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Pulmonary Telerehabilitaion for Patients with Chronic Obstructive Pulmonary Disease: Systematic Review and Meta-Analysis

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ABSTRACT

Background: Chronic obstructive pulmonary disease (COPD) is a leading cause of morbidity and mortality, with pulmonary rehabilitation forming a cornerstone of management. However, traditional programs are often limited by accessibility barriers. Telerehabilitation (TR) has emerged as a potential alternative, but its clinical effectiveness remains variably reported.

Objective: This study aimed to evaluate the efficacy of pulmonary telerehabilitation in improving exercise capacity, dyspnea, QoL, and healthcare utilization in adults with COPD.

Methods: Six databases (PubMed, Scopus, PEDro, CENTRAL, VHL, and Web of Science) were searched for randomized controlled trials (RCTs) comparing TR to usual care or center-based PR in adults with COPD. Inclusion criteria followed the PIOCS framework. Two reviewers independently screened studies, extracted data, and assessed methodological quality using the PEDro scale. Levels of evidence were classified using the Modified Sackett Scale. Meta-analyses were conducted only where clinical and statistical homogeneity existed. Otherwise, narrative synthesis was performed. **Results:** Nine RCTs (n=624) were included, with seven eligible for meta-analysis. TR programs varied in format, including video conferencing, smartphone apps, and web-based modules. Exercise capacity improved significantly, with a pooled standardized mean difference (SMD) of 0.37 [95% CI: 0.14–0.60]; moderate heterogeneity (I^2=48%). Dyspnea did not show a significant pooled effect initially (SMD = −0.16), but sensitivity analysis revealed a significant improvement (SMD = −0.37; I^2=21%). Health related Quality of life (HRQoL), measured by CAT, also improved significantly (SMD = −0.63), with adjusted analysis confirming robustness. Several studies reported reduced hospitalizations. Study quality was high in 6/9 trials (PEDro ≥6). Evidence levels were: Level I for exercise capacity, Health related quality of life, and hospitalizations; Level II for dyspnea, HRQoL, and self-efficacy.

Conclusion: Pulmonary telerehabilitation significantly improved exercise capacity and HRQoL in patients with COPD and demonstrated a meaningful reduction in dyspnea severity upon sensitivity analysis. These findings support telerehabilitation as an effective and accessible alternative to conventional rehabilitation, particularly for patients facing barriers to in-person care.

Keywords: Chronic obstructive pulmonary diseases, Dyspnea, exercise capacity, pulmonary rehabilitation, Telerehabilitation.

INTRODUCTION

Chronic obstructive pulmonary diseases (COPD) is a common and progressive respiratory condition that contributes considerably to worldwide morbidity and mortality. Risk factors including smoking, environmental pollution, and occupational exposure enhance its impact, especially in low-resource settings where underdiagnosis is widespread [(1)]. In addition to its high mortality rate, COPD places a substantial strain on healthcare systems due to frequent hospitalizations, complex management needs, and long-term care costs [(2)].

Pulmonary rehabilitation is an evidence-based strategy that improves exercise tolerance, alleviates symptoms, and improves QoL in COPD patients [(3)]. These programs usually include supervised exercise, instruction, and behavioral support. However, participation in traditional rehabilitation is often hindered by barriers such as geographic distance, transportation challenges, and scheduling conflicts, limiting accessibility and adherence [(4)].

Telerehabilitation (TR) has emerged as a feasible and scalable alternative to center-based rehabilitation, offering remote access to structured exercise programs and educational resources. It is particularly beneficial for individuals in underserved or rural areas, providing scheduling flexibility and continuous remote monitoring of patient progress [(5, 6)]. By integrating digital tools, TR addresses many limitations of conventional models, improving engagement and enabling personalized care [(7)].

Although traditional pulmonary rehabilitation remains the gold standard, its limitations in reach and adherence necessitate alternative solutions. TR offers a viable approach by leveraging technology to deliver exercise training, education, and clinician support remotely. This model holds particular promise for improving access and adherence in populations facing logistical barriers. However, despite growing interest and pilot implementations, there remains a lack of clarity regarding the overall efficacy of TR in improving exercise-related outcomes such as functional capacity and endurance in patients with COPD.

Therefore, the objective of this systematic review was to comprehensively evaluate the effect of TR on

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exercise capacity among individuals with COPD. Understanding the efficacy and quality of evidence supporting TR interventions is essential to guide clinicians, inform policy decisions, and enhance the integration of digital health strategies into routine COPD management.

METHODS

1-Study design and registration: This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [(8)] to ensure methodological rigor, transparency, and reproducibility. The review protocol was prospectively registered in Faculty of Physical Therapy Cairo University.

2-Search strategy: A comprehensive literature search was carried out across six electronic databases: PubMed, Web of Science (WOS), Scopus, PEDro, Virtual Health Library (VHL), and the Cochrane Central Register of Controlled Trials (CENTRAL). The search was unrestricted by publication year and included studies up to the most recent search date. Keywords such as "chronic obstructive pulmonary disease," "COPD," "telerehabilitation," "remote pulmonary rehabilitation," and "telehealth" were combined using Boolean operators. The search strategies were tailored to each database and limited to studies published in English involving human participants. To maximize comprehensiveness, reference lists of the included articles were manually reviewed for additional eligible studies.

3- Eligibility criteria: Studies were selected according to predefined inclusion and exclusion criteria based on the PIOCS framework [(8)]. Eligible studies included RCTs involving adult patients (≥18 years) with COPD who received TR interventions either independently or as an adjunct to standard care. Comparators included traditional center-based pulmonary rehabilitation, usual care, or no intervention. The primary outcomes were related to exercise capacity, dyspnoea and HRQoL.

Exclusion criteria: Observational studies, review articles, case series and non-English publications, or abstracts without full-text availability.

