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Efficacy of high-frequency chest wall oscillations *vs.* lung flute in chronic obstructive pulmonary disease patients with post-COVID

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Abstract. – OBJECTIVE: In chronic obstructive pulmonary disease (COPD), high-frequency chest wall oscillations (HFCWO) and lung flute (LF) are used to improve COPD patients' pulmonary functions, exertional dyspnea, as well as life quality. This comparative study aimed to assess the efficiency of HFCWO *vs.* LF in post-coronavirus-disease (COVID) men with COPD.

PATIENTS AND METHODS: Sixty post-COVID men with COPD, who were aged 40-60 years old, were included in this HFCWO-*vs.*-LF comparative study and were divided into two groups. One group (N=30) received HFCWO, and the other group (N=30) received LF three times per week. Both groups' pulmonary functions, including forced vital capacity (FVC), forced expiratory volume at the first second (FEV1), the ratio of FEV1/FVC (FEV1/FVC), forced expiratory flow between 25% and 75% of the pulmonary volume (FEF25-75%) were assessed. Also, the COPD assessment test score (CAT score) and 6-minute walk distance (6MWD) were measured before and following the trial.

RESULTS: Regarding all variables (post-COVID patients' FVC, FEV1, FEV1/FVC, FEF25-75%, CAT score, as well as 6MWD), both groups had substantial changes after the three-week HFCWO-*vs.*-LF interventional period as the *p*-value was below 0.05. The changes in post-COVID patients' FEV1, FEV1/FVC, and 6MWD were high in the HFCWO group, while the changes in post-COVID patients' CAT score, FVC, and FEF25-75% were high in the LF group.

CONCLUSIONS: HFCWO is more efficient than the LF in improving pulmonary functions and exertional dyspnea in post-COVID men with COPD.

Key Words:
COPD, Post-COVID, Pulmonary functions, Exertional dyspnea, High-frequency chest wall oscillation, Lung flute.

Introduction

Coronavirus disease (COVID) is now one of the deadliest pandemics ever documented in human history. As post-COVID patients' number rises globally, it is essential to continue analyzing post-COVID pulmonary sequelae/complications to promote clinical therapies, especially in patients with chronic illnesses[1] such as chronic obstructive pulmonary disease (COPD)[2,3]. Patients recuperating from the acute phase of COVID-19 could experience long-lasting multi-system dysfunctions[4]. Respiratory system dysfunctions, such as weak respiratory muscle strength, declined forced vital capacity (FVC), reduced diffusing lung capacity for carbon monoxide (DLCO), decreased total lung capacity (TLC), and low 6-minute walking distance (6MWD) are some of the main post-COVID sequelae[5].

The Lung flute (LF) - a hand-held device that can be easily used without the need for an extra power supply - is an acoustic instrument that was designed in 2002 to encourage the expectoration of sputum through LF-induced production of acoustic waves. These waves go down along the trache-

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obronchial tree with a frequency equal to 18-22 Hz and pressure equal to 2.5 cmH_2O to move the secretions and sputum from the distal airways to the central ones when the patient exhales softly via the LF device's mouthpiece. Consequently, LF can improve sputum clearance/expectoration[6].

The Vest™ device (Hill-Rom, The Vest-Model 104 Airway Clearance Device, North Charleston, USA) is another device that is an efficient tool for assisting airway clearance in chronic respiratory disorders, including COPD. The Vest™ device utilizes high-frequency chest wall oscillations (HFCWO) to decrease the viscosity of airway secretions to be mobilized from tiny to bigger airways to be easily expectorated/suctioned. Typically, a treatment session of HFCWO (conducted *via* the Vest™ device) or LF lasts between 10 and 30 minutes[7]. This research aims to determine the efficiency of HFCWO using the Vest™ device *vs.* LF in post-COVID men with COPD.

Patients and Methods

Design and Settings

A comparative design was performed. From October to December 2022, sixty post-COVID men with COPD were gathered from the Al-Azhar University Hospital and Al-Zahraa University Hospital. Given the prevalence of smoking among men more than women in Egypt, the selection of patients with pulmonary obstruction related to smoking was from men only.

Inclusion Criteria

The included post-COVID men with COPD aged 40-60 years old. Men were included in this study immediately after recovering from COVID-19 and no more than three months after this recovery. Patients were enrolled if they had a COPD diagnosis at least two years ago. Patients who experienced irreversible or partially reversible airflow obstruction were also included. COPD patients whose ratio of forced expiratory volume in one second (FEV1) to FVC (FEV1/FVC%) < 70%[8-10] after using a bronchodilator were included.

