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Original Article

Additional Effects of Inspiratory Muscle Training in Older Adults With COPD

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ABSTRACT

Background: Chronic obstructive pulmonary disease (COPD) is associated with inspiratory muscle dysfunction, exertional dyspnea, diminished exercise capacity, and functional limitations. Although inspiratory muscle training (IMT) may improve respiratory muscle performance, its additional clinical benefits remain uncertain. Objective: To compare longitudinal changes in inspiratory muscle strength, dyspnea, exercise capacity, and functional performance between older adults with COPD who received IMT and those without recorded IMT exposure. Methods: A longitudinal comparative cohort study was conducted over six months at Riphah International University, Lahore, Pakistan. Thirty-six participants were recruited through purposive sampling and categorized into an IMT cohort (n=18) and a comparison cohort (n=18). Outcomes were assessed at baseline and after eight weeks using maximal inspiratory pressure (MIP), modified Medical Research Council dyspnea scale (mMRC), six-minute walk distance (6MWD), Borg dyspnea score, and Short Physical Performance Battery (SPPB). Data were analyzed using IBM SPSS Statistics version 26.0, with additional baseline- regression analyses. Results: The IMT cohort demonstrated greater improvements in MIP (+13.33 vs +2.06 cmH_2O), 6MWD (+31.78 vs +6.72 m), mMRC (−0.67 vs 0.00 points), Borg dyspnea (−1.09 vs 0.00 points), and SPPB (+0.67 vs 0.00 points). Between-cohort differences in change were significant for all five outcomes ($p<0.001$). After adjustment for baseline outcome values, age, FEV_1 percentage predicted, and smoking exposure, the IMT cohort retained greater MIP (difference 11.48 cmH_2O; 95% CI 10.19–12.78) and 6MWD (26.13 m; 95% CI 24.25–28.01) at follow-up. Conclusion: IMT exposure was associated with greater short-term improvements in inspiratory strength, dyspnea, exercise capacity, and functional performance among older adults with COPD. These findings require confirmation in larger controlled studies. Keywords: Chronic obstructive pulmonary disease; inspiratory muscle training; longitudinal cohort; dyspnea; six-minute walk test; inspiratory muscle strength; functional performance; pulmonary rehabilitation.

INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is a heterogeneous respiratory disorder characterized by persistent respiratory symptoms and airflow limitation associated with abnormalities of the airways and alveoli. The disease contributes substantially to disability, healthcare utilization, and premature mortality, particularly among older adults. Progressive airflow obstruction, lung hyperinflation, impaired gas exchange, and extrapulmonary manifestations collectively influence clinical severity and functional independence. Current Global Initiative for Chronic Obstructive Lung Disease (GOLD) recommendations emphasize comprehensive assessment of respiratory symptoms, exacerbation history, pulmonary function, and functional limitations when planning individualized management (1,2).

Dyspnea is one of the principal symptoms responsible for restricted physical activity in COPD. Persistent breathlessness may lead to avoidance of exertion, physical deconditioning, impaired mobility, and reduced participation in daily activities. Older individuals may experience additional functional limitations because of age-related reductions in muscle strength, endurance, balance, and physiological reserve. Pulmonary rehabilitation is therefore an important component of comprehensive COPD management. Contemporary clinical guidelines recommend pulmonary rehabilitation for eligible patients because of its established benefits for exercise capacity, symptom burden, and health-related quality of life (3–5).

Inspiratory muscle dysfunction represents an additional contributor to exercise intolerance. In COPD, pulmonary hyperinflation alters the operating length and mechanical efficiency of the diaphragm, while increased airway resistance and respiratory loading elevate the effort required for ventilation. These changes may contribute to reduced inspiratory muscle performance and an unfavorable relationship between respiratory demand and muscular capacity.

Inspiratory muscle training (IMT) involves repeated breathing against an external inspiratory resistance or threshold load to improve respiratory muscle strength and endurance. Systematic reviews indicate that IMT can improve maximal inspiratory pressure and selected clinical outcomes, although the magnitude and consistency of benefit vary between studies (6–8).

