Effectiveness and safety of home-based *versus* centre-based exercise programmes for pulmonary hypertension: a systematic review with meta-analysis

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Shareable abstract (@ERSpublications)
Home-based exercise programmes may be viable alternatives to centre-based ones for PH patients, with similar clinical benefits. However, limited self-monitoring data impacts safety assessment. Further research is needed to define optimal implementation. https://bit.ly/4kO92xa

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Abstract

Introduction Pulmonary hypertension is a pathophysiological disorder with poor prognosis. Exercise intolerance and lower physical activity levels are common features of pulmonary hypertension and affect patients' quality of life. Exercise training effectively improves clinical outcomes in this population, but access to rehabilitation centres is often limited. A home-based exercise training component could be an accessible and cost-effective alternative, but the efficacy and safety of this approach in pulmonary hypertension remain unclear.

Methods We conducted a systematic review and meta-analysis of studies retrieved from six international databases. The studies evaluated home-based exercise interventions in patients with pulmonary hypertension, including both stand-alone and hybrid setups, and assessed safety, efficacy (exercise capacity, cardiorespiratory outcomes and functional class) and adherence.

Results We included 19 studies. Compared with inactive controls, home-based exercise training improved the 6-min walk distance (mean difference (MD) 54.85 m, $p<0.01$), peak oxygen uptake (standardised MD 0.83 $mL \cdot kg^{-1} \cdot min^{-1}$, $p<0.01$), ventilatory efficiency (MD −3.93, $p<0.01$) and quality of life scores. Improvements in clinical outcomes were comparable between home-based and centre-based interventions. No clinical worsening or exercise training-related severe adverse events were reported; however, most studies did not report health-related self-monitoring strategies at home. The level of adherence was generally high, and the drop-out rates were comparable between home-based and centre-based interventions.

Conclusion Home-based exercise interventions appear to be viable alternatives to centre-based programmes for patients with pulmonary hypertension, showing comparable improvements in clinical outcomes. However, limited reporting on self-monitoring may affect the overall safety assessment. Further research is needed to determine the optimal implementation of these interventions.

Introduction

Pulmonary hypertension (PH) is a pathophysiological disorder associated with multiple clinical conditions and characterised by a poor prognosis [1, 2]. The PH spectrum accommodates five distinct subgroups: Group 1: pulmonary arterial hypertension (PAH); Group 2: PH due to left heart disease; Group 3: PH due

to lung diseases, hypoxia or both; Group 4: chronic thromboembolic PH (CTEPH); and Group 5: PH with unclear multifactorial mechanisms [1]. Regardless of the aetiology, patients with PH present with progressive exercise intolerance that impacts quality of life (QoL) and autonomy [1, 3, 4]. Although optimised pharmacological therapies have been effective in terms of improving the survival rate, adjuvant therapies are a relevant part of the treatment for decreasing disease progression and, consequently, maintaining QoL [1].

Exercise training (ET) has historically been discouraged for patients with PH, but recent recommendations highlight the efficacy of ET in patients with stable and optimal pharmacological therapy [1–8]. This shift has been supported by growing evidence that increased sedentary behaviour is associated with worsened clinical function and QoL in this population [9–11]. Access to rehabilitation centres, however, is often limited and constitutes a major barrier to ET for this population [12].

Alternatively, home-based programmes have emerged as a feasible strategy to provide ET to clinical populations [13, 14], as endorsed by global health organisations [15, 16]. Notably, accelerated advancements in telehealth and remote rehabilitation technologies over the past 5 years have enabled an increase in home-based exercise programmes [13], potentially overcoming geographic barriers often experienced by patients with PH [12–14]. However, it is necessary to comprehensively examine current home-based interventions for patients with PH. Furthermore, the absence of a detailed analysis of the efficacy and safety of home-based exercise models may hinder their implementation in patient care for this population.

Previous systematic reviews and meta-analyses investigating the effects of ET on PH-related outcomes included a pooled analysis of centre-based (both inpatient and outpatient), home-based and hybrid exercise programmes [17], precluding the assessment and interpretation of the safety and effectiveness of a home-based exercise component. Thus, we conducted a systematic review and meta-analysis to determine whether the remote, home-based exercise component, alone or as part of a hybrid programme, is safe and efficient in improving the clinical outcomes of patients with PH. As a secondary goal, this review discussed adherence to these exercise interventions. Comparisons were then performed against a nonphysical activity control condition and centre-based interventions.

Methods

Registration

The present study followed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (figure 1) [18] and was registered in the International Prospective Register of Systematic Reviews (PROSPERO CRD42022304934) [19].

Search strategy and studies selection

Searches were performed by two independent members of the research team (ICR and SMS) until March 2022 and updated in September 2023, using six electronic databases (PubMed, Web of Science, Cochrane, Scopus, SPORTDiscus and CINAHL (*via* EBSCOhost)). The descriptors for the searches were defined using Medical Subject Headings (whenever possible) and were related to the target population ("pulmonary hypertension" OR "pulmonary arterial hypertension" OR "chronic thromboembolic pulmonary hypertension" OR "CTEPH" OR "pulmonary heart disease") and intervention ("home-based program" OR "home-based exercise*" OR "telerehabilitation" OR "home-based rehabilitation" OR "home-based training" OR "home-based physical activity" OR "home exercise" OR "home physical activity" OR "physical activity at home" OR "exercise at home" OR "tele exercise" OR "unsupervised exercise program*" OR "home-based physical activity" OR "physical activity apps" OR "outpatient training" OR "hybrid training" OR "cardiac rehabilitation" OR "training at home" OR "rehabilitation"). Finally, to identify other relevant studies, we also screened reference lists from the selected studies and review articles, and conducted a search on Google Scholar.

Eligibility criteria

The eligibility criteria were determined according to the Population, Intervention, Comparison, Outcomes, Study design (PICOS) framework [18–20], and no restrictions on language or publication date were applied.

The inclusion criteria of the studies were as follows: 1) to be conducted on any group of PH (groups 1–5); 2) to include home-based exercise either as the predominant strategy of rehabilitation (>90% of the sessions being undertaken at home) or as part of a hybrid programme; 3) to include assessments of at least one of the following: safety, feasibility, efficacy, adherence, QoL, cardiorespiratory capacity and/or

