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Review Paper

Infection control and antimicrobial stewardship in the ICU: Preventing ARDS among burn patients

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ABSTRACT

Acute respiratory distress syndrome (ARDS) represents a severe and often fatal complication in patients with extensive burn injuries admitted to intensive care units (ICUs). The pathophysiological continuum linking burn-related immune dysregulation, infection, and sepsis is recognized as a major driver of pulmonary inflammation and alveolar damage. This narrative review synthesizes current evidence on infection control and antimicrobial stewardship (AMS) as integrated strategies to prevent infection-driven lung injury and reduce the burden of acute lung injury in burn ICUs. Burn patients are uniquely predisposed to healthcare-associated infections and multidrug-resistant (MDR) organisms due to disrupted skin barriers, invasive procedures, and prolonged antimicrobial exposure. Studies have reported that structured infection prevention programs including hand hygiene, wound care standardization, and device-care bundles significantly decrease sepsis incidence and improve clinical outcomes. Complementary AMS initiatives focusing on appropriate antibiotic selection, dosing optimization, and de-escalation have been associated with reduced antimicrobial pressure and improved microbial ecology. Integration of these approaches within a unified clinical governance framework has been shown to enhance infection prevention efficiency and limit ARDS-related complications. The effectiveness of such integration depends on multidisciplinary engagement involving intensivists, infectious disease specialists, pharmacists, and nursing staff. Technological advances, including microbiological surveillance, artificial intelligence driven prediction models, and microbiome-based monitoring, are increasingly being incorporated to strengthen early infection detection and optimize stewardship interventions in burn care.

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1. Introduction

Acute Respiratory Distress Syndrome (ARDS) is a life-threatening form of respiratory failure characterized by acute onset of bilateral pulmonary infiltrates and severe hypoxaemia not fully explained by cardiac failure or fluid overload [1]. In intensive care unit (ICU) patients, ARDS remains a major contributor to morbidity and mortality, with mortality rates historically between 30–40% or higher depending on underlying risk factors [2]. In the burn-injured population, ARDS poses a substantial clinical burden. A recent systematic review and meta-analysis found that the pooled incidence of ARDS among burn patients was approximately 24% (95% CI 0.20-0.28) and the pooled mortality about 31% (95% CI 0.18-0.44) in the burn setting [3]. The incidence was higher in mechanically ventilated patients (~37%) and those with inhalation injury (~41%) [3]. These data underscore the high risk of pulmonary complications in burn injury and the need for targeted preventive strategies. Infection and sepsis are central drivers of ARDS development in burn patients. Severe burns lead to loss of the skin barrier, massive inflammatory responses and risk of secondary infection and sepsis [4,5]. Sepsis in burn patients often triggers diffuse endothelial damage and increased alveolar–capillary permeability, precipitating ARDS [6]. In addition, inhalation injury further increase the risk of lung injury in the burned patient [7].

Given the high incidence and poor outcomes of ARDS in burn patients, combined preventive strategies incorporating infection control and antimicrobial stewardship (AMS) appear critically important [8]. Infection control in the ICU burn environment may reduce the incidence of pneumonia, bloodstream infections (BSIs) and sepsis, thereby decreasing ARDS risk. Simultaneously, AMS may limit inappropriate broad-spectrum antibiotic use, reduce emergence of multidrug-resistant (MDR) organisms and thereby reduce severe lung injury triggered by difficult-to-treat infections [8,9].

To summarize the available literature on infection control and AMS in ICU burn units and to examine how these strategies may contribute to the prevention of ARDS among burn patients. The review will address pathophysiological links, evidence for infection prevention strategies, stewardship programs, and propose future directions in this high-risk population.

2. Pathophysiological links between burn injury, infection, and ARDS

Severe burn injuries not only damage skin and underlying tissues but also trigger profound systemic responses that predispose to pulmonary complications such as ARDS [10]. In the ICU setting, burn patients frequently develop a combination of massive inflammatory activation, loss of barrier protections and increased risk of infectious complications. These factors converge to create a milieu in which pulmonary endothelial and epithelial injury can progress rapidly into ARDS [11]. Understanding the mechanistic links among burn-induced inflammation, infectious triggers and lung injury is therefore essential for designing preventive strategies targeting ARDS in this high-risk group. Below we explore the major mechanistic domains: first the systemic inflammatory response induced by burn injury, then infectious triggers of ARDS in the burn context, and finally how host-microbe interactions amplify lung injury processes. In Figure 1, the process of burn injury progression to ARDS is graphically illustrated. The image serves to visually simplify the complex physiological progression leading to ARDS, aiding in a clearer understanding of the underlying mechanisms.

