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Comparison of Lyophilized and Dry Powder Colistin Formulations for Nebulized Treatment of Pneumonia Caused by Carbapenem-Resistant Gram-Negative Bacteria: A Retrospective Before-and-After Cohort Study

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Abstract

Objective: To compare the clinical effectiveness, safety, and respiratory therapist-reported usability of lyophilized and dry powder colistin formulations administered by nebulization for carbapenem-resistant Gram-negative bacterial (CRGNB) pneumonia.

Methods: This single-center retrospective before-and-after cohort study included adult intensive care unit patients with hospital-acquired or ventilator-associated pneumonia caused by CRGNB who received nebulized colistin for ⩾72 hours. Patients treated from January 2025 to February 2026 received dry powder colistin, whereas those treated from March to July 2026 received the lyophilized formulation. Both formulations were administered at 133.6 mg colistin base activity every eight hours using the same jet nebulizer. The primary outcome was favorable clinical response on day 14. Secondary outcomes included clinical response on Days 7 and 28, microbiological eradication on Days 7, 14, and 28, mortality, adverse events, and respiratory therapist-reported usability.

Results: A total of 50 patients were included, with 20 in the lyophilized colistin group and 30 in the dry powder colistin group. Both groups had comparable baseline characteristics and disease severity, including APACHE II scores. Day-14 favorable clinical response rates were comparable between groups (65.0% vs. 63.3%; p=0.904). No significant differences were observed in clinical response, microbiological eradication, in-hospital mortality, or pneumonia-related mortality. However, although these differences did not reach statistical significance, numerically higher day-7 clinical response (90.0% vs. 76.7%) and microbiological eradication rates (90.0% vs. 66.7%) were observed with the lyophilized formulation. No bronchospasm or acute kidney injury occurred. Respiratory therapists reported significantly shorter reconstitution and nebulization times, less impact on daily workload, and less frequent nebulizer cup overflow with the lyophilized formulation (all p<0.001).

Conclusion: Lyophilized and dry powder nebulized colistin demonstrated comparable overall clinical effectiveness and safety in CRGNB pneumonia. However, the lyophilized formulation provided substantially greater usability and administration efficiency. Larger prospective studies are needed to determine whether its favorable early clinical and microbiological trends translate into meaningful clinical benefits.

Categories: Therapeutics, Internal Medicine, Infectious Disease
Keywords: colistin, dry powder formulations, lyophilized formulations, nebulization, pneumonia

Introduction

Carbapenem-resistant Gram-negative bacteria (CRGNB), including carbapenem-resistant *Acinetobacter baumannii* (CRAB), carbapenem-resistant *Pseudomonas aeruginosa* (CRPA), and carbapenem-resistant *Enterobacterales* (CRE), have become a leading cause of hospital-acquired pneumonia (HAP) and ventilator-associated pneumonia (VAP) worldwide [1-4]. These pathogens are associated with markedly limited treatment options, prolonged intensive care unit (ICU) and hospital stays, and higher rates of treatment failure compared with pneumonia caused by susceptible organisms [2,5]. Mortality attributable to CRGNB pneumonia remains substantial, particularly among critically ill and mechanically ventilated patients, and has been compounded by the slow pace of novel antibiotic development relative to the emergence of resistance [6-8]. As a result, clinicians have increasingly relied on older agents, such as polymyxins, to manage infections for which few alternatives exist [9].

Colistin (polymyxin E) is one of the few agents retaining reliable in vitro activity against many CRGNB pathogens and has re-emerged as a salvage therapy for CRGNB pneumonia [10,11]. However, intravenous

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colistin is limited by nephrotoxicity and by inconsistent lung tissue penetration, which may result in suboptimal drug concentrations at the site of infection [12]. Inhaled (nebulized) colistin has therefore been proposed as an adjunct or alternative to systemic therapy, delivering high local drug concentrations directly to the airways while potentially reducing systemic toxicity [13]. Clinical studies and meta-analyses have suggested that adjunctive inhaled colistin may improve clinical cure rates and microbiological eradication in patients with CRGNB pneumonia, although the certainty of this evidence remains limited by heterogeneity in dosing, delivery devices, and formulation across studies [14-16].

