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REVIEW

Effects on Exercise Tolerance and Functional Outcomes of Eccentric versus Concentric Aerobic Exercise in People with COPD: A Systematic Review and Meta-Analysis

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Introduction and Objectives: Chronic obstructive pulmonary disease (COPD) is associated with peripheral muscle weakness, dyspnoea and decreased exercise tolerance. Eccentric aerobic exercise (ECC), characterised by contractions during muscle stretching, is becoming an alternative to concentric aerobic exercise (CON) in this population, due to its reduced cardiorespiratory demand. The main objective of this systematic review, following the PRISMA criteria, is to determine the benefits of ECC versus CON on exercise tolerance in people with COPD.

Methods: A literature search was conducted in PubMed, Cochrane, Google Scholar and PEDro databases until March 2025. Only randomised controlled trials published in the last 10 years and with exercise tolerance and functional outcomes analysed were included.

Results: Six randomised controlled trials were included (n=154), with good methodological quality (PEDro 6–7) and moderate certainty of evidence. The ECC showed benefits compared to CON in improvement of quadriceps strength (−0.15 [−0.51, 0.22] p=0.43); reduction of dyspnoea (−0.74 [−1.15, −0.34] p <0.001) and lower limb fatigue (−2.29, p < 0.001), a higher work rate (−0.48 [−1.07, 0.12] p =0.12), improvements in Timed Up and Go (TUG) (−2.03 [−2.90, −0.16] p< 0.001) and decrease heart rate (−14.37 [−18.24, −10.50] p < 0.01), suggesting increased cardiorespiratory efficiency. In contrast, the CON showed an improvement in endurance time (1.05 [0.45, 1.64] p<0.01) and oxygen saturation (1.79 [0.62, −2.97] p < 0.01) (IC 95%).

Conclusion: ECC is presented as an effective and safe strategy to improve exercise tolerance in people with COPD in terms of saturation, dyspnoea, fatigue and heart rate, while CON improves endurance time. However, further studies are required to confirm its long-term functional benefits and its applicability in other pathologies and also treatment protocols are needed to standardize the use of eccentric exercise.

Keywords: aerobic exercise, eccentric, COPD, downhill

Introduction

Chronic obstructive pulmonary disease (COPD) is a respiratory condition characterized by persistent symptoms such as dyspnoea, cough, and sputum production, along with clinical events such as exacerbations, caused by alterations in the airways and alveoli, resulting in progressive airflow obstruction.[1] This disease not only impacts lung function, but also is associated with extrapulmonary comorbidities, such as peripheral muscle dysfunction, which contribute to a poorer prognosis.[2] In particular, muscle weakness in the lower limbs limits mobility and promotes sedentary behavior, aggravating functional performance and quality of life. This deterioration perpetuates a negative spiral of functional decline that can culminate in severe disability.[3–5]

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COPD also represents a significant challenge for healthcare systems. In the European Union, COPD-related costs amount to €38.6 billion annually, equivalent to 56% of the budget allocated to respiratory diseases.[6] The prevalence and morbidity of COPD continue to increase due to smoking, population ageing, and environmental pollution.[7] In fact, it is estimated that by 2030 COPD will be one of the leading causes of death worldwide.[8]

Pulmonary rehabilitation is the cornerstone of non-pharmacological management of COPD and has been shown to improve dyspnoea, exercise capacity, and quality of life across all severity stages.[5,9,10] However, the high intensity required to induce muscular adaptations with traditional concentric exercise (CON), such as cycling on a regular bicycle or walking uphill, may not be tolerated by people with severe COPD due to dyspnoea and early lower limb fatigue, thus limiting its effectiveness.[11] This limitation highlights the need for modalities that can induce peripheral muscle adaptations with lower ventilatory and metabolic demands,[5,12] a role in which eccentric exercise (ECC) may be particularly advantageous.[13,14]

Considering these limitations, ECC, characterized by muscle lengthening during contraction,[15] emerges as a promising alternative. In clinical practice, ECC can be implemented through different strategies, such as downhill walking[15–17] or specialized ECC bicycles, where the pedals are moved in reverse by an electric motor while the person applies resistance to maintain a predetermined pedaling cadence.[18–20]

Thanks to its higher efficiency, ECC allows for significant improvements in muscle power with a metabolic and cardiorespiratory demand four to five times lower than that of CON.[13,14] Furthermore, it has the potential to increase muscle strength and mass without exacerbating dyspnoea, making it an attractive option for people with severe COPD.[14] However, although its safety and tolerability have been demonstrated in preliminary studies, there is still limited evidence regarding its effectiveness compared with conventional exercise in pulmonary rehabilitation programs.[13,14,21,22]

Beyond COPD, ECC has been shown to improve muscle strength and functional performance in older adults,[23] in people with neurological conditions,[24,25] and in individuals with coronary artery disease, inducing improvements in maximal capacity similar to CON, but with lower cardiorespiratory demands.[26,27] This reflects greater energy efficiency, which may be particularly relevant for individuals with reduced energetic reserves. Taken together, these findings suggest a potential for translating ECC into COPD rehabilitation programs.

The aim of this systematic review is to analyze the effects of eccentric aerobic exercise compared with traditional concentric exercise on muscle strength, functional capacity, maximal aerobic capacity, lung function, and quality of life in adults with COPD. Additionally, the potential benefits of ECC in terms of exercise tolerance, lower limb fatigue, and dyspnoea will be assessed, providing a solid evidence base to inform the development of more effective therapeutic guidelines, optimizing interventions for people with COPD, improving their quality of life, and reducing the burden on healthcare systems.

Materials and Methods

This review followed the preferred reporting guidelines for systematic reviews and meta-analyses (PRISMA).[28] The protocol was registered with PROSPERO (CRD420251007647).

Eligibility Criteria

The PICO (Population, Intervention, Comparator and Outcome) framework was used to establish eligibility criteria. The population included human subjects of either sex, aged 18 years or older and diagnosed with COPD, recruited at any time since disease diagnosis and with any degree of disease. The intervention had to comprise eccentric aerobic exercise, with or without additional elements; the physical exercise programme had to be administered under the supervision of health professionals and its parameters (intensity, duration, frequency, etc) specified. The comparison had to involve a similar exercise programme whose aerobic training phase was based on concentric exercise (control group). Studies had to include outcome measures in relation to quadriceps muscle strength, exercise tolerance, maximal aerobic capacity, perceived degree of dyspnoea and/or lower limb fatigue. Muscle strength was considered a relevant outcome despite the aerobic focus of the intervention, given the well-documented capacity of ECC to induce peripheral muscle adaptations in addition to its aerobic benefits, which are clinically relevant in COPD rehabilitation.[13,14] Only original randomised controlled trials published in peer-reviewed journals were included.

The exclusion criteria were: studies including people with respiratory pathologies other than COPD or with severe comorbidities that may significantly affect the response to training; studies in which the main intervention does not include eccentric aerobic training as part of the experimental treatment; studies that do not include a structured training programme but are limited to a single session with the performance of a stress test and studies that do not specify the parameters of the physical exercise administered. Conference abstracts were excluded due to the limited methodological details and outcome data provided, which make it difficult to assess study quality.

