utility analysis with quality-adjusted life-years (QALYs) as outcome measure was performed. The QALYs were estimated based on the health utility scores at 0, 3, 6 and 12 months, by applying the area-under-the-curve method. The evaluation was performed from a societal perspective, making a distinction between healthcare and non-healthcare costs (absenteeism from paid and unpaid work). In a sensitivity analysis presenteeism was also included in the societal perspective. Non-parametric bootstrapping was used, involving 1000 replications, to calculate uncertainty around the costs and effects estimates. Based on these results a cost-effectiveness acceptability curve was constructed by plotting the proportion of costs and effects pairs for which home-based CR is cost-effective compared to centre-based CR, for a range of values of the willingness to pay for a QALY (λ).

Results

Between March 2013–December 2014 we included 90 CR patients (10 female/80 male, mean age 59.2 ± 8.5 years), of which 78 completed the study. Patients received PCI (*n* = 44), CABG (*n* = 22) or medication only (*n* = 12) during the hospital admission before entering CR. One patient randomised to centre-based CR was erroneously allocated to the home-based group and one patient randomised to home-based CR was allocated to the centre-based group by the clinical staff. Baseline characteristics are provided in Table 1. A total of 12 patients were lost to follow-up (home-based group: *n* = 8; centre-based group: *n* = 4). Reasons for loss to follow-up were withdrawal from the study (*n* = 8), comorbidities (*n* = 3) and death (*n* = 1). While their demographic characteristics were similar (one female/11 male, mean age 58.9 ± 10.7), the patients that were lost to follow-up had significantly lower physical fitness at baseline compared to those who completed the intervention ($-3.75 \text{ O}_2 \text{ ml}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$, *p* = 0.02). Figure 1 provides a flowchart of the randomisation and follow-up during the study. During the one-year study period, eight centre-based patients (three PCI, two angina pectoris, three coronary angiography) and two home-based patients (one PCI, one CABG) were hospitalised for cardiac reasons.

Table 1. Patient characteristics at baseline.

	Centre-based CR <i>n</i> = 45	Home-based CR <i>n</i> = 45
Male/female (<i>n</i>)	40/5	40/5
Age (years)	57.7 ± 8.7	60.5 ± 8.8
Length (cm)	178.5 ± 8.1	176.7 ± 7.5
BMI	28.2 ± 3.9	27.8 ± 4.8
Diagnosis		
ACS with PCI, <i>n</i> (%)	19 (42%)	24 (53%)
ACS without PCI, <i>n</i> (%)	5 (11%)	5 (11%)
AP with PCI, <i>n</i> (%)	4 (10%)	3 (7%)
AP without PCI, <i>n</i> (%)	0 (0%)	4 (10%)
CABG, <i>n</i> (%)	17 (38%)	9 (20%)
Medication		
Beta-blocker, <i>n</i> (%)	42 (93%)	40 (89%)
Statins, <i>n</i> (%)	45 (100%)	44 (98%)
Anti-platelets, <i>n</i> (%)	44 (98%)	45 (100%)
ACE-i/ARB, <i>n</i> (%)	37 (82%)	29 (64%)

ACE-i: angiotensin converting enzyme inhibitor; ACS: acute coronary syndrome; AP: angina pectoris; ARB: angiotensin receptor blocker; BMI: body mass index; CABG: coronary artery bypass graft; CR: cardiac rehabilitation; PCI: percutaneous coronary intervention.

