Cardio-Oncology

RESEARCH

Open Access

Effects of home-based exercise with telehealth guidance in lymphoma cancer survivors entering cardio-oncology rehabilitation: rationale and design of the tele@home study

Katerina Chamradova[1,2], Ladislav Batalik[1,3*], Petr Winnige[1,3], Filip Dosbaba[1,3], Martin Hartman[1,2], Katerina Batalikova[1], Andrea Janikova[4], Svatopluk Nehyba[5], Marian Felsoci[5], Garyfallia Pepera[6] and Jing Jing Su[7*]

Abstract

Background Participation in cardio-oncological rehabilitation is low, and the effects incline to decrease after the initial rehabilitation term. Home-based exercise has the potential to enhance involvement in cardio-oncology rehabilitation and was demonstrated to be feasible, safe, and helpful in increasing short-term cardiorespiratory fitness. The lasting effects on cardiorespiratory fitness and physical activity are uncertain. Hence, a novel approach via telehealth management based on objectively measured exercise at home was proposed.

Objectives To improve self-monitoring, such as self-confidence, behavioral change, and goal setting for individual exercise, and afterward, increase long-term effects concerning cardiorespiratory fitness.

Design This randomized controlled trial compares a 12-week guided home exercise telehealth intervention with a center-based exercise intervention of the same duration and intensity of exercise in lymphoma cancer survivors entering cardio-oncology rehabilitation after treatment. Participants will be instructed to exercise gradually at 60–85% of their maximum heart rate for 30–50 min 3 times a week. Participants will receive individual remote guidance (feedback about frequency, duration, and exercise intensity) by preferred contact (phone call, text message) once a week based on shared exercise data through the web platform. The primary outcome is a change in cardiorespiratory fitness expressed as maximal oxygen uptake assessed through cardiopulmonary exercise test at baseline, 12 weeks, and 1 year. Secondary objectives are quality of life, muscle strength, body composition, incidence of adverse events, and exercise adherence.

Summary This study will determine whether a telehealth model is effective and safe compared to a center-based model in cancer survivors and whether exercise prescriptions are followed by participants. Additionally, an overview

*Correspondence:
Ladislav Batalik
batalik.ladislav@fnbrno.cz
Jing Jing Su
jjsu@twc.edu.hk
Full list of author information is available at the end of the article

of the long-term effectiveness of telehealth cardio-oncology rehabilitation will be provided. This approach aligns with the trend of moving non-complex healthcare services into the patients' home environment.

Trial registration ClinicalTrials.Gov Identifier: NCT05779605

Keywords Cardio-oncology rehabilitation, Home-based exercise, Cancer survivors, Telehealth, Telemonitoring

Introduction

Cancer survivorship and supportive care are critical areas of focus, given the significant morbidity, mortality, and harsh treatment regimens associated with the disease [1]. The International Agency for Research on Cancer projected a substantial increase in global cancer cases and deaths by 2020, underscoring the urgent need for sustainable approaches to cancer management and prevention [2]. While advancements in treatment have led to improved survival rates, many cancer survivors grapple with long-term physical and mental health challenges arising from treatment side effects [3–5].

Exercise interventions have become pivotal in cancer treatment and supportive care [6]. Previous systematic reviews have demonstrated the benefits of center-based exercise (CBE) interventions, including enhanced physical and psychosocial well-being [7]. However, various barriers, such as logistical challenges and limited access to specialized rehabilitation services, hinder the implementation of CBE programs [8].

Lymphoma, a cancer originating in the lymphatic system, significantly impacts cardiovascular health, necessitating the integration of exercise programs into patient care. Treatments like chemotherapy and radiotherapy, especially those involving anthracyclines, often lead to cardiotoxic effects, including heart failure and arrhythmias. Chest radiation can cause coronary artery disease and valvular heart damage [9, 10]. Additionally, the chronic inflammation associated with lymphoma exacerbates atherosclerosis, further increasing cardiovascular risk [11]. Patients frequently have comorbid conditions such as hypertension and diabetes, heightening cardiovascular vulnerability [12]. Regular exercise has been shown to mitigate these risks by improving cardiovascular fitness, reducing inflammation, and managing comorbid conditions. Therefore, integrating structured exercise programs is crucial for improving cardiovascular outcomes and overall quality of life in lymphoma patients [6, 7].

Home-based exercise (HBE) programs present a promising alternative [13, 14], particularly regarding accessibility barriers exacerbated by the COVID-19 pandemic [15]. Telemedicine-enabled HBE has been proposed as a feasible, safe, and cost-effective approach to optimizing supportive cancer care [16, 17]. Preliminary studies have shown promising results, indicating improvements in cardiorespiratory fitness and health-related quality of life (HRQL) among cancer survivors participating in telemedicine-based exercise programs [18, 19].

HBE has gained considerable attention due to its potential to provide flexible and accessible options for physical activity, particularly for individuals facing barriers to attending supervised exercise sessions [20]. Several studies have demonstrated that HBE, when combined with proper monitoring and support, can yield outcomes comparable to supervised exercise in terms of improving cardiorespiratory fitness, muscle strength, and overall quality of life [21]. For instance, a systematic review by Buffart et al. [22] concluded that home-based interventions are effective in enhancing the physical and psychosocial well-being of cancer survivors, comparable to center-based programs. These findings suggest that HBE can be a viable alternative to traditional supervised exercise, offering similar health benefits while accommodating the practical needs of participants.Despite these encouraging findings, the long-term efficacy of telemedicine-enabled HBE remains uncertain, warranting further investigation through rigorously designed randomized controlled trials [23]. The Tele@home study aims to fill this gap by comparing the effectiveness of HBE with remote guidance and telemonitoring to traditional CBE in improving long-term cardiorespiratory fitness among cancer survivors [24]. Additionally, the study will assess training adherence, HRQL, adverse effects, and body composition between the two exercise interventions. Monitoring training adherence is crucial for evaluating intervention feasibility and effectiveness, while assessing HRQL provides insight into the broader impact of the interventions on participants' well-being. Evaluating adverse effects is essential for ensuring participant safety and optimizing intervention protocols, while measuring body composition allows for a comprehensive assessment of physical health and potential changes resulting from the interventions [25–27].

We hypothesize that HBE with remote guidance and telemonitoring will enhance long-term motivation and effectiveness in independent exercise among cancer survivors, leading to superior cardiorespiratory fitness outcomes. Furthermore, we anticipate that the cost of

telemonitoring and information and communication technology services will be offset by reduced expenses associated with preventative care due to fewer supervised CBE sessions required.

Methods

Study design

The Tele@home study is structured as a single-center, single-blind, parallel-group randomized controlled trial, conducted at the University Hospital Brno in the Czech Republic. Prior to participation, all individuals will be required to provide written informed consent. Data will be gathered at three distinct time points: baseline (T0), 3 months post-baseline (T1), and 12 months post-baseline (T2) (see Fig. 1). The study protocol has received approval from the Institutional Ethics Committee of the University Hospital Brno, Czech Republic. Additionally, in accordance with WHO recommendations, the trial has been registered in the clinical trial registry (ClinicalTrials.gov Identifier: NCT05779605) [28].