Sources of Information

Searches were conducted until March 2025 using the online electronic databases PubMed, The Cochrane Library for Clinical Trials (CENTRAL), Google Scholar and PEDro. In addition, the reference lists of selected articles and relevant systematic reviews were manually screened to identify other potentially eligible studies.

Search Strategy

The search strategy was designed based on the PICO framework to identify all relevant studies on eccentric aerobic exercise-based training in people with COPD.

To ensure the relevance of the evidence to current clinical practice and training technologies, the search was limited to studies published in the last 10 years (2015–2025). In 2015, the first article on the effect of ECC on the quality of life in a patient with COPD was published[29] (case report), so it has been considered as the starting point for this review.

PubMed

Search terms used: ("eccentric" OR "downhill") AND ("exercise" OR "rehabilitation" OR "training" OR "practice" OR "workout" OR "contraction" OR "pulmonary rehabilitation") AND ("lung disease" OR "COPD"). Filters applied: humans, randomized controlled trials (RCTs), publications from 2015 to 2025, and languages English, Spanish, or French.

Cochrane CENTRAL

Search terms used: ("eccentric" OR "downhill") AND ("exercise" OR "rehabilitation" OR "training" OR "practice" OR "workout" OR "contraction") AND "COPD". Search fields: title, abstract, and keywords. Filters applied: Trials published between 2015 and 2025. No language filters were available; eligible RCTs were identified through manual screening.

Google Scholar

Search terms used: (eccentric OR downhill) AND COPD. Filters applied: publications from 2015 to 2025, all languages, all study types. Due to database limitations, no filters for study design or population were available, and eligible RCTs were selected manually.

PEDro

Search terms used: "COPD" AND "eccentric" in the Title and Abstract fields. Filters applied: publications from 2015 onwards and "Match all search terms (AND)" to ensure that all terms appeared in each record. Only studies meeting the eligibility criteria for RCTs were included after manual screening.

Study Selection Process

Two members of the research team (G.M.C and T.F.P) conducted the initial search. After elimination of duplicates, the titles and abstracts were examined, discarding records that did not fit the scope of this review. Subsequently, the full texts of abstracts that did not provide sufficient information for exclusion or that appeared potentially suitable for inclusion were obtained. Both authors (G.M.C and T.F.P) then independently assessed the full texts and selected studies for inclusion based on the information available. Discrepancies between reviewers were resolved by discussion.

Data Extraction Process

Data from each study included in this review were extracted independently by two authors (G.M.C. and T.F.P.) into an Excel spreadsheet. The two authors then compared the two spreadsheets and resolved inconsistencies through discussion in order to achieve a consensus data extraction table.

List of Data

Information on several key variables was collected from the included studies. With respect to publication details, data on the authors, year of publication, and journal were recorded.

Regarding study design, the type of randomisation, the level of blinding (single, double, etc), and the experimental design (parallel group, cross-over, or other) were documented.

Regarding the population, data on sample size and demographic characteristics, including gender, age, and body mass index (BMI), were documented. Baseline functional status was also recorded, measured by forced expiratory volume in 1 second (FEV1) and COPD grade according to the Global initiative for chronic obstructive lung disease (GOLD) scale. Additionally, the homogeneity of the sample in terms of baseline characteristics was assessed.

For the intervention, detailed information was collected on the duration of the training programme, the frequency of the sessions (number of sessions per week), the duration and intensity of the sessions, the type of exercise performed (such as cycloergometer, treadmill, or strength exercises), the progression of the exercise and the existence of familiarisation and follow-up sessions. For the comparator, the same data were recorded as for the intervention.

For the outcomes, primary and secondary outcome variables were distinguished. Primary variables included means and standard deviations (SD) of indicators such as muscle strength, exercise tolerance, maximal aerobic capacity, dyspnoea and lower limb fatigue, assessed both before and after the training period. Secondary variables comprised the inferential statistical parameters used to assess differences between groups. In addition, all outcomes consistent with each outcome domain were collected, regardless of the measurement scales or time points used. If some outcomes were not comparable, notes were made to justify their exclusion. For those that used different measurement scales, the standardized mean difference was applied.

Finally, other relevant variables were collected, such as programme adherence, exercise tolerance and any reported adverse events. For missing or uncertain data, the intention-to-treat principle was assumed in analyses where indicated. If critical information was missing, it was explicitly recorded, and where possible, authors were contacted for clarification.

Assessment of Risk of Bias of Individual Studies

PEDro Scale

The risk of bias of individual studies was assessed using the Physiotherapy Evidence Database (PEDro) scale,[30,31] a validated tool for evaluating the methodological quality of randomized controlled trials in rehabilitation research. The PEDro scale evaluates internal validity and statistical reporting, assigning one point per criterion met (maximum score: 10), with the first item related to external validity excluded from the total score. Higher scores indicate higher methodological quality. Methodological quality was classified as: ≥9 points = excellent, 6–8 = good, 4–5 = moderate, <4 = low.[31]

Two independent reviewers (G.M.C. and T.F.P.) assessed each study, resolving discrepancies through discussion. The PEDro scale was selected because it is widely recognized in physiotherapy and exercise-based interventions, ensuring standardized evaluation of methodological rigor.

RoB 2.0

The risk of bias was also assessed using the Cochrane Risk-of-Bias Tool for Randomized Trials (RoB 2.0),[32] which complements the PEDro scale by evaluating five domains: bias arising from the randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and selection of reported results.

Two independent reviewers (G.M.C. and T.F.P.) applied the RoB 2.0 tool to each study, with disagreements resolved by discussion. Risk of bias judgments were categorized as low, some concerns, or high, following Sterne et al.[32]

Assessment of the Certainty of the Evidence

The certainty of the evidence for each outcome was assessed using the GRADE (Grading of recommendations, assessment, development, and evaluation) system.[33,34] This system classifies evidence into four categories: high, moderate, low, and very low, based on the following domains:

Risk of Bias

Evaluated using PEDro scores and RoB 2.0 assessments, considering limitations such as lack of participant and therapist blinding inherent to exercise interventions.

Inconsistency (Heterogeneity)

Examined using I^2 statistics across studies for each outcome. Outcomes with $I^2 > 50\%$ were considered to have substantial heterogeneity.

Imprecision

Evaluated by examining confidence intervals (CIs). Outcomes with wide CIs or CIs including the null value were downgraded.

Indirectness

Considered applicability of interventions and populations to the review question.

Publication Bias

Assessed qualitatively by examining study reporting and comprehensiveness of included trials.

Decisions on downgrading or maintaining evidence certainty were made collectively by two independent reviewers (G.M.C. and T.F.P.), with discrepancies resolved through discussion. Random-effects models were used in meta-analyses where substantial heterogeneity was detected, and fixed-effects models were applied when heterogeneity was low.

Data Synthesis

Review Manager software (RevMan 5.4) was used to perform the meta-analysis (The Cochrane Collaboration, 2020). For those variables that were measured on the same scale in the included studies, the mean difference was used.To determine the overall effect, the p-value of the Z-statistic was interpreted. If $p < 0.05$, the null hypothesis is rejected and the alternative hypothesis is accepted, demonstrating that the overall effect is not produced by chance. A 95% confidence interval was determined. Heterogeneity among included studies was calculated using the I^2 statistic, which describes the percentage of variability due to heterogeneity rather than chance.