In clinical practice, inhaled colistin is available in two formulations, lyophilized powder and dry powder, both of which require reconstitution before nebulization. Differences in formulation may influence drug preparation, nebulization efficiency, and drug delivery. However, direct comparisons of their clinical effectiveness, safety, and healthcare professionals' experiences with preparation and administration remain limited. Therefore, we conducted this study to compare lyophilized and dry powder colistin formulations for nebulized treatment in patients with pneumonia caused by CRGNB.

Materials And Methods

Study design and population

This single-center retrospective cohort study was conducted at Chi Mei Medical Center, Tainan, Taiwan, between January 2025 and July 2026. The study protocol was reviewed and approved by the Institutional Review Board of Chi Mei Medical Center (IRB No. 11509-006). The requirement for informed consent was waived by the ethics committee due to the retrospective nature of the study involving anonymized patient data. All procedures were carried out in accordance with institutional guidelines and the ethical standards of the responsible committees, as well as the principles outlined in the Declaration of Helsinki.

Patient selection

All patients aged ⩾18 years who received nebulized colistin in the ICU for the treatment of HAP or VAP caused by CRGNB were eligible for inclusion. Pneumonia was diagnosed according to the American Thoracic Society/Infectious Diseases Society of America (ATS/IDSA) guidelines [17]. To ensure adequate assessment of treatment exposure, eligible patients were required to have received nebulized colistin prepared from either a lyophilized powder or dry powder formulation for at least 72 hours, with a consistent inhaled colistin dose of 133.6 mg every 8 hours throughout the entire treatment course.

Patients were excluded if they were younger than 18 years; had community-acquired pneumonia; had post-obstructive pneumonia secondary to a tumor or other mechanical airway obstruction; had respiratory isolates that did not meet the predefined criteria for carbapenem resistance, were not considered the causative pathogens, or were intrinsically resistant to colistin; received both formulations during the same pneumonia episode; or had insufficient clinical information to assess the primary outcome. Pregnant or breastfeeding women were also excluded. For patients with more than one eligible pneumonia episode, only the first episode was included.

Colistin formulations and nebulization procedures

Both colistin formulations evaluated in this study were manufactured by TTY Biopharm Company Limited, Taiwan. Each vial of either the lyophilized powder or dry powder formulation contained 160 mg of colistimethate sodium (CMS), equivalent to 66.8 mg of colistin base activity (CBA). For each administration, two vials were used, corresponding to a total dose of 320 mg of CMS (133.6 mg CBA), administered every 8 hours. All doses of nebulized colistin were prepared and administered by respiratory therapists in accordance with the institutional administration protocol. Following reconstitution, colistin was delivered using a jet nebulizer manufactured by Besmed. Both colistin formulations were reconstituted with 4 mL of normal saline (0.9% NaCl) and administered via nebulization using an oxygen flow rate greater than 7 L/min. The same nebulization method was applied to patients receiving either formulation to minimize differences in drug delivery attributable to the administration technique.

Intervention

During the study period, patients were categorized into two cohorts according to the colistin formulation received. The sequential use of the two formulations in our institution was primarily driven by a change in hospital procurement. The dry powder formulation was used during the earlier study period, followed by the lyophilized formulation after the institutional procurement policy was changed. The lyophilized colistin formulation was introduced at Chi Mei Medical Center in March 2026. Accordingly, patients treated between January 2025 and February 2026 received the dry powder formulation, whereas those treated between March and July 2026 received the lyophilized formulation, constituting a before-and-after cohort study. Patients in both groups were managed by the same ICU healthcare teams, and the standard operating procedures for clinical management, antimicrobial treatment, and supportive care remained consistent throughout the study periods.

Data collection

Demographic characteristics and baseline clinical variables were retrieved from the electronic medical records. Disease severity was assessed using the Acute Physiology and Chronic Health Evaluation II (APACHE II) score calculated on the day of ICU admission. The Charlson Comorbidity Index (CCI), Sequential Organ Failure Assessment (SOFA) score, and SOFA-2 score were also calculated on the day nebulized colistin therapy was initiated. The patients' clinical conditions were assessed through serial chest radiographs, microbiological findings, vital signs, and laboratory data, including hematologic parameters, inflammatory markers, liver and renal function tests, coagulation profiles, and other clinically relevant biochemical measurements.

