Current Problems in Cardiology 51 (2026) 103218

Contents lists available at ScienceDirect

Current Problems in Cardiology

journal homepage: www.elsevier.com/locate/cpcardiol

Effects of concurrent training on atrial fibrillation burden, fitness and physical activity after pulmonary vein isolation: Study protocol for a randomized controlled trial

Marcos Echevarría-Polo, MSc [a,b,**], Adrián Hernández-Vicente, PhD [a,b], Pablo Vadillo-Martín, MD,MSc [c], Fabian Sanchis-Gomar, MD, PhD [d,e,*], Jorge Melero-Polo, MD [c], Mercedes Cabrera-Ramos, MD [c], Isabel Montilla-Padilla, MD [c], Andrea Rucco, MSc [f], Juan Pablo Martínez, PhD [f,g], Pablo Laguna, PhD [f,g], Esther Pueyo, PhD [f,g], Javier Ramos-Maqueda, MD, PhD [c,e,h,1], Nuria Garatachea, PhD [a,b,2]

[a] EXER-GENUD "Growth, Exercise, NUtrition and Development" Research Group, University of Zaragoza, Zaragoza, Spain
[b] Faculty of Health and Sports Sciences, University of Zaragoza, Huesca, Spain
[c] Arrhythmias Unit, University Hospital Clinico Lozano Blesa Zaragoza. Aragón Health Research Institute, Spain
[d] Department of Medicine, Division of Cardiovascular Medicine, Stanford University School of Medicine, Stanford, CA, USA
[e] Department of Health Sciences, University of Burgos, Burgos, Spain
[f] BSICoS Group, Aragon Institute of Engineering Research (I3A), IIS Aragón, University of Zaragoza, Zaragoza, Spain
[g] GIIS032 Research Group, Centro de Investigación Biomédica de Aragón, Zaragoza, Spain
[h] Centro de Investigación Biomédica en Red en Bioingeniería, Biomateriales y Nanomedicina (CIBER-BBN), Zaragoza, Spain

ARTICLE INFO

Keywords:
Atrial fibrillation
Pulmonary vein isolation
Ablation
Exercise
Cardiac function
Physical fitness

ABSTRACT

Background: Pulmonary vein isolation (PVI) is an effective treatment for atrial fibrillation (AF), but many patients remain inactive after the procedure for fear of AF recurrence. Evidence supports moderate exercise to improve outcomes of this procedure; however, there are no clear guidelines for returning to physical exercise after PVI. We aim to evaluate the effects of a combined endurance and resistance training (CT) intervention on cardiac function, physical fitness, activity levels, body composition, quality of life, and AF burden after PVI.

Methods and results: We will conduct a randomized controlled trial with 68 participants, approximately 15 months after PVI, randomized 1:1 to a CT or control group. The CT program consists of supervised training sessions combining moderate-intensity endurance and resistance work three times a week for 12 weeks. Outcomes will be assessed at three time points: at baseline, after the intervention, and after 12 weeks of follow-up, including echocardiographic and electrocardiographic parameters, fitness tests, physical activity monitoring, body composition, health-related quality of life, and AF burden monitored by an implantable cardiac Holter. We

* Corresponding author at: Stanford University Medical Center. Department of Medicine, Division of Cardiovascular Medicine. 453 Quarry Rd MC 5687. Stanford, CA 94304.
** Corresponding author at: Department of Electronic Engineering and Communications. University of Zaragoza, Calle Pedro Cerbuna, 12. 50009 Zaragoza, Spain.
E-mail addresses: mechevarria@unizar.es (M. Echevarría-Polo), fabian.sanchis@uv.es, sangofa@stanford.edu (F. Sanchis-Gomar).
[1] Javier Ramos-Maqueda and Nuria Garatachea are joint senior authors.
[2] Both authors contributed equally

https://doi.org/10.1016/j.cpcardiol.2025.103218

Available online 27 November 2025
0146-2806/© 2025 Elsevier Inc. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

expect that CT intervention will improve cardiac function, increase physical fitness and activity levels, optimize body composition, and improve quality of life without recurrence of AF.
Conclusions: This protocol is the first to examine the effects of return to exercise training in AF patients after PVI using objective monitoring tools. The simplicity and scalability of the intervention support its safe integration into clinical practice to promote physical activity and improve patient outcomes after PVI.

CLINICAL PERSPECTIVE

What is known about the topic?

Atrial fibrillation (AF) is the most frequent sustained arrhythmia and a leading cause of morbidity, mortality, and healthcare costs.

Pulmonary vein isolation (PVI) effectively reduces AF recurrence, but many patients remain inactive afterward due to fear of relapse and lack of exercise guidance.

Although moderate exercise improves functional capacity and quality of life, no clear recommendations exist for structured training after PVI.

What Will Be the Clinical Implications?

This trial is the first to assess a concurrent training program (endurance + resistance) after PVI using objective cardiac and physiological monitoring.

The intervention is simple, safe, and scalable, suitable for both hospital and outpatient rehabilitation.

Findings may provide evidence-based exercise prescriptions for post-ablation patients, guide future secondary prevention protocols, and support the integration of structured physical activity into routine AF management.

Introduction

Atrial fibrillation (AF) confers a 1.5- to 2.0-fold increased risk of all-cause mortality and morbidity[1,2]. Its global incidence and prevalence continue to rise, with ~50 million people projected to be affected by 2030[3,4]. AF also drives heavy health care utilization[3,5]. In Europe, the median annual cost per patient is €3,930 (US$ PPPs 5,622) versus €38,256 (US$ PPPs 40,717) in the United States[6]. Modifiable lifestyle factors such as physical inactivity, obesity, alcohol consumption, and smoking substantially contribute to AF onset and progression, underscoring the need for preventive strategies[7–9].

Pulmonary vein isolation (PVI) is a type of ablation that is currently considered the primary treatment for AF, with 60%-80% success[10,11], defined as freedom from AF beyond the 60-day post-procedural blanking period (BP), during which early AF recurrences are not considered treatment failure[12]. This procedure is safe and more effective than antiarrhythmic drugs in reducing arrhythmic load and can be performed using radiofrequency[13], cryoablation, or, more recently, pulsed-field ablation[14–16].

The current European Society of Cardiology (ESC), American College of Cardiology (ACC), and American Heart Association (AHA) guidelines recognize moderate-intensity exercise, excluding athletes, as an effective adjunct to reduce symptoms and AF burden and to improve functional capacity and quality of life[9,17,18]. A recent systematic review of exercise-based cardiac rehabilitation following PVI reported beneficial effects on AF burden, physical fitness, and adverse event rates[19]. However, most trials inadequately describe the exercise intervention and fail to report essential information[20]. Moreover, no studies have specifically addressed the return to physical exercise after PVI, and there are no clear recommendations[21]. Moreover, many published programs require specialized equipment, extensive materials, and spacious facilities, limiting their implementation[17–19]. Therefore, there is a need for shorter, simpler interventions that can be implemented in both hospital and outpatient settings, maintaining participant motivation without the burden of complex logistical demands.

