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Effect of Virtual Reality-Based Training on Pulmonary Functions and Quality of Life in Patients with COPD

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ABSTRACT

Background: Chronic Obstructive Pulmonary Disease (COPD) is a frequent cause for death worldwide. It is identified by dyspnea, cough, increased sputum, and exhaustion, brought on by a decrease in physical activity, sleep issues, social isolation, anxiety, and despair. Virtual reality (VR) games are suggested as an alternate or supplemental activity to traditional pulmonary rehabilitation (PR) programs, which aid in illness management by enhancing patients' functional ability and quality of life (QoL).

Objectives: This study aimed to determine the efficacy of combining VR with a standard PR program in COPD patients.

Materials and subjects: 60 male and female patients with COPD with a mean age of 57.75±1.695 years were recruited for a randomized controlled trial (RCT) from August 2024 to March 2025. They were distributed into 2 groups: Group A received a VR intervention with the ordinary PR program, and group B received PR only for 10 weeks.

Results: VR enhances PR outcomes. While both groups benefited from PR, group A (with VR) showed slightly better improvements in 6MWD, HR, and oxygenation, suggesting that VR can enhance engagement and efficiency of pulmonary rehabilitation. Oxygenation and exercise capacity remain impaired, despite improvements, in COPD patients, highlighting the chronic nature of COPD and the need for continuous rehabilitation efforts. Significant reductions in dyspnea and fatigue scores post-PR demonstrate the impact of the PR program in enhancing patient QoL. While exercise capacity improved, lung function parameters (FEV1, FVC) showed minimal change, indicating that PR mainly improved functional capacity rather than reversing lung damage. Overall, the two groups indicated significant enhancement in 6MWD, oxygen saturation (SpO_2), heart rate (HR), and dyspnea and fatigue symptoms after PR. However, Group B exhibited slightly greater improvements in 6MWD and SpO_2, suggesting a potential advantage in their response to rehabilitation. **Conclusion:** As VR rehabilitation programs securely allow for individualized rehabilitation and the capacity to customize exercise regimens to patients' demands, they may improve adherence and participation among COPD patients and improve the efficacy of PR.

Keywords: COPD, Virtual reality, Pulmonary rehabilitation, Exercise capacity.

INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is characterized by dyspnea, cough, increased sputum, and exhaustion, which caused a fatality of 3.23 million worldwide in 2019. Consequently, common complications include decreased physical activity, sleep issues, social isolation, nervousness, and depression, they result in a significant financial strain that has a major effect on healthcare systems worldwide, with yearly treatment expenses of over $2.1 trillion [1, 2]. The annual costs were around £1.9 billion; 140,000 hospitalizations and one million bed days were reported in the UK [3]. The diminished exercise capacity in COPD patients is directly correlated with impaired cardiopulmonary function, but a proper exercise regimen could enhance the cardiopulmonary functions and exercise tolerance, reducing the hazards of hospitalization and overall causes of death [4].

Pulmonary rehabilitation (PR) programs should involve a variety of health care professionals (HCPs) to address the various facets of patient training. These programs could greatly enhance exercise tolerance, quality of life (QoL) and dyspnea manifestations, while lowering anxiety and despair (GOLD, 2023). Furthermore, following an active lifestyle and regular exercise can preserve the advantages of traditional PR [5]. However, patient acceptance of PR is limited, and rates of completion are minimal, due to difficulties joining classes due to transportation issues, exhaustion, lack of drive, interruptions of daily routines, quality of conversations with medical professionals, depression, disease burden and low awareness and disbelief in rehabilitation outcomes [6, 7]. To completely alter the sedentary behavior of COPD patients, standard PR may need to incorporate gaming elements into rehabilitation, which would bring enjoyment, joy, socialization, and a competitive spirit [8]. Innovative digital technology presents special chances to execute PR programs at home that are specified to the individual requirements of each patient, increase uptake and offer precise data on the patients' compliance [9]. According to **Colombo *et al.*** [10], VR refers to a 3-D computer model of reality that may or may not be real. With VR, users can move about while getting multimodal stimulation that aims to create the impression that they are in a different location. They can also interact with the environment to create feelings of immersion and effort, which could provide exercise at home. By increasing access to pulmonary rehabilitation, the VR-PR enhances productivity and improves the health of patients with long-term respiratory conditions [7, 11]. Immersion VR has been shown to boost exercise frequency and satisfaction. However, exertion

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perceptions are equivalent or lower, and immersive virtual reality was demonstrated to improve exercise performance, frequency of physical activity, and satisfaction relative to non-VR situations [12]. Highly immersive VR environments can facilitate both exercise engagement and enjoyment. Since VR is additionally used to regulate sensory feedback, specialized environments may be able to alter exercise outcomes, ratings of perceived effort (RPE), and dyspnea [11]. Even though using games as part of a training program might be beneficial, a well-designed program should be customized to the patients' requirements and skills [8]. One of the crucial ways to lessen exercise intolerance and provide these people a better, more active lifestyle is to increase physical activity by improving exercise capacity. Furthermore, VR was discovered to improve emotional states and moods [13].

PATIENT AND METHODS

60 patients with COPD, ages 50 to 60, of both sexes, were admitted to the Chest Diseases Department Outpatient Clinic at Najran Hospital and King Khaled Medical City in the Kingdom of Saudi Arabia (KSA) between July 2024 and March 2025 as part of this RCT. The participants were distributed into two groups: Group (A), the study group that did PR+VR and group (B), the control group that performed PR alone. Prior to being included in the study, each subject provided written informed consent.

Inclusion criteria: 1) Patients of both genders. 2) Who meet the criteria for COPD as stated by the most recent Global Initiative on Obstructive Lung Disease [2]. 3) Who have been diagnosed with COPD based on a comprehensive medical history and physical examination, a history of smoking cigarettes or shisha, exposure to interior biomass fuel and spirometric measures demonstrating irreversible airflow blockage. 4) Classification 2 and 3 spirometric stages. 5) Aged between 50 and 60; and 6) with a BMI between 25 and 34.9 kg/m².

Exclusion criteria: Patients who did not sign their consent, who had acute respiratory failure and other respiratory inflammatory diseases, who had pneumonia, tuberculosis, or acute exacerbation, who had insulin-dependent diabetes mellitus, who had undergone chest or cardiac surgeries, who had cardiac failure class (NYHA III or IV), who were less than six months after myocardial infarction, all of which can contribute to weight loss and also those who had advanced uncontrolled hypertension, neurological, muscular, and joint disorders that hindered their ability to perform pulmonary rehabilitation exercises.

Sample size (Figure 1): According to **Jin *et al.*** [14], the F-test MANOVA within and between interaction effects was applied to compute the sample size, which had 80% power at $\alpha = 0.05$ level, two measures for two groups, and an effect size of 0.4. The minimal appropriate sample size was 52, with 8 (15%) participants added as dropouts, for a total sample size of 60 subjects (30 per group). The G*Power software (version 3.0.10) was utilized to compute the sample size, as follows:

$$n = \frac{N(z262)}{Ne2+(z262)} = 6 = \frac{600((1.196)2(.53)2)}{600(0.05)2+(1.96)2(0.53)2}$$

