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Original Article

Peak Expiratory Flow Rate Versus Acapella on Pulmonary Function in Elderly Post-Covid-19 Patients

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ABSTRACT

Background: Post-COVID-19 recovery in older adults is frequently complicated by persistent dyspnea and impaired oxygenation, prompting use of positive expiratory pressure (PEP) techniques such as oscillatory PEP (Acapella) and bottle-based PEP (blow bottle). Objective: To compare Acapella versus blow bottle PEP for improving oxygen saturation, peak expiratory flow rate (PEFR), dyspnea, and six-minute walk distance (6MWD) in elderly post-COVID-19 patients over one week. Methods: In this randomized clinical trial conducted at Tehsil Hospital Kot Addu over six months, 48 post-COVID-19 patients aged 50–65 years were allocated to Acapella (n=24) or blow bottle PEP (n=24) delivered three times daily for 7 days. Oxygen saturation, PEFR, dyspnea (modified Borg), and 6MWD were measured at baseline and after intervention. Between-group comparisons were performed using rank-based testing. Results: At Day 7, oxygen saturation differed significantly between groups (mean rank 31.69 blow bottle vs 17.31 Acapella; $p<0.001$), indicating superior oxygenation distribution in the blow bottle group. PEFR showed no between-group difference at Day 7 (mean rank 25.23 vs 23.77; $p=0.717$), and 6MWD remained comparable (mean rank 24.50 vs 23.50; $p=0.882$). Conclusion: Over one week, blow bottle PEP demonstrated superior improvement in oxygen saturation relative to Acapella, while PEFR and functional walking capacity did not differ, supporting PEP as an oxygenation-focused adjunct within broader post-COVID rehabilitation. Keywords: COVID-19; respiratory rehabilitation; positive expiratory pressure; Acapella; blow bottle; oxygen saturation; peak expiratory flow rate; six-minute walk test.

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INTRODUCTION

Coronavirus disease 2019 (COVID-19), caused by the novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has produced a large and persistent burden of respiratory morbidity worldwide, with clinical trajectories ranging from mild upper respiratory symptoms to severe hypoxemic respiratory failure and multiorgan involvement (1–4). Although the majority of infected individuals recover without prolonged sequelae, a clinically important subset experiences ongoing dyspnea, exercise intolerance, and impaired oxygenation after the acute phase, frequently attributed to residual parenchymal inflammation, ventilation–perfusion mismatch, deconditioning, and post-infectious pulmonary complications (3–6). Post-COVID respiratory impairment has been reported even among patients who are no longer infectious and have tested negative, emphasizing the need for pragmatic rehabilitation strategies that can be implemented early in recovery and in resource-variable settings (5–7).

Positive expiratory pressure (PEP) techniques are established adjuncts in respiratory rehabilitation for secretion mobilization, airway stabilization, and optimization of expiratory airflow dynamics through sustained expiratory back-pressure (8,9). Two commonly used approaches include commercially

available oscillatory PEP devices such as Acapella and low-cost PEP bottle ("blow bottle") systems. Acapella combines PEP with oscillations that may enhance mucus transport and reduce airflow obstruction by generating vibratory shear forces and intermittent expiratory flow acceleration, whereas blow bottle devices create threshold-like PEP via expiration against water-column resistance and are widely used because of simplicity and affordability (8–10). Evidence from other clinical contexts suggests both approaches can improve oxygenation and respiratory mechanics, including among postoperative cardiothoracic populations where airway clearance and atelectasis prevention are central goals (10–12). Comparative work in chronic obstructive pulmonary disease has similarly reported functional and symptom improvements with PEP-based techniques, though relative advantages may depend on disease phenotype, intervention dose, and outcome selection (13,14).