Study population

The study will include participants aged 18 and above who have been diagnosed with hemato-oncological malignancy/lymphoma and have completed systemic chemotherapy-based treatment, transitioning to outpatient cancer rehabilitation (see Fig. 1). Additional criteria for inclusion are a clinically stable state (remission), the ability to undergo physical training and cardiopulmonary exercise testing, proficiency in the Czech language, and providing signed informed consent. Access to internet facilities and a personal computer at home are also required.

Exclusion criteria will be determined based on participants' health status as assessed through electronic medical records screening, excluding those with acute heart disease or decompensation within the previous 6 weeks, severe psychological or cognitive disorders. Additionally, individuals with significant musculoskeletal issues that limit their ability to undergo cardiopulmonary exercise testing or self-reported participation in physical activity meeting recommended levels (150 min per week) or current involvement in another supervised exercise program will be excluded [29].

Recruitment & randomization

Participants will be randomly assigned in a 1:1 ratio to either the home-based telehealth exercise (HBE)

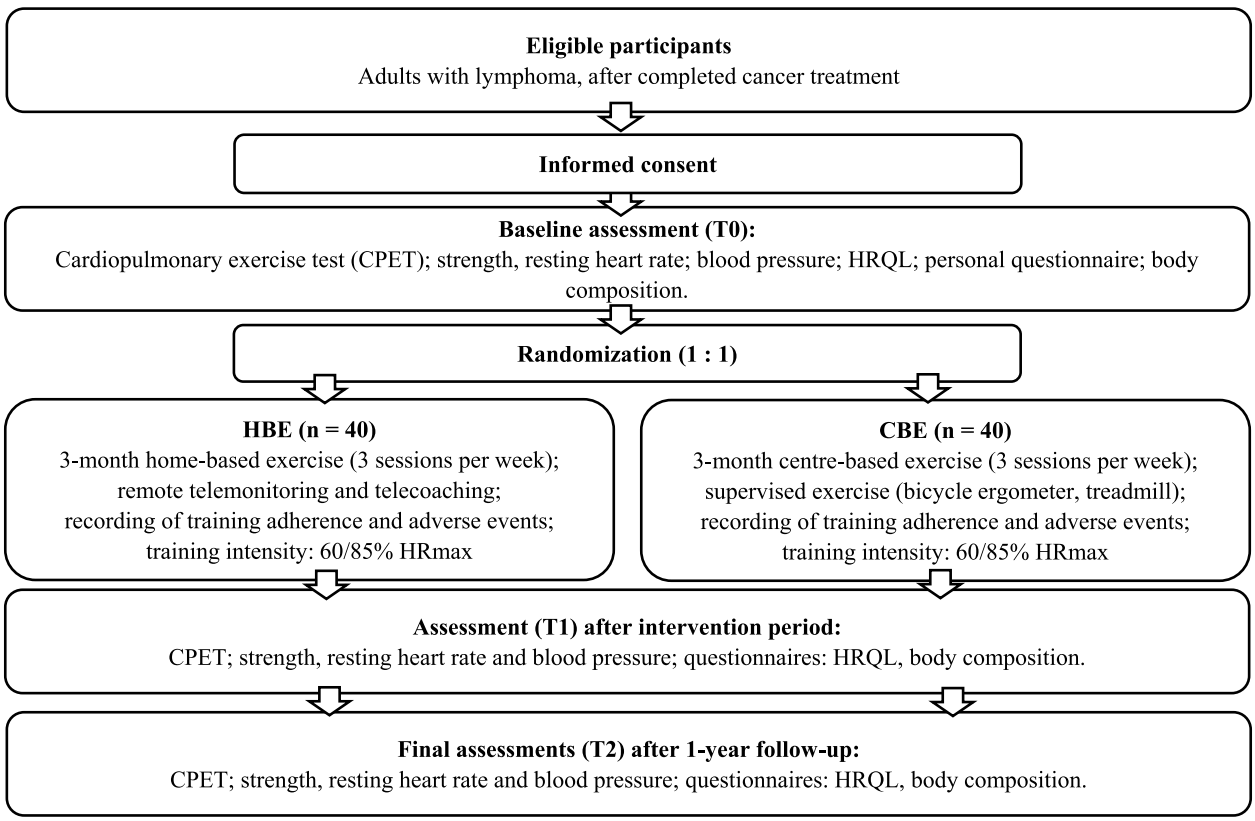

Fig. 1 The study flow chart

experimental group or the center-based exercise (CBE) control group using a computer-generated sequence with variable blocking sizes (2/4). Treatment allocation will remain concealed until completion of baseline examinations, with allocation revealed through sequentially numbered, sealed, opaque envelopes. While participants cannot be blinded to treatment allocation, researchers conducting examinations during follow-up periods (T1, T2) will be blinded to treatment assignment.

Intervention

The exercise program will be prescribed according to the current American College of Sports Medicine recommendations [30]. In both groups, the participants participate in a 3-month exercise program with three aerobic and resistance training sessions (30 to 50 min/session) a week (Table 1). Participants are instructed to exercise with a training intensity of 60–85% of their maximal heart rate, which is assessed during maximal cardiopulmonary exercise testing at baseline. Participants in the HBE group will undertake the first three training sessions in an outpatient clinic under direct supervision of the physiotherapist. During these sessions, participants are familiarized with training duration and intensity. They will be educated on using the valid wearable heart rate sensor (Polar M430, a commercially available device designed for long-term use) [31]. If is detected an inappropriate function of the wrist-worn heart rate sensor M430, the valid chest-strap H7 Polar sensor is available as an alternative to measure exercise heart rate zone [32].

Further on, the participants will be asked to choose their preferred training modality in a home-based environment and obtain instructions and advice on using them. Participants are instructed to use the wearable sensor properly and upload the training data to the web platform (Polar Flow) via the Internet. Participants can check the platform Polar Flow, review their exercise data and results, and see whether they keep their personal aims. Each exercise session will be extended with a resistance exercise part 3 times a week (Table 1).

The personal coach (physiotherapist/exercise specialist in rehab) will regularly access the training data on the web platform. The coach will provide remote guidance (feedback about frequency, duration, and training intensity) via preferred contact (phone call, text message) once a week (Fig. 2).

Regarding potential safety reasons, participants will be instructed to contact the study investigators or their medical doctor to experience any symptoms during or after the exercise training. After 3 months, the telemonitored exercise sessions are finished. After this period, the participants will be recommended to continue personal exercises with the heart rate sensor and web platform.

