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Effects of inspiratory muscle training on physical fitness in cystic fibrosis: a systematic review and meta-analysis

Aydan Asli Aksel-Uylar^{1*} , Ceyhun Topcuoglu² , Melda Saglam¹ and Naciye Vardar-Yagli¹

Abstract

Background Cystic fibrosis (CF) is a multisystem disease primarily affecting the lungs. It impacts physical fitness due to increased bronchial secretions and exercise intolerance. Inspiratory muscle training (IMT) is recommended as a pulmonary rehabilitation approach. Therefore, we aimed to examine the effect of inspiratory muscle training on health-related physical fitness in CF.

Methods Articles were searched in five databases from inception to June 2025. All randomized controlled trials comparing IMT with a control group in individuals with cystic fibrosis were included. Four randomized controlled trials involving a total of 90 individuals with CF met the inclusion criteria.

Results A significant difference was found in the change in maximal work capacity, maximal minute ventilation, and exercise duration during the exercise test in the IMT group compared to the control group. However, no significant difference was observed in the change in maximal oxygen uptake, 6-minute walk test distance, and oxygen saturation during the 6-minute walk test between the IMT group and the control group.

Conclusion The therapeutic effectiveness of IMT for physical fitness is still uncertain. The evidence is not enough to assess how IMT can be used to enhance health-related physical fitness in CF. Further research should explore the optimal intensity and duration of IMT training needed to improve cardiorespiratory fitness. Additionally, future studies should evaluate how effective IMT is when examining its impact on health-related physical fitness.

Keywords health-related physical fitness, cardiorespiratory fitness, body composition, respiratory muscles, cystic fibrosis

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Introduction

Cystic fibrosis (CF) is a genetic disorder that affects systems heavily reliant on exocrine secretion [1]. Lung disease is the main cause of mortality and morbidity [2]. Thick, sticky mucus makes the lungs prone to infection and chronic airway inflammation [3].

Pulmonary disease causes weakness in inspiratory and peripheral muscles along with a loss of lean mass [4]. Inspiratory muscle weakness results in decreased lung function [5]. A key reason for respiratory muscle weakness in individuals with CF is the imbalance between respiratory workload and respiratory capacity [6]. When malnutrition and hyperinflation are combined with increased airway resistance caused by inflammation, respiratory muscle weakness becomes unavoidable [6]. Inspiratory muscle training (IMT) is a treatment for respiratory muscle weakness, chronic airflow limitation, and dyspnea [5]. It has been shown to improve inspiratory muscle strength, lung function, and exercise capacity in various chronic lung diseases [7].

IMT aims to increase inspiratory muscle strength and endurance with specific equipment [8]. IMT includes exercise training and normocapnic hyperpnea. Exercise training can be flow, threshold, or resistive [9]. Normocapnic hyperpnea enhances inspiratory muscle strength by using maximal voluntary ventilation for a set period [9]. IMT is known to improve inspiratory muscle strength and exercise capacity by reducing the perception of dyspnea in people with CF [5].

Physical fitness is a key predictor of pulmonary exacerbations and mortality in this population [10]. Health-related physical fitness involves the ability to perform physical activities, including cardiorespiratory fitness, muscular strength and endurance, body composition, and flexibility [11].

Secretion-related airway obstruction and dynamic hyperinflation affect the optimal length of the diaphragm and accessory respiratory muscles, making them prone to fatigue [12]. Reduced respiratory muscle strength leads to decreased ventilation efficiency, causing dyspnea and CO₂ retention during exertion in people with CF [13]. IMT can reduce airway obstruction and dynamic hyperinflation, thereby improving the breathing mechanics [14]. For this reason, IMT can enhance cardiorespiratory fitness, which is one aspect of physical fitness [6].

An increase in respiratory efficiency can indirectly lead to improvements in peripheral muscle endurance, along with less dyspnea and delayed fatigue [15]. It has been reported that IMT increases peripheral muscle oxygenation and decreases fatigue in other populations [16, 17]. Additionally, IMT may help delay pulmonary exacerbations by improving mucus clearance and reducing the negative effects of exacerbations on muscle strength and endurance [18].

The literature suggests that, when combined with other treatment methods, IMT training can improve body composition by reducing body fat percentage [19, 20]. Therefore, body composition is also one of the parameters that arouses curiosity.

As far as we know, the effect of IMT, which is widely used in people with CF, on all parameters of health-related physical fitness has not been investigated before this systematic review. This review aims to determine the impact of IMT on physical fitness in children and adults with CF.

Materials and methods

This systematic review and meta-analysis were registered (PROSPERO registration number: CRD42022380541). This study was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [21].

Eligibility criteria

The inclusion criteria were: (a) children and adults diagnosed with CF; (b) all types of inspiratory muscle training; (c) randomized clinical trials reporting data on inspiratory muscle training (in terms of intensity, type, duration, and frequency); (d) articles written in English. The exclusion criteria were: (a) studies that only have abstracts, such as group studies or conference presentations; (b) other chronic respiratory diseases besides CF; (c) combined training programs; (d) recommendations only.

