Multiple Drug Resistance in Burn Patients

Abstract

Infections, the most common consequenceand the main cause of mortality for burn patients, thrive in environments created by burn wounds.After severe burns, the immune system is suppressed, which makes invasive infections like pneumonia and urinary tract infections more likely to occur. Emerging infections that are resistant to many drugs provide a challenge to therapy, requiring the development of novel antimicrobial medications and rigorous procedures to limit infection. Because these infections have a high morbidity and death rate, the rise of multidrug-resistant organisms (MDROs) in burn victims is a serious issue. Because of their wide wound surfaces, weakened immune systems, and need for several invasive operations and extended hospital stays, burn patients are especially vulnerable to MDROs. The increasing prevalence of multidrug-resistant organisms (MDROs) in burn patients presents a serious risk to both patient outcomes and efficient treatment. Due to their weakened skin barrier, extended hospital stays, and frequent use of intrusive devices—all of which promote the spread of infections—burn victims are especially susceptible.

Keywords: Infections, burn, Multiple Drug Resistance

Introduction

Despite a global decline in the incidence of burn injuries and decreasing mortality rates due to advancements in burn care systems, burn injuries remain a significant public health issue, with an estimated 11 million cases annually(1). These injuries are particularly prevalent in low- and middle-income countries (LMICs), where socioeconomic factors, hazardous work conditions, and inadequate safety regulations exacerbate the risk(2)(3). Burn wounds create an optimal environment for infections, which are the most frequent complications and leading cause of death among burn patients(4)(5). The immune suppression following severe burns increases susceptibility to invasive infections, including pneumonias, urinary tract infections (UTIs), and bloodstream infections (BSIs)(6). Emerging multi-drug-resistant pathogens further complicate treatment, necessitating innovative antimicrobial therapies and stringent infection control measures(7). The burden of burns, measured in disability-adjusted life years (DALYs), remains substantial, with significant economic losses, particularly in LMICs where access to specialized burn care is limited(8)(9).

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The emergence of multidrug-resistant organisms (MDROs) in burn patients is a significant concern due to the high morbidity and mortality associated with these infections. Burn victims are particularly susceptible to MDROs because of their compromised immune systems, extensive wound surfaces, and the need for prolonged hospital stays and multiple invasive procedures(10)(11)(12). Studies have shown that MDROs, including Pseudomonas aeruginosa, Staphylococcus aureus, and Enterobacter species, are frequently isolated from burn patients, with Pseudomonas aeruginosa being notably prevalent(13)(14)(15). The incidence of MDROs in burn units is influenced by factors such as antibiotic exposure, the use of invasive devices, and inadequate antimicrobial treatment(6)(16).

Epidemiology of MDROs

Burn wounds, initially sterile, become colonized by bacteria over time, with early colonization typically involving gram-positive bacteria from the skin, such as Staphylococcus aureus, within the first two days(16). As the wound environment evolves, gram-negative bacteria from the respiratory and gastrointestinal tracts, including Pseudomonas aeruginosa and Acinetobacter baumannii, become predominant(17). The incidence of multidrug-resistant organisms (MDROs) in burn patients is notably high, with studies indicating that 11.3% to 65.85% of burn patients acquire MDROs during their hospital stay. These infections significantly impact patient outcomes, leading to increased morbidity, mortality, and length of hospital stay(18)(19). Risk factors for MDRO acquisition include extensive total body surface area (TBSA) burns, prolonged hospital stays, and the use of invasive devices such as catheters and ventilators(20)(21)(11).

Burn patients are particularly susceptible to infections from multidrug-resistant organisms (MDROs), which significantly complicate their treatment and increase morbidity and mortality rates. Studies have consistently shown that infections in burn patients are predominantly caused by a few key pathogens. For instance, a study conducted in a U.S. military burnIntensive Care Unit(ICU) from 2003-2008 identified Acinetobacter baumannii, Pseudomonas aeruginosa, Klebsiella pneumoniae, and Staphylococcus aureus as the most common bacteria, accounting for 76% of all infections. This aligns with findings from various other studies. For example, Pseudomonas aeruginosa and Staphylococcus aureus are frequently reported as prevalent pathogens in burn units, with Pseudomonas aeruginosa being particularly noted for its high resistance rates and association with increased mortality(11)(22)(23). Additionally, Enterococcus spp. and Enterobacter spp., though less common, are still significant contributors to the

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infection burden in burn patients(12)(14)(20). The prevalence of these pathogens underscores the importance of continuous microbiological surveillance and the implementation of stringent infection control measures, such as hand hygiene and antimicrobial stewardship, to mitigate the spread of MDROs(16)(24). Moreover, the risk factors for MDRO acquisition in burn patients include prolonged hospital stays, the use of invasive devices, and inadequate antimicrobial treatment, which necessitate targeted interventions to improve patient outcomes(25).

