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REVIEW

A Network Meta-Analysis of Aerobic, Resistance, Endurance, and High-Intensity Interval Training to Prioritize Exercise for Stable COPD

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Purpose: While the benefits of exercises for chronic obstructive pulmonary disease (COPD) are well-established, the relative effectiveness of different exercise types for stable COPD remains unclear. This network meta-analysis aims to investigate the comparative effects of aerobic exercise (AE), resistance training (RT), endurance training (ET), and high-intensity interval training (HIIT) in stable COPD.

Methods: Electronic searches were performed in PubMed, Embase, and the Cochrane library to identify relevant randomized controlled trials (RCTs) investigating the effects of exercises on 6-minute walk test distance (6MWD), forced expiratory volume in one second (FEV1), and forced vital capacity (FVC), and St. George's Respiratory Questionnaire (SGRQ) score. Two authors screened the retrieved articles, extracted relevant data, and assessed the risk of bias. Network meta-analysis was conducted using Stata 14.0.

Results: This study included a total of 19 studies involving 951 patients with stable COPD. HIIT emerged as the most favorable exercise type for enhancing 6MWD, with a probability of 82.9%. RT exhibited the greatest efficacy in reducing SGRQ scores, with probability of 49.8%. Notably, ET demonstrated superiority in improving FEV1 and FVC, with probabilities of being most effective at 78.1% and 42.0%, respectively.

Conclusion: This study suggests that HIIT may be a viable intervention for improving exercise capacity in stable COPD patients, compared to AE, RR, and ET. RT may hold promise for improving quality of life, and ET may demonstrate superiority in improving pulmonary function. However, variation in response likely depends on patient characteristics, program parameters, and delivery context. Future research should explore the synergistic effects of combining RT with ET/HIIT, focusing on patient subgroups, optimal dosing, and settings, as current guidelines indicate this combination may offer the most significant benefits.

Keywords: COPD, exercise, pulmonary function, quality of life, network meta-analysis

Introduction

Chronic obstructive pulmonary disease (COPD) is a progressive, heterogeneous lung condition characterized by airflow limitation, which significantly impairs exercise capacity, contributing to dyspnea, and exercise intolerance.[1] These symptoms often result in reduced physical activity levels and a reduced quality of life.[2] Exercise-based pulmonary rehabilitation is a cornerstone of COPD management, aiming to improve exercise capacity, alleviate symptoms, and enhance overall well-being for patients.[3–6]

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Several guidelines strongly recommend a comprehensive approach to pulmonary rehabilitation, which typically includes resistance training (RT) and endurance training (ET).[7–10] Aerobic exercise (AE), encompassing activities such as walking, cycling, or swimming, is a well-established strategy documented to improve exercise capacity and health-related quality of life in COPD patients.[11–13] Resistance training (RT) focuses on building muscle strength and endurance, which can significantly improve functional capacity and reduce dyspnea, allowing patients to engage in daily activities with greater ease.[14–16]

Despite these established guidelines,[7–10] there remains a gap in understanding the relative effectiveness of various exercise modalities when applied individually or in specific combinations within pulmonary rehabilitation programs.[17] Endurance training (ET), a subset of AE focused on sustained moderate-intensity exercise, offers distinct benefits. Studies suggest ET can specifically improve cardiovascular health and exercise tolerance in COPD patients.[18,19] High-intensity interval training (HIIT), characterized by alternating short bursts of high-intensity exercise with recovery periods, represents a relatively new approach for COPD management.[20] Although emerging evidence suggests potential benefits of HIIT, optimal training parameters and safety considerations for this population necessitate further exploration.[21]

While comprehensive, combined exercise programs dominate the research landscape in pulmonary rehabilitation, understanding the specific contributions and relative effectiveness of different exercise modalities is critical for optimizing and personalizing rehabilitation strategies, which has been underscored by the potential to tailor rehabilitation programs more precisely to the unique needs and capabilities of each patient.[1] A network meta-analysis provides a powerful statistical technique to compare multiple exercise modalities, even when direct head-to-head comparisons are spares[22] This approach extends beyond traditional pairwise comparisons, allowing for a more nuanced understanding of how different exercise interventions rank in terms of key outcomes, such as exercise capacity, pulmonary function, and quality of life.[23] A prior network metanalysis sought to compare AE, RT, ET, and HIIT in COPD but did not distinguish between stable and exacerbated COPD, potentially limiting the generalizability of its findings.[24]

In response to this gap, this network meta-analysis focusing specifically on patients with stable COPD, aiming to elucidate the comparative effects of AE, RT, ET, and HIIT on exercise capacity, pulmonary function, and quality of life. By synthesizing the available evidence, we aim to offer a clearer picture of the most effective exercise strategies within this specific patient population. This will empower healthcare professionals to tailor pulmonary rehabilitation programs more effectively, taking into account not only the exercise types but also patient characteristics that may influence their response to these interventions. Ultimately, this work aims to contribute to improved COPD management and better patient outcomes by informing practice with the most up-to-date and comprehensive evidence.

Methods

This network meta-analysis was reported according to the Preferred Reporting Items for Systematic Review incorporating Network Meta-Analysis (PRISMA) guidelines (as shown in Table S1)[25] and conducted in accordance with the Cochrane Collaboration Handbook.[26] The protocol of this network meta-analysis has been registered on Open Science Framework platform, with a registration identifier of 10.17605/OSF.IO/WMN58.

Eligibility Criteria

Studies were eligible if: (1) they enrolled adults (≥18 years) with stable COPD (defined as no hospital admission or exacerbation for at least 4 or 8 weeks, and no medication changes according to Global Initiative for Chronic Obstructive Lung Disease [GOLD] guideline); (2) they compared AE, RT, ET, and HIIT against control (CON) or one of four exercise types, with the minimum follow-up time of 3 months; (3) they reported exercise capacity which was measured by 6-minute walk distance (6MWD), pulmonary function which was reflected by forced expiratory volume in one second (FEV1) and forced vital capacity (FVC), and quality of life which was measured by St George's Respiratory Questionnaire (SGRQ); and (4) they were original randomized controlled trials (RCT) published in English. Furthermore, for duplicate publications identified from the same research group, we include only the most complete or recent version.

Studies were excluded if they: (1) were animal or cellular experiments, case reports, plans for scientific experiments, reviews, letters, editorials, conference papers, etc.; (2) missed research data or serious errors in the literature; (3) were lack of the full text; and (4) considered intervention which was not one of the pre-defined types we are interested in.