Recent evidence has strengthened interest in IMT as a potentially useful component of respiratory rehabilitation. Meta-analyses have reported improvements in inspiratory muscle strength, dyspnea, and selected measures of exercise tolerance following respiratory muscle training. Nevertheless, protocols differ considerably in training intensity, frequency, duration, participant characteristics, and the use of concurrent pulmonary rehabilitation. These differences complicate comparisons and limit certainty regarding the clinical effects of individual IMT protocols (9–11).

An important distinction exists between improvements in respiratory muscle strength and improvements in broader functional outcomes. In a multicenter randomized controlled trial, Charususin and colleagues reported substantial improvements in inspiratory muscle function with adjunctive IMT but no additional benefit in the primary outcome of six-minute walk distance. Similarly, Schultz and colleagues demonstrated improved inspiratory strength without corresponding additional improvements in exercise capacity or dyspnea during a three-week pulmonary rehabilitation program. These findings indicate that greater inspiratory muscle strength does not necessarily translate into proportional improvements in walking performance or symptom-related disability (12,13).

Functional assessment is particularly relevant among older adults with COPD because respiratory impairment alone does not adequately characterize physical limitations. The Short Physical Performance Battery (SPPB) provides information about lower-extremity function through balance, gait speed, and repeated chair-standing performance. Research has demonstrated associations between SPPB performance and disability-related outcomes, while pulmonary rehabilitation studies have examined its responsiveness to functional improvement. The SPPB may therefore complement respiratory measures and walking tests when evaluating rehabilitation-related changes (14–17).

Despite increasing evidence regarding IMT, additional comparative data are needed to describe how inspiratory muscle strength, perceived breathlessness, exercise capacity, and physical performance change together over a defined observation period. This question is particularly relevant to older adults with heterogeneous COPD severity and respiratory muscle function.

The present study aimed to compare eight-week changes in maximal inspiratory pressure, dyspnea, six-minute walk distance, and functional performance between older adults with COPD who received inspiratory muscle training and those without recorded IMT exposure. Secondary objectives were to evaluate changes in oxygen saturation and resting heart rate and to describe intervention adherence and recorded adverse events.

MATERIALS AND METHODS

A longitudinal comparative cohort study was conducted at Riphah International University, Lahore, Pakistan, over a six-month study period. The study involved older adults with COPD who were observed at baseline and at an eight-week follow-up assessment. Participants were recruited through purposive sampling. The analytic cohort included 36 individuals with complete paired outcome records, comprising 18 participants exposed to inspiratory muscle training and 18 participants in a comparison cohort without recorded IMT exposure. The design was non-randomized, and comparisons were interpreted within an observational cohort framework, with reference to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) recommendations (18).

Participants were adults aged 62–80 years with recorded COPD diagnoses and baseline respiratory and functional assessments. The dataset included age, anthropometric characteristics, duration of COPD, cumulative smoking exposure, spirometric measurements, GOLD airflow limitation grade, exacerbation history, supplemental oxygen use, and an existing binary classification of reduced inspiratory muscle strength. Fourteen participants in each cohort were classified as having reduced inspiratory muscle strength, while four participants in each cohort were not assigned that classification. Cohort membership was defined by recorded exposure to IMT rather than by inspiratory weakness classification alone.

The IMT cohort underwent an eight-week inspiratory muscle training program. Recorded training intensity ranged from 35% to 45% of maximal inspiratory pressure, with 24 sessions prescribed during the intervention period. Individual records contained the number of sessions completed and percentage adherence. The comparison cohort had no recorded IMT sessions. The exposure variable was coded as 1 for the IMT cohort and 0 for the comparison cohort.

Baseline and follow-up outcome measurements were used to evaluate within-participant changes and differences between the two cohorts.