Endurance training is the traditional cornerstone of cardiac rehabilitation owing to its well-established physiological adaptations[22,23], and moderate-intensity continuous training (MICT) is considered safe and effective for reducing AF risk and secondary cardiovascular events[24]. Resistance training also improves muscular strength and function while favorably modifying cardiovascular risk factors[25,26]. Combining endurance and resistance training, referred to as concurrent training (CT), often produces greater overall benefits than either alone across different populations[25]. Accordingly, we propose a CT intervention that can be conducted in a simple setting to assess its effect on patients and to establish exercise recommendations after PVI that can be safely performed outside the hospital environment, with support from a sports scientist or even autonomously.

Exercise intervention rationale

AF symptoms, before PVI, often result in less active lifestyles, which negatively impact patients' health[7,27]. Even several months after PVI, many patients do not return to active lifestyles and exercise practice for fear of AF recurrence. Nevertheless, one month after PVI, the patient can return to sports if there is no recurrence of AF[21]. However, it is not known whether this could result in AF

recurrence in the future. Thus, no firm recommendation can be made on the "safe" dose of sport after PVI[21].

Endurance training improves cardiovascular function and can also reduce the burden of AF in patients with recurrent AF[17,28]. The 2018 Physical Activity Guidelines Advisory Committee Report recommends 150 minutes/week of moderate-intensity endurance exercise for all adults to improve cardiovascular health[29]. In people with AF or other cardiovascular diseases, similar cardiovascular adaptations are achieved through moderate and vigorous physical exercise[17,30]. The American College of Sports Medicine (ACSM) proposes a range of 64-76% of maximum heart rate (HRmax) as moderate intensity[31]. Given a heterogeneous sample of men and women of different ages and physical conditions, HRmax will be calculated using the equation of Gellish et al[32]. The ACSM suggests at least 3 days/week for this kind of training and a session duration that may progress from 20 to 60 minutes of endurance work[34], in addition to resistance training, consistent with clinical trials in patients after PVI similar to our protocol[33,34].

Resistance training improves cardiometabolic risk profiles and reduces cardiovascular disease[25,31]. At least two resistance days per week and at least one set of 8-12 repetitions (4-6 repetitions in reserve; RIR) per exercise (8-10 different exercises involving major muscle groups) are necessary to find muscle adaptations[25,28,35]. For untrained individuals, current literature shows that large muscle strength gains can be achieved with short (<60s) and moderate (60-120s) rest intervals between sets[36].

In this regard, combining both exercise types (CT) produces greater positive effects than performing them separately[25]. For this reason, a 12-week CT intervention is proposed, in which the first 4 weeks will progressively increase the volume to meet the WHO minimum physical activity recommendations, i.e., 150 min of moderate PA and 2 resistance days, during the last 8 weeks[19,37].

The purpose of this study is to evaluate how a CT intervention impacts AF burden, cardiac structure and electrical activity, physical fitness, PA levels, body composition, and health-related quality of life (HRQoL) in patients who have undergone PVI.

Study design

Overview

This protocol describes a randomized controlled trial (RCT) registered at ClinicalTrials.gov (identifier: NCT06832033) and approved by the Clinical Research Ethics Committee of Aragón (CEICA, Spain; Ref. C.I.PI24/174). Any modifications to the protocol during the course of the study will require prior approval from the Ethics Committee. The study design and reporting adhere to the SPIRIT guidelines (supplementary table 1)[38]. Individuals who meet the criteria and agree to participate must provide written informed consent before enrollment.

Participants

Participants will be recruited by a cardiologist and a sports scientist at the department of cardiology of the Lozano Blesa University Hospital Clinic, based on the following eligibility criteria:

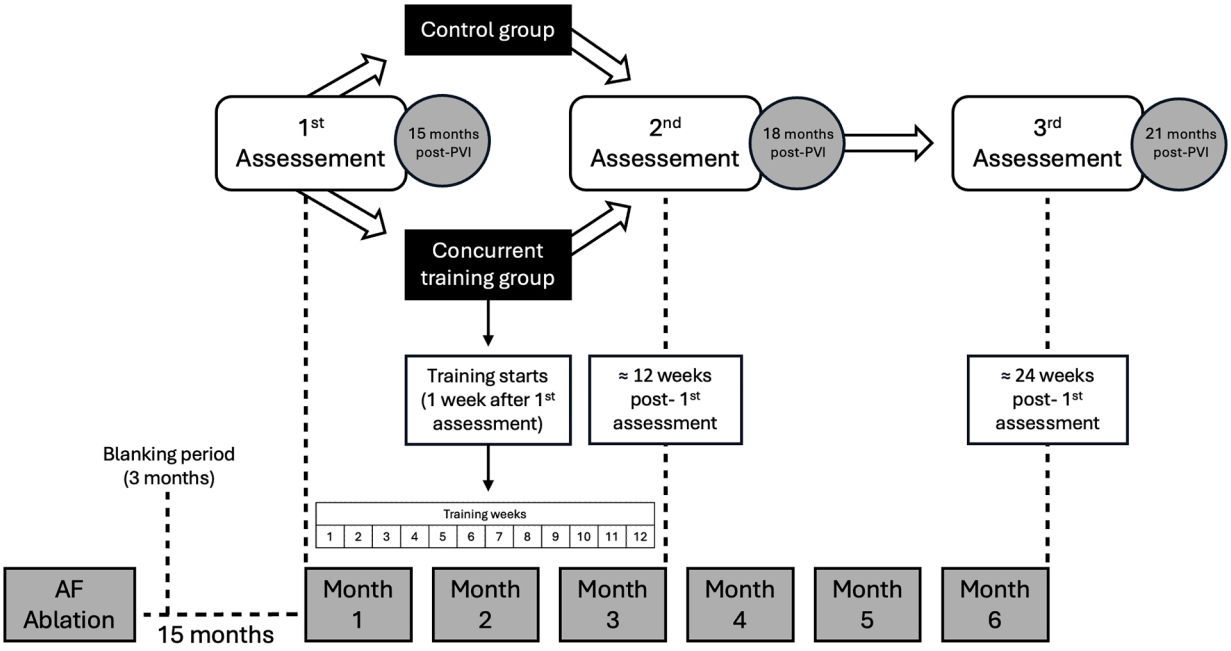


Fig. 1. Study timeline.

Inclusion criteria

The eligibility of candidate patients is based on the following inclusion criteria: (a) Adults aged 18 years or older; (b) Individuals who underwent PVI ~15 months before enrollment.

Exclusion criteria

Exclusion criteria are: (a) Severe atrial dilatation; (b) Structural heart disease; (c) Body mass index (BMI) >40 kg/m^2; (d) Presence of any absolute contraindication to exercise; (e) AF recurrence post-PVI[39].

Sample size

Sample size calculation was performed using the G*Power software (3.1 version). The F-test family was selected as the statistical test; we used ANOVA with a within-between interaction for 2 groups and 3 measurement points, assuming a correlation of 0.5 between repeated measures. To detect a medium effect ($f = 0.25$) with 80% power at α=0.05, 56 participants (28/group) are required. Allowing for 20% attrition, we added 12 participants (6 per group), yielding a target sample of 68 (34/group).

Randomization and intervention

Participants will be randomly assigned to one of two groups: (1) control group (CG) and (2) CT group (CTG). To ensure equity, eligible participants will be randomized (1:1) to a CTG or CG via https://www.randomizer.org, stratified by sex and age. A sports scientist will communicate the allocation. Both groups will receive usual medical care and standardized physical activity advice; only the CTG will undertake the exercise intervention. Except for the sports scientist delivering CT, the research and medical teams will remain blinded to allocation. Unblinding will occur only if it is essential for participant safety.