Information Sources

A first systematic literature search was conducted on March 5, 2023 on the PubMed, EMBASE, and Cochrane Library. The search strategy included a combination of title, abstract, keywords terms. A detailed search strategy is available in Supplementary materials Data S1. To ensure comprehensiveness, the search was supplemented by weekly automatic alters from the databases until the end of July, 2024, and hand-searching of references from relevant systematic reviews.

Study Selection

Two authors independently screened titles and abstracts of studies retrieved from targeted databases and reference lists of previously published systematic reviews to identify those meeting the pre-defined inclusion criteria. Full texts of the articles were obtained for potentially eligible studies and independently assessed by both authors for compliance with the eligibility criteria. Disagreements were resolved through discussion until consensus was reached. The present network metanalysis did not restrict participants by age, gender, body mass index, or publication date.

Data Extraction

Data were extracted from the final selection of articles using a pre-defined data extraction form in Excel 2016. The form captures key information including first author, publication year, country, exercise types, sample size of each study, GOLD grading of included patients, mean age of patients, details of exercises, exercise duration, and outcome measures.

Risk of Bias Assessment

Two independent authors utilized the revised Cochrane Risk of Bias tool (Rob 2)[27] to assess potential biases across seven key domains: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other biases. Following the Cochrane guidelines, each domain was categorized as having a "low risk", "some concerns" or "high risk" of bias.[28] The overall risk of bias for each study was then determined based on this individual domain assessment. Studies with minimal risk across all domains were classified as having a "low" overall risk of bias. Studies with some domains raising concerns were categorized as having "some concerns" overall. Finally, any study with a single domain assessed as having a "high risk" of bias was classified as having a "high" overall risk of bias. Finally, we employed the R package and Shiny web application, robvis,[29] to generate graphical representations of the risk of bias profile for each included study.

Statistical Analysis

The network meta-analysis based on the frequency-based framework was performed by Stata 16.0. We investigated the comparative effects of various exercise types on exercise capacity, pulmonary function, and quality of life in patients with stable COPD. Unlike traditional meta-analysis relying on pairwise comparisons, our frequency-based framework integrates information from both direct and indirect comparisons. To quantify intervention effects, we employed mean differences (MD) with 95% confidence interval (CI) and addressed potential inconsistencies between direct and indirect evidence using node-splitting approach. A p-value greater than 0.05 indicated consistency, allowing us to proceed with the consistency model. Conversely, the inconsistency model was chosen if a statistically significant difference emerged. To comprehensively assess and rank the exercise interventions, we utilized the surface under the cumulative ranking probability (SUCRA) plot. SUCRA values highlight the probability of an intervention being the most effective, with larger areas under the curve indicating a greater likelihood of superiority.[30] Finally, we drew comparison-adjusted funnel plot to visually inspect the risk of publication bias.

Results

Study Selection

Our initial search identified 19 relevant studies from a prior meta-analysis. To update the evidence bases, we conducted a comprehensive search across PubMed, EMBASE, and the Cochrane library, retrieving a total of 814 articles. After removing duplicate articles and registered protocols, 513 studies remained for the initial eligibility assessment. Following a through screening of titles and abstracts, we excluded 507 studies for the following reasons: 63 were conference abstracts, 97 were review articles and 347 were unrelated to the topic of our network meta-analysis. We then conducted a detailed full-text screening of the remaining six studies; however, none met our selection criteria. Therefore, we finally included 19 articles[1,16,31–48] in this updated network meta-analysis (Figure 1).

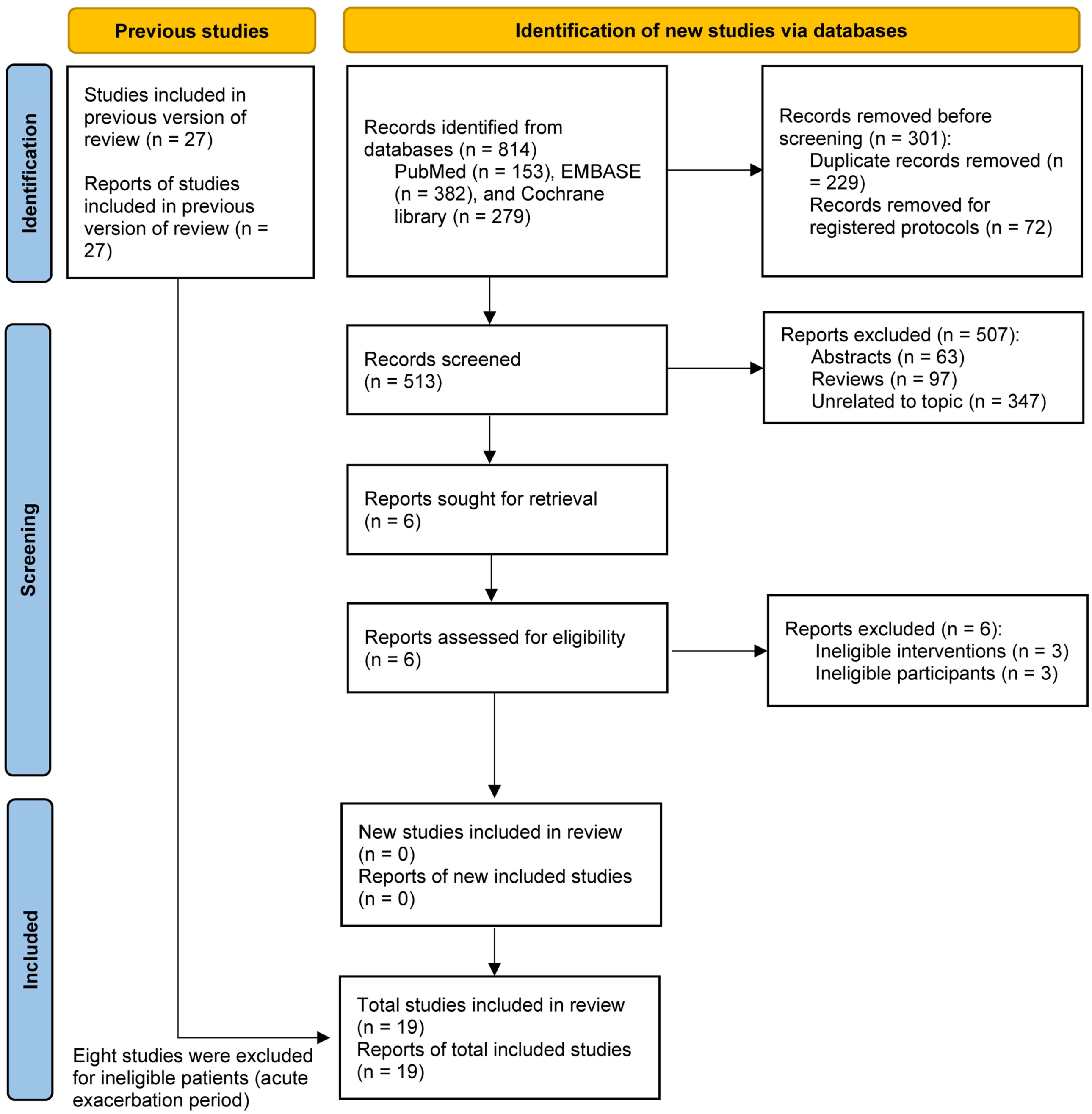

Figure 1 PRISMA flow diagram of study selection.

