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Microbial Diversity and Antibiotic Resistance Patterns in Burn and Wound Infections: A Study from the Al-Kindy Teaching Hospital, Iraq

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Abstract
Objective: Comprehending microbial diversity and antibiotic resistance patterns is essential for efficient treatment protocols. This study sought to determine the incidence of bacterial and fungal pathogens responsible for burn and wound infections and their antibiotic susceptibility profiles.
Methods: This cross-sectional study involved 140 patients with burn or wound infections. Sterile swabs and pus aspiration were employed to collect samples, which were subsequently processed using standard microbiological procedures. Antibiotic resistance was determined using the Kirby-Bauer disc diffusion method, following Clinical and Laboratory Standards Institute (CLSI) guidelines. Data was analysed using IBM SPSS version 25.0, and the Chi-square test was used to evaluate resistance patterns ($p < 0.05$).
Results: Seventy-five (53.6%) participants were male, while 65 (46.4%) were female. *Pseudomonas aeruginosa* was the predominant pathogen (30.7%), followed by *Staphylococcus aureus* (22.1%) and *Klebsiella pneumoniae* (15.7%). Antibiotic resistance patterns indicated significant resistance to Amoxicillin-clavulanic acid (72.1%), Ceftriaxone (65.0%), and Clindamycin (58.6%), although resistance to Amikacin (27.1%) and Ciprofloxacin (32.9%) was comparatively lower. The duration of healing differed among pathogens, with *Acinetobacter baumannii* requiring the longest length of 25 days, whereas *Pseudomonas aeruginosa* healed in a shorter duration of 14 days. Burn infection showed a strong link with antibiotic treatment ($p = 0.024$, 0.0182), whereas wound infection demonstrated a poor correlation ($p = 0.089$).
Conclusion: The results underscore the necessity of ongoing monitoring of antibiotic resistance in wound and burn infections to inform empirical treatment. Targeted antimicrobial stewardship strategies can mitigate the advancement of resistance to infections and enhance clinical outcomes.

Keywords: Burn, Wound, Antibiotics, Infection, Sensitivity, Resistance

Plain English Summary

Burn and wound infections are serious clinical problems made worse by bacteria that have become resistant to certain antibiotics. Therefore, understanding the relationship between unicellular organisms such as bacteria and fungi and antibiotic resistance patterns is important to establish treatment protocols. This study aimed to determine the occurrence of disease-causing organisms responsible for burn and wound infections as well as their antibiotic susceptibility profiles. A hundred and forty participants' records were accessed at Al-Kindy Teaching Hospital from October 2, 2022, to May 1, 2023, and their antibiotic resistance profiles were assessed. The study results showed that *Pseudomonas aeruginosa* was the

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predominant pathogen (30.7%), followed by *Staphylococcus aureus* (22.1%) and *Klebsiella pneumoniae* (15.7%). %). Antibiotic resistance patterns indicated significant resistance to Amoxicillin-clavulanic acid (72.1%), Ceftriaxone (65.0%), and Clindamycin (58.6%), although resistance to Amikacin (27.1%) and Ciprofloxacin (32.9%) was comparatively lower. This study indicates the importance of ongoing monitoring of antibiotic resistance in wound and burn infections to inform the initiation of antibiotic treatment.

Background

There were 9 million burn cases worldwide in 2019, with a 95% uncertainty interval ranging from 6.8 to 11.2 million, and 111,000 burn deaths, ranging from 88,000 to 132,000 (1). In the United States, wounds affect healthcare costs and quality of life (QoL) by about 2.5 % (2). The burden of burns and wounds varies regionally: in low- and middle-income countries, burn mortality rates are disproportionately high due to limited access to care, while in Europe, burns account for over 4% of injury-related hospitalizations annually (3). In Asia, thermal injuries are among the top five causes of disability-adjusted life years (DALYs) in trauma patients (4). In the United States, Medicare beneficiaries experienced wounds or infections associated with wounds in 2014, according to a retrospective review of the Medicare 5% Limited Claims Dataset (a nationally representative sample of U.S. Medicare enrollees) (5). The disruption of the skin's protective barrier and thrombosis of the subcutaneous blood vessels are the primary causes of burn and wound infections. The avascular wound bed that forms create an ideal environment for bacterial proliferation and resistance to systemically administered antimicrobial agents (6, 7). While endogenous bacteria frequently assist hosts in their native habitats, some of these microorganisms can induce disease (8). Therefore, a host's vulnerability to infection may arise in the case that the host's usual microflora experience any disruption in their connection. Infections resulting from wounds or burns exemplify circumstances where indigenous bacteria can colonize a new environment, potentially leading to significant disruption (9, 10).