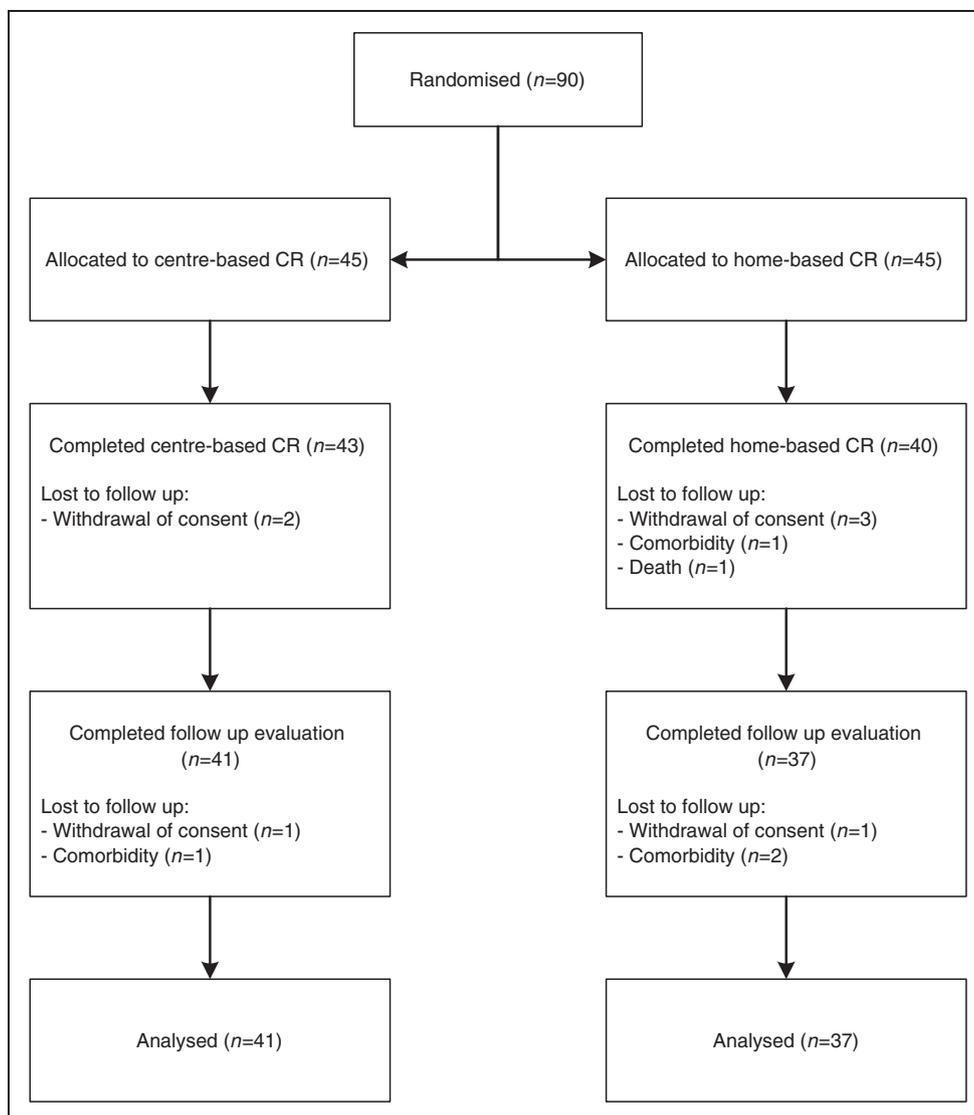


Figure 1. Flow diagram of the study.
CR: cardiac rehabilitation.

Adherence

Patients in the centre-based group attended 20.6 ± 4.3 training sessions (86% of the expected 24 sessions, ranging from 6–25) during CR at the outpatient clinic. The duration of supervised centre-based training sessions was 60 min, and included a warming-up and cooling-down. Training intensity was prescribed at 70–85% of HR_{max} , and heart rate was measured occasionally to contain the prescribed training intensity. After the three introductory sessions in the hospital, patients in the home-based group performed 22.0 ± 6.8 sessions at home in the first 12 weeks (ranging from 13–41). Session duration, including warming up and cooling down, in the home-based group was 64.0 ± 21.1 min, of which 43.0 ± 14.8 min was in the prescribed training

zone of 70–85% of HR_{max} . Average training intensity was $74.0 \pm 3.6\%$ of HR_{max} . Heart-rate data of one person could not be used due to incorrect values of the heart-rate monitor caused by premature ventricular contractions. No serious adverse events were recorded during centre-based and home-based training. Patients in the home-based group were more satisfied with their CR programme compared to patients in the centre-based group (home-based: 8.7/10, centre-based: 8.1/10, $p = 0.02$).