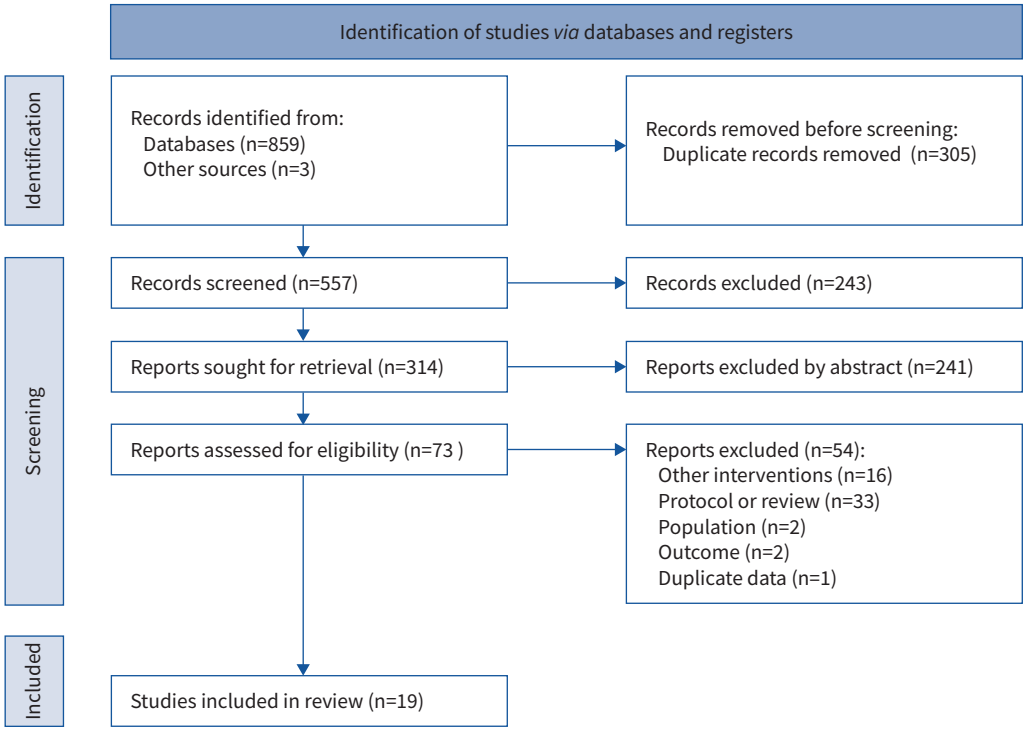

FIGURE 1 Study flowchart.

haemodynamic parameters; and 4) studies conducted on adults (⩾18 years). For the study design, we included randomised controlled trials (RCTs), randomised uncontrolled trials or uncontrolled trials (*i.e.* before *versus* after trials (BATs)). Only randomised studies were considered for meta-analysis to ensure methodological rigour and reliability. Following the A MeaSurement Tool to Assess systematic Reviews (AMSTAR) 2 principles, the BATs were included in the systematic review to provide a comprehensive overview of the available evidence [21]. For comparison, we considered interventions involving centre-based exercise and hybrids. Studies were excluded if they were protocol studies, observational or acute exercise studies.

On completion of the searches, two members of the research team (ICR and SMS) independently selected the articles using a two-stage strategy, namely 1) title and abstract screening and 2) full-text review. Any discrepancies were solved through discussion between the two members. The selection was made using the software Rayyan QCRI (https://www.rayyan.ai/).

Data extraction

Data were extracted by two researchers (ICR and SMS) using a standardised spreadsheet and following the PICOS framework [18, 20, 21]. Study authors were contacted to request additional or missing data. The data extracted comprised author (data), participant information (*e.g.* sample size, mean and range age, gender, disease aspects), methods (*e.g.* study design, total duration of study, study setting, withdrawals, date of study, data analysis, intention-to-treat (ITT)), characteristics of the intervention (*e.g.* description of intervention, comparison, control of intervention, method of delivery, duration and frequency, exercise type, volume and intensity supervision, monitoring, support components), outcome data (*e.g.* mean±SD, absolute change (Δ)) and notes (*e.g.* funding for study and notable conflicts of interest of study authors).

Description of the outcomes

Primary outcomes

The study had four primary outcomes. 1) Efficacy: determined as functional exercise capacity (6-min walk distance (6MWD)), exercise capacity (peak oxygen uptake ($\dot{V}_{O_2peak}$)) and ventilatory efficiency (minute ventilation by carbon dioxide output ($\dot{V}_E/\dot{V}_{CO_2}$) slope) obtained during cardiopulmonary exercise testing (CPET) [22], and World Health Organization functional class (WHO-FC) [23]; 2) safety: adverse events associated with the ET (desaturation (decrease in oxygen saturation measured by pulse oximetry

(S_{pO_2}) >4%), light-headedness, dizziness, syncope or presyncope, hypotension, exercise-related mortality) [2]; 3) clinical worsening and disease progression established by investigators (hospitalisation, FC worsening and/or requirement for additional pharmacological therapy); and 4) adherence: established by investigators description.

Secondary outcomes

The secondary outcomes were 1) health-related QoL established *via* a generic questionnaire (Short Form Health Survey 36 (SF-36) domains); 2) CPET-derived parameters (heart rate (HR) at rest and peak, S_{pO_2} at rest and peak, oxygen pulse (O_2/HR)); and 3) haemodynamic parameters obtained by echocardiogram (pulmonary artery systolic pressure (PASP)).

Assessment of risk of bias

Two review authors (ICR and SMS) analysed the studies' quality using the revised Cochrane risk-of-bias tool for randomised trials (RoB 2) (supplementary figure S1) [24]. This tool has five domains: 1) risk of bias arising from the randomisation process; 2) risk of bias due to deviations from the intended interventions (effect of assignment to intervention and effect of adhering to intervention); 3) missing outcome data; 4) risk of bias in the measurement of the outcome; and 5) risk of bias in the selection of the reported result. The tool then produces an overall risk of bias. Each source of bias within these domains was classified as high, low or unclear. The classifications were supported by quotations from the study report and a justification for our judgment (supplementary figure S1). Of note, the blinding of the intervention group (*i.e.* participants and providers) was not addressed by the authors of the trials; therefore, item 2.1 was marked as "yes" across the studies. However, the remaining elements of the blinding domain were assessed individually; as a result, not all studies were classified as having a low risk of bias in this domain. In the case of missing data, a loss of up to 15% was considered acceptable [25]. The Consensus on Exercise Reporting Template (CERT) was then used to assess the quality of reporting [26].

Data analysis: systematic review

A narrative synthesis was performed to describe and explore the data from the studies. Studies are described in the text and tables and were organised by key details, characteristics of the population (sample size, age range, gender, PH aetiology, WHO-FC), intervention and the following outcomes: 1) safety (*i.e.* the occurrence of any health-related adverse event), 2) adherence (*i.e.* the degree of compliance to the exercise sessions), 3) main efficacy outcomes, 4) secondary outcomes and 5) study design. Predominantly home-based and hybrid (centre-based combined/followed by home-based) exercise interventions were described in terms of exercise type, frequency, duration and intensity. A control group (absence of exercise intervention) or centre-based settings (both inpatient and outpatient) were used as comparisons. Intensity was defined and described based on subjective (*e.g.* authors' description of the intervention) or objective (*e.g.* achieved HR or rating of perceived effort (RPE)) information provided by the authors. Finally, we summarised aspects related to the delivery of the intervention, such as supervision, monitoring and use of support components, as previously described [27].

Data analysis: meta-analysis

The data analysis was performed in accordance with the Cochrane Handbook for Systematic Reviews of Interventions [28, 29]. The primary and secondary outcomes were computed considering the following comparisons: 1) home-based interventions (pooled analysis of hybrid and exclusively home-based) *versus* control (no exercise intervention) and 2) home-based *versus* centre-based interventions. Meta-analyses were only performed if there were at least three studies including the outcome within each comparison or two studies in the subgroup analysis. Absolute changes were reported as the difference from baseline. When not provided, we imputed them as described in detail in the Cochrane Handbook [29]. Studies were combined using random-effects meta-analysis, which was conducted using the Hedge's g mean differences (MD) or standardised mean difference (SMD) when the values were on different scales [30]. Restricted maximum likelihood was used to estimate between-study variance [31]. The drop-out rates were analysed using risk difference (RD). Meta-analyses were performed in RStudio version 4.02 (www.r-project.org), performed with the "metacont" and the "metabin" functions of the meta packages [32]. Although not included in the meta-analysis, the uncontrolled trials are qualitatively described in the text.

The heterogeneity among the trials in each meta-analysis was measured *via* the I^2 statistic procedure and classified as low (I^2<30%), moderate (I^2=30–50%), substantial (I^2=50–75%) or considerable (I^2>75%) heterogeneity [33].