Results

Study Selection

The literature search yielded a total of 83 results. After removing 29 duplicates using the Zotero bibliographic manager, the titles and abstracts of the remaining 54 articles were screened, leading to the exclusion of 42 studies that did not meet the scope of this review. The full texts of the remaining 12 articles were then assessed for eligibility, resulting in the inclusion of six studies in this review (Figure 1).

Characteristics of the Studies

All included studies are parallel-group randomised clinical trials, with an experimental group performing ECC and a control group performing CON. The total final sample size was 154 patients, with variability between studies ranging from 15 to 35 participants, and group sizes ranging from 7 to 18 individuals. All studies calculated their samples from previous power analyses; however, in two of them, the final size did not reach the initial estimate.[15,17] The distribution between ECC and CON training groups was balanced in all studies. Characteristics of the studies, including population, intervention, and outcomes, are summarized in Table 1. All studies reported outcome measures at baseline (pre-

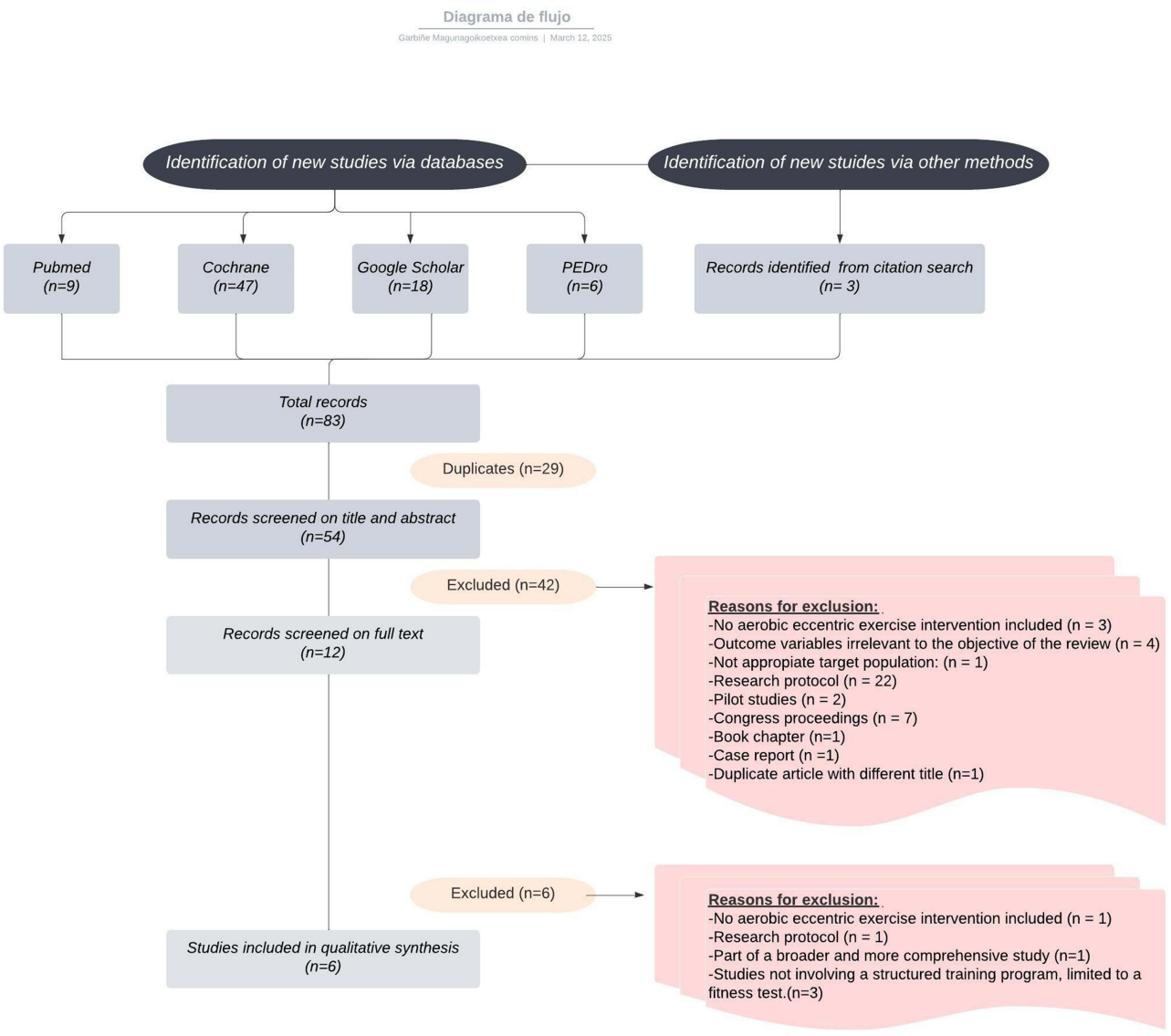

Figure 1 Flow chart of the process of selecting eligible studies.

intervention) and immediately post-intervention. Only one study[16] included an additional follow-up assessment at 3 months post-intervention.

In terms of population characteristics, all studies enrolled people with COPD, but with different degrees of severity according to the GOLD classification (from II to IV). The most frequent severity grade in three of the studies was GOLD III (severe), with prevalences of 47%, 46.66% and 62.5% in each study.[16,18,20] However, two studies did not specify the exact percentages of GOLD II and III patients,[15,17] while another included exclusively GOLD II patients.[19] The mean age of the patients varied slightly, ranging from 62 to 69.65 years.

In terms of gender distribution, most studies included more men than women. Two studies had all-male samples,[18,20] while two others had male predominance.[15,17] Only two of the six studies included an equal distribution between men and women.[16,19] BMI was reported in all included studies. The mean BMI for participants in the ECC groups ranged from 22.1 to 29.1 kg/m², while in the CON groups it ranged from 23.0 to 28.1 kg/m². Overall, baseline BMI values were similar between groups across studies, indicating comparable body composition at baseline.

Regarding the intervention, the duration of training ranged from 4 to 12 weeks, with a mode of 12 weeks. The frequency ranged from 2 to 5 sessions per week, with 3 sessions per week being the most common. Except for one study