Information sources and search strategy

Articles were searched using keywords and Medical Subject Headings (MeSH) terms in PubMed/Medline, Scopus, Cochrane Library, Web of Science, and PEDro databases from inception to June 2025. In addition, references from original articles and reviews were also examined. The search terms included: “Cystic Fibrosis” AND (“Breathing Exercises” OR inspiratory muscle training OR respiratory muscle training OR ventilatory muscle training) AND (“Physical Fitness” OR “Cardiorespiratory Fitness” OR cardiorespiratory endurance OR aerobic fitness OR musc* strength OR musc* endurance OR “Body Composition” OR flexib* OR Pliability).

Data extraction

The PICO model was used to select the articles and was defined in the study as follows: P (population): Individuals with cystic fibrosis; I (intervention): Inspiratory muscle training, including resistive loading (flow-resistive and pressure threshold) and normocapnic hyperpnea training; C (comparison): Control group (such as sham training or cystic fibrosis not exposed to IMT); O (outcome): Cardiorespiratory fitness (results of the test used, such as

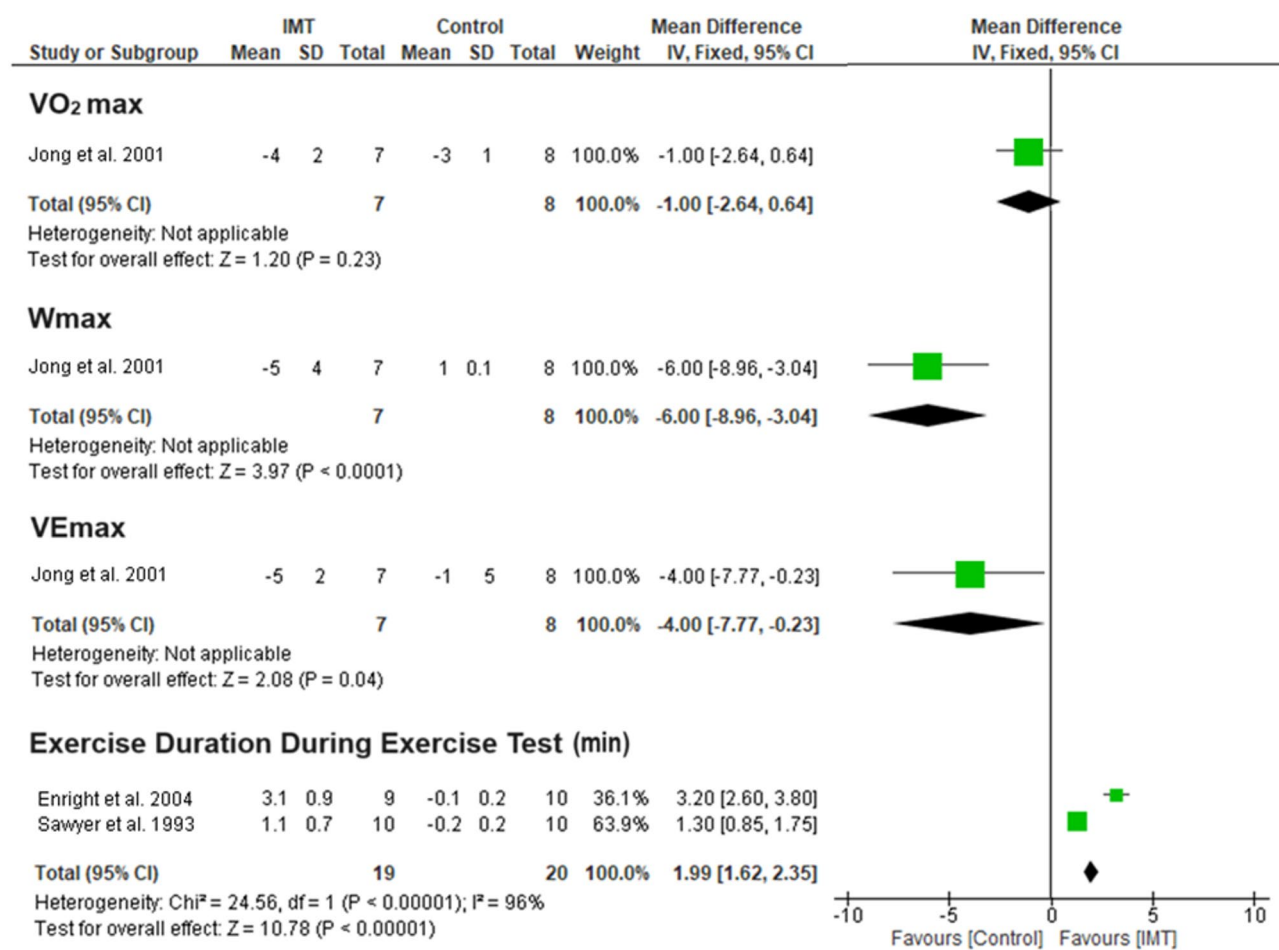


Fig. 1 Comparison of Wmax, VEmax, and exercise duration between the intervention and control groups