Results

Literature search

The search of the databases identified 859 studies and three were derived from other sources (previous reviews and references). Following the removal of duplicates (n=305), 557 publications were screened for inclusion. Of these, 484 were excluded after reviewing the title (n=243) and abstract (n=241). From the 73 papers selected for full reading, 54 were excluded due to the absence of intervention (n=33), the absence of a home-based component (n=16) or for other reasons (n=5). Therefore, 19 studies were included in the review and are listed in the qualitative analysis. Among these, 11 studies were suitable for meta-analysis (figure 1).

Study characteristics

The methodological characteristics of all studies are detailed in table 1. Among the 19 included studies, 10 were RCTs, two were randomised uncontrolled trials and seven were BATs. In total, these studies enrolled 899 patients, mainly adults and older adults (*i.e.* 35–65 years old).

Most of these studies (n=8) were conducted in patients with WHO-FC II and III. Regarding the PH aetiology, the majority of the patients included (51%) belonged to groups 1 (idiopathic PAH, 35%) and 4 (CTEPH, 16% of the patients).

Risk of bias

Overall, 63.1% of the studies were deemed to have high risk of bias and 36.9% with some concerns (supplementary figure S1). Methodological issues mainly arose from the "randomisation process" (seven BATs and eight randomised studies lacked clear randomisation descriptions) and the "selection of reported results" (17 studies lacked prespecified plans or clinical trial registration). In "deviations from intended interventions", blinding was not feasible, resulting in three high-risk studies (no ITT analysis, loss >15% participants) and three with some concerns (no ITT analysis, loss <15% participants). For "missing outcome data", most studies (n=16) had low risk. In "measurement of outcome", seven studies had "some concerns" (assessors aware of group allocation) and one was high risk (control group had single-point measurement) [38].

Consensus on exercise reporting template

The quality of the exercise reporting (*via* CERT) showed an average score of 11.1 (range 4–16). Domains that were not generally addressed included a detailed description of motivation strategies, a detailed description of the intervention (exercise characteristics, mode of execution, how progression occurred) and adherence reporting.

Intervention characteristics: ET programme

The intervention characteristics employed in the studies are detailed in table 2. The interventions lasted from 6 to 24 weeks, with a frequency ranging from 3 to 7 days per week. Each session lasted from 5 to 90 min. The majority of the studies (n=15) used a multimodal home-based exercise routine comprising aerobic, strength and respiratory training. One study employed aerobic exercises and stretching [38]; one study used aerobic exercises, stretching and respiratory training [41]; one study employed exclusively upper extremity aerobic exercise [39]; and one study used aerobic and strengthening exercises for lower limbs [6]. The majority of the aerobic sessions used walking, either exclusively [37, 38] or associated with cycling [2, 5, 8, 34, 35, 37, 38, 40, 42, 44, 45, 47–49]. As for the mode of aerobic exercise, eight studies exclusively employed a constant workload (both in-hospital and at home). Eleven studies employed interval bicycle ergometer training during the centre-based phase and did not specify whether this modality was maintained in the home-based training [2, 5, 8, 37, 42, 44–49].

Regarding exercise equipment, 12 studies used cycle ergometers and dumbbells, one study also combined water bottles for the strengthening training [34], one study used an arm ergometer (in-hospital) [39], two studies did not include equipment in the exercise routine [41, 42] and three studies did not provide information regarding the use of equipment [39, 40, 43]. Exercise sessions were considered as moderate-to-high intensity, which was monitored by RPE (target 3–6 on a 6–10 Borg Scale) (n=4 studies) and/or % of peak heart rate (HR_{peak}) (50–80% of the HR_{peak}) (n=15 studies).

None of the stand-alone home-based studies provided supervision to the participants [34–36, 40]. Two studies using this setup did not report any information regarding supervision [40, 41]. Among the 13 hybrid home-based trials, only one study reported that the home-based exercise sessions were remotely supervised [38]. The remaining studies reported that only the in-hospital phase was supervised. Finally, most exercise interventions (n=18 out 19 studies) included a strategy for monitoring either the intensity of

TABLE 1 Methodological characteristics of included studies

Study	Population				Intervention type	Comparison	Outcomes[¶]/instruments	Study design	Adverse events[+]
	Total patients (n)[#]	Functional class	Sex	Age, years (weighted mean±SD)					
Butāne *et al.*, 2022 [34]	21	II–III	M	66.8±14.2	Home-based	Control group	6MWD	RCT	None
Butāne *et al.*, 2021 [35]	19	II–III	F	64.5±17.7	Home-based	Control group	6MWD	RCT	None
Wojciuk *et al.*, 2021 [36]	46	II–III	M+F	51.7±15.0	Home-based	Control group	6MWD, QoL (SF-36), S_{pO_2}, WHO-FC	RCT	Fatigue (n=1); sudden increase in HR during training (n=1)
Grünig *et al.*, 2021 [37]	129	II–IV	M+F	53.6±12.5	Hybrid home-based	Control group	6MWD, QoL (SF-36), $\dot{V}_{O_2peak}$, $\dot{V}_E/\dot{V}_{CO_2}$, HR, S_{pO_2}, PASP, WHO-FC	RCT	General training group: arrhythmia (n=3) At home: not addressed by the authors
Rakhmawati *et al.*, 2020 [38]	39	I–II	M+F	36.6±9.6	Hybrid home-based	Control group	6MWD, WHO-FC	RCT	Hybrid home-based: None
Yilmaz *et al.*, 2020 [39]	23	I–III	M+F	37.6±14.1	Home-based	Centre- based	6MWD, QoL (SF-36), $\dot{V}_{O_2peak}$, $\dot{V}_E/\dot{V}_{CO_2}$, HR, O_2/HR, WHO-FC	RT	None
Babu *et al.*, 2019 [40]	84	I–IV	M+F	49.4±14.6	Home-based	Control group	6MWD, QoL (SF-36), WHO-FC	RCT	None
Karapolat *et al.*, 2019 [41]	30	II–III	M+F	44.0±13.5	Home-based	Centre-based	6MWD, QoL (SF-36), $\dot{V}_{O_2peak}$, PASP	RT	None
Fukui *et al.*, 2016 [6]	43	I–IV	M+F	66.6±10.0	Hybrid home-based	Control group	6MWD, $\dot{V}_{O_2peak}$, $\dot{V}_E/\dot{V}_{CO_2}$, O_2/HR, HR, S_{pO_2}, WHO-FC	RCT	None
Ehlken *et al.*, 2016 [5]	87	II–IV	M+F	56.0±15.0	Hybrid home-based	Control group	6MWD, $\dot{V}_{O_2peak}$, O_2/HR, HR, WHO-FC	RCT	Not addressed by the authors
Ihle *et al.*, 2014 [42]	17	II–III	M+F	62.0±13.0	Hybrid home-based	None	6MWD, QoL (SF-36)	Pre-post study	None
Inagaki *et al.*, 2014 [43]	8	II–III	F	63.9±12.2	Hybrid home-based	None	6MWD, PASP, WHO-FC	Pre-post study	In-hospital: mild presyncope in one session (n=1) At home: none
Kabitz *et al.*, 2014 [44]	7	III–IV	M+F	59.6±11.1	Hybrid home-based	None	6MWD	Pre-post study	None
Becker-Grünig *et al.*, 2013 [45]	20	II–III	M+F	48.0±11.0	Hybrid home-based	None	6MWD, QoL (SF-36), $\dot{V}_{O_2peak}$, $\dot{V}_E/\dot{V}_{CO_2}$, O_2/HR, S_{pO_2}, HR, PASP, WHO-FC	Pre-post study	In-hospital: oxygen desaturation At home: not addressed by the authors
Ley *et al.*, 2013 [46]	20	II–III	M+F	50.5±11.0	Hybrid home-based	Control group	6MWD, WHO-FC	RCT	Not addressed by the authors
Grünig *et al.*, 2012 [47]	183	I–IV	M+F	53.0±15.0	Hybrid home-based	None	6MWD, $\dot{V}_{O_2peak}$, $\dot{V}_E/\dot{V}_{CO_2}$, O_2/HR, HR, PASP, WHO-FC	Pre-post study	In-hospital: syncope (n=1); presyncope (n=1); arrhythmia (n=3) At home: not monitored