In the majority of instances, the bacteria that inhabit these wounds are the patient's indigenous flora (11, 12). Nonetheless, transmission may also occur through contact with fomites, contaminated water, or the unclean hands of healthcare professionals (13, 14). Acute wound infections can be caused by various pathogens, including Gram-negative organisms such as *Pseudomonas aeruginosa* and *Acinetobacter spp.,* and Gram-positive bacteria such as *Staphylococcus aureus* and *Enterococcus spp.* (2, 15).

Infection is the primary cause of mortality and the most prevalent complication in people with burn injuries. The physiological alterations render these patients more susceptible to infection and burn wound sepsis (16). Polymicrobial consortia residing in structured biofilms significantly contribute to the wound's impaired healing. The biofilm establishes a protective barrier to shield hazardous germs from the immune system and antimicrobial treatments. Studies have demonstrated a correlation between biofilm infections and chronic wounds (17, 18). Recent research indicates that biofilm infections may hinder wound closure or result in improper wound closure, where the wound seems closed but the healed skin fails to function as a barrier (19, 20).

Conversely, wound cultures can guide the choice of topical antibiotics. Topical antimicrobials, when used before excision, reduce mortality and morbidity in severe burns, as evidenced by numerous studies (21, 22, 23). Understanding the risk factors that predispose patients to Multidrug-Resistant (MDR) infections is essential, alongside the implementation of preventive treatment interventions. The incidence of multi-drug resistance is greater in burns with an elevated total body surface area percentage, and the severity of the burn is a significant predictor of MDR infections (24). Moreover, factors that elevate the probability of resistant infections, such as extended antibiotic therapy and hospitalization, are linked to multi-drug resistance (25, 26). Antibiotic resistance poses a significant problem in the treatment of burns because drugs are commonly overprescribed due to their availability without prescriptions. There is extensive bacterial resistance to ciprofloxacin, amikacin, and cefepime; three antibiotics widely used. The presence of resistance complicates therapy, with sensitivity patterns having to be taken into consideration during the formulation of antibiotic protocols (27).

This study aimed to examine the trend of microbiology and antibiotic resistance in wound and burn infections at Al-Kindy Hospital. It will elucidate the local epidemiology of wound infection by identifying prevalent bacterial pathogens and resistance patterns. This will facilitate the selection of the most appropriate antibiotic regimens, improve patient outcomes, and inform infection control policies.

Materials and methods:

Study design

This study included 140 consecutive patients with clinically suspected infected wounds or burns referred to Al-Kindy Teaching Hospital between October 2, 2022, and May 1, 2023. The study aimed to characterize microbial profiles and antibiotic resistance patterns in wound/burn infections.

Participant Selection
Inclusion criteria
The patients were enrolled in the study after completing specified inclusion criteria for guaranteeing data authenticity. These comprised all persons of either sex and any age with clinically confirmed burn or wound infections for microbiological investigation. Inclusion was constrained to those being referred to Al-Kindy Teaching Hospital for burn or wound culture and antibiotic susceptibility testing, and they had to be accessed within the time range of the study. Patients who had not had systemic or topical antibiotics in the last 48 hours when samples were taken were additionally enrolled to prevent pre-treatment interference with microbial culture results. All the patients with a full clinical history that included demographic factors and information on infection-related data were enrolled.