Physical fitness

Patients in both groups improved their peak VO_2 from baseline to discharge from CR (centre-based +11% $p < 0.01$, home-based +15% $p < 0.01$) without significant between-group differences ($p = 0.25$). After one

year, there was a significant improvement from baseline in peakVO₂ in both groups without between-group difference (centre-based +16%, $p < 0.01$, home-based +17%, $p < 0.01$, between groups $p = 0.89$). The effect sizes showed a large treatment effect in the home-based group after discharge and one-year follow-up ($d = 0.87$ and $d = 0.86$ respectively) and a moderate effect in the centre-based group ($d = 0.68$ and $d = 0.75$ respectively). Similarly, both groups improved VO₂ uptake at VAT, maximum workload and workload per kg after discharge from CR and maintained those values at follow-up, similar to peakVO₂ (Table 2).

Physical activity

Out of the 249 scheduled physical activity assessments, 190 assessments (76%) were completed. A total of 135 assessments (71%) were identified as successful (i.e. at least one day of at least eight hours of useful heart-rate and ACC data). Assessments were mostly unsuccessful because of insufficient useful heart-rate data (38/55). The average duration of successfully recorded data was 35.3 ± 17.5 h per patient, divided over 3.3 ± 1.4 days. Although patients in the centre-based group improved their PAL at discharge from CR ($p = 0.05$), PAEE was similar at discharge ($p = 0.11$). At one-year follow-up both PAL and PAEE were similar to baseline ($p = 0.20$ and $p = 0.38$ respectively). Effect sizes showed a small treatment effect after discharge and one-year follow-up (PAL $d = 0.31$ and $d = 0.13$ respectively, PAEE $d = 0.24$ and $d = 0.19$ respectively). Patients in the home-based group did not improve their PAL or PAEE at discharge from CR ($p = 0.71$ and $p = 0.50$) or at follow-up ($p = 0.34$ and $p = 0.80$, Table 2). Effect sizes show a small to no treatment effect after discharge and one-year follow-up (PAL $d = 0.10$ and $d = 0.04$ respectively, PAEE $d = 0.06$ and $d = 0.15$ respectively). Both at discharge from CR and at follow-up there were no between-group differences (PAL: $p = 0.31$, $p = 0.65$, PAEE: $p = 0.39$ and $p = 0.85$). In a sensitivity analysis with a different threshold (at least three days of at least eight hours of useful heart-rate and ACC data) less data was available (131 successful assessments), but the results were similar to the main analysis.

A sensitivity analysis that compared physical fitness and physical activity levels between 'as treated' groups, showed no significant change in PAL after the three-month rehabilitation period among patients in the centre-based group ($p = 0.51$). All other results were similar to the intention-to-treat analysis.

Health-related quality of life and psychological status

Although HRQoL in the centre-based group improved after the three-month rehabilitation period ($p < 0.01$),

HRQoL was similar to baseline at one-year follow-up ($p = 0.94$). HRQoL in the home-based group was unchanged at discharge from CR ($p = 0.07$) and at follow-up ($p = 0.56$). There were no significant between-group differences at discharge and at follow-up ($p = 0.79$ and $p = 0.61$, respectively). HRQoL improved on the physical and social subscales at discharge and follow-up in both groups. The emotional subscore decreased at follow-up in both groups. There were no between-group differences on either of the subscales (Table 2). Anxiety scores decreased at follow-up in both groups (centre-based $p < 0.05$, home-based $p = 0.01$) without differences between groups ($p = 0.73$). Depression scores were similar between baseline and follow-up in both groups, without differences between groups ($p < 0.01$).

Cost-effectiveness analysis

The QALYs calculated for the centre-based group (0.78 ± 0.08) were similar to the QALYs for the home-based group (0.77 ± 0.13 , $p = 0.73$). The mean costs for the CR programme was similar between groups (Table 3), €336 per patient in the centre-based group and €314 per patient in the home-based group. The total healthcare costs per patient were €437 lower for the home-based group (95% confidence interval (CI) -562 to 1436). However, this difference was not significant. Costs for visits to the GP (mean difference €33, 95% CI 0 to 66, $p < 0.05$) and visits to the specialist (mean difference €158, 95% CI 1 to 315, $p < 0.05$) were lower for patients in the home-based group.

