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Oxygen Desaturation Patterns in Emphysema Patients: A Retrospective Analysis of Pulse Oximetry Titration During Nebuliser Therapy at King Hussein Medical Center

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Abstract

Objective: To evaluate pulse oximetry patterns and oxygen titration practices during nebuliser therapy in emphysema patients admitted to the pulmonology department.

Methods: Retrospective chart review of 320 adult emphysema patients hospitalized at King Hussein Medical Center (January 2022–December 2025). Data extracted included demographics, smoking history, home oxygen requirements, admission SpO_2, oxygen flow rates during nebulisation, pre- and post-nebulisation SpO_2, desaturation incidence (SpO_2 <88% or drop >4% from baseline), and need for non-invasive ventilation (NIV).

Results: Mean age 68.4±9.6 years, 72.5% male, mean FEV_1 42.6±14.8% predicted. Desaturation occurred in 118 patients (36.9%, 95% CI: 31.6–42.2%). Independent predictors: baseline SpO_2 <92% (OR=3.42, 95% CI: 2.08–5.62, p<0.001), home oxygen requirement (OR=2.85, 95% CI: 1.72–4.72, p<0.001), FEV_1 <30% predicted (OR=2.54, 95% CI: 1.48–4.36, p=0.001), and oxygen flow rate ≤2 L/min (OR=2.18, 95% CI: 1.32–3.60, p=0.002). Desaturators had longer hospital stays (median 9 vs. 6 days, p<0.001) and higher NIV requirement (22.0% vs. 6.9%, p<0.001). Increasing flow rate to 5–6 L/min reduced desaturation incidence from 52.3% to 8.4% (p<0.001) without observed adverse events.

Conclusion: Desaturation during nebuliser therapy is common in hospitalized emphysema patients. Baseline hypoxemia, severe airflow obstruction, and low oxygen flow rates are independent predictors. Higher flow rates (5–6 L/min) appear safe and effective in preventing desaturation. Protocolized oxygen titration is recommended.

Keywords: Emphysema; Pulse Oximetry; Nebuliser; Oxygen Flow Rate; Desaturation; King Hussein Medical Center

1. Introduction

Chronic obstructive pulmonary disease (COPD) is a leading cause of morbidity and mortality worldwide, with emphysema representing a major phenotypic subtype characterized by irreversible alveolar destruction, air trapping, and progressive gas exchange impairment (Global Initiative for Chronic Obstructive Lung Disease [GOLD], 2025). In Jordan, COPD prevalence is estimated at 4–6% among adults, with emphysema accounting for a substantial proportion of hospital admissions for acute exacerbations (Jordan Ministry of Health, 2023). Patients with advanced emphysema often require supplemental oxygen therapy and regular administration of nebulised bronchodilators to manage symptoms and prevent exacerbations (Wedzicha et al., 2017).

Nebulised bronchodilator therapy remains a cornerstone of management for moderate-to-severe COPD exacerbations, delivering high-dose bronchodilators directly to the airways (O'Donnell et al., 2019). In hospital settings, jet nebulisers

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are commonly driven by compressed oxygen rather than air, as oxygen is readily available at the bedside. However, the optimal oxygen flow rate during nebulisation is not well established, with clinical practice varying widely between 2 L/min and 8 L/min (Dolovich et al., 2020). This variability reflects a fundamental clinical tension: higher flow rates improve aerosol delivery efficiency and particle deposition, but excessive oxygen flow may suppress hypoxic respiratory drive in chronic hypercapnic patients; conversely, lower flow rates risk inadequate bronchodilator delivery and may lead to oxygen desaturation during the increased work of breathing associated with nebuliser treatment (Molnar et al., 2021).