4- Study selection: Two reviewers separately examined titles and abstracts, then assessed the entire text of possibly suitable publications. Disagreements were settled by consulting with a third reviewer. The study selection process was recorded using a PRISMA flow diagram **(figure 1).**

5- Data extraction: Two reviewers extracted data independently, using a form that includes authorship and publication year, research location, sample size and patient demographics, intervention parameters (e.g., duration, method of administration and frequency), comparator details, and primary outcomes. Any disagreements between reviewers were settled by consensus or adjudication by a third reviewer.

6- Methodological quality assessment and level of evidence: The methodological quality of each included study was evaluated using the Physiotherapy Evidence Database (PEDro) scale [(9)]. This validated tool comprises 11 items, 10 of which contribute to the total score (range: 0–10). It assesses random allocation, disguised allocation, baseline comparability, blinding of participants, therapists, and assessors, adequate follow-up, use of intention-to-treat analysis, between-group comparisons, and reporting of variability and effect sizes. Studies scoring **6 or above** were considered to have **"good" methodological quality**, those scoring 4–5 were considered "fair," and those scoring below 4 were "poor." Risk of bias assessment was conducted independently by two reviewers, with disagreements resolved by consensus. The strength of the evidence, we employed the **Modified Sackett Scale [(10)]**, which stratifies studies into levels based on methodological rigor. This framework was used to interpret the reliability and clinical applicability of the synthesized findings.

Data analysis

Meta-analysis were carried out using the Comprehensive Meta-analysis (CMA) program (Biostat, Englewood, NJ, USA). Pooled estimates were derived for studies that reported comparable results using continuous metrics. Standardized mean differences (SMDs) were calculated with 95% confidence intervals (CIs), and a random-effects model was used to account for inter-study heterogeneity. The I^2 statistic was used to quantify statistical heterogeneity, with thresholds of 25%, 50%, and 75% indicating low, moderate, and high respectively. A p-value of ≤ 0.05 indicated statistical significance. Meta-analysis was recorded only where there was significant clinical and statistical homogeneity between trials. In cases of significant heterogeneity, meta-analysis was avoided in favor of a qualitative narrative synthesis. Furthermore, sensitivity analyses were carried out to investigate the robustness of the meta-analysis results by analyzing the effect of omitting studies with a high risk of bias or methodological discrepancies.

RESULTS

Literature search results: A comprehensive literature search was conducted to identify RCTs assessing the effectiveness of pulmonary TR in patients with COPD. The search strategy combined relevant keywords using Boolean operators: *(Telerehabilitation OR Telehealth OR "Remote Pulmonary Rehabilitation") AND ("Chronic Obstructive Pulmonary Disease" OR COPD)*. Searches were performed across six databases: PubMed, Cochrane CENTRAL, PEDro, VHL, Scopus, and WOS. A filter was applied to the PubMed search to include only RCTs.

The initial search retrieved 2,379 records, after removing 455 duplicate entries, a total of 1,924 unique records remained for screening. Title and abstract screening excluded 1,875 records due to ineligible populations, interventions, or study designs (e.g. observational studies, or reviews). The remaining 49 articles were retrieved for full-text review and were assessed, 40 articles were excluded. Ultimately, 9 RCTs met the inclusion criteria and were included in the final review and 7 studies were included in the meta-analysis **(Figure 1).**

2 Included Studies: Nine RCTs [11–19] fulfilled the predefined eligibility criteria and were included in this systematic review. Each study investigated the impact of pulmonary TR interventions of different formats (e.g. videoconferencing, smartphone applications, web platforms, remote monitoring, and home-based coaching) in patients with COPD, focusing on outcomes of exercise capacity, dyspnoea, and HRQoL.

Characteristics of included studies:

The nine included RCTs offered a broad perspective on the implementation of TR for COPD. Studies ranged from small pilot trials, such as **Tabak *et al.*** [11] in the Netherlands using a wearable accelerometer and smartphone diary over four weeks, to large-scale equivalence and non-inferiority trials like **Holland *et al.*** [13] in Australia and **Bourne *et al.*** [18] in the UK. The latter compared online pulmonary rehabilitation (myPR) with face-to-face PR and found comparable improvements in exercise capacity and CAT scores, confirming non-inferiority. **Holland *et al.*** [13] similarly observed short-term equivalence in 6 MWD and QoL outcomes between home-based and center-based programs, although benefits diminished over 12 months.

Other studies focused on long-term interventions and comorbid populations. **Palmira *et al.*** [14] conducted a 4-month TR study in Italy targeting patients with both COPD and CHF, integrating telemonitoring and phone support, which led to improved exercise tolerance and fewer adverse events. **Vasilopoulou *et al.*** [12] in Greece extended this approach over a full year, employing video calls and mobile spirometers, and reported significant reductions in exacerbation rates, hospitalizations, and ED visits. In Spain, **Galdiz *et al.*** [19] delivered a 12-month TR maintenance program for post-PR patients, which improved self-efficacy and HRQoL, despite modest changes in 6 MWT.

Further diversity in intervention scope and geography was reflected in studies such as **Tsai *et al.*** [15], which showed significant gains in endurance and CRDQ scores through an 8-week real-time video-based exercise program in Australia. The most extended study of **Zanaboni *et al.*** [17] that was a 2-year multicenter trial across Norway, Australia, and Denmark. It revealed sustained 6MWD improvements and reduced hospital service use in the TR group.

Lastly, **Chaplin *et al.*** [16] conducted a feasibility RCT in the UK using an interactive web-based platform. While, both intervention and control groups improved in exercise tolerance and QoL, the web group experienced a notably higher dropout rate, potentially linked to baseline anxiety.

Methodological quality of the included studies

Methodological quality was assessed using the **PEDro scale**. All nine studies met the basic criteria for eligibility specification and random allocation. Seven studies [11, 13, 15–19] reported adequate allocation concealment, while **Palmira *et al.*** [14] **and Vasilopoulou *et al.*** [12] did not. Baseline comparability was confirmed across all studies. Blinding of participants and therapists was not reported in any study, which is expected in behavioral and exercise interventions. However, **five studies** [13–18] employed blinded outcome assessors.