Basic Characteristics of Included Studies

A total of 19 studies encompassing 951 stable COPD patients from 8 countries were analyzed. The studies investigated the effects of 5 exercise interventions on individuals ranging in age from 59 to 73.6 years old. The number of patients across the intervention groups was as follows: 450 in AE, 70 in RT, 35 in ET, and 44 in HIIT. The control group of 352 patients received CON. Further details regarding characteristics of the included studies are presented in Table 1.

Risk of Bias

A comprehensive risk-of-bias assessment was conducted on the 19 included studies, with detailed results presented in Figure 2. This analysis identified potential limitations in several domains, particularly regarding randomization and blinding procedures. Specifically, 7 studies[16,32,35,39,42,43,48] lacked adequate description of the randomization process and allocation concealment methods. This raises concerns about selection bias, potentially influencing the comparability of intervention groups. Two studies[16,33] were judged to be at high risk of bias due to missing outcome data. Seven studies[16,36,37,41,45–47] relied on self-reported outcomes by patients, which introduces a potential source of measurement bias. Due to the inherent nature of the interventions, double-blinding patients and those implementing the interventions was not feasible in any of the studies. None of the studies reported selective bias, therefore the risk of bias was considered low. Based on the assessment, 11 studies[33,35–37,40,42–46,48] were classified as having a high risk of bias, 5 studies[16,32,39] with some concerns, and 5 studies[31,34,38,41,47] with a low risk of bias.

Evidence Network

Our network meta-analysis visualized in Figure 3 to represent the interrelationships between exercise modalities for managing patients with stable COPD. Each node represents a distinct exercise type, and the lines connecting them depict head-to-head comparisons between modalities in the included studies. The thickness of these lines reflects volume of studies comparing those specific exercise interventions, with wider lines representing a greater number of comparative studies between the exercise modalities.

6mwd

This analysis included 15 studies involving a total of 816 patients. Notably, of these studies, 11 studies compared AE with CON, 2 studies compared RT with CON, 1 study compared ET with CON, 2 studies compared AE with ET, and 1 study compared AE with ET. Inconsistency tests (detailed in Figure S1 and S2) revealed no significant evidence of inconsistency ($p>0.05$), allowing for the use of a consistency model in the network meta-analysis. The analysis demonstrated that both AE and HIIT yielded statistically significant improvements in MWD compared to CON (AE: MD 44.91, 95% CI: 22.67–67.14; HIIT: MD 77.95, 95% CI: 18.20–137.70). Furthermore, HIIT displayed a significant advantage over RT in enhancing 6MWD (MD: 82.85, 95% CI: 6.56–159.14). No significant differences were observed in pairwise comparisons for the remaining interventions (see Figure 4). Loop-based inconsistency analysis (Figure S3) corroborated the robustness of these findings. HIIT emerged as the most probable intervention to improve 6MWD based on cumulative ranking probabilities (PrBest: 82.9%, Figure 5). AE and ET also demonstrated promising probabilities (AE: PrBest: 8.4%; ET: PrBest: 8.2%).

FEV1

Eight studies involving a total of 399 participants were included in the analysis. Of these studies, 5 studies compared AE with CON, 1 study compared ET with CON, 1 study compared AE with RT, 1 study compared AE with ET, and 2 studies compared AE with HIIT. As shown in Figure S1, global inconsistency test showed an insignificant result ($p=0.199$), and local inconsistency test also revealed insignificant results (as presented in Figure S2). Therefore, we selected a consistency model to perform network meta-analysis. According to the results, AE (MD: 0.26, 95% CI: 0.05 to 0.47) demonstrated superior improvement in the FEV1 compared to CON, with statistically significant difference. No significant differences were observed in pairwise comparisons for the other interventions (as shown in Figure 4). Furthermore, loop-based inconsistency using node-splitting approach showed

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Table 1 Baseline characteristics of 19 studies included in this network meta-analysis