Continued

TABLE 1 Continued

Study	Population				Intervention type	Comparison	Outcomes[¶]/instruments	Study design	Adverse events[+]
	Total patients (n)[#]	Functional class	Sex	Age, years (weighted mean±SD)					
Nagel *et al.*, 2012 [48]	35	II–IV	M+F	61.0±15.0	Hybrid home-based	None	6MWD, $\dot{V}_{O_2peak}$, $\dot{V}_E/\dot{V}_{CO_2}$, O_2/HR, HR, S_{pO_2}, PASP, QoL (SF-36), WHO-FC	Pre-post study	In-hospital: n=5 patients had an adverse event, in two cases it was related or possibly related to the training programme; syncope (n=1) At home: not addressed by the authors
Grünig *et al.*, 2011 [49]	58	II–IV	M+F	51.0±12.0	Hybrid home-based	None	6MWD, $\dot{V}_{O_2peak}$, $\dot{V}_E/\dot{V}_{CO_2}$, HR, QoL (SF-36), WHO-FC	Pre-post study	In-hospital: dizziness without fainting after bicycle ergometer training (n=2) At home: not addressed by the authors
Mereles *et al.*, 2006 [8]	30	II–IV	M+F	50.0±13.0	Hybrid home-based	Control group	6MWD, $\dot{V}_{O_2peak}$, $\dot{V}_E/\dot{V}_{CO_2}$, HR, PASP, QoL (SF-36), WHO-FC	RCT	In-hospital: dizziness without fainting immediately after bicycle ergometer training (n=2), oxygen desaturation (n=1) At home: not addressed by the authors

6MWD: 6-min walking distance; CPET: cardiopulmonary exercise test; F: female; HR: heart rate; M: male; O_2/HR: oxygen pulse obtained *via* CPET; PASP: pulmonary arterial systolic pressure obtained *via* echocardiography; QoL: quality of life obtained *via* SF-36; RCT: randomised control trial; RT: randomised uncontrolled trial; SF-36: Short Form Health Survey 36; S_{pO_2}: peripheral saturation from pulse oximeter; $\dot{V}_E/\dot{V}_{CO_2}$: minute ventilation by carbon dioxide output slope obtained *via* CPET; $\dot{V}_{O_2peak}$: peak oxygen consumption obtained *via* CPET; WHO-FC: World Health Organization functional class. [#]: before randomisation; [¶]: outcomes analysed by the review team; [+]: adverse events not related to exercise were not included in the table (*e.g.* haemoptysis, respiratory infection, herpes zoster).

TABLE 2 Intervention characteristics

Study	Intervention type	Type of exercise	Frequency/ duration#	Time (min)	Intensity	Supervision	Monitoring	Support components	Drop-out (n)	Adherence	CERT
Butāne *et al.*, 2022 [34]	HB	Aerobic exercise, strengthening exercises, respiratory training, relaxation	5/12	20–40	RPE as 5–6 on 6–10 Borg scale, progression based on individual tolerability	None	Weekly phone calls, on-site consultations (at the beginning and after 4 and 12 weeks)	Training programme featured with self-control monitoring, educational and motivational elements provided by a physiotherapist	HB: 0 CG: 2	90%	15
Butāne *et al.*, 2021 [35]	HB	Aerobic exercise, strengthening exercises, respiratory training, relaxation	5/12	20–40	RPE as 5–6 on 6–10 Borg scale, progression based on individual tolerability	None	Weekly phone calls, on-site consultations (at the beginning and after 4 and 12 weeks)	Training programme featured self-control monitoring educational and motivational elements provided by a physiotherapist	HB: 1 CG: 2	NR	15
Wojciuk *et al.*, 2021 [36]	HB	Aerobic exercise, strengthening exercises, respiratory training	5/24	45–60	RPE as 4–5 on 6–10 Borg scale and HR at 60–70% of HR reserve, progression based on individual tolerability	None	Self-control diary, HR, blood pressure, dyspnoea and fatigue (10-point Borg Scale), number of steps (pedometer), scheduled appointments	Patients received a booklet containing detailed descriptions and photographs of the exercises and recommendations	HB: 7 CG: 23	91.8%	8
Rakhmawati *et al.*, 2020 [38]	HHB	Aerobic exercise, stretching	In-hospital: 1 session in every 2 weeks/12 At home: 3/12	30–45	In-hospital: 60–70% of the maximum HR At home: individualised based on 6MWD Progression NR	In-hospital: supervised At home: virtually supervised	In-hospital: blood pressure, HR and oxygen saturation were monitored by nurses At home: periodical phone and video calls and text messages on the day of exercise	None	HHB: 1 CG: 3	NR	7

Continued

TABLE 2 Continued

Study	Intervention type	Type of exercise	Frequency/ duration[#]	Time (min)	Intensity	Supervision	Monitoring	Support components	Drop-out (n)	Adherence	CERT
Yilmaz *et al.*, 2020 [39]	CB/HB	Upper extremity aerobic exercise	CB: 3/6 HB: 21/6 (3 per day)	CB: 15–45 HB: 120 times[+]	CB: RPE as 3–4 modified Borg scale and 50–80% of maximum HR HB: NR CB progression: 2.5–5 watts·week^{-1} according to HR concerning individual tolerability HB progression: NR	CB: supervised; HB: none	CB: blood pressure, HR, oxygen saturation, breathing frequency, dyspnoea, upper limb fatigue HB: self-control diary	None	HB: 1 CB: 2	100%	11
Babu *et al.*, 2019 [40]	HB	Aerobic exercise, strengthening exercises, stretching	7/12	5–40	RPE as 4–10 Borg scale, progression of session time and intensity based on individual tolerability	NR	Weekly phone calls	An exercise logbook was provided to all patients in the intervention group and they were assessed through the follow-up period	HB: 8 CG: 9	45.2%	16
Karapolat *et al.*, 2019 [41]	CB/HB	Aerobic exercise, stretching, respiratory training	3/8	45–60	50–70% of maximum aerobic capacity and 13–15 Borg scale, progression NR for either	NR	NR	CB: none HB: exercise table with the dates and placemarks for patients' compliance; guides for exercises	HB: 3 CB: 3	NR	4
Fukui *et al.*, 2016 [6]	HHB	Aerobic exercise, strengthening exercises for lower limbs	In-hospital: 7/1, and 1 or 2 weekly sessions during "at home" period At home: 3–5/11	30–60	40–60% of HR reserve, and 12–13 Borg scale, progression NR	In-hospital: supervised At home: none	In-hospital: HR, oxygen saturation At home: daily record (frequency and time)	Lifestyle guidance, counselling, psychological support	HHB: 1	NR	10

