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Role of Fiberoptic Bronchoscopy-Guided Bronchoalveolar Lavage with Local Gentamicin Instillation in the Treatment of Ventilator-Associated Pneumonia

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Abstract

Background: Ventilator-associated pneumonia (VAP) is a frequent and serious complication among mechanically ventilated critically ill patients, associated with prolonged mechanical ventilation, longer ICU stay, and increased morbidity and mortality. Fiberoptic bronchoscopy enables direct airway clearance, accurate microbiological sampling, and targeted local antimicrobial delivery, and may serve as a valuable adjunct to conventional VAP treatment.

Aim of the Work: To evaluate the therapeutic effect of fiberoptic bronchoscopy-guided bronchoalveolar lavage (BAL) with local gentamicin instillation, as an adjunct to conventional treatment, in mechanically ventilated patients with VAP.

Patients and Methods: A prospective randomized comparative study was conducted on mechanically ventilated adult patients with VAP admitted to the Critical Care Unit of Al-Zahraa University Hospital between May 2025 and May 2026. Ninety patients were randomized into two equal groups; after two patients were transferred to another hospital, 88 patients (44 per group) were included in the final analysis. Group A received conventional VAP treatment only, while Group B received conventional treatment plus fiberoptic bronchoscopy-guided BAL with local intrabronchial gentamicin (5 mg/kg), repeated every other day for 7 days. Oxygen saturation (SpO_2), FiO_2, PaO_2, PaO_2/FiO_2 (P/F) ratio, peak airway pressure, body temperature, total leukocytic count (TLC), and C-reactive protein (CRP) were assessed before and after treatment.

Results: Baseline demographic and clinical characteristics were comparable between groups. After treatment, Group B showed significantly higher SpO_2 (91.77 ± 3.33% vs. 86.00 ± 3.99%, P<0.0001), PaO_2 (101.75 ± 7.48 vs. 90.69 ± 9.05 mmHg, P=0.009), and P/F ratio (2.57 ± 0.88 vs. 1.88 ± 0.71, P<0.0001), together with lower FiO_2 requirements (43.68 ± 15.04% vs. 55.57 ± 19.89%, P=0.002) and peak airway pressure (25.57 ± 5.93 vs. 30.00 ± 4.83 cmH_2O, P=0.010). TLC and CRP decreased more markedly in Group B, with significant between-group differences after treatment and at final follow-up. Group B also achieved earlier and more pronounced normalization of body temperature.

Conclusion: Adding fiberoptic bronchoscopy-guided BAL with local gentamicin to conventional VAP treatment was associated with greater improvement in oxygenation and respiratory mechanics, more rapid resolution of fever, and a greater reduction in inflammatory markers compared with conventional treatment alone, supporting its use as an effective adjunctive therapy in appropriately selected mechanically ventilated patients with VAP.

INTRODUCTION

Ventilator-associated pneumonia (VAP) is a hospital-acquired pneumonia that develops in patients receiving invasive mechanical ventilation for at least 48 hours. It is one of the most common nosocomial infections among mechanically ventilated patients, with a reported prevalence of 5–40% depending on the clinical setting and diagnostic criteria.[1] Clinically, VAP poses a significant health risk for patients

admitted to the intensive care unit (ICU), causing increased mortality, longer hospital stays, and higher healthcare costs.[2]

Pathophysiologically, endotracheal intubation interferes with the normal protective function of the upper airway, stimulates mucus production, and impairs sputum clearance — mechanisms that underlie the development of VAP and make intensive airway management essential for its prevention.[3] Interobserver variability and differences in diagnostic algorithms between institutions further contribute to variability in reported VAP incidence and complicate comparisons between studies.[4]

With the development of medical technology, fiberoptic bronchoscopy has assumed an important role in the diagnosis and treatment of respiratory diseases.[5] Beyond relieving upper and lower airway obstruction through removal of retained secretions, it enables identification of the causative organism and guides appropriate antibiotic selection, which is of major importance for effective treatment of pulmonary infection.[6] Bronchoalveolar lavage (BAL) can be used to treat VAP through removal of viscid and copious secretions, direct instillation of antibiotics into the bronchial tree, and microbiological examination of BAL fluid to guide appropriate antibiotic administration.

The purpose of the present study was to evaluate the therapeutic effect of fiberoptic bronchoscopy-guided BAL with local gentamicin instillation, as an adjunct to conventional treatment, in patients with ventilator-associated pneumonia.