Study	Country	Exercise	Sample Size (M/F)	GOLD Grading	Mean Age, Years	Interventions and Intensity	Intervention Duration	Outcomes
Breyer et al 2010[32]	Australia	AE	30 (14/16)	GOLD II-IV	61.9	75% HRmax, Nordic walking	1h/d, 3d/w, 12w	6MWD
		CON	30 (13/17)		59.0	No exercise intervention		
Chan et al, 2011[33]	China	AE	70 (69/1)	GOLD I-III	71.7	Tai Chi	60min, 2d/w, 12w	FVC, EFV1, 6MWD
		CON	67 (58/9)		73.6	No extra exercise was recommended		
Chen et al, 2022[34]	China	AE	15 (13/2)	GOLD II-III	73.5	Daily walking plan using pedometer: gradually increase steps to 10000, starting from patients' baseline and reaching 100-110% of patients' previous week's average.	12h/d, 7d/w, 6w	FEV1, FVC, 6MWD
		CON	11 (9/2)		71.9	Walking at home for >30 minutes daily		
Donesky-Cuenco et al, 2009[35]	USA	AE	14 (14/0)	n.r.	72.2	Maximal effort, Iyengar yoga	1h/d, 2d/w, 12w	6MWD
		CON	15 (11/4)		67.7	Usual care		
Farias et al, 2014[37]	Brazil	AE	18 (11/7)	n.r.	64.6	Participants in two educational sessions and walk after class	40-60min, 5d/w, 8w	6MWD, SGRQ
		CON	16 (16/0)		70.5	Participants in only two educational sessions		
Özer et al, 2021[41]	Turkey	AE	30 (4/26)	n.r.	n.r.	Yoga, 10min standing breath exercise, 10min seated breath exercise with asana, 10min stretching breath exercise with asana, 20min deep seated breath exercise, 10min stretching deep relaxation.	60-90min, 2d/w, 8w	EFV1, FVC
		CON	30 (10/20)			No intervention is made		
Wootton et al, 2014[46]	Australia	AE	95 (56/39)	GOLD II-IV	69.0	Starts at 80% speed walking, supervised training increases by 5 min every 6 sessions, maxing at 45 min.	30-45min, 2-3d/w, 8-10w	6MWD, SGRQ
		CON	48 (28/20)		68.0	Do not participate in athletic training		
Yeh et al, 2010[47]	USA	AE	5 (3/2)	GOLD II-III	65.0	Tai Chi: gentle movement, relaxation, and breath exercise in just 5 forms.	2d/w, 12w	6MWD
		CON	5 (3/2)		66.0	Usual care		
Yudhawati et al, 2019[48]	Indonesia	AE	15 (15/0)	GOLD I-IV	64.4	Yoga	60min, 2d/w, 12w	FEV1, 6MWD, SGRQ
		CON	15 (15/0)		65.3	Pulmonary rehabilitation manual provided		
Wootton et al, 2017[45]	Australia	AE	62 (38/24)	n.r.	69.0	Walk training needed (Borg≤5)	30-45min, 2-3d/w, 8-10w	6MWD, SGRQ
		CON	39 (24/15)		68.0	Do not do any athletic training		
Borghi-Silva et al, 2009[31]	USA	AE	20 (13/7)	GOLD II-III	67.0	70% maximal speed, treadmill	30min, 3d/w, 6w	6MWD
		CON	14 (14/0)		67.0	Inhalers for control, avoid aerobic exercise		

Duruturk et al, 2016[36]	Turkey	AE	14 (13/1)	GOLD II-III	61.2	Calisthenics training: 1-2 weeks, 10-15 repetitions/exercise; 3-4 weeks, 15-20 repetitions/exercise; 5-6 weeks, 25-30 repetitions/exercise.	20-45min, 3d/w, 6w	FEV1, FVC, 6MWD, SGRQ
		ET	15 (11/4)		61.2	50-70% VO_2max, cycle training	20-45min, 3d/w, 6w	
		CON	13 (11/2)		63.8	Only one 30min educational session and continue current treatment	6w	
Gamper et al, 2019[38]	Switzerland	AE	8 (5/3)	GOLD III-IV	65.6	50-70% (GOLD IV) or 70-80% (GOLD III) HRmax, outdoor walking	30min, 6d/w, 3w	6MWD
		ET	8 (5/3)		63.0	50-70% (GOLD IV) or 70-80% (GOLD III) Wmax, cycling ergometer		
Lake et al, 1990[39]	Australia	RT	6 (6/0)	COLD IV	62.0	40s (with 20s rest) repeat 3 times in 3min	1h/d, 3d/w, 8w	FEV1, FVC
		AE	6 (6/0)		71.8	Walk		
Vonbank et al, 2012[43]	Australia	ET	12 (8/4)	GOLD I-IV	61.8	60% VO_2peak, cycle ergometer	20-60min, 2d/w, 12w	SGRQ
		RT	12 (8/4)		60.0	1-4 weeks, 2 sets per week, one set consists of 8-15 repetitions; 4-8 weeks, 3 sets per week, one set consists of 8-15 receptions; 8-12 weeks, 4 sets per week, one set consists of 8-15 repetitions, maximal effort repeat, strength training		
Varga et al, 2007[42]	Hungary	HIIT	17 (11/6)	n.r.	67.0	30min cycling, 2min at 90% followed by 1min at 50% peak work rate, cycling	45min, 3d/w, 8w	FEV1, FVC
		AE	22 (19/3)		61.0	80% of peak work rate, cycling		
Wang et al, 2017[44]	China	HIIT	27 (27/0)	n.r.	70.0	70% VO2max, 3 sets per week, one set consists of 3 repetitions, cycling ergometer	30min, 3d/w, 8w	FEV1, FVC, 6MWD, SGRQ
		AE	26 (26/0)		69.8	90% HRmax, walking		
Chen et al, 2018[16]	China	RT	25 (22/3)	n.r.	69.0	Borg≤5, thera-band resistance and self-gravity resistance	20-30min, 3d/w, 12w	6MWD
		CON	22 (15/7)		64.9	Routine care includes health education, nutrition and psychological support, etc.		
O'Shea et al, 2007[40]	Australia	RT	27 (27/0)	GOLD III-IV	66.9	3 sets per week, one set consists of 8-12 repetitions, maximal effort repeat, resistance bands	3d/w, 12w	6MWD
		CON	27 (27/0)		68.4	No intervention is made		

Abbreviations: COPD, chronic obstructive pulmonary disease; AE, aerobic exercise; RT, resistance training; ET, endurance training; HIIT, high-intensity interval training; CON, control; GOLD, global initiative for COPD; 6MWD, 6-minute walk distance; FEV1, forced expiratory volume in one second; FVC, forced vital capacity; SGRQ, St George's Respiratory Questionnaire; VO_2max, maximum oxygen consumption; VO_2peak, peak oxygen uptake; HR, heat rate; n.r., not reported.