Table 1 Exercise intervention

Warm up (duration 10 min)	
*Marching on the spot (5 min) *Flexibility activities: Upper back stretch, Chest stretch, Back - waist mobility, Calf stretch, Hamstring stretch, Quadriceps stretch (5 min)	
Core of exercise session (gradual)	
Continuous aerobic exercise training (30–50 min)	**Resistance training (10–20 min)**
Intensity: 60–85% HRmax[a]	Intensity: 13–15 RPE
Modality (HBE): cycling, walking, Nordic walking Modality (CBE): stationary ergometer, treadmill	Exercise no.1: pelvic bridge (solid surface) Exercise no.2: squat (with the use of a chair) Exercise no.3[b]: dumbbell biceps curl (seated) Exercise no.4[b]: dumbbell shoulder external rotation (seated)
	Modality (HBE): water bottles/dumbbells Modality (CBE): dumbbells
Week 1–2: each session duration 30 min	Week 1–2: each session 2 sets (8 reps)
Week 3–4: each session duration 30–40 min	Week 3–4: each session 2–3 sets (8–12 reps)
Week 5–12: each session duration 30–50 min	Week 5–12: each session 2–4 sets (8–15 reps)
Cool down (duration 10 min)	
*Marching on the spot (5 min) *Flexibility activities; same as warm up (5 min)	

RPE Borg Rating of Perceived Exertion Scale (6–20), *CBE* Centre-based exercise, *HBE* Home-based exercise

[a] HRmax obtained from the baseline cardiopulmonary exercise test

[b] Weights are set individually in the range of 0.5–2.5 kg

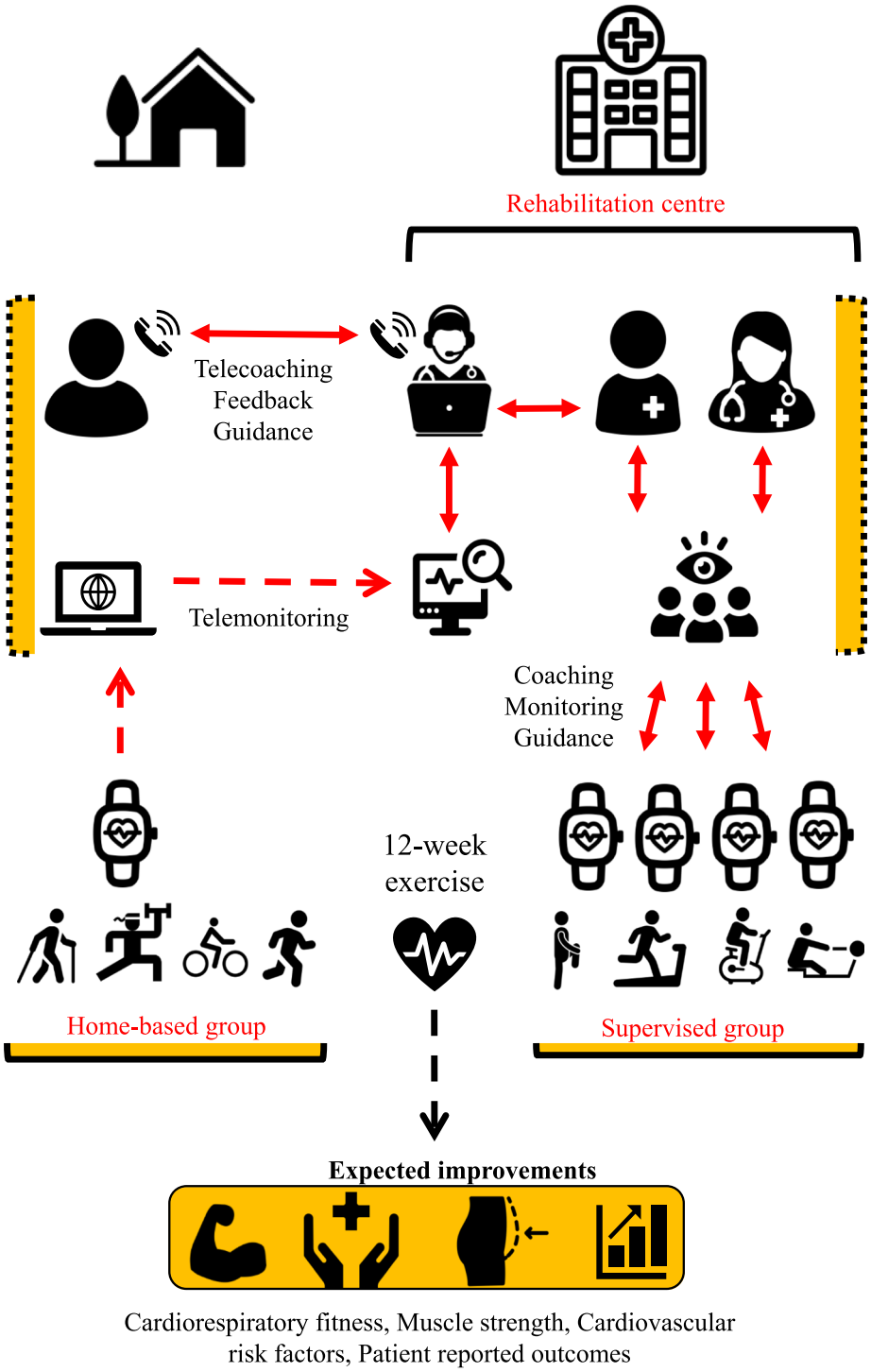

Fig. 2 Overview of home-based exercise supported with telemonitoring and telecoaching

In the CBE group, participants receive a group-based exercise program at the outpatient clinic under the direct supervision of physiotherapists specializing in exercise rehab. The participants in the CBE group will receive a similar exercise prescription; an individually tailored exercise program on a treadmill and/or a bicycle ergometer and resistance part [29, 33, 34]. During the exercise program, physiotherapists will track

exercise adherence. After the 3-month supervised exercise period, the physiotherapists will encourage the participants to continue physical exercises in their environment.

If participants miss sessions, they will be encouraged to make them up to maintain their adherence rate. They can add additional sessions in subsequent weeks to reach the required number of sessions. However, it is important to note that participants will not exceed safe exercise limits, and any make-up sessions should be spaced appropriately to avoid overtraining and potential injury. The study investigators will provide guidance on how to safely make up missed sessions.

Telemonitoring

After the initial supervised training sessions, participants in the home-based exercise (HBE) group will transition to exercising in their home environment. A personal coach will provide remote telemonitoring supervision by monitoring participants' physical interventions and offering feedback and support through regular phone calls or text messages. At the outset of the exercise program, each participant will have an individual meeting with the coach to establish personal training goals. This personalized approach can have a positive impact on overall improvement by fostering a concrete relationship and allowing the coach to tailor each participant's exercise regimen to their abilities. Encouraging participant activity and cooperation will foster a sense of responsibility for their results. The coach will employ motivational interviewing, an effective technique for eliciting behavioral changes in various domains [29].

Remote monitoring and supervision will adhere to the gold standard for exercise rehabilitation, comprising three components: warm-up, core exercise, and cool-down. Each phase will be precisely timed and set at specific intensities according to the heart rate zones determined in the baseline cardiopulmonary exercise test. The coach will regularly monitor whether participants adhere to the exercise prescription in terms of duration and intensity and advise them to adjust the program as needed based on their analysis. If a participant is unable to continue with the prescribed exercise, the participant and coach will explore alternative modalities or plans. For example, if the target heart rate zone is not reached during cycling, the participant will be directed to engage in brisk walking instead.

Outcomes

The primary outcome of the study is the change in cardiorespiratory fitness, expressed as peak oxygen uptake, which will be assessed at baseline, 3 months, and 12 months into the intervention. Secondary outcomes include health-related quality of life (HRQL), training adherence, intervention safety, and cost-effectiveness evaluation. HRQL will be evaluated at baseline, 3 months, and 1 year. Training adherence, safety, and costs will be monitored in both groups over the course of the 3-month training program. An overview of the study design is provided in Fig. 1.