The average non-healthcare costs per patient, consisting of absenteeism from paid and unpaid work, were €2723 lower for patients in the home-based group (95% CI -699 to 6145, $p = 0.12$). This difference was mainly caused by the costs for absenteeism from paid work, which was €2691 per patient lower in the home-based group (95% CI -676 to 6059, $p = 0.12$). From a societal perspective (i.e. the sum of healthcare and non-healthcare costs), costs per patient were €3160 lower for patients in the home-based group (95% CI -460 to 6780, $p = 0.09$). Costs for presenteeism were €2926 per patient lower in the home-based group (95% CI -1072 to 6924, $p = 0.15$). Including these costs in the total costs from a societal perspective leads to a difference of €6084 in favour of the home-based group (95% CI -76 to 3259, $p = 0.07$).

Although there were no significant differences in societal costs between groups, almost all components were lower in the home-based group. Furthermore, the non-significant differences in QALYs in favour of the centre-based group were small (Figure 2). This resulted in a higher probability of cost-effectiveness for home-based training than centre-based training from a

Table 2. Main outcome measures at baseline, discharge and follow-up after home-based and centre-based cardiac rehabilitation (CR).

	Centre-based CR			Home-based CR			Between groups p-value	
	Baseline	Discharge CR	Follow-up	Baseline	Discharge CR	Follow-up	0–12 weeks	0–52 weeks
Physical fitness								
Peak VO ₂ (ml min ⁻¹ kg ⁻¹)	24.0 ± 5.6	26.5 ± 7.1 ^c	27.5 ± 8.1 ^c	24.4 ± 6.7	27.9 ± 7.5 ^c	27.7 ± 6.9 ^c	0.308	0.865
Peak VO ₂ (ml min ⁻¹)	2115.8 ± 477.5	2336.5 ± 598.4 ^c	2441.1 ± 643.6 ^c	2072.8 ± 616.9	2324.6 ± 641.8 ^c	2380.0 ± 606.3 ^c	0.640	0.826
VAT at VO ₂ (ml min ⁻¹)	1293.4 ± 250.3	1459.1 ± 328.5 ^c	1454.6 ± 303.0 ^c	1244.5 ± 317.4	1432.1 ± 442.4 ^c	1380.2 ± 304.1 ^c	0.173	0.619
Peak workload (Watt)	183.4 ± 47.6	203.7 ± 61.8 ^c	208.9 ± 61.8 ^c	178.9 ± 52.4	200.9 ± 52.5 ^c	202.1 ± 54.3 ^c	0.747	0.719
Workload/kg	2.08 ± 0.57	2.31 ± 0.68 ^c	2.38 ± 0.75 ^c	2.03 ± 0.58	2.33 ± 0.61 ^c	2.34 ± 0.62 ^c	0.305	0.938
HR _{max} (beats min ⁻¹)	142.6 ± 16.7	146.7 ± 22.4	149.6 ± 23.8 ^b	140.4 ± 17.6	142.2 ± 15.5	141.4 ± 16.5	0.428	0.069
RER	1.24 ± 0.11	1.20 ± 0.13	1.17 ± 0.15 ^b	1.24 ± 0.11	1.21 ± 0.15	1.17 ± 0.18 ^b	0.891	0.816
BMI	28.0 ± 3.6	28.0 ± 3.8	28.1 ± 4.0	28.4 ± 5.1	27.8 ± 4.7	27.9 ± 4.2 ^a	0.093	0.275
Physical activity								
PAEE	2.37 ± 0.83	2.76 ± 1.16	2.63 ± 1.02	2.26 ± 1.03	2.39 ± 1.07	2.49 ± 1.16	0.386	0.846
PAL	1.95 ± 0.86	2.38 ± 1.02 ^a	2.13 ± 1.00	2.09 ± 0.92	2.22 ± 0.99	2.14 ± 1.06	0.311	0.650
Questionnaires								
HRQoL total	5.45 ± 0.14	5.90 ± 0.13 ^b	5.43 ± 0.12	5.62 ± 0.20	6.00 ± 0.13 ^b	5.75 ± 0.10	0.792	0.609
HRQoL physical	5.25 ± 0.14	5.85 ± 0.15 ^b	5.72 ± 0.18 ^b	5.38 ± 0.22	5.93 ± 0.15 ^b	6.20 ± 0.14 ^c	0.866	0.271
HRQoL social	5.67 ± 0.15	6.33 ± 0.10 ^c	6.16 ± 0.15 ^b	6.03 ± 0.21	6.36 ± 0.12	6.50 ± 0.11 ^b	0.237	0.928
HRQoL emotional	5.50 ± 0.15	5.72 ± 0.14	4.75 ± 0.13 ^b	6.20 ± 0.14	5.85 ± 0.16	5.07 ± 0.10 ^c	0.498	0.929
HADS anxiety	3.98 ± 3.36	3.20 ± 2.80	2.85 ± 2.62	3.70 ± 3.09	3.10 ± 2.39	2.31 ± 1.90 ^b	0.776	0.728
HADS depression	2.01 ± 2.33	2.33 ± 2.52	3.80 ± 2.90 ^c	2.23 ± 2.80	2.14 ± 2.61	3.24 ± 2.35	0.525	0.256
PHQ	3.09 ± 3.07	2.89 ± 2.99	3.33 ± 4.06	3.16 ± 3.73	2.21 ± 3.00	2.18 ± 2.79	0.314	0.139