Outcomes

The primary outcome was the favorable clinical response rate on day 14 after the initiation of nebulized colistin therapy. Clinical responses were primarily evaluated through medical record reviews, based on changes in vital signs, reductions in oxygen requirements, improvements in inflammatory markers, and changes in chest radiographic findings. A favorable clinical response was defined as complete resolution or an improvement of at least 50% in the signs and symptoms of pneumonia. Secondary outcomes included favorable clinical response rates on Days 7 and 28; microbiological eradication rates on Days 7, 14, and 28; in-hospital all-cause mortality; in-hospital pneumonia-related mortality; and nebulization-related respiratory and systemic adverse events, primarily including bronchospasm and acute kidney injury.

Microbiological eradication was defined as the absence of the causative pathogen in follow-up respiratory cultures. For patients without available follow-up cultures, those demonstrating clinical improvement were classified as having presumed microbiological eradication, which was included in the overall microbiological eradication outcome. However, because follow-up respiratory cultures may have been more frequently performed in patients with persistent symptoms or greater disease severity, restricting the analysis to patients with available follow-up cultures could introduce selection bias. Therefore, a sensitivity analysis based solely on microbiologically confirmed eradication was not performed.

In-hospital mortality was defined as death from any cause during the index hospitalization. All patients were followed until hospital discharge or death, and survival status was determined according to the final outcome of the index hospitalization.

Respiratory therapist experience assessment

A structured questionnaire was administered to respiratory therapists who had experience preparing and administering both nebulized colistin formulations during the study period. The questionnaire was designed to compare the practical usability of the dry powder and lyophilized powder formulations from the perspective of respiratory therapists. Each therapist evaluated the two formulations separately. The questionnaire assessed four domains: the time required to reconstitute each colistin vial, the nebulization time per colistin dose, perceived impact of colistin inhalation therapy on daily workload, and the nebulizer cup overflow with two colistin vials after treatment.

Statistical analysis

Continuous variables are presented as mean ± standard deviation (SD), whereas categorical variables are expressed as frequencies and percentages. Between-group differences in continuous variables were assessed using the independent-samples t-test. For categorical variables, Pearson's chi-square test without continuity correction was applied when all expected cell counts were ⩾5; otherwise, the two-sided Fisher's exact test was used. For the paired ordinal responses obtained from respiratory therapists, two-sided exact paired permutation tests were performed using the original ordinal category scores while preserving the paired observations. Chi-square statistics (χ^2) were reported for Pearson's chi-square tests, whereas standardized paired score statistics (Z) were reported for the paired permutation tests. All statistical tests were two-sided, and a p-value < 0.05 was considered statistically significant. Statistical analyses were performed using IBM SPSS Statistics (Version 25.0; IBM Corp., Armonk, NY).

Results

Baseline characteristics

A total of 50 patients were included in the study, including 20 who received the lyophilized colistin formulation and 30 who received the dry powder formulation. Baseline demographic and clinical characteristics were comparable between the two groups (Table *1*). There were no significant differences between the lyophilized and dry powder groups in mean age (68.4 vs. 69.3 years; p=0.843) or the proportion of male patients (70.0% vs. 63.3%; p=0.626). The distribution of hospital-acquired and ventilator-associated pneumonia was also similar between groups (p=0.895). Measures of disease severity, including APACHE II, CCI, SOFA, and SOFA-2 score, did not differ significantly between groups. Baseline laboratory parameters and concomitant intravenous antibiotic use were comparable (all p>0.05). Furthermore, the distribution of causative pathogens was also similar between the two groups (Table *2*).