2.1 Systemic inflammatory response in burn patients

Severe burn injury initiates a profound systemic inflammatory response characterized by increased levels of pro-inflammatory cytokines and immune dysregulation [12].

This systemic response contributes to endothelial activation, increased capillary permeability, and extravasation of fluid into the interstitial and alveolar spaces. Burn-mediated disruption of the alveolar–capillary barrier leads to increased pulmonary permeability and predisposition to acute lung injury [7,12]. The increased hydrostatic and permeability load, together with fluid resuscitation practices, further promote pulmonary edema and alveolar flooding, setting the stage for ARDS [12].

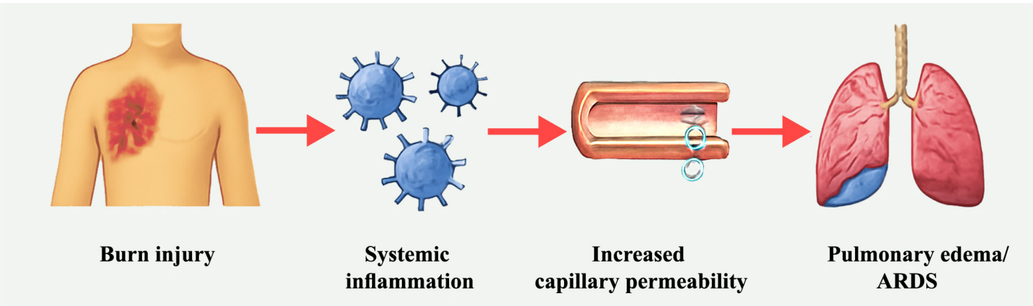

Figure 1. A medical flowchart illustrating the progression from burn injury to ARDS in four stages: 1) Burn injury, 2) Systemic inflammation, 3) Increased capillary permeability, and 4) Pulmonary edema/ARDS. Arrows connect each stage to show the sequential progression.

2.2 *Infectious triggers of ARDS*

Infection and sepsis are well-recognized precipitating factors of ARDS, especially in the context of burn injury. Burn patients are at high risk of wound infection, ventilator associated pneumonia (VAP) and BSIs due to compromised skin barrier and prolonged ICU stays [13,14]. Inhalation injury adds direct airway damage, leading to impaired mucociliary clearance, airway obstruction and increased susceptibility to pneumonia and ARDS [15]. In burn-related ARDS, common pathogens include Gram-negative organisms such as *Pseudomonas aeruginosa* and *Acinetobacter* spp., and Gram-positive bacteria such as *Staphylococcus aureus*. The high pathogen load and virulence drive persistent inflammation and lung injury [16].

2.3 *Host–microbe interactions and lung injury*

At the cellular level, infections cause the release of endotoxins, activation of neutrophils, and subsequent endothelial and epithelial injury. Endotoxin-mediated endothelial damage increases vascular permeability and worsens alveolar flooding [17,18]. In the lung, neutrophil activation leads to release of proteases, reactive oxygen species (ROS) and neutrophil extracellular traps (NETs), which further damage the alveolar epithelium and perpetuate the vicious cycle of inflammation and injury [17]. In burn ICU patients, the interplay of systemic inflammation from the burn, high pathogen burden and altered host immune response converges to facilitate the development of ARDS [17].

3. Infection control strategies in burn ICUs

Burn patients in ICUs are highly susceptible to infections due to skin barrier loss, immune suppression, and frequent use of invasive devices [19]. These infections often lead to sepsis and may precipitate ARDS; therefore, strict infection control programs are essential to improve survival and reduce complications [8,20]. Evidence suggests that comprehensive prevention bundles covering environmental hygiene, device care, and active surveillance significantly decrease infection and mortality rates in burn ICUs [20].

3.1 *Environmental and procedural measures*

In the specialized burn ICU setting, the prevention of infection starts with environmental and procedural controls tailored to the unique vulnerabilities of patients with major burns. Isolation rooms equipped with negative pressure ventilation or dedicated air-filtration systems help limit airborne transmission of pathogens as well as containment of highly resistant organisms [8]. Guidelines for burns services emphasize separate access pathways, filtered ventilation, and dedicated rooms to minimize cross-contamination [8].

Rigorous hand hygiene and barrier nursing (gloves, gowns, aprons) remain foundational. One longitudinal analysis in a burn ICU found non-compliance in hand hygiene preceded MDR *Acinetobacter baumannii* outbreaks [21]. Wound management in burn patients is equally critical. Sterile dressing techniques, early excision and grafting of necrotic tissue reduce bacterial load and the risk of invasive infection, which in turn may reduce downstream lung injury. Furthermore, the use of single-patient equipment or strict decontamination protocols for shared devices is recommended, given the propensity of burn wounds to serve as reservoirs for environmental contamination [22,23].