BMI: body mass index; HADS: Hospital Anxiety and Depression Scale; HR_{max}: maximum heart rate; HRQoL: health-related quality of life; PAEE: physical activity energy expenditure; PAL: physical activity level; PHQ: patient health questionnaire; RER: respiratory exchange ratio; VAT: ventilatory anaerobic threshold; VO₂: oxygen consumption.

Values are presented as mean ± standard deviation.

^aSignificant difference compared with baseline, $p < 0.05$; ^bsignificant difference compared with baseline, $p < 0.01$; ^csignificant difference compared with baseline, $p < 0.001$.

Table 3. Average healthcare and non-healthcare costs per patient for home-based or centre-based cardiac rehabilitation (CR) (in €, price level 2015).

Healthcare costs	Centre-based CR (n = 45)		Home-based CR (n = 45)		Mean difference	
	Volume, ^a %	Costs, €	Volume, ^a %	Costs, €	Costs, €	p-Value
Healthcare visits						
General practitioner	78.3	114 ± 93	81.8	80 ± 64	33	0.048
Specialist	95.5	537 ± 449	93.9	379 ± 295	158	0.048
Physical Therapist	43.5	250 ± 387	51.5	304 ± 464	-54	0.548
Psychologist	30.4	110 ± 266	21.2	61 ± 123	49	0.259
Dietician	21.7	23 ± 34	33.3	31 ± 51	-8	0.397
CR nurse	39.1	22 ± 36	27.3	19 ± 32	3	0.633
Other	13.0	31 ± 139	6.1	9 ± 28	22	0.297
Healthcare admission						
A&E department	17.4	37 ± 64	23.5	49 ± 87	-12	0.452
Hospital admission	8.7	682 ± 2300	24.2	503 ± 1245	179	0.645
Day treatment	13.0	69 ± 164	14.7	47 ± 112	22	0.455
Other						
Medication		645 ± 411		624 ± 441	21	0.817
CR programme costs		336 ± 68		314 ± 68	22	0.128
Total healthcare costs		2855 ± 2797		2419 ± 1968	437	0.392
Non-healthcare costs						
Paid absenteeism	35.0	5980 ± 7823	27.3	3289 ± 8467	2691	0.117
Unpaid absenteeism	31.8	589 ± 869	16.1	557 ± 1314	32	0.893
Presenteeism	52.6	8433 ± 10689	23.5	5507 ± 8601	2926	0.152
Total non-healthcare costs^b		6569 ± 8170		3846 ± 8400	2723	0.119
Total non-healthcare costs with presenteeism		15002 ± 16120		9353 ± 15114	5649	0.121
Total societal costs^b		9425 ± 8714		6265 ± 8813	3160	0.087
Total societal costs with presenteeism		17858 ± 16510		11772 ± 15349	6085	0.070

A&E: accident and emergency department.