Multi-Model Strategies for Preventionand Control

Infection prevention and control in burn centers is critical due to the high prevalence of multi-drug-resistant organisms(MDROs), which can originate from the patient's own microbes or the hospital environment. Effective cleaning and disinfection of hospital surfaces are essential in reducing the burden of MDROs. Enhanced cleaning methods, such as the use of ultraviolet (UV) devices and hydrogen peroxide vapor, have been shown to significantly lower infection rates, with some studies reporting reductions of up to 85% in certain MDROs(26)(27). Burn patients are particularly vulnerable to infections due to the loss of the skin barrier and induced immunosuppression, which increases their susceptibility to both localized and systemic infections(11)(14). The implementation of strict infection control measures, including hand hygiene, environmental disinfection, and the use of personal protective equipment, is crucial in managing MDRO outbreaks in burn units(25)(28). Studies have demonstrated that multi-model strategies, including ongoing staff education, cohorting or isolation of patients, and preemptive barrier precautions, can effectively reduce the incidence of healthcare-associated infections (HAIs) caused by MDROs(28)(29). Additionally, early excision of burn and wound grafting are essential to decrease the duration of hospitalization, infectious risk, and mortality. The use of novel antimicrobial therapies, such as cold plasma and topical antiseptics(15), along with rapid diagnostic tests and appropriate antimicrobial stewardship, further aids in combating MDRO infections(30).

Rubin et al.2023 demonstrated that universal patient decolonization effectively halted a Methicillin-resistant Staphylococcus aureusoutbreak in a burn ICU, highlighting the critical role of decolonization in controlling nosocomial infections in high-risk settings(31). Similarly, Yahia et al. 2023 found that the application of nasal mupirocin significantly reduced MRSA infections, underscoring the efficacy of targeted decolonization protocols(32). However, universal contact precautions alone have shown limited effectiveness in curbing the spread of multidrug-resistant organisms (MDROs), possibly due to high rates of hand contamination after glove removal, which can undermine the

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benefits of such precautions(33). This is supported by findings that emphasize the importance of comprehensive infection control measures, including rigorous hand hygiene practices(34). Additionally, antimicrobial stewardship programs, which aim to optimize the use of antibiotics, have been shown to improve patient outcomes and reduce MDRO infections, particularly when combined with other infection control strategies such as decolonization and environmental cleaning(35). For instance, a study on the implementation of a nasal antiseptic decolonization program in ICUs reported a reduction in healthcare-associated infections (HAIs), including MRSA bacteremia, further validating the effectiveness of decolonization measures(36).

Antimicrobial stewardship

Antimicrobial stewardship (AMS) is a critical strategy in healthcare aimed at optimizing the use of antimicrobial agents to improve patient outcomes, enhance safety, and reduce the incidence of infections such as *Clostridium difficile*(37). The emergence of multidrug-resistant organisms (MDROs) is a significant concern, particularly in burn infections, which are highly susceptible to these resistant pathogens(38). AMS programs are designed to address this issue by implementing a range of interventions, including the prudent selection, dosage, and duration of antimicrobial therapy, as well as the de-escalation of empiric therapy based on microbiology results(39). These programs also emphasize the importance of infection control measures, such as hand hygiene and the use of computerized alert systems, to prevent the spread of drug-resistant bacteria within healthcare facilities(40). In the intensive care unit (ICU), where the prevalence of resistant pathogens and the complexity of pharmacology are particularly high, AMS interventions have been shown to improve the quality and quantity of antimicrobial prescribing without compromising patient outcomes(41). Additionally, AMS programs have demonstrated significant benefits in reducing hospital stay lengths, readmission rates, and mortality associated with infections, as well as lowering healthcare costs and the incidence of Clostridium difficile colitis(42).