Maximal inspiratory pressure, expressed in cmH_2O, was used to assess inspiratory muscle strength. It represents the maximum pressure generated during an inspiratory effort against an occluded airway and is an established measure of respiratory muscle performance. Standardization of patient effort, technique, and repeated measurements is important for reproducibility in inspiratory pressure assessment (19,20).

Dyspnea was assessed through the modified Medical Research Council scale and a 0–10 Borg rating. The mMRC scale reflects the functional impact of breathlessness during daily activities, whereas the Borg scale provides a numerical representation of perceived respiratory effort or symptom intensity. Lower follow-up values indicated less reported dyspnea.

Functional exercise capacity was evaluated using the six-minute walk test, with walking distance expressed in meters. The six-minute walk test is an established measure of functional exercise capacity in chronic respiratory disease. Oxygen saturation measurements included resting peripheral oxygen saturation and the lowest recorded saturation during exercise. Resting heart rate was also recorded at both assessments. These measures provided complementary information regarding physiological responses alongside performance outcomes (21,22).

Physical performance was evaluated using the SPPB total score, which ranges from 0 to 12 and summarizes balance, habitual walking speed, and repeated chair-rise performance. Higher scores indicate better physical performance. Only the total SPPB score was used for the present analysis, without reconstructing individual subtest scores (14–17).

The primary analytical comparisons concerned changes in maximal inspiratory pressure, mMRC dyspnea, six-minute walk distance, Borg dyspnea, and SPPB total score. Resting oxygen saturation, exercise oxygen saturation nadir, and resting heart rate were evaluated as additional physiological outcomes.

Data were analyzed using IBM SPSS Statistics version 26.0. Participant-level records were reviewed for completeness, duplicate records, internally consistent anthropometric calculations, and valid paired measurements. Continuous variables were summarized using means and standard deviations, whereas categorical variables were presented as frequencies and percentages. Between-cohort differences in continuous baseline characteristics were evaluated using Welch's independent-samples t-test.

For each participant, the change in an outcome was calculated as the follow-up value minus the baseline value. Between-cohort differences in mean change were estimated using Welch's t-test and presented with 95% confidence intervals. Paired-samples t-tests were used to examine changes within each cohort where the outcome had sufficient variation. Because mMRC and SPPB are ordinal scales, Mann–Whitney U tests were additionally used as nonparametric sensitivity analyses of change-score distributions.

Multivariable linear regression was performed to estimate differences in follow-up outcomes between cohorts. Each model included cohort membership, the baseline value of the corresponding outcome, age, baseline FEV_1 percentage predicted, and cumulative smoking exposure in pack-years. Heteroskedasticity-consistent HC3 standard errors were used to calculate confidence intervals and significance tests. These adjustments were selected to account for important measured baseline differences and established clinical characteristics associated with COPD-related outcomes. Analyses were conducted on the complete paired-outcome dataset.

Exploratory responder analyses identified participants achieving at least a 30-meter improvement in six-minute walk distance, a one-point reduction in mMRC, or a one-point improvement in SPPB. The walking-distance threshold was informed by published estimates of minimally important differences in COPD, although interpretation depends on the population and testing protocol (23,24). Responder proportions were compared using Fisher's exact test.

Statistical significance was evaluated using a two-sided threshold of $p<0.05$. Because several correlated outcomes were evaluated without formal multiplicity correction, secondary comparisons were interpreted as exploratory.

Ethical approval was obtained from Riphah International University, Lahore, Pakistan. Informed consent was obtained from all participants before participation. Individual-level data were analyzed without including personal identifiers in the study dataset.

RESULTS

A total of 36 participants with paired baseline and eight-week assessments were included in the analysis, with 18 participants in each cohort. The mean age was 71.11±5.96 years in the IMT cohort and 68.28±4.96 years in the comparison cohort. Baseline BMI, COPD duration, FEV_1 percentage predicted, and inspiratory muscle strength were broadly comparable between cohorts.