AIM OF THE WORK

To evaluate the effect of adding regular fiberoptic bronchoscopy-guided bronchoalveolar lavage with local antibiotic administration in the bronchial tree to conventional VAP treatment in critically ill mechanically ventilated patients.

Primary Outcome:

The effect of adding regular BAL with intrabronchial antibiotic administration to conventional VAP treatment, on oxygenation and respiratory mechanics.

Secondary Outcome:

To assess the association between regular BAL with antibiotic administration and improvement in ventilatory, clinical, and laboratory parameters.

PATIENTS AND METHODS

Study Design and Setting

This prospective randomized comparative study was conducted in the Critical Care Unit of Al-Zahraa University Hospital, Al-Azhar University, Cairo, Egypt, from May 2025 to May 2026, after approval of the Ethics Committee of the Critical Care and Emergency Medicine Department, Faculty of Medicine, Al-Azhar University (approval no. 2746, May 2025), and informed written consent from patients or their relatives.

Patient Selection

Ninety mechanically ventilated patients diagnosed with VAP were randomized into two equal groups (45 per group); after two patients were transferred to another hospital during follow-up, 88 patients (44 per group) were included in the final analysis. Sample size was calculated using G*Power (version 3.1.9.7) based on an expected difference of 24% derived from previous research, with α error = 0.05 and power = 80%, yielding 45 patients per group.

Inclusion Criteria: Adult patients (≥ 18 years) who were critically ill, mechanically ventilated, and diagnosed with VAP based on clinical, radiological, and laboratory criteria (new progressive pulmonary infiltrate, fever, leucocytosis or leucopenia, and decreased oxygen saturation).

Exclusion Criteria: Patients < 18 years; pregnant women; patients with pre-existing pulmonary disease (lung cancer, idiopathic pulmonary fibrosis, COPD, or previous lung surgery); patients with sleep apnea; and patients with renal impairment (elevated serum creatinine with decreased GFR).

Intervention

Group A (control) received conventional VAP treatment only, with empirical antibiotic therapy selected according to risk factors for multidrug-resistant organisms and the local ICU antibiogram, directed against Gram-negative bacilli including Pseudomonas aeruginosa and Staphylococcus aureus, with MRSA coverage (vancomycin or linezolid) added when indicated. Group B (study) received conventional treatment plus fiberoptic bronchoscopy-guided BAL with local intrabronchial gentamicin (5 mg/kg).

Bronchoscopy was performed without disconnecting the patient from the ventilator, under continuous cardiorespiratory monitoring and adequate sedation. The tracheobronchial tree was systematically inspected and thick secretions, mucus plugs, and purulent material aspirated from both main and segmental bronchi. BAL was performed in the bronchopulmonary segment showing the most prominent radiological infiltrate and/or purulent secretions, by instilling sterile normal saline in 20-mL aliquots (total 100–120 mL) with gentle aspiration after each aliquot; the recovered fluid was sent for Gram staining and quantitative culture. Gentamicin 5 mg/kg diluted in 20 mL sterile normal saline was then instilled through the working channel into the affected segment, and the procedure was repeated every other day for 7 days.

Clinical, Laboratory, and Ventilatory Assessment

All patients underwent comprehensive clinical assessment (level of consciousness, vital signs, SpO_2, and respiratory system examination) at baseline and every other day for 7 days. Laboratory investigations (complete blood count, CRP, arterial blood gases, serum electrolytes, and renal and liver function) and chest X-ray were performed at baseline and repeated during follow-up. Ventilatory parameters (FiO_2, PEEP, peak airway pressure, tidal volume, and P/F ratio) were recorded at baseline and before and after BAL every other day for 7 days.

Statistical Analysis

Data were analyzed using SPSS version 27. Normality was assessed using the Shapiro-Wilk and Kolmogorov-Smirnov tests. Normally distributed continuous data were presented as mean ± SD and compared using the independent-sample t-test (between groups) and paired-sample t-test (within groups). Categorical data were presented as frequency and percentage and compared using the Chi-square or Fisher's exact test. Repeated measurements were analyzed using a general linear model adjusted with the Bonferroni test. A two-tailed P value < 0.05 was considered statistically significant.

RESULTS

Ninety-five mechanically ventilated patients were assessed for eligibility; five did not meet the inclusion criteria. The remaining 90 patients were randomized equally into Group A and Group B. During follow-up, one patient from each group was transferred to another hospital, so the final analysis included 88 patients (44 per group).