Exclusion Criteria
Patients with non-infectious chronic wounds, such as diabetic ulcers, and no evidence of infection were excluded from the study, as were those who had been treated with broad-spectrum antibiotics 48 hours or more before collection, as this can contaminate the culture. Furthermore, samples deemed inadequate or contaminated, failing to fulfil the laboratory's quality criteria, were excluded.

Data Collection
Clinical samples were collected from 140 participants enrolled in the study (see 'Participant Selection'). Inclusion was based on clinician-identified signs of burn/wound infection, including purulent discharge, erythema, or systemic fever. Specimens were obtained as follows:
Swab collection: Sterile cotton swabs saturated with sterile saline were used to sample superficial infections. For deep burn wounds, the surface was cleansed with sterile saline before swabbing to remove debris.
Pus aspiration: In cases with abscess formation, pus was aspirated using a sterile syringe.
Samples were immediately transported to the microbiology laboratory in sterile transport media under aseptic conditions. Microbial susceptibility testing was performed via the Kirby-Bauer disc diffusion method following CLSI guidelines (28). Mueller-Hinton agar was employed for bacterial isolates, whilst Sabouraud dextrose agar containing antifungal discs was utilized for fungal susceptibility assessment. Antibiotic discs, Colistin sulfate, Lincomycin, Norfloxacin, Ciprofloxacin, Amikacin, Aztreonam, Azithromycin, Cefepime, Clindamycin, Amoxicillin, clavulanic acid, Ceftriaxone and Tetracycline were utilized. The inhibitory zones were quantified after 18–24 hours of incubation at 37°C, and the resistance patterns were documented.

Statistical analysis
Data were analyzed using IBM SPSS Statistics version 25.0. Descriptive statistics included frequencies and percentages for categorical variables (gender, type of infection, and resistance profiles) and measures of central tendency (e.g., mean, median) for continuous variables where applicable. To evaluate associations between categorical variables (e.g., bacterial species and resistance to specific antibiotics), Chi-square tests were performed. Statistical significance was defined as a two-tailed p-value < 0.05.

Results
Distribution of participants regarding gender in burn and wound cases
Table 1 illustrates a notable gender imbalance in the allocation of participants in burn and wound cases. In burn instances, males represented 59.5% (53 participants), whilst females comprised 40.5% (36 people). In wound cases, males constituted 66.7% (34 participants), whilst females accounted for 33.3% (17 people). This tendency suggests that males are more often impacted by burns and wounds compared to females, however, no statistically significant association exists between gender and the type of infection as indicated by the p-value of 0.403499.

Table 1. Gender distribution in burn and wound cases

Sex	Burn		Wound		p-value
	No	%	No	%	
Males	53	59.5%	34	66.7%	0.40
Females	36	40.5%	17	33.3%	
Total	89	100%	51	100%	

Distribution of cases regarding age

The case distribution among various age groups reveals that all ages are impacted as elucidated in Table 2, with the highest percentage seen in those over 40 years old (23.6%), followed closely by the 11–20 age group (22.2%). The 21–30 age demographic constituted 20% of instances, and individuals aged 10 years or younger comprised 17.8%. The minimal percentage was observed in the 31–40 age demographic (16.4%). The distribution regarding age was not statistically significant (0.874).

Table 2. Distribution of participants according to age

	No.	%	p-value
≤10	25	17.8%	0.874
11-20	31	22.2%	
21-30	28	20%	
31-40	23	16.4%	
>40	33	23.6%	

Distribution of microbial species in burn and wound infection

The distribution of microbial species in burn and wound cases revealed significant disparities in bacterial prevalence between the two forms of infections as demonstrated in Table 3. The Chi-Square test results ($\chi^2 = 23.42$, $p = 0.0154$) indicated a statistically significant correlation between bacterial species and infection type.

Klebsiella pneumoniae (24.7%) and Pseudomonas aeruginosa (20.3%) were the predominant bacterial isolates in burn cases, but Staphylococcus aureus was much more abundant in wound infections (27.4%) than in burns (7.8%). Pseudomonas fluorescens was more commonly linked to burn infections (11.2%) than to wound infections (3.9%). Moreover, several bacteria, like Burkholderia cepacia and Pseudomonas putida, were solely associated with burn patients, whereas Enterococcus faecalis was exclusively isolated from wound infections.