The included post-COVID participants with COPD were allowed to take 2 puffs of inhaled 100-µg salbutamol [GlaxoSmithKline (gsk); France (Glaxo-Wellcome Production); packed by GlaxoSmithKline SAE, Cairo, Egypt). After 20 minutes of inhaling salbutamol, if the patients' FEV1 increased to < 200 ml or if the patients' FEV1 was < 12% of baseline value, men were included.

Exclusion Criteria

The following patients were excluded: 1) Patients with malignant disease, burns in the chest, or acute infection; 2) Patients with a history of osteoporosis, significant gastro-esophageal reflux, and hiatus hernia; 3) Patients with a recent acute cardiac incident and congestive heart failure; 4) Patients with any significant musculoskeletal disorders.

Randomization

60 post-COVID men with COPD were assigned to one of the two study groups, the HFCWO group and the LF group via a computer-developed randomization list.

Thirty patients (HFCWO group) delivered vest-based HFCWO device (model 104, Hill-Rom, The Vest-Model 104 Airway Clearance Device, North Charleston, USA) as well as their prescribed medications three times per week for three consecutive weeks, with each session lasting 15-30 minutes. The thirty patients of the other group, the LF group, delivered an oscillatory positive expiratory pressure (OPEP) device, lung flute (THERAPEUTIC, medical acoustics company, Las Vegas, USA) as well as their prescribed medications three times per week, twice a day for three consecutive weeks, with each session lasting 10-15 minutes (Figure 1).

Interventional Procedures of Application of Vest-Based HFCWO Device

- Post-COVID men with COPD were instructed to be in a relaxed and comfortable upright sitting posture.
- Then, the authors connected the circumferential inflatable Vest™ device to the patient's chest wall.
- Authors were cautious not to restrict patients' breathing when the vest was working.
- First, the Vest™ device's air pulse generator was set at a low-frequency pattern. Secondly, this pattern was increased to the recommended level of the Vest™ device's frequency. The optimal/recommended oscillating frequency was 13-15 Hz, based on every man's tolerance.
- Each post-COVID man with COPD received three HFCWO sessions weekly for 3 weeks (every HFCWO session was 15-30 minutes).
- Post-COVID men with COPD were monitored throughout HFCWO sessions for changes in their respiratory pattern/rate, work of breathing, pulse rate, and skin coloration.