3.2 *Device-associated infection prevention*

Device-associated infections (DAIs) constitute a major source of morbidity in burn ICUs and can serve as triggers for systemic inflammation and ARDS. Central-line associated bloodstream infections (CLABSI), catheter-associated urinary tract infections (CAUTI) and especially VAP are common in this population due to prolonged ICU stays, invasive monitoring, and the compromised immune state of patients with large total body surface area (TBSA) burns [24-26]. In burn ICU settings, adherence to insertion and maintenance bundles for central lines has been shown to correlate with lower CLABSI rates, although compliance varies widely [27]. VAP prevention bundles comprising elevation of the head of bed, daily sedation interruption, oral hygiene with antiseptic rinse, closed-circuit suction and minimized ventilator days have demonstrated potential efficacy in ICU populations, although data specific to burn units remain limited [28].

3.3 *Surveillance and early detection*

Active surveillance and early detection of infection are vital components of infection control in burn ICU units [29]. Continuous monitoring of hygiene compliance (hand hygiene, protective equipment use) and periodic environmental cultures may provide early warning of outbreak risk, as documented in an 11-year burn centre cohort where rising non-compliance preceded pathogen outbreaks [20]. Tracking local microbial resistance patterns and device-associated infection incidence allows burn ICU teams to adjust empirical antibiotic protocols and isolate patients earlier, thereby interrupting the chain of transmission [30,31]. Implementation of infection prevention policies with audit-feedback loops has been associated with reductions in DAI and shorter ICU lengths of stay in the burn context [28].

4. Antimicrobial stewardship in burn ICU settings

Burn ICUs face a critical challenge of balancing early, life-saving antimicrobial therapy with the prevention of antimicrobial resistance. High antibiotic exposure, invasive procedures, and prolonged hospitalization make stewardship essential. Effective AMS programs optimize antibiotic use, minimize MDR infections, and indirectly reduce sepsis-related complications such as ARDS [9,32,33].

4.1 Rationale for AMS in burn units

Patients admitted to ICU settings are exposed to high antimicrobial pressure due to frequent invasive procedures, prolonged hospitalization and a high incidence of wound, bloodstream and ventilator-associated infections [30]. The emergence of MDR organisms in ICUs, particularly burn units is documented, with one review showing MDR organisms colonization or infection in 11.3% of adult burn admissions, and a predominant of carbapenem-resistant *Pseudomonas* [34]. These resistant pathogens increase the risk of refractory sepsis and may precipitate inflammatory lung injury terminating in ARDS [35]. The challenge in burn ICUs is to balance the need for timely empirical antimicrobial therapy given the high risk of infection and sepsis against the imperative of avoiding unnecessary broad-spectrum use that drives further resistance [9]. An effective AMS program serves as a key preventive strategy that disrupts the progression from infection to sepsis, lung injury, and ultimately ARDS.

4.2 Core components of AMS programs

Key components of AMS in the burn ICU environment include formulary restrictions, de-escalation strategies, antibiotic cycling or rotation (where applicable), dosing optimization and the use of rapid microbiological diagnostics [9,30]. For example, in a wound and burn care setting in Nepal, a post-prescription review and feedback intervention resulted in significant reductions in days of therapy for penicillins, cephalosporins and aminoglycosides, and an increase in recommended antibiotic documentation and de-escalation practices [36]. Moreover, AMS in burn units has shown significant benefits, including a reduction in antimicrobial use (11%-38%), lower costs, and fewer adverse events. Interventions also led to decreased antimicrobial resistance rates over time [37]. Dosing optimization is particularly important in burn patients, given altered pharmacokinetics and pharmacodynamics during the hyper-metabolic phase, which can impede achievement of therapeutic antimicrobial concentrations [38]. Rapid diagnostics (such as molecular assays) enable earlier targeted therapy and avoid prolonged empirical broad-spectrum use [39].

4.3 Clinical impact of AMS on ARDS prevention

Direct evidence explicitly linking AMS interventions to reductions in ARDS incidence among burn ICU patients is scarce. However, a consistent body of indirect evidence supports a plausible pathway by which AMS may reduce ARDS risk. A landmark systematic review and meta-analysis demonstrated that AMS programs reduce infections and colonization with antibiotic-resistant bacteria at the hospital level, thereby decreasing the reservoir of multidrug-resistant organisms and consequently lowering the risk of severe, difficult-to-treat infections [33]. Implementation studies in ICU settings have shown that stewardship interventions reduce overall antibiotic consumption and can specifically decrease BSIs due to MDR Gram-negative pathogens without increasing mortality [40,41]. Pharmacokinetic-guided dosing and rapid microbiological diagnostics core stewardship tools improve target attainment and facilitate early de-escalation, both of which limit unnecessary broad-spectrum exposure and selection pressure for resistance [42]. Burn units in many centers continue to report high MDR organisms burden, underscoring the potential benefit of tailored AMS in this population [43]. By limiting severe infection and sepsis, AMS programs may interrupt the cascade that leads to endothelial injury, diffuse alveolar damage and ARDS. Burn ICUs that integrate infection prevention with stewardship hold the greatest promise for reducing ARDS-related morbidity and mortality.