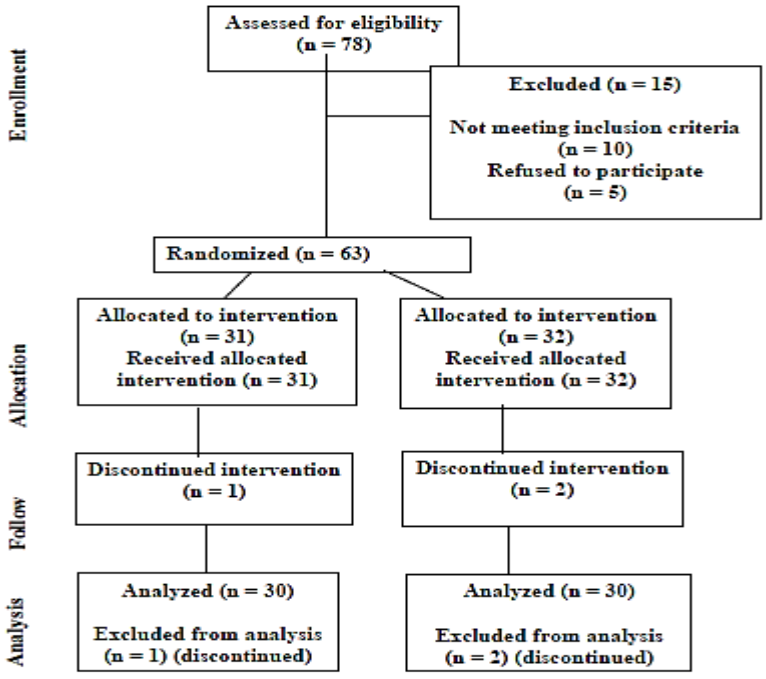

Figure (1): CONSORT diagram presents the participants flow during every stage of a randomized trial.

n= sample size; Z = the standard value corresponding to the 95% confidence level, which is 1.96; σ = standard deviation = $\sum(s-\mu)^2/n]\sqrt{}$; e = sampling error 0.05.

Participants were randomly allocated into 2 groups: The study group (group A) and the control group (group B). Group A received the PR program with virtual reality, and Group B (the control group) underwent the PR program alone. At baseline and following the rehabilitation program, all patients had their ventilatory function test, pulse, oxygen saturation, 6MWD, dyspnea rating utilizing the BORG scale and health-related quality of life measured utilizing the St. George's Respiratory Questionnaire specific version for IPF (SGRQ-I).

Assessment procedure: All assessments were conducted prior to and after the PR program: **1.** BMI (weight in kilograms divided by height in meters squared). FFM was evaluated using a Body Fat Analyzer BT 905 (BIA BT-905) (Skylark Device Co., Taipei, Taiwan). FFMI (FFM in kilograms divided by height in meters squared).
2. St. George Respiratory Questionnaire (SGRQ): To determine the health impairment in COPD patients, the modified SGRQ (SGRQ-C) consists of part I for the symptom score and part II for the activity and impact scores and an overall score is also produced.
3. Exercise capacity assessment by the 6MWT.
4. COPD symptoms assessment by the Modified British Medical Research Council Questionnaire (mMRC) [(15)].
5. The combined assessment test (CAT) score, an eight-item test, was utilized to determine the health status impairment in COPD [(16)].
6. Arterial blood gas measurements where PO_2, PCO_2, and SpO_2 were measured [(17)].
7. Evaluation of functional severity by spirometry [(18)] was done by Master Screen PFT No. 781040, where forced expiratory volume in the first second (FEV1), forced vital capacity (FVC), and FEV1–FVC were evaluated. Moderate and severe (Stages II and III; 30-80% FEV1 predicted)
8. Berg balance scale (BBS): to evaluate the elderly person's balance using a series of pre-planned exercises. A five-point ordinal scale (zero representing the lowest degree of function and four the most) was used for each of the list's fourteen items. A score of less than 45 indicates that people are more vulnerable to falling, a score of less than 49 denotes that people are in danger of falling, and a score of 56 denotes functional balance.

Interventions

Pulmonary rehabilitation program (PRP): The PRP comprises a 2-hour session twice a week for 10 weeks [(14)]. Typical groups had six to ten people, and classes were held in the hospital halls and health centers. Patients performed respiratory muscle training, endurance and strengthening exercises. Exercise was done on a treadmill. Additionally, they followed the ATS recommendations for PR by performing stretching exercises and simple floor exercises with and without weights. 1-Routine physical therapy program for PR training: Pursed-lip breathing, abdominal breathing, and abdominal resistance [(19)] were used for both groups (A & B).

1. Conventional therapy [(19)]:

a. Pursed-lip breathing: The patients were told to sit comfortably, take a forced inhalation through their nostrils for two to three seconds, and then hold it for another two seconds. The patients were then instructed to pucker their lips and exhale for four to five seconds through their pursed lips. The entire procedure was performed for 15 to 20 minutes per day.
b. Abdominal breathing: The patients were told to keep their knees bent and their hands resting on their upper abdomens as they maintained a half-lying position. The hands on the abdomen stayed stationary and went up and down in tandem with each breath. Additionally, the entire procedure was performed every day for 15 to 20 minutes.
c. Abdominal resistance training: The patients were placed in a supine position, and for five minutes at a time, a sandbag on their abdomen moved up and down in response to inhalation and expiration. The sandbag weight was increased suitably based on the patient's capability. An hour prior to and following the abdominal resistance training, the patients got their usual low-flow oxygen treatment.
a) Personalized endurance exercise training depending on 60–80% of 6MWT speed reached.
b) Strengthening exercises for large muscular groups in the upper and lower limbs utilizing Theraband and weights (three sets and eight repetitions each with resting in-between of about 1.30 min) where resistance was determined relying on 50–75% of 1 RM, and repeated at the 4th week.
c) Daily breathing exercises such as pursed-lip breathing, diaphragmatic breathing and stretching exercises for main respiratory muscles.

Traditional pulmonary rehabilitation (Groups A and B): They underwent traditional PR without VR. Sessions lasted 2 hours, twice weekly for 10 weeks, plus the same home breathing exercise component. Along with the aforementioned PR program, both groups received 30 minutes of daily home-program breathing exercises.

2. VR-based pulmonary rehabilitation program (group A only).

Study design overview: Group A underwent a 10-week virtual reality pulmonary rehabilitation program using VR-PR. Participants in the trial received a VR headset (Pico Interactive, Pico, Goblin) developed by Concept Health Technologies (CHT). The PR in the VR app was embedded in the headset, and a small probe (Nonin 3150) was worn during exercise to measure the patient's HR and oxygen saturation levels (SpO_2). During the rehabilitation session, the patients' SpO_2 and HR during exercises were measured using pulse oximeter data

remotely. The VR system allowed patients to complete rehabilitation exercises and educational content remotely, while real-time data (HR and SpO_2) were monitored through a web-based dashboard.

VR equipment used

- Pico Goblin Headset (by Pico Interactive), with a built-in VR app.
- Nonin 3150 pulse oximeter probe for real-time HR and SpO_2 tracking. Heart rate was monitored during the training to make sure patients didn't surpass their age-predicted MHR (208–0.7 x age**)** [(20)].
- Kinect® Adventures (Microsoft Game Studios, Washington, US) used as an intensity-controlled exercise platform with interactive mini-games.
- HTC Vive system with motion-tracking sensors for immersive lower-limb training using an avatar.

VR rehabilitation content

Modules (Total: 8):

- Educational Videos: High-quality visual and audio effects to promote understanding and retention.
- Exercise Modules (5–7): Instructor-led seated and standing exercises via a 3D avatar.
- Interactive Gaming: Games target agility, coordination, endurance, dynamic balance, and coordination while preventing obstacles and strengthening the flexibility of the lower body and upper extremities [(21)].
- Performance Monitoring: Real-time visual feedback in the VR display for HR and SpO_2.

Schedule: Daily sessions (20 minutes/day). Biweekly interactive VR therapy (2 hours/session, twice per week). Daily home breathing exercises (30 minutes) for both groups [(22)].

Ethical consideration: The study protocol was accepted by Cairo University Faculty of Physical Therapy Ethics Committee (NO: PT.REC/012/006006--------- Egypt). Before the study's start, all the participants were made aware of the study objectives and methodology. Confidentiality was assured, and all patients signed a consent form. The Helsinki Declaration was followed throughout the study.