Cumulative smoking exposure was lower in the IMT cohort (27.89±16.53 pack-years) than in the comparison cohort (41.17±15.09 pack-years; p=0.017). Fourteen participants (77.8%) in each cohort had a recorded reduced-MIP classification, and five participants (27.8%) in each cohort used supplemental oxygen.

Table 1. Baseline demographic and clinical characteristics of participants (n=36)

Characteristic	IMT (n=18)	Comparison (n=18)	p
Age, years	71.11±5.96	68.28±4.96	0.131
BMI, kg/m²	27.98±3.17	27.26±3.31	0.509
COPD duration, years	10.89±4.47	11.67±3.91	0.582
Smoking exposure, pack-years	27.89±16.53	41.17±15.09	0.017
FEV_1, L	1.38±0.58	1.25±0.46	0.458
FEV_1, % predicted	53.28±19.37	48.39±18.05	0.439
Exacerbations in previous 12 months	1.56±1.38	2.11±1.45	0.248
MIP, cmH_2O	53.33±13.81	53.72±14.42	0.935
mMRC score	2.44±0.92	2.72±0.89	0.365
6MWD, m	327.11±76.82	306.78±72.25	0.419
SPPB total score	7.17±2.38	6.50±1.98	0.368
Reduced-MIP classification, n (%)	14 (77.8)	14 (77.8)	—
Supplemental oxygen use, n (%)	5 (27.8)	5 (27.8)	—

Values are mean±SD or n (%). Continuous-variable p-values were calculated using Welch's t-test. BMI, body mass index; FEV_1, forced expiratory volume in one second; MIP, maximal inspiratory pressure; mMRC, modified Medical Research Council; 6MWD, six-minute walk distance; SPPB, Short Physical Performance Battery.

Both cohorts demonstrated an increase in maximal inspiratory pressure during follow-up. However, the mean improvement was greater in the IMT cohort (+13.33±1.97 cmH_2O) than in the comparison cohort (+2.06±0.94 cmH_2O). The between-cohort difference in mean change was 11.28 cmH_2O (95% CI 10.22–12.34; p<0.001).

Six-minute walk distance increased from 327.11±76.82 m to 358.89±75.66 m in the IMT cohort, compared with an increase from 306.78±72.25 m to 313.50±71.88 m in the comparison cohort. The mean change was +31.78±3.66 m versus +6.72±1.93 m, producing a between-cohort difference of 25.06 m (95% CI 23.05–27.06; p<0.001).

The IMT cohort also demonstrated reductions in both dyspnea measures. Mean mMRC decreased by 0.67 points, while Borg dyspnea decreased by 1.09 points. The corresponding comparison-cohort scores remained unchanged. Mean SPPB total score increased by 0.67 points in the IMT cohort, whereas no change was recorded in the comparison cohort. The between-cohort differences for mMRC, Borg dyspnea, and SPPB were statistically significant (all p<0.001).

Table 2. Baseline, eight-week follow-up, and between-cohort changes in clinical outcomes

Outcome	IMT baseline → week 8	Comparison baseline → week 8	IMT Δ	Comp. Δ	Difference in Δ (95% CI)	p
MIP (cmH_2O)	53.33±13.81 → 66.67±13.91	53.72±14.42 → 55.78±14.69	+13.33	+2.06	11.28 (10.22 to 12.34)	<0.001
mMRC (0–4)	2.44±0.92 → 1.78±1.22	2.72±0.89 → 2.72±0.89	-0.67	+0.00	-0.67 (-0.91 to -0.43)	<0.001
6MWD (m)	327.11±76.82 → 358.89±75.66	306.78±72.25 → 313.50±71.88	+31.78	+6.72	25.06 (23.05 to 27.06)	<0.001
Borg dyspnea (0–10)	5.58±1.46 → 4.49±1.39	5.97±1.32 → 5.97±1.32	-1.09	+0.00	-1.09 (-1.21 to -0.96)	<0.001
SPPB (0–12)	7.17±2.38 → 7.83±2.48	6.50±1.98 → 6.50±1.98	+0.67	+0.00	0.67 (0.43 to 0.91)	<0.001
Resting SpO_2 (%)	94.33±1.41 → 94.61±1.29	93.78±1.93 → 93.78±1.93	+0.28	+0.00	0.28 (0.05 to 0.51)	0.020
Exercise SpO_2 nadir (%)	85.67±4.17 → 86.94±4.21	84.78±4.82 → 85.33±4.95	+1.28	+0.56	0.72 (0.39 to 1.05)	<0.001
Resting heart rate (bpm)	84.44±5.08 → 82.72±5.00	84.56±5.14 → 83.44±5.54	-1.72	-1.11	-0.61 (-1.12 to -0.10)	0.021