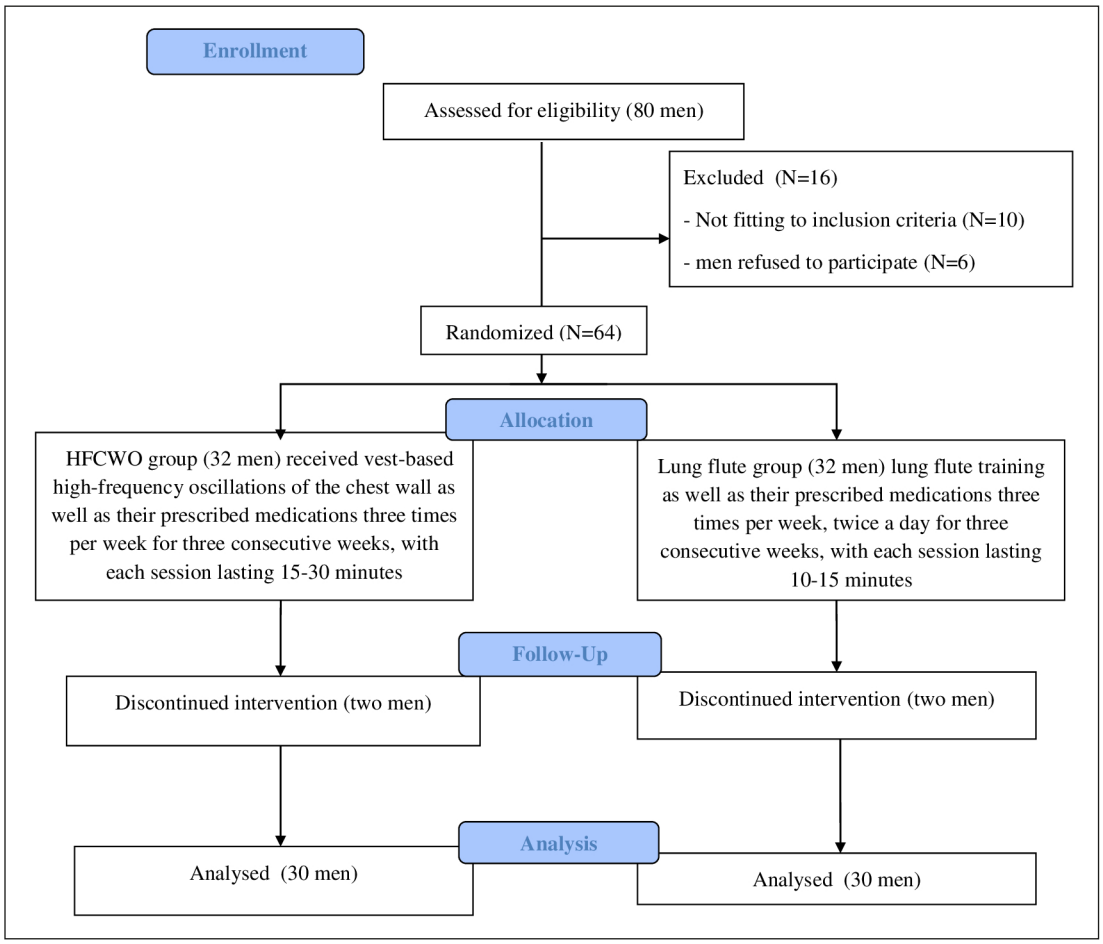

Figure 1. Flow chart of participating COPD men with post-COVID during the 3-week interventional study

- After completing the HFCWO session, the post-COVID men with COPD were ordered to start deep breathing and cough to clear their loosened airway secretions[11].

Interventional Procedures of Lung Flute

- Post-COVID men with COPD were sitting in a relaxed posture so their backs were not touching the bed/chair.
- Men's heads were slightly tilted in a downward direction so their throats were maximally opened. This was done to allow the breath-induced acoustic waves to flow from the LF into men's lungs.
- Post-COVID men with COPD were ordered to hold the LF device pointing down.
- Post-COVID men with COPD were instructed to inhale a little deeper than normal, then men were ordered to place their lips completely around the lung flute's mouthpiece to gently blow out through the lung flute's mouthpiece as if a man was trying to blow out a candle. After that, post-COVID men with COPD were instructed to remove the lung flute's mouthpiece quickly to inhale again.
- After inhalation, post-COVID men with COPD were ordered to put the lung flute's mouthpiece back in their mouth to gently blow out through the lung flute's mouthpiece.
- The lung flute's mouthpiece was removed, and post-COVID men with COPD were ordered to wait 5 seconds (in which normal breaths were taken). Every two blows using a lung flute were considered one-set lung flute training.
- Post-COVID men with COPD were ordered to perform 20 sets of LF training. After every 5-set LF training, patients were ordered to perform three huffs followed by three coughs to assist in clearing men's secretions[6].
- Every LF-training session lasted from 10 minutes to 15 minutes to be repeated twice daily. LF-training sessions were applied three times weekly for 3 successive weeks.

Outcomes

The following primary outcomes related to the functions of ventilation in post-COVID men with COPD were measured: FVC, FEV1, FEV1/FVC%, and forced expiratory flow at 25 and 75% of the pulmonary volume (FEF25-75%) at baseline and after three weeks in both groups.

Before and following LF or HFCWO interventions, a 6MWD was administered to assess the patient's functional capacity. Also, a score of the COPD assessment test (CAT score) was performed. To be noted, 6MWD and CAT score were the secondary outcomes of this comparative research.

Blinding

Outcome assessors of post-COVID patients' outcomes (FVC, FEV1, FEV1/FVC%, FEF25-75%, 6MWD, and CAT score) were not informed of the details of HFCWO and LF interventions to avoid intentional changes of results.

Sample Size of Post-COVID Men with COPD

The sample size of post-COVID men with COPD was determined before starting this HFCWO-*vs*.-LF comparative study using G*POWER statistical German software (the used version in this comparative study was 3.1.9.2; Franz Faul, Universitat-Kiel, Germany). A two-tailed *t*-test was used in the calculation of the sample size of post-COVID men with COPD at 80% statistical power to record an effect size of 0.82 for outcomes of pulmonary functions. To complete this HFCWO-*vs*.-LF comparative study, 54 post-COVID men with COPD were needed. Authors of this HFCWO-*vs*.-LF comparative study raised the number of post-COVID men with COPD to 64 men to avoid the by-author supposed drop-out rate of 20%