Table 1 Characteristics of Included Studies

Author Year	Design	Population	Intervention (ECC vs CON)	Measured Variables	Key Outcomes
Pancera et al (2024)[16]	Blinded assessor RCT	COPD: GOLD II 23%, GOLD III 47%, GOLD IV 30% N=30 (ECC:15; CON:15) Mean age: 68.3 15 M 15F BMI: ECC 22.09 ± 6.41; CON 23.96 ± 5.92	ECC: CON cycle + CON strength (UE) + ECC walking + ECC strength (LE) CON: CON cycle + CON strength (UE and LE) ● 4 weeks. Not familiarization sessions. Follow-up assessment at 3 months. ● 5 double sessions (morning and afternoon)/week ● ECC: 150 minutes; CON: 120 minutes ● Intensity: Cycle: 50% of the estimated PWR; CON strength: 60–70% of 1RM; ECC strength: 110–120% of 1RM; ECC Walking: 75% of the 6MWT speed and −10% incline. ● Progression: Cycle (mBorg < 5 = + 10 W; mBorg 5or 6 = + 0 W; mBorg > 6 = −10 W); CON strength [(Week 1 (20×2) and Week 2 (20×3) at 60% 1RM; Week 3 (15×3) and Week 4 (10×4) at 70% of 1RM]; ECC walking (mBorg < 5 = + 0.5 km/h; mBorg 5or 6 = + 0km/h; mBorg > 6 = −0.5 km/h); ECC strength [(Week 1 (10×3) and Week 2 (10×4) at 110 of 1RM; Week 3 (10×3) and Week 4 (10×4) at 120 of 1RM]	Muscle function or strength: ● Q Isometric PT ● Q RFD ● Q Steadiness ● Allometric power ● HGS ● Q MVC ● Relative standing and sitting ● Q Neuromuscular economy ● Leg muscle quality Functional exercise capacity: ● 6MWT ● 4mGS and 10mGS ● 5 STS Symptom/Dyspnea: ● BID and MRC dyspnea scale Mortality: ● BODE	ECC improved Q PT, RFD and muscle quality by 17 ±23% (P<0.001), 19 ±24% and 16±20% (both P<0.05) A significant between-group difference for RFD (56±94 Nm/s, P=<0.001) was found after training in ECC. Both (ECC and CON) showed clinically relevant improvements in 6MWT, 4mGS, dyspnea rate and mortality risk, with no significant differences between groups Adherence: ECC 87%; CON 87% Adverse effects: none reported
Moezy et al (2018)[15]	Blinded assessor RCT	COPD: GOLD II or III, data not specified Initial sample N=32; Final N=30 (ECC:14; CON:16) Mean age: 65.6 24 M 6F BMI: ECC 23.87 ± 2.43; CON 24.42 ± 2.91	ECC: warm-up (walking+ static stretching) + ECC walking CON: free CON walking (with an attendant) on flat surface ● 12 weeks + 2 familiarization sessions. No follow-up. ● 3 sessions/week ● 15–60 min ● Intensity: mBorg: 3 (for low speed) and 4 (for high speed) ● Progression: treadmill Incline: −5° (week 3–6) and −7,5° (week 6–12); session duration: from 15 minutes in initial sessions to 60 minutes in final sessions; Speed: Week 1–3: low speed <3 km/h; Week 3–6: slow and fast speed. Ratio 3:2; Week 6–9: ratio 2:3; Week 9–12: high speed >5 km/h.	Functional exercise capacity: ● 6MWT ● TUG ● SCT Maximal aerobic capacity: ● Sat O2 ● HR	ECC improved FEV1, FEV1/FVC, 6MWD, SGRQ (symptoms) and SatO2 in rest (all of them P<0.05). SCT, SGRQ (activity), SGRQ (impacts) and SGRQ (total score) also improved (all of them p<0.001), while no such effects were observed in the CON group. A significant between-group difference was found in the ECC group for 6MWT, TUG (all with P < 0.05). Adherence: ECC 88%; CON=100% Adverse effects: minimal muscle soreness and similar between groups
MacMillan et al (2017)[18]	RCT	COPD: GOLD II 26.67%, GOLD III 46.66%, GOLD IV 26.67% N=15 (ECC:8; CON:7) Mean age: 65.67 15M 0F BMI: ECC 26.5 ± 1.9; CON 26.7 ± 2.8	ECC: ECC cycle CON: CON cycle ● 10weeks (first 2 weeks of familiarization). No follow-up. ● 3 sessions/week ● 30minutes ● Intensity target: CON cycle: 60–80% of PWR achieved at baseline; ECC cycle: four times the 60–80% PWR achieved at baseline. Both pedaling frequency of 60 rev-min ● Progression: intensity: 20–40% of the intensity target at week 1 and 2; 100% of the intensity target at week 3–10. Sesión duration: 20 minutes Week 1 and 30 minutes week 2–10.	Muscle function or strength: ● Q Isometric PT ● Muscle quality ● Total isokinetic work ● Q Cross-Sectional Area Symptom/ Dyspnea: ● Leg fatigue (mBorg) ● Dyspnea (mBorg) Maximal aerobic capacity: ● PWR ● Workload	ECC group trained on at a workload that was 3 times that of CON group, at a lower leg fatigue and dyspnea. ECC increased Q PT (P<0.01), muscle quality (P<0.05) and isokinetic work (p <0.05), whereas CON had no such effect. However, ECC did not result in fiber hypertrophy (there was no increase in mean in Q Cross-Sectional Area. PWR only increased significantly in the CON group (P <0.05) although both groups achieved the mínimum clinically important difference for PWR. Adherence: ECC 87%; CON 86% Adverse effects: ECC 1 acute exacerbation (training delayed 1 week), 2 knee pain (completed training); CON 1 low back pain (training delayed 9 days), 1 hip pain (completed training)

(*Continued*)

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Table 1 (Continued).