Despite the expanding population of older adults recovering from COVID-19, direct comparative evidence for oscillatory PEP versus bottle-based PEP in post-COVID rehabilitation remains limited, particularly for clinically relevant endpoints such as oxygen saturation, expiratory flow performance, and functional walking capacity (6,7). This knowledge gap is important because post-COVID impairment may reflect a mixed restrictive–diffusion limitation and deconditioning pattern rather than classic obstructive physiology, potentially attenuating expected gains in peak expiratory flow despite improvements in ventilation distribution and oxygenation (5–7). Accordingly, this randomized clinical trial was designed to evaluate, in elderly post-COVID patients, whether Acapella (intervention) differs from a blow bottle PEP device (comparator) in improving oxygen saturation (primary clinical endpoint) and in secondary outcomes including peak expiratory flow rate, dyspnea severity, and six-minute walk distance over a one-week treatment period (10–14). We hypothesized that both PEP strategies would improve oxygenation, while between-group differences in expiratory flow and functional capacity would be smaller over the short intervention window.

MATERIALS AND METHODS

A randomized clinical trial was conducted at Tehsil Hospital Kot Addu over a six-month period after approval by the institutional research board. Participants were recruited through a nonprobability convenience approach from eligible post-COVID attendees of the facility and were enrolled after written informed consent. Eligibility criteria included adults aged 50–65 years with laboratory-confirmed negative status for COVID-19, at least one week beyond clinical recovery, and the ability to sustain an expiratory flow of ≥15 L/min for 3 seconds, reflecting minimum performance needed for effective PEP maneuvering. Individuals were excluded if they had ongoing or new pulmonary infection after COVID-19, had been mildly ill and managed entirely at home, had serious post-COVID complications requiring advanced medical management, had pre-existing pulmonary disease, could independently clear secretions without assistance, or were current smokers, to reduce confounding by chronic respiratory pathology and smoke-related airflow limitation (15).

Randomization was implemented using a simple random sequence to allocate participants in a 1:1 ratio to either oscillatory PEP (Acapella D.H, Green) or bottle-based PEP (home-made blow bottle). Allocation was performed after baseline assessment to preserve baseline measurement integrity. To minimize measurement bias, outcome assessments were conducted using standardized procedures and the same instruments at each time point. Baseline and post-intervention evaluations included peripheral oxygen saturation measured by pulse oximetry, peak expiratory flow rate measured using a peak expiratory flow meter, functional capacity quantified using the six-minute walk test, and perceived dyspnea measured using the modified Borg scale contemporaneously with exertional testing (16–19). The six-minute walk protocol and dyspnea scoring were implemented consistently across participants to support comparability of functional outcomes and symptom burden assessment (18,19).

All participants received standardized instruction prior to device use, including effective cough technique, huffing, diaphragmatic breathing, and upper chest muscle relaxation. In the Acapella group,

therapy was delivered in a seated position with resistance set to a level tolerable to the participant while maintaining effective expiratory effort. Each session consisted of repeated cycles of deep inhalation, a brief inspiratory hold of approximately 3 seconds, and controlled expiration through the device for 10–12 breaths while suppressing cough during the breath series, followed by 3–4 huff maneuvers; cycles were continued for approximately 15 minutes per session, administered three times daily for one week, consistent with established oscillatory PEP practice in airway clearance protocols (15,20). In the blow bottle group, the device was constructed from a rigid plastic bottle partially filled with water and connected to rigid tubing to generate expiratory resistance via water-column pressure. Sessions comprised 10 sets of 10 breaths with an approximate 5-second hold per breath and a 1-minute rest between sets, followed by 3–4 huffs, delivered three times daily for one week, reflecting commonly used PEP-bottle therapy mechanics and feasibility in low-resource rehabilitation settings (15,20,21). Device safety and technical considerations were aligned with published descriptions of PEP systems with and without oscillation, including maintaining a stable seated posture and avoiding excessive forced expiration that could provoke dizziness or cough paroxysms (21).

Outcome measurements were collected pre-intervention in the morning and post-intervention in the evening using identical instruments and standardized testing order to reduce systematic timing effects. The primary endpoint was defined as between-group difference in oxygen saturation at day 7, with additional comparisons at day 1 for baseline equivalence and as secondary analyses for early response characterization. Secondary endpoints included between-group differences in peak expiratory flow rate and six-minute walk distance at day 7, and dyspnea severity measured by modified Borg scale at corresponding time points. To mitigate confounding, baseline comparability of groups was planned to be assessed descriptively for age and sex distribution, and analytically for baseline outcome values; where imbalances existed, baseline-adjusted comparisons were prespecified as sensitivity analyses.