Continued

TABLE 2 Continued

Study	Intervention type	Type of exercise	Frequency/ duration[#]	Time (min)	Intensity	Supervision	Monitoring	Support components	Drop-out (n)	Adherence	CERT
Inagaki *et al.*, 2014 [43]	HHB	Aerobic exercise, strengthening exercises, respiratory training	In-hospital: 1/12 At home: 6/12	20–60	In-hospital: 60% of the maximum HR At home: should involve only minor dyspnoea Progression NR	In-hospital: supervised At home: none	Daily record	Weekly in-hospital classes provided by a physiotherapist about the benefits and importance of daily exercise, walking pace, and energy conservation; self-management strategies to deal with disease exacerbation	HHB: 0	NR	7
Mereles *et al.*, 2006 [8][¶]		Aerobic exercise, strengthening exercises, respiratory training	In-hospital: 7/3 At home: 5/12	30–90	60–80% of the HR at peak oxygen uptake in exercise test Progression based on individual tolerability	In-hospital: supervised At home: none	In-hospital: HR, oxygen saturation At home: phone calls (every 2 weeks), open unstructured questionnaire at the final assessment in week 15	In-hospital: first 3 weeks in the hospital, patients underwent mental training At home: training guidance, a cycle ergometer and a manual were offered	HHB: 0	92%	13
Grünig *et al.*, 2021 [37][¶]									HHB: 10 CG: 3	NR	12
Ehlken *et al.*, 2016 [5] [¶]									HHB: 8 CG: 0	NR	9
Ihle *et al.* 2014 [42][¶]									HHB: 0	NR	11
Kabitz *et al.*, 2014 [44][¶]									HHB: 0	100%	11
Becker-Grünig *et al.*, 2013 [45][¶]									HHB: 5	NR	11
Ley *et al.* 2013 [46][¶]									HHB: 0 CG: 0	NR	10
Nagel *et al.*, 2012 [48][¶]									HHB: 13	89.7%	13
Grünig *et al.*, 2012 [47][¶]									HHB: 3	NR	12
Grünig *et al.*, 2011 [49][¶]									HHB: 3	NR	12

CB: centre-based; CERT: consensus on exercise reporting template; CG: control group; HB: home-based; HHB: hybrid home-based; HR: heart rate; NR: not reported; RPE: rating of perceived exertion; 6MWD: 6-min walking distance. [#]: Frequency/duration reported as sessions per week/weeks in total; [¶]: studies that reported using the same intervention protocol; [+]: reported the duration of home-based exercise sessions as "time" instead of minutes.

the exercise (HR, blood pressure, fatigue by RPE scale, number of steps by pedometers) or the compliance (*e.g.* phone calls, training logs or daily exercise chart) [5, 6, 8, 34–40, 42–49].

As for the supportive components provided alongside the core ET interventions, 10 studies provided the patients with "mental training"; two used educational and motivational components [34, 43]; one offered a booklet containing detailed exercise descriptions with pictures and recommendations [36]; one study provided an "exercise table with dates and pace marks" [38]; one used a logbook [40]; one offered "lifestyle guidance", counselling and psychological support [6]; and two studies did not offer any support components for the patients [38, 39]. These supporting measures were intended to complement and reinforce the ET interventions, rather than serve as stand-alone therapies.

Effects of interventions on primary outcomes

Safety: adverse effects

Adverse effects were documented in 16 studies (table 1), with no severe events linked to ET (such as mortality, clinical worsening or symptoms requiring discontinuation). Among home-based protocols (n=6), one study reported fatigue and increased HR from one subject [36], while the rest reported no adverse events. Among the hybrid interventions (n=13), eight studies reported the occurrence of ET-related side effects only during the in-hospital phase [5, 8, 37, 45–49], which included the following minor/mild events: arrhythmias [37], presyncope [37, 43], syncope [37, 48], supraventricular tachycardia [47], dizziness [8, 47] and O_2 desaturation [8, 41]. These studies did not monitor (n=1) or did not address (n=7) whether adverse events were monitored at home. Only five hybrid studies kept the monitoring during the home-based phase and found no adverse events [6, 38, 42–44].

Functional exercise capacity: 6MWD

Functional exercise capacity assessed *via* 6MWD was measured in all studies. Improvements were reported in favour of the home-based/hybrid home-based intervention in 16 studies (supplementary table S1) [5, 8, 34–40, 43–49]. A meta-analysis of 11 studies showed significant improvement favouring the home-based group over the inactive control (MD 54.85 m, 95% CI 31.54–78.16 m, p<0.01, I^2=90%), with no difference compared to the centre-based group (MD −30.37 m, 95% CI −78.49–17.74, p>0.05, I_2=69%) (figure 2a).

Exercise capacity: $\dot{V}_{O_2peak}$

The $\dot{V}_{O_2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$) was assessed in 10 studies [5, 6, 8, 37, 39, 41, 45, 47–49]. Nine studies reported improvements in favour of the home-based/hybrid home-based intervention compared to the inactive control group (supplementary table S1) [5, 6, 8, 37, 39, 41, 47–49]. The meta-analysis considering six studies showed a significant improvement of the $\dot{V}_{O_2peak}$ in favour of the home-based compared to the control group (SMD 0.83 $mL \cdot kg^{-1} \cdot min^{-1}$, 95% CI 0.38–1.27 $mL \cdot kg^{-1} \cdot min^{-1}$, p<0.01, I^2=68%), and no difference between the home-based and centre-based groups (SMD −0.31 $mL \cdot kg^{-1} \cdot min^{-1}$, 95% CI −0.90–0.29, p>0.05, I^2=0%) (figure 2b).

Ventilatory efficiency: $\dot{V}_E/\dot{V}_{CO_2}$

The $\dot{V}_E/\dot{V}_{CO_2}$ slope derived from a CPET was investigated in nine studies [5, 6, 8, 37, 39, 45, 47–49]. Individually, none of the studies reported any differences in this outcome. However, the meta-analysis considering three studies showed a significant improvement of the $\dot{V}_E/\dot{V}_{CO_2}$ slope in favour of the home-based compared to the inactive control group (MD −3.93, 95% CI −7.69– −0.16, p<0.01, I^2=35%) (figure 3a).

WHO-FC and clinical worsening

The WHO-FC in PH patients was assessed in 13 studies (tables 1 and S1). Six studies [6, 8, 37, 39, 40, 49] reported improvement of WHO-FC in the home-based/hybrid interventions compared to control groups or after the training programme. Seven studies reported no differences between conditions [5, 36, 38, 43, 45, 47, 48]. None of the studies reported worsening in WHO-FC, hospitalisation or requirement for additional pharmacological therapy, regardless of the intervention/control group.