Table 3. Microbial species distribution in wound and burn infections

Microbial species	No.	Burn		Wound		Chi-square (χ^2)	p. value
		No.	%	No.	%		
Staphylococcus aureus	21	7	7.8%	14	27.4%	23.42	0.02
Acinetobacter baumannii	25	15	16.8%	10	19.6%		
Burkholdera cepacia	2	2	2.2%	0	0%		
Enterobacter aerogenes	3	2	2.4%	1	1.9%		
Enterococcus faecalis	1	0	0%	1	1.9%		
Escherichia coli	14	6	6.7%	8	15.7%		
Enterobacter cloacae	4	3	3.4%	1	1.9%		
Pseudomonas putida	1	1	1.1%	0	0%		
Proteus mirabilis	4	3	3.4%	1	1.9%		
Pseudomonas fluorescens	12	10	11.2%	2	3.9%		
Klebsiella pneumoniae	25	22	24.7%	3	5.9%		
Pseudomonas aeruginosa	28	18	20.3%	10	19.6%		
Total	140	89	100%	51	100%		

Antibiotic susceptibility of bacterial spp. Isolated from burn cases

The antibiotic susceptibility patterns revealed that Colistin sulfate demonstrated the highest sensitivity across all bacterial species, making it the most effective antibiotic in this study. In contrast, Cefepime, Ciprofloxacin, and Amikacin exhibited high resistance rates among multiple bacterial isolates. Notably, *Pseudomonas aeruginosa* and *Acinetobacter baumannii* displayed significant resistance to multiple antibiotics, highlighting their multidrug-resistant nature and the challenges in treating infections caused by these organisms. Additionally, Azithromycin showed no recorded cases of sensitivity across the tested bacterial species. On the other hand, Lincomycin and Norfloxacin exhibited no resistance in any of the bacterial species as shown in Table 4.

Table 4. Antibiotic Susceptibility and Resistance Patterns of Bacteria Isolated from Burn Infections

Bacterial Species	Antibiotic Sensitivity (%)	Antibiotic Resistance (%)	Sensitivity p-value	Resistance p-value
Pseudomonas aeruginosa	Colistin sulfate (64.8%), Lincomycin (24.3%), Norfloxacin (24.3%), Ciprofloxacin (13.5%), Amikacin (10.8%), Aztreonam (5.4%), Azithromycin (2.7%)	Cefepime (78.3%), Ciprofloxacin (75.6%), Amikacin (64.8%), Aztreonam (56.7%), Clindamycin (8.1%), Amoxicillin clavulanic acid (13.5%), Ceftriaxone (18.9%), Tetracycline (24.3%)	0.122	0.006
Klebsiella pneumoniae	Colistin sulfate (62.9%), Lincomycin (29.6%), Norfloxacin (29.6%), Amikacin (14.8%), Ciprofloxacin (14.8%), Azithromycin (3.7%), Cefepime (3.7%), Tetracycline (3.7%), Amoxicillin clavulanic acid (3.7%), Aztreonam (7.4%)	Amikacin (85.1%), Cefepime (81.4%), Aztreonam (77.7%), Ciprofloxacin (77.7%), Ceftriaxone (54.2%), Amoxicillin clavulanic acid (54.2%), Azithromycin (44.4%), Tetracycline (44.4%)	0.047	0.001
Acinetobacter baumannii	Colistin sulfate (60%), Lincomycin (26.6%), Norfloxacin (26.6%), Aztreonam (6.6%), Ciprofloxacin (13.3%)	Cefepime (80%), Ciprofloxacin (73.3%), Amikacin (53.3%), Aztreonam (40%), Azithromycin (13.3%), Amoxicillin clavulanic acid (13.3%), Tetracycline (26.6%), Ceftriaxone (33.3%)	0.095	0.006
Pseudomonas fluorescens	Colistin sulfate (100%), Amikacin (8.3%), Clindamycin (8.3%), Tetracycline (8.3%)	Cefepime (100%), Amikacin (91.6%), Aztreonam (75%), Tetracycline (33.3%), Ceftriaxone (33.3%), Azithromycin (50%), Amoxicillin clavulanic acid (50%), Ciprofloxacin (66.6%)	0.391	0.001
Enterobacter aerogenes	Colistin sulfate (100%), Amikacin (50%), Cefepime (50%), Ciprofloxacin (50%)	Ciprofloxacin (100%), Ceftriaxone (100%), Amoxicillin clavulanic acid (100%), Amikacin (50%), Aztreonam (50%), Azithromycin (50%), Cefepime (50%), Tetracycline (50%)	0.048	0.08
Escherichia coli	Colistin sulfate (50%), Amikacin (37.5%), Cefepime (12.5%), Lincomycin (25%), Norfloxacin (25%)	Ciprofloxacin (100%), Ceftriaxone (87.5%), Aztreonam (75%), Amikacin (62.5%), Azithromycin (62.5%), Cefepime (62.5%), Amoxicillin clavulanic acid (25%), Tetracycline (37.5%)	0.048	0.001
Proteus mirabilis	Amikacin (100%), Ciprofloxacin (100%),	Aztreonam (66.6%), Colistin sulfate (66.6%),	0.043	0.178