Variable	Lyophilized (n = 20)	Dry powder (n = 30)	χ^2 value	p-value*
Age, year	68.4 ± 18.9	69.3 ± 15.8	-	0.843
Male, n (%)	14 (70)	19 (63.3)	0.238	0.626
Height, cm	151.0 ± 32.1	154.7 ± 26.8	-	0.656
Body weight, kg	59.7 ± 17.8	59.7 ± 11.3	-	0.990
Type of pneumonia, n (%)			0.017	0.895
Hospital-acquired pneumonia	5 (25)	8 (26.7)		
Ventilator-associated pneumonia	15 (75)	22 (73.3)		
Severity				
APACHE II score	26.5 ± 7.0	25.7 ± 7.4	-	0.702
Charlson comorbidity index	9.4 ± 4.4	10.0 ± 4.0	-	0.621
SOFA	7.7 ± 3.9	8.6 ± 4.0	-	0.405
SOFA-2	6.5 ± 3.8	7.5 ± 3.8	-	0.368
Duration of colistin therapy, days	12.7 ± 6.1	13.1 ± 5.4	-	0.824
Laboratory findings				
WBC, 10^3 /uL	14.8 ± 8.8	15.6 ± 8.5	-	0.755
Neutrophil (%)	80.8 ± 17.4	80.9 ± 15.6	-	0.992
Hemoglobin, g/dL	9.2 ± 1.9	8.8 ± 1.8	-	0.450
Platelet, 10^3 /uL	205.6 ± 135.6	220.1 ± 158.0	-	0.738
C-reactive protein, mg/dL	125.7 ± 74.0	99.5 ± 73.7	-	0.468
Procalcitonin, ng/ml	17.3 ± 36.2	9.5 ± 22.4	-	0.584
Creatinine, mg/dL	1.2 ± 1.3	1.7 ± 1.6	-	0.232
Lactate, mg/dL	2.2 ± 2.2	3.1 ± 2.4	-	0.291
Concomitant intravenous antibiotics, n (%)				
Carbapenems	8 (40)	11 (36.7)	0.057	1.000
Other beta-lactams	9 (45)	10 (33.3)	0.693	0.553
New BL/BLIs	4 (20)	4 (13.3)	0.397	0.697
Polymyxins	5 (25)	15 (50)	3.125	0.140
Tigecycline/minocycline	5 (25)	7 (23.3)	0.018	1.000
Amikacin	1 (5)	1 (3.3)	0.087	1.000
Fluoroquinolones	2 (10)	5 (16.7)	0.443	0.687

TABLE 1: Clinical characteristics of patients in the before and after cohorts

APACHE II: Acute Physiology and Chronic Health Evaluation II; SOFA: Sequential Organ Failure Assessment; BL/BLIs: beta-lactam/beta-lactamase inhibitors

* Continuous variables were compared using the independent-samples t-test, whereas categorical variables were compared using the chi-square test.

Parameter	Lyophilized (n = 20)	Dry powder (n = 30)	χ^2 value	p-value*
Causative pathogens, n (%)				
Acinetobacter baumannii	8 (40)	10 (33.4)	0.155	0.694
Klebsiella pneumoniae	8 (40)	13 (43.3)	0.009	0.923
Pseudomonas aeruginosa	2 (10)	4 (13.3)	-	1.000 †
Escherichia coli	2 (10)	2 (6.7)	-	1.000 †
Enterobacter spp.	0 (0)	1 (3.3)	-	1.000 †

TABLE 2: Causative pathogens at baseline

* Pearson's χ^2 test without continuity correction was used when all expected cell counts were ≥5; otherwise, two-sided Fisher's exact test was used (†). χ^2 values are reported only for Pearson tests (df = 1).

Clinical outcomes and safety

Clinical outcomes were generally comparable between the two formulations (Table 3). The day-14 favorable clinical response rate, the primary outcome, was 65.0% in the lyophilized group and 63.3% in the dry powder group (p=0.904). Favorable clinical response rates on days 7 and 28 were also comparable between groups (90.0% vs. 76.7%, p=0.285; and 60.0% vs. 60.0%, p=1.000, respectively). Microbiological eradication rates showed no significant between-group differences on days 7, 14, or 28 (90.0% vs. 66.7%, p=0.091; 90.0% vs. 83.3%, p=0.687; and 90.0% vs. 83.3%, p=0.687, respectively). In-hospital mortality was 40.0% in the lyophilized group and 43.3% in the dry powder group (p=0.815), while pneumonia-related mortality was 25.0% and 26.7%, respectively (p=0.895). No bronchospasm or acute kidney injury was observed in either group.

Parameter	Lyophilized (n = 20)	Dry powder (n = 30)	χ^2 value	p-value*
Mortality, n (%)	8 (40)	13 (43.3)	0.055	0.815
Pneumonia-related mortality, n (%)	5 (25)	8 (26.7)	0.017	0.895
Favorable clinical response, n (%)				
Day 7	18 (90)	23 (76.7)	-	0.285†
Day 14	13 (65)	19 (63.3)	0.014	0.904
Day 28	12 (60)	18 (60)	0.000	1.000
Microbiological eradication rates, n (%)				
Day 7	18 (90)	20 (66.7)	-	0.091†
Day 14	18 (90)	25 (83.3)	-	0.687†
Day 28	18 (90)	25 (83.3)	-	0.687†
Adverse event, n (%)				
Bronchospasm	0 (0)	0 (0)	-	-
Acute kidney injury	0 (0)	0 (0)	-	-

TABLE 3: Outcomes of patients in the before and after cohorts

*Pearson's χ^2 test without continuity correction was used when all expected cell counts were ≥5; otherwise, two-sided Fisher's exact test was used (†). χ^2 values are reported only for Pearson tests (df = 1).