Follow-up rates exceeded 85% in four studies. Intention-to-treat (ITT) analysis was reported in five studies [13, 15, 17–19], while the remainder lacked clear ITT protocols. All studies performed between-group comparisons and reported variability metrics. PEDro scores ranged from **5 to 8**. The highest-quality studies [13, 15, 17] scored 8/10. **Tabak *et al.*** [11] and **Vasilopoulou *et al.*** [12] scored 5 and were rated as "Fair." The remaining six studies were rated "Good," with scores of 6 or 7.

Level of evidence of included studies

The **Modified Sackett Scale** [10] was used to classify the level of evidence based on PEDro scores. The level of evidence analysis revealed that **exercise capacity**, **HRQoL**, and **hospitalization outcomes** are supported by **Level I evidence**, reflecting high methodological quality and consistent findings across multiple RCTs. Improvements in exercise capacity, measured by 6-minute walk distance (6 MWD), were observed across several good-quality studies and confirmed through meta-analysis. Similarly, significant gains in CAT scores and reductions in acute care utilization (Hospitalizations and emergency department visits) were consistently reported, particularly in studies by **Palmira *et al.*** [14]**, Vasilopoulou *et al.*** [12]**,** and **Zanaboni *et al.*** [17]**,** which collectively achieved moderate-to-high PEDro scores. These outcomes demonstrate robust and reliable benefits of TR in COPD management.

In contrast, outcomes such as **dyspnea**, **HRQoL**, **psychological status**, **self-efficacy**, and **adherence** were supported by **Level II or II–III evidence**. Although most studies were rated as good

quality, some inconsistencies in statistical significance and between-group differences limited the strength of evidence. For example, dyspnea outcomes became significant only after sensitivity analysis, and self-efficacy showed improvements in only one trial. Psychological outcomes and HRQoL demonstrated within-group benefits but lacked consistent superiority over control groups. Nonetheless, high adherence and compliance rates, even when descriptively reported, reinforce the feasibility and acceptability of pulmonary TR across diverse settings and populations.

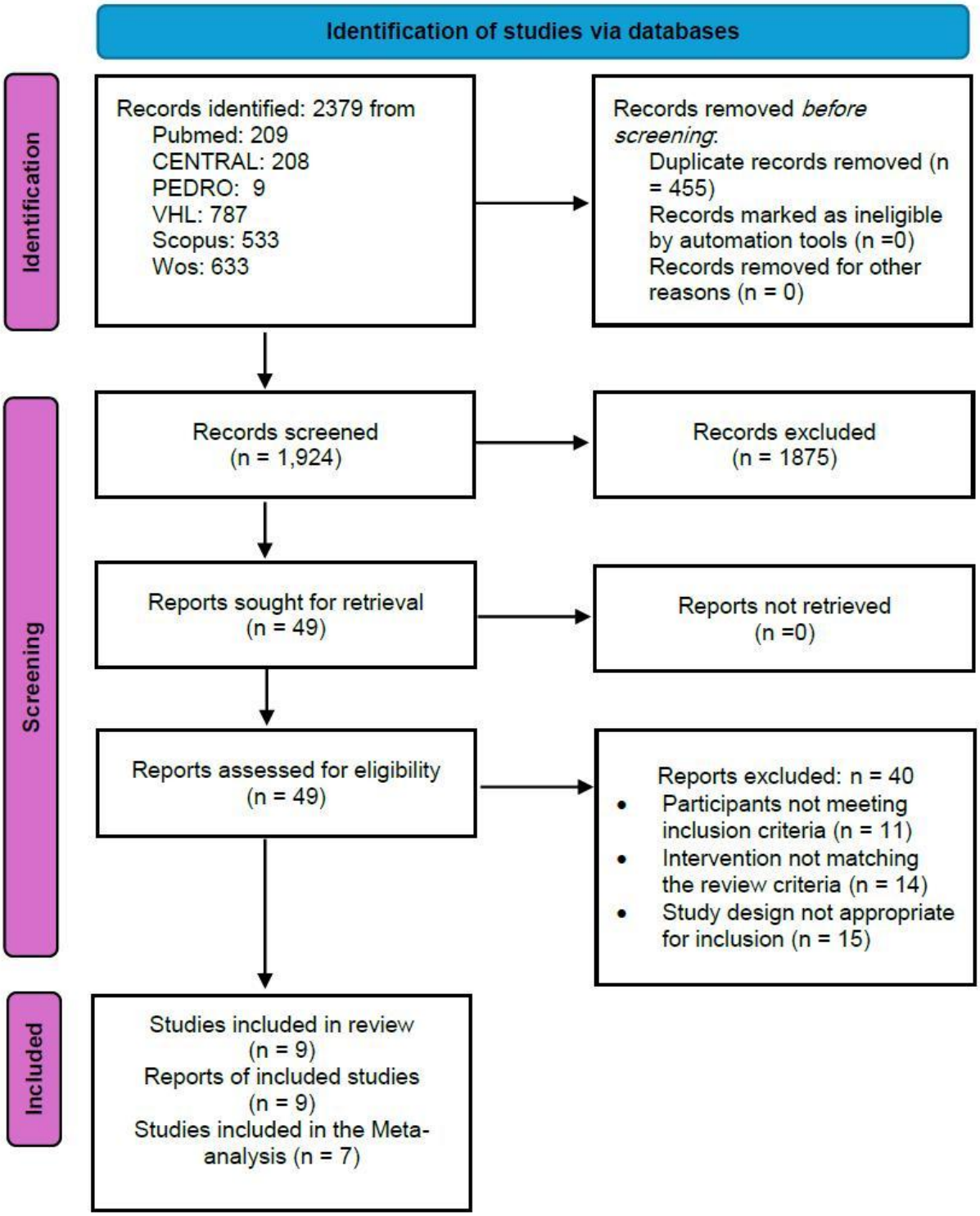

Figure (1): Prisma Flow Diagram.