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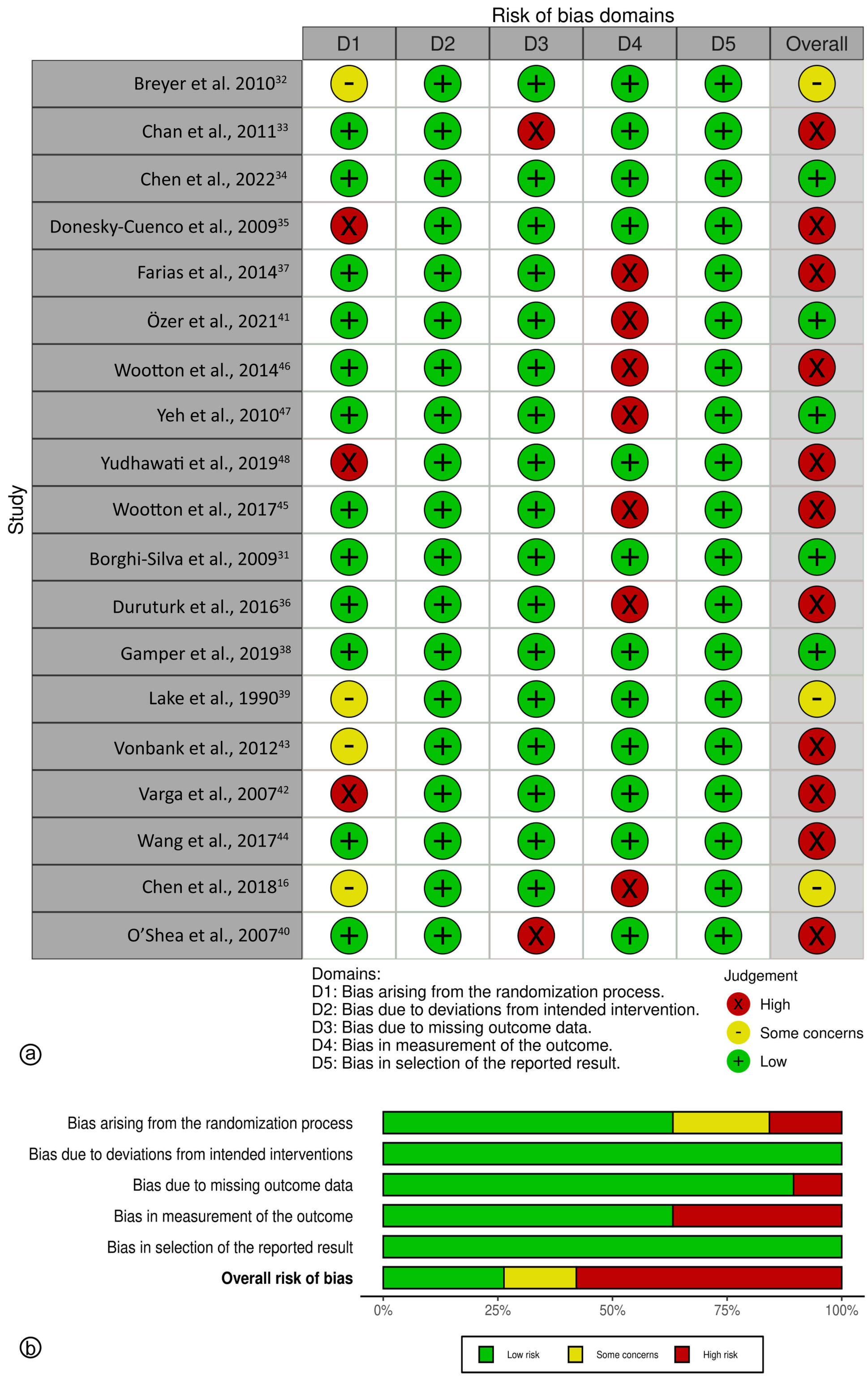

Figure 2 Risk of bias of (**a**) traffic-light plot and (**b**) summary plot.

an insignificant result, indicating the robustness of these results (see Figure S3). Based on the cumulative probability results, ET (PrBest: 42.0%), RT (PrBest: 31.0%), and AE (PrBest: 26.2%) were identified as the top three exercises for improving FVC (see Figure 5).

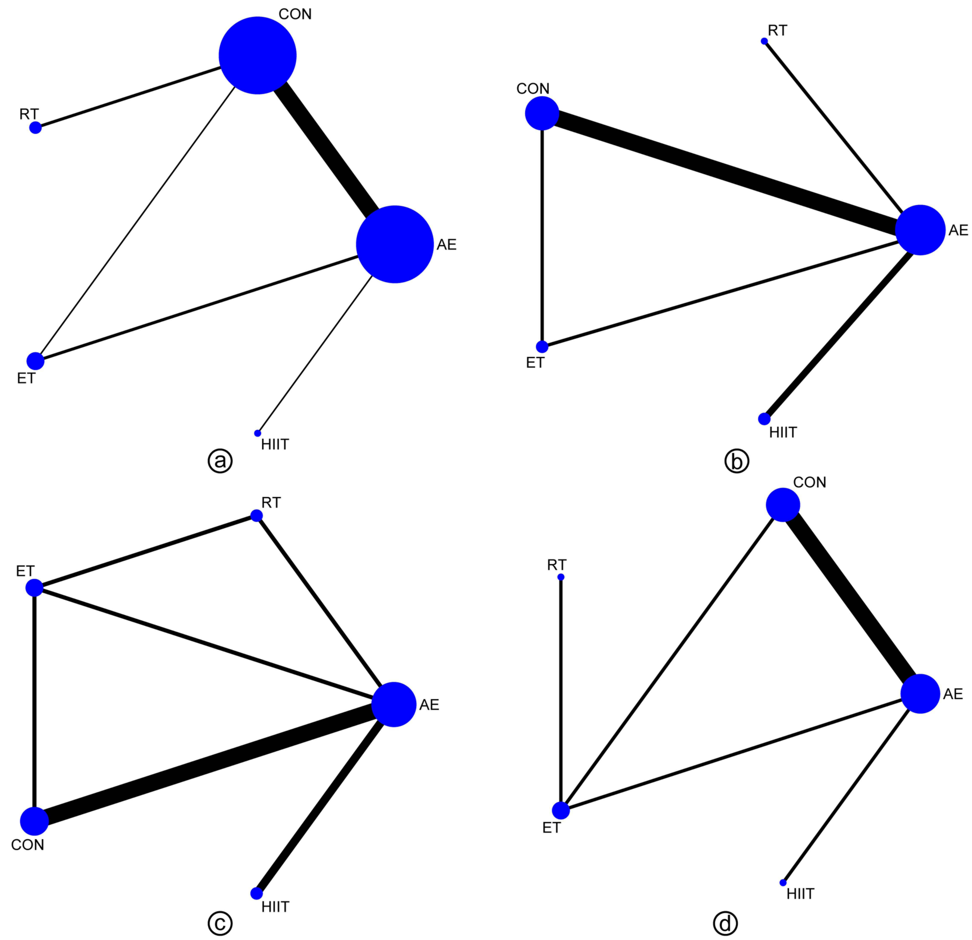

Figure 3 Evidence network for (**a**) 6MWD, (**b**) FEV1, (**c**) FVC, and (**d**) SGRQ, respectively. 6MWD, 6-minute walk distance; FEV1, forced expiratory volume in one second; FVC, forced vital capacity; SGRQ, St George's Respiratory Questionnaire; AE, aerobic exercise; RT, resistance training; ET, endurance training; HIIT, high-intensity interval training; CON, control.