The exercise intervention is described following the Consensus Exercise Reporting Template (CERT): Explanation and Elaboration Statement[40], with the 16 required items detailed in Supplementary Table 2. As illustrated in Fig. 1, the study will span 6 months per patient. Three assessment points are scheduled: the first at 15 ± 2 months post-PVI, corresponding to the start of the exercise intervention (i.e., ~1 year after the 60-day blanking period), the second at 12 ± 2 weeks, coinciding with the end of the 12-week intervention, and the third at 12 ± 2 weeks after the completion of the training program, representing a follow-up assessment. Based on the estimated recruitment rate, the study is expected to last approximately 2 years.

The intervention will be conducted in a temperature-controlled, ventilated room at the Sports Activities Service of the University of Zaragoza, equipped with dumbbells, benches, and cycle ergometers; a semi-automatic external defibrillator will be available on site for safety. Assessments will be taken at the hospital and at the sports facility of the University of Zaragoza.

Intervention description

Training frequency, intensity, and duration

Participants assigned to the CTG will attend three supervised sessions/week over 12 weeks (36 sessions). Sessions will be held Monday through Thursday, with the option to choose between morning (11:30 a.m.) or afternoon (4:30 p.m.) time slots, ensuring a minimum interval of 24 hours between sessions. The progression and structure of the training program are detailed in Table 1.

As shown in Table 1, each session will last 35–75 minutes and include both resistance and endurance work. The endurance component will consist of MICT (64–76% HRmax), with volume increasing during the first 5 weeks (30-50 min/session) and remaining

Table 1
Weekly progression of CT intervention.

Week	Session duration (min)	Resistance work*			Endurance work **
		Reps.	Rest (s)	Freq. (day/week)	Duration (min/session)
1	35-55	8	40-50	1	30
2	40-60	8	40-50	1	35
3	45-65	10	60	1	40
4	50-70	12	60-70	1	45
5	55-75	8	40-50	2	50
6	55-75	8	40-50	2	50
7	55-75	8	40-50	2	50
8	55-75	10	60	2	50
9	55-75	10	60	2	50
10	55-75	10	60	2	50
11	55-75	12	60-70	2	50
12	55-75	12	60-70	2	50

* Always 1 set per exercise and 8 exercises, 4-6 RIR.
** It is included in the 3 weekly sessions, always at moderate-intensity (64-76% HRmax).

constant throughout the final 8 weeks to meet WHO recommendations (150 min/week)[34].

Resistance training will be performed with 8 exercises (1 set each), progressing from 8 to 12 repetitions in weeks 1–4 and again in weeks 5–8[21,25,28], emphasizing maximal concentric speed. The frequency will increase from 1 to 2 sessions per week after week 4. The intensity will be maintained between 4 and 6 RIR (~60-80% 1RM)[38], except in week 1, when light loads will be used to familiarize yourself with the exercises. The loads will be adjusted weekly for each exercise.

Session structure

Each training session will consist of 3 parts: (1) warm-up, (2) central part (comprising either endurance training alone or combined resistance plus endurance training) and (3) cool-down[41]. Each of these parts is described in detail below:

1) Warm-up: For sessions that include both resistance and endurance training, the warm-up will consist of 10 repetitions of each of 4 suspension-based exercises, as illustrated in Fig. 2. For endurance sessions, the warm-up will consist of the first 2 minutes on a stationary bike, gradually increasing intensity until reaching 64-76% HRmax.
2) Resistance training: Each resistance training session will include 8 exercises: 5 upper body and 3 lower body (Fig. 3). The resistance exercises will follow a sequence that prioritizes larger muscle groups at the beginning, followed by exercises targeting smaller muscle groups. All resistance exercises will be performed using free weights, including dumbbells and bars.
3) Endurance training: Endurance training will be performed following the resistance exercises, using a Technogym Group Cycle cycloergometer (Technogym S.p.A., Cesena, Italy). Each subject will adjust the cycle ergometer setup identically at the beginning of every session to ensure proper positioning and comfort throughout the workout. Table 1 outlines the progression of the endurance component across the 12-week CT. Pedaling cadence and power output (watts) will vary throughout each session and will be adjusted as needed to maintain HR within the prescribed moderate-intensity (64-76% HRmax).
4) Cool-down: After the endurance training, subjects will perform 2 minutes of low intensity pedaling to progressively reduce HR <64% HRmax, followed by stretching exercises (Fig. 4) to promote a subjective feeling of relaxation and facilitate the physiological transition to resting levels[28,42].

Supervision and adherence

An experienced sports scientist will supervise all sessions. Exercise sessions will be conducted in small groups (2-6 participants) with individualized guidance. Participants will not perform other exercise sessions and will be asked to maintain their habitual lifestyle throughout the trial.

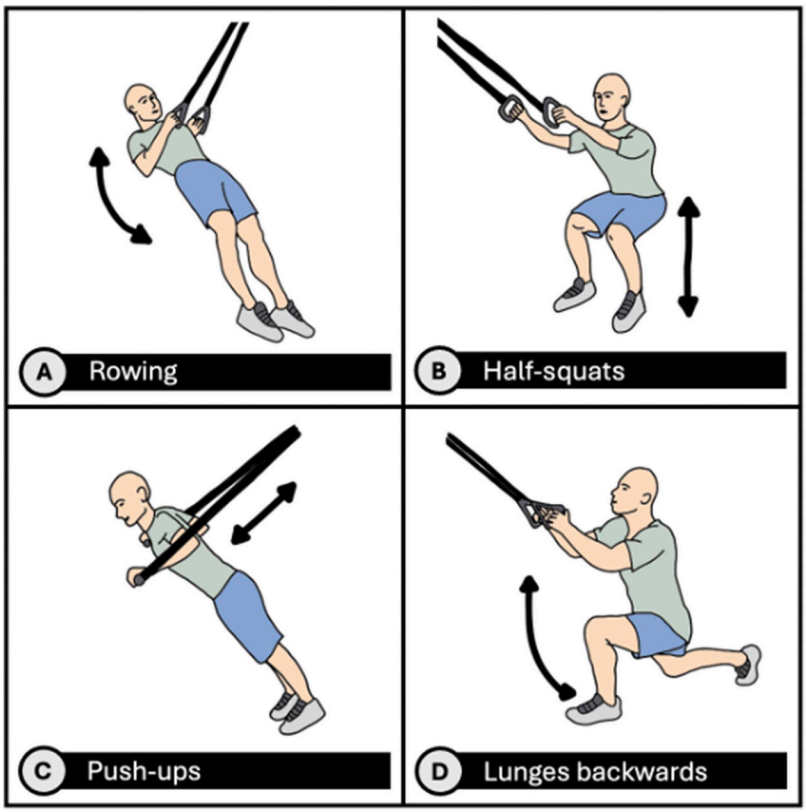


Fig. 2. Warm-up exercises with suspension straps.