Table (1): Characteristics of Includes studies

Study ID	*Study Design*	*Country*	*Sample Size*	*Participant Characteristics*	*Intervention Details*	*Duration & Follow-up*	*Technology Used*	*Comparator / Control*	*Outcomes Measured*	*Results*
***Tabak et al., 2014** (11)*	RCT (pilot)	Netherlands	34 (30 completed)	COPD patients; mean age ~66; M:F = 8:6 (interv.), 11:5 (control)	Activity coach (3D accelerometer + smartphone) + web portal symptom diary	4 weeks	3D accelerometer, smartphone (HTC), web portal	Usual care (medication, physiotherapy)	Physical Activity (Steps/day), Dyspnea (CCQ, MRC), Fatigue (MFI-20)	Health related Quality of life improved in intervention group (p=0.046); no sig. diff in steps/day; high compliance
***Tsai et al., 2017** (15)*	RCT	Australia	37 (20 in tele group)	Stable COPD; mean age 74; FEV1 ~64% predicted	Real-time supervised video exercise, 3x/week for 8 weeks	8 weeks	Laptop, video software, cycle ergometer	Usual care (no exercise training)	QOL (CRDQ), Endurance (ESWT), Physical Activity (PA measures), Self-efficacy (self-efficacy scale)	Significant improvement in ESWT and self-efficacy
***Chaplin et al., 2017** (16)*	RCT (Feasibility Trial)	UK	103 (Web: 51, PR: 52)	COPD; FEV1<80%, MRC 2–5, mean age 66, web-literate, 74.5% male in web group	Interactive web-based PR (aerobic & strength training, education, self-monitoring); weekly support	6–8 weeks	Website dashboard, email/phone check-ins, online diaries	In-person PR: 2x/week, 2 hours/session for 7 weeks (exercise + education)	QOL (CRQ-SR), Endurance (ESWT, ISWT), Self-efficacy (PRAISE), Anxiety/Depression (HADS), Health related Quality of life (CAT), Knowledge (BCKQ)	Significant within-group gains in ESWT and CRQ-D; no between-group difference; higher dropout in web group (57%)
***Bourne et al., 2017** (18)*	RCT (non-inferiority)	UK	90 (Online PR n=64, Face-to-face n=26)	COPD, mMRC ≥ 2, age ≥40, mean age ~70, M:F ~62:38%, FEV1% pred: 58–60%	myPR online PR: 6-week video exercise + education, 2–5x/week	6 weeks	Online myPR platform, internet-enabled devices	Face-to-face PR (same program)	QOL (CAT, SGRQ), Endurance (6MWT), Dyspnea (mMRC), Anxiety/Depression (HADS)	Online PR non-inferior; similar 6MWT/CAT improvements; safe and well tolerated
***Holland et al., 2017** (13)*	RCT (equivalence)	Australia	166	COPD; mean age ~69; median 4 comorbidities	Home-based PR: 1 home visit + 7 weekly calls; unsupervised exercise + education	8 weeks + 12-month follow-up	Telephone, exercise diaries, pedometers	Center-based PR, 2x/week for 8 weeks	QOL (CRQ), Endurance (6MWD), Self-efficacy (PRAISE), Anxiety/Depression (HADS), Hospitalizations	Home PR equivalent short-term; gains lost at 12 months; higher completion in home PR (91% vs 49%)

Palmir, 2017 *(14)*	RCT	Italy	Not specified (CHF + COPD group)	CHF (NYHA II–IV) and COPD (GOLD B–D); MMSE ≥16	4-month telerehab + telemonitoring: ECG, pulse oximeter, exercise, nurse & physio support via phone	4 months	ECG, pulse oximeter, telephone	Usual care (GP, meds, lifestyle education)	QOL (questionnaires), Endurance (exercise tolerance test, unspecified), Physical Activity (PA measures), Dyspnea (unspecified), Hospitalizations, Death	Improved exercise tolerance and reduced adverse events in intervention group
Vasilopoulou et al., 2017 *(12)*	RCT	Greece	150 (47 in home-based group)	Moderate–severe COPD; FEV1 < 80%; age >40; 93.6% male	Home-based tele-rehab (video, calls, app, devices); 3x/week for 12 months	2-month PR + 12-month follow-up	Tablet, Bluetooth spirometer, web platform	Hospital-based rehab, usual care	QOL (unspecified), Hospitalizations, ED visits, Exacerbation rate	Significant reduction in exacerbations, hospitalizations, and ED visits vs. control
Galdiz et al., 2021 *(19)*	RCT	Spain	94 (46 in TelePR group)	Moderate–severe COPD, post-PR; BODE index 3–7; mean age 73–75	Supervised telerehab via app + exercise kit, 3x/week for 12 months	8-week PR + 12-month follow-up	Mobile app, oximeter, bike, phone	Usual care (general advice, no exercise)	QOL (CRQ, SF-36), Endurance (6MWT), Exacerbations	Improved 6MWT and self-efficacy; no significant difference in exacerbations
Zanaboni et al., 2023 *(17)*	RCT	Norway, Australia, Denmark	120	Moderate–severe COPD; age 40–80; ≥1 hospitalization in prior year	Supervised telerehab vs. unsupervised home treadmill use for 2 years	2 years	Treadmill, tablet, pulse oximeter, video system	Standard care	QOL (unspecified), Endurance (6MWT), Health related Quality of life (CAT), Hospitalizations, ED visits, Anxiety/Depression (HADS)	Reduced hospitalizations and ED visits; 6MWT gains sustained; improved Health related Quality of life (1 year)

RCT: Randomized controlled study; COPD: Chronic obstructive pulmonary disease; M:F: Male to female ratio; PR: Pulmonary rehabilitation; CCQ: Clinical COPD Questionnaire; MRC: Medical Research Council dyspnea scale; MFI-20: Multidimensional Fatigue Inventory – 20 item version; mMRC: Modified Medical Research Council dyspnea scale; FEV1: Forced expiratory volume in 1 second; 6MWT: Six-minute walk test; CAT: COPD Assessment Test; SGRQ: St. George's Respiratory Questionnaire; HADS: Hospital Anxiety and Depression Scale; 6MWD: Six-minute walk distance; CRQ: Chronic Respiratory Disease Questionnaire; PRAISE: Pulmonary Rehabilitation Adapted Index of Self-Efficacy; CHF: Congestive heart failure; NYHA: New York Heart Association classification; GOLD: Global Initiative for Chronic Obstructive Lung Disease; MMSE: Mini-Mental State Examination; ECG: Electrocardiogram; GP: General practitioner; PA: Physical activity; QoL: Quality of life; ED: Emergency department; BODE: Body mass index, airflow obstruction, dyspnea, and exercise capacity index; SF-36: 36-Item Short Form Health Survey; ESWT: Endurance shuttle walk test; CRDQ: Chronic Respiratory Disease Questionnaire; ISWT: Incremental shuttle walk test; CRQ-SR: Chronic Respiratory Questionnaire – Self Report; BCKQ: Bristol COPD Knowledge Questionnaire.