Data collection: Data were gathered from all the study participants involving age, weight, height (BMI), smoking history, use of walking aids, pulmonary function parameters and balance tests (BBS, BES Test, and 6MWT) prior to and after training.

Statistical analysis

Data analysis was done utilizing SPSS version 25.0 for Windows (SPSS Inc., Chicago, IL, USA). The mean ± standard deviation (SD) for normally distributed data and the median with interquartile range (IQR) for non-normally distributed data were employed to display the quantitative variables. Qualitative parameters were presented as percentages and absolute counts. The Shapiro–Wilk test was applied to check the normality of continuous data. Normally distributed data were examined by the Independent Samples t-test for between-group comparisons, whilst non-normally distributed data were examined by the Mann–Whitney U test. The chi-square test was implemented to compare categorical data when anticipated frequencies were small. Both the Wilcoxon signed-rank test for non-normally distributed parameters and the paired t-test for normally distributed data were employed for within-group comparisons. One-way Analysis of Variance (ANOVA) was utilized for comparing means across more than two groups when data met normality assumption and homogeneity of variance. To determine the association between baseline characteristics and outcome variables such as the change in total SGRQ score (ΔSGRQ) or six-minute walk test distance (Δ6MWT), *Spearman's rank correlation* was utilized for non-parametric data and *Pearson's correlation* for parametric data. In addition, *MANOVA* was employed to assess the interaction impacts of time and treatment groups on key outcome variables (e.g., 6MWT, BBS). For all analyses, statistical significance level was set at $p < 0.05$.

RESULTS

The baseline characteristics of COPD patients pre-treatment were displayed in table (1). 60 patients were involved in the study and grouped into two groups. Each group contained 30 patients. COPD patients' demographic and clinical data (n=60) were compared. The mean age of COPD patients was 57.75±1.695 years. The gender distribution among COPD patients was 33 males and 27 females. Anthropometric measurements showed no significant variations across groups. The mean height of COPD patients was 165.63±4.09 cm. Body mass in COPD patients averaged 78.43±8.4 kg, and BMI values were 28.39±2.85 kg/m². Body composition analysis revealed that fat-free mass (FFM) was in COPD patients (59.65±3.96 kg). However, the fat-free mass index (FFMI) was 21.09±1.15 kg/m².

Table (1): Participants' characteristics of both groups

Parameter	Group A (n=30)	Group B (n=30)
Age (years)	56.57 ± 2.45	56.7 ± 2.68
Sex (M/F)	18/12	15/15
Height (cm)	165.1 ± 4.25	166.2 ±3.78
Body mass (kg)	78.4 ± 8.3	78.06 ± 8.17
BMI (kg/m²)	28.78 ± 2.9[a]	28.3 ± 2.65[b]
FFM	59.65±3.96[a]	58.7±3.21[b]
FFMI	21.89±1.1[a]	21.29±1.21[a]
HR (b/min)	82.5 ± 4.1[a]	82.7 ± 3.98[b]
SpO_2 (%)	92.33 ± 1.87[a]	92± 1.48[b]
FEV1 (L)	1.17 ± 0.31[a]	1.19± 0.26[b]
FEV1(% Pred)	46.8 ± 5.86[a]	48.87±8.02[b]
FVC (L)	2.25 ± 0.29[a]	2.39 ± 0.74[b]
FEV1/FVC (%)	52.6 ± 14.75[a]	52.65±15.89[b]
MRC	2.43 ± 0.55[a]	2.37 ± 0.49[b]
Current smoker	3 (10%)	1 (5%)
Smoking the past	15 (50%)	14 (46.67%)
Never smoker	12 (40%)	15 (50%)
GOLD St. I	0	0
GOLD St. II	18	17
GOLD St. III	12	13
GOLD St. IV	0	0
6MWD (m)	267.03±46.16[a]	270.5±41.18[b]
mMRC	2.44±0.56[a]	2.37±0.49[b]

M: Male, F: female, cm: Centimeters, kg: Kilograms, BMI: Body Mass Index, m2: squared Meters, HR: Heart Rate, SPO2: oxygen saturation, FEV1(L): Forced Expiratory Volume in 1 second (Liter), Pred.: predicted, FVC: Forced Vital Capacity. MRC: Medical Research Council Dyspnea scale, 6MWD: Six Minute Walk Distance, m: Meters; GOLD St.: standard; Mean ± SD are indicated for all columns unless stated. Similar superscript [a]: significant difference. mMRC, modified-Medical Research Council. *Mann–Whitney U-test.

The comparison of functional and physiological parameters between the VR and the control group before and after PR (Table 2) demonstrated significant improvements in exercise capacity after the interventions were noticed in both groups; however, the enhancement was more pronounced in Group A (the VR group).

The six-minute walking distance (6MWD) was significantly increased from 260.8 ± 28.8 m to 400.0 ± 25.0 m in the VR group compared with 261.03 ± 32.2 m to 390.5 ± 25.38 m in the PR only-group. Similarly, walking speed improved significantly in the study group (4.5 ± 0.9 to 5.2 ± 0.8 km/h), indicating superior functional performance with VR-assisted training. Post-exercise oxygen saturation (SpO_2) increased markedly in Group A (91.4 ± 2.3 to 95.2 ± 2.0 %), with a minor desaturation during exertion (ΔSpO_2 = –1.0 ± 2.0 %), while the control group showed a less favorable change.

Both groups showed significant reduction in the post-exercise heart rate (HR) and ΔHR values, with greater reductions in Group A (ΔHR = 18.4 ± 11.0 to 5.0 ± 8.0 bpm), reflecting improved cardiovascular efficiency and exercise tolerance. Also, the dyspnea score declined more substantially in the study group (3.19 ± 2.0 to 2.0 ± 1.8), indicating better symptom control.

Table (2): Comparisons between both groups before and after PR

Parameter	Study group (Group A)		Control group (Group B)	
	Before PR+VR	After PR+VR	Before PR	After PR
6MWD (m)	260.8±28.8	400.0±25.0[a]*	261.03±32.2	390.5±25.38
Walking Speed(km/h)	4.5 ±0.9	5.2 ±0.8[a]*	4.5 ±0.9	4.8 ±0.9
Post SpO_2 (%)	91.4±2.3[a]	95.2±2.0a*	91.7±2.2[a]	93.7±2.8
Δ SpO_2 (%)	-1.52±3.8ab‡	-1.0±2.0‡*	-1.49±3.9ab‡	-2.4±3.6‡
Post HR (bpm)	100.9±6.2	95.0±5.0a*	101.3±5.9	95±5.7
Δ HR (bpm)	18.4±11.0ab‡	5.0±8.0a‡*	18.9±11.0ab‡	7.87±10.0a‡
Δ Dyspnea (score)	3.19±2.0‡	2.0±1.8‡*	3.39±2.0‡	3.08±2.2‡

*****Significant differences within-group change; **#:** Significant differences between-group comparisons.

Table (3) showed that both the VR group (Group A) and the control group (Group B) demonstrated significant improvements in functional performance following rehabilitation. The 6MWD increased markedly in both groups, from 260.8 ± 28.8 m to 368.7 ± 34.2 m in the VR group and from 261.03 ± 32.2 m to 390.5 ± 25.4 m in the control group, indicating enhanced exercise capacity after PR.

Walking speed also improved significantly in both groups (from 4.5 ± 0.9 to 4.8 ± 0.9 km/h), reflecting better endurance and mobility efficiency.