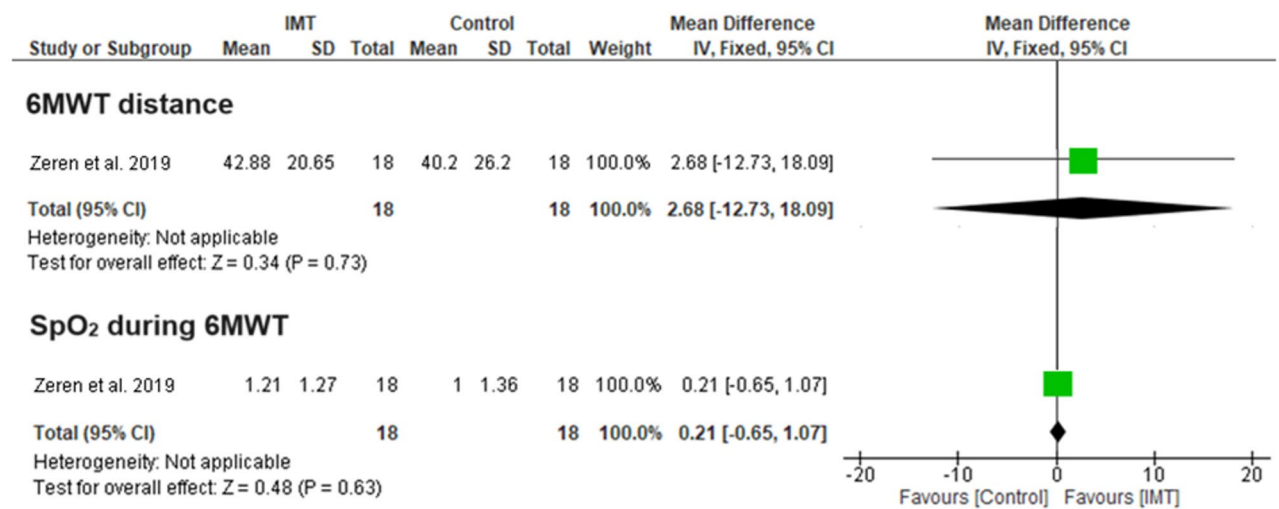


Fig. 2 Comparison of 6 MWT distance and oxygen saturation during 6 MWT between the intervention and control groups

maxVO₂ for CPET), muscular endurance (number of repetitions or time), muscular strength (maximal strength), body composition (weight, height, BMI, waist-hip ratio, adiposity ratio, fat mass, fat-free mass, bone mass), flexibility (sit and reach test, etc.) [22]. The selected variables of outcomes are shown in Figs. 1 and 2. All randomized controlled trials comparing IMT with a control group were included. Trials in which exercise training

was added to IMT were excluded. Two authors (NVY and AAAU) independently screened the databases, titles, and abstracts of the trials. The authors then assessed the full text of potentially relevant studies according to the inclusion/exclusion criteria. The reasons for excluding studies were recorded. Similarly, data extraction was performed by two other authors (MS and CT), and the results were compared. If consensus was not reached, they discussed until agreement was achieved. Full-text studies published in English were included in the systematic review. Studies with abstracts only (conferences, study groups, etc.) were excluded. Reviews and grey literature were not included. Authors of articles for which procedure details could not be obtained were contacted by e-mail. Articles from authors who did not respond to the e-mail could not be included. Data from the eligible studies identified for inclusion were extracted into a Windows Excel spreadsheet, including the title, author, year of publication, study design, sample size, outcomes, and main findings. All eligible trials were entered into Review Manager software.

Risk of bias

The revised Cochrane Risk of Bias Tool (RoB2) was used to evaluate the risk of bias in the included trials (Fig. 3). This method assessed the randomization process, deviations from the intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. The risk of bias was evaluated by two independent authors. In case of disagreement, the authors consulted a third and fourth person.

Quality assessment

The methodological quality of randomized controlled studies was assessed using the Physiotherapy Evidence Database (PEDro) scale [23]. The PEDro scale includes

11 items, but the total score is out of 10, with the first item not scored. Scores from 9 to 10 are considered 'perfect,' scores from 6 to 8 are labeled 'good,' scores from 4 to 5 are classified as 'moderate,' and scores below 4 are deemed 'poor' [24]. Two authors independently evaluated the articles, and any disagreements were resolved through consensus with a third and fourth party. The PEDro scale is a reliable and valid measure [24, 25].