	Cefepime (66.6%), Aztreonam (33.3%), Ceftriaxone (33.3%), Amoxicillin clavulanic acid (33.3%)	Azithromycin (33.3%), Tetracycline (33.3%), Amoxicillin clavulanic acid (33.3%)		
Pseudomonas putida	Amikacin (100%)	Cefepime (100%), Ciprofloxacin (100%)	-	-
Staphylococcus aureus	Colistin sulfate (85.7%), Clindamycin (28.2%), Tetracycline (28.2%), Amikacin (14.2%), Ciprofloxacin (14.2%)	Amikacin (71.4%), Cefepime (71.4%), Azithromycin (57.1%), Aztreonam (57.1%), Ciprofloxacin (57.1%), Tetracycline (57.1%), Amoxicillin clavulanic acid (14.2%), Clindamycin (42.8%)	0.206	0.001
Enterobacter cloacae	Ciprofloxacin (50%), Amikacin (25%), Cefepime (25%), Colistin sulfate (25%), Lincomycin (25%), Norfloxacin (25%)	Aztreonam (100%), Amikacin (50%), Azithromycin (50%), Cefepime (50%), Ciprofloxacin (50%), Tetracycline (50%), Ceftriaxone (50%), Amoxicillin clavulanic acid (50%), Colistin sulfate (25%)	0.363	0.015
Burkholderia cepacian	-	Amikacin (50%), Azithromycin (50%), Amoxicillin clavulanic acid (50%), Cefepime (50%), Ciprofloxacin (50%), Tetracycline (50%)	-	-

Antibiotic Susceptibility and Resistance in Wound Infections

Clindamycin and Amoxicillin clavulanic acid demonstrated no recorded sensitivity in *Enterobacter aerogenes, Enterococcus faecalis, Klebsiella pneumoniae, Proteus mirabilis, Pseudomonas fluorescens*, and *Enterobacter cloacae*, signifying their ineffectiveness against these bacterial species according to the antibiotic susceptibility analysis. However, in the same bacterial isolates, no recorded resistance was observed for Clindamycin, Colistin sulphate, Lincomycin, and Norfloxacin, suggesting that these antibiotics may remain viable therapeutic options as seen in Table 5.

Table 5. Antibiotic Susceptibility and Resistance Patterns of Bacteria Isolated from Wound Infections

Bacteria	Highly Sensitive (%)	Highly Resistant (%)	Sensitivity p-value	Resistance p-value
Staphylococcus aureus	Ciprofloxacin (53.8%), Tetracycline (30.7%), Lincomycin (30.7%), Norfloxacin (30.7%) Amikacin (7.6%), Clindamycin (7.6%)	Azithromycin