Cardiorespiratory fitness

Cardiorespiratory fitness is a crucial outcome measure in this study due to its strong association with overall health, physical function, and mortality, particularly in cancer survivors [35]. Cardiorespiratory fitness analysis will be conducted using the automated metabolic system Metalyzer 3b (Biophysics GmbH, Leipzig, Germany) and through a progressive increment cardiopulmonary exercise test on the bicycle ergometer Ergoselect 100 (Ergoline Bitz, Germany) up to the level of limited symptom maximum. These tools are chosen for their high validity and reliability in measuring peak oxygen uptake (VO2 max), a gold standard for assessing cardiorespiratory fitness [36, 37].

The cardiopulmonary exercise test (CPET) will be performed according to the recommendations of the European Society of Cardiology and the American Heart Association, ensuring standardized and reproducible testing conditions [38]. The ramp protocol will be utilized for the stress test, consisting of a 2-min warm-up at 10 watts, followed by incremental increases of 15 watts per minute for men and 10 watts per minute for women, with a final 2-min cool-down period at 10 watts. A cardiologist will be present during the testing to assess any abnormal signs on the electrocardiogram (ECG) and independently evaluate ventilation thresholds. This approach ensures safety and accuracy in detecting cardiopulmonary responses to exercise [39].

Health-related quality of life

HRQL will be assessed in the standardized questionnaire SF-36. The questionnaire version has been translated and validated into the Czech language [40]. Normative representative study validity, reliability, sensitivity, and task complexity for the European population have been proved [41]. SF-36 was chosen in our study as an assessment tool for its full usability, functional coherence, and high responsibility in repeated testing. The SF-36 consists of eight domains: Physical Functioning, Role Limitations due to Physical Health, Bodily Pain, General Health Perceptions, Vitality, Social Functioning, Role Limitations due to Emotional Health, and Mental Health. Scores for each domain range from 0 to 100, with higher scores indicating better HRQL.

Training adherence

Training adherence will be monitored using the Polar Flow web application, which allows for accurate tracking of exercise frequency, duration, and intensity. Adherence data will be collected through the wearable Polar heart rate monitors (Polar M430), which have been validated for their accuracy in measuring heart rate and physical activity levels [32]. Regular monitoring of training adherence is essential to evaluate the feasibility and effectiveness of the exercise intervention and to identify any barriers to participation [42].

High session attendance rates were defined as attending at least 80% of the sessions. Participants will be instructed to exercise three times per week, resulting in a total of 36 sessions over the 12-week intervention period. Therefore, to be considered compliant, participants must complete at least 29 sessions.

Compliance definition

Compliance will be defined as completing at least 80% of the prescribed exercise sessions. This threshold is chosen based on evidence suggesting that high adherence rates are necessary to achieve significant health benefits from exercise interventions [43].

Monitoring and reporting

Adherence data will be collected and reviewed weekly by the study investigators. The Polar Flow web application will automatically log each exercise session, including its frequency, duration, and intensity. This data will be used to calculate the overall adherence rate for each participant.

Cost-effectiveness

In the economic evaluation, the effects of both interventions will be compared and their difference in costs will be analyzed. A cost-effectiveness analysis will be conducted using quality-adjusted life years (QALYs) as outcome measures. This approach allows for a comprehensive assessment of the economic impact of the interventions, providing valuable information for healthcare decision-makers [44].

Costs will encompass various aspects of rehabilitation, including professional wages (such as physiotherapists, medical doctors, nurses), assessments (such as exercise testing), equipment (such as heart rate monitors), and other healthcare utilization during the first year of follow-up. QALYs will be calculated based on the health utility gain scores obtained from the SF-36 questionnaire administered at baseline, 3 months, and 1 year. Sensitivity analyses will be conducted from the healthcare perspective to assess the robustness of the findings.

This preventive approach aligns with studies demonstrating that regular exercise decreases healthcare utilization and costs [45, 46]. The use of commercially available and validated wearable technology (e.g., Polar M430 heart rate monitors) minimizes costs compared to developing proprietary equipment. These devices provide reliable data for monitoring and adjusting exercise programs without frequent in-person assessments [47].

A range of studies have demonstrated the potential of telehealth and wearable technology in improving healthcare outcomes and reducing costs [48, 49]. Polisena [50] provides a systematic review of the cost-effectiveness of home telehealth for chronic diseases, suggesting that it has the potential to reduce costs from the healthcare system and insurance provider perspectives. These findings collectively underscore the value of telehealth and wearable technology in preventive healthcare.

Body composition measurement

Body composition will be assessed using bioelectrical impedance analysis (BIA) with the InBody 370S multi-frequency analyzer scales. Participants will follow the manufacturer's instructions, maintaining contact with the scale's hand and foot electrodes while multiple electrical currents pass through the arms, legs, and trunk at frequencies of 1, 5, 50, 250, and 500 kHz. The scale will measure the impedance of these electrical currents to determine various body composition parameters, including body fat mass, skeletal muscle mass, and total body water. The complete BIA examination will last approximately 60 s.

Validation studies of bioelectrical impedance analysis in assessing body composition in cancer patients have demonstrated strong correlations with computed tomography, suggesting its usefulness as a more convenient alternative for measuring visceral fat area and skeletal muscle mass [51, 52].

Handgrip strength

Handgrip strength will be evaluated using a digital hand grip meter (Sagita, Mariestad, Sweden). Participants will be seated with their elbow flexed at 90 degrees during the assessment. Grip strength will be measured three times, and the average score will be calculated. The digital hand grip meter is a commonly used tool known for its reliability in test-retest evaluations and is recommended for assessing cancer survivors post-treatment [53].

Incidence of adverse events

The systematic recording and evaluation of AEs are critical for maintaining participant safety and for making any necessary adjustments to the intervention protocols

[54]. To assess the safety of the study, investigators will promptly report any adverse events (AEs) occurring throughout the duration of the study. Additionally, any malfunctions in the web platform or telehealth devices will be documented. The presentation will include the number and percentage of participants experiencing AEs, as well as the total number of AEs. A detailed list of participants experiencing AEs will be provided, specifying the type of event, start and end times, duration, severity, actions taken, and the event's relationship to exercise (see Supplemental Table 1).

In the event of an adverse event (AE), participants will be instructed to contact the study investigators or their medical doctor if they experience any symptoms during or after the exercise training. Investigators will assess the situation to determine whether to suspend the participant's intervention or halt the entire study. They will proceed with diagnosis and appropriate treatment as necessary. In cases of severe AEs, immediate action will be taken to ensure participant safety, and the incidents will be reported to the study clinician within 24 h.

Power analysis

The sample size analysis is derived from an anticipated increase in cardiorespiratory fitness of 4.7 ml/kg/min peak oxygen uptake, with a standard deviation of 8.6 ml/kg/min, based on data from Courneya et al. [55]. To test the null hypothesis with a statistical power of 90% and a statistical significance level of 5%, the study requires the inclusion of 36 experimental and 36 control participants. Accounting for a 10% dropout rate during the 12-month follow-up period, a total of 80 participants need to be randomized evenly between the experimental and control groups.