Author Year	Design	Population	Intervention (ECC vs CON)	Measured Variables	Key Outcomes
Inostroza et al (2022)[19]	RCT	COPD: GOLD II 100% N=20 (ECC:10; CON:10) Mean age: 69.65 10M 10F BMI: ECC 29.1 ± 5.4; CON 28.1 ± 5.9	ECC: ECC cycle CON: CON cycle ● 12 weeks + 4 familiarization sessions. No follow-up. ● 2 session/week during week 1–2 +3 sessions/week during week 3–12 ● 30 minutes ● Intensity: 11–13 on the Borg scale. ● Progression: perceived effort on the Borg scale: Week 1–2 (Borg scale 11), Week 3 (Borg 12), and Week 4–12 (Borg 13); interval duration: Week 1–7 (3 intervals of 10 minutes + 2 minutes rest between intervals) and Week 7–12 (2 intervals of 15 minutes with 2 minutes rest between intervals); week frequency: week 1 and 2: 2 session/week and week 3–12: 3 sessions/week	Muscle function or strength: ● Q Isometric PT ● Q RFD (RFD $_{50}$ and RFD $_{100}$) Functional exercise capacity: ● 6MWT ● TUG ● SAWT and SDWT Maximal aerobic capacity: ● Power output ● HR and Sat O2 ● Workload Symptom/ Dyspnea: ● Dyspnea (mBorg)	ECC group trained on at a workload that was 3 times that of CON group (p<0.001) showing 1.5±2.1% greater Sat O2, 24.7±4.1% lower HR and 64.4 ±29.6% lower dyspnea than CON group. (P <0.001) Both ECC and CONC reduced (P < 0.05) SAWT and SDWT improved, but only ECC improved (P < 0.05) RFD 69–199%, TUG 13.6± 13.6%, and 6MWT 25.3± 27.7%. Adherence: ECC 100%; GC 100% Adverse effects: none reported
Camillo et al (2020)[17]	Blinded assessor RCT	COPD: GOLD II or III, data not specified; With or without CMF Initial sample N=44; Final N=35 (ECC: 18; CON: 17). Without CMF: N=20 (ECC: 11; CON 9) Mean ag: 62 28M 16F BMI: ECC 24 ± 7; CON 27 ± 6	ECC: CON Cycle + ECC walking +CON strength (UE+ LE) + UE ergometer + stairs CON: CON Cycle + CON walking +CON strength (UE+ LE) + UE ergometer + stairs ● 12 weeks (1st week of familiarization). No follow-up. ● 3 sessions/week ● 60–90 minutes ● Intensity: cycle: 60–70% of the PWR; ECC and CON walking: 75% of 6MWTspeed; Strength: 3×8 at 70% of 1RM; ● Progression: CON walking: Progressing in incline+; ECC walking: constant negative incline of 10° (no progression)	Muscle function or strength: ● Q Isometric PT Functional exercise capacity: ● 6MWT ● Step counts/day Maximal aerobic capacity: ● Endurance Time ● Oxygen uptake ● PWR Symptom/ Dyspnea: ● Leg fatigue (mBorg) ● Dyspnea (mBorg) ● mMRC	Significant and clinically relevant increases in 6MWD were observed in both groups (p<0.001), with no significant between-group differences. However, 94% of patients in ECC exceeded the minimally important difference metres for 6MWT, compared to 65% in CON (p=0.03). ECC patients showed a trend towards greater improvements in other outcomes, particularly in dyspnea measures (mBorg and mMRC). In the subgroup without CMF, ECC training was clearly superior for improving 6MWD and dyspnea (mMRC). Adherence: ECC 75%; CON 85% Adverse effects: ECC shin splints (n=2); CON Mild intermittent hip pain (n=1), recurrence of pre-existing back pain (n=2)
Bourbeau et al (2020)[20]	Blinded assessor RCT	COPD: GOLD II 16.67%, GOLD III 62.5%, GOLD IV 20.83% N=24 (ECC:13; CON:11) Mean age: 66.9 24M 0F BMI: ECC 24.9 ± 5.4; CON 25.8 ± 5.8	ECC: ECC cycle CON: CON cycle ● 10 weeks + 2 weeks of familiarization. No follow-up. ● 3 sessions/week ● 30 minutes ● Intensity: CON cycle: 60–80% of PWR achieved at baseline; ECC cycle: four times the 60–80% PWR achieved at baseline. Both pedaling frequency of 60 rev-min	Muscle function or strength: ● Q isometric PT ● Q isokinetic peak power ● Q isikinetic PT Maximal aerobic capacity: ● PWR ● VE ● Endurance time ● HR Functional exercise capacity: ● 6MWT ● Stairs number ● Step counts/day Symptom/Dyspnea: ● Leg fatigue (mBorg) ● Dyspnea (mBorg)	ECC group trained at 4-fold higher power than CON at similar relative HR intensities. Isometric and isokinetic Q PT improved significantly after ECC (p<0.05) but not CON; between-group difference was significant for isometric PT. (p<0.05). Dyspnea at peak power output decreased significantly after ECC, with a between-group difference (p<0.05). VE and leg fatigue remained unchanged post-training, but leg fatigue and dyspnea were significantly lower during ECC vs CON at equivalent HR intensities (p<0.05). 6MWD improved significantly and clinically in ECC, but no between-group difference was observed. Peak cycling power and endurance time increased significantly in both groups (p<0.05). Adherence: ECC 91%; CON 77% Adverse effects: ECC knee pain due to pre-existing osteoarticular problems (patella syndrome, knee arthritis) (n=2); CON Low back pain (required stopping training for 3 sessions) (n=1)

Abbreviations: RTC, randomized controlled trial; ECC, Eccentric; CON, concentric; M, male; F, female; CMF, critical muscle fatigue; UE, upper extremities; LE, lower extremities; PWR, peak workrate; 1RM, 1-repetition máximum; 6MWT, 6-minute walk test; mBorg, modified Borg Scale; Q, Quadriceps; PT, peak torque; RFD, rate of force development; MVC, Maximal voluntary contraction; HGS, Handgrip strength; 4mGS, 4-meter gait speed; 10mGS, 10-meter gait speed; 5STS,5-repetition sit-to-stand; TUG, Timed up and go; SCT, stair climbing test; SAWT, stairs ascending walking time; SDWT, stair descending walking time, BID, Barthel Index dyspnea; MRC, Medical Research Council; BODE, Body Mass Index Degree of Airflow Obstruction Dyspnea, and Exercise Capacity; mMRC, modified Medical Research Council scale; FEV1, Forced Expiratory Volume in 1 second; FVC, Forced Vital Capacity; HR, heart rate; SatO2, O2 saturation.

that included double sessions (morning and afternoon),[16] all other studies implemented single sessions. The duration of each session ranged from 15 to 150 minutes, with a mode of 30 minutes.

Regarding the type of exercise, four studies used exclusively aerobic exercise,[15,18–20] while two included strength exercises.[16,17] Three studies used a cycloergometer,[18–20] one a treadmill,[15] and two combined both,[16,17] although the comparison between ECC and CON was made only with the treadmill. In the cycloergometer studies, one set the initial intensity based on the Borg scale,[19] while the others were based on the maximal work rate in the stress test.[16–18,20] In the treadmill studies, one set the intensity based on the Borg scale,[15] while the other two based it on the speed achieved in the 6-minute walk test.[16,17]

Since ECC is perceived as less demanding, two studies matched the intensity of the two groups based on relative heart rate,[18,20] three matched the intensity based on perceived exertion on the Borg scale,[15,16,19] and one study did not establish matching criteria.[17] In addition, four studies used continuous training[16–18,20] and two used intervallic training.[15,19]

The main outcomes assessed were aerobic capacity, muscle strength and functional capacity. All studies, except one,[16] analysed measures of aerobic ability such as heart rate, oxygen saturation, and peak power rating (PWR), among others, although with considerable heterogeneity in the variables used. The same was true for the assessment of muscle strength: although all studies measuring muscle strength included isometric maximal quadriceps torque (isometric PT), there was great variability in the other strength measures used.

In contrast, variables related to patient symptoms were more homogeneous. Four of the five studies that assessed symptoms used the modified Borg scale to measure dyspnoea and lower limb fatigue.[17–20] Of these, three measured both variables,[17,18,20] while one focused only on dyspnoea.[19]

Exercise tolerance was assessed in all but one study,[18] using tests such as walking, getting up from a chair or going up and down stairs. The 6-minute walk test (6MWT) was the most commonly used test, appearing in all studies, followed by the Timed Up and Go test (TUG), used in two.[15,19] Three studies included functional measures related to stair climbing and descending, although with different methodologies,[15,19,20] and two studies counted total daily steps.[17,20]

Adherence and adverse events were generally favorable across the included studies. Adherence to the training programs was high, with ECC groups ranging from 75% to 100% and CON groups ranging from 77% to 100%, indicating that both exercise modalities were feasible and well tolerated by people with COPD. Adverse events were minimal and mostly mild. Two studies reported no adverse effects.[16,19] Moezy et al[15] observed only minor muscle soreness, similar between groups; in Mac Millan et al[18] the ECC group experienced one acute exacerbation and two cases of knee pain, while the CON group reported one episode of low back pain and one case of hip pain and Camillo et al[17] reported ECC-related shin splints in two participants, and in the CON group mild intermittent hip pain (n=1) and recurrence of pre-existing back pain (n=2). Finally, Bourbeau et al[20] described knee pain due to pre-existing osteoarticular conditions in two ECC participants, and low back pain in one CON participant that required pausing training for three sessions. Overall, the data suggest that ECC is feasible, well tolerated, and associated with a low incidence of mild, transient adverse events, comparable to CON.