Rapid identification and antimicrobial susceptibility testing

Rapid identification and antimicrobial susceptibility testing (AST) are essential for optimizing antibiotic use and improving patient outcomes, particularly in critical infections like bloodstream infections (BSI). The Accelerate PhenoTest BC Kit is a notable advancement, providing pathogen identification and resistance profiles in approximately 7 hours, significantly faster than the traditional 48-72 hours required by conventional methods(43). This rapid turnaround is crucial for timely adjustments in treatment, potentially reducing morbidity and mortality associated with infections. Similar rapid testing systems, such as the

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BiofireFilmarray and Verigene, also offer the capability to detect multiple bacteria and antibiotic resistance genes, enhancing the speed and accuracy of diagnosis(44). The EUCAST-RAST method, for instance, can provide results within 4 to 8 hours, although its efficacy varies among different pathogens, with Staphylococcus aureus showing 100% categorical agreement at 4 hours(45). Other innovative approaches include the FAST™ System, which isolates and concentrates microorganisms from positive blood cultures within 30 minutes, allowing for direct downstream testing and rapid resistance detection(46). Additionally, methods like the microfluidic ladder-based system and automated platforms that use fluorescently labelledrRNA probes have reduced AST turnaround times to as little as 4-5 hours, maintaining high accuracy and agreement with traditional methods(47)(48)(49).

Ventilator-associated pneumonia (VAP) is a significant concern in burn patients, often leading to severe outcomes if not promptly and accurately treated. The initial use of inappropriate antibiotics can exacerbate these outcomes, particularly due to the prevalence of multidrug-resistant organisms (MDROs) in these settings. Rapid diagnostic methods have emerged as crucial tools in identifying the causative pathogens and their resistance profiles, thereby guiding more effective and targeted antibiotic therapy. Techniques such as multiplex PCR, which can identify a wide range of pathogens and resistance markers within hours, have shown promise in improving diagnostic accuracy and speed(50). Similarly, nanopore-based metagenomic next-generation sequencing (mNGS) can detect pathogens and antimicrobial resistance genes within approximately 5 hours, significantly faster than traditional cultures(51)(52). Other methods like GeneXpert Carba-R, which identifies carbapenem-resistant genes directly from clinical samples, have demonstrated high sensitivity and specificity, aiding in the rapid detection of resistant strains such as Acinetobacter baumannii and Klebsiella pneumoniae(53). These advancements are particularly beneficial in the ICU, where VAP is common and associated with high morbidity and mortality(54). The use of these rapid diagnostic tools can help in the early initiation of appropriate antimicrobial therapy, reducing the risk of MDROs and improving patient outcomes(55).

PNA-FISH (Peptide Nucleic Acid Fluorescence in Situ Hybridization) is a molecular technique that allows for the rapid identification of microorganisms directly from clinical samples without the need for traditional culturing methods. This method uses fluorescently labelledpeptide nucleic acid probes that hybridize to specific ribosomal RNA sequences of target pathogens, enabling their visualization under a fluorescence microscope. PNA-FISH has been FDA-approved for use in blood cultures and has shown promise in detecting pathogens in burn

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wounds, as demonstrated in animal studies. The application of PNA-FISH in burn wounds is particularly advantageous because it provides rapid results, which is crucial for timely and appropriate treatment. Traditional culture methods can take several days to yield results, whereas PNA-FISH can identify pathogens within hours, thus facilitating quicker clinical decisions. This rapid identification is essential in burn wound management, where infections can quickly progress to sepsis and other severe complications(56)(57)(58). Moreover, the use of PNA-FISH can help reduce the empirical use of broad-spectrum antibiotics, thereby minimizing the risk of developing multi-drug resistant organisms (MDROs)(59)(60). Studies have shown that culture-independent methods like PNA-FISH and FISHseq provide additional diagnostic information that can be missed by conventional culture techniques, including the detection of nonplanktonic bacterial life forms and microbial biofilms, which are often implicated in chronic and non-healing wounds(61)(62).

Treatment Options for MDROs

Methicillin-resistant *Staphylococcus aureus*

Vancomycin remains the first-line treatment for methicillin-resistant *Staphylococcus aureus* (MRSA) infections, but its use is challenging in burn patients due to variable renal function, necessitating careful dosage to achieve therapeutic trough concentrations of 15-20 mg/L. However, AUC-based dosage is preferred to minimize nephrotoxicity and ensure efficacy, especially when the minimum inhibitory concentration (MIC) exceeds 2 mcg/mL, at which point alternative therapies are recommended(63)(64). Daptomycin serves as a viable alternative for MRSA wound and bloodstream infections, offering simpler renal dosing and higher efficacy at doses of 8-10 mg/kg daily for critically ill patients, although it is ineffective for lung infections due to inactivation by pulmonary surfactant(65)(66).