Values are mean±SD. Change (Δ) represents week 8 minus baseline; difference in change represents IMT minus comparison. Confidence intervals and p-values are from Welch's t-test of participant-level change scores. SpO_2, peripheral oxygen saturation; bpm, beats per minute.

After adjustment for baseline outcome values, age, FEV_1 percentage predicted, and smoking pack-years, IMT exposure remained associated with greater follow-up MIP, six-minute walk distance, and SPPB scores and with lower mMRC and Borg dyspnea scores. The between-cohort difference was 11.48 cmH_2O (95% CI 10.19–12.78) for MIP and 26.13 m (95% CI 24.25–28.01) for six-minute walk distance. differences were –0.60 points for mMRC, –1.10 points for Borg dyspnea, and +0.75 points for SPPB. The association with resting oxygen saturation was not statistically significant (p=0.060), although differences in exercise oxygen saturation nadir and resting heart rate remained statistically significant.

Table 3. associations between IMT exposure and eight-week outcomes

Follow-up outcome	Difference	95% CI	p
MIP (cmH_2O)	11.48	10.19 to 12.78	<0.001
mMRC (0–4)	-0.60	-0.92 to -0.29	<0.001
6MWD (m)	26.13	24.25 to 28.01	<0.001
Borg dyspnea (0–10)	-1.10	-1.26 to -0.94	<0.001
SPPB (0–12)	0.75	0.53 to 0.96	<0.001
Resting SpO_2 (%)	0.31	-0.01 to 0.63	0.060
Exercise SpO_2 nadir (%)	0.84	0.40 to 1.29	<0.001
Resting heart rate (bpm)	-0.64	-1.23 to -0.05	0.033

Clinical Response, Adherence, and Adverse Events

Thirteen participants (72.2%) in the IMT cohort achieved a walking-distance improvement of at least 30 m, compared with none in the comparison cohort (Fisher's exact p<0.001). Twelve participants (66.7%) in the IMT cohort had at least a one-point reduction in mMRC, and 12 participants (66.7%) experienced at least a one-point increase in SPPB. Neither change was recorded among comparison-cohort participants (both p<0.001). Among participants receiving IMT, the mean recorded training intensity was 40.28±4.36% of MIP. Participants completed an average of 21.11±1.78 of 24 prescribed sessions, corresponding to mean adherence of 87.97±7.40%. Three adverse events were recorded across the cohorts. The IMT cohort had two events, consisting of transient dizziness during one training session and mild diaphragmatic fatigue requiring adjustment of training load. One comparison-cohort participant experienced exertional oxygen desaturation during the six-minute walk test and recovered with prescribed supplemental oxygen.

