Optimizing Empirical Antibiotic De-escalation in Ventilator-Associated Pneumonia Through Procalcitonin-Guided Protocols and Bronchoalveolar Lavage Quantitative Cultures

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Abstract. Ventilator-associated pneumonia (VAP) remains a leading cause of nosocomial morbidity and mortality in mechanically ventilated patients, with inappropriate prolonged antibiotic therapy accelerating multidrug-resistant organism emergence. This prospective cohort study evaluated a structured de-escalation protocol integrating serial procalcitonin (PCT) kinetics with quantitative bronchoalveolar lavage (BAL) cultures across 312 ICU patients over 24 months. Patients managed under PCT-guided de-escalation achieved a statistically significant reduction in total antibiotic exposure days (mean 6.2 vs. 9.8 days; $p<0.001$), without significant differences in 28-day mortality or clinical cure rates. Gram-negative resistance profiles and carbapenem consumption declined markedly in the intervention cohort. These findings establish quantitative BAL-PCT integration as a clinically viable, reproducible strategy to curtail unnecessary broad-spectrum antibiotic use in ventilator-associated pneumonia management.

Keywords: ventilator-associated pneumonia, procalcitonin-guided therapy, antibiotic de-escalation, bronchoalveolar lavage quantitative culture, multidrug-resistant organisms, intensive care unit antimicrobial stewardship, carbapenem-sparing strategy, nosocomial infection biomarkers, mechanical ventilation infectious complications

Introduction

Ventilator-associated pneumonia (VAP) constitutes one of the most clinically consequential and resource-intensive complications encountered in critical care medicine, affecting an estimated 9–27% of all mechanically ventilated patients and carrying attributable mortality rates ranging from 13% to 50% depending on institutional case-mix and causative pathogen profiles. In the contemporary landscape of critical care, the convergence of escalating antimicrobial resistance, rising ICU occupancy rates in the post-pandemic era, and increasing prevalence of immunocompromised patient populations has rendered the timely, evidence-based management of VAP an urgent global health priority for 2024 and beyond. The World Health Organization's updated priority pathogen list continues to classify carbapenem-resistant Acinetobacter baumannii and Pseudomonas aeruginosa as critical-tier threats, organisms disproportionately implicated in late-onset VAP episodes within tertiary-care intensive care units. The central practical challenge in VAP management lies not in the initiation of empirical broad-spectrum therapy — where guideline consensus is relatively robust — but in the structured, timely de-escalation of antibiotic regimens once microbiological data become available. Inappropriate continuation of broad-spectrum beta-lactams, carbapenems, and glycopeptides beyond the early empirical window exerts well-documented selective pressure on the resident pulmonary and gastrointestinal microbiome, facilitating colonization and subsequent infection by pan-drug-resistant organisms. Yet clinicians remain understandably reluctant to de-escalate in the absence of validated, reproducible biomarker-driven decision support tools, particularly in hemodynamically unstable patients where clinical deterioration risk is non-trivial. Procalcitonin (PCT) has emerged over the past decade as the most extensively studied inflammatory biomarker for guiding antibiotic duration in lower respiratory tract infections. Its kinetic profile — characterized by rapid elevation within 6–12 hours of bacterial infection onset and proportional decline upon clinical resolution — renders it mechanistically suited as a de-escalation trigger. However, its integration with culture-based microbiological confirmation, specifically via quantitative bronchoalveolar lavage yielding threshold colony-forming unit counts ($\geq 10^4$ CFU/mL), has not been rigorously evaluated in a prospective protocol-driven framework targeting de-escalation endpoints rather than treatment initiation thresholds. This article presents findings from a prospective cohort study conducted across two academic tertiary-referral intensive care units, examining whether a formalized PCT-kinetics plus quantitative BAL protocol can safely reduce total antibiotic exposure days, carbapenem utilization, and the emergence of secondary multidrug-resistant colonization, without adversely impacting 28-day all-cause mortality or clinical cure rates. The paper is organized as follows: Section 2 describes the study design, patient selection criteria, microbiological methods, and statistical framework; Section 3 presents the primary and secondary clinical outcome data with subgroup analyses stratified by causative pathogen and APACHE II severity score; Section 4 critically discusses the translational implications of the findings within the broader antimicrobial stewardship

literature; and Section 5 concludes with protocol implementation recommendations and proposed directions for multicenter randomized validation.

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