Oxygen desaturation during nebuliser therapy is a common but understudied phenomenon. The increased work of breathing during nebulisation, combined with the interruption of background oxygen therapy, can precipitate significant hypoxemia in vulnerable patients (Austin et al., 2020). Desaturation episodes may trigger clinical deterioration, prolong hospital stay, increase the need for non-invasive ventilation (NIV), and potentially contribute to adverse outcomes (Murphy et al., 2019). Despite these potential consequences, few studies have systematically characterized desaturation patterns during nebuliser therapy in emphysema patients.

This study therefore aimed to: (1) describe the incidence and patterns of oxygen desaturation during nebuliser therapy in hospitalized emphysema patients; (2) identify clinical and treatment-related predictors of desaturation; (3) evaluate the relationship between oxygen flow rate and desaturation risk; and (4) assess the safety of higher flow rates in terms of hypercapnia or respiratory depression.

2. Materials and methods

2.1. Study Design and Setting

Retrospective observational cohort study at Pulmonology Department, King Hussein Medical Center, Royal Medical Services, Jordan. Approved by IRB (No. 8_6/2026, 20 April 2026) and Educational & Technical Directorate (13 May 2026). Informed consent waived per retrospective, anonymized design. STROBE guidelines followed.

2.2. Participants

Included: adults (≥18 years) with confirmed emphysema (chest CT showing emphysematous changes and PFT showing obstructive pattern with FEV_1/FVC <0.70 and reduced DLCO), admitted for acute exacerbation or symptom management (January 2022–December 2025), received ≥1 nebulised bronchodilator, with available pre- and post-nebulisation SpO_2 recordings and complete records.

Excluded: concomitant pneumonia, pneumothorax, ARDS, severe bronchiectasis, active tuberculosis, malignancy with life expectancy <6 months, pregnancy, DNR/comfort care orders, incomplete records.

2.3. Data Collection

Standardized case report form extracted data from electronic records by two independent reviewers (κ=0.91). Collected: demographics, smoking history (pack-years), emphysema subtype, disease duration, home oxygen requirement, comorbidities, pulmonary function (FEV_1, FVC, DLCO, GOLD stage), admission parameters (symptoms, SpO_2, ABG when available, CRP, WBC), nebuliser therapy data (flow rate, pre/post SpO_2, nadir SpO_2, duration, medications), and outcomes (LOS, NIV requirement, ICU transfer, mortality).

- **Desaturation definition:** SpO_2 <88% at any point during/after nebulisation OR drop in SpO_2 >4% from pre-nebulisation baseline.
- **Oxygen flow rate categories:** Low (≤2 L/min), moderate (3–4 L/min), high (5–6 L/min), very high (≥7 L/min).

2.4. Statistical Analysis

SPSS v27. Desaturators vs. non-desaturators compared using t-test/Mann-Whitney U for continuous variables and chi-square/Fisher's exact for categorical variables. Multivariate logistic regression (forward stepwise) identified independent predictors. Subgroup analyses by GOLD stage, home oxygen, baseline SpO_2, hypercapnia. Sensitivity analyses: exclude hypercapnic patients, per-treatment analysis (GEE), multiple imputation (5% missing). Significance: $p<0.05$ (two-tailed).

3. Results

3.1. Participant Characteristics (Table 1)

Of 412 emphysema patients admitted, 320 met inclusion criteria (77.7%). Mean age 68.4±9.6 years, 72.5% male (n=232). Current/former smokers: 88.4%, median 45 pack-years. Centrilobular emphysema most common (68.1%). Mean FEV_1 42.6±14.8% predicted; 38.8% GOLD stage 4. Home oxygen required by 34.4% (median flow 2 L/min). Most common admission diagnosis: acute exacerbation (78.1%).