Costs are presented in € (price index of 2015) as mean ± standard deviation.

^aVolumes are percentages of patients who incurred costs for that item.

^bcosts are presented without presenteeism.

societal perspective (Figure 3), varying between 97% (willingness-to-pay of €0 per QALY) and 75% (willingness-to-pay of €100,000 per QALY). When presenteeism is included in the societal costs, this probability then varied between 95–90%. From a healthcare perspective, the probability that home-based training was more cost-effective than centre-based training varied between 80–40% for the same willingness-to-pay levels.

For the accepted willingness-to-pay per QALY in The Netherlands (€20,000–€40,000),⁴³ we can conclude that home-based training appears to be more cost-effective than centre-based training.

Discussion

We found no significant differences in physical fitness between home-based exercise training with

telemonitoring guidance and centre-based exercise training in patients with low-to-moderate cardiac risk entering CR. Also, we were unable to detect a change in physical activity levels at one-year follow-up in both groups. Whereas HRQoL and psychological status were similar in both groups, patient satisfaction was higher in the home-based group. Our cost-effectiveness analysis showed that home-based training with wearable sensors is likely to be more cost-effective than centre-based training in cardiac rehabilitation patients.

Our short-term results are in line with the conclusions of the systematic review by Taylor et al., who demonstrated that home-based and centre-based CR are equally effective in improving short-term physical fitness.¹⁵ Long-term effectiveness of home-based CR is less well established and seems to be related to the content of the intervention. We demonstrated that with

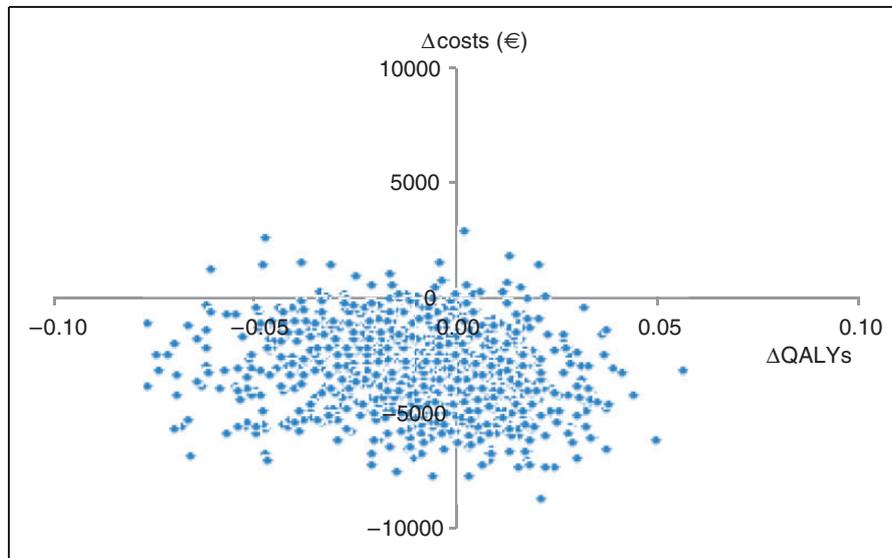


Figure 2. Overview of incremental costs and effects (quality-adjusted life-years (QALYs)) of home-based cardiac rehabilitation (CR) compared with centre-based CR.