Sample size participation rate

At the University Hospital Brno, approximately 300 to 350 newly diagnosed patients with lymphoma are treated each year, with nearly half of them undergoing systemic therapy. Overall, the Department of Internal Medicine Hematology – Oncology manages over 2500 lymphoma survivors who attend regular outpatient follow-ups after completing cancer treatment. This patient pool represents a significant potential participant base for the proposed study. (Target sample size: 80 participants, with an expected enrollment of 25 to 30 patients per year).

Furthermore, our pilot feasibility investigation demonstrated a solid chance of study completion, with a recruitment rate of 42.9% [19]. This rate is comparable to exercise-based trials conducted in the lymphoma population (26–49%) [56–58].

To mitigate potential biases and ensure balanced representation, our study intends to stratify participants based on lymphoma subtype and treatment history. By accounting for these factors, we aim to minimize confounding variables and obtain more accurate insights into the relationship between exercise intervention and patient outcomes across different lymphoma subgroups.

Statistics

Data analysis will be conducted using the latest version of SPSS, with an intention-to-treat principle whenever applicable. Descriptive statistics will be computed for the socio-demographic and clinical data. Normality assumptions for the variables will be tested using the Kolmogorov-Smirnov (KS) test. Baseline comparability between the two study groups will be assessed using independent sample t-tests or chi-square tests, as appropriate. Generalized estimating equations (GEE) models will be used to compare changes in outcomes across time points between the groups. The GEE model can estimate missing data based on the maximum likelihood estimation method. Potential confounding variables will be selected based on statistical incomparability, as there are no clinically known covariates in the outcomes. Baseline variables with $p < 0.2$ will be adjusted to obtain a more precise estimation of the intervention effect. All data analyses will be conducted with a 5% significance level (two-tailed).

The adherence rate will be calculated as the percentage of completed sessions out of the total prescribed sessions. Participants will be categorized as compliant ($\geq 80\%$ adherence) or non-compliant ($< 80\%$ adherence). Statistical analyses will include (i) Descriptive Statistics (We will report the mean and standard deviation of adherence rates, as well as the proportion of participants meeting the compliance threshold), (ii) Comparative Analysis (Differences in adherence rates between the intervention and control groups will be analyzed using independent sample t-tests or chi-square tests, as appropriate), and (iii) Regression Analysis (Multivariate regression models will be used to identify predictors of adherence, including demographic, clinical, and psychosocial factors).

Impact of non-compliance

To address potential biases due to non-compliance, sensitivity analyses will be conducted. These analyses will compare the primary and secondary outcomes between compliant and non-compliant participants to assess the impact of adherence on the study results. By clearly defining and rigorously monitoring training adherence, we aim to ensure the validity and reliability of our study findings. Participants' adherence to the exercise regimen is crucial for evaluating the true effectiveness of the intervention.

Discussion

The Tele@home study aims to deliver personalized exercise-based rehabilitation care through innovative telehealth guidance to cancer survivors at cardiovascular risk due to cancer therapies. Specifically, the study focuses on lymphoma cancer survivors who face various cardiovascular diseases and risks. The primary objective is to evaluate the effectiveness of HBE combined with telemonitoring guidance compared to CBE. Our hypothesis suggests that implementing HBE with online coaching will enhance motivation and self-efficacy among lymphoma cancer survivors, consequently leading to improved long-term cardiorespiratory fitness compared to conventional CBE.

Previous research has established the safety and efficacy of HBE, which is similar to regular CBE [59, 60]. However, our study stands out for incorporating telemonitoring and telecoaching guidance throughout the HBE intervention, coupled with a comprehensive 1-year follow-up period. Notably, such a combination of telehealth tools in the rehabilitation of lymphoma cancer survivors has been scarcely explored in clinical trials [19].

Advancements in wearable sensor technology have enhanced the validity of heart rate measurements while concurrently reducing costs. By leveraging these telehealth devices, we can mitigate the bias inherent in self-reported results based on questionnaires or written training diaries, which often lack reliability and fail to track physical expenditure effectively [61]. Telehealth intervention studies prioritize early survivor motivation, activation of self-responsibility, and the cultivation of self-efficacy focused on maintaining a healthy lifestyle [24]. This approach empowers cancer survivors to initiate behavioral changes in their home environment right from the onset of the rehabilitation intervention [62].

Telemonitoring tools play a crucial role in measuring exercise intensity during HBE, enabling telecoaching to adopt an individualized approach based on real-time exercise data. Studies have confirmed that such interventions can counteract the tendency for survivors to lapse into inactivity post-completion of short-term CBE [63]. However, prior studies on HBE interventions in cancer survivors have reported inconsistent adherence to exercise prescription, particularly when relying on self-measurement or web-based platforms [19]. We hypothesize that employing validated technology-assisted measurement of exercise intensity asynchronously available on a web-based platform will yield more reliable results regarding exercise adherence among lymphoma survivors.

Ensuring sustainable improvements is pivotal in our study. Beyond assessing immediate HRQL enhancements, we prioritize long-term follow-up to measure intervention longevity. Following the initial phase, our protocol includes extended monitoring to track progress and assess the durability of benefits. Moreover, we will examine factors influencing sustainability, such as exercise adherence and disease status. By capturing these data, we aim to understand sustained HRQL improvements among lymphoma survivors, informing future care practices. This approach underscores our commitment to long-lasting patient well-being [64, 65].

The proposed telehealth intervention for HBE in lymphoma cancer survivors is designed to be a cost-effective alternative to traditional CBE programs. Traditional CBE programs incur significant costs related to the use of medical facilities, including maintenance, utilities, and staffing (physiotherapists, medical doctors, nurses) [66]. By transitioning to a telehealth model, these overhead costs can be significantly reduced or even eliminated. Patients often face financial and logistical barriers to accessing CBE programs, such as travel expenses and time off work. HBE mitigates these costs by allowing patients to exercise from home, potentially increasing adherence and participation rates [67, 68].

Once established, telehealth platforms benefit from economies of scale, meaning the marginal cost of adding new participants decreases. The initial investment in technology and training can be amortized over a growing number of users [69]. Effective telehealth interventions can lead to better health outcomes, reducing the incidence of hospital readmissions and other costly medical interventions.

The use of Polar heart rate (HR) monitors in our telehealth intervention reduces costs by decreasing the need for continuous in-person supervision, optimizing healthcare professionals' time, and lowering labor costs. It minimizes the need for frequent facility visits, thus reducing operational expenses and associated patient costs such as travel and time off work. The monitors provide real-time data, enabling efficient management and adjustments to exercise programs without additional testing or in-person evaluations. Accurate monitoring helps prevent overexertion and related adverse health events, reducing costly medical interventions.

By supporting long-term adherence to exercise regimens, HR monitors contribute to sustained health benefits and lower future medical costs. Additionally, Polar HR monitors are cost-effective compared to proprietary systems, offering validated accuracy and reliability. The scalability of this technology allows for managing larger patient populations without proportional cost increases, making it economically viable for widespread implementation.