Pre-exercise SpO_2 increased significantly after rehabilitation, reaching 94.5 ± 2.8% in the VR group and 95.6 ± 2.13% in the control group, compared to post-exercise SpO_2 improvement, suggesting enhanced oxygen utilization during exertion. The change in SpO_2 (ΔSpO_2) values became less negative after PRP in both groups, indicating a reduction in oxygen desaturation during walking. Heart rate responses also indicated favorable adaptation; pre- and post-exercise HR values decreased after training, and the ΔHR reduction (from approximately 18 bpm to around 9–8 bpm) reflects improved cardiovascular efficiency and recovery capacity.

Perceptual responses to exercise, including dyspnea and fatigue, showed similar patterns in both groups. Although post-exercise dyspnea and fatigue scores increased as expected due to exertion, the Δ values remained stable, indicating that the improved physical performance was achieved without additional subjective discomfort. The GRAIL technology combines treadmill training, motion capture, and virtual reality to provide effective improvement in gait and endurance during PR.

Table (3): GRAIL 6 min. walk distance (6-MWD) before and after PRP

Parameter	Before PRP		After PRP	
	Group A	**Group B**	**Group A**	**Group B**
6MWD, m	260.8±28.8	261.03±32.2	368.7±34.2^{a*}	390.5±25.4^{a*}
Walking speed, km/h	4.5 ±0.9	4.5 ±0.9	4.8 ±0.9^{a*}	4.8 ±0.9^{a*}
Pre SpO2, %	92±1.48^{ab}	92.33±1.87^{ab}	94.5±2.8^{a*}	95.6±2.13^{a*}
Post SpO2, %	91.4±2.3^{a}	91.7±2.2^{a}	93.8±2.6^{a}	93.7±2.8^{a}
Δ SpO2, %	-1.52±3.8^{ab‡}	-1.49±3.9^{ab‡}	-2.3±3.3‡*	-2.4±3.6‡*
Pre HR, bpm	82.5±4.2^{b}	82.4±14.9^{b}	78.73± 3.6	77.87± 3.02
Post HR, bpm	100.9±6.2	101.3±5.9	98.5± 7.2	95± 5.7
Δ HR, bpm	18.4±11.0^{ab‡}	18.9±11.0^{ab‡}	9.77±10.0^{a‡}	7.87±10.0^{a‡}
Pre-dyspnea	1.29±1.3^{a}	1.32±1.1^{a}	1.4±1.32^{a}	1.52±1.4^{a}
Post-dyspnea	4.5±2.0^{a}	4.61±2.2^{a}	4.6±2.3^{a}	4.6±2.3^{a}
Δ dyspnea score	3.19±2.0‡	3.39±2.0‡	3.2±2.2‡	3.08±2.2‡
Pre fatigue	1.51±1.5^{a}	1.54±1.7^{a}	1.5±1.3^{a}	1.5±1.3^{a}
Post fatigue	4.32±2.4^{a}	4.34±2.4^{a}	4.6±2.3^{a}	4.62±2.3^{a}
Δ fatigue, score	2.81±2.3‡	2.8±2.3‡	3.1±2.1‡	3.12±2.1‡

a: Significant change compared to Group A (1), b: Significant change compared to Group B (1), ‡: Indicates the change (Δ) value (post-pre values), *: Significant difference within the group over time (pre vs. post comparisons). GRAIL: Gait Real-time Analysis Interactive Laboratory, GRAIL is a package for gait analysis and training using a treadmill, motion capture, VR, and camera.

The best 6MWT performance before and after PR in both groups was compared during the overground and GRAIL conditions table (4). Both groups demonstrated significant improvements following PR, with greater gains observed under the GRAIL condition. The 6MWD increased in both groups, from 449.7 ± 89.3 m to 471 ± 88 m in the VR group and from 453 ± 85 m to 476.4 ± 86.8 m in the control group, indicating enhanced functional capacity. Walking speed was higher during the GRAIL test compared with overground performance, reflecting improved gait control and endurance ($p < 0.001$). Also, SpO_2 parameters were significantly improved in both groups, particularly under the GRAIL condition, where post-exercise SpO_2 increased and desaturation (ΔSpO_2) were markedly reduced ($p < 0.001$). Heart rate responses demonstrated better cardiovascular adaptation, with lower post-exercise HR and smaller ΔHR values under GRAIL compared with overground testing ($p < 0.001$). Symptom scores for dyspnea and fatigue followed a similar pattern: both were lower under GRAIL conditions, and the changes (Δ values) were significantly reduced compared with overground performance ($p < 0.05$). This indicated that patients experienced less apparent exertion and fatigue while achieving superior walking performance with GRAIL training.

Table (4): Best 6MWT in the overground and GRAIL condition before and after PR in both groups

	Overground 6MWT (1)		**GRAIL 6MWT (2)**		T	*p*
Parameter	**Group A**	**Group B**	**Group A**	**Group B**		
6MWD, m	449.7±89.3	453±85	471±88[a*]	476.4±86.8[a*]		
Walking speed, km/h	5.1 ±0.6	6.7 ±0.7	4.8 ±0.8[a]	6.9 ±0.7	<0.001[a]	<0.001
Pre SpO2, %	94.9±2.1[a]	96.6±1.4[a]	95.2±1.5[a]	97.2±1.0[a]	0.36[a]	0.01[a]
Post SpO2, %	87.8±6.7[a]	94.5±3.4[a]	93.1±4.7[a]	97.2±1.2[a]	<0.001[a]	<0.001[a]
Δ SpO2, %	-7.1±5.9[a‡]	-1.2±3.4[a]	-2.0±4.4[a‡]	0.0±0.9[a]	<0.001[a]	0.02[a]
Pre HR, bpm	85.0±13.6	72.3±11.9	83.5± 14.5	67.1± 11.9	0.3	0.001
Post HR, bpm	114.5±15.8	119.6±18.6	102± 18.3	99.7± 21.1	<0.001	<0.001
Δ HR, bpm	29.5±11.8[a‡]	47.3±15.7[a]	19.1±10.5[‡]	32.6±15.1[‡]	<0.001[a]	<0.001[a]
Pre dyspnea, score	1.4±1.2[a]	0.1±0.3[a]	1.3±1.3[a]	0.2±0.3[a]	0.51[a]	0.02[a]
Post dyspnea, score	5.4±2.2[a]	1.2±1.0[a]	4.8±2.3[a]	1.2±1.0[a]	0.01[a]	0.95[a]
Δ dyspnea, score	4.0±2.3[a‡]	1.1±0.9[a]	3.4±2.2[‡]	1.0±0.9[a‡]	0.01[a]	0.54[a]
Pre fatigue, score	1.5±1.3[a]	0.2±0.3[a]	1.5±1.4[a]	0.3±0.6[a]	067[a]	0.12[a]
Post fatigue, score	5.3±2.3[a]	1.2±1.1[a]	4.6±2.4[a]	1.3±1.1[a]	0.01[a]	0.57[a]
Δ fatigue, score	3.7±2.2[a‡]	1.1±1.0[a‡]	3.2±2.1[‡]	1.1±1.0[‡]	0.02[a]	0.77[a]

COPD: chronic obstructive pulmonary disease; 6MWT: 6-minute walk test; 6MWD: 6-minute walk distance; SpO2: pulse oxygen saturation; HR: heart rate; bpm, beats per minute; ‡: Significant change across pre and post symptoms per trail; *: Significant change across pre and post GRAIL 6MWT within each group; a: Non-parametric test was used

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Table (5) showed the comparison of spirometric parameters and functional outcomes between the VR group and the control group before and after the interventions, as well as post-treatment changes in respiratory and exercise performance measures. At baseline, both groups showed non-statistically significant differences concerning spirometric indices. The distribution of patients with FEV_1 <50% and ≥50% was also comparable between the two groups (p = 0.556), confirming homogeneity in baseline pulmonary function. The mean FEV_1% predicted was 60.35 ± 12.69 in the VR group and 59.12 ± 12.24 in the control group (p = 0.500), and the mean FEV_1/FVC ratio was 60.80 ± 7.71 and 60.10 ± 7.01, respectively (p = 0.672). After PR, both groups demonstrated improvement in dyspnea, walking distance, and lung function parameters, though the magnitude of change was greater in the VR group. The reduction in mMRC dyspnea score was significantly higher in the VR group (ΔmMRC = −0.50 ± 0.50) compared with the control group (ΔmMRC = −0.25 ± 0.43; p = 0.022). Similarly, the VR group showed a higher improvement in mMRC category (50% vs. 23.33%; p = 0.021). Also, the functional exercise capacity, indicated by the increase in Δ6MWD, was improved more in the VR group (54.87 ± 31.06 m) compared to the control group (36.62 ± 23.49 m), demonstrating a superior functional gain following the intervention. Although post-treatment improvements in FEV_1 and FEV_1/FVC ratios were observed in both groups, these changes did not reach statistical significance (p > 0.05).