Statistical analysis

RevMan 5.4 (Copenhagen, Denmark) was used to analyze the collected data. Since the results in meta-analyses were evaluated using the same measurements, the mean difference (MD) was reported with a 95% confidence interval (CI), and significance was set at $p < 0.05$. The heterogeneity test, expressed by I^2 , was performed to assess heterogeneity. In this test, 75% indicated high heterogeneity, 50% moderate heterogeneity, 25% low heterogeneity, and 0% true homogeneity. Differences between groups were analyzed using the fixed effects model.

Results

Study selection

Following the database search, 360 potentially eligible articles were identified. Of these, 85 articles were excluded due to duplicate records. An additional 266 articles were excluded based on their title and abstract. Two articles were excluded because they did not involve IMT intervention, one was excluded due to exercise training in the intervention group, one was excluded because the full text was unavailable, and one was excluded for lack of randomization. Ultimately, four randomized controlled trial (RCT) articles remained and were included in the study (Fig. 4).

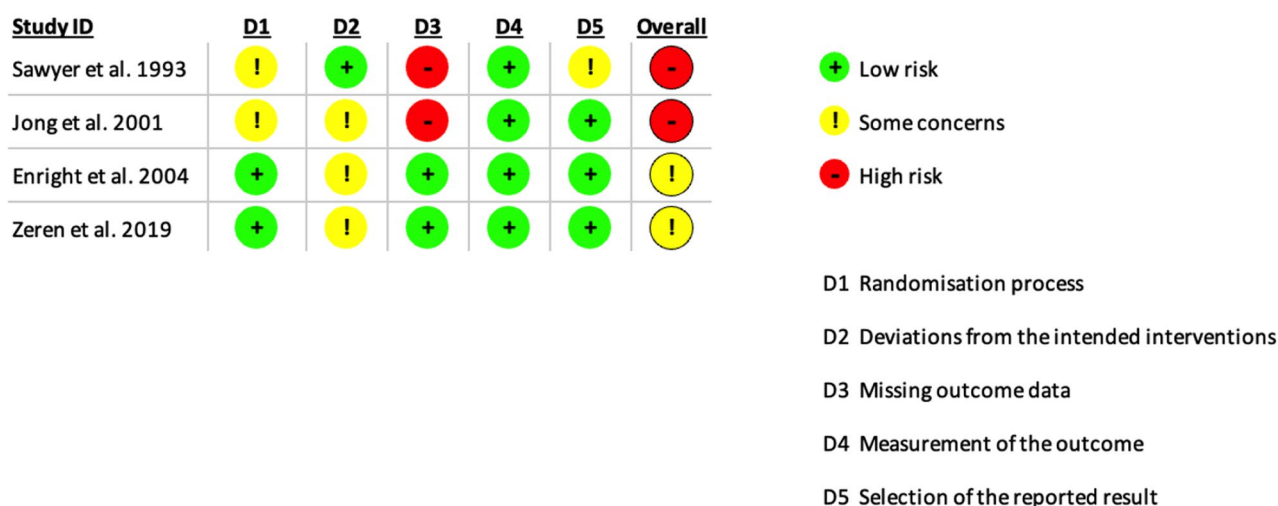


Fig. 3 Summary of the risk of bias for the trials included in this systematic review