Despite its potential, this research has some limitations. In exercise-based studies, blinding subjects for allocation is unfeasible. Moreover, telecoaching via the Polar Flow web-based platform necessitates internet connectivity at home, and proficiency in technological literacy and computer skills is imperative. Although baseline instructions and informational booklets are provided, limited technological skills among participants may pose initial challenges during the study, such as connectivity issues or difficulties in uploading training data.

Future perspective

If the results of the Tele@home study demonstrate that HBE using telemonitoring and telecoaching is more effective than CBE in enhancing long-term cardiorespiratory fitness, there will be strong grounds for making HBE interventions as readily available as CBT for motivating cancer survivors to exercise within their home environments. Additionally, the implementation of HBE may offer economic advantages. With hospital budgets decreasing and CBE cancer rehabilitation being underutilized, there's a pressing need for innovative and cost-effective rehabilitation and preventive medicine strategies. If HBT with telemonitoring and telecoaching meets these criteria, it could serve as a viable alternative to regular CBE rehabilitation for lymphoma survivors, allowing many to access rehabilitation without significantly increasing overall costs.

This initiative aligns with the National Strategy for the Computerization of Public Health of the Czech Republic, approved by the government for the period 2016–2026 [70]. The strategy emphasizes transferring non-complex health services from hospitals to patients' homes, particularly through the implementation of telemedicine and e-health delivery [71]. The outcomes of the Tele@home study may thus hold implications for the digital transformation of supportive care and rehabilitation for cancer survivors.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40959-024-00249-7.

Supplementary Material 1: Supplemental Table 1. Assessment of the severity of an adverse events [72].

Acknowledgements
We are thankful to Dr. Vladimir Konecny for his scientific mentorship in this study.

Authors' contributions
All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Andrea Janikova, Marian Felsoci, Filip Dosbaba, Petr Winnige, Martin Hartman and Svatopluk Nehyba. The first draft of the manuscript was written by Katerina Chamradova, Ladislav Batalik, Garyfallia Pepera, and Jing Jing Su. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding
Supported by Ministry of Health of the Czech Republic, grant nr. NU23-09-00048. All rights reserved.

Availability of data and materials
The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The Internal Review Board at the University Hospital Brno approved this study on 8th June, 2022 (Approval number 05-080622/EK).

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Rehabilitation, University Hospital Brno, Brno, Czech Republic. [2]Department of Rehabilitation and Sports Medicine, 2nd Faculty of Medicine, Charles University, University Hospital Motol, Prague, Czech Republic. [3]Department of Physiotherapy and Rehabilitation, Faculty of Medicine, Masaryk University, Brno, Czech Republic. [4]Department of Internal Medicine–Hematology and Oncology, University Hospital Brno, Brno, Czech Republic. [5]Department of Internal Medicine and Cardiology, University Hospital Brno, Brno, Czech Republic. [6]Clinical Exercise Physiology and Rehabilitation Research Laboratory, Physiotherapy Department, School of Health Sciences, University of Thessaly, Lamia, Greece. [7]School of Nursing, Tung Wah College, Hong Kong, China.

Received: 30 June 2023 Accepted: 19 July 2024
Published online: 30 July 2024

References

1. Shapiro CL. Cancer survivorship. New Engl J Med. 2018;379:2438–50.
2. Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A, et al. Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin. 2020;68(6):394–424.
3. Bower JE. Cancer-related fatigue–mechanisms, risk factors, and treatments. Nat Rev Clin Oncol. 2014;11:597–609.
4. Vejpongsa P, Yeh ET. Prevention of anthracycline-induced cardiotoxicity: challenges and opportunities. J Am Coll Cardiol. 2014;64:938–45.
5. Phillips JL, Currow DC. Cancer as a chronic disease. Collegian. 2010;17:47–50.
6. Schmitz KH, Campbell AM, Stuiver M, Pinto BM, Schwartz AL, Morris GS, et al. exercise is medicine in oncology: engaging clinicians to help patients move through cancer. CA Cancer J Clin. 2019;69:468–84.
7. Spence RR, Heesch KC, Brown WJ. Exercise and cancer rehabilitation: a systematic review. Cancer Treat Rev. 2010;36:185–94.
8. Stubblefield MD. The underutilization of rehabilitation to treat physical impairments in breast cancer survivors. PMR. 2017;9:317–23.
9. Bjerring AW, Smeland KH, Stokke T, Haugaa KH, Holte E, Rösner A, Kiserud CE, Edvardsen T, Sarvari SI. Long-term cardiac effects of modern treatment for Hodgkin's lymphoma. Cardiooncology. 2024;10(1):19. https://doi.org/10.1186/s40959-024-00222-4.
10. Divakaran S, Lopez DM, Parks SM, Hainer J, Ng AK, Blankstein R, Di Carli MF, Nohria A. Functional testing, coronary artery calcifications, and outcomes in Hodgkin lymphoma survivors treated with chest radiation. Cardiooncology. 2023;9(1):5. https://doi.org/10.1186/s40959-023-00157-2.
11. Shen R, Zou T. Association between cancer and cardiovascular toxicity: a nationwide cross-sectional study on NHANES 1999–2018. Cardiovasc Toxicol. 2024;24(4):351–64. https://doi.org/10.1007/s12012-024-09845-6.
12. Lee SF, Luque-Fernandez MA, Chen YH, Catalano PJ, Chiang CL, Wan EY, Wong IC, Chen MH, Ng AK. Doxorubicin and subsequent risk of cardiovascular diseases among survivors of diffuse large B-cell lymphoma