Table (2): PEDRO scale for the included studies

Study ID	Eligibility criteria specified	Random allocation	Concealed allocation	Baseline comparability	Blinding of subjects	Blinding of therapists	Blinding of assessors	>85% follow-up	Intention-to-treat analysis	Between-group comparison	Point measures & variability reported	PEDro Score (out of 10)	Quality of the study
Tabak et al., 2014	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	5	Fair
PALMIRet al., 2017	Yes	Yes	No	Yes	No	No	Yes	No	No	Yes	Yes	6	Good
Bourne et al., 2017	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	7	Good
Holland et al., 2017	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	8	Good
Chaplin et al., 2017	Yes	Yes	Yes	Yes	No	No	Yes	No	No	Yes	Yes	6	Good
Vasilopoulou et al., 2017	Yes	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	5	Fair
Tsai et al., 2017	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	8	Good
Galdiz et al., 2021	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	6	Good
Zanaboni et al., 2023	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	8	Good

Descriptive analysis of data

- **Primary outcomes:**

1. Effect of TR on Exercise Capacity: Across the majority of included studies, pulmonary TR was associated with improvements in exercise capacity among patients with COPD. **Palmira *et al.*** [14] reported a 60-meter increase in 6 MWD in the intervention group, compared to a 15-meter decline in controls, with gains maintained at six months. Similarly, **Tsai *et al.*** [15] found significant within-group improvements in both endurance shuttle walk test (ESWT) time and 6 MWD, with between-group differences favouring the intervention. **Bourne *et al.*** [18] demonstrated non-inferiority of online PR compared to face-to-face delivery, with a 23.8-meter adjusted mean difference in 6MWT. Longer-term improvements were reported in **Vasilopoulou *et al.*** [12] and **Zanaboni *et al.*** [17], with over 50% of patients in the intervention groups exceeding the minimal important difference (MID) for 6 MWD. **Galdiz *et al.*** [19] observed a non-significant mean increase of 19.9 meters, particularly among those without exacerbations. **Chaplin *et al.*** [16] showed significant within-group improvements in ESWT across both study arms, while **Holland *et al.*** [13] demonstrated equivalence between home and center-based PR programs, though long-term sustainability was limited. Notably, **Tabak *et al.*** [11] reported no significant change in daily step count, suggesting that intervention duration and format may influence outcomes.

2. Effect of TR on dyspnea: Dyspnea severity, as measured by scales such as the mMRC, MRC, and CRQ-D, showed consistent improvement across several trials. **Bernocchi *et al.*** [14] observed a decrease in MRC scores in the intervention group, in contrast to a slight increase among controls. Both **Vasilopoulou *et al.*** [12] and **Zanaboni *et al.*** [17] reported significant improvements in mMRC scores at six months. In **Galdiz *et al.*** [19], CRQ-D showed beneficial effects, particularly for patients with higher baseline symptoms. **Chaplin *et al.*** [16] also noted within-group CRQ-D improvements, although no significant between-group differences were observed.

3. Effect of TR on HRQoL: Improvements in HRQoL were evident across multiple trials. **Palmira *et al.*** [14] reported a notable reduction in CAT scores and enhanced emotional functioning, as measured by MLHFQ. **Bourne *et al.*** [18] found online PR to be non-inferior to face-to-face in CAT and SGRQ outcomes. **Tsai *et al.*** [15] demonstrated significant within-group CRDQ improvements, approaching statistical significance in between-group comparisons. Maintenance of quality-of-life benefits over 12 months was reported by **Vasilopoulou *et al.*** [12], while **Galdiz *et al.*** [19] observed a +9.7 point improvement in SF-36 MCS scores and favorable changes in CRQ-E.
Holland *et al.* [13] found comparable CRQ outcomes between groups, and **Tabak *et al.*** [11] noted modest CCQ improvements only within the intervention group.

- **Secondary outcomes**

1. Hospitalizations and emergency department visits: Reduction in acute care utilization was one of the most compelling findings. **Palmira *et al.*** [14] documented significantly fewer hospitalizations (21 vs. 37) and longer event-free survival in the intervention group. **Vasilopoulou *et al.*** [12] reported a reduction in acute exacerbations, hospitalizations, and ED visits, with TR being an independent predictor of lower ED use (IRR 0.116, $p < 0.001$). Likewise, **Zanaboni *et al.*** [17] observed reduced hospitalization incidence (1.18 vs. 1.88 events/person-year) and fewer recurrent hospital events. Although **Holland *et al.*** [13] did not find statistically significant differences, there was a favorable trend toward delayed respiratory-related admissions in the home-based group.
2. Psychological outcomes (Anxiety and depression): Findings for psychological well-being were mixed. **Bourne *et al.*** [18] and **Holland *et al.*** [13] both observed reductions in anxiety and depression in all groups, but without significant differences between arms. Conversely, **Tsai *et al.*** [15] reported significant improvements in both anxiety and depression scores favoring TR. **Chaplin *et al.*** [16] detected no group differences, though web-based dropouts had higher baseline anxiety. **Zanaboni *et al.*** [17] also found no significant psychological effects.