Risk of Bias in Individual Studies

PEDro Scores

PEDro scores for the included studies ranged from 6 to 7 points (mean 6), indicating overall "good" methodological quality (6–8 points) (Table 2). All studies were randomized clinical trials. Blinding of participants and therapists was largely unfeasible due to the nature of the interventions, which represents an inherent limitation and explains why criteria 5 and 6 of the PEDro scale were not met. Assessor blinding was reported in four studies,[15–17,20] while the remaining two did not specify whether this procedure was applied.[18,19]

RoB 2.0 Assessments

The RoB 2.0 tool provided complementary evaluation across five bias domains. Among the included RCTs, Bourbeau et al[20] presented the lowest risk of bias, with low risk across all domains. The remaining studies had unclear overall risk: Moezy

Table 2 PEDro Scale Scores of the Studies

Study	PEDro Scale											Total Score
	1	2	3	4	5	6	7	8	9	10	11	
Pancera (2024)[16]	1	1	1	0	0	0	1	1	1	1	1	7/10
Moezy (2018)[15]	1	1	0	1	0	0	1	1	0	1	1	6/10
MacMillan (2017)[18]	1	1	0	1	0	0	0	1	1	1	1	6/10
Inostroza (2022)[19]	1	1	0	1	0	0	0	1	1	1	1	6/10
Camillo (2020)[17]	1	1	1	1	0	0	1	0	0	1	1	6/10
Bourbeau (2020)[20]	1	1	1	1	0	0	1	0	1	1	1	7/10

et al,[15] MacMillan et al,[18] and Inostroza et al[19] had two domains classified as some concerns, whereas Pancera et al[16] and Camillo et al[17] had only one domain with some concerns (Figure 2).

Results of Individual Studies

Table 1 summarises the main characteristics of the included studies.

Synthesis Results

Quantitative results shown in (Figure 3).

Quadriceps Muscle Strength

Five studies assessed quadriceps isometric peak torque (Q isometric PT) in Newton, with a total sample of 120 subjects.[16–20] The results indicate an improvement in quadriceps muscle strength in the experimental group compared to the control group (−0.15 [−0.51, 0.22] p=0.43). Heterogeneity between studies was low (I^2 = 29%) and d= 0.43 who is a medium effect.

Exercise Tolerance

Four studies measured exercise tolerance through the six-minute walk test (6MWT) in metres, with a total of 119 subjects.[15–17,20] An improvement in distance covered was observed in the control group compared to the experimental group (28.70 [−7.51, 64.91] p=0.12). Heterogeneity between studies was low (I^2 = 48%) and small effect (d=0.35).

Figure 2 Risk of bias assessment.

Three studies (n=74) measured exercise tolerance as the percentage improvement in metres from baseline.[16,19,20] The results favoured the control group (0.17 [−0.30, 0.64] p=0.48), with medium heterogeneity (I^2 = 67%) and small effect (d=0.36).

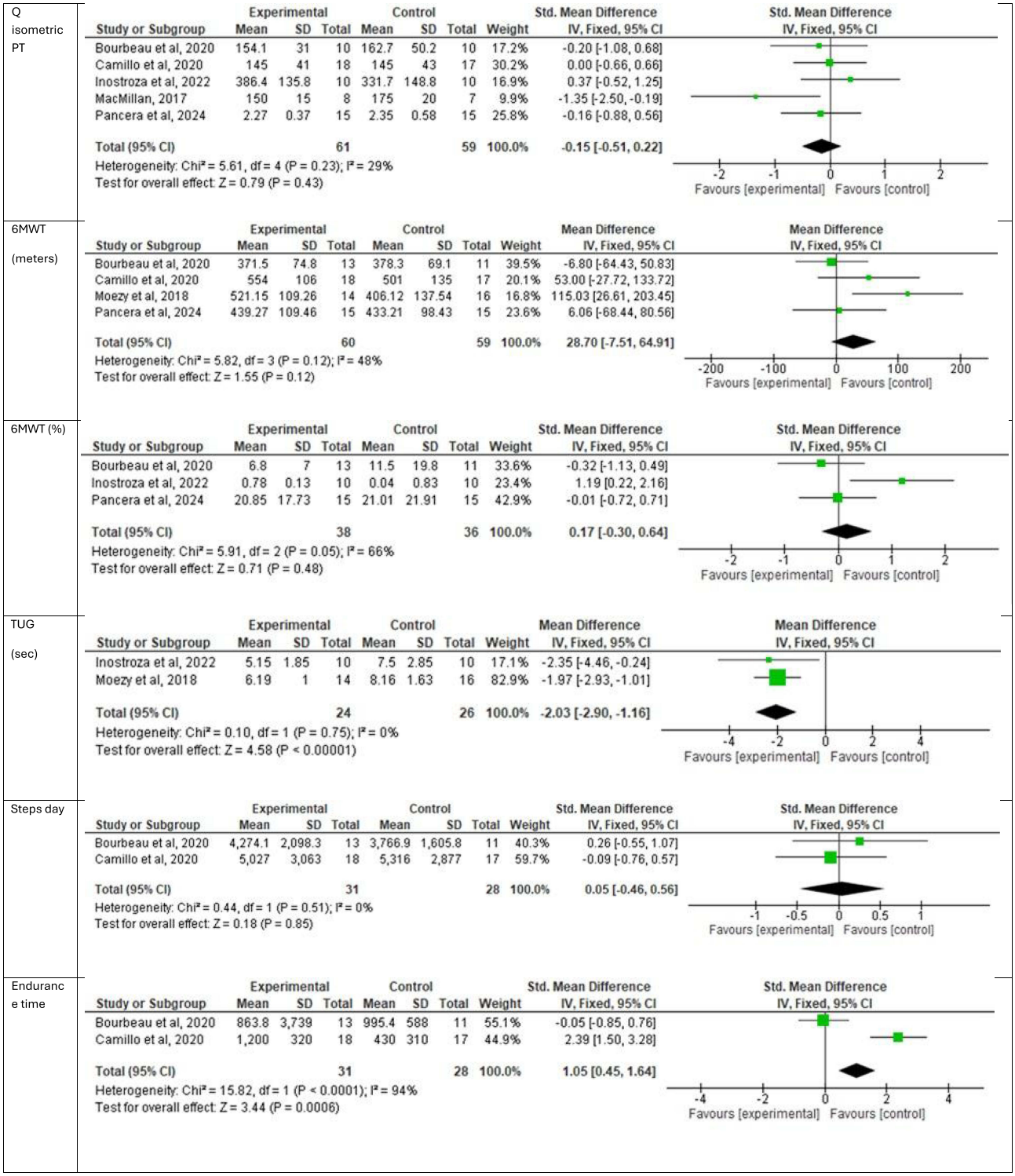

Figure 3 Continued.