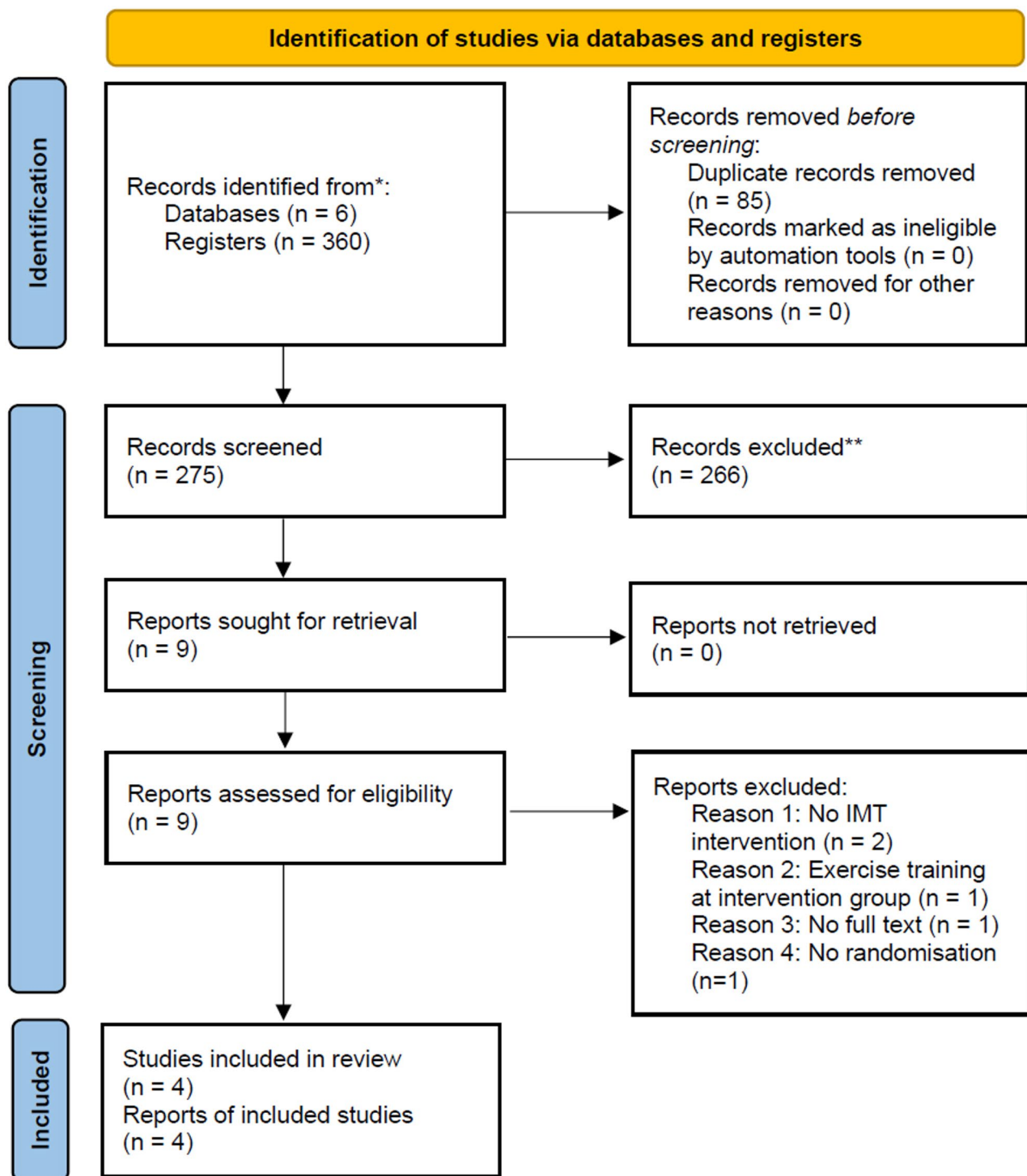


Fig. 4 Flow chart

Study characteristics

A total of 90 individuals with CF (IMT: 44, CG: 46) were included in the review. The sample sizes of the included studies ranged from 15 to 36, and the participants' mean ages were between 11 and 25 years. The trials were conducted in the Netherlands, the United Kingdom, the

USA, and Turkey. In all the trials, IMT training was performed with a threshold loading device. The training programs lasted between 6 and 10 weeks, with training sessions occurring 3 to 7 times per week. The intensity of inspiratory muscle training varied from 30% to 80% of Pimax. Inspiratory muscle training sessions lasted

Table 1 Characteristics of individuals with CF

Study	Age (years)	Gender, male (%)	Height, weight or BMI	FEV ₁ (%) (pred.)	RV (L, % pred.)	Inclusion criteria	Exclusion criteria
Sawyer et al. (1993) [26]	IMT: 11.46 ± 2.45 CG: 9.76 ± 2.57	IMT: 60 CG: 50	IMT: 39.8 (kg), 147 (cm) CG: 33.8 (kg), 138 (cm)	IMT: 89 ± 20% CG: 92 ± 29%	IMT: 1.45 ± 0.49 (L) CG: 1.37 ± 0.65 (L) IMT: 210 ± 62% CG: 211 ± 89%	- Diagnosis of cystic fibrosis	-
Jong et al. (2001) [27]	IMT: 17 ± 5.2 CG: 19 ± 5.5	IMT: 50 CG: 50	IMT: 50 ± 13 (kg), 167 ± 15 (cm) CG: 54.6 ± 12 (kg), 169 ± 13 (cm)	IMT: 70 ± 25% CG: 70 ± 29%	IMT: 2.08 ± 0.99 (L) CG: 1.81 ± 1.33 (L)	-Diagnosis of cystic fibrosis -Be willing to participate	-
Enright et al. (2004) [5]	IMT: 24.8 ± 5.5 CG: 21.3 ± 2.7	IMT: 44 CG: 60	IMT: 59.9 ± 12.1 (kg), 164 ± 9 (cm) CG: 65.8 ± 10.3 (kg), 168 ± 8.4 (cm)	IMT: 64.2 ± 29.7% CG: 63.1 ± 27.8%	IMT: 1.80 ± 0.70 (L) CG: 2.00 ± 0.60 (L) IMT: 133.30 ± 51.10% CG: 116.00 ± 32.80%	-Diagnosis of cystic fibrosis -Change in symptoms or treatment within one month -FEV ₁ within 10% of the best value recorded in the previous 12 months	-Cor pulmonale, liver cirrhosis, or diabetes mellitus -Receiving oral steroids
Zeren et al. (2019) [3]	IMT: 11.66 ± 2.42 CG: 10.47 ± 2.03	IMT: 50 CG: 44	IMT: 17.65 ± 2.40 (kg/m ²) CG: 17.96 ± 2.49 (kg/m ²)	IMT: 79.36 ± 13.67% CG: 78.69 ± 15.91%	-	- Diagnosis of cystic fibrosis - FEV ₁ > %70	-History of acute exacerbation or hospitalization in the past month -Active participation in another supervised physical therapy program -Diagnosed comorbidities that may affect mobilization or balance