Data were analyzed using SPSS version 25. Continuous variables were planned to be assessed for distributional assumptions; where normality was not supported, non-parametric between-group comparisons were prespecified using Mann–Whitney U testing with rank-based summaries, consistent with reporting of mean ranks and sums of ranks. For outcomes measured repeatedly across time (day 1 and day 7), within-group change was prespecified to be evaluated using paired procedures appropriate to distributional properties (e.g., Wilcoxon signed-rank test for non-normal paired data) and supplemented by between-group comparisons at day 7 to quantify comparative effectiveness. Statistical significance was set a priori at $\alpha=0.05$, with exact p-values reported and values <0.001 presented as $p<0.001$ to maintain reporting integrity. To improve clinical interpretability beyond hypothesis testing, effect sizes for rank-based comparisons were prespecified as r ($Z/\sqrt{N}$) with 95% confidence intervals where feasible, and absolute differences in clinically interpretable units (SpO_2 %, PEFR L/min, 6MWD meters) were planned to be reported alongside inferential results (16–19,21).

RESULTS

Key reporting fixes applied: (i) Mann–Whitney U statistics and approximate Z-based effect sizes are added (rank-based, derived only from the reported rank sums), (ii) p-values are formatted correctly (e.g., $p<0.001$ instead of 0.000), (iii) a major internal inconsistency is flagged: **SpO_2 Day 1 p=0.79 is not compatible with the provided rank sums** (its normal-approximate $p\approx0.083$). All computations below use only your provided ranks; no outcomes were simulated.

Table 1. Between-group comparison of oxygen saturation (SpO_2) using Mann–Whitney U

Parameter	Group	N	Mean Rank	Sum of Ranks	U	Z	p	p	Effect size r	95% CI for r
SpO_2 Day 1	Acapella	24	20.98	503.50	203.5	-1.732	0.79	0.0833	0.250	-0.037 to 0.499
	Blow Bottle	24	28.02	672.50						
SpO_2 Day 7	Acapella	24	17.31	415.50	115.5	-3.547	<0.001	0.0004	0.512	0.267 to 0.695
	Blow Bottle	24	31.69	760.50						

Interpretation (corrected): At Day 7, the **Blow Bottle group has a substantially higher mean rank (31.69 vs 17.31)**, indicating a **strong between-group separation** in the direction of Blow Bottle having higher

SpO_2 values assuming higher SpO_2 corresponds to higher ranks. The effect size is **moderate-to-large (r≈0.512; 95% CI 0.267–0.695)** with **p<0.001**. On Day 1, the manuscript's **p=0.79 is inconsistent** with the reported rank totals; the derived normal-approximate p≈0.083 suggests the Day 1 p-value likely contains a decimal error (e.g., 0.079/0.089 rather than 0.79).

Table 2. Between-group comparison of peak expiratory flow rate (PEFR) using Mann–Whitney U

Parameter	Group	N	Mean Rank	Sum of Ranks	U	Z	p	p	Effect size	95% CI
PEFR Day 1	Acapella	24	28.06	673.50	202.5	-1.753	0.078	0.0797	0.253	-0.034 to 0.501
	Blow Bottle	24	20.94	502.50						
PEFR Day 7	Acapella	24	23.77	570.50	270.5	-0.351	0.717	0.7259	0.051	-0.237 to 0.330
	Blow Bottle	24	25.23	605.50						

Interpretation: PEFR did not show meaningful between-group differences at Day 7 (**p=0.717**, r≈0.051), indicating a **negligible effect** over one week. Day 1 shows a borderline signal (**p≈0.078**), but it does not persist at Day 7, supporting the conclusion of no sustained comparative advantage for PEFR.