Baseline demographic characteristics and primary ICU admission diagnoses were comparable between groups, with no statistically significant differences in age, sex distribution, or diagnosis (Table 1).

Table (1): Baseline Demographic and Clinical Characteristics of the Studied Groups

	Group A		Group B		P value
	Mean	SD	Mean	SD	
age	61.23	10.39	58.86	11.28	0.309
Gender	N	%	N	%	
Female	19	43.2%	20	45.5%	0.830
Male	25	56.8%	24	54.5%	
Diagnosis					
Brain hemorrhage	6	13.6%	4	9.1%	0.340
cardiac arrest	2	4.5%	2	4.5%	
Cardiogenic shock	0	0.0%	1	2.3%	
CIDP	1	2.3%	1	2.3%	
DCL	1	2.3%	3	6.8%	
DKA	2	4.5%	2	4.5%	
Hepatic Coma	0	0.0%	2	4.5%	
hypokalemia	1	2.3%	1	2.3%	
hyponatremia	1	2.3%	1	2.3%	
ischemic stroke	0	0.0%	5	11.4%	
meningitis	2	4.5%	0	0.0%	
Pneumonia	2	4.5%	2	4.5%	
Post operative	4	9.1%	4	9.1%	
RTA	2	4.5%	2	4.5%	
sepsis	8	18.2%	4	9.1%	
septic shock	1	2.3%	4	9.1%	
stroke	9	20.5%	3	6.8%	
suspect meningitis	0	0.0%	2	4.5%	
Trauma	2	4.5%	1	2.3%	

**Neurological disorders (stroke, brain hemorrhage) and sepsis/septic shock were the most frequent ICU admission diagnoses in both groups. Data are mean ± SD or number (%); independent-sample t-test; Chi-square/Fisher's exact test.*

Following the fluid/treatment course, both groups showed significant improvement in oxygenation and respiratory mechanics compared with baseline; however, the improvement was significantly greater in Group B for every parameter assessed (Tables 2–6).

Table (2): Comparison of Oxygen Saturation (SpO_2) Between the Studied Groups Before and After Treatment

SpO_2 (%)	Group A		Group B		P value
	Mean	SD	Mean	SD	
Baseline	83.61	3.49	85.07	4.80	0.202
After treatment	86.00	3.99	91.77	3.33	< 0.0001
Difference (baseline/after)	2.39	2.90	6.70	2.37	< 0.0001

Within-group P value (baseline vs. after treatment): Group A < 0.0001, Group B < 0.0001. Data are mean ± SD; independent-sample t-test; paired-sample t-test.

Table (3): Comparison of Fraction of Inspired Oxygen (FiO_2) Between the Studied Groups Before and After Treatment

FiO_2 (%)	Group A		Group B		P value
	Mean	SD	Mean	SD	
Baseline	68.64	21.33	63.30	19.32	0.222
After treatment	55.57	19.89	43.68	15.04	0.002
Difference (baseline/after)	13.07	12.45	19.61	8.16	0.004

Within-group P value (baseline vs. after treatment): Group A < 0.0001, Group B < 0.0001. Data are mean ± SD; independent-sample t-test; paired-sample t-test.

Table (4): Comparison of Arterial Partial Pressure of Oxygen (PaO_2) Between the Studied Groups Before and After Treatment

PaO_2 (mmHg)	Group A		Group B		P value
	Mean	SD	Mean	SD	
Baseline	74.46	10.43	78.63	12.93	0.427
After treatment	90.69	9.05	101.75	7.48	0.009
Difference (baseline/after)	16.23	3.56	23.13	6.60	0.006

Within-group P value (baseline vs. after treatment): Group A < 0.0001, Group B 0.001. Data are mean ± SD; independent-sample t-test; paired-sample t-test.

Table (5): Comparison of Peak Airway Pressure Between the Studied Groups Before and After Treatment

Peak pressure (cmH_2O)	Group A		Group B		P value
	Mean	SD	Mean	SD	
Baseline	37.81	4.82	41.02	7.82	0.130
After treatment	30.00	4.83	25.57	5.93	0.010
Difference (baseline/after)	7.81	3.64	15.45	4.29	< 0.0001

Within-group P value (baseline vs. after treatment): Group A 0.002, Group B < 0.0001. Data are mean ± SD; independent-sample t-test; paired-sample t-test.