Respiratory therapist-reported usability

Respiratory therapist-reported usability favored the lyophilized formulation across all assessed domains (Table 4). The lyophilized formulation required less time for reconstitution, with most preparation times being less than 1 minute, whereas reconstitution of the dry powder formulation generally required more than 2 minutes (p<0.001). The nebulization time per dose was also shorter with the lyophilized formulation (p<0.001). Besides, the lyophilized formulation was associated with a more favorable perceived impact on daily workload. Overall, 34.5% of respondents reported being satisfied with the lyophilized formulation compared with 3.5% for the dry powder formulation, whereas dissatisfaction was reported by 44.8% of respondents for the dry powder formulation and none for the lyophilized formulation (p<0.001). In addition, nebulizer cup overflow occurred less frequently with the lyophilized formulation than with the dry powder formulation (p<0.001).

Parameter	Lyophilized	Dry powder	Paired score Z	p-value*
Time required to reconstitute each colistin vial, n (%)			5.128	< 0.001
< 1 min	19 (65.5)	0 (0)		
1-2 mins	10 (34.5)	3 (10.3)		
> 2 mins	0 (0)	26 (89.7)		
Nebulization time per colistin dose (2 vials), n (%)			3.182	< 0.001
< 15 mins	8 (27.6)	0 (0)		
15-30 mins	18 (62.1)	16 (55.2)		
> 30 mins	3 (10.3)	13 (44.8)		
Perceived impact of colistin inhalation therapy on daily workload, n (%)			3.889	< 0.001
Satisfied	10 (34.5)	1 (3.5)		
Neutral	19 (65.5)	15 (51.7)		
Dissatisfied	0 (0)	13 (44.8)		
Nebulizer cup overflow with two colistin vials, n (%)			4.226	< 0.001
Rarely	24 (82.8)	5 (17.2)		
Occasionally	5 (17.2)	18 (62.1)		
Frequently	0 (0)	6 (20.7)		

TABLE 4: Respiratory therapist–reported usability of two nebulized colistin formulations (n = 29)

*Two-sided exact paired permutation tests used the original ordinal category scores, preserving each therapist's paired responses. Z denotes the standardized paired score statistic.

Discussion

In this retrospective before-and-after cohort study of patients with pneumonia caused by CRGNB, we found that lyophilized and dry powder colistin formulations had comparable clinical effectiveness and safety when administered by nebulization. Clinical response, microbiological eradication, and mortality outcomes did not differ significantly between the two formulations. Importantly, however, the lyophilized formulation was associated with substantially better reported usability among respiratory therapists, including shorter preparation and nebulization times, less perceived impact on daily workload, and less frequent nebulizer cup overflow. These findings suggest that, although the two formulations may provide comparable clinical outcomes, the choice of formulation may have important practical implications for the delivery of inhaled colistin in critically ill patients.

The comparable clinical outcomes observed in this study are clinically relevant given the limited therapeutic options for CRGNB pneumonia. In our cohort, the Day 14 favorable clinical response rate was similar between patients receiving lyophilized and dry powder colistin, as were clinical response rates on Days 7 and 28. Microbiological eradication rates were also comparable at all assessed time points. These findings suggest that differences in formulation did not translate into meaningful differences in treatment effectiveness under the standardized dosing and nebulization conditions used in our institution. Notably, both formulations were administered at the same colistin dose and using the same jet nebulizer, which may

have minimized differences attributable to drug delivery technique.

Safety outcomes were likewise comparable. No bronchospasm or acute kidney injury was observed in either treatment group. These findings are consistent with the rationale for inhaled colistin, which allows high local concentrations in the respiratory tract while potentially limiting systemic exposure compared with intravenous administration. However, the absence of observed adverse events should be interpreted cautiously because of the small sample size and retrospective study design. The study was not powered to detect uncommon adverse events, and therefore cannot establish equivalent safety profiles between the two formulations.