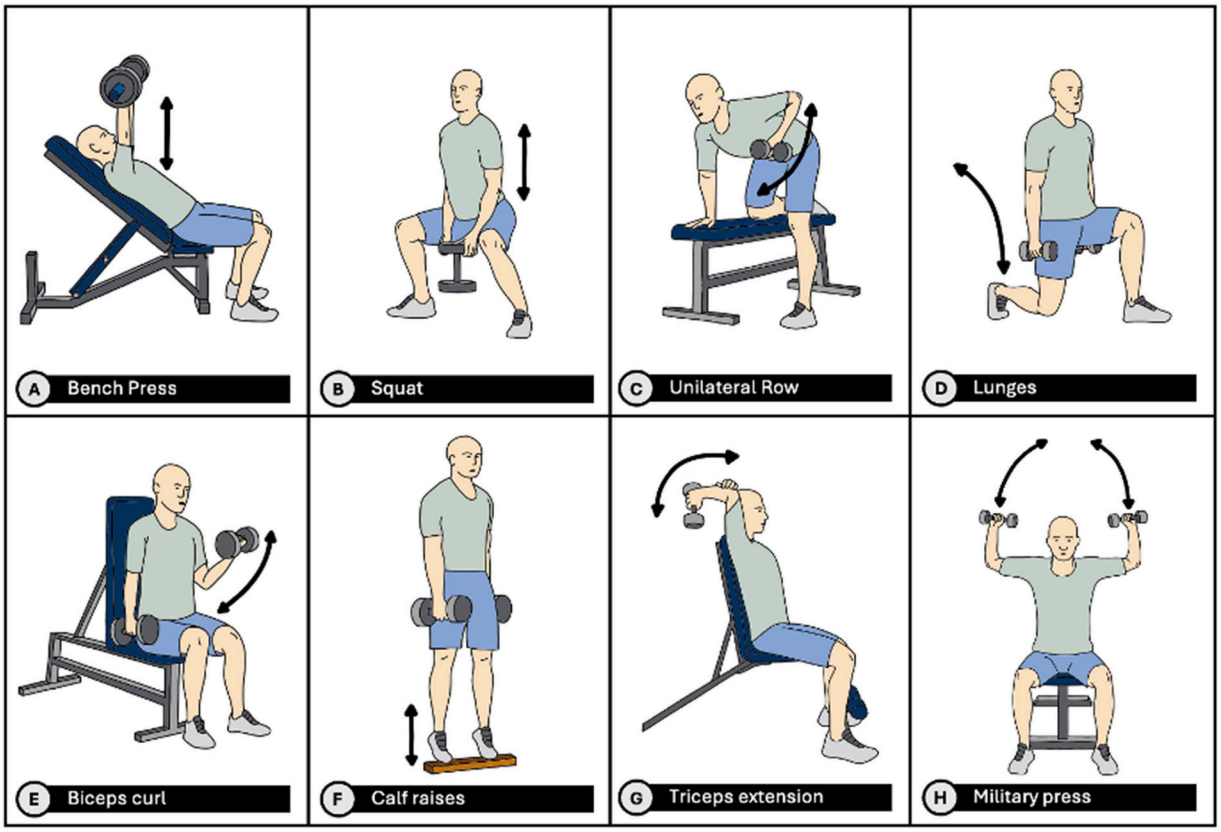


Fig. 3. Resistance exercises.

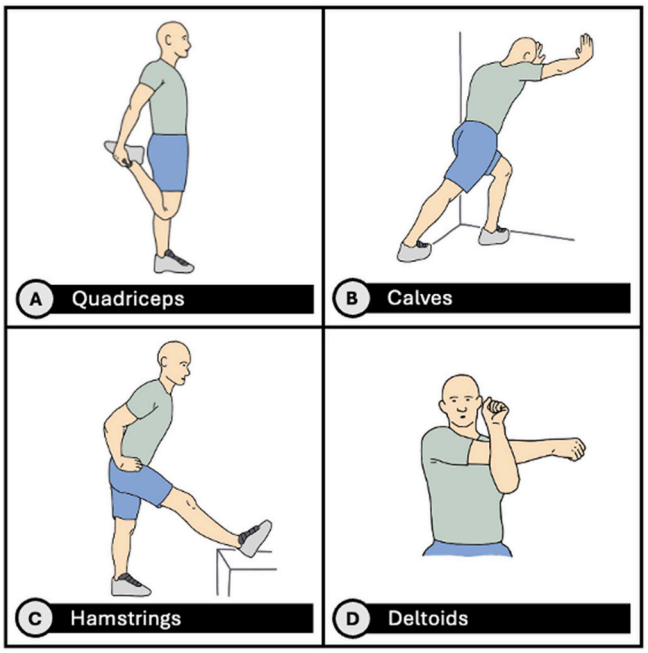


Fig. 4. Cool-down exercises.

Training sessions will be scheduled weekly by the supervising trainer; no home-based component is included. The room is equipped with a designated strength area, with materials such as dumbbells, benches, discs and bars and an area with stationary bicycles to develop endurance work.

During each training session, the sports scientist will record the following information in the database: (i) attendance of participants at training sessions; (ii) maximum and mean heart rate and heart rate variability of the session (using a Polar H10 connected to a Polar Pacer Pro Watch); (iii) perceived exertion at the end of the session using the adapted Borg scale[43]; (iv) any adverse effects (pain, discomfort, etc.).

At the end of each month, the trainer will evaluate each participant́s attendance rate. If attendance falls below 75%, the trainer will assess potential causes and provide constructive feedback to encourage adherence and improve participation. Participants may voluntarily withdraw from the trial at any time.

All participants will continue to receive standard pharmaceutical care throughout the study. They should maintain their normal PA as much as possible and will not be able to participate in any new exercise programs. Intervention will be stopped or modified in case of adverse events, participant request, or investigator's clinical judgment.

Outcome variables

The outcomes will include: (1) echocardiographic parameters, (2) electrocardiographic recordings, (3) physical fitness tests, (4) PA levels, (5) body composition, (6) HRQoL, and (7) AF burden. All assessments will take place at the Sports Activities Service of the University of Zaragoza, except for the echocardiogram and electrocardiogram, which will be performed at the hospital.

Outcome variables will be assessed at three time points (see Fig. 1 or Table 2). At each time point, participants will attend two assessment days scheduled within one week or less. Different variables will be measured on each day, as detailed below. All tests will be conducted by a sports scientist, except the echocardiogram, which will be done by a cardiologist.

Long-term cardiac monitoring will be performed using the Reveal LINQ-II™ implantable cardiac monitor (Medtronic, Minneapolis, MN, USA), which was implanted previous to the PVI. This device will record AF burden, allowing for quantification and characterization of arrhythmic episodes to monitor AF progression and assess treatment efficacy. It will also provide daily and weekly mean heart rate (HR) data to evaluate autonomic nervous system (ANS) adaptation over time.

Table 2
Participant timeline: Schedule of enrollment, interventions, and assessments.

	TRIAL PERIOD				
	Enrollment	**Post-randomization**			**Close-out**
TIMEPOINT	*M -1*	*Wk -1 (M 15)*	*Wk 12 (M 18)*	*Wk 24 (M 21)*	*Wk 36 (M 24)*
ENROLLMENT:					
Eligibility screen	X				
Informed consent	X				
Randomization	X				
INTERVENTION/ COMPARATOR:					
Concurrent Training		→	→		
ASSESSMENTS:					
General information, Echocardiogram, ECG Accelerometry, HRQoL, anthropometric data and fitness		X	X	X	
Results report					X

ECG, electrocardiogram; HRQoL, Health-Related Quality of Life; M, month; Wk, week.