IMT inspiratory muscle training, CG control group, BMI body mass index, FEV₁ forced expiratory volume in 1 s, RV residual volume

Table 2 Characteristics of the studies

Study	Year	Country	Group (n)	Study design	Intervention	Outcome measurements
Sawyer et al.	1993	USA	IMT: 10 CG: 10	IMT vs. CG	IMT: 30 min a day, 7 days a week, for 10 weeks, 60% of their Pimax CG: 10% of their Pimax, for 10 weeks	Exercise duration during exercise test
Jong et al.	2001	Netherlands	IMT: 7 CG: 8	IMT vs. CG	IMT: 20 min a day, 5 days a week, for 6 weeks. First week: 20% of Pimax, second week: 30% of Pimax; last 4 week: 40% of Pimax CG: 10% of Pimax, for 6 weeks	VO ₂ max, Wmax, VEmax
Enright et al.	2004	United Kingdom	IMT: 9 CG: 10	IMT vs. CG	IMT: 3 days a week, for 8 weeks, 80% of Pimax. Rest period between each inspiratory effort was reduced from 60 to 45, 30, 15, 10, and 5 s CG: Patients did not participate in any form of training	Exercise duration during exercise test
Zeren et al.	2019	Turkey	IMT: 18 CG: 18	IMT vs. CG	IMT: 30 min a day, 7 days a week, for 8 weeks, 30% of their Pimax, for 1 week. Weekly MIP measurements adjusted training intensity to 30% of MIP CG: Chest physical therapy and physical activity counselling	6MWT distance, SpO ₂ during 6MWT

IMT inspiratory muscle training, CG control group, Pimax maximal inspiratory pressure, MIP maximal inspiratory pressure, VO₂ max maximal oxygen uptake, Wmax maximal work capacity, VEmax maximal minute ventilation, 6MWT 6-minute walk test, SpO₂ oxygen saturation

between 15 and 30 min, with repetitions occurring 3 to 7 days per week (Tables 1 and 2).

Quality of studies

The quality of each study was evaluated using the PEDro score. The PEDro scores for the included studies ranged from 6 to 10. Enright et al. and Zeren et al. studies achieved perfect quality, while Sawyer et al. and Jong et al. studies were of good quality (Table 3).

Training group versus control group

Cardiorespiratory fitness

Cardiopulmonary exercise test (CPET) The maximal oxygen uptake (VO₂ max), maximal work capacity (Wmax), and maximal minute ventilation (VEmax) were analyzed in one of four trials (45 patients), and exercise duration (minutes) during the exercise test was analyzed in two trials (39 patients).

Table 3 Quality assessment of randomized clinical trials - PEDro scale

Authors	Eligibility criteria	Random allocation	Concealed allocation	Baseline comparability	Blinding (participant)	Blinding (therapist)	Blinding (assessor)	Adequate Follow-Up	Intention to Treat Analysis	Between-Group Comparisons	Point Estimates and Variability	Total
Sawyer et al. 1993 [26]	No	Yes	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	7
Jong et al. 2001 [27]	No	Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes	6
Enright et al. 2004 [5]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	10
Zeren et al. 2019 [3]	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	9

In the study by Jong et al., the average O_2 consumption per kg was recorded as $33 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in both groups before training, $29 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in the training group, and $30 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in the control group after the intervention. O_2 consumption was similar across both groups. The mean Wmax decreased from 111 watts to 106 watts in the training group, while it increased from 125 watts to 126 watts in the control group. VEmax decreased from 45 L/min to 40 L/min in the training group and from 59 L/min to 58 L/min in the control group. In the control group, the change in Wmax and VEmax was significantly greater compared to the training group [27].

According to the study by Enright et al., who examined exercise duration during the exercise test, it increased from 7.2 min to 10.3 min [5]. According to the study by Sawyer et al., the exercise duration in the training group increased from 11.8 min to 12.95 min [26]. In both studies, the exercise duration during the test showed a significantly larger increase in the training group compared to the control group.