Table (5): Comparison across both groups regarding before treatment spirometric function tests

	Group A (N=30)	Group B (N=30)	t	P
FEV1% predicted (Mean ±SD)	60.35±12.69	59.12±12.24	−0.674*	0.500 (NS)
<50% [n (%)]	8 (20)	6 (15)	0.346†	0.556 (NS)
≥50% [n (%)]	32 (80)	34 (85)		
FEV1/FVC (Mean ±SD)	60.80±7.71	60.10±7.01	0.425‡	0.672 (NS)
post-treatment change in modified-Medical Research Council, 6 MWD, and spirometric parameters.				
ΔmMRC (mean±SD)	−0.50±0.50	−0.25±0.43	−2.295*	0.022 (Sg)
No change [n (%)]	15 (50)	23 (76.67)	5.333†	0.021 (Sg)
Decrease [n (%)]	15 (50)	7 (23.33)		
Δ6MWD (mean ±SD)	54.87±31.06	36.62±23.49	−5.189*	
ΔFEV1	167±0.76	102±0.73		<0.351 (NS)
ΔFEV1/ FVC	1.70±0.67	1.05±0.78		<0.761 (NS)

FEV1, forced expiratory volume in the first second; FVC, forced vital capacity. *Mann–Whitney U-test. †χ2-test. ‡ Independent samples Student's t-test. 6MWD, 6 min walk distance; mMRC, modified-Medical Research Council; Sg: significant; *Mann–Whitney U-test. † χ2 –test.

Table (6) shows the comparison of the Saint George's Respiratory Questionnaire (SGRQ) assessment results in the two groups before and after PR. Both groups demonstrated significant improvements in all SGRQ domains, symptoms, activity, impact, and total scores, following treatment, indicating better perceived respiratory health and quality of life. In the VR group, the mean symptom score decreased from 53.5 ± 18.3 to 41.63 ± 16.88 ($p = 4.4E{-}19$), while the activity score improved from 57.16 ± 25.1 to 45.62 ± 23.3 ($p = 1.1E{-}15$). Similarly, the impact score declined from 47.5 ± 18.1 to 35.53 ± 17.88 ($p = 1.3E{-}13$), and the total SGRQ score improved markedly from 52.72 ± 14.9 to 40.92 ± 13.58 ($p = 2.4E{-}20$). In the control group (PR only), comparable but slightly less pronounced improvements were observed: symptom, activity, impact, and total scores all decreased significantly ($p < 0.001$ for all).

Table (6): Comparison between groups regarding pre-and post-treatment health status evaluation measured by SGRQ

	Group A (n=30)			**Group B (n=30)**		
SGRQ	**Before PR+VR**	**After PR+VR**	*P value*	**Before PR**	**After PR**	*P value*
Symptoms	53.5±18.3	41.63±16.88	4.4E-19	54±21.48	38.7±19.1	3.15E-15*
Activity	57.16±25.1	45.62±23.3	1.1E-15	43.47±25.34	33.7±22.5	1.3E-12*
Impact	47.5±18.1	35.53±17.88	1.3E-13	49.13±23.31	37±22.3	8.2E-16*
Total	52.72±14.9	40.92±13.58	2.4E-20	44.86±14.61	36.27±11.1	6.9E-10*

SGRQ, Saint George respiratory questionnaire. *Independent samples Student's t-test.

Table (7) presents the statistical comparison of anthropometric, spirometric, and clinical parameters in both groups before and after the PR program. Overall, both groups exhibited improvements in several physiological indicators following the intervention, though most changes did not reach statistical significance. Body mass index (BMI) showed a slight reduction after PR (from 27.50 ± 2.50 to 25.45 ± 4.18 kg/m², $p = 0.424$). On the other hand, the fat-free mass index (FFMI) decreased modestly but significantly ($p = 0.020$), likely reflecting changes in body composition associated with training and improved metabolic activity. Arterial blood gas parameters showed favorable changes, with PaO_2 increasing (51.94 ± 11.5 to 64.68 ± 7.3 mmHg) and $PaCO_2$ reduction (44.32 ± 7.5 to 40.82 ± 5.27 mmHg), indicating that gas exchange efficiency was improved, but differences were not statistically significant. The SpO_2 was notably improved from 90.33 ± 1.67% to 96.27 ± 1.6%, suggesting enhanced oxygenation after PRP. Pulmonary function parameters, including FEV_1 and FEV_1/FVC, demonstrated mild improvement post-rehabilitation (FEV_1: 64.2 ± 22.9 to 68.10 ± 15.10; FEV_1/FVC: 49.04 ± 15.93 to 53.28 ± 13.49), but these changes were not statistically significant ($p > 0.05$). Functional capacity, assessed via the 6MWT, was improved modestly in both groups (291.82 ± 88.6 to 326.82 ± 58.13 m, $p = 0.757$). This was accompanied by a reduced dyspnea severity (mMRC score was reduced from 2.18 ± 1.07 to 1.54 ± 0.54, $p = 0.720$). The CAT score showed a negligible change after the intervention.

Table (7): Statistical comparison between different variables in both groups before and after the PRP

Variables	**Group A**			**Group B**		
	Before PRP	After PRP	*P value*	Before PRP	After PRP	*P- value*
BMI (kg/m²)	27.50±2.50	25.45±4.180	0.424	27.50±2.50	25.45±4.180	0.424
FFMI (kg/m²)	19.32±1.9	18.73±3.069	0.020	19.32±1.9	18.73±3.069	0.020
PO2	51.94±11.5	64.68±7.3	0.640	51.94±11.5	64.68±7.3	0.640
PCO2	44.32±7.5	40.82±5.27	0.071	44.32±7.5	40.82±5.27	0.071
SpO2	90.33±1.67	96.27±1.6	0.884	90.33±1.67	96.27±1.6	0.884
FEV1	64.2±22.9	68.10±15.10	0.070	64.2±22.9	68.10±15.10	0.070
FEV1/FVC	49.04±15.93	53.28±13.49	0.563	49.04±15.93	53.28±13.49	0.563
6MWT	291.82±88.6	326.82±58.13	0.757	291.82±88.6	326.82±58.13	0.757
mMRC	2. 18±1.07	1.54±0.54	0.720	2. 18±1.07	1.54±0.54	0.720
CAT score	24.45±8.8	27.09±5.5	0.995	24.45±8.8	27.09±5.5	0.995

6MWT, 6-min walk test; CAT, COPD assessment test; FEV1, forced expiratory volume in the first second; FFMI, fat-free mass index; FVC, forced vital capacity; mMRC, Modified British Medical Research Council for dyspnae; PCO2, arterial partial pressure of carbon dioxide; PO2, arterial partial pressure of oxygen; SpO2, oxygen saturation.