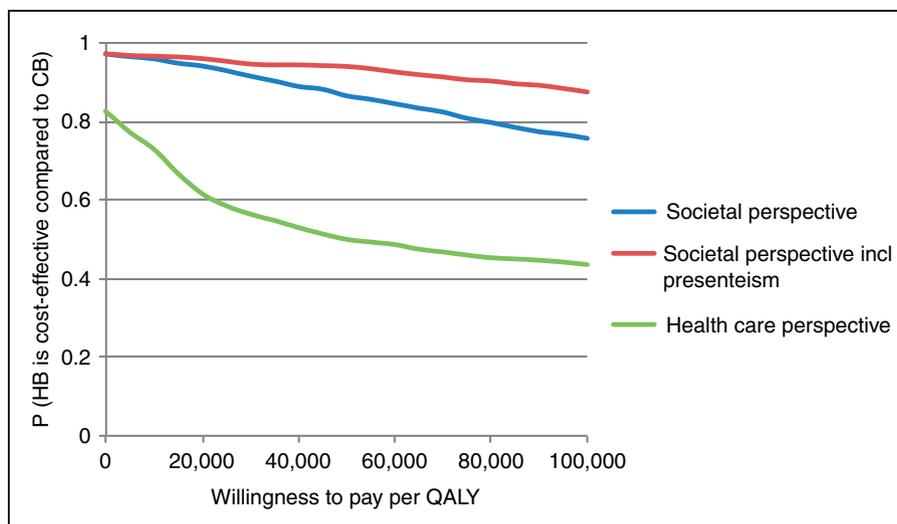


Figure 3. Cost-effectiveness acceptability curves for home-based (HB) cardiac rehabilitation (CR) compared with centre-based (CB) CR. QALY: quality-adjusted life-year.

motivational coaching strategies and objective feedback on training data, patients in the home-based group are able to maintain their physical fitness levels at one year. This is consistent with the findings of Aamot et al., who employed a similar monitoring strategy during the study.⁴⁴ Interestingly, patients in our centre-based group were able to maintain their physical fitness levels as well, in contrast to prior centre-based CR studies.^{44,45} This may be attributed to the fact that due to the nature of our intervention, with its focus on technology and individual training, mainly young and motivated patients participated in our study. These patients,

randomised to either home-based or centre-based CR, were able to maintain their physical fitness levels independently. Therefore, based on this study we cannot conclude that home-based CR leads to superior long-term physical fitness. However, our data showed that for this patient population, home-based CR is effective to improve and maintain physical fitness levels similar to those in centre-based CR. Moreover, home-based CR was associated with high patient satisfaction levels and low costs for absenteeism from work. Therefore, we postulate that implementation of home-based CR can increase uptake, especially among

younger cardiac patients with the ambition to return to work as soon as possible.

Physical inactivity is associated with most chronic diseases,¹¹ but CR is often focused on improvement of physical fitness rather than increasing physical activity levels and preventing physical inactivity. Although we monitored physical activity levels before and after CR, the telemonitoring guidance was mainly focused on physical fitness improvement. As a result, neither the centre-based nor the home-based training influenced the physical activity levels. These results are in line with previous studies that showed that exercise interventions focused on physical fitness improvement in cardiac patients did not result in an improvement in physical activity.^{46–48} Yet, other studies that combined an exercise intervention with a physical activity intervention during CR, did improve physical activity levels.^{19,49} This implies that an improvement in physical fitness is not necessarily associated with an improvement in physical activity levels. Therefore, we recommend that exercise interventions are complemented with physical activity coaching, to influence daily activity behaviour. Ideally, physical activity coaching is based on objective and accurate data to maximise effectiveness,⁵⁰ and remains available after the completion of CR. On-demand coaching can identify a relapse into an inactive lifestyle, which is often observed after completion of CR. In this way, coaching is available when it is needed the most. Currently, physical activity in CR studies is often assessed by questionnaires or accelerometers.⁵¹ With the development of wearable technology, a more reliable and accurate assessment of physical activity levels is available.^{14,52} The methodology used in this study, combining heart rate with accelerometer data to estimate physical activity energy expenditure, can be considered as a first step towards accurate physical activity monitoring using wearable sensors in cardiac rehabilitation patients.