A particularly important finding was the difference in usability reported by respiratory therapists. The lyophilized formulation required substantially less time for reconstitution and was associated with shorter nebulization sessions. Respiratory therapists also reported a more favorable impact on their daily workload and less frequent nebulizer cup overflow with the lyophilized formulation. These practical differences may be clinically meaningful in intensive care settings, where respiratory therapists frequently manage mechanically ventilated patients and where repeated nebulized treatments can add to the complexity of routine care. The findings therefore extend the comparison beyond conventional clinical outcomes and highlight the importance of formulation-related workflow considerations in the implementation of inhaled antimicrobial therapy.

Lyophilization is a freeze-drying process that produces a stable, low-moisture drug formulation for reconstitution [18]. Compared with conventional dry powders, lyophilized products may offer improved stability and faster, more consistent reconstitution [19]. The major disadvantages of lyophilization include a more complex manufacturing process, longer production time, and higher production costs [20]. Owing to their favorable pharmaceutical properties, several clinically important antimicrobial agents are currently supplied as lyophilized powders for reconstitution, including tigecycline, cefiderocol, ceftobiprole, and delafloxacin [21-24]. Although lyophilized formulations may involve higher manufacturing costs, their advantages in reducing preparation time and improving workflow efficiency could help offset these additional expenses. Nevertheless, their overall economic benefits remain uncertain, and further studies are warranted to evaluate the cost-effectiveness of both formulations.

Lyophilization primarily improves drug stability and shelf life rather than intrinsic antimicrobial activity. Therefore, it is not expected to enhance antimicrobial potency when the active ingredient and administered dose are equivalent [25]. Notably, CMS is an inactive prodrug that requires hydrolysis to generate microbiologically active colistin both in vitro and in vivo [26]. Because CMS is chemically unstable in aqueous environments and may undergo spontaneous conversion and degradation after reconstitution, maintaining the drug in a stable, low-moisture state until immediately before administration may be advantageous [26]. Beyond facilitating faster and more consistent reconstitution, lyophilization may minimize drug degradation and variability in dose delivery, potentially improving pulmonary exposure to active colistin. Although it does not enhance intrinsic antibacterial potency, these advantages may contribute to more consistent antimicrobial exposure in clinical practice.

In our study, the lyophilized colistin formulation did not demonstrate a statistically significant improvement in overall clinical effectiveness compared with the dry powder formulation. Nevertheless, numerically higher favorable clinical response and microbiological eradication rates were observed in the lyophilized formulation group on Day 7, although these differences did not reach statistical significance. Given the relatively small sample size, the study may have been underpowered to detect modest between-group differences. These findings therefore raise the possibility that the lyophilized formulation may provide an early clinical and microbiological benefit over the dry powder formulation, although this hypothesis requires confirmation in larger studies.

Our study has several limitations. First, the retrospective before-and-after design precluded blinding of the investigators, potentially introducing assessment bias. Furthermore, the sequential use of the two formulations may have introduced temporal confounding due to potential changes in clinical practice and supportive care over time. Second, this was a single-center study with a relatively small sample size, which limits statistical power and the generalizability of the findings. Third, although baseline demographic characteristics, disease severity, laboratory findings, concomitant antibiotics, and causative pathogens were generally comparable between groups, residual confounding cannot be excluded. Fourth, the inclusion of presumed eradication without microbiological confirmation may have resulted in an overestimation of the actual eradication rates. Fifth, the usability assessment was based on respiratory therapist-reported experience and therefore may be subject to subjective reporting and recall bias. Finally, the study evaluated a single dosing regimen and a single nebulization device, and the findings may not be generalizable to other doses, nebulizer systems, or clinical settings.

Conclusions

In conclusion, lyophilized and dry powder colistin formulations demonstrated comparable clinical effectiveness and safety for nebulized treatment of CRGNB-associated pneumonia in this retrospective cohort. However, the lyophilized formulation was associated with substantially more favorable usability

characteristics among respiratory therapists. These findings suggest that hospital pharmacy and therapeutics committees should consider not only clinical effectiveness and safety but also drug preparation time, workflow efficiency, and acquisition costs when selecting inhaled colistin formulations. Larger prospective studies are warranted to confirm these findings and further evaluate their clinical and economic implications.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Jin-Wei Liu, Jheng-Yan Wu, Chih-Cheng Lai, Hung-Jen Tang, Hung-Jui Chen

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Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. ChiMei Medical center issued approval 11509-006. This study was approved by the Institutional Review Board of Chi Mei Medical Center (IRB 11509-006). **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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