FVC

Eight studies involving a total of 393 participants were included in the analysis. Of these studies, 4 studies compared AE with CON, 1 study compared ET with CON, 1 study compared AE with RT, 1 study compared AE with ET, 2 studies compared AE with HIIT, and 1 study compared RT with ET. As shown in Figure S1, global inconsistency test showed an insignificant result (p=0.355), and local inconsistency test also revealed insignificant results (as presented in Figure S2). Therefore, we selected a consistency model to perform network meta-analysis. According to the results, AE (MD: 0.40, 95% CI: 0.26 to 0.55) and HIIT (MD: 0.38, 95% CI: 0.24 to 0.53) demonstrated superior improvement in the FVC compared to CON, with statistically significant differences. No significant differences were observed in pairwise comparisons for the other interventions (as shown in Figure 4). Furthermore, loop-based inconsistency using node-splitting approach showed an insignificant result, indicating the robustness of these results (see Figure S3). Based on the cumulative probability results, ET (PrBest: 78.1%), AE (RT: 9.8%), and HIIT (PrBest: 8.7%) were identified as the top three exercises for improving FEV1 (see Figure 5).

SGRQ

Seven studies involving a total of 427 participants were included in the analysis. Of these studies, 5 studies compared AE with CON, 1 study compared ET with CON, 1 study compared AE with ET, 1 study compared AE with HIIT, and 1 study compared RT with ET. As shown in Figure S1, global inconsistency test showed an insignificant result (p=0.533), and local inconsistency test also revealed insignificant results (as presented in Figure S2). Therefore, we selected

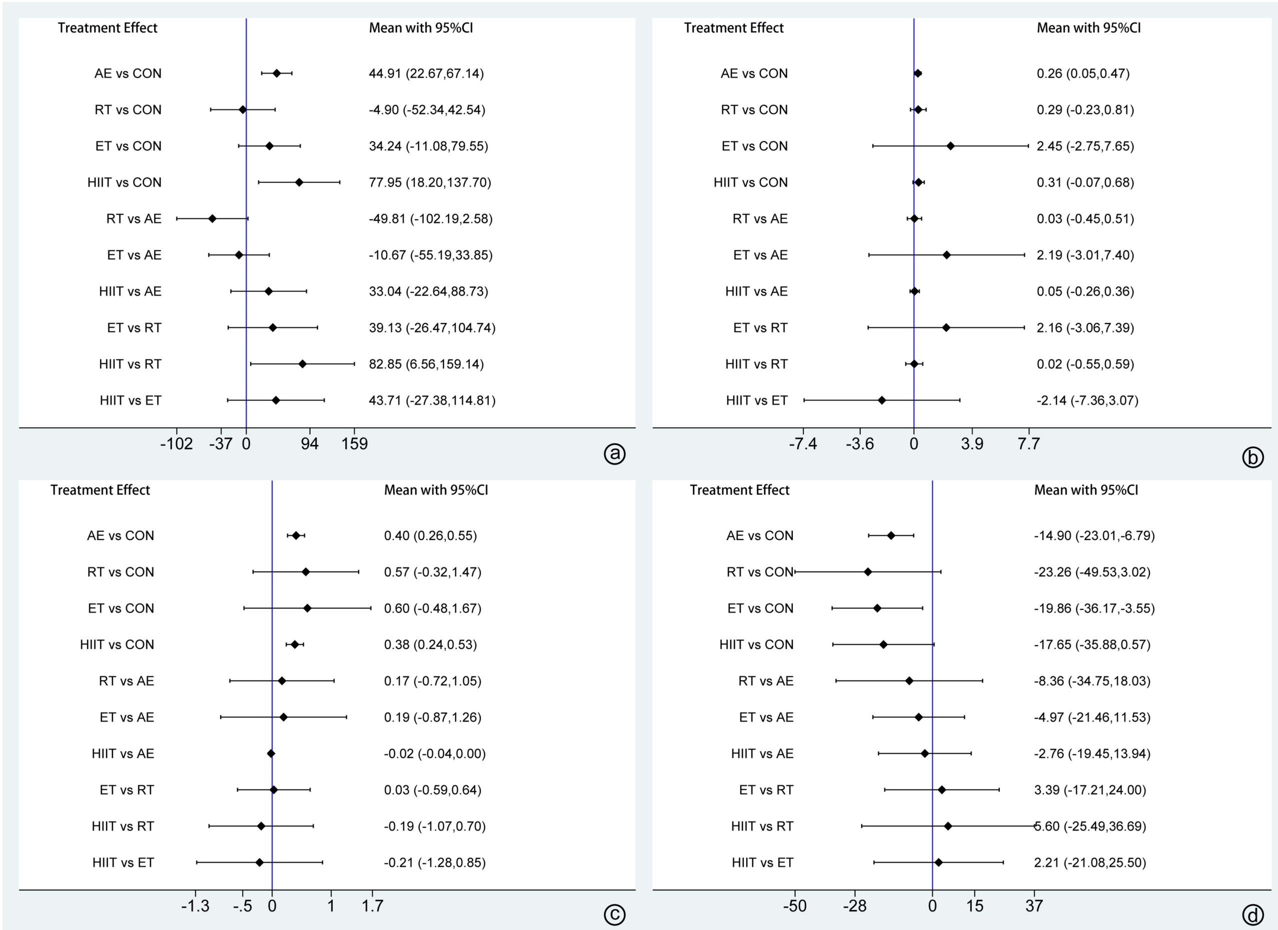

Figure 4 Network meta-analysis of (**a**) 6MWD, (**b**) FEV1, (**c**) FVC, and (**d**) SGRQ, respectively. 6MWD, 6-minute walk distance; FEV1, forced expiratory volume in one second; FVC, forced vital capacity; SGRQ, St George's Respiratory Questionnaire; AE, aerobic exercise; RT, resistance training; ET, endurance training; HIIT, high-intensity interval training; CON, control; CI, confidence interval.

a consistency model to perform network meta-analysis. According to the results, AE (MD: −14.90, 95% CI: −23.01 to −6.79) and ET (MD: −19.86, 95% CI: −36.17 to −3.55) demonstrated superior improvement in the SGRQ compared to CON, with statistically significant differences. No significant differences were observed in pairwise comparisons for the other interventions (as shown in Figure 4). Furthermore, loop-based inconsistency using node-splitting approach showed an insignificant result, indicating the robustness of these results (see Figure S3). Based on the cumulative probability results, RT (PrBest: 49.8%), HIIT (PrBest: 24.9%), and ET (PrBest: 19.5%) were identified as the top three exercises for improving FVC (see Figure 5).