Assessments

Day 1

Participants will go to the hospital in the afternoon, between 3:30 and 7:30 pm. Basic demographic data will be collected, including sex, date of birth, and hand dominance (right or left).

Echocardiogram. A transthoracic echocardiogram will be performed by a single trained observer using a Vivid iQ ultrasound scanner (GE HealthCare, Chicago, IL, USA). All measurements will be averaged over three cardiac cycles, and we will follow current recommendations of the American Society of Echocardiography and the European Association of Cardiovascular Imaging[44]. Standard 2D imaging, Doppler, and tissue Doppler will evaluate cardiac structure and function. Atrial size and function will be assessed using four-chamber views and volumetric analysis based on the modified Simpson's method[44], with additional functional parameters calculated according to Schaaf et al[45]. Atrial strain will be analyzed using speckle tracking in the 4-chamber view, and left ventricular strain will be assessed using two-dimensional speckle tracking in parasternal and apical long-axis projections. Strain analysis will be performed using EchoPAC^{TM} software (v204.129) in accordance with current international recommendations[46].

Electrocardiogram (ECG). A 10-minute, 12-lead ECG will be recorded using the H12+™ Digital Holter Recorder (Hillrom, Baxter International Inc.) with 2.5 μV amplitude resolution (20 bits) and a sampling frequency of 1000Hz. All the ECG signals will be preprocessed using band-pass filtering to reduce baseline wandering and high-frequency noise[47]. In sinus rhythm, QRS detection will be performed using a wavelet-based multi-lead delineator[48]. Ectopic beats will be identified using an algorithm based on the integral pulse frequency modulation model[49]. Heart rate variability (HRV) analysis will be performed to assess ANS modulation of cardiac electrical activity. Linear and nonlinear HRV indices in the time and frequency domains will be calculated[50]. Atrial electrophysiological properties will be evaluated by measuring the duration, morphology, rugosity, and temporal variability of the P wave[51].

Accelerometry. The Axivity AX6 triaxial wrist-worn accelerometer (Axivity Ltd, Newcastle upon Tyne, UK) will be used to measure PA levels[52]. Devices will be programmed with Open Movement software (OMGUI, version 1.0.0.43; Newcastle University, UK) to capture acceleration over 7 days at 100Hz, with a dynamic range of ±8g[53,54], in line with standard procedures for measuring daily PA in humans[55].

Day 2

The second assessment day will take place between 1:00 and 8:00 pm at a University of Zaragoza sports facility. The tests and their sequence are detailed below:

HRQoL questionnaire. HRQoL will be assessed using the validated Spanish versions of the EQ-5D-5L and SF-36 questionnaires[56,57], the latter of which is widely used in patients with AF[20].

Anthropometric data. Height will be measured without shoes using a stadiometer SECA 225 (SECA, Hamburg, Germany) to the nearest 0.1 cm. Body mass (kg) and body composition (fat and fat-free mass) will be assessed using a bioimpedance analyzer (TANITA MC780MA-N, Tanita, Tokyo, Japan).

Handgrip. Manual grip strength will be measured with a dynamometer (TAKEI TKK-5401) according to the NHANES (National Health and Nutrition Examination Survey) Muscle Strength Procedures Manual[58]. The position will be standing, with the legs separated at shoulder height, the arms in slight abduction, and the gaze straight ahead.

Five times sit-to-stand test. Participants will be asked to complete five repetitions of the sit-to-stand movement as fast as possible[59,60]. The initial and final positions will be seated.

30 seconds sit-to-stand test. Similar to the five-times sit-to-stand test, participants will be asked to complete as many repetitions of the sit-to-stand movement as possible for 30 seconds[61,62]. The number of repetitions completed will be recorded. The initial position will be seated; standing up at the end counts as half a repetition.

6-minute walk test (6MWT). Given the possible heterogeneity of the sample and the high proportion of elderly patients, the 6MWT will be performed as in the senior fitness test battery[63].

Statistical methods

Assumptions will be checked using the Shapiro–Wilk test (normality), the Levene test (homoscedasticity), and the Mauchly test (sphericity). A repeated-measures ANOVA with Bonferroni correction will assess group (CG vs. CTG) × time (baseline, second, third assessment) interactions. If assumptions are violated, within-group changes will be analyzed with the Wilcoxon signed-rank test and between-group differences with the Mann–Whitney U test, both with Bonferroni correction. Correlations and linear regressions will explore associations between variables. Significance will be set at $p < 0.05$. An interim analysis will be conducted by a designated team member once 50% of participants in each group complete the 3-month follow-up, and results will be reviewed to assess ethical conduct and study feasibility. To address potential participant dropout, both per-protocol and intention-to-treat analyses will be performed. Per-protocol includes participants who attend≥75% of sessions and complete baseline and post-intervention assessments; intention-to-treat includes all who complete baseline and at least one follow-up assessment after group allocation.

Discussion

The prevalence of AF continues to rise globally[4], and PVI is the most effective therapeutic strategy available[10]. Nevertheless, many patients remain sedentary or refrain from returning to physical activity post-PVI due to fear of recurrence, despite the well-documented health risks associated with inactivity[37].

The present study aims to investigate the effects of a CT program in patients who have undergone PVI. While previous studies have explored the benefits of cardiac rehabilitation programs initiated shortly after PVI[19], many lack methodological transparency and detailed intervention reporting aligned with SPIRIT or CERT guidelines (supplementary tables 1 and 2)[40,64], thereby limiting reproducibility and clinical applicability.

A distinguishing feature of this protocol is its delayed initiation: the intervention begins 1 year after the blanking period, allowing evaluation of exercise effects once patients have stabilized post-procedure. Moreover, the study uses objective, technology-based monitoring tools to assess exercise intensity, physiological adaptation, and arrhythmic risk, thereby adding methodological rigor to the evaluation.

Notably, the design prioritizes feasibility and scalability. The CT program is structured for delivery in a simple, non-hospital setting and is supervised by a sports scientist, with the potential to be adapted for autonomous implementation. This represents a step forward in developing safe, evidence-based exercise recommendations for patients following PVI, an area where current guidelines remain vague or lack long-term data.

If the intervention proves effective, this protocol may serve as a foundation for integrating physical exercise into standard post-PVI care, offering a practical, accessible approach to improving patient outcomes beyond the clinical setting.

Conclusions

To our knowledge, this is the first protocol to examine the impact of CT, and the hypothesis proposes that this combination improves clinically relevant outcomes without AF. The use of objective, technology-based monitoring tools will allow for more accurate conclusions to be drawn about patients who underwent PVI a year ago and are now recurrence-free. The results are expected to contribute to the development of safe and effective exercise guidelines for post-PVI patients, applicable in supervised sports centers or, potentially, in autonomous settings outside the hospital.

Funding sources

This study has been partially supported by Consejo Superior de Deportes (Unión Europea –Next Generation EU) through project EXP75053, by Agencia Estatal de Investigación – Ministerio de Ciencia e Innovación through projects PID2022-140556OB-I00 and TED2021-130459BI00 and by Gobierno de Aragón through T39_23R group. Funders do not have any involvement in or authority over study design, data collection, study management, data analysis, writing of research reports, or the decision to submit manuscripts for publication.