3. Self-efficacy: Self-efficacy, evaluated by the Pulmonary Rehabilitation Adapted Index of Self-Efficacy (PRAISE) scale, showed mixed outcomes. **Tsai *et al.*** [15] noted a significant increase in the intervention group. **Chaplin *et al.*** [16] reported improvements in both arms, but without statistical differences. **Holland *et al.*** [13] and **Zanaboni *et al.*** [17] did not observe any notable change.
4. Adherence and compliance: Adherence to TR was generally high. **Holland *et al.*** [13] reported a 91% completion rate for home-based PR, compared to 49% for center-based care. **Vasilopoulou *et al.*** [12] achieved 93.5% compliance over one year, while **Galdiz *et al.*** [19] reported 92% session attendance and 60% overall exercise adherence. **Tsai *et al.*** [15] showed excellent adherence despite minor technical issues. Conversely, **Chaplin *et al.*** [16] observed a 57% dropout rate in the web group, likely linked to anxiety. **Zanaboni *et al.*** [17] reported high engagement and minimal safety concerns.

Quantitative synthesis of results

1. Effect of TR on exercise capacity using 6 MWD: Meta-analysis of six RCTs (n = 624) revealed a pooled standardized mean difference (SMD) of **0.37 [0.14, 0.60]**, indicating a **moderate and statistically significant** improvement in 6MWD with TR. The most prominent effect was observed in **Palmira *et al.*** [14] (SMD = 0.86), followed by **Vasilopoulou *et al.*** [12] (SMD = 0.52) and **Zanaboni *et al.*** [17] (SMD = 0.27).

Moderate heterogeneity was detected (I^2 = 48%), but it was not statistically significant (p = 0.09) (Figure 2).

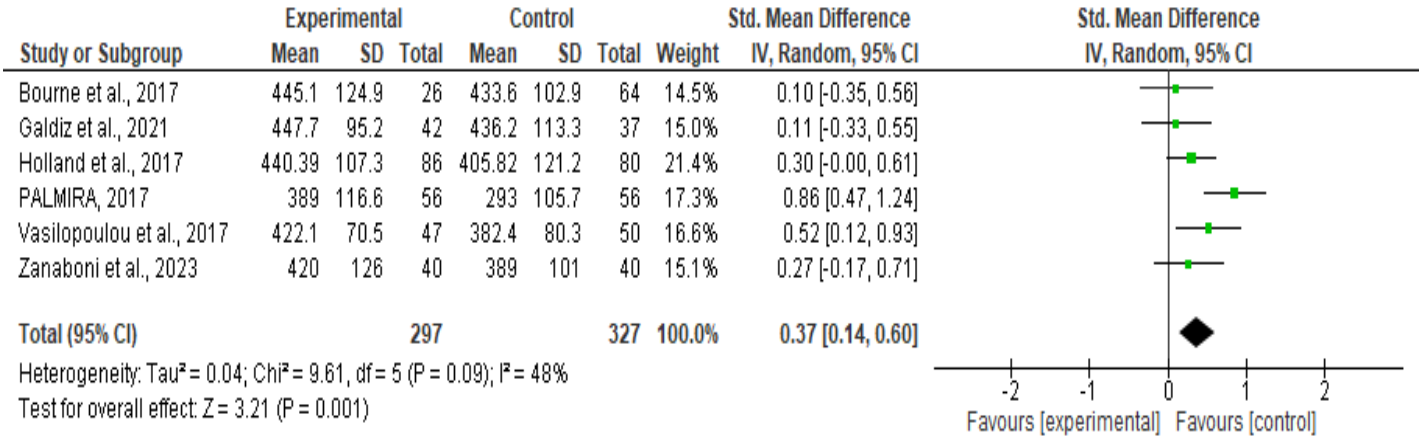

Figure (2): Effect of TR on 6 MWD.

2. Effect of TR on dyspnea using mMRC: The pooled SMD across six studies for mMRC scores was **−0.16 [−0.67 to 0.34]**, indicating a non-significant overall effect (p = 0.53). Heterogeneity was high (I^2 = 90%). Sensitivity analysis excluding **Holland *et al.*** [13], which reported an unusually large effect, resulted in a revised SMD of **−0.37 [−0.58 to −0.17]** (p = 0.0004) and reduced heterogeneity (I^2 = 21%) (Figure 3).

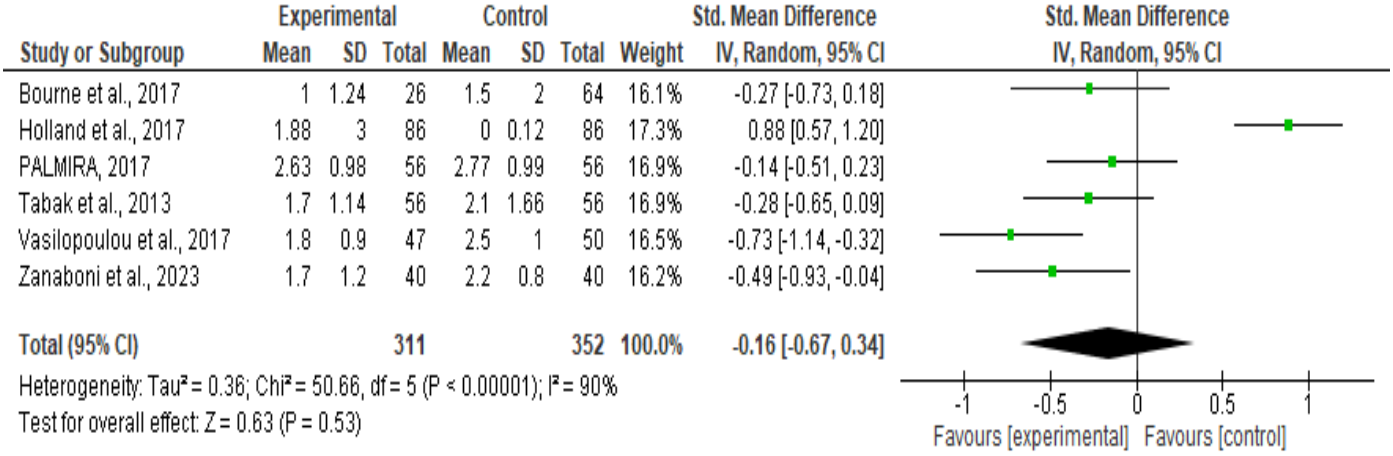

Figure (3): Effect of TR on Modified Medical Research Council (mMRC).