Table (6): Comparison of PaO_2/FiO_2 (P/F) Ratio Between the Studied Groups Before and After Treatment

P/F ratio	Group A		Group B		P value
	Mean	SD	Mean	SD	
Baseline	1.21	0.40	1.34	0.51	0.176
After treatment	1.88	0.71	2.57	0.88	< 0.0001
Difference (baseline/after)	0.67	0.44	1.23	0.47	< 0.0001

Within-group P value (baseline vs. after treatment): Group A < 0.0001, Group B < 0.0001. Data are mean ± SD; independent-sample t-test; paired-sample t-test.

Total leukocytic count (TLC) and CRP were comparable between groups at baseline and decreased significantly in both groups after treatment; the reduction was significantly greater in Group B, both after

treatment and at final follow-up (Tables 7 and 8).

Table (7): Comparison of Total Leukocytic Count (TLC, ×10³/mm³) Between the Studied Groups Throughout Follow-up

TLC	Group A		Group B		P value
	Mean	SD	Mean	SD	
Baseline	13.82	3.18	12.80	2.95	0.120
After treatment	13.12	2.34	11.34	2.82	0.002
At final follow-up	12.19	2.44	10.85	2.54	0.014

Within-group P value (baseline vs. after treatment / final follow-up) was < 0.05 for both groups at both time points. Data are mean ± SD; general linear model adjusted with Bonferroni test.

Table (8): Comparison of C-Reactive Protein (CRP, mg/L) Between the Studied Groups Throughout Follow-up

CRP	Group A		Group B		P value
	Mean	SD	Mean	SD	
Baseline	212.18	75.20	198.70	67.95	0.380
After treatment	182.66	73.97	153.02	46.07	0.027
At final follow-up	150.05	73.36	123.41	45.84	0.044

Within-group P value (baseline vs. after treatment / final follow-up) was < 0.001 for both groups at both time points. Data are mean ± SD; general linear model adjusted with Bonferroni test.

Body temperature was comparable between groups at baseline. Serial measurements showed progressive improvement in both groups, with Group B reaching significantly lower temperatures from the first night onward (P = 0.022), and the greatest between-group difference observed on the third night (P < 0.001) (Table 9).

Table (9): Serial Temperature Measurements (°C) During Follow-up

Time point	Group A	Group B	P value
Day 1, morning	38.99 ± 0.56	38.86 ± 0.49	0.223
Day 1, night	38.62 ± 0.54	38.34 ± 0.59	0.022
Day 2, morning	38.45 ± 0.54	38.23 ± 0.52	0.054
Day 2, night	38.18 ± 0.57	37.85 ± 0.48	0.005
Day 3, morning	37.98 ± 0.57	37.75 ± 0.39	0.030
Day 3, night	37.78 ± 0.57	37.22 ± 0.35	< 0.001

Data are mean ± SD; general linear model adjusted with Bonferroni test. Within-group reductions from Day-1 morning were significant (P < 0.001) at every subsequent time point in both groups.

DISCUSSION

In the present prospective comparative study of 88 mechanically ventilated patients with VAP, no statistically significant differences were observed between groups regarding age, sex distribution, or primary ICU admission diagnosis, indicating that the two groups were well matched at baseline. This is consistent with the meta-analysis by Tang et al.[8] and the prospective study of Wu and Liu,[9] both of whom reported comparable baseline demographic characteristics between bronchoscopy and conventional treatment groups. The predominance of neurological disorders and sepsis as underlying admission diagnoses in the present cohort is also consistent with the review by Papazian et al.,[7] who identified these as among the most common conditions preceding VAP, and with Howroyd et al.,[10] who highlighted impaired mucus clearance as a key mechanism sustaining infection in such patients.

Baseline oxygenation and respiratory mechanics (PaO_2, FiO_2, P/F ratio, and peak airway pressure) were comparable between groups, indicating similar disease severity at enrolment. After treatment, both groups improved significantly, but the improvement was significantly greater with fiberoptic bronchoscopy-guided BAL, with higher PaO_2 and P/F ratio and lower FiO_2 and peak airway pressure in Group B. This is consistent with Wu and Liu[9] and with Tang et al.,[8] who reported that bronchoscopic clearance of secretions restores airway patency, improves alveolar recruitment and ventilation-perfusion matching, and enhances lung compliance, thereby improving gas exchange and reducing airway pressures. Zhang et al.,[11] in a large retrospective MIMIC-IV cohort, similarly found bronchoscopy to be associated with better outcomes, although they cautioned that residual confounding related to patient selection and timing could not be excluded. In contrast, Papazian et al.[7] concluded that current evidence does not support routine therapeutic bronchoscopy in every VAP patient and that its use should be reserved for carefully selected cases — a view broadly consistent with the present study's design and inclusion criteria.