CRediT authorship contribution statement

Marcos Echevarría-Polo: Conceptualization, Methodology, Investigation, Writing – original draft. **Adrián Hernández-Vicente:** Conceptualization, Methodology, Investigation and Writing – review & editing. **Pablo Vadillo-Martín:** Methodology, Software and Writing – review & editing. **Fabian Sanchis-Gomar:** Writing – review & editing. **Jorge Melero-Polo:** Resources and Writing – review & editing. **Mercedes Cabrera-Ramos:** Resources. **Isabel Montilla-Padilla:** Resources. **Andrea Rucco:** Methodology, Software and Writing – review & editing. **Juan Pablo Martínez:** Software and Writing – review & editing. **Pablo Laguna:** Software. **Esther Pueyo:** Project administration, Resources, Software and Writing – review & editing. **Javier Ramos-Maqueda:** Project administration, Resources and Writing – review & editing. **Nuria Garatachea:** Conceptualization, Supervision, Project administration, Methodology and Writing – review & editing.

Authorship

All authors had access to the data and a role in writing the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.cpcardiol.2025.103218.

References

1. Emdin CA, Wong CX, Hsiao AJ, Altman DG, Peters SA, Woodward M, Odutayo AA. Atrial fibrillation as risk factor for cardiovascular disease and death in women compared with men: systematic review and meta-analysis of cohort studies. *BMJ*. 2016;532:h7013. https://doi.org/10.1136/bmj.h7013.