Linezolid, an oxazolidinone antibiotic, is frequently employed to treat methicillin-resistant *Staphylococcus aureus* (MRSA) pneumonia and skin infections due to its efficacy against Gram-positive bacteria and its ability to achieve high concentrations in lung fluid and tissues(67)(68). Its mechanism involves binding to the 50S ribosome, inhibiting protein synthesis, which is effective against a range of Gram-positive organisms, including multi-resistant strains(69)(70). However, its bacteriostatic nature, which inhibits bacterial growth rather than killing the bacteria outright, makes it less suitable for bloodstream infections (BSI) where bactericidal (bacteria-killing) activity is often preferred(71). In critically ill patients, the pharmacokinetics and pharmacodynamics of linezolid can be significantly altered, necessitating careful consideration of dosing regimens to ensure therapeutic efficacy while minimizing the risk of

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adverse effects(72)(73). Long-term use of linezolid is limited by potential severe side effects, including bone marrow suppression, peripheral neuropathy, and optic neuropathy, which can lead to acute multiorgan failure, especially in patients with preexisting comorbidities(74)(75). Despite these risks, linezolid has shown a high clinical success rate in treating Gram-positive infections in critically ill patients, with a reported success rate of 82.2% in a multi-center study(76).

Ceftaroline, a fifth-generation cephalosporin, is notable for its efficacy against methicillin-resistant Staphylococcus aureus (MRSA) due to its strong binding affinity to penicillin-binding protein 2a (PBP-2a)(77). It has been approved for treating community-acquired pneumonia (CAP) and complicated skin and soft tissue infections (cSSTIs) in both adults and children, demonstrating similar clinical and microbiological efficacy to existing treatments(78)(79). Ceftaroline has shown promising results in treating MRSA pneumonia, including in burn patients, with a common dosing regimen of 600 mg every 12 hours, although an eight-hour dosing schedule is also frequently used(80)(81). Resistance to ceftaroline among MRSA strains has been documented, with variations in resistance rates observed across different regions. For instance, a study found that 2.9% of pediatric MRSA isolates exhibited reduced susceptibility to ceftaroline, particularly among healthcare-associated infections(82). Another study identified that 7.69% of MRSA isolates had increased minimum inhibitory concentrations (MICs) for ceftaroline, indicating emerging resistance(83). The resistance is often linked to mutations in the mecA gene, which encodes PBP2a, although secondary chromosomal mutations may also contribute(84). Despite these challenges, ceftaroline remains a valuable option for treating severe infections caused by resistant pathogens, including MRSA, due to its broad-spectrum activity and favorable safety profile(85).

Eravacycline and omadacycline, both derived from tetracycline, have shown promising results against methicillin-resistant Staphylococcus aureus (MRSA) in laboratory settings. Omadacycline is approved for treating community-acquired bacterial pneumonia (CABP) and acute bacterial skin and skin structure infections (ABSSSI)(86)(87). It has demonstrated efficacy comparable to other antibiotics in clinical trials for these indications, with a favorable safety profile and lower risk of adverse events leading to discontinuation (88)(89). Additionally, omadacycline has shown significant activity against Mycobacterium abscessus, a challenging pathogen, in both in vitro and animal studies, suggesting its potential for treating difficult lung infections(90)(91). Eravacycline, on the other hand, is approved for complicated intra-abdominal infections and has shown high effectiveness against multidrug-resistant Acinetobacter baumannii, particularly when combined with other

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antibiotics like amikacin(92). Both antibiotics exhibit broad-spectrum activity and have been evaluated for their pharmacokinetics in patients with various comorbidities, indicating no need for dose adjustments based on these factors(93). Omadacycline also possesses unique immunomodulatory properties, which may enhance its therapeutic potential in conditions where immune response modulation is beneficial(94).

Therapeutics for Vancomycin-Resistant Enterococcal

Vancomycin-resistant enterococci (VRE) are significant nosocomial pathogens, with Enterococcus faecium exhibiting higher rates of vancomycin resistance compared to Enterococcus faecalis(95). These bacteria are notorious for their ability to resist most anti-gram-positive agents, posing a substantial challenge in clinical settings (96). While VRE may occasionally be susceptible to β-lactams, such instances are rare, necessitating alternative treatment strategies(97). Linezolid and high-dose daptomycin are commonly used treatment options for VRE infections. Linezolid, an oxazolidinone, has been particularly effective, although resistance to this drug has also been reported in some strains(98). High-dose daptomycin, often combined with other antibiotics such as ampicillin, ceftriaxone, or ceftaroline, has shown efficacy in treating VRE infections, especially in cases of persistent bacteremia and infective endocarditis(99). Additionally, newer antibiotics like eravacycline and omadacycline have demonstrated activity against VRE, although eravacycline is less effective for urinary tract infections (UTIs)(100). The prevalence of VRE in clinical settings, particularly in intensive care units (ICUs), underscores the need for stringent infection control measures and antibiotic stewardship programs to mitigate the spread of these resistant pathogens(101).