Publication Bias Test

We assessed the publication bias of this research of every outcome by funnel plots. The horizontal coordinate is the effect size, and the vertical coordinate is the standard error. The studies were evenly distributed on both sides of the midline and were more symmetrical in distribution, but some fell outside the funnel, indicating possible publication bias and small sample effects (as shown in Figure S4).

Discussion

Main Findings

This network meta-analysis of 19 RCTs reporting data from 951 participants with stable COPD demonstrates that exercise programs are efficacious in enhancing exercise capacity, pulmonary function, and overall quality of life.

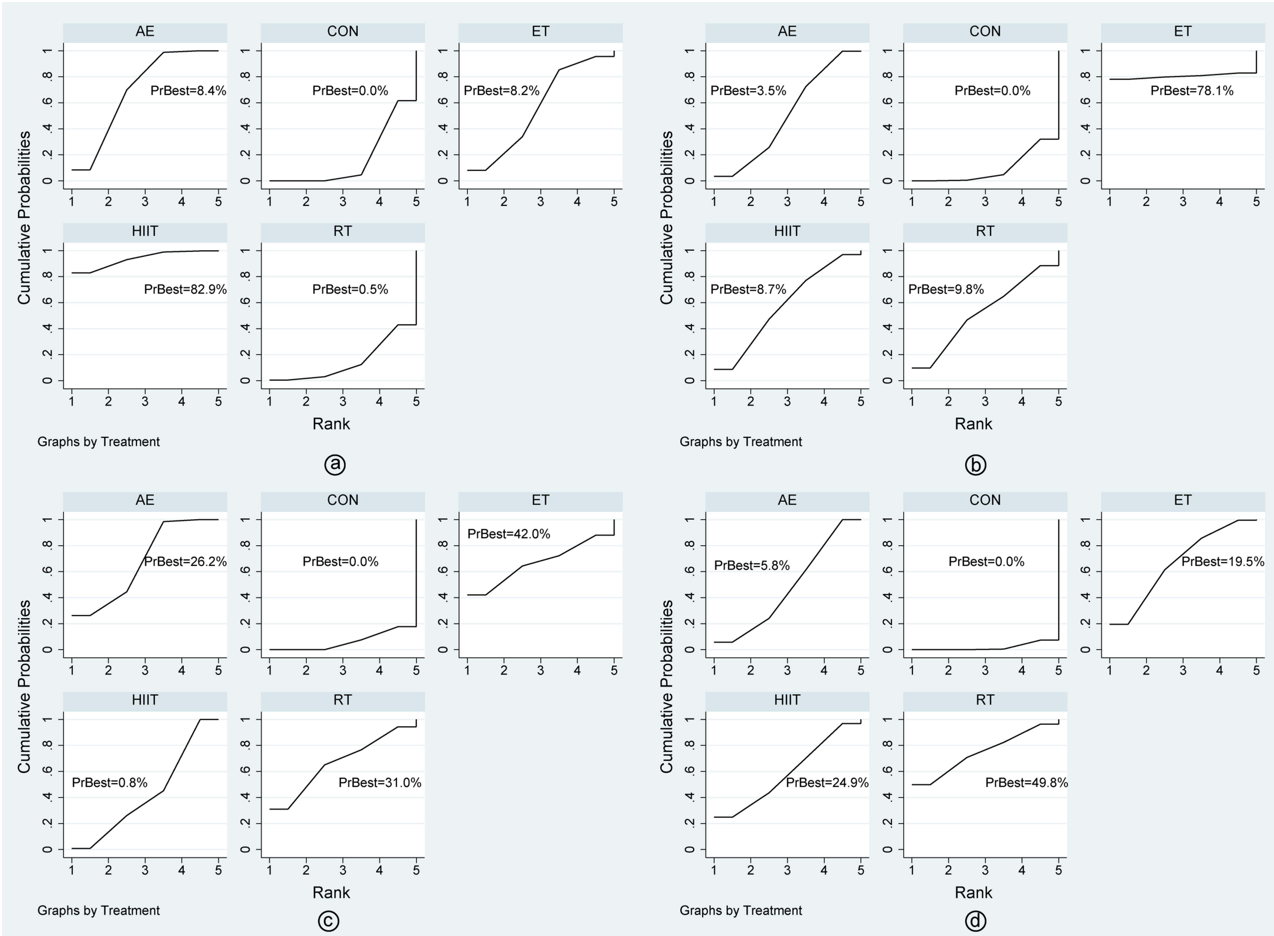

Figure 5 SUCRA analysis of (**a**) 6MWD, (**b**) FEV1, (**c**) FVC, and (**d**) SGRQ, respectively. 6MWD, 6-minute walk distance; FEV1, forced expiratory volume in one second; FVC, forced vital capacity; SGRQ, St George's Respiratory Questionnaire; AE, aerobic exercise; RT, resistance training; ET, endurance training; HIIT, high-intensity interval training; CON, control.

Notably, the analysis suggests that HIIT may be more effective in improving the exercise capacity. Conversely, RT may be the most effective exercise modality for improving overall quality of life, while ET may be preferable for improving pulmonary function.

Interpretation of Findings

HIIT is a form of exercise characterized by alternating periods of relatively intense activity with brief intervals of rest or low-intensity exercise, facilitating physical recovery.[49] The present network meta-analysis identified HIIT as the most effective exercise modality for enhancing exercise capacity in patients with stable COPD. Moreover, there is a growing body of evidence suggesting that HIIT provides superior benefits compared to traditional aerobic exercise, such as moderate-intensity continuous training (MICT).[50] For example, Schulté B et al[51] found that both HIIT and MICT effectively improve cardiorespiratory fitness and quality of life in patients undergoing coronary artery bypass graft surgery (CABG), with greater improvements observed in HIIT groups. These promising findings aligns with the current understanding of physiological adaptations induced by HIIT. Specifically, the short bursts of high-intensity effort challenge the cardiovascular system, demonstrating improving maximal oxygen uptake, a well-recognized determinant of exercise capacity.[52] Furthermore, HIIT may promote mitochondrial function and improve muscle efficiency, potentially enabling COPD patients to utilize oxygen more effectively during exercise.[53] Research could further explore optimal design parameters (eg, frequency, intensity, and duration) of HIIT program specifically tailored the patients with stable COPD.