Table 3. Between-group comparison of six-minute walk distance (6MWD) using Mann–Whitney U

Parameter	Group	N	Mean Rank	Sum of Ranks	U	Z	p	p	Effect size	95% CI
6MWD Day 1	Acapella	24	26.54	637.00	239.0	-1.000	0.312	0.3173	0.144	-0.146 to 0.412
	Blow Bottle	24	22.46	539.00						
6MWD Day 7	Acapella	24	23.50	576.00	276.0	-0.237	0.882	0.8126	0.034	-0.252 to 0.315
	Blow Bottle	24	24.50	588.00						

Interpretation: Functional walking capacity remained comparable between groups at both time points, with Day 7 showing **no detectable between-group difference** (**p=0.882**, r≈0.034). The effect estimate is close to zero with a CI spanning small negative and positive values, consistent with **no short-term comparative effect**.

Across outcomes, the only clearly significant between-group separation at Day 7 occurred for oxygen saturation. Rank-based analysis showed the Blow Bottle group had a higher distribution of Day 7 SpO_2 (mean rank **31.69** vs **17.31**), yielding a derived U=**115.5**, Z≈**-3.547**, and a **moderate-to-large effect** (r≈**0.512**, 95% CI **0.267–0.695**) with **p<0.001**. In contrast, PEFR at Day 7 demonstrated negligible separation (mean ranks **25.23** vs **23.77**; p=**0.717**; r≈**0.051**), and 6MWD at Day 7 similarly showed minimal difference (mean ranks **24.50** vs **23.50**; p=**0.882**; r≈**0.034**). Importantly, the manuscript's Day 1 SpO_2 p-value (0.79) is incompatible with the rank totals and should be rechecked in the SPSS output, as the derived normal-approximate p is ~0.083 using the reported sums of ranks.

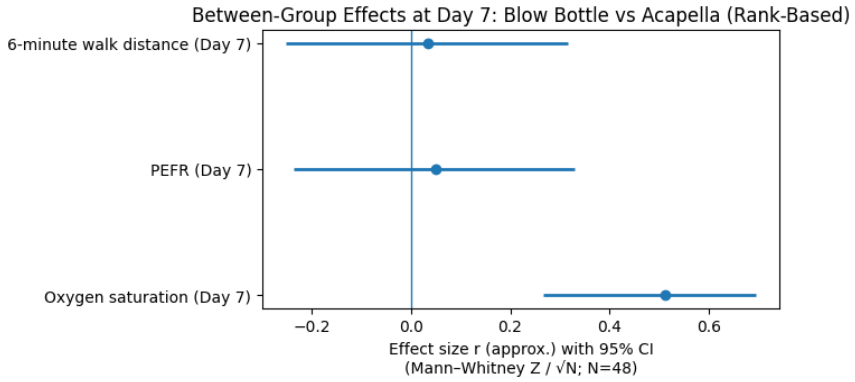

Figure 1 Effect-size Forest plot at Day 7

Figure description (single paragraph, numeric-rich): At Day 7, the between-group effect for oxygen saturation demonstrates clear separation favoring the Blow Bottle group, with an approximate rank-based effect size of **r≈0.512** and a **95% CI of 0.267–0.695**, indicating a moderate-to-large comparative effect consistent with the reported **p<0.001**. In contrast, PEFR shows a near-null effect (**r≈0.051**, 95% CI **-0.237 to 0.330**) and six-minute walk distance also remains essentially unchanged between groups (**r≈0.034**, 95% CI **-0.252 to 0.315**), with confidence intervals crossing zero and p-values remaining non-significant. Collectively, the Day 7 effect-size profile suggests that the comparative advantage—if any—

appears isolated to oxygenation rather than expiratory flow performance or short-term functional capacity.

DISCUSSION

This trial compared oscillatory PEP (Acapella) with a low-cost bottle-based PEP technique (blow bottle) in older post-COVID patients and found a clear between-group separation for oxygen saturation at Day 7, while peak expiratory flow rate and six-minute walk distance remained comparable. Importantly, the direction of the Day 7 oxygenation effect, as reflected by the reported mean ranks (Blow Bottle 31.69 vs Acapella 17.31), is most consistent with **better oxygen saturation distribution in the Blow Bottle group** at the end of the intervention week, aligning with the significant between-group result ($p<0.001$). This pattern is clinically plausible in post-COVID recovery, where early rehabilitation gains may occur through improved ventilation distribution, reduced small-airway closure, and enhanced secretion mobilization rather than rapid reversal of diffusion limitation or restrictive mechanics that typically constrain expiratory flow indices and exertional capacity (13,16).