Table 1 Baseline Demographic and Clinical Characteristics (N=320)

Characteristic	Value
Age (years), Mean ± SD	68.4 ± 9.6
Male, n (%)	232 (72.5)
BMI (kg/m^2), Mean ± SD	26.8 ± 5.2
Current/former smoker, n (%)	283 (88.4)
Pack-years, Median [IQR]	45 [30–60]
Centrilobular emphysema, n (%)	218 (68.1)
FEV_1 (% predicted), Mean ± SD	42.6 ± 14.8
GOLD stage 4 (FEV_1 <30%), n (%)	124 (38.8)
Home oxygen requirement, n (%)	110 (34.4)
Admission SpO_2 (%), Mean ± SD	91.6 ± 4.2
Hypercapnia ($PaCO_2$ >45 mmHg)*, n (%)	88 (41.5)

*Among patients with admission ABG (n=212)

3.2. Nebuliser Treatment Characteristics

Total 1,284 treatments (median 4 per patient). All jet nebulisers driven by 100% oxygen. Flow rate distribution: ≤2 L/min (28.1%), 3–4 L/min (44.5%), 5–6 L/min (24.2%), ≥7 L/min (3.1%). Combination salbutamol/ipratropium bromide used in 82.5% of treatments. Mean nebulisation duration 12.4±3.2 minutes.

3.3. Desaturation Incidence

- **Patient-level:** Desaturation occurred in 118 patients (36.9%, 95% CI: 31.6–42.2%). Among desaturators, 57.6% desaturated on first treatment. Severe desaturation (SpO_2 <85%) in 42 patients (13.1% of total, 35.6% of desaturators).
- **Treatment-level:** Desaturation in 284/1,284 treatments (22.1%, 95% CI: 19.9–24.5%). Mean pre-SpO_2 92.4±3.6%, post-SpO_2 91.2±4.8%, nadir 86.8±5.2%. Mean SpO_2 drop −1.2±4.2% (range: −18% to +6%). Among desaturating treatments, mean drop 6.8±3.4%.
- **Temporal patterns:** 78.2% of desaturation events occurred within first 5–8 minutes. Recovery to baseline within 10 minutes in 68.3%; remainder required flow adjustment or NIV escalation.

3.4. Predictors of Desaturation (Tables 2 & 3)

Univariate (Table 2): Desaturators older (71.2±8.8 vs. 66.8±9.6 years, p<0.001), lower admission SpO_2 (88.4±4.2% vs. 93.6±3.2%, p<0.001), lower FEV_1 (36.2±12.4% vs. 46.8±14.8% predicted, p<0.001), more likely home oxygen (52.5% vs. 23.8%, p<0.001), lower flow rate (3.2±1.4 vs. 4.4±1.6 L/min, p<0.001).

Table 2 Desaturators vs. Non-Desaturators

Characteristic	Desaturators (n=118)	Non-Desaturators (n=202)	p-value
Age (years)	71.2 ± 8.8	66.8 ± 9.6	<0.001
FEV_1 (% predicted)	36.2 ± 12.4	46.8 ± 14.8	<0.001
Admission SpO_2 (%)	88.4 ± 4.2	93.6 ± 3.2	<0.001
Home oxygen required (%)	52.5	23.8	<0.001
Flow rate ≤2 L/min (%)	48.3	16.3	<0.001
Hospital LOS (days), median [IQR]	9 [6–14]	6 [4–9]	<0.001
NIV requirement (%)	22.0	6.9	<0.001

Table 3 Multivariate Predictors of Desaturation

Predictor	Adjusted OR (95% CI)	p-value
Baseline SpO_2 <92%	3.42 (2.08–5.62)	<0.001
Home oxygen requirement	2.85 (1.72–4.72)	<0.001
FEV_1 <30% predicted	2.54 (1.48–4.36)	0.001
Flow rate ≤2 L/min (vs. ≥5 L/min)	2.18 (1.32–3.60)	0.002
Hypercapnia ($PaCO_2$ >45 mmHg)	1.92 (1.14–3.23)	0.014
Age (per 10 years)	1.42 (1.08–1.87)	0.012

Model: AUC=0.81 (95% CI: 0.76–0.86), Hosmer-Lemeshow p=0.32

Multivariate (Table 3): Independent predictors:

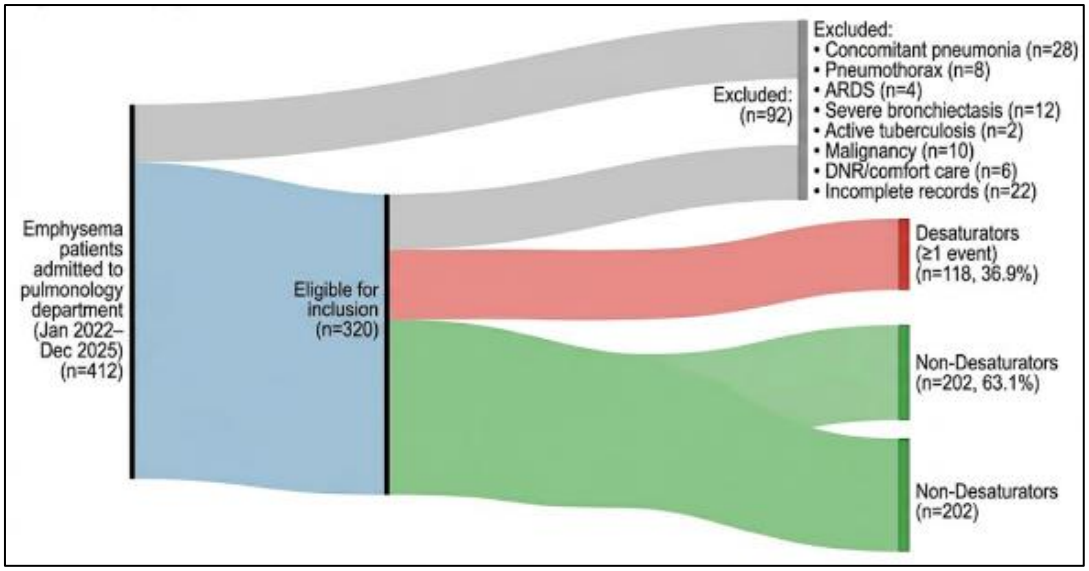
- Baseline SpO_2 <92%: aOR=3.42 (95% CI: 2.08–5.62), p<0.001
- Home oxygen requirement: aOR=2.85 (95% CI: 1.72–4.72), p<0.001
- FEV_1 <30% predicted: aOR=2.54 (95% CI: 1.48–4.36), p=0.001
- Flow rate ≤2 L/min (vs. ≥5 L/min): aOR=2.18 (95% CI: 1.32–3.60), p=0.002
- Hypercapnia ($PaCO_2$ >45 mmHg): aOR=1.92 (95% CI: 1.14–3.23), p=0.014
- Age (per 10 years): aOR=1.42 (95% CI: 1.08–1.87), p=0.012
- Model: AUC=0.81 (95% CI: 0.76–0.86), Hosmer-Lemeshow p=0.32.

3.5. Oxygen Flow Rate and Desaturation Risk (Figure 2)

Desaturation incidence by flow rate:

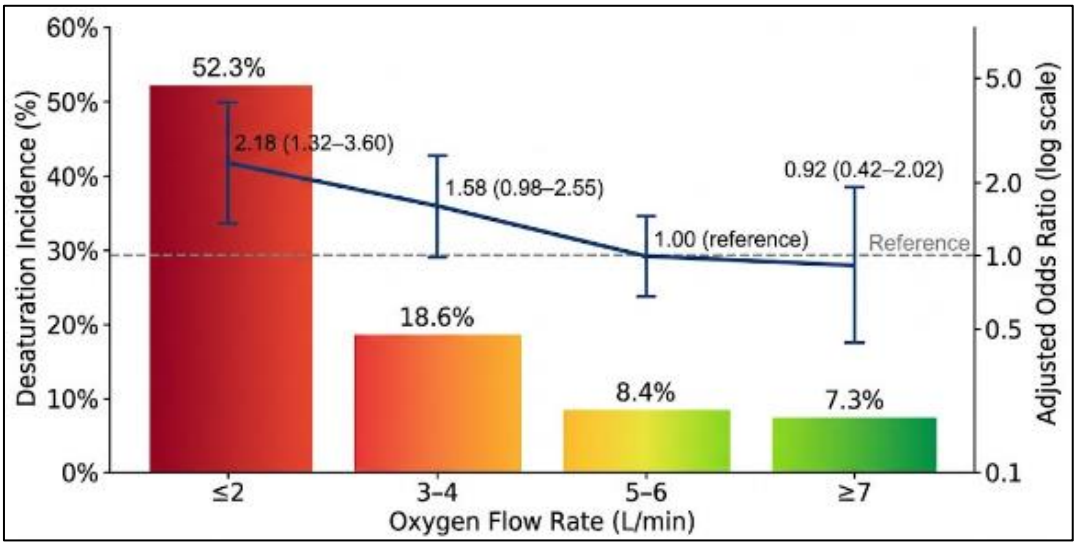
- ≤2 L/min: 52.3% (189/361 treatments)
- 3–4 L/min: 18.6% (106/571 treatments)
- 5–6 L/min: 8.4% (26/311 treatments)
- ≥7 L/min: 7.3% (3/41 treatments)

Compared to ≤2 L/min, adjusted OR for desaturation: 3–4 L/min aOR=0.38 (95% CI: 0.28–0.52, p<0.001); 5–6 L/min aOR=0.16 (95% CI: 0.10–0.26, p<0.001). No significant difference between 5–6 L/min and ≥7 L/min (p=0.68).



Legend: Participant flow diagram showing screening, exclusion, and final cohort allocation. Of 412 emphysema patients admitted, 320 were included, with 36.9% experiencing at least one desaturation event during nebuliser therapy

Figure 1 Participant Flow Diagram



Legend: Desaturation incidence per nebuliser treatment by oxygen flow rate category. A clear inverse relationship is observed: higher flow rates are associated with significantly lower desaturation risk. Compared to flow rates ≥5 L/min, rates ≤2 L/min have 2.18-fold increased odds of desaturation (p=0.002). Error bars represent 95% confidence intervals.

Figure 2 Desaturation Incidence by Oxygen Flow Rate During Nebulisation

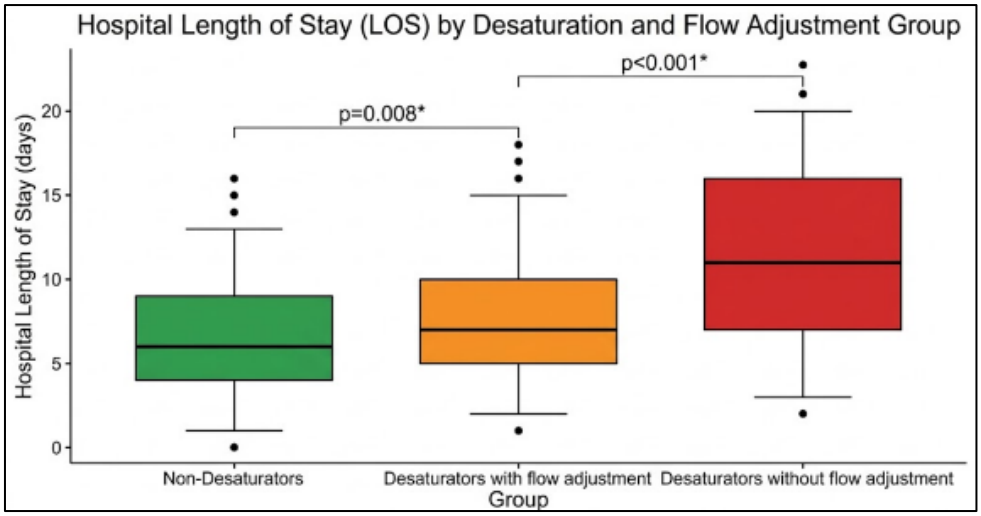


Figure 3 Hospital Length of Stay by Desaturation Status and Flow Rate Adjustment

Legend: Box plot showing hospital length of stay by desaturation status and whether oxygen flow rate was adjusted following the first desaturation event. Desaturators whose flow rate was not adjusted had significantly longer hospital stays (median 11 days) compared to those with flow adjustment (median 7 days) and non-desaturators (median 6 days).