Adherence and compliance

Details of home-based interventions are summarised in table 2. Adherence was reported in only seven studies. Five studies demonstrated ⩾90% adherence in home-based/hybrid interventions (range 45.2–100%) [8, 35, 36, 39, 44]. Regarding compliance, five studies reported zero discontinuation of the training [8, 42–44, 46]. Nine studies reported the drop-out of up to seven patients per group [6, 34, 35, 38, 39, 41, 45, 47, 49]. Additionally, we extracted data on drop-outs from 11 studies. In this sense, the home-based

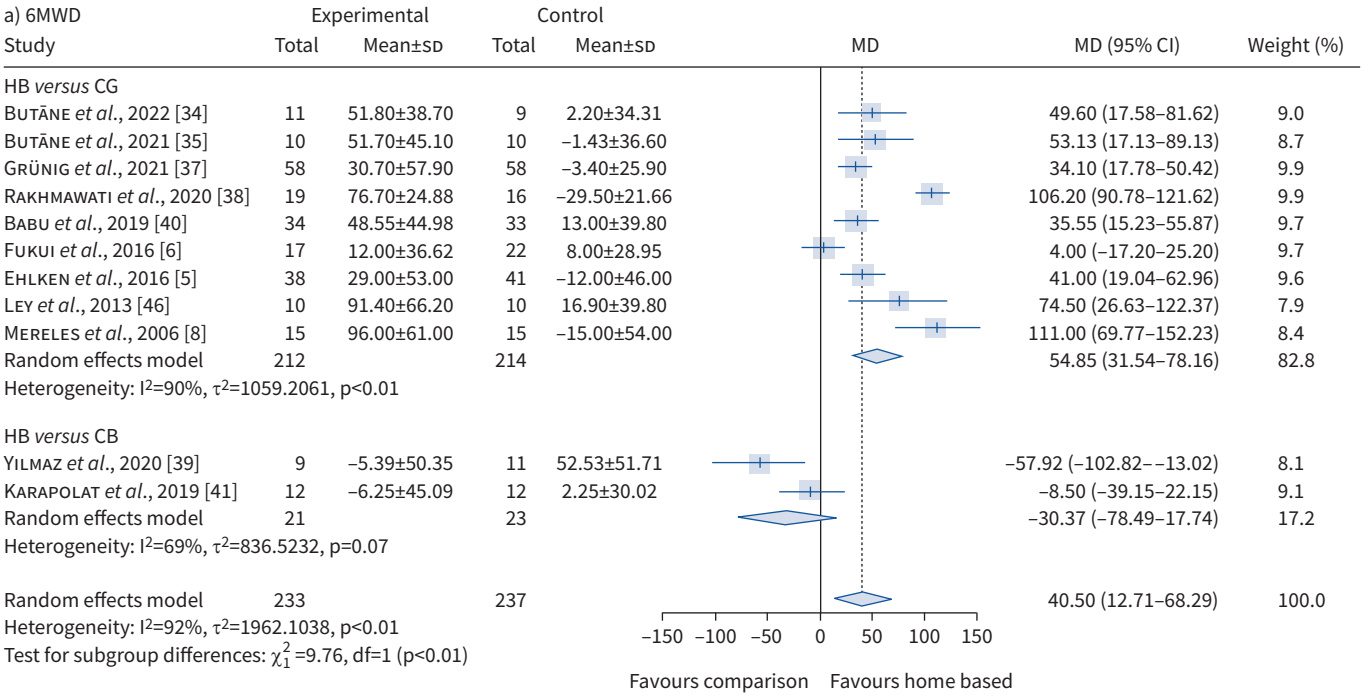

FIGURE 2 Forest plots of the meta-analyses of home-based/hybrid home-based (HB) interventions *versus* a control group (CG) and centre-based (CB) interventions for a) 6-min walk distance (6MWD) and b) peak oxygen uptake ($\dot{V}_{O_2peak}$). MD: mean difference.

intervention did not differ between control (RD 0.00, 95% CI −0.07–0.08, p>0.05, I^2=52%) or centre-based groups (RD 0.06, 95% CI −0.16–0.28, p>0.05, I^2=41%) (supplementary figure S2).

Effects of interventions on secondary outcomes

Health-related QoL

The QoL (*via* SF-36 questionnaire) was assessed in 10 of the 19 studies, four exclusively home-based (supplementary table S1). Four studies [37, 39, 41, 42] did not find differences between the home-based/hybrid intervention and control group/centre-based groups for any of the QoL subscales. Five studies reported improvement in "physical functioning" and "vitality" [8, 36, 40, 48, 49], four studies in "mental health" [8, 37, 40, 49], three studies in "social functioning" [8, 40, 49], two studies in "general health perception" [40, 49] and only one study reported improvement in "bodily pain" [45] in home-based/hybrid interventions compared to a control group.

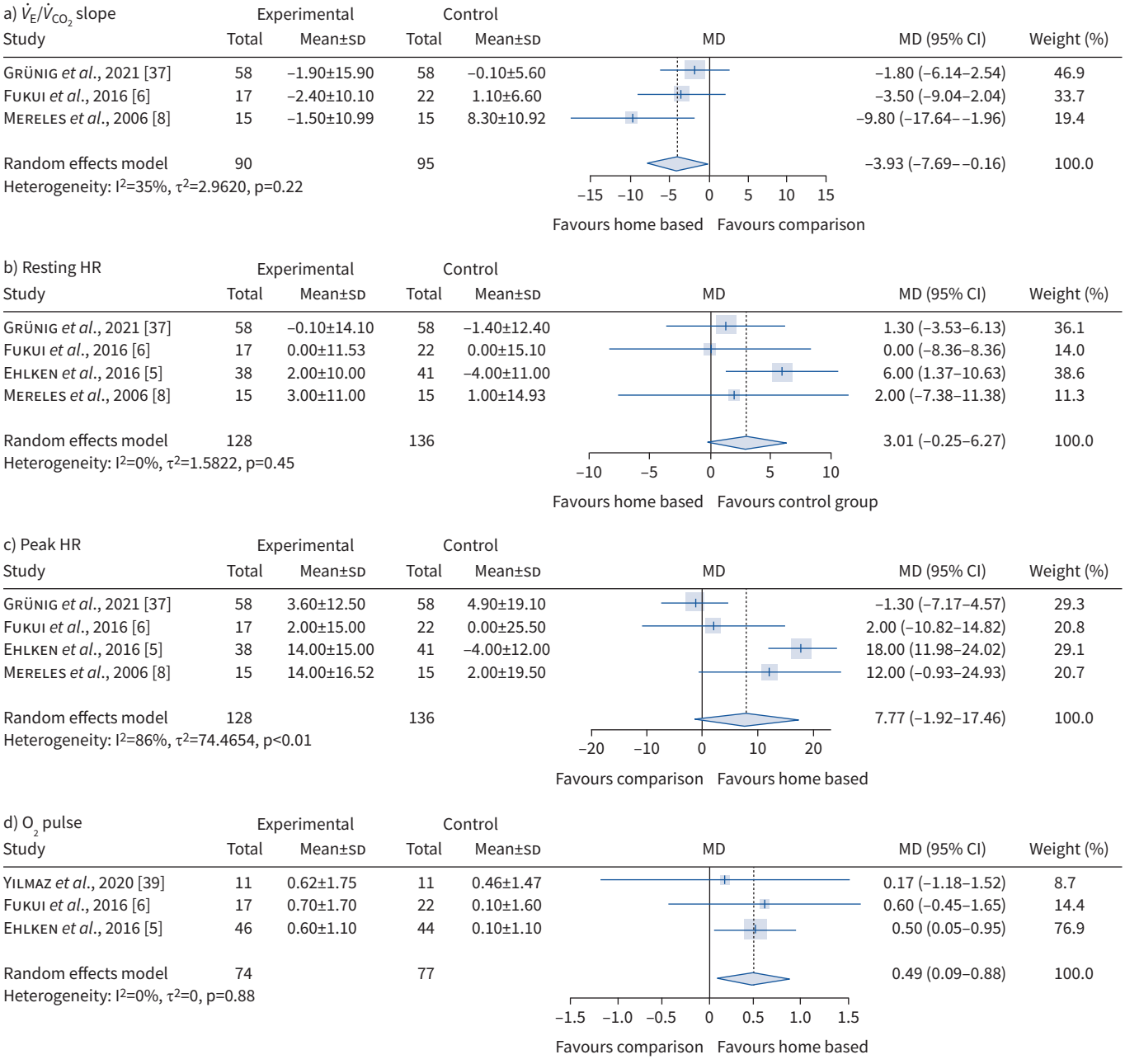

FIGURE 3 Forest plots of the meta-analyses of home-based/hybrid home-based interventions *versus* a control group for a) ventilatory efficiency (minute ventilation/carbon dioxide output ($\dot{V}_E/\dot{V}_{CO_2}$) slope) obtained during cardiopulmonary exercise testing, b) resting heart rate (HR), c) peak HR and d) O_2 pulse. MD: mean difference.