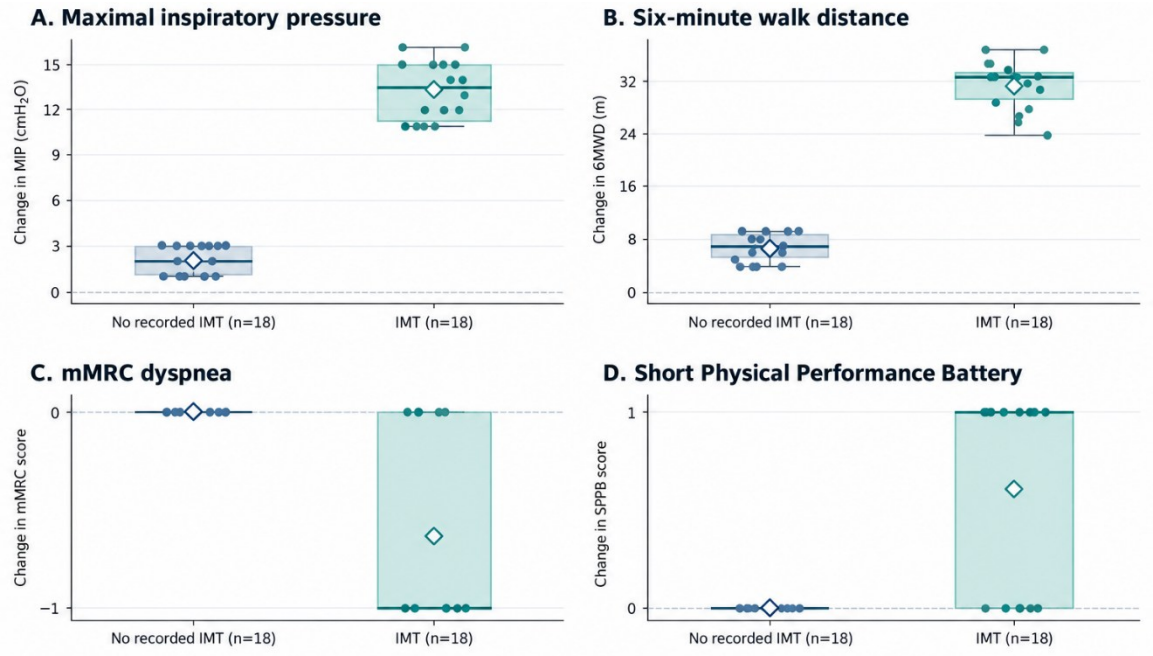


Figure 1. Eight-week within-participant changes in maximal inspiratory pressure, six-minute walk distance, mMRC dyspnea, and SPPB total score. Individual points represent participants; boxes indicate interquartile ranges, lines show medians, and diamonds show means.

The figure illustrates eight-week within-participant changes in maximal inspiratory pressure (MIP), six-minute walk distance (6MWD), modified Medical Research Council (mMRC) dyspnea score, and Short Physical Performance Battery (SPPB) score among older adults with chronic obstructive pulmonary disease (COPD), comparing participants with recorded inspiratory muscle training (IMT; n=18) against those without recorded IMT (n=18). Participants in the IMT group demonstrated substantially greater improvements in inspiratory muscle strength, with MIP increases ranging approximately from 11 to 16 cmH_2O, compared with 1 to 3 cmH_2O in the non-IMT group. Similarly, improvements in 6MWD were considerably larger in the IMT group (approximately 24–36 m) than in the non-IMT group (approximately 4–9 m). Dyspnea scores decreased by one point in most IMT participants, whereas no change was observed in the non-IMT

group. Functional performance also improved among IMT participants, with SPPB scores increasing by one point in several individuals, while remaining unchanged in the comparison group. The boxplots represent interquartile ranges, horizontal lines indicate medians, individual dots represent participant-level changes, and white diamonds indicate mean values. Overall, the findings demonstrate consistently greater improvements in respiratory muscle strength, exercise capacity, dyspnea, and physical performance among participants receiving IMT, suggesting a potential additional benefit of IMT in the rehabilitation of older adults with COPD, although causal effects cannot be established from these descriptive comparisons alone.

DISCUSSION

This longitudinal comparative cohort study identified greater eight-week improvements in inspiratory muscle strength, dyspnea, exercise capacity, and physical performance among older adults with COPD exposed to inspiratory muscle training. The strongest association was observed for maximal inspiratory pressure, while improvements in walking distance and symptom-related outcomes were also evident. These findings remained statistically significant after adjustment for baseline outcome values, age, pulmonary function, and smoking exposure. However, the observational design prevents attributing the differences exclusively to the training intervention.