Meta-analysis was conducted by calculating the mean difference (MD) between the training and control groups for changes in $VO_{2\text{max}}$, W_{max} , VE_{max} , and exercise duration during the exercise test. A fixed effect model was used for inspiratory muscle training. Significant differences were found in the changes in W_{max} , VE_{max} , and exercise duration (minutes) during the test for the inspiratory muscle training group compared to the control group (MD -6.00 W , 95% CI $-8.96 - -3.04 \text{ W}$, $p < 0.0001$; MD -4 L/min , 95% CI $-7.77 - -0.23 \text{ L/min}$, $p = 0.04$; MD 1.99 , 95% CI $1.62 - 2.35 \text{ min}$, $p < 0.00001$). No significant difference was observed in VO_2 max change between the groups (MD -1.00 ml/kg/min , 95% CI $-2.64 - 0.64 \text{ ml/kg/min}$, $p = 0.23$). Among the articles analyzed, 1 was of perfect quality, and 2 were of good quality.

Six minute walk test The 6MWT distance and SpO_2 during 6MWT were analyzed in one of four trials (72 patients). In the study by Zeren et al., the IMT group walked 561 m before training and 603 m after training in 6MWT. The control group increased from 544 m to 584 m. During the test, oxygen saturation decreased by 1.86% in the IMT group before training, while it decreased by 0.66% after training. The change in 6MWT distance and SpO_2 during 6MWT were similar in both the training and control groups [3].

A meta-analysis was conducted by calculating the mean difference (MD) between the training and control groups for the change in 6MWT distance and SpO_2 during 6MWT. A fixed effect was used for inspiratory muscle training. No significant difference was observed in the changes in 6MWT distance and SpO_2 during 6MWT between the inspiratory muscle training group and the control group (MD 2.68 m , 95% CI $-12.73 - 18.09 \text{ m}$,

$p = 0.73$; MD 0.21%, 95% CI -0.65 to 1.07% , $p = 0.63$) (Fig. 2).

Summary of the risk of bias

Four articles reported random sequence generation for selection bias, and two included allocation concealment. Blinding was reported in the outcome assessment of three articles, while one provided no explicit information. In two articles, all participants completed IMT training, and all data were available. The remaining two articles did not report an “intention to treat” analysis, indicating potential attrition bias. Reporting bias was identified in one study (Fig. 3).

Discussion

To our knowledge, this is the first systematic review and meta-analysis to examine the effect of IMT training on health-related physical fitness parameters in individuals with CF. The results of the study show that IMT training increased the duration of the cardiopulmonary exercise test, which is a marker of cardiopulmonary fitness, compared to the control group. However, no significant findings were observed in the results of the 6-minute walk test, a submaximal exercise test, although it favored the intervention group. This meta-analysis confirms the effectiveness of IMT training in increasing exercise test duration in individuals with CF. Other health-related parameters such as muscular strength and endurance, body composition, and flexibility were not reported in IMT studies involving individuals with CF. Therefore, the discussion will primarily focus on cardiopulmonary fitness.

In the literature, it has been reported that the inability to maintain high-level ventilation during exercise limits maximal aerobic capacity [28]. Like skeletal muscles, inspiratory muscles also respond to training in relation to the applied load. Improvement in maximal voluntary ventilation (MVV) occurs with increases in inspiratory muscle strength and endurance [29]. Believing that cardiorespiratory fitness could benefit from IMT training, we began our investigation with this concept in mind.

One meta-analysis and one systematic review examined the effect of respiratory muscle training (RMT) in individuals with CF [9, 30]. These two studies explored RMT's impact on exercise capacity and various other outcomes. In the systematic review by Stanford et al., it was highlighted that the effect of IMT training on exercise capacity, supported by limited evidence, remains uncertain [9].

According to a meta-analysis published in 2024 examining children and adolescents with cystic fibrosis, there was no statistically significant difference, although improvement in 6MWT distance was observed with respiratory muscle training [30]. However, as the author

notes, the included studies varied in training level and methodology. IMT was applied in one study included in this analysis, while expiratory muscle training was used in another. In the meta-analysis by Stanford et al., no significant change in 6MWT distance was observed with respiratory muscle training [9]. Our meta-analysis focused only on IMT training and included all studies involving children, adolescents, and adults. Consistent with the literature, no significant improvement in 6MWT distance was found.

We also investigated the SpO₂ value during the test. Martin et al. shows that a decrease below 90% saturation during the 6MWT is related to lung transplantation risk and mortality in adults with CF [31]. Peripheral oxygen saturation is an important parameter that may influence cardiopulmonary fitness. Among the included studies, only the study by Zeren et al. was reported, and according to our analysis, no significant difference was observed between the groups in the change after training [3]. IMT alone seems to be insufficient for improving submaximal exercise capacity. Additionally, based on the available data, IMT does not appear to have an effect on oxygen saturation during exercise testing.