Statistical Analysis

SPSS (version 22, IBM Corp., Armonk, NY, USA) was employed to conduct the statistical analysis for the outcomes of this HFCWO-*vs*.-LF investigational study. Descriptive statistics for the mean and standard deviation of age, weight, height, and body mass index (BMI) were estimated by utilizing an unpaired *t*-test. The paired *t*-test was utilized to estimate significant improvements in FVC, FEV1, FEV1/FVC%, FEF25-75%, and 6MWD prior to and following treatment within groups, whereas the unpaired *t*-test was utilized to analyze variations between groups prior to and following treatment. The Wilcoxon signed-rank test, as well as independent-sample Mann-Whitney U analysis, were utilized to identify the variations in CAT scores between the two cohorts prior to and following treatment. To be noted, α=0.05 was the significant threshold.

Results

Randomly, 60 adult men were allocated into two comparable groups. Age, weight, height, and BMI were not significantly different between the two groups ($p > 0.05$; Table I).

Employing an unpaired *t*-test, no significant variations were seen before treatment averages in FVC, FEV1, FEV1/FVC%, FEF25-75%, and 6MWD between both groups with *p*-values (0.06, 0.068, 0.906, 0.731, and 0.53, respectively) (Table II). Both groups had substantial changes after HFCWO or LF interventions regarding all variables (FVC, FEV1, FEV1/FVC%, FEF25-75%, and 6MWD), as the *p*-value was lower than 0.05 (Table II). Table II shows that the percentage of changes was greater in the HFCWO group *vs.* the LF group regarding FEV1, FEV1/FVC%, and 6MWD, but the change was greater in the LF group compared to the HFCWO group, regarding FVC as well as FEF25-75%.

Using the independent-sample Mann-Whitney U analysis, there was no significant difference seen pre-intervention as well as post-treatment

Table I. Demographic information and physical features for both patient groups.

	HFCWO group		Lung flute group		Comparison		
Items	Mean	SD	Mean	SD	*t*-value	*p*-value	S
Age (years)	54.47	4.23	54.63	4.64	0.145	0.885	NS
Weight (kg)	70.4	11.12	69.57	8.57	0.325	0.746	NS
Height (cm)	168.4	7.68	170.7	5.86	1.287	0.203	NS
BMI (kg/m^2)	24.7	2.5	23.8	1.9	1.565	0.123	NS

*SD = Standard deviation. *p* = Probability. S = Significance. BMI = Body mass index. NS = Non-significant (because *p*-value is < 0.05).

Table II. Comparison of the two groups before and after treatment FVC, FEV1, FEV1/FVC%, FEF25-75%, and 6MWD means± standard deviations.

	HFCWO group		Lung flute group		Comparison of groups	
	Before	After	Before	After	Before	After
FVC	1.55±0.58	1.9±0.56	1.77±0.24	2.23±0.34	p=0.06	p=0.008
Comparison within groups	*p < 0.05		*p < 0.05			
Percent of change	22.6%		25.9%			
FEV1	0.74±0.3	1.06±0.35	0.87±0.2	1.19±0.3	p=0.068	p=0.143
Comparison within groups	*p < 0.05		*p < 0.05			
Percent of change	43.2%		36.7%			
FEV1/FVC%	48.6±10.8	56.4±10.9	48.9±8.7	53.03±8.2	p=0.906	p=0.178
Comparison within groups	*p < 0.05		*p < 0.05			
Percent of change	16.2%		8.4%			
FEF25-75%	0.56±0.3	0.75±0.4	0.53±0.19	0.79±0.24	p=0.731	p=0.691
Comparison within groups	*p < 0.05		*p < 0.05			
Percent of change	33.9%		47.2%			
6MWD	245.1±44.2	307.6±58.7	262.1±16.3	307.5±20.7	p=0.53	p=0.995
Comparison within groups	*p < 0.05		*p < 0.05			
Percent of change	25.5%		17.3%			

FVC = Forced vital capacity. *p < 0.05 is statistically significant. HFCWO = High-frequency chest wall oscillation. FEV1 = Forced expiratory volume in one second. 6MWD = Six-minute walk distance. FEV1/FVC% = Ratio of forced expiratory volume in one second to forced vital capacity. FEF25-75% = Forced expiratory flow at 25 and 75% of the pulmonary volume.

between both cohorts regarding CAT score since the p-values were 0.882 and 0.778, respectively. There was a significant change in CAT score for both groups following the treatment employing the Wilcoxon Signed-Rank test, as the p-value was below 0.05. The change in the percentage of CAT scores for both groups was 33.4% and 35.3%, respectively (Table III).