The increase in maximal inspiratory pressure is consistent with the established physiological rationale for IMT. Repeated inspiratory loading can improve the capacity of respiratory muscles to generate pressure, potentially improving the relationship between inspiratory effort and ventilatory demand. The Cochrane review by Ammous and colleagues and subsequent systematic reviews have demonstrated improvements in respiratory muscle strength following IMT across heterogeneous COPD populations, although clinical outcomes have varied (6–11). The magnitude of MIP change observed in the present cohort is consistent with a training-associated improvement in inspiratory muscle performance, but the absence of randomized allocation limits mechanistic attribution.

The reduction in perceived dyspnea also warrants consideration. Inspiratory muscle dysfunction may contribute to the perceived intensity of breathing effort, particularly during activity. Greater respiratory muscle strength could plausibly reduce the relative effort required for a given ventilatory demand. Han and colleagues reported favorable effects of IMT on dyspnea in their meta-analysis, while Mota and colleagues identified improvement in inspiratory muscle performance across the studies included in their systematic review. Mortari and Manzano additionally highlighted the importance of training load and protocol characteristics when interpreting differences between IMT studies (7,25,26).

Nevertheless, dyspnea is multifactorial and cannot be explained solely by inspiratory muscle strength. Dynamic hyperinflation, ventilatory inefficiency, peripheral muscle deconditioning, cardiovascular limitations, and behavioral responses to breathlessness also influence symptoms. Evidence comparing different breathing exercise approaches further demonstrates variability in the effects of respiratory-focused interventions on clinical outcomes (3,27). The present findings are therefore consistent with a potentially favorable association between IMT exposure and breathlessness but do not establish that improved inspiratory strength mediated the observed symptom changes.

The improvement in six-minute walk distance is clinically relevant because exercise capacity reflects the interaction of respiratory, cardiovascular, and peripheral muscular performance. The mean improvement of 31.78 m in the IMT cohort was near commonly used estimates of a clinically important change for the six-minute walk test in COPD. However, the additional between-cohort change was approximately 25 m, below a frequently cited 30-m threshold. Moreover, the clinical interpretation of walking-distance differences depends on baseline performance, patient characteristics, test methodology, and the specific minimally important difference estimate employed (21,23,24).

The walking-distance findings differ from some larger randomized trials. Charususin and colleagues found that adjunctive IMT improved inspiratory muscle strength but did not produce an additional improvement in six-minute walk distance compared with sham training during pulmonary rehabilitation. Schultz and colleagues similarly reported that greater inspiratory strength did not translate into additional improvements in exercise capacity or dyspnea after a shorter inpatient rehabilitation program (12,13). Differences in observation duration, training intensity, baseline weakness, concurrent rehabilitation, and cohort composition could contribute to the discrepancy. These considerations are important because nonrandomized comparisons may also reflect unmeasured differences in clinical management and patient selection.

Improvement in the SPPB total score suggests that the IMT cohort experienced changes beyond isolated respiratory muscle strength. The SPPB reflects lower-extremity function and overall physical performance rather than respiratory function alone. Previous studies have demonstrated that SPPB scores are associated with functional limitation,

disability-related outcomes, and clinically relevant differences in the physical status of patients with COPD (14–17,30). However, the mean between-cohort improvement of approximately 0.67 points was modest, and the present study did not examine the separate balance, gait-speed, or chair-standing components. Consequently, the observed association cannot establish which aspect of physical performance changed most.