3. Effect of TR on HRQoL using CAT Score: Three studies [12, 14, 17] were included in the meta-analysis assessing CAT scores. The pooled SMD was **−0.63 [−1.04 to −0.21]** (p = 0.003), indicating a **moderate and statistically significant** benefit. Sensitivity analysis excluding a subgroup from **Palmira *et al.*** [14] reduced heterogeneity to 0% and yielded an adjusted SMD of **−0.42 [−0.72 to −0.12]** (p = 0.006) (Figures 4, 5 & 6)).

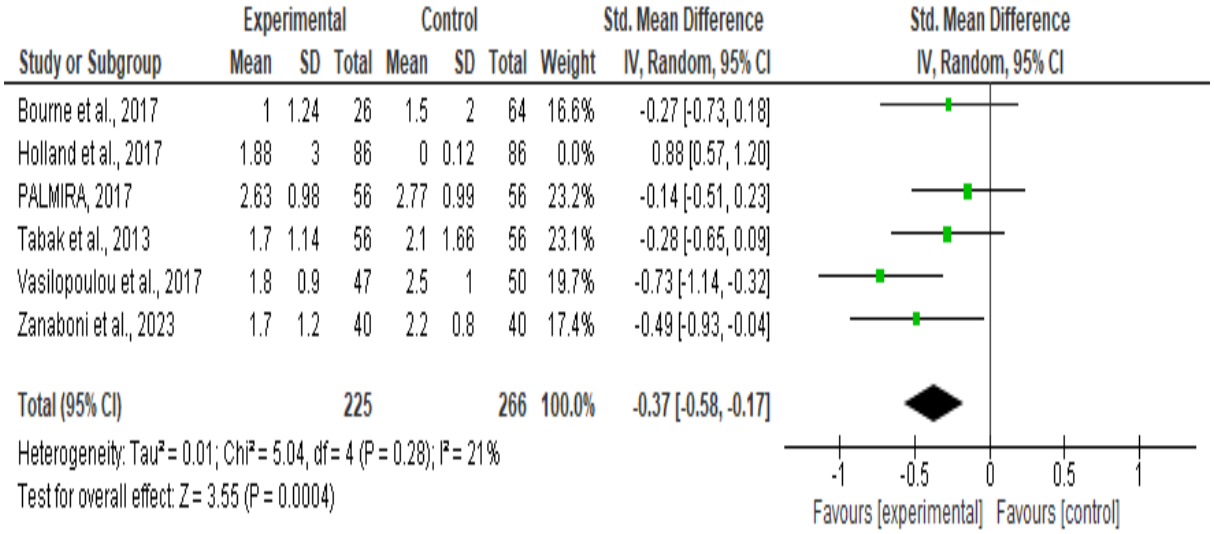

Figure (4): Effect of TR on mMRC after sensitivity analysis

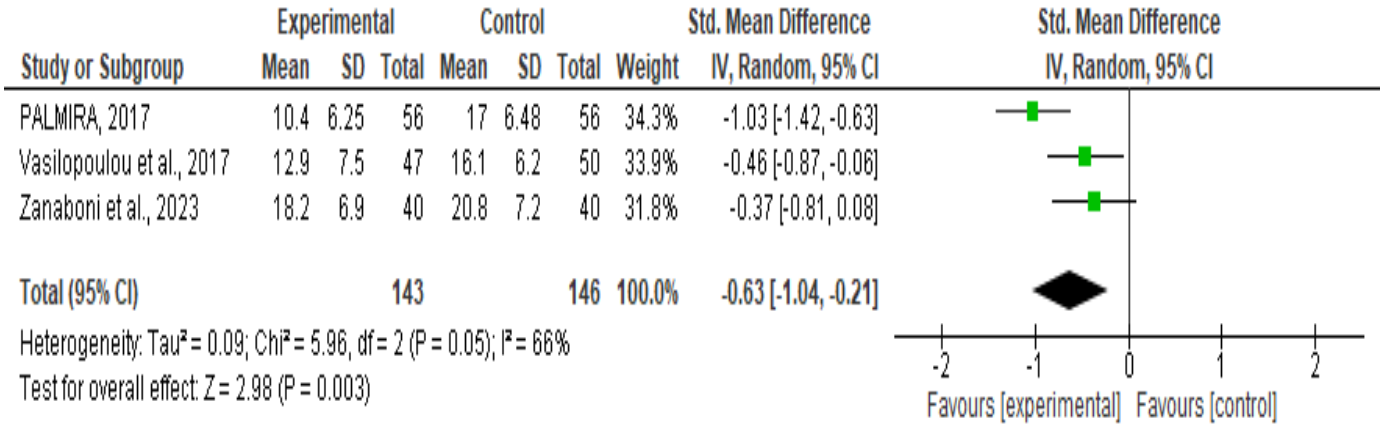

Figure (5): Effect of TR on HRQoL as measured by the COPD Assessment Test (CAT) score.