Discussion

Results of this comparative study showed that HFCWO is more efficient than the LF in improving pulmonary functions in post-COVID patients with COPD patients, but the mechanisms of Vest™ device or LF in improving pulmonary functions are difficult to explain.

High-frequency chest wall oscillations are pressurized air pulses produced by the Vest™ device. Application of HFCWO on the patient's chest wall can loosen transient spikes of cephalad airflow bias in the patient's lower airways and move trapped secretions from it to the upper airways. HFCWO generated via the Vest™ device reduces cross-linkages and viscoelasticity of mucus; consequently, Vest™ system-induced production of HFCWO increases ciliary beating and mucociliary clearance from airways[12]. Increased HFCWO-induced airway clearance may explain the improvement in the measured variables of the HFCWO group.

Regarding the LF device, LF-induced production of sound/acoustic waves can be transmitted to the different segments of the tracheobronchial tree. This transmission can vibrate tracheobronchial secretions. This vibration increases

Table III. Comparison of both groups before- and after-CAT score's mean±SD.

	HFCWO group		Lung flute group		Comparison of groups	
	Before	After	Before	After	Before	After
CAT score	25.7±4.3	17.1±4.9	25.5±4.1	16.5±4	p=0.882	p=0.778
Comparison within groups	* p < 0.05		* p < 0.05			
Percent of change	33.4%		35.3%			

HFCWO = High frequency chest wall oscillations. CAT = COPD assessment test. SD: standard deviation, *p < 0.05 is statistically significant.

the lower respiratory tract's mucociliary clearance[6]. Increased LF-induced airway clearance may explain the improvement in the measured variables of the LF group.

Our findings are congruent with those of Mahajan et al[13], who indicated that HFCWO is well tolerated in hospitalized people with acute exacerbation of COPD or acute asthma and relieves dyspnea significantly.

Two pieces of research compared the effect of Vest™ system-producing HFCWO *vs.* the usual/traditional chest physical therapy on bronchiectasis[14] or cystic fibrosis[15] patients' pulmonary functions (FVC and FEV1) and CAT score. Besides enhanced fatigue and breathing efficiency, the two studies[14,15] demonstrated that Vest™ device-producing HFCWO is an effective treatment tool in mobilizing secretions, improving FVC and FEV1, and enhancing CAT score in patients with bronchiectasis[14] or cystic fibrosis[15].

In agreement with our post-treatment findings of lung functions between HFCWO and LF groups, a study reported that the use of Vest™ device-producing HFCWO or flutter device (this device resembles LF) in patients with acute exacerbation of COPD significantly improved patients' spirometric indices but no statistically significant difference between HFCWO or flutter in patients' post-treatment lung (spirometric) functions[16].

The findings of this investigation concurred with those of Ahmed et al[17], who stated that the use of a lung flute is an appropriate physiotherapy method/device in COPD patients because it can assist in sputum expectoration, contribute to the stabilization or enhancement of respiratory functions, and improve cooperation and autonomy of patients.

In contrast, the results of a study conducted in 2014 did not report substantial improvements in COPD patients' lung functions after 26-week lung-flute treatment (a small size sample may be the cause of non-reported changes in lung functions)[18].

Limitations

Long-term tracking of LF or HFCWO results was the main limitation of this HFCWO-*vs.*-LF comparative trial. Future trials working on post-COVID patients with COPD must address this limitation.

Conclusions

HFCWO is more efficient than the lung flute in improving pulmonary functions and COPD-associated exertional dyspnea, as well as enhancing life quality in post-COVID patients with COPD.

Conflict of Interest

The authors declare no conflict of interest.

Ethics Approval

Cairo University's Ethical Committee provided its permission (No.: P.T.REC/012/003822) to conduct this HFCWO-*vs.*-LF comparative research. All post-COVID men with COPD were briefed about the purpose and potential risks of this HFCWO-*vs.*-LF comparative research. Helsinki rules were followed during the application of lung flute or HFCWO interventions on post-COVID patients with COPD. Our study, which was conducted on post-COVID patients with COPD, was registered on www.clinicaltrials.gov [NCT05591781].

Informed Consent

All post-COVID men with COPD filled out the consent form.

Funding

None.

Authors' Contributions

All authors contributed in an equal manner in all steps of this HFCWO-*vs.*-LF comparative trial and in all parts of writing, revising, and approving the final version of this manuscript.

Availability of Data and Materials

Data of post-COVID participants with COPD are available upon request.

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