Regarding clinical parameters, the bronchoscopy group achieved earlier and more pronounced resolution of fever and a significantly greater rise in SpO_2, consistent with the findings of Sheng et al.[12], who reported improved bacterial clearance, oxygenation, and respiratory mechanics with bronchoscopy-guided BAL in severe VAP, and with the meta-analysis of Miao et al.,[13] who found that therapeutic bronchoscopy facilitates secretion clearance and optimizes antimicrobial therapy. Direct instillation of gentamicin into the infected bronchopulmonary segment, combined with BAL-guided microbiological sampling, likely enhanced local bacterial eradication and accelerated resolution of the systemic inflammatory response in the present study.

Inflammatory markers (TLC and CRP) were comparable between groups at baseline and decreased significantly in both groups after treatment, with a significantly greater reduction in the bronchoscopy group. This parallels the findings of Wu and Liu[9] and Sheng et al.,[12] who both reported greater reductions in inflammatory biomarkers with bronchoscopic bronchoalveolar lavage, attributed to more effective mechanical clearance of purulent secretions and earlier, pathogen-directed antimicrobial therapy.

Overall, the present findings support fiberoptic bronchoscopy-guided BAL with local gentamicin instillation as an effective adjunctive intervention that improves oxygenation, respiratory mechanics, fever resolution, and inflammatory markers in mechanically ventilated patients with VAP, while acknowledging — in line with Papazian et al.[7] — that careful patient selection remains essential for its appropriate use.

CONCLUSION

Fiberoptic bronchoscopy-guided bronchoalveolar lavage with intrabronchial gentamicin, added to conventional treatment, was associated with greater improvement in oxygenation, lower ventilatory requirements, improved respiratory mechanics, and a greater reduction in inflammatory markers compared with conventional treatment alone. Therapeutic fiberoptic bronchoscopy with local gentamicin therefore represents an effective adjunctive option for appropriately selected patients with ventilator-associated pneumonia.

LIMITATIONS AND RECOMMENDATIONS

Limitations:

(1) Relatively small, single-center sample, limiting generalizability.

(2) Heterogeneity of the critically ill population regarding diagnosis and cause of mechanical ventilation.

(3) Relatively short follow-up period, limiting assessment of long-term clinical and microbiological outcomes.

Recommendations:

(1) Fiberoptic bronchoscopy-guided BAL should be considered as an adjunctive intervention in selected mechanically ventilated patients with VAP, particularly those with retained secretions or mucus plugging.

(2) BAL specimens should be routinely obtained during bronchoscopy to improve microbiological diagnosis and guide culture-directed antibiotic therapy.

(3) Local intrabronchial antibiotic instillation may be considered in carefully selected patients according to institutional protocols and susceptibility results.

(4) Larger multicenter randomized trials with longer follow-up are needed to evaluate effects on mortality, ventilation duration, and length of stay.

Declarations

Ethics approval:

According to ICH- good clinical practice, Declaration of Helsinki, and World Health Organization guidelines, the Research Ethics Committee of the Faculty of Medicine for Girls, Cairo, Al-Azhar University (FMG-IRB) met at the Faculty of Medicine for Girls, Nasr City. The required documents were submitted according to the committee's guidelines and ethical permission was granted with reference number of 2746.

consent to participate:

Written informed consent was obtained from patients after explaining the study to them.

Consent for publication:

Written informed consent was obtained from the patients for publication of the current study.

Competing interests:

No financial and non-financial competing interest exists.

Funding:

No funding was needed.

Author Contribution

MAEAEE and ISM contributed to the conception and design of the study. MAEAEE, ISM, SHG, and KMM contributed to sample collection and routine laboratory investigations analysis. Statistical analyses were done by MAEAEE and ISM. The first and final drafts of the manuscript were performed by MAEAEE and ISM. All authors read and approved the first and final manuscript.

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None

Availability of data:

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Code availability:

Not applicable. No custom computer code or software algorithms were used to generate results for this study.

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