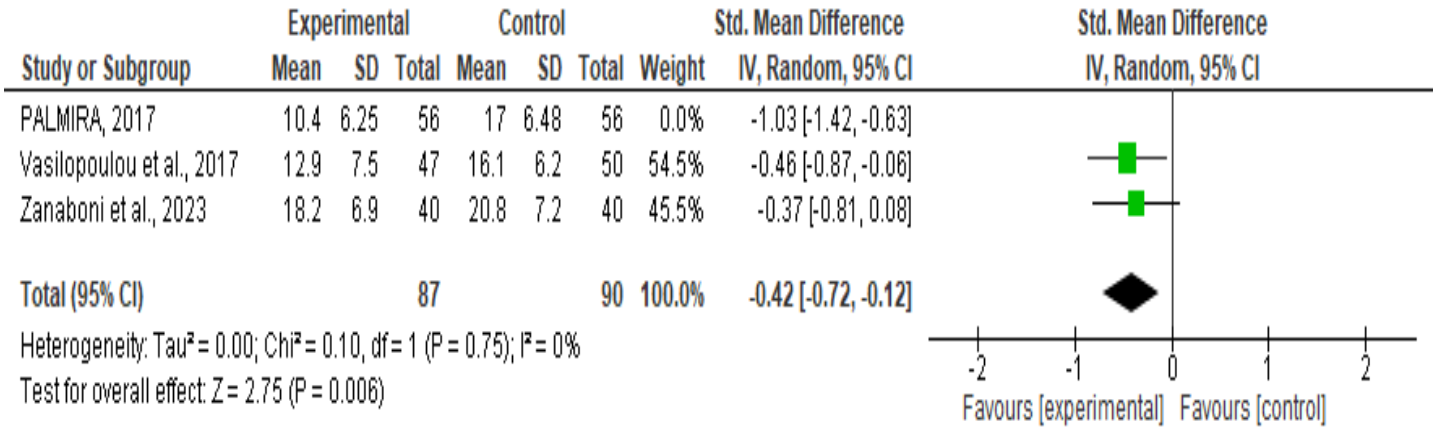

Figure (6): Effect of TR on HRQoL as measured by the COPD Assessment Test (CAT) score after sensitivity analysis.

DISCUSSION

This systematic review evaluated the effectiveness of pulmonary TR in patients with COPD by synthesizing data from nine RCTs. These studies varied in design, population size, and intervention modalities—including video-based training, mobile apps, wearable sensors, and remote coaching. Adhering to PRISMA 2020 guidelines, the review applied robust methodological tools including the PEDro scale for quality appraisal and the modified Sackett scale for evidence grading. Despite differences in protocol duration and delivery format, all trials assessed functional, symptomatic, and quality-of-life outcomes, yielding a comprehensive perspective on TR potential across diverse healthcare contexts.

The evidence base consisted of over 600 participants, with trials predominantly conducted in Europe and Australia. Interventions consistently integrated endurance or resistance training, educational components, and remote monitoring, with many offering extended follow-up periods. Meta-analytic findings demonstrated a statistically significant improvement in exercise capacity using 6MWD (SMD = 0.37 [0.14 to 0.60]), supported by robust trials like **Palmira *et al.*** [14], **Vasilopoulou *et al.*** [12], and **Zanaboni *et al.*** [17]. While the initial pooled effect on dyspnea was non-significant (SMD = −0.16), sensitivity analysis confirmed a meaningful reduction (SMD = −0.37) after removing one outlier study. Similarly, TR significantly improved CAT scores (SMD = −0.63), with heterogeneity eliminated after adjustment, underscoring the reliability of its benefits in HRQoL and symptom relief.

The included studies were largely of good methodological quality. Three trials of **Holland *et al.*** [13], **Tsai *et al.*** [15], and **Zanaboni *et al.*** [17] achieved the highest PEDro score of 8, with six others rated as "good." Despite challenges inherent in blinding physical rehabilitation trials, most studies used randomized designs, reported group comparability at baseline, and provided transparent outcome reporting. These findings echo broader evidence from **Cox *et al.*** [20] which emphasizes the role of allocation concealment, blinded outcome assessors, and ITT analysis in enhancing trial validity. Moreover, seven of the nine included studies qualified as Level I evidence per the Modified Sackett Scale, confirming the robustness of the clinical data.

The review's findings aligned with prior meta-analyses and trials. **Horton *et al.*** [21] and **Liu *et al.*** [22] showed that home-based TR programs produced comparable or superior gains in 6MWD compared to in-person PR. Reductions in dyspnea were consistent

with results from **Maltais *et al.*** [23] and **Armstrong *et al.*** [24], who found that remote exercise training and digital coaching could significantly improve mMRC scores. Improvements in HRQoL were supported by **Polgar *et al.*** [25], **McCarthy *et al.*** [26], and **Bourne *et al.*** [27], while decreased hospitalizations and ED visits reflected findings by **Chen *et al.*** [28] and **Vitacca *et al.*** [29]. Though psychological outcomes were not consistently reported, supporting studies such as **Serber *et al.*** [30] and **Cox *et al.*** [31] suggested that integrated psychosocial elements enhance emotional resilience in TR.

This review also identified limitations that warrant attention. Heterogeneity in intervention design, duration, supervision, and outcome measures posed challenges to synthesis and generalizability. Although sensitivity analyses improved the reliability of meta-analytic findings, differences in follow-up periods, adherence tracking, and reporting formats limited the comparability of long-term effects. Additionally, participant and therapist blinding were rarely feasible, and intention-to-treat analysis was inconsistently applied. Only English-language RCTs were included. Future research should standardize TR protocols, integrate mental health support, and evaluate implementation outcomes such as cost-effectiveness and accessibility in underserved populations.

Findings of this review showed that pulmonary TR is a clinically effective and safe intervention for managing COPD, offering significant improvements in exercise capacity and HRQoL, as demonstrated by high-quality RCTs and confirmed through meta-analyses. Although the effects on dyspnea, and psychological outcomes were mixed, sensitivity analyses revealed notable improvements in dyspnea, and most studies reported stable or positive psychological trends. TR was also associated with reduced hospitalizations and emergency department visits, indicating a meaningful impact on healthcare utilization. High adherence and minimal adverse events across studies support the feasibility and acceptability of TR as a non-inferior alternative to conventional pulmonary rehabilitation, particularly for patients with limited access to center-based care.

CONCLUSION

This systematic review and meta-analysis highlighted that pulmonary TR is an effective intervention for managing COPD, particularly in enhancing exercise capacity, dyspnea and HRQoL, particularly when the access to conventional pulmonary rehabilitation is limited.

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