Table (8) showed that the balance performance improved substantially in both groups, as reflected by significant increases in the Berg Balance Scale (BBS) and Balance Evaluation Systems Test (BESTest) scores.

In the VR group, BBS increased from 45.53 ± 3.3 to 53.83 ± 3.44 (p = 7.28E−16), and BESTest from 65.43 ± 3.01 to 81.77 ± 4.10 (p = 1.89E−15), indicating superior postural control and stability compared with Group B, which also improved but to a lesser extent. Physiological indicators showed favorable changes after PR in both groups. The PaO_2 was significantly increased (the VR group: 50.2 ± 5.34 to 60.63 ± 5.77 mmHg, p = 5.29E−11; the control group: 51.83 ± 5.71 to 62.5 ± 4.8 mmHg, p = 2.11E−11), accompanied by reductions in $PaCO_2$, reflecting improved gas exchange efficiency. Also, the SpO_2 was significantly increased in both groups, confirming enhanced oxygenation post-intervention.

Lung function, as measured by FEV_1, improved significantly in both groups ($p < 0.001$), while FEV_1/FVC ratios remained stable ($p > 0.9$), suggesting that PR mainly enhanced ventilatory efficiency. The 6MWT was markedly improved in both groups (the VR group: 267 ± 46 to 289 ± 32 m; the control group: 271 ± 41 to 290.5 ± 25.4 m; $p < 0.001$), indicating enhanced functional exercise capacity. Significant reductions was reported in the mMRC dyspnea scores and lower but statistically significant improvements in CAT scores, indicating symptom burden and perceived exertion were positively changed.

Table (8): Statistical comparison between both groups before and after the PRP

	Group A			**Group B**		
Variable	**Before PR+VR**	**After PR+VR**	***P value***	**Before PRP**	**After PRP**	***P value***
BBS	45.53±3.3	53.83±3.44	7.28E-16	45.6±3.26	48.1±2.35	0.001487
BESTest	65.43±3.01	81.77±4.10	1.89E-15	64.91±6.33	71.53±2.44	4.02E-10
FFMI kg/m^2	19.97±1.89	18.6±1.12	0.00145	20.73±1.93	19.0±1.19	8.69E-06
PO2	50.2±5.34	60.63±5.77	5.29E-11	51.83±5.71	62.5±4.8	2.11E-11
PCO2	44.8±2.47	40.17±2.69	3.92E-09	44.3±2.75	42.47±2.96	0.027178
SpO2	92.0±1.48	94.5±2.80	0.00023	92.33±1.18	95.6±2.13	5.16E-08
FEV1	46.8±5.86	40.17±2.69	8.07E-07	48.87±8.02	43.97±7.24	1.13E-07
SpO2	92.0±1.48	94.5±2.80	0.000227	92.33±1.87	95.6±2.13	5.16E-08
FEV1	41.97±3.79	46.87±5.86	8.07E-07	43.97±7.24	48.87±8.02	1.13E-07
FEV1/FVC	52.60±14.75	52.38±13.94	0.9094	52.65±15.9	51.91±14.27	0.9146
6MWT	267±46	289±32	2.89E-12	271±41	290.5±25.4	8.39E-14
mMRC	2.44±0.56	2.16±0.41	0.0125	2.37±0.49	2.10±0.27	0.0027
CAT score	25.8±3.69	26.4±3.46	0.0082	25.2±3.28	26.5±4.19	0.0059
BBS	45.53±3.3	53.83±3.44	7.28E-16	45.6±3.26	48.1±2.35	0.001487
BESTest	65.43±3.01	81.77±4.10	1.89E-15	64.91±6.33	71.53±2.44	4.02E-10

BBS, Berg Balance Scale; BESTest, Balance Evaluation Systems Test.

Table (9) showed that Δ6MWD was negatively correlated with age (r = −0.369, p = 0.019), indicating that younger participants achieved greater improvements in walking distance. Similarly, the higher baseline dyspnea severity (mMRC score) was negatively correlated with functional gain (r = −0.354, p = 0.025), suggesting that patients with more severe breathlessness at baseline experienced smaller improvements after PR. On the contrary, the baseline spirometric measures such as FEV_1% predicted (r = +0.386, p = 0.014) and FEV_1/FVC% predicted (r = +0.380, p = 0.016) were positively correlated with Δ6MWD, indicating that better baseline pulmonary function was associated with greater functional improvement. Also, the PaO_2 (r = +0.360, p = 0.022) showed a positive relationship, while, the $PaCO_2$ showed a weak, nonsignificant negative correlation (r = −0.288, p = 0.072), highlighting the role of adequate baseline oxygenation in predicting rehabilitation success. Health status, as assessed by the SGRQ demonstrated consistent negative correlations with Δ6MWD across all subdomains, symptoms (r = −0.430, p = 0.006), activity (r = −0.380, p = 0.015), impact (r = −0.438, p = 0.005), and total score (r = −0.394, p = 0.012), indicating that worse baseline health status was associated with smaller functional gains. Also, the baseline 6MWD itself was positively correlated with Δ6MWD (r = +0.391, p = 0.013), indicating that patients with higher initial exercise capacity tended to achieve greater final improvements.

Table (9): Correlation between Baseline Variables and difference in 6MWD after PR

Variable	Correlation Coefficient (r)	P-Value	Significance
Age (years)	-0.369	0.019	Significant
mMRC	-0.354	0.025	Significant
FEV1% Predicted	+0.386	0.014	Significant
FEV1/FVC% Predicted	+0.380	0.016	Significant
PaO2 (mmHg)	+0.360	0.022	Significant
PaCO2 (mmHg)	-0.288	0.072	Nonsignificant
SGRQ (Symptoms)	-0.430	0.006	Significant
SGRQ (Activity)	-0.380	0.015	Significant
SGRQ (Impact)	-0.438	0.005	Significant
SGRQ (Total)	-0.394	0.012	Significant
Baseline 6MWD (m)	+0.391	0.013	Significant

6MWD: 6-minute walk distance; FEV1: Forced expiratory volume in 1 second; FVC: Forced vital capacity; mMRC: Modified Medical Research Council Dyspnea Scale; PaO_2: Partial arterial oxygen tension; $PaCO_2$: Partial arterial carbon dioxide tension; SGRQ: Saint George Respiratory Questionnaire.

DISCUSSION

COPD impacts numerous structural and functional aspects of the lungs, significantly affecting a patient's overall health. Using exercises for the upper and lower limbs, the PR program (PRP) included peripheral muscle training. In this study, training was for 2 hours/session, twice a week for ten weeks (20 sessions, 40 hours). **Shaaban *et al.*** [23] begin with 5 minutes, and extended the time by 5 minutes at each session, up to 30 minutes. To improve muscle endurance, the trigger sensitivity was gradually reduced. The subsequent session was conducted with increased trigger sensitivity by 10% of the original MIP if the patient could tolerate 30 minutes of PR. compared to 18 sessions by **Hassaneen *et al.*** [24]. **El Gazzar *et al.*** [25] depended on training for 60 minutes exercise per session, 2-3 sessions weekly for 8 weeks. **Rutkowski *et al.*** [26] performed a lower number of PR and PR+VR sessions.

Concerning sample size, this study was comparable to studies by **Rutkowski *et al.*** [26], and **Mohammed *et al.*** [27] with 25, and 30 COPD patients per group, respectively. A lower number (15 participants/group, total 30 patients) was used by **Hassaneen *et al.*** [24]. A higher sample size was utilized in research by **Shehata *et al.*** [28] and **Shaaban *et al.*** [23], who involved 80 and 108 COPD patients respectively. The age of participants was an average of 56.7 (50-60 years old) in the current study, which is comparable to 45-60 years in the **Hassaneen *et al.*** [24] study, and higher mean ages varied between 52-78 years (mean= 65) by **Alsharaway** [29], 61.9±4.7 and 61.81±6.61 (58.42-66.25 years) were recruited by **Semary *et al.*** [30] and **Mohammed *et al.*** [27], respectively.