This network meta-analysis provides compelling evidence that ET offers the most significant improvement in pulmonary function compared to another three exercise types, which align with established physiological principles governing respiratory adaption to exercise. ET promotes angiogenesis, resulting in a greater number of capillaries surrounding alveoli,[54] which facilitates a more efficient exchange of gases between blood and air. In addition, the diaphragm and other respiratory muscles experience increased strength and fatigue resistance, leading to more efficient ventilation during exercise.[55] Furthermore, regular exercise imposing chronic workload on the respiratory system can enhance the elasticity of lung tissue, resulting in easier expansion and contraction during breathing.[56]

The positive impact of RT on the overall quality of life in patients who are at the stable phase of COPD is a noteworthy outcome. Increased muscle strength and function from RT can significantly improve daily activities, leading to reduced fatigue and breathlessness, two major symptoms that negatively impact quality of life in COPD.[57] Furthermore, RT has been demonstrated to decrease hospital admissions and improve overall wellbeing, further contributing to improved quality of life for COPD patients.[58] Research could further investigate the specific mechanisms by which RT improves the overall quality of life in COPD, potentially including its impact on anxiety, depression, and social participation, which are all known to influence quality of life in this patient population.

Comparison with Previous Meta-Analyses

A key strength of our study lies in its focus on patients with stable COPD. This approach stands in contrast to previous network meta-analyses, such as those by Priego-Jiménez et al[59] and Jian et al[24] which included patients across all COPD stages. While these broader analyses provide valuable insights, our targeted approach on stable COPD allows for a more precise comparison of the effectiveness of various exercise interventions for this specific patient population. Previous network meta-analyses have played a crucial role in advancing our understanding of the effectiveness of exercise for COPD patients. For instance, the work by Couto et al[56] highlighted the overall benefits of exercise-based interventions in improving core COPD symptoms and quality of life. However, their study did not differentiate between the effects of various exercise modalities. By focusing on stable COPD and incorporating a range of exercise modalities, our study provides a more nuanced understanding of how different exercise programs impact key outcomes like exercise capacity, dyspnea, and fatigue. This level of detail offers healthcare professionals more specific guidance when designing personalized exercise regimens for patients with stable COPD.

Strengths and Limitations

The present network meta-analysis exhibited some strengths. Firstly, this study represents the first attempt to compare the effectiveness of different exercise programs on patients with stable COPD, providing reliable evidence for the optimal exercises with scientific value in alleviating symptoms of stable COPD. Secondly, we rigorously adhered to the evidence-based recommendations for network meta-analysis, ensuring the authenticity and reliability of the results.

Certainty, our study was not without limitations. First, the number of included studies on different exercises varied considerably. For instance, twelve studies involved AE, while only 2 studies involved HIIT, and all 2 studies compared AE with HIIT. The evidence presented in this review indicates that, when compared to other exercises, the utilization of HIIT can significantly enhance the exercise capacity, ET is able to significantly improve pulmonary function, while RT has the capacity of significantly improving quality of life. However, the number of studies on RT, ET, and GIIT are limited. To overcome this limitation, future RCTs should include a larger number of participants in order to thoroughly determine the potential of RT, ET, and HIIT in terms of patient-related outcomes. Second, the narrow and restrictive eligibility criteria used in this study may have affected the generalizability of our findings, especially regarding the selection of outcome measures and the duration of the exercise programs included. Third, while spirometry measures such as FEV1 and FVC are essential for assessing lung function, the absence of these outcomes in our network meta-analysis may have limited our ability to fully evaluate the interventions' effects on pulmonary physiology. Additionally, the ongoing debate about the impact of exercise on lung function in COPD is noteworthy; the marginal improvements in lung function observed with exercise are frequently attributed more to variations in technique than to actual physiological changes. This suggests that our findings related to exercise interventions should be interpreted with caution. Future research should include more comprehensive spirometry data to provide clearer insights into the physiological effects of exercise in this population. Fourth, preliminary evaluations have revealed the potential significance of novel parameters, such as perimeter thoracic mobility[60] and Partial Arterial Carbon Dioxide Pressure (PaCO2),[61] in assessing the impact of pulmonary rehabilitation on patients with COPD. However, the role of these parameters in evaluating the efficacy of different exercises modalities remains unexplored. Consequently, future research should prioritize the investigation and application of these emerging metrics within the context of exercise interventions for patients with CODP. Finally, while the studies included in this analysis were RCTs, potential biases may still exist due to the challenges of double-blinding exercises.

Conclusions

This study herein showed that exercise intervention can effectively improve, exercise capacity, pulmonary function, and the overall quality of life of patients who are at the stable phase of COPD. HIIT may be recommended to improve 6MWD, and ET may be recommended to improve pulmonary function, while RT may be recommended to improve the overall quality of life. Tailoring exercise plan to consider COPD severity, patient preferences, and comorbidities is crucial for optimal outcomes. Given the limited number and quality of the included studies, our findings should be interpreted cautiously. However, instead of broadly calling for more high-quality RCTs with large sample size, future research should also focus on exploring the variations in response driven by patient characteristics, program parameters (such as exercise dosage), and other contextual factors like setting and supervision. Specific research designs could involve stratifying participants based on these variables to better understand their impact on the outcomes. Additionally, it would be valuable to investigate the combined effects of RT and ET/HIIT, as this approach may yield the greatest overall benefit, aligning with current exercise guidelines for COPD management.

Clinical implications

The findings from our network meta-analysis suggest that different exercise modalities offer distinct benefits for stable COPD patients, with HIIT, RT, and ET each showing particular strengths in improving exercise capacity, quality of life, and pulmonary function, respectively. However, considering the potential complementary effects of these exercise modalities, clinical practice might benefit from integrating RT with ET or HIIT to better address the multifaceted needs of COPD patients, therefore optimizing overall therapeutic benefits.

Abbreviations

COPD, chronic obstructive pulmonary disease; AE, aerobic exercise; RT, resistance training; ET, endurance training; HIIT, high-intensity interval training;

CON, control; GOLD, Global Initiative for Chronic Obstructive Lung Disease; 6MWD, 6-minute walk distance; FEV1, forced expiratory volume in one second; FVC, forced vital capacity; SGRQ, St George's Respiratory Questionnaire; RCT, randomized controlled trial; MD, mean difference; CI, confidence interval; SUCRA, surface under the cumulative ranking probability.

Data Sharing Statement

All data generated or analyzed during this study are included in this published article.

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Study Approval Statement

Ethics approval was not required.

Consent to Participate Statement

Written informed consent was not required.

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Disclosure

The authors report no conflicts of interest in this work.

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