Addressing Carbapenem Resistance in *Klebsiella pneumoniae*

Klebsiella pneumoniae carbapenemases (KPCs) are a significant contributor to carbapenem resistance in Enterobacteriaceae, posing a severe public health threat due to their rapid spread and high mortality rates, particularly in immunocompromised patients(102)(103). The introduction of new β-lactam/β-lactamase inhibitors (BL/BLIs) like ceftazidime-avibactam has shown promise against KPC-producing strains, but resistance is emerging, often due to mutations in the KPC enzyme(104)(105)(106). These inhibitors are ineffective against class B metallo-β-lactamases (MBLs) and some class D β-lactamases, necessitating alternative treatments(107)(108). Combination therapies and novel drugs such as cefiderocol, which has shown high activity against MBL-producing isolates, are being explored to address these resistant strains(109)(110). Plazomicin and eravacycline are also effective against

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carbapenem-resistant K. pneumoniae (CRKP), but their clinical data is limited, and resistance issues persist(109).

Effectiveness of Ceftolozane-Tazobactam Against Resistant *Pseudomonas aeruginosa*

Ceftolozane-tazobactam (C/T) is a potent combination drug used to treat serious infections caused by Pseudomonas aeruginosa, including multidrug-resistant (MDR) and carbapenem-resistant strains. Despite tazobactam's inability to inhibit carbapenemases, C/T remains effective against many resistant strains due to ceftolozane's robust activity against P. aeruginosa, including carbapenem-resistant isolates when resistance mechanisms other than carbapenemase production are involved(111)(112). Studies have shown that C/T is highly active against P. aeruginosa, with susceptibility rates exceeding 90% in various regions, although resistance can occur, particularly in strains harboringmetallo-beta-lactamases (MBLs) like blaIMP and blaVIM(113)(114)(115). Comparative studies indicate that C/T and ceftazidime-avibactam (CAZ-AVI) have similar effectiveness and safety profiles for treating MDR P. aeruginosa infections, with no significant differences in clinical outcomes such as mortality and clinical cure rates(116). Additionally, imipenem-cilastatin-relebactam (IMI-REL) has shown efficacy against P. aeruginosa, including strains resistant to C/T, although resistance patterns vary geographically(117). Cefiderocol (CFD) is another promising agent, demonstrating high effectiveness against various resistant strains, including those resistant to C/T, and showing synergistic effects when combined with other antimicrobials like CAZ-AVI and fosfomycin(118).

Carbapenem-Resistant *Acinetobacter baumannii*

Acinetobacter baumannii, a significant nosocomial pathogen, often exhibits resistance to carbapenems, posing a substantial treatment challenge(119)(120). Polymyxins, such as colistin, are effective against carbapenem-resistant A. baumannii (CRAB) but are associated with severe nephrotoxicity and neurotoxicity, limiting their use(121)(122). Minocycline remains a viable option, although its efficacy can be compromised by biofilm formation, which necessitates higher antibiotic concentrations to eradicate biofilm-associated cells compared to planktonic cells(123). Tigecycline, while useful, has shown higher mortality rates when used as monotherapy compared to combination therapies, such as cefoperazone/sulbactam, which have demonstrated better clinical outcomes in CRAB bloodstream infections (BSI)(124)(125). Cefiderocol, a novel siderophore cephalosporin, has shown potent activity against multi-drug-resistant Gram-negative pathogens, including CRAB, and is particularly effective against strains with various β-lactamase enzymes(125)(126).

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Conclusion

The increasing prevalence of multidrug-resistant organisms (MDROs) in burn patients poses a significant threat to effective treatment and patient outcomes. Burn patients are particularly vulnerable due to their compromised skin barrier, prolonged hospital stays, and frequent use of invasive devices, which facilitate the spread of infections. The emergence of MDROs, such as methicillin-resistant Staphylococcus aureus (MRSA) and resistant strains of Pseudomonas, complicates treatment further. Effective infection control measures, including stringent hygiene practices and antimicrobial stewardship, are essential to limit the spread of these organisms and reduce antibiotic pressure that is selected for resistant strains. Regular microbiological surveillance and sensitivity testing are crucial for guiding appropriate antibiotic use and preventing the escalation of resistance.

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