Pulmonary haemodynamic parameter

Seven studies, comprising 378 patients, estimated the changes in resting PASP before and after intervention/control [8, 37, 41, 43, 45, 47, 48]. Two of these studies observed a reduction of the resting PASP in a hybrid home-based compared to a control group [37] or a pre-exercise period [47], while no differences were observed between groups in the other five studies. Additionally, four studies evaluated the peak PASP obtained during a CPET and found no difference between intervention and control groups for this outcome (supplementary table S1) [8, 45, 47, 48].

HR

Resting and peak HR obtained from a CPET were assessed in nine studies [5, 6, 8, 37, 39, 45, 47–49]. Only one study reported a reduction of resting HR after the hybrid home-based programmes compared to the

pre-intervention period [49]. The other studies did not find differences between groups for the resting HR. The meta-analysis considering four studies showed no differences between hybrid home-based programmes and inactive control groups (MD 3.01, 95% CI −0.25–6.27, p>0.05, I^2=0%) (figure 3b). Regarding the peak HR, the majority of the studies (n=6) reported an increase in this outcome in favour of the hybrid home-based intervention *versus* control groups [5, 8, 45, 47–49]. However, the meta-analysis with four studies reported no differences between these two conditions (MD 7.77, 95% CI −1.92–17.46, p>0.05, I^2=86%) (figure 3c).

S_{pO_2}

Resting oxygen saturation (S_{pO_2}) was assessed in only four studies [37, 38, 45, 48]. Two studies reported improvement of this outcome after home-based [36] and hybrid intervention [37] compared to the pre-intervention period. Five studies assessed the peak S_{pO_2} derived from a CPET and found no differences between groups or conditions for this outcome (supplementary table S1) [6, 36, 37, 45, 48].

O_2/HR

The oxygen pulse (O_2/HR) derived from CPET was investigated in six studies [5, 6, 39, 45, 47, 48]. The meta-analysis considering three studies showed a significant improvement of this outcome in favour of the home-based group compared to the control group (MD 0.49, 95% CI 0.09–0.88, p<0.01, I^2=0%) (figure 3d).

Discussion

Summary and interpretation of key findings

Home-based interventions, whether they were implemented as stand-alone programmes or as part of a hybrid approach, were found to be associated with improvements in exercise capacity, cardiorespiratory outcomes and QoL. Meta-analysis suggested that these outcomes may be comparable to those achieved through centre-based interventions. Notably, no severe adverse events were reported in home-based interventions. However, most studies did not report equipping participants with health-related self-monitoring tools, which may have implications for overall safety assessment. Taken together, these findings provide promising evidence that home-based ET could serve as a feasible alternative to centre-based programmes for patients with PH. Furthermore, high adherence rates suggest the feasibility and acceptability of home-based ET within this population.

To our knowledge, this is the first systematic review and meta-analysis to directly compare home-based exercise interventions with exclusively centre-based programmes in this population. Previous systematic reviews and meta-analyses investigating the effects of ET on PH-related outcomes combined data from centre-based (both inpatient and outpatient), home-based and hybrid programmes [17], thereby precluding the isolated assessment and interpretation of the safety and effectiveness of home-based exercise components.

Safety is a critical aspect when considering ET for stable patients with PH [2]. In this sense, no severe adverse events related to ET were observed across the studies reviewed, including those conducted exclusively in a home-based setup [34–36, 39–41]. Resting and exercise-induced hypoxaemia (a marker of disease severity) [50] was not observed in any study. These data, in addition to the absence of clinical worsening, are aligned with the current literature [2] and favour the safety of home-based ET in patients with stable PH. It should be noted, however, that only Wojciuk *et al.* [36] provided patients with objective tools to detect health-related complications at home, such as an oximeter and HR monitor. The lack of information regarding home self-monitoring raises the question of whether the reviewed protocols were indeed safe, because patients were not equipped to identify and report any adverse events, such as exercise-related desaturation or a sudden decrease in blood pressure. In this context, a more robust approach involving self-monitoring and remote supervision was recently demonstrated by McCormack *et al.* [51], who showed in a pilot study with PH patients that such a setup could promote patient independence while ensuring safety during home-based exercise sessions.

When assessing safety, it is also important to consider the variability in patient characteristics across different WHO-FC and aetiological groups. The current evidence, which is predominantly based on FC II and III patients, may not apply to those in more severe functional classes, such as FC IV, in whom the risk of overexertion could be greater [23]. Additionally, most research has focused on Group 1 (PAH), with limited data on exercise interventions for other PH aetiologies, such as Group 3 (PH due to interstitial lung disease). Each group presents distinct clinical characteristics that could affect the safety and effectiveness of home-based exercise. For example, Group 1 patients may experience concerns related to vasodilator therapy, which could increase the risk of hypotension [52], whereas Group 3 patients may face challenges with exercise-related

oxygen desaturation [53]. Although none of the studies reported severe adverse events in these groups, they did not address how potential issues would be identified or managed in a home-based setting.

A tailored exercise programme that considers the individual's PH group and functional class is essential for ensuring safety. All included studies reported that participants were pharmacologically stable and that exercise intensity was individually adjusted on the basis of objective/subjective markers of effort or saturation [47], which contributes to safety. However, future studies should investigate patients' ability to self-monitor and report adverse events, because current evidence suggests that many patients may not be adequately equipped to do so.

Exercise capacity was one of the main efficacy outcomes assessed in this review because of its prognostic value for PH. The meta-analysis revealed that home-based ET improved the 6MWD and $\dot{V}_{O_2peak}$ compared with the inactive control group. These improvements occurred to the same extent as those reported in a centre-based ET [5, 6, 8, 37, 38, 43–49]. The disease course progressively affects both exercise capacity markers [2–4, 54]. Conversely, experimental and clinical studies with PH provide evidence that chronic exercise ameliorates $\dot{V}_{O_2}$ and the 6MWD *via* cardiovascular, pulmonary and musculoskeletal adaptations [2, 55]. Indeed, the present meta-analysis revealed that, compared with inactive ET, home-based ET improved ventilatory efficiency (determined by the $\dot{V}_E/\dot{V}_{CO_2}$ slope) and cardiac output (determined by the O_2 pulse), which suggests an increase in pulmonary vascular perfusion and cardiac function with exercise [5, 6, 8, 37, 39]. Such cardiorespiratory ameliorations are supported by previous meta-analyses conducted with inpatient/outpatient protocols [17, 56, 57]; however, our recent data suggest that home-based ET may also stimulate these positive adaptations.

The increase in the O_2 pulse might be partially mediated by an increase in right ventricular function, as previously reported by Zeng *et al*. [56]. Indeed, the vast majority of the studies in the present review reported an increase in peak HR, an indicator of chronotropic function, after home-based ET. This meta-analysis was conducted using this outcome, with four studies not showing differences between home-based and inactive control groups, which could be due to the substantial heterogeneity between studies (I^2=86%).