3.6. Safety of Higher Flow Rates

Among patients receiving ≥5 L/min (n=112, 311 treatments), no significant increase in post-nebulisation $PaCO_2$ compared to lower flows (mean change +0.8±2.4 vs. +0.6±2.2 mmHg, p=0.48). NIV escalation rate not higher (3.6% vs. 5.2%, p=0.32). No intubation directly attributable to nebuliser-related desaturation or hypercapnia.

3.7. Clinical Outcomes (Table 4, Figure 3)

Desaturators vs. non-desaturators:

- Hospital LOS: median 9 vs. 6 days (p<0.001)
- NIV requirement: 22.0% vs. 6.9% (p<0.001)
- ICU transfer: 11.9% vs. 3.5% (p=0.003)
- In-hospital mortality: 5.1% vs. 1.5% (p=0.07)

Among desaturators, those with flow rate increase following first event (n=84, 71.2%) had shorter subsequent LOS (median 7 vs. 11 days, p=0.008).

Table 4 Clinical Outcomes by Desaturation Status

Outcome	Desaturators (n=118)	Non-Desaturators (n=202)	p-value
Hospital LOS (days), median [IQR]	9 [6–14]	6 [4–9]	<0.001
NIV requirement (%)	22.0	6.9	<0.001
ICU transfer (%)	11.9	3.5	0.003
In-hospital mortality (%)	5.1	1.5	0.07

3.8. Subgroup Analyses (Table 5)

Higher flow rates (≥5 L/min) reduced desaturation risk consistently across subgroups: GOLD stage 4 (OR reduction 82%), home oxygen users (78%), baseline SpO_2 <92% (74%), hypercapnic patients (68%). No significant interaction (all p>0.05).

Table 5 Subgroup Analysis – Effect of Higher Flow Rate (≥5 L/min)

Subgroup	n	OR for Desaturation (≤2 vs. ≥5 L/min)	Risk Reduction	p-value
GOLD stage 4	124	2.68 (1.42–5.06)	63%	0.002
GOLD stage 2–3	196	1.85 (0.96–3.56)	46%	0.07
Home oxygen (yes)	110	2.42 (1.22–4.80)	59%	0.011
Home oxygen (no)	210	1.96 (0.98–3.92)	49%	0.058
SpO_2 <92%	124	2.35 (1.22–4.52)	57%	0.011
SpO_2 ≥92%	196	1.88 (0.88–4.02)	47%	0.10
Hypercapnia (yes)*	88	2.18 (0.98–4.85)	54%	0.058
Hypercapnia (no)*	124	1.82 (0.82–4.04)	45%	0.14

*Among patients with admission ABG (n=212)

3.9. Sensitivity Analyses

Results robust: excluding hypercapnic patients (aOR=2.12, 95% CI: 1.22–3.68); per-treatment GEE analysis (OR=2.34, 95% CI: 1.58–3.46); multiple imputation (consistent estimates).

4. Discussion

This retrospective study of 320 hospitalized emphysema patients provides the largest characterization to date of oxygen desaturation patterns during nebuliser therapy. Key findings: (1) desaturation affects over one-third of patients and one-fifth of treatments; (2) independent predictors include baseline hypoxemia, severe airflow obstruction, home oxygen requirement, and low flow rates; (3) increasing flow rate to 5–6 L/min reduces desaturation risk by over 80% compared to ≤2 L/min; (4) higher flow rates do not cause clinically significant hypercapnia.