5. Integration of infection control and AMS for ARDS prevention

The integration of infection control and AMS programs in burn ICUs represents a synergistic approach to mitigating infection-driven complications such as ARDS. Burn patients are particularly susceptible to severe infections due to compromised skin barriers and immune dysregulation, making coordinated strategies essential. When infection control measures such as hand hygiene adherence, environmental decontamination, and device care bundles are implemented alongside AMS protocols, they collectively reduce both infection incidence and antimicrobial pressure that drive MDR and systemic inflammation [44,45]. Evidence from institutional studies supports the complementary nature of these programs. For instance, hospitals implementing combined infection control and AMS interventions have reported declines in VAP and BSIs, both major precursors to sepsis and ultimately acute lung injury [30,46]. An interrupted time series conducted in a tertiary burn center demonstrated that implementing a best-practice infection prevention and control bundle led to a reduction in healthcare-associated infections, primarily burn wound infections, followed by pneumonia and sepsis [47]. Similarly, the integration of microbiological surveillance within stewardship initiatives has enabled early detection of resistant organisms, optimizing antimicrobial selection and minimizing unnecessary exposure [37,48].

Effective integration of infection control and AMS relies on strong multidisciplinary teamwork. A “bug team” model including nurses, pharmacists, infection control specialists, and physicians effectively reduced VAP through coordinated monitoring and feedback [49]. Likewise, ICU-based AMS programs incorporating audit and feedback have decreased antibiotic use without increasing mortality, underscoring the value of interprofessional collaboration [50]. By merging infection control and stewardship under a unified clinical governance framework, burn ICUs can disrupt the cascade linking infection, sepsis, and lung injury. Such integration not only lowers infection rates and antibiotic resistance but also contributes to reduced ARDS incidence and improved overall patient outcomes [36,44].

6. Emerging perspectives and research priorities

Emerging technologies, particularly artificial intelligence (AI) models, show great promise by demonstrating high accuracy in predicting hospital-acquired infections in ICU settings [51]. Additionally, microbiome-based surveillance reveals gut or skin dysbiosis as an independent risk factor for critical-illness outcomes [52]. Integrating AI-driven risk classification with microbiome monitoring may enable early detection of infection risk before overt sepsis or acute lung injury develops [53]. However, critical research gaps remain. Few longitudinal studies in burn ICUs track infection or resistance patterns over time, and very limited data exist on pathogen-specific mechanisms of ARDS triggered by burn-related infection [54]. Furthermore, correlations between burn severity, antimicrobial resistance emergence, and ARDS incidence are poorly defined. Future investigations should focus on multicenter prospective studies in burn ICUs, interventional trials of combined AMS and infection-control strategies, and rigorous validation of AI and microbiome-based diagnostic tools tailored to this vulnerable group.

7. Conclusion

Infection control and AMS represent dual, core strategies in preventing acute lung injury among burn patients in intensive care units. Evidence across multiple studies supports that comprehensive infection control measures including environmental hygiene, device-care bundles, and active surveillance combined with well-structured AMS programs, substantially reduce healthcare-associated infections and antimicrobial resistance. The integration of these strategies within a unified clinical governance framework disrupts the infection-sepsis-lung injury cascade, lowering acute lung injury incidence and improving survival outcomes. Sustainable progress depends on multidisciplinary collaboration, continuous staff education, and institutional policies that reinforce adherence to infection prevention and rational antibiotic use. Moreover, the adoption of advanced diagnostic technologies and data-driven stewardship models can enhance early infection detection and therapy optimization. However, significant gaps persist regarding pathogen-specific mechanisms of ARDS in burn injury and the long-term impact of integrated AMS-infection control programs. Future multicenter, prospective studies are warranted to standardize preventive protocols and evaluate their efficacy across diverse burn ICU settings, ensuring that evidence-based stewardship becomes an integral part of critical care practice for this vulnerable population.

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Authors' contributions

HA, NK: conceptualized and defined the scope of the review. HA, KK, OKM: conducted the literature search and organized the data. HA, KK, OKM: prepared the initial draft of the manuscript. NK: provided critical revision and intellectual input to refine the manuscript. All authors read and approved the final version of article.

Conflict of interest

No potential conflict of interest was reported by the authors.

Ethical declarations

Not applicable.

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