in Hong Kong. Blood Adv. 2020;4(20):5107–17. https://doi.org/10.1182/bloodadvances.2020002737.
13. Antoniou V, Davos CH, Kapreli E, Batalik L, Panagiotakos DB, Pepera G. Effectiveness of home-based cardiac rehabilitation, using wearable sensors, as a multicomponent, cutting-edge intervention: a systematic review and meta-analysis. J Clin Med. 2022;11(13):3772. https://doi.org/10.3390/jcm11133772.
14. Thomas RJ, Beatty AL, Beckie TM, Brewer LC, Brown TM, Forman DE, Franklin BA, Keteyian SJ, Kitzman DW, Regensteiner JG, Sanderson BK, Whooley MA. Home-based cardiac rehabilitation: a scientific statement from the American Association of Cardiovascular and Pulmonary Rehabilitation, the American Heart Association, and the American College of Cardiology. Circulation. 2019;140(1):e69–89. https://doi.org/10.1161/CIR.0000000000000663.
15. Ijsbrandy C, Hermens RPM, Boerboom LWM, Gerritsen WR, van Harten WH, Ottevanger PB. Implementing physical activity programs for patients with cancer in current practice: patients' experienced barriers and facilitators. J Cancer Surviv. 2019;13:703–12.
16. Batalik L, Chamradova K, Winnige P, Dosbaba F, Batalikova K, Vlazna D, et al. Effect of exercise-based cancer rehabilitation via telehealth: a systematic review and meta-analysis. BMC Cancer. 2024;24(1):600.
17. Stefani L, Klika R, Mascherini G, Mazzoni F, Lunghi A, Petri C, et al. Effects of a home-based exercise rehabilitation program for cancer survivors. J Sports Med Phys Fitness. 2019;59:846–52.
18. Filakova K, Janikova A, Felsoci M, et al. Home-based cardio-oncology rehabilitation using a telerehabilitation platform in hematological cancer survivors: a feasibility study. BMC Sports Sci Med Rehabil. 2023;15(1):38. https://doi.org/10.1186/s13102-023-00650-2. Published 2023 Mar 23.
19. Batalik L, Filakova K, Radkovcova I, et al. Cardio-oncology rehabilitation and telehealth: rationale for future integration in supportive care of cancer survivors. Front Cardiovasc Med. 2022;9:858334. https://doi.org/10.3389/fcvm.2022.858334. Published 2022 Apr 15.
20. Mikkelsen MK, et al. The effect of a supervised exercise intervention on physical activity and quality of life in cancer survivors: a randomized controlled trial. Acta Oncol. 2016;55(10):1367–74.
21. Lahart IM, et al. The effects of home-based exercise interventions on health-related quality of life in cancer survivors: a systematic review and meta-analysis. Psychooncology. 2018;27(7):1675–87.
22. Buffart LM, et al. Physical and psychosocial benefits of home-based exercise training for cancer survivors: a systematic review and meta-analysis. Psychooncology. 2017;26(9):1239–51.
23. Rossi A, Garber CE, Ortiz M, Shankar V, Goldberg GL, Nevadunsky NS. Feasibility of a physical activity intervention for obese, socioculturally diverse endometrial cancer survivors. Gynecol Oncol. 2016;142:304–10.
24. Sagarra-Romero L, Butragueño J, Gomez-Bruton A, Lozano-Berges G, Vicente-Rodríguez G, Morales JS. Effects of an online home-based exercise intervention on breast cancer survivors during COVID-19 lockdown: a feasibility study. Support Care Cancer. 2022;30(7):6287–97. https://doi.org/10.1007/s00520-022-07069-4.
25. Velikova G, Booth L, Smith AB, et al. Measuring quality of life in routine oncology practice improves communication and patient well-being: a randomized controlled trial. J Clin Oncol. 2004;22(4):714–24. https://doi.org/10.1200/JCO.2004.06.078.
26. Schmitz KH, Courneya KS, Matthews C, et al. American College of Sports Medicine roundtable on exercise guidelines for cancer survivors [published correction appears in Med Sci Sports Exerc. 2011 Jan;43(1):195]. Med Sci Sports Exerc. 2010;42(7):1409–26. https://doi.org/10.1249/MSS.0b013e3181e0c112.
27. Caan BJ, Cespedes Feliciano EM, Kroenke CH. The importance of body composition in explaining the overweight paradox in cancer-counterpoint. Cancer Res. 2018;78(8):1906–12. https://doi.org/10.1158/0008-5472.CAN-17-3287.
28. World Health Organization. International Clinical Trial Registry Platform: trial registration data set (version 1.3). World Health Organization; 2017. Available at: https://www.who.int/clinical-trials-registry-platform/network/who-data-set. Cit. 23.5.2021.
29. Miller WR, Rollnick S. Motivational interviewing: helping people change. New York: Guilford Press; 2012.
30. Campbell KL, Winters-Stone KM, Wiskemann J, May AM, Schwartz AL, Courneya KS, et al. Exercise guidelines for cancer survivors: consensus statement from international multidisciplinary roundtable. Med Sci Sports Exerc. 2019;51:2375–90.
31. Janicki GJ, Porcari JP, Jagim AR, Emineth K, Dorberstein S, et al. The accuracy of heart rate and energy expenditure measurements using the PolarM430 watch during exercise. Int J Res Ex Phys. 2020;15(2):91–105.
32. Etiwy M, Akhrass Z, Gillinov L, et al. Accuracy of wearable heart rate monitors in cardiac rehabilitation [published correction appears in Cardiovasc Diagn Ther. 2020 Jun;10(3):644-645]. Cardiovasc Diagn Ther. 2019;9(3):262–71. https://doi.org/10.21037/cdt.2019.04.08.
33. Gloc D, Nowak Z, Nowak-Lis A, et al. Indoor cycling training in rehabilitation of patients after myocardial infarction. BMC Sports Sci Med Rehabil. 2021;13(1):151. https://doi.org/10.1186/s13102-021-00379-w. Published 2021 Nov 29.
34. Viamonte SG, Joaquim AV, Alves A, et al. Impact of a COmprehensive cardiac REhabilitation framework among high cardiovascular risk cancer survivors: protocol for the CORE trial. Int J Cardiol. 2023;371:384–90. https://doi.org/10.1016/j.ijcard.2022.09.075.
35. Schmid D, Leitzmann MF. Cardiorespiratory fitness as predictor of cancer mortality: a systematic review and meta-analysis. Ann Oncol. 2015;26(2):272–8.
36. Gitt AK, et al. Peak oxygen uptake – a critical reappraisal with reference to the new recommendations of the European Society of Cardiology. Eur Heart J. 2002;23(9):1332–6.
37. Hansen JE, Sue DY, Wasserman K. Predicted values for clinical exercise testing. Am Rev Respir Dis. 1984;129(2 Pt 2):S49-55.
38. Guazzi M, Adams V, Conraads V, Halle M, Mezzani A, Vanhees L, et al. EACPR/AHA Scientific Statement. Clinical recommendations for cardiopulmonary exercise testing data assessment in specific patient populations. Circulation. 2012;126:2261–74.
39. Mezzani A, et al. Aerobic exercise intensity assessment and prescription in cardiac rehabilitation: a joint position statement of the European Association for Cardiovascular Prevention and Rehabilitation, the American Association of Cardiovascular and Pulmonary Rehabilitation, and the Canadian Association of Cardiac Rehabilitation. Eur J Prev Cardiol. 2009;16(4):375–82.
40. Petr P. Dotazník SF-36 o kvalitě života podmíněné zdravím. Kontakt. 2000;2:26–30.
41. Aaronson NK, Muller M, Cohen PD, Essink-Bot ML, Fekkes M, Sanderman R, et al. Translation, validation, and norming of the Dutch language version of the SF-36 Health Survey in community and chronic disease populations. J Clin Epidemiol. 1998;51:1055–68.
42. Hawley-Hague H, et al. The feasibility of recruiting older adults to a community-based exercise programme: a mixed-methods study. BMC Public Health. 2014;14:650.
43. Marcus BH, Williams DM, Dubbert PM, et al. Physical activity intervention studies: what we know and what we need to know: a scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism (Subcommittee on Physical Activity); Council on Cardiovascular Disease in the Young; and the Interdisciplinary Working Group on Quality of Care and Outcomes Research. Circulation. 2006;114(24):2739–52.
44. Drummond MF, et al. Methods for the economic evaluation of health care programmes. 4th ed. Oxford: Oxford University Press; 2015.
45. Kraal JJ, Van den Akker-Van Marle ME, Abu-Hanna A, Stut W, Peek N, Kemps HM. Clinical and cost-effectiveness of home-based cardiac rehabilitation compared to conventional, centre-based cardiac rehabilitation: results of the FIT@Home study. Eur J Prev Cardiol. 2017;24(12):1260–73. https://doi.org/10.1177/2047487317710803.
46. Batalik L, Filakova K, Sladeckova M, Dosbaba F, Su J, Pepera G. The cost-effectiveness of exercise-based cardiac telerehabilitation intervention: a systematic review. Eur J Phys Rehabil Med. 2023;59(2):248–58. https://doi.org/10.23736/S1973-9087.23.07773-0.
47. Gresham G, et al. Wearable activity monitors in oncology trials: current use of an emerging technology. Contemp Clin Trials. 2018;64:13–21.
48. Caperchione CM, et al. An interdisciplinary approach to understanding the cost-effectiveness of supervised and unsupervised physical activity programs among breast cancer survivors. Cancer Causes Control. 2019;30(8):873–80.
49. Snoswell CL, Taylor ML, Comans TA, Smith AC, Gray LC, Caffery LJ. Determining if telehealth can reduce health system costs: scoping review. J