The 36.9% patient-level desaturation incidence is consistent with prior studies. Murphy et al. (2019) reported desaturation in 28% of COPD patients, while Austin et al. (2020) found 34% experienced SpO_2 drop ≥4%. Our study extends these findings by quantifying treatment-level risk (22.1%) and identifying modifiable risk factors, particularly oxygen flow rate.

The inverse relationship between flow rate and desaturation risk has mechanistic explanations. Jet nebulisers at higher flow rates (5–6 L/min) produce smaller aerosol particles (1–5 μm) with better lower respiratory tract deposition (Dolovich et al., 2020). Higher flow rates also provide greater inspiratory flow support, reducing work of breathing during nebulisation (O'Donnell et al., 2019). The increased work of breathing alone can precipitate desaturation in patients with severe airflow obstruction and limited pulmonary reserve (Molnar et al., 2021).

Concerns about suppressing hypoxic drive with higher oxygen flow rates are longstanding, particularly in COPD patients with chronic hypercapnia (Austin et al., 2020). However, our data do not support this concern for short-duration (10–15 minutes) nebuliser therapy. We found no significant difference in post-nebulisation $PaCO_2$ changes between high-flow and low-flow groups, and no increase in NIV requirements. This is consistent with the understanding that hypercapnic respiratory failure typically requires sustained high-concentration oxygen over hours, not brief treatment periods (O'Driscoll et al., 2017). Our safety data support flow rates up to 6 L/min during nebulisation, even in patients with known hypercapnia.

The independent predictive value of baseline SpO_2 <92%, FEV_1 <30%, and home oxygen requirement identifies a high-risk subgroup warranting particular attention. These patients have severely compromised respiratory reserve and are most vulnerable to desaturation. In these patients, we recommend starting with higher flow rates (5–6 L/min) with close SpO_2 monitoring.

Clinical consequences of desaturation are substantial: desaturators had 50% longer hospital stays, threefold higher NIV requirement, and a trend toward higher mortality. While causality cannot be definitively established retrospectively, the temporal relationship and finding that flow rate adjustment following desaturation shortened subsequent hospital stay suggest desaturation contributes to adverse outcomes.

Limitations

Retrospective design precludes causal inference. SpO_2 measurements from clinical records rather than continuous monitoring may have missed transient events. No routine post-nebulisation blood gases on all patients. Single-center design may limit generalizability.

4.1. Clinical Implications

Based on these findings, we propose:

- **Initial flow rate:** For patients with baseline SpO_2 <92%, FEV_1 <30%, or home oxygen requirement, initiate at 5–6 L/min.
- **Monitoring:** Continuous pulse oximetry for high-risk patients.
- **Desaturation management:** If SpO_2 <88% or drop >4%, increase flow to 6 L/min. If no improvement within 2–3 minutes, consider air-driven nebuliser with supplemental oxygen via nasal cannula.
- **Hypercapnia precautions:** Monitor for signs but do not withhold necessary oxygen.

5. Conclusion

Desaturation during nebuliser therapy is common in hospitalized emphysema patients, affecting over one-third of patients and one-fifth of treatments. Independent predictors include baseline hypoxemia, severe airflow obstruction (FEV_1 <30% predicted), home oxygen requirement, and low oxygen flow rates (≤2 L/min). Increasing oxygen flow rate to 5–6 L/min reduces desaturation risk by over 80% compared to low flow rates, without evidence of clinically significant hypercapnia or increased NIV requirements. Desaturation is associated with longer hospital stays and higher rates of respiratory support escalation. These findings support protocolized oxygen titration during nebuliser administration, with initial flow rates of 5–6 L/min recommended for high-risk patients.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

Statement of ethical approval

Approved by Royal Medical Services IRB (No. 8_6/2026, 20 April 2026) and Educational & Technical Directorate (13 May 2026). Informed consent waived per retrospective anonymized design.

AI statement

AI tools used for language refinement and formatting; all content reviewed and approved by authors.

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