Amelioration of central haemodynamics is often described as a result of ET among PH patients [56]. Zeng *et al*. [56], for example, reported a marked reduction in resting PASP after 3–15 weeks of ET in patients with PH, which might be mediated by a reduction in vascular remodelling. However, we were unable to conduct a meta-analysis on the impact of home-based ET on the PASP because of insufficient data. Only two studies reported a reduction in this outcome compared with an inactive group/pre-intervention [37, 47], partially suggesting a reduction in pulmonary vascular resistance. When assessed during exercise, no differences were found between any of the conditions or groups. However, it remains unclear whether the absence of differences could be due to the duration or the characteristics of the home-based ET protocol employed in the studies.

The WHO-FC is a well-established predictor of clinical worsening and mortality among all forms of PH [1]. In the present review, almost half of the studies reported an improvement in FC after home-based ET, which aligns with previous meta-analyses [17]. On the basis of previous evidence from PH patients, improvements in WHO-FC might be partially explained by improvements in exercise capacity and ventilatory efficiency [58]. The majority of the studies included in our systematic review reported improvements in some QoL categories in the home-based ET component compared with an inactive control group [8, 36, 40, 45, 47–49]. This result might be partially mediated by better WHO-FC and exercise capacity, because these outcomes are closely associated with the ability to perform daily life activities and, therefore, with QoL [3, 59]. Notably, increased physical activity levels have broader beneficial effects on a range of health-related markers associated with PH, such as reduced anxiety and improved sleep quality [7, 9, 10, 60].

However, it is important to acknowledge that while physical exercise can contribute to improvements in QoL, the literature consistently emphasises the need for a comprehensive care approach [61, 62]. Combining home-based exercise with multidisciplinary interventions, including psychosocial support, education and symptom management, may be essential to achieve meaningful and sustained enhancements in the QoL of this population. Hence, having a home-based exercise component as part of the therapeutic strategy in PH might promote benefits beyond physiological outcomes for this population, particularly when the exercise is integrated into a broader, patient-centred care model.

Key characteristics and trends of the home-based ET component

The interventions described in the included studies varied in terms of duration, frequency and session length, with programmes lasting from 6 to 24 weeks [36, 39] and sessions occurring from 3 to 7 days per

week [36, 39, 40], lasting from 5 to 90 min [35, 36, 39, 40]. This flexibility might accommodate different patient needs and is crucial for home-based exercise interventions in which feasibility and engagement are key. A common trend was the use of multimodal exercise routines, with 15 studies combining aerobic, strength and respiratory training to improve overall health outcomes [5, 34, 36, 39, 40, 45]. Walking was the most common aerobic exercise and was often paired with cycling because of its accessibility. However, while interval training was used in the centre-based phase of some studies, its continuation in home-based phases was often unclear, indicating a gap in reporting.

Cycle ergometers and dumbbells were the most frequently used equipment, supporting aerobic and strength training. Some studies have used minimal or no equipment [41, 42], which could increase accessibility for patients with limited resources.

Exercise intensity is generally moderate to high and is monitored through RPE and HR_{peak} targets to individualise training [34, 36]. The lack of supervision in stand-alone home-based studies remains a limitation, given that only one study employed remote supervision [38], underscoring the need for oversight to ensure adherence and safety [51].

In addition to ET training, supporting components such as mental training, motivational strategies and educational materials have been widely incorporated to enhance engagement and adherence. This holistic approach acknowledges the importance of addressing psychological factors alongside physical rehabilitation [61, 62].

Limitations and methodological considerations

The number of studies conducted exclusively in a home-based setting was limited, hindering the comparison of clinical outcomes between stand-alone home-based ET and other groups (inactive control and centre-based ET). The average reporting score for the evaluated intervention, as assessed by the CERT, was 11.1, which is relatively moderate compared with studies in other populations [63, 64]. However, there is room for improvement in transparency, particularly in domains such as motivation tactics and a detailed intervention description (including exercise characteristics, execution mode and progression methods). The absence of these characteristics limits a more assertive analysis of an optimal home-based exercise protocol and constrains the assessment of its feasibility and reproducibility.

Several studies exhibited a high risk of bias (63.1%), particularly with respect to randomisation, blinding and reporting biases, potentially compromising the reliability and validity of the findings. Moreover, the studies included in this review displayed significant heterogeneity in study design, outcome measures and patient characteristics, potentially limiting the comparability of the results and affecting the robustness of our findings.

Compliance and adherence, both indicators of feasibility [65], were greatly underreported by the studies. Our meta-analysis revealed no difference in drop-out rates between interventions and higher rates of adherence, which provides support for the implementation of home-based ET. However, further studies with comprehensive descriptions are needed before any definitive conclusions regarding the feasibility of home-based interventions can be drawn.

Meaningful comparisons across PH categories were not feasible due to the small sample size and the heterogeneity of the study characteristics. Additionally, the authors did not present results stratified by WHO-FC and aetiology, which precludes a thorough analysis of the efficacy and safety of interventions within each PH group. Further research is essential to assess these aspects of home-based interventions across all PH groups, particularly in patients with severe FCs and complex comorbidities.

Clinical implications and future directions

Regular physical activity and ET have been shown to significantly improve exercise capacity, muscular function, QoL and other predictors of mortality in PH patients [2, 5, 44, 47, 49]. Poor accessibility of rehabilitation services is one of the main barriers experienced by this population, precluding their engagement in regular physical activity [12]. The findings of this systematic review and meta-analysis suggest that home-based exercise interventions, either as stand-alone interventions or as part of hybrid programmes, appear to be effective alternatives for improving clinical outcomes. The incorporation of a home-based component could balance cost and effectiveness, making exercise rehabilitation more accessible to individuals who face geographic barriers or who do not adapt well to inpatient rehabilitation.

However, a standardised approach to self-monitoring and detailed reporting of adverse events is essential for establishing the safety of home-based exercise programmes with a higher level of evidence. Future RCTs should address these limitations by equipping patients with self-monitoring tools, virtual supervision and clear action plans in cases of health-related events.

Despite the identification of common characteristics in home-based exercise protocols, the heterogeneity of protocols and limited studies prevent further analysis of the optimal exercise therapy characteristics. Future research should refine intervention designs and incorporate more rigorous study methodologies and standardised protocols, enabling the assessment of optimal exercise characteristics that balance effectiveness and safety. Ultimately, the inclusion of future RCTs will also enable analysis of the efficacy and safety of exclusively home-based interventions.

Conclusion

Stand-alone or hybrid exercise interventions appear to be a viable alternative to exclusively centre-based programmes for patients with PH. These interventions demonstrate comparable improvements in clinical outcomes. No severe adverse events were linked to home-based ET; however, the lack of reports on self-monitoring may impact the overall safety assessment. Future research should focus on refining these interventions, equipping patients with self-monitoring tools, and exploring their long-term benefits.

Points for clinical practice

- Home-based exercise interventions may serve as effective alternatives to centre-based programmes for patients with pulmonary hypertension, improving exercise capacity and quality of life.
- Incorporating a home-based component can enhance access to rehabilitation, especially for patients facing geographic or logistical barriers.
- Hybrid exercise models that combine supervised and home-based training may offer a balanced solution between effectiveness, safety and cost.
- Clinicians should consider structured self-monitoring strategies and patient education to support the safe implementation of home-based programmes.

Questions for future research

- What are the optimal characteristics (type, intensity, frequency) of home-based exercise programmes for improving outcomes in pulmonary hypertension?
- How can self-monitoring tools and virtual supervision be best integrated to enhance safety and adherence in home-based interventions?
- What are the most effective strategies for reporting and managing adverse events in unsupervised or remotely supervised exercise programmes?
- Can exclusively home-based exercise training demonstrate comparable safety and efficacy to centre-based or hybrid models in large-scale, high-quality randomised controlled trials?

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