Med Internet Res. 2020;22(10):e17298. https://doi.org/10.2196/17298. Published 2020 Oct 19.
50. Polisena J, Coyle D, Coyle K, McGill S. Home telehealth for chronic disease management: a systematic review and an analysis of economic evaluations. Int J Technol Assess Health Care. 2009;25(3):339–49. https://doi.org/10.1017/S0266462309990201.
51. Kim EY, Kim SR, Won DD, Choi MH, Lee IK. Multifrequency bioelectrical impedance analysis compared with computed tomography for assessment of skeletal muscle mass in primary colorectal malignancy: a predictor of short-term outcome after surgery. Nutr Clin Pract. 2020;35(4):664–74. https://doi.org/10.1002/ncp.10363.
52. Ogawa H, Fujitani K, Tsujinaka T, et al. InBody 720 as a new method of evaluating visceral obesity. Hepatogastroenterology. 2011;58(105):42–4.
53. Zhuang CL, Zhang FM, Li W, et al. Associations of low handgrip strength with cancer mortality: a multicentre observational study. J Cachexia Sarcopenia Muscle. 2020;11(6):1476–86. https://doi.org/10.1002/jcsm.12614.
54. Loke YK, et al. Systematic review of adverse effects: framework for a structured approach. BMC Med Res Methodol. 2006;6:22.
55. Courneya KS, Sellar CM, Stevinson C, McNeely ML, Peddle CJ, Friedenreich CM, Tankel K, Basi S, Chua N, Mazurek A, Reiman T. Randomized controlled trial of the effects of aerobic exercise on physical functioning and quality of life in lymphoma patients. J Clin Oncol. 2009;27:4605–12.
56. Courneya KS, Sellar CM, Trinh L, et al. A randomized trial of aerobic exercise and sleep quality in lymphoma patients receiving chemotherapy or no treatments. Cancer Epidemiol Biomarkers Prev. 2012;21(6):887–94. https://doi.org/10.1158/1055-9965.EPI-12-0075.
57. Streckmann F, Kneis S, Leifert JA, et al. Exercise program improves therapy-related side-effects and quality of life in lymphoma patients undergoing therapy. Ann Oncol. 2014;25(2):493–9. https://doi.org/10.1093/annonc/mdt568.
58. Furzer BJ, Ackland TR, Wallman KE, et al. A randomised controlled trial comparing the effects of a 12-week supervised exercise versus usual care on outcomes in haematological cancer patients. Support Care Cancer. 2016;24(4):1697–707. https://doi.org/10.1007/s00520-015-2955-7.
59. Morrison KS, Paterson C, Toohey K. The feasibility of exercise interventions delivered via telehealth for people affected by cancer: a rapid review of the literature. Semin Oncol Nurs. 2020;36(6):151092. https://doi.org/10.1016/j.soncn.2020.151092.
60. Batalik L, Winnige P, Dosbaba F, Vlazna D, Janikova A. Home-based aerobic and resistance exercise interventions in cancer patients and survivors: a systematic review. Cancers (Basel). 2021;13(8):1915. https://doi.org/10.3390/cancers13081915. Published 2021 Apr 15.
61. Hills AP, Mokhtar N, Byrne NM. Assessment of physical activity and energy expenditure: an overview of objective measures. Front Nutr. 2014;1:5. https://doi.org/10.3389/fnut.2014.00005. Published 2014 Jun 16.
62. Gilchrist SC, Barac A, Ades PA, et al. Cardio-oncology rehabilitation to manage cardiovascular outcomes in cancer patients and survivors: a scientific statement from the American Heart Association. Circulation. 2019;139(21):e997–1012. https://doi.org/10.1161/CIR.0000000000000679.
63. Brouwers RWM, Kemps HMC, Herkert C, Peek N, Kraal JJ. A 12-week cardiac telerehabilitation programme does not prevent relapse of physical activity levels: long-term results of the FIT@Home trial. Eur J Prev Cardiol. 2022;29(7):e255–7. https://doi.org/10.1093/eurjpc/zwac009.
64. Antoniou V, Kapreli E, Davos CH, Batalik L, Pepera G. Safety and long-term outcomes of remote cardiac rehabilitation in coronary heart disease patients: a systematic review. Digit Health. 2024;10:20552076241237660. https://doi.org/10.1177/20552076241237661. Published 2024 Mar 25.
65. Pepera G, Antoniou V, Su JJ, Lin R, Batalik L. Comprehensive and personalized approach is a critical area for developing remote cardiac rehabilitation programs. World J Clin Cases. 2024;12(12):2009–15. https://doi.org/10.12998/wjcc.v12.i12.2009.
66. Goode AD, Reeves MM, Eakin EG. Telephone-delivered interventions for physical activity and dietary behavior change: an updated systematic review. Am J Prev Med. 2012;42(1):81–8.
67. Argent R, Daly A, Caulfield B. Patient involvement with home-based exercise programs: can connected health interventions influence adherence? JMIR Mhealth Uhealth. 2018;6(3):e47. https://doi.org/10.2196/mhealth.8518. Published 2018 Mar 1.
68. Rabin C, Bock B. Desired features of smartphone applications promoting physical activity. Telemed J E Health. 2011;17(10):801–3.
69. Chakrabarti O. Telehealth: emerging evidence on efficiency. Int Rev Econ Financ. 2019;60:257–64.
70. Národní strategie elektronického zdravotnictví ČESKÉ REPUBLIKY. Ministerstvo zdravotnictví České republiky; 2016. Available at: https://ncez.mzcr.cz/sites/default/files/Attachment/Narodni_strategie_elektronickeho_zdravotnictvi_v1.0_1.pdf. Cit. 31.5.2021.
71. Těšinová JK, Dobiášová K, Dušek Z, Tobiášová A. Development of telemedicine in the Czech Republic from patients' and other key stakeholders' perspective. Front Public Health. 2023;11:1202182. Published 2023 Oct 23. https://doi.org/10.3389/fpubh.2023.1202182.
72. Kasi PM, Tawbi HA, Oddis CV, Kulkarni HS. Clinical review: Serious adverse events associated with the use of rituximab - a critical care perspective. Crit Care. 2012;16(4):231. https://doi.org/10.1186/cc11304. Published 2012 Aug 31.

Publisher's Note