2. Odutayo A, Wong CX, Hsiao AJ, Hopewell S, Altman DG, Emdin CA. Atrial fibrillation and risks of cardiovascular disease, renal disease, and death: systematic review and meta-analysis. *BMJ*. 2016;354:i4482. https://doi.org/10.1136/bmj.i4482.
3. Tsao CW, Aday AW, Almarzooq ZI, Anderson CAM, Arora P, Avery CL, Baker-Smith CM, Beaton AZ, Boehme AK, Buxton AE, Commodore-Mensah Y, Elkind MSV, Evenson KR, Eze-Nliam C, Fugar S, et al. Heart disease and stroke statistics-2023 update: a report from the a report from the American heart association. *Circulation*. 2023;147:93–621. https://doi.org/10.1161/CIR.0000000000001123.
4. Chugh SS, Havmoeller R, Narayanan K, Singh D, Rienstra M, Benjamin EJ, Gillum RF, Kim YH, McAnulty Jr JH, Zheng ZJ, Forouzanfar MH, Naghavi M, Mensah GA, Ezzati M, Murray CJ. Worldwide epidemiology of atrial fibrillation: a global burden of disease 2010 study. *Circulation*. 2014;129:837–847. https://doi.org/10.1161/CIRCULATIONAHA.113.005119.
5. Deshmukh A, Iglesias M, Khanna R, Beaulieu T. Healthcare utilization and costs associated with a diagnosis of incident atrial fibrillation. *Heart Rhythm O2*. 2022;3:577–586. https://doi.org/10.1016/j.hroo.2022.07.010.
6. Buja A, Rebba V, Montecchio L, Renzo G, Baldo V, Cocchio S, Ferri N, Migliore F, Zorzi A, Collins B, Amrouch C, De Smedt D, Kypridemos C, Petrovic M, O'Flaherty M, et al. The cost of atrial fibrillation: a systematic review. *Value Health*. 2024;27:527–541. https://doi.org/10.1016/j.jval.2023.12.015.
7. Ricci C, Gervasi F, Gaeta M, Smuts CM, Schutte AE, Leitzmann MF. Physical activity volume in relation to risk of atrial fibrillation. A non-linear meta-regression analysis. *Eur J Prev Cardiol*. 2018;25:857–866. https://doi.org/10.1177/2047487318768026.
8. Gallagher C, Hendriks JML, Elliott AD, Wong CX, Rangnekar G, Middeldorp ME, Mahajan R, Lau DH, Sanders P. Alcohol and incident atrial fibrillation - a systematic review and meta-analysis. *Int J Cardiol*. 2017;246:46–52. https://doi.org/10.1161/CIR.0000000000001123.
9. Van Gelder IC, Rienstra M, Bunting KV, Casado-Arroyo R, Caso V, Crijns HJGM, De Potter TJR, Dwight J, Guasti L, Hanke T, Jaarsma T, Lettino M, Løchen ML, Lumbers RT, Maesen B, et al. 2024 ESC guidelines for the management of atrial fibrillation developed in collaboration with the european association for cardio-thoracic surgery (EACTS). *Eur Heart J*. 2024;45:3314–3414. https://doi.org/10.1093/eurheartj/ehae176.
10. Arbelo E, Brugada J, Blomström-Lundqvist C, Laroche C, Kautzner J, Pokushalov E, Raatikainen P, Efremidis M, Hindricks G, Barrera A, Maggioni A, Tavazzi L, Dagres N. Contemporary management of patients undergoing atrial fibrillation ablation: in-hospital and 1-year follow-up findings from the ESC EHRA atrial fibrillation ablation long-term registry. *Eur Heart J*. 2017;38:1303–1316. https://doi.org/10.1093/eurheartj/ehw564.
11. Phlips T, Taghji P, El Haddad M, Wolf M, Knecht S, Vandekerckhove Y, Tavernier R, Duytschaever M. Improving procedural and one-year outcome after contact force-guided pulmonary vein isolation: the role of interlesion distance, ablation index, and contact force variability in the 'CLOSE'-protocol. *Europace*. 2018;20:419–427. https://doi.org/10.1093/europace/eux376.
12. De Becker B, El Haddad M, De Smet M, François C, Tavernier R, le Polain de Waroux JB, Duytschaever M, Knecht S. Early atrial fibrillation recurrence post catheter ablation: Analysis from insertable cardiac monitor in the era of optimized radiofrequency ablation. *Hearth Rhythm*. 2024;21:521–529. https://doi.org/10.1016/j.hrthm.2024.01.020.
13. Noseworthy PA, Gersh BJ, Kent DM, Piccini JP, Packer DL, Shah ND, Yao X. Atrial fibrillation ablation in practice: assessing CABANA generalizability. *Eur Heart J*. 2019;40:1257–1264. https://doi.org/10.1093/eurheartj/ehz085.
14. K.H. Kuck, J. Brugada, A. Fürnkranz, A. Metzner, F. Ouyang, K.R. Chun, A. Elvan, T. Arentz, K. Bestehorn, S.J. Pocock, JP. Albenque, C. Tondo; FIRE AND ICE investigators, cryoballoon or radiofrequency ablation for paroxysmal atrial fibrillation, N Engl J Med 374 (206) 393-394. https://doi.org/10.1056/NEJMoa1602014.
15. Wittkampf FHM, van Es R, Neven K. Electroporation and its relevance for cardiac catheter ablation. *JACC Clin Electrophysiol*. 2018;4:977–986. https://doi.org/10.1016/j.jacep.2018.06.005.
16. Tabaja C, Younis A, Hussein AA, Taigen TL, Nakagawa H, Saliba WI, Sroubek J, Santangeli P, Wazni OM. Catheter-based electroporation: a novel technique for catheter ablation of cardiac arrhythmias. *JACC Clin Electrophysiol*. 2023;9:2008–2023. https://doi.org/10.1016/j.jacep.2023.03.014.
17. Joglar JA, Chung MK, Armbruster AL, Benjamin EJ, Chyou JY, Cronin EM, Deswal A, Eckhardt LL, Goldberger ZD, Gopinathannair R, Gorenek B, Hess PL, Hlatky M, Hogan G, Ibeh C, et al. 2023 ACC/AHA/ACCP/HRS guideline for the diagnosis and management of atrial fibrillation: a report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. *Circulation*. 2024;149:1–156. https://doi.org/10.1161/CIR.0000000000001193.
18. Oesterle A, Giancaterino S, Van Noord MG, Pellegrini CN, Fan D, Srivatsa UN, Amsterdam EA. Effects of supervised exercise training on atrial fibrillation: a meta-analysis of randomized controlled trials. *J Cardiopulm Rehabil Prev*. 2022;42:258–265. https://doi.org/10.1097/HCR.0000000000000665.
19. Kurasawa Y, Maeda H, Tamaru T, Sasaki T, Matsumori K, Yokokawa Y, Kitagawa T. Safety and effectiveness of exercise-based cardiac rehabilitation for patients with atrial fibrillation following radiofrequency catheter ablation therapy: a systematic review and meta-analysis. *Cureus*. 2023;15, e50476. https://doi.org/10.7759/cureus.50476.
20. Buckley BJR, Risom SS, Boidin M, Lip GYH, Thijssen DHJ. Atrial fibrillation specific exercise rehabilitation: are we there yet? *J Pers Med*. 2022;12:610. https://doi.org/10.3390/jpm12040610.
21. Pelliccia A, Sharma S, Gati S, Bäck M, Börjesson M, Caselli S, Collet JP, Corrado D, Drezner JA, Halle M, Hansen D, Heidbuchel H, Myers J, Niebauer J, Papadakis M, et al. 2020 ESC Guidelines on sports cardiology and exercise in patients with cardiovascular disease. *Eur Heart J*. 2021;42:17–96. https://doi.org/10.1093/eurheartj/ehaa605.
22. Leggio M, Fusco A, Coraci D, Villano A, Filardo G, Mazza A, Loreti C, Serafini E, Biscotti L, Bernabei R, Padua L, Giovannini S. Exercise training and atrial fibrillation: a systematic review and literature análisis. *Eur Rev Med Pharmacol Sci*. 2021;25:5163–5175. https://doi.org/10.26355/eurrev_202108_26530.
23. Ismail H, McFarlane JR, Nojoumian AH, Dieberg G, Smart NA. Clinical outcomes and cardiovascular responses to different exercise training intensities in patients with heart failure. a systematic review and meta-analysis. *JACC Heart Fail*. 2013;1:514–522. https://doi.org/10.1016/j.jchf.2013.08.006.
24. Wang Y, Wang Y, Xu D. Effects of different exercise methods and intensities on the incidence and prognosis of atrial fibrillation. *Trends Cardiovasc Med*. 2024;34:510–515. https://doi.org/10.1016/j.tcm.2024.01.002.
25. Paluch AE, Boyer WR, Franklin BA, Laddu D, Lobelo F, Lee DC, McDermott MM, Swift DL, Webel AR, Lane A. Resistance exercise training in individuals with and without cardiovascular disease: 2023 update: a scientific statement from the American heart association. *Circulation*. 2024;149:217–231. https://doi.org/10.1161/CIR.0000000000000118.
26. Fisher S, Smart NA, Pearson MJ. Resistance training in heart failure patients: a systematic review and meta-analysis. *Heart Fail Rev*. 2022;27:1665–1682. https://doi.org/10.1007/s10741-021-10169-8.
27. Garcia L, Pearce M, Abbas A, Mok A, Strain T, Ali S, Crippa A, Dempsey PC, Golubic R, Kelly P, Laird Y, McNamara E, Moore S, de Sa TH, Smith AD, et al. Non-occupational physical activity and risk of cardiovascular disease, cancer and mortality outcomes: a dose-response meta-analysis of large prospective studies. *Br J Sports Med*. 2023;57:979–989. https://doi.org/10.1136/bjsports-2022-105669.
28. Liguori G. *ACSM's Guidelines For Exercise Testing And Prescription*. eleventh ed. Philadelphia: Wolters Kluwer; 2021.
29. 2018 Physical Activity Guidelines Advisory Committee. 2018 Physical Activity Guidelines Advisory Committee scientific report, US Department of Health and Human Services, Washington DC, 2018.
30. Skielboe AK, Bandholm TQ, Hakmann S, Mourier M, Kallemose T, Dixen U. Cardiovascular exercise and burden of arrhythmia in patients with atrial fibrillation - A randomized controlled trial. *PLoS One*. 2017;12, e0170060. https://doi.org/10.1371/journal.pone.0170060.
31. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM, Nieman DC, Swain DP. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc*. 2011;43:1334–1359. https://doi.org/10.1249/MSS.0b013e318213fefb.
32. Gellish RL, Goslin BR, Olson RE, McDonald A, Russi GD, Moudgil VK. Longitudinal modeling of the relationship between age and maximal heart rate. *Med Sci Sports Exerc*. 2007;39:822–829. https://doi.org/10.1097/mss.0b013e31803349c6.
33. Risom SS, Zwisler AD, Rasmussen TB, Sibilitz KL, Madsen TL, Svendsen JH, Gluud C, Lindschou J, Winkel P, Berg SK. Cardiac rehabilitation versus usual care for patients treated with catheter ablation for atrial fibrillation: results of the randomized CopenHeart$_{RFA}$ trial. *Am Heart J*. 2016;181:120–129. https://doi.org/10.1016/j.ahj.2016.08.013.