The current study included male and female patients similar to **Shehata *et al.*** [30] and **Shaaban *et al.*** [23], while, **Mosa *et al.*** [31] and **Mohammed *et al.*** [27] selected male patients.

The baseline pulmonary function of both groups was determined (Table 1). The Bottom of the Form Participants' characteristics of both groups, including age, gender, weight, height, BMI, FFM, FFMI, and smoking status, were determined (Table 1). A comparison between Group A (PR + VR) and Group B (PR Alone) indicated no significant variations in age, sex, height, or BMI among the groups (p > 0.05), confirming comparability. Table 1 compares 30 patients in Group A and 30 patients in Group B, assessing their demographic and clinical characteristics. The mean age was similar across groups, with Group A at 56.57 ± 2.45 years and Group B at 56.7 ± 2.68 years, showing no significant difference (p=0.97). Gender distribution varied slightly, with Group A comprising 18 males and 12

females, while Group B had 15 males and 15 females. Similarly, non-significant variations were noted in age and BMI across both groups [23]. **Mohammed *et al.*** [27] reported no significant variations across groups, except for BMI and the duration of occupational exposure to farming ($p < 0.05$).

Male/female ratios were 18/12 and 15/15 for groups A and B respectively. On the other hand, in the study of **Mosa *et al.*** [31] and **Mohammed *et al.*** [27] selected male patients, while males represented 82.22% participants in the study of **Semary *et al.*** [30]. Anthropometric measurements, including height and body mass, were also comparable. The mean height in group A was 165.1 ± 4.25 cm, while group B averaged 166.2 ± 3.78 cm (p=0.051). Body mass showed minimal variation, with group A at 78.4 ± 8.3 kg and group B at 78.06 ± 8.17 kg (p=0.918). Similarly, BMI values were 28.78 ± 2.9 kg/m² in group A and 28.3 ± 2.65 kg/m² in group B (p=0.72), indicating no significant variations. mean BMI of about 24 kg/m2 was reported by **Semary *et al.*** [30].

When comparing the non-muscle-depleted, muscle-depleted, and cachectic groups prior to PRP, **Alsharaway** [29] found statistically significant variations in the mean BMI values. The body composition of group A had a slightly higher FFM and FFMI at 59.65 ± 3.96 kg and 21.89 ± 1.1 kg/m² compared to 58.7 ± 3.21 kg and 21.29 ± 1.21 kg/m² in group B respectively. No statistically significant variations were noted concerning the baseline pulmonary function test parameters at baseline visits among the study groups (Table 1). Cardiovascular and respiratory parameters demonstrated similar trends between the two groups. Heart rate (HR) was nearly identical, recorded at 82.5 ± 4.1 bpm in group A and 82.7 ± 3.98 bpm in group B. Oxygen saturation (SpO_2%) showed minor variation, with group A at 92.33 ± 1.87% and group B at 92 ± 1.48%. Lung function tests indicated no significant changes across the groups. FEV1 values were 1.17 ± 0.31 L in group A and 1.19 ± 0.26 L in group B, while FEV1% predicted was 46.8 ± 5.86% in group A versus 48.87 ± 8.02% in group B (p=3.2e-11). Similarly, forced vital capacity (FVC) was 2.25 ± 0.29 L in group A and 2.39 ± 0.74 L in group B (p=9.65e-9). The FEV1/FVC ratio was nearly identical between both groups, recorded at 52.6 ± 14.75% in group A and 52.65 ± 15.89% in group B (p=0.000008) (Table 2). Both COPD groups ' lung function and clinical parameters had significantly lower SpO_2, FEV1, FEV1%, FVC, and FEV1/FVC% ($p < 0.001$).

HR was significantly increased in COPD patients, indicating cardiovascular strain. COPD patients had a markedly reduced 6MWD, showing impaired functional capacity. Similarly, **Shaaban *et al.*** [23] indicated no significant variations across the study groups concerning the baseline FEV1 predicted and FEV1/FVC predicted. These findings were higher than those obtained by **Alsharaway** [29], who reported the mean FEV1 at 28.10±10.52, the mean FEV1/FVC at 42.56±15.97 and the CAT score at 12.56±5.28 in the cachectic group. The lowest mean values of FEV1 were 28±10 and 38±14 in the cachectic and the muscle-depleted groups, respectively. This is lower than the baseline means of FEV1 and FEV1/FVC reported by **Shehata *et al.*** [28], which were 60.35±12.69 vs. 59.12±12.24 and 60.80±7.71 vs. 60.10±7.01 for group 1 and group 2 respectively.

Table (1) showed the pre-treatment functional status (mMRC and 6MWD), with no significant difference in mMRC scores (dyspnea) or 6MWD between A and B groups before the intervention, ensuring an unbiased starting point. Both groups showed significantly reduced 6MWD and dyspnea scores, reflecting the impact of COPD on exercise capacity and respiratory health. No significant difference in dyspnea severity was noted (2.43 ± 0.55 in group A and 2.37 ± 0.49 in group B (p=1.87e-10)) utilizing the Medical Research Council (MRC) scale scores. Smoking history was comparable between groups, with 10% of group A being current smokers compared to 5% in group B, while past smoking rates were 50% in group A and 46.67% in group B. When assessing COPD severity using the GOLD classification, group A had 18 in GOLD stage II and 12 in stage III, compared to 17 in stage II and 13 in GOLD stage III in group B, showing no major differences across the two groups (p=0.354).

Exercise capacity, evaluated by the 6MWD, showed similar results. Patients in group A walked 267.03 ± 41.2 meters, while those in group B walked 270.5 ± 73.9 meters (p=3.2e-11). Overall, no significant variations were found across both groups in most demographic and clinical parameters. Both groups exhibited comparable lung function, dyspnea scores, disease severity, and exercise capacity. Moderate-to-severe COPD, FEV1% was 47%; similarly, FEV1% 30–79% participated in the study of **Mohammed *et al.*** [27]. On the other hand, **Xie *et al.*** [32] comprised more severe COPD patients (FEV1% < 50, GOLD stage IV). In contrast, before the intervention, there was significant variation among the groups in resting DBP, O_2 saturation, 6MWT distance, post-6MWT HR, number of stoppage times throughout 6MWT, post-6MWT dyspnea utilizing the Borg scale, and predicted FEV% ($p < 0.05$) [27]. Groups A and B were similar in most clinical parameters before the intervention, ensuring fairness in comparison. FFMI was significantly lower in both COPD groups, but there were no significant variations across both groups.

Table (2) presented the impact of PR on Lung Function (FEV1, FVC, FEV1/FVC). In the current study, group A (PR+VR) showed significant improvements in FEV1, FEV1/FVC, and FVC, while group B (PR only) showed non-significant changes. Group A demonstrated a mean increase of FEV1 (Cohen's d = 0.78), FVC (Cohen's d = 1.01), and FEV1/FVC (Cohen's d = 0.86), supporting the benefits

of PR. The spirometric pulmonary functions was improved by up to 2% [30].

Table (3) presents an improvement in exercise capacity (6MWD) following PR alone. The current study demonstrated a 41.15% increase in the six-minute walk distance (6MWD) post-pulmonary rehabilitation (PR), which is higher than the improvements observed in studies by **Mosa *et al.*** [31] and **Mohammed *et al.*** [27] who reported increases of over 30%. **Mosa *et al.*** [33] reported a post-treatment 6MWD of 301.65 ± 61.78 meters in patients receiving standard chest physiotherapy. **Mohammed *et al.*** [27] highlighted significant improvements in 6MWD following three months of training.