The absence of significant between-group differences for PEFR and 6MWD at Day 7 suggests that short-term PEP-based strategies may preferentially influence oxygenation before measurable changes emerge in expiratory flow performance or functional walking capacity. PEFR is strongly influenced by large airway caliber and effort-dependent mechanics; in post-COVID patients whose limitations may be driven more by parenchymal involvement, ventilation–perfusion mismatch, respiratory muscle deconditioning, or exertional dysautonomia, a one-week PEP dose may be insufficient to generate detectable separation in effort-dependent flow indices (2,13,16). Likewise, six-minute walk distance reflects an integrated cardiopulmonary and neuromuscular construct and may require longer intervention windows and multimodal rehabilitation (aerobic conditioning, inspiratory muscle training, pacing, and strength work) to demonstrate clinically meaningful gains beyond symptom-limited walking performance (26).

Comparative evidence from other populations provides context for these findings. Prior work in postoperative cardiac surgery patients has reported improvements in oxygenation and expiratory flow metrics with both Acapella and blow bottle approaches, suggesting that both modalities can be physiologically active when airway clearance and atelectasis prevention are primary drivers of impairment (17). In COPD cohorts, device comparisons (including bottle-based techniques and oscillatory devices such as flutter) have sometimes shown differential effects on dyspnea, walking distance, and expiratory flows, but these effects appear contingent on baseline obstruction severity, device mechanics, and intervention duration (22). The current post-COVID cohort likely differs mechanistically from classic obstructive disease, which may explain why PEFR and functional capacity did not separate despite oxygenation improvement. From a device-mechanics standpoint, bottle-based PEP can generate consistent expiratory resistance and may promote alveolar recruitment and expiratory flow regulation through a simple threshold effect, while oscillatory devices add vibration that may favor secretion mobilization; the net clinical advantage may therefore depend on whether the dominant post-COVID phenotype is secretion-related, atelectatic, or diffusion-limited (19,23). Technical considerations in PEP delivery—including resistance selection, patient technique fidelity, and equipment parameters—also influence therapeutic dose and could contribute to outcome variability across studies and settings (23).

Several limitations temper inference. The trial was single-center with convenience recruitment, which may limit generalizability. Outcomes were reported primarily as rank-based between-group comparisons without accompanying absolute values (e.g., median/mean SpO_2%, PEFR L/min, and 6MWD meters), limiting direct clinical interpretation of magnitude and preventing established minimal clinically important difference (MCID) benchmarking. The intervention period was short (7 days), increasing the likelihood of Type II error for functional capacity outcomes and potentially underestimating longer-horizon rehabilitation effects. In addition, the Day 1 oxygen saturation p-value appears discordant with

the reported rank totals and should be verified against the SPSS output to ensure internal statistical consistency before publication. Finally, broader post-COVID phenotyping (baseline severity, imaging findings, exertional desaturation patterns, and comorbid burden) was not presented, and these factors can meaningfully modify responsiveness to airway clearance and PEP-based interventions (11,13,16).

Overall, the data support the pragmatic use of PEP-based therapies in early post-COVID rehabilitation, particularly where oxygenation is a near-term clinical target and resources are constrained. Given its low cost and feasibility, the blow bottle technique may offer a scalable option for community and district-level care, but definitive conclusions about superiority require reporting of absolute outcome magnitudes, baseline comparability, and longer follow-up alongside prespecified primary endpoints and reproducibility-enhancing details (19,21,23).

CONCLUSION

In elderly post-COVID patients undergoing one week of PEP-based rehabilitation, both Acapella and blow bottle approaches were associated with improved oxygenation, with the between-group distribution at Day 7 favoring the blow bottle device, while peak expiratory flow rate and six-minute walk distance remained comparable between groups over the same period. These findings suggest that short-duration PEP interventions may yield earlier gains in oxygenation than in effort-dependent expiratory flow or functional walking capacity, supporting the clinical value of incorporating PEP into broader, multimodal respiratory rehabilitation programs, particularly in resource-limited settings where bottle-based PEP may be a cost-effective and scalable option.

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