34. Kato M, Ogano M, Mori Y, Kochi K, Morimoto D, Kito K, Green FN, Tsukamoto T, Kubo A, Takagi H, Tanabe J. Exercise-based cardiac rehabilitation for patients with catheter ablation for persistent atrial fibrillation: a randomized controlled clinical trial. *Eur J Prev Cardiol*. 2019;26:1931–1940. https://doi.org/10.1177/2047487319859974.
35. Helms ER, Cronin J, Storey A, Zourdos MC. Application of the repetitions in reserve-based rating of perceived exertion scale for resistance training. *Strength Cond J*. 2016;38:42–49. https://doi.org/10.1519/SSC.0000000000000218.
36. Grgic J, Schoenfeld BJ, Skrepnik M, Davies TB, Mikulic P. Effects of rest interval duration in resistance training on measures of muscular strength: a systematic review. *Sports Med*. 2018;48:137–151. https://doi.org/10.1007/s40279-017-0788-x.
37. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, Carty C, Chaput JP, Chastin S, Chou R, Dempsey PC, DiPietro L, Ekelund U, Firth J, Friedenreich CM, et al. World health organization 2020 guidelines on physical activity and sedentary behaviour. *Br J Sports Med*. 2020;54:1451–1462. https://doi.org/10.1136/bjsports-2020-102955.
38. Chan AW, Boutron I, Hopewell S, Moher D, Schulz KF, Collins GS, Tunn R, Aggarwal R, Berkwits M, Berlin JA, Bhandari N, Butcher NJ, Campbell MK, Chidebe RCW, Elbourne DR, et al. SPIRIT 2025 statement: updated guideline for protocols of randomized trials. *Nat Med Nat*. 2025;31:1784–1792. https://doi.org/10.1038/s41591-025-03668-w.
39. Balady GJ, Williams MA, Ades PA, Bittner V, Comoss P, Foody JM, Franklin B, Sanderson B, Southard D. Core components of cardiac rehabilitation/secondary prevention programs: 2007 update: a scientific statement from the American Heart Association Exercise, Cardiac Rehabilitation, and Prevention Committee, the Council on Clinical Cardiology; the Councils on Cardiovascular Nursing, Epidemiology and Prevention, and Nutrition, Physical Activity, and Metabolism; and the American Association of Cardiovascular and Pulmonary Rehabilitation. *Circulation*. 2007;115:2675–2682. https://doi.org/10.1161/CIRCULATIONAHA.106.180945.
40. Slade SC, Dionne CE, Underwood M, Buchbinder R. Consensus on exercise reporting template (CERT): explanation and elaboration statement. *Br J Sports Med*. 2016;50:1428–1437. https://doi.org/10.1136/bjsports-2016-096651.
41. Gibson AL, Wagner DR, Heyward VH. *Advanced Fitness Assessment And Exercise Prescription*. nineteenth ed. Champaign: Human Kintics; 2019.
42. Behm DG. *The Science And Physiology Of Flexibility And Stretching: Implications And Applications In Sport Performance And Health*. first ed. Abingdon: Routledge; 2018.
43. Borg G. *Borg's Perceived Exertion And Pain Scales*. Champaign: Human Kinetics; 1998.
44. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, Flachskampf FA, Foster E, Goldstein SA, Kuznetsova T, Lancellotti P, Muraru D, Picard MH, Rietzschel ER, Rudski L, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *J Am Soc Echocardiogr*. 2015;28:1–39. https://hdl.handle.net/2268/221545.
45. Schaaf M, Andre P, Altman M, Maucort-Boulch D, Placide J, Chevalier P, Bergerot C, Thibault H. Left atrial remodelling assessed by 2D and 3D echocardiography identifies paroxysmal atrial fibrillation. *Eur Heart J Cardiovasc Imaging*. 2017;18:46–53. https://doi.org/10.1093/ehjci/jew028.
46. Leischik R, Littwitz H, Dworrak B, Garg P, Zhu M, Sahn DJ, Horlitz M. Echocardiographic evaluation of left atrial mechanics: function, history, novel techniques, advantages, and pitfalls. *Biomed Res Int*. 2015;2015, 765921. https://doi.org/10.1155/2015/765921.
47. Sörnmo L. *Atrial Fibrillation From An Engineering Perspective*. first ed. Cham: Springer; 2018.
48. Martínez JP, Almeida R, Olmos S, Rocha AP, Laguna P. A wavelet-based ECG delineator: evaluation on standard databases. *IEEE Trans Biomed Eng*. 2004;51:570–581. https://doi.org/10.1109/TBME.2003.821031.
49. Mateo J, Laguna P. Analysis of heart rate variability in the presence of ectopic beats using the heart timing signal. *IEEE Trans Biomed Eng*. 2003;50:334–343. https://doi.org/10.1109/TBME.2003.808831.
50. Van Den MP, Berg J, Haaksma J, Brouwer RG, Tieleman G, Mulder G, Crijns HJGM. Heart rate variability in patients with atrial fibrillation is related to vagal tone. *Circulation*. 1997;96:1209–1216. https://doi.org/10.1161/01.CIR.96.4.1209.
51. Acampa M, Lazzerini PE, Martini G. Atrial cardiopathy and sympatho-vagal imbalance in cryptogenic stroke: pathogenic mechanisms and effects on electrocardiographic markers. *Front Neurol*. 2018;9:469. https://doi.org/10.3389/fneur.2018.00469.
52. Echevarría-Polo M, Marín PJ, Pueyo E, Maqueda JRamos, Garatachea N. Variability and reliability of the Axivity AX6 accelerometer in technical and human motion conditions. *Sensors*. 2025;25:2480. https://doi.org/10.3390/s25082480.
53. OpenMovement · openmovementproject/openmovement Wiki · GitHub. https://github.com/openmovementproject/openmovement/wiki/OpenMovement, 2018 (accessed 2025 Mar 12).
54. Arvidsson D, Fridolfsson J, Börjesson M. Measurement of physical activity in clinical practice using accelerometers. *J Intern Med*. 2019;286:137–153. https://doi.org/10.1111/joim.12908.
55. Migueles JH, Cadenas-Sanchez C, Ekelund U, Delisle Nyström C, Mora-Gonzalez J, Löf M, Labayen I, Ruiz JR, Ortega FB. Accelerometer data collection and processing criteria to assess physical activity and other outcomes: a systematic review and practical considerations. *Sports Med*. 2017;47:1821–1845. https://doi.org/10.1007/s40279-017-0716-0.
56. Badia X, Roset M, Montserrat M, Herdman M. The Spanish version of EuroQol: a description and its applications. *Eur Qual Life Scale Med Clin*. 1999;112:79–85.
57. Alonso J, Prieto L, Antó J. The Spanish version of the SF-36 Health Survey (the SF-36 health questionnaire): an instrument for measuring clinical results. *Med Clin*. 1995;104:771–776.
58. National Health and Nutrition Examination Survey (NHANES). Muscle Strength Procedures Manual, Centers for Disease Control and Prevention, Atlanta, 2013.
59. Albalwi AA, Alharbi AA. Optimal procedure and characteristics in using five times sit to stand test among older adults: a systematic review. *Medicine*. 2023;102, e34160. https://doi.org/10.1097/MD.0000000000034160.
60. Goldberg A, Chavis M, Watkins J, Wilson T. The five-times-sit-to-stand test: validity, reliability and detectable change in older females. *Aging Clin Exp Res*. 2012;24:339–344. https://doi.org/10.1007/BF03325265.
61. Lein DH, Alotaibi M, Almutairi M, Singh H. Normative reference values and validity for the 30-second chair-stand test in healthy young adults. *Int J Sports Phys Ther*. 2022;17:907–914. https://doi.org/10.26603/001c.36432.
62. Jones CJ, Rikli RE, Beam WC. A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. *Res Q Exerc Sport*. 1999;70:113–119. https://doi.org/10.1080/02701367.1999.10608028.
63. Rikli RE, Jones CJ. Development and validation of a functional fitness test for community- residing older adults. *J Aging Phys Act*. 1999;7:129–161. https://doi.org/10.1093/geront/gns071.
64. Chan AW, Tetzlaff JM, Altman DG, Laupacis A, Gøtzsche PC, Krleža-Jerić K, Hróbjartsson A, Mann H, Dickersin K, Berlin JA, Doré CJ, Parulekar WR, Summerskill WS, Groves T, Schulz KF, et al. SPIRIT 2013 statement: defining standard protocol items for clinical trials. *Ann Intern Med*. 2013;158:200–207. https://doi.org/10.7326/0003-4819-158-3-201302050-00583.