Tables (3-5) displayed the impact of PR on Dyspnea (mMRC Score). The current study supports these findings, with group A (PR+VR) showing a more significant decrease in dyspnea scores than group B (PR alone). This suggests that VR-enhanced PR may further improve respiratory endurance. **Shehata *et al.*** [28] reported that 50% of patients receiving PR exhibited improvement in dyspnea, compared to only 25% in those who received medical treatment alone. Table (6) displayed the effect of PR on clinical parameters (SpO_2, HR, CAT & 5RSTS). In the current study, group A (PR+VR) demonstrated a greater increase in post-PR SpO_2, a greater reduction in heart rate (HR), and a larger improvement in CAT scores compared to group B (PR only). Moreover, upon ending the exercise training, RT indicated a better improvement in anxiety relative to ET in these patients [33]. While **Bhatt *et al.*** [34] reported no significant effects.

Table (5) displayed the effectiveness of VR as a supplementary technique for PR. A study group that received VR alongside traditional PR (the VR group) was compared to a control group that underwent only traditional PR to determine the efficacy of VR in patients underwent PR. The goal of VR treatment was to assist patients in establishing mental balance, identifying their psychological resources, and activating their innate recovery processes.

The study indicated significant improvements in exercise capacity and 6MWD following the implementation of PR+VR (Table 6). In the current study, group A (PR+VR) improved from 260.8±28.8 m to 400.0±25.0 m (an increase of 107.9 m), while group B (PR only) improved from 261.03±32.2 m to 390.5±25.4 m. This suggests PR significantly enhanced exercise tolerance, with VR providing additional benefits. **Mohammed *et al.*** [27] reported an improvement of 84.2 m in the IMT group, which was lower than the 107.9 m increase in the current study's PR+VR group.

Mosa *et al.* [31] also reported significant improvements in 6MWD post-PR, although they reported increases (around 66 m and 56 m respectively) but were less than those observed in the present study. The higher 6MWD increase in the current study relative to previous research may be attributed to 1) the use of VR-enhanced PR, which may have increased patient engagement and motivation. 2) A longer training duration (10 weeks) compared to the 6–8 weeks in some previous studies. 3) The inclusion of behavioral strategies, which encouraged higher adherence to physical activity post-PR. VR technologies have a slight favorable impact on exercise ability. The use of diverse training methods limited the general benefits of the interventions. In the studies that involved games designed to improve dynamic balance, strengthen both lower and upper extremities and increase endurance, the 6MWT significantly exceeded the minimum clinically important change of 35 m between the study groups, providing additional stimulation. Although there was no discernible decrease in dyspnea, spirometry values demonstrated beneficial effects [26].

Group A (PR+VR) showed significant improvements in FEV1, FVC, and FEV1/FVC, while group B (PR only) did not show any significant changes. Mean improvement in group A: FEV1 (Cohen's d = 0.78), FVC (Cohen's d = 1.01), and FEV1/FVC (Cohen's d = 0.86). group B did not exhibit significant improvements in pulmonary function. Dyspnea (mMRC score) decreased significantly in both groups post-PR. Greater reduction in group A (-0.50±0.50) relative to group B (-0.25±0.43), p = 0.022. 50% of patients in group A exhibited improvement, while in group B, only 23.33% improved. **Mohammed *et al.*** [27] found that mMRC scores decreased by 1.5 points in the PR-trained group, compared to a 1-point decline in the DB+PLB group, which is similar to the present study's findings.

Shehata *et al.* [28] found that PR reduced dyspnea in 50% of patients, compared to only 25% in those receiving medical treatment alone. The larger reduction in dyspnea in group A compared to group B suggests that VR may enhance respiratory endurance by providing interactive, engaging training. SGRQ total scores improved significantly post-PR in both groups. In group A, the SGRQ overall scores reduced from 52.72±14.9 to 40.92±13.58, with a p-value of 2.44E-20. group B: 44.86±14.61 to 36.27±11.1 (p = 6.903E-10). Group A experienced a greater decrease in symptoms relative to group B. **Shehata *et al.*** [28] confirmed PR's significant impact on the QoL improvements in COPD patients. The greater improvement in group A's quality of life suggests that VR-enhanced PR may provide additional psychological and functional benefits. Previous studies also found PR improved symptom burden, activity limitation, and overall quality of life, consistent with the current study.

Post-exercise SpO_2 improved in both groups, but group A showed greater gains (95.2±2.0% vs. 93.7±2.8%). Post-exercise HR was significantly diminished in group A (95.0±5.0 bpm vs. 95±5.7 bpm in group B), indicating better cardiovascular adaptation. Fatigue scores improved significantly, with group A exhibiting a larger reduction than group B. **Shaaban *et al.*** [23] showed that PR significantly improved SpO_2, HR

and fatigue levels, supporting the current study's findings.

Zeng *et al.* [12] were found VR-based interventions to enhance exercise performance, reduce breathlessness, and increase patient motivation, aligning with the current study's PR+VR results. The current findings align with earlier research, demonstrating that PR, especially when combined with VR, led to significant improvements in 6MWD, lung function and dyspnea relief compared to traditional PR alone. The data support the idea that longer-duration PR programs (≥10 weeks) yield superior functional and physiological outcomes compared to shorter programs (3-8 weeks). Moreover, VR-enhanced PR showed greater benefits in improving exercise capacity, reducing dyspnea and enhancing cardiovascular adaptation highlighting its potential role in optimizing rehabilitation for COPD patients. These findings emphasize the need for personalized PR programs specific to certain patient requirements and disease degrees to maximize the long-term benefits of rehabilitation.

In the current study, the PR+VR group demonstrated superior improvements in 6MWD, pulmonary function, dyspnea reduction, and QoL compared to PR alone. These results match with earlier research but indicate that VR-enhanced PR may offer additional benefits, especially in exercise tolerance and cardiovascular efficiency. VR significantly enhanced lung function in COPD patients, as evidenced by the FEV1 ($MD = 7.29$, $p < .01$) and FEV1/FVC ($MD = 6.71$, $p < .01$) of 10 RCTs with 539 participants, according to **Liu *et al.*** [7].

VR in conjunction with endurance training (ET) did not significantly impact the 6WMT in individuals with COPD as compared to ET alone ($p > .05$). VR in conjunction with PR was more successful in raising 6WMT in COPD patients than PR alone ($MD = 30.80$, $p < .01$). When paired with PR, VR can help people with COPD improve their lung function and exercise tolerance. Breathing responses throughout exercise can be affected by education or previous exercise experiences and changes in visual input impact perceptions of dyspnea in cycling exercise. The VR cycling course's steepness (gradient) may cause the pedaling resistance to be lower or greater than anticipated [35].

CONCLUSION

Incorporating VR into PR yielded superior outcomes in physical performance, oxygenation, balance, and quality of life. The more significant improvements in group A underscore the potential of VR as a beneficial, engaging tool for PR. Patients with better baseline respiratory function and activity levels experienced greater improvements, highlighting the value of early intervention. Long-term rehabilitation is necessary to maintain gains, especially in oxygenation and functional capacity. Combining traditional PR with VR may enhance both immediate and long-term outcomes by maintaining motivation and reducing perceived exertion. Continuous monitoring of oxygen levels during exercise is recommended, especially for patients with lower baseline SpO_2. Identifying and enrolling patients earlier in PR programs may lead to better rehabilitation outcomes. Targeting symptom reduction (like dyspnea and fatigue) can significantly improve patients' exercise tolerance and QoL. Exploring remote VR rehabilitation options can improve accessibility for patients in rural or low-resource settings.

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