When the CPET test parameters were analyzed, it was observed that the improvement in test duration with IMT training was greater than in the control group. This finding contradicts the meta-analysis by Cai et al., which examined the effect of inspiratory and expiratory muscle training on exercise duration and found no difference [30]. It was also noted that the quality of evidence was very low.

Increased airway resistance and chronic cough in individuals with CF are linked to a sustained increased workload on the respiratory muscles [32]. Sovtik et al. note that this may create a conditioning effect on the respiratory muscles, and maintaining muscle strength and IMT may result in limited improvement in exercise capacity [32].

Another issue to discuss is that IMT increases the CPET duration while not changing the 6MWT distance. The 6MWT is a submaximal test in which the patient walks at their own pace, whereas CPET is a maximal test performed according to specific protocols [33]. Improvements in inspiratory muscle strength and endurance delay the respiratory muscle fatigue and shortness of breath that individuals would reach during maximum effort [34]. Patients rarely reach this respiratory limit during the 6MWT. The ceiling effect of the 6MWT also masks the gains made by participants [35]. Additionally, since CPET is a laboratory test, it is more likely to reflect changes in ventilatory efficiency [36].

Hyperinflation is defined as the residual volume (RV) exceeding the expected value [37]. This condition reduces vital capacity (VC), leading to diaphragm flattening,

alveolar hypoventilation, and hypercapnia [37]. IMT training strengthens inspiratory muscles, shortens the inspiration time, and prolongs the expiration time [37]. This has the potential to reduce the hyperinflation. This is one of the expected indirect benefits of IMT on health-related physical fitness parameters. In the included studies, when examining RV, it is observed that in two studies, the measured value exceeds the expected value. The expected percentages of the other two studies were uncertain. Therefore, the level of benefit observed in the study may have varied.

Muscular strength and endurance, which are health-related physical fitness parameters, gain more importance as the lifespan of individuals with CF increases [38]. Chronic respiratory diseases are expected to decrease peripheral muscle strength by impairing peripheral muscle oxidative metabolism [39]. However, research on the effectiveness of IMT has not specifically focused on peripheral muscle strength and endurance. It is likely to influence peripheral muscle strength, making it an open question for further investigation.

Individuals with CF have lower fat-free mass, lean body mass, and BMI compared to their healthy peers [40]. Malabsorption and systemic inflammation in CF lead to protein loss, muscle damage, and reductions in lean body mass and fat-free mass. This may cause dysfunction of the diaphragm, the primary inspiratory muscle, and accessory inspiratory muscles [41]. Therefore, the effects of IMT training on body composition in CF are worth investigating. In the included studies in this meta-analysis, body composition is not reported as an outcome but only described in the initial evaluations of the groups. Since malabsorption and digestive problems in the gastrointestinal tract are common in the CF population, it is not surprising that they are mentioned in the descriptive characteristics of the groups [40]. However, the effect of IMT on body composition in individuals with CF could not be analyzed because no data on body composition were provided after the intervention.

Trunk flexibility is closely related to thoracic mobility [42]. Both trunk flexibility and thoracic mobility are affected by postural impairments caused by increased accessory respiratory muscle activation, decreased bone mineral density and muscle mass, hyperinflation, and changing rib angles in CF [43]. The most commonly observed postural issue is increased thoracic kyphosis [43]. Unfortunately, studies on flexibility in CF are quite limited. In the literature, respiratory muscle strength has been found to be associated with thoracic mobility in healthy individuals [44]. However, this meta-analysis does not allow us to comment on the relationship. More RCTs are needed to determine whether this relationship exists in individuals with CF. This represents a gap in the literature that awaits further investigation.

Limitations

The recommendation for IMT training is at least 30% of the Pimax for 12 weeks [45]. While the application is performed twice daily for low to moderate loads, it is sufficient to do it 3 days a week for high intensity. Three of the trials in our review involved low to moderate intensity, and one trial involved high-intensity IMT. This may have contributed to the variability in results.

The inclusion of only randomized controlled trials in the meta-analysis resulted in a small number of studies being analyzed. The variation in the intensity, duration, and frequency of IMT training across the included studies makes it hard to interpret the training's effectiveness.

Conclusion

The therapeutic effectiveness of IMT remains uncertain regarding physical fitness. The current evidence is insufficient to evaluate the use of IMT for enhancing health-related physical fitness in children and adults with CF. Further research is needed to determine the appropriate intensity and duration of IMT training required to improve cardiorespiratory fitness. Future studies should also assess the effectiveness of IMT when examining its impact on health-related physical fitness.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13102-025-01430-w>.

Supplementary Material 1.

Authors' contributions

A.A.U.: Conceptualization, Formal analysis, Investigation, Writing - Original Draft**C.T.:** Formal analysis, Investigation, Writing - Original Draft**M.S.:** Conceptualization, Methodology, Investigation, Writing - Review & Editing**N.Y.:** Conceptualization, Investigation, Writing - Review & Editing.

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Data availability

The database can be accessed upon request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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