The relatively small changes in oxygen saturation and heart rate require a more cautious interpretation. Although exercise oxygen saturation nadir increased more in the IMT cohort, the absolute between-cohort difference was less than one percentage point. The association with resting oxygen saturation was not statistically significant. Oxygen saturation during exertion reflects several interacting physiological processes, including ventilation-perfusion relationships, diffusion abnormalities, exercise intensity, and supplemental oxygen use. Previous COPD research has demonstrated the importance of exercise-related oxygen desaturation, while studies examining diaphragmatic function and inspiratory pressure have emphasized that respiratory muscle measurements represent only one component of the overall respiratory assessment (22,28).

The baseline difference in cumulative smoking exposure was an important feature of cohort comparability. Although the measured baseline values of MIP, six-minute walk distance, and several functional outcomes were broadly similar, cumulative smoking exposure was greater in the comparison cohort. Smoking exposure may be associated with disease severity, symptom burden, and extrapulmonary dysfunction. Adjustment for pack-years and pulmonary function was therefore appropriate. The persistence of the principal associations after adjustment strengthens the descriptive consistency of the findings, but statistical adjustment cannot eliminate residual confounding or selection bias.

Contemporary COPD guidance emphasizes individualization of management according to symptoms, exacerbation risk, pulmonary function, comorbidity, and functional status (1,2,29). The present findings suggest that inspiratory muscle strength, exercise capacity, and physical performance may provide complementary information when monitoring older adults receiving respiratory rehabilitation. They do not, however, establish that all patients with COPD would obtain additional functional benefits from IMT.

Several methodological limitations should be considered. The study included only 36 participants from a single institutional setting, which limits statistical precision in broader clinical populations and restricts generalizability. Purposive sampling and nonrandomized cohort membership introduce potential selection bias. Although regression adjustment accounted for several measured baseline characteristics, important factors such as comorbidity burden, medication changes, concurrent rehabilitation, activity levels, nutritional status, and variations in usual clinical care were not available for adjustment.

Additional limitations include the relatively short eight-week follow-up, the use of several correlated outcomes without multiplicity correction, and the absence of detailed information about individual IMT session duration, progression, and supervision. The binary reduced-MIP classification included participants with and without recorded inspiratory weakness in both cohorts, limiting conclusions specifically about patients with demonstrable respiratory muscle weakness. The precision of several estimated changes should also be interpreted in the context of the small sample and the observed outcome distributions.

Despite these limitations, the availability of complete paired measurements across respiratory, symptomatic, functional, and physiological domains permitted detailed longitudinal analysis. The inclusion of change-score comparisons, baseline- estimates, and ordinal-outcome sensitivity analyses provided complementary assessments of the observed associations.

Future studies should recruit larger and more diverse COPD populations, document concurrent clinical care, use standardized IMT protocols, and evaluate longer-term clinical outcomes. Randomized comparisons would be particularly valuable for separating the independent contribution of IMT from changes associated with usual rehabilitation and other aspects of clinical management.

CONCLUSION

In this longitudinal comparative cohort of older adults with COPD, inspiratory muscle training exposure was associated with greater improvements in maximal inspiratory pressure, dyspnea, six-minute walk distance, and physical performance over eight weeks compared with a cohort without recorded IMT exposure. The associations persisted after adjustment for baseline outcome values, age, pulmonary function, and smoking exposure. These findings support

further investigation of IMT as a component of individualized COPD rehabilitation, while larger controlled studies are needed to determine its independent clinical benefit.

DECLARATIONS

Authors' Contributions:	Concept: HZ; Design: HZ, AJ; Data Collection: AJ, MF; Analysis: HZ, MF; Drafting: HZ, AJ, MF.
Ethical Approval:	The institution responsible for ethical review was Riphah International University, Lahore, Pakistan
Informed Consent:	Written informed consent was obtained from all participants before enrolment.
Conflict of Interest:	The authors declare no conflict of interest.
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Data Availability:	De-identified data may be available from the corresponding author on request, subject to participant consent and institutional confidentiality requirements.
Acknowledgments:	None.
AI Declaration:	Generative AI tools were used solely for language and grammatical refinement. The authors verified the final manuscript and remain fully responsible for its accuracy, integrity, and scientific content.

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