Although cost-effectiveness of an innovative intervention is essential for wide scale implementation, cost-effectiveness analyses on home-based CR programmes are scarce. Taylor et al. described four randomised controlled trials and concluded that although the costs included in the analyses varied between studies, the costs between home-based and centre-based CR appeared to be similar.¹⁵ In two further studies Frederix et al. indicated that a comprehensive telerehabilitation programme was more cost-effective than regular CR,⁵³ while Kidholm et al. showed that a cardiac telerehabilitation programme was not more cost-effective compared to regular centre-based CR.⁵⁴ However, the latter two studies provided additional telerehabilitation services after conventional CR, resulting in additional healthcare costs, which hampers the likelihood of implementation. Our results indicate that a

telerehabilitation programme with equal duration to a regular CR programme could be a cost-effective alternative without increasing costs associated with the CR intervention. In our study, the average medical costs per patient were in favour of home-based CR. In addition, from a societal perspective the average costs per patient were €3160 higher for patients in centre-based CR. However, this difference was not significant. This difference was mainly caused by absenteeism from paid work between groups. Whereas patients in the home-based group were able to schedule their training sessions in their own time, patients in the centre-based group were obliged to visit the outpatient clinic during office hours, twice a week.

Limitations

A first limitation of our study was the lack of blinding for the physician for patient allocation during the assessments of physical fitness at discharge and follow-up. Therefore, knowledge of group allocation could have affected the assessments. However, data from the maximal exercise tests (i.e. maximum heart rate and respiratory exchange ratio) showed that exhaustion was similar between groups. Second, although physical activity levels were assessed accurately by combining a heart rate monitor with an accelerometer, several patients experienced discomfort while wearing the chest-strap of the heart rate monitor for five consecutive days. Consequently, some patients terminated the physical activity assessment prematurely, resulting in a lower reliability of data. We expect that with the development of wrist-based heart-rate monitors, future studies can avoid this limitation. Third, the home-based intervention required patients to have basic PC and Internet skills to install and use the software platform. Nonetheless, some patients experienced problems with installing the software platform and uploading exercise data on the platform. This could have hindered the use of the software platform, therefore limiting the effectiveness of the telemonitoring guidance. Fourth, training intensity during supervised training sessions in the outpatient clinic was only measured at set intervals to ensure the prescribed intensity range. Therefore, no continuous heart rate data was available, and no comparison of training volume between groups was possible.

As mentioned in the discussion, the patients included in our study were not representative of the general CR population. Due to our selection process, we included mainly young and motivated patients that preferred to participate in home-based training. This can explain why the centre-based group were able to maintain their long-term physical fitness levels, even when they started with centre-based training and had to make the

transition to the home environment without guidance. In addition, many patients expressed their preference for home-based training and were subsequently disappointed when randomised to the centre-based group. This was supported by the lower patient satisfaction score in the centre-based group. Furthermore, the external validity of the results are limited because patients with a strong preference for one trial arm were possibly not participating due to the risk of being randomised in the non-preferred trial-arm. If preference-based trial-arms are included in a study design, a more mixed cardiac rehabilitation population can be obtained. However, this study design has substantial consequences on the sample size and costs of the study. Similarly, a blended study design can prevent demoralisation after randomisation in the non-preferred trial-arm. In this design, patients that prefer home-based training can switch from supervised centre-based training to home-based training with telemonitoring guidance when it is considered safe by the physicians. Subsequently, effectiveness can be compared between patients that complete centre-based training and patients that switched to home-based training during CR.

Conclusion

This study shows comparable results for home-based CR and centre-based CR with respect to improving physical fitness and health-related quality of life. Furthermore, exercise adherence of patients in the home-based CR was high and patient-satisfaction was significantly higher than patients in the centre-based group. Home-based CR has the potential to increase overall participation in exercise-based CR, especially for cardiac patients with the ambition to return to work quickly or with transportation difficulties. In addition, home-based CR appears to have lower societal costs and to be more cost-effective than centre-based CR. Therefore, we conclude that home-based training with telemonitoring guidance is a useful alternative to conventional centre-based training for young and motivated low-to-moderate cardiac risk patients entering CR.

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Author contribution

JK, EA, HK and NP contributed to the conception and design of the work. JK, HK, NP, EA, WS and AA

contributed to the acquisition, analysis, or interpretation of data for the work. JK, EA, HK and NP drafted the manuscript. All authors critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of work ensuring integrity and accuracy.

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