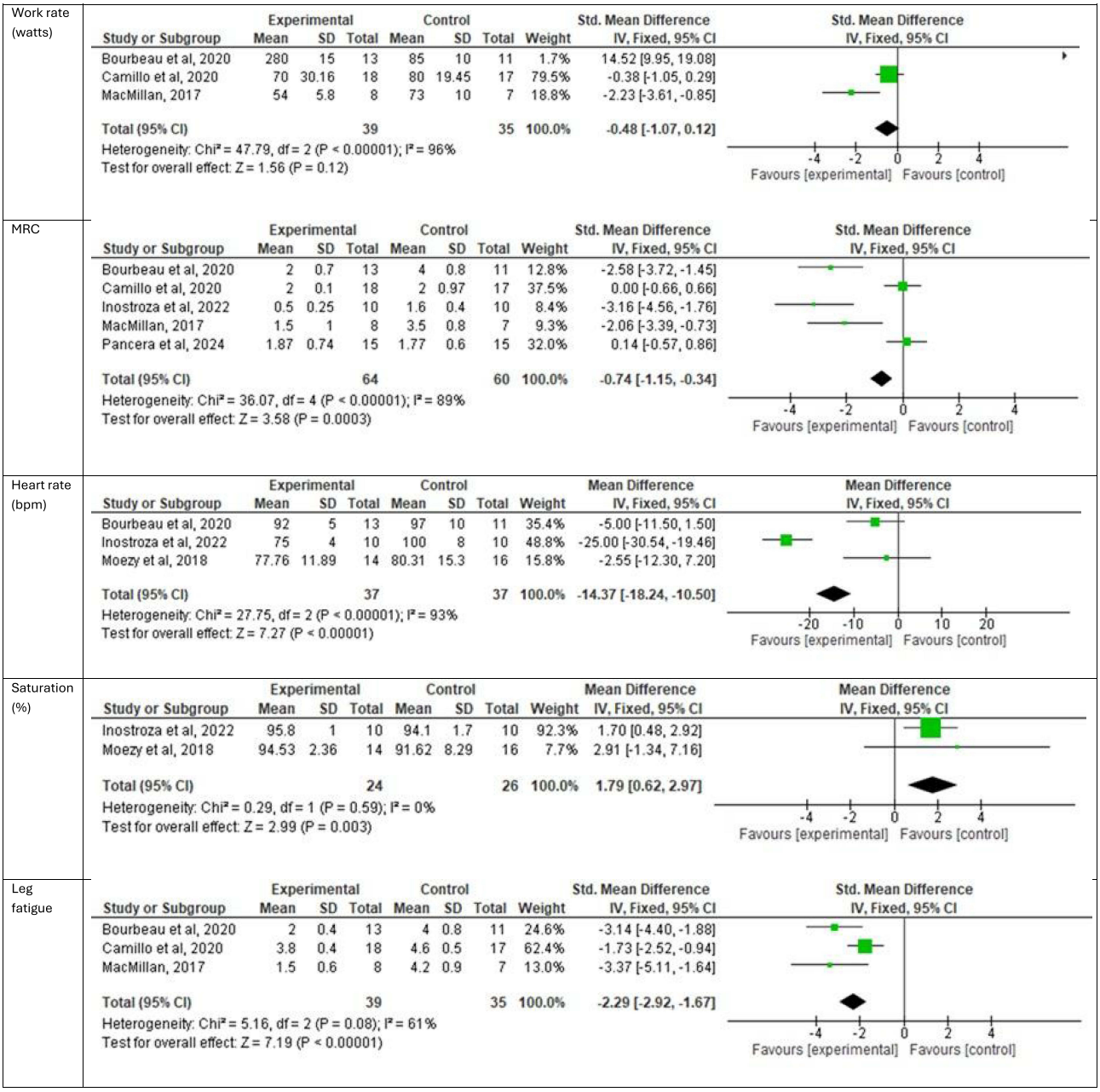

Figure 3 Quantitative results.

Two studies (n=50) assessed exercise tolerance using the TUG in seconds.[15,19] The results showed an improvement in the experimental group compared to the control (−2.03 [−2.90, −0.16] p< 0.001), with homogeneous studies (I^2 = 0%) and a large effect (d=1.15).

Activity Level and Aerobic Ability

The studies by Bourbeau et al and Camillo et al[17,20] (n=59), measured the total number of daily steps, finding similar results in both groups (−0.05 [−0.46, 0.56] p=0.85), with homogeneous studies (I^2 = 0%) and a null effect (d=0).

These same studies also assessed endurance time, where a significant improvement was observed in the control group compared to the experimental group (1.05 [0.45, 1.64] p<0.01), with high between-study heterogeneity (I^2 = 94%) and a large effect (d=0.9).

Three studies (n=74) analysed work rate in watts,[17,18,20] showing a higher work rate in the experimental group (−0.48 [−1.07, 0.12] p =0.12), with high heterogeneity (I^2 = 96%) and d= 0.7 who is a medium effect.

Regarding exercise adaptations, two studies (n=50) analysed oxygen saturation,[15,19] finding an increase in oxygen saturation in the control group compared to the experimental (1.79 [0.62, −2.97] p < 0.01), with loss heterogeneity (I^2 =0%) and small effect (d=0.47).

Regarding heart rate, in addition to these two studies, Bourbeau et al[20] also analysed this variable. With a total of 74 participants, a reduction was observed in the experimental group compared to the control (−14.37 [−18.24, −10.50] p < 0.01), despite high heterogeneity (I^2= 93%) and d= 0.66 who is a medium effect.

Dyspnoea and Lower Limb Fatigue

Five studies (n= 124) assessed dyspnoea and its evolution over weeks of training,[16–20] finding a reduction in the experimental group (−0.74 [−1.15, −0.34] p <0.001), despite high heterogeneity between studies (I^2 = 89%) and medium effect (d=0.77).

Three of these articles (n= 74) also analysed lower limb fatigue after training,[17,18,20] reporting lower values in the experimental group (−2.29 [−2.92, −1.67] p<0.001), with moderate heterogeneity (I^2 = 61%) and a large effect (d=1.6).

Certainty of Evidence

Table 3 summarizes the certainty of evidence across outcomes. Overall, all outcomes were rated as moderate certainty.

Evidence certainty was primarily downgraded due to:

Risk of Bias

Limitations in participant and therapist blinding inherent to exercise interventions, and small sample sizes.

Table 3 Level of Evidence of the Articles

Outcome	Studies and Risk of Bias	Sample	Effect	Heterogeneity (I^2)	Certainty of Evidence and Justification	
Q isometric PT	5: uncertain (4); low (1)	120	ECC non-significant improvement -0.15 [−0.51, 0.22] p=0.43	Low (29%)	**Moderate**	Risk of bias Imprecision (CI includes the null value)
6MWT (meters)	4: uncertain (3); low (1)	119	CON non-significant improvement 0.33 [−0.03, 0.70] p=0.08	Low (22%)	**Moderate**	Risk of bias Imprecision (CI includes the null value)
6MWT (%predicted)	3: uncertain (2); low (1)	74	CON non-significant improvement (0.17 [−0.30, 0.64] p=0,48)	Medium (67%)	**Moderate**	Risk of bias Inconsistency (medium heterogeneity) Imprecision (CI includes 0 and is wide)
TUG	2: uncertain	50	ECC significant improvement -1.20 [−1.81, −0.59] p<0.001	Low (0%)	**Moderate**	Risk of bias Imprecision (few studies)
Daily steps	2: uncertain (1); low (1)	59	ECC and CON similar results -0.05 [−0.46, 0.56] p=0.85	Low (0%)	**Moderate**	Risk of bias Imprecisión (CI includes 0 and is wide)
Endurance time	2: uncertain (1); low (1)	59	CON significant improvement 0.84 [0.24, 1.44] p<0.05	High (95%)	**Moderate**	Risk of bias Inconsistency (high heterogeneity)
Work rate	3: uncertain (2); low (1)	74	ECC non-significant improvement (−0.48 [−1.07, 0.12] p =0,12)	High (96%)	**Moderate**	Risk of bias Inconsistency (high heterogeneity) Imprecision (CI includes 0 and is wide)
Oxygen Saturation	2 uncertain	50	ECC significant improvement (−0.71 [−0.13, −1.29] p = 0.02)	Medium (26%)	**Moderate**	Risk of bias Imprecisión (few studies)
Heart Rate	3: uncertain (2); low (1)	74	ECC significant reduction (improvement) (−0.73 [−1.25, −0.22] p < 0.01)	High (88%)	**Moderate**	Risk of bias Inconsistency (high heterogeneity)
Dyspnea	5: uncertain (4); low (1)	124	ECC significant reduction (improvement) (−0.74 [−1.15, −0.34] p <0.001)	High (89%)	**Moderate**	Risk of bias Inconsistency (high heterogeneity)
Lower Limb Fatigue	3: uncertain (2); low (1)	74	ECC significant reduction (improvement) (−2.29 [−2.92, −1.67] p <0.001)	Medium (61%)	**Moderate**	Risk of bias Inconsistency (medium heterogeneity)

Inconsistency

Moderate to high heterogeneity across studies (I^2 26–96%).

Imprecision

Confidence intervals were wide or included the null effect.

Discussion

The objective of this review was to compare the effects on exercise tolerance and functional outcomes of eccentric aerobic exercise (ECC) versus concentric exercise (CON) in people with COPD. Improvements, with a large or medium effect (d>0.6) were observed in quadriceps strength, functionality (measured with the Timed Up and Go test), work rate, dyspnoea, leg fatigue, and resting heart rate in the experimental group.

The demographics of the participants were similar in all studies: a predominance of men, with a mean age between 62 and 62.9 years and a diagnosis of COPD stages GOLD II–III. The duration of the pulmonary rehabilitation programmes ranged from 4–12 weeks, with 12 weeks being the most common, as recommended by the American Thoracic Society clinical practice guideline.[35] Sessions ranged from 15–150 minutes, with an average duration of 30 minutes.[36] Traditionally, the aerobic exercises used in pulmonary rehabilitation are mainly the updown treadmill and the cycloergometer, but the emergence of new training methods in the general population, such as ECC, makes it necessary to review these traditional methods.

The outcomes analyzed in this review — including endurance time, Timed Up and Go test (TUG) time, 6-minute walk test (6MWT) distance, daily step count, as well as symptoms of dyspnoea and lower-limb fatigue — are widely recognized as indicators of exercise tolerance and functional capacity in people with COPD. Therefore, the evidence synthesized supports framing our results within these patient-centered domains. However, the differences in sample size between the studies and the exercise protocol followed mean that the endurance time, work rate, heart rate, and dyspnoea outcomes are highly heterogeneous (I > 75%), making their results more questionable.

The most analysed variable in the studies of this meta-analysis was quadriceps muscle strength. All studies, except Moezy et al,[15] included it among their objectives. A recent review published in 2023[37] already confirmed that ECC increases quadriceps strength, measured during both isometric and eccentric contraction. Several studies have analysed the effects of ECC on the quadriceps,[38–40] obtaining improvements in peak torque, thickness and hypertrophy, respectively. Although all of them were performed in healthy subjects, they support the strength improvement associated with ECC, in line with the articles included in this review.

The fact that this variable is the most commonly used is not irrelevant, since in people with COPD quadriceps weakness is associated with reduced exercise tolerance, poorer functional performance, poorer quality of life and reduced physical activity.[41]

People with more severe COPD have been found to have greater quadriceps fatigue and dyspnoea both at rest and during exercise,[42] the latter being the most limiting symptom of the disease.[43] Likewise, studies such as that by Rodio et al have linked increased quadriceps strength through ECC to lower levels of pain and fatigue in healthy subjects,[44] which could explain the decrease in dyspnoea, assessed using the Medical Research Council (MRC) scale and improvement in muscle fatigability observed in the articles in this review.

In general, a reduction in dyspnoea should translate into an increase in functional ability.[45] In the articles reviewed, functionality was assessed using 6MWT and TUG, with mixed results. While times in the TUG test were better in subjects who performed ECC, in the 6MWT it was the participants who followed a CON programme who covered more distance, although without statistically significant differences. This difference could be attributed to the nature of the tests: the 6MWT is a linear test that measures the distance walked in 6 minutes,[46] whereas the TUG involves getting up from a chair, walking 3 metres and sitting down again.[47]

Traditionally, the TUG test has been the most widely used test in the elderly population for its reliability in predicting the risk of falls and frailty,[47] especially because it includes functional transfers. Eccentric quadriceps exercise training has been associated with improved functionality[48] and a reduction in the number of falls in older people,[49] as well as improving gait pattern, symmetry[50] and shock absorption.[51] Activities such as getting up or sitting down from a chair

involve eccentric contractions of the quadriceps,[52] as does walking downhill, which could explain the good results of the experimental group in this test.

On the other hand, the 6MWT is linear and of longer duration (6 minutes compared to approximately 10 seconds for the TUG,[53] which could explain the better results of the group in terms of endurance time.

Regarding the steps per day variable, no differences were observed between the two groups, with a homogeneity of 0% between the two groups and a null effect, so it would not be a variable that provides significant information in this review.

Finally, one of the main advantages of ECC over CON is that it allows greater tolerance to effort (measured in terms of absolute power).[54] This means a lower maximum heart rate during exercise, as observed in this review, as well as a lower ventilatory demand[55] and an improvement in oxygen saturation, as demonstrated by Har-NIr et al[56] in their study on multiple sclerosis and ECC. However, these results differ from those obtained in this review. Perhaps because in patients with obstructive respiratory pathology, it would be more interesting to study the effects on hypercapnia than the effects on oxygen saturation.[57]

Limitations

This review has certain limitations. Firstly, the number of articles included, despite presenting a significant clinical effect, is still too small to extrapolate the data to the general population.

The protocols followed in the studies were not similar. There is a lot of variability between the type of exercise (walking or cycling), session time, and training duration among the selected articles, making it difficult to determine the benefits of eccentric versus concentric training. Therefore, it would be interesting to first establish a treatment protocol that unifies criteria before conducting new studies.

Future Lines of Research

None of the review articles indicated whether any musculoskeletal injury occurred, despite evidence that poorly executed eccentric exercise can cause muscle damage.[58] The need for standardized, multicenter, and long-term protocols could emphasize the emergence of possible injuries. This information would be useful in determining which types of patients with comorbidities might or might not benefit from this type of training.

Given that all participants in this review were people diagnosed with COPD, it would be interesting to research the effect of eccentric aerobic exercise training on other respiratory or cardiac pathologies.

Conclusions

Eccentric aerobic exercise is a valid alternative to concentric aerobic exercise in the training of people with COPD, contributing to improved exercise tolerance in terms of heart rate, fatigue and dyspnoea and functionality, while CON improves endurance time. However, further studies are required to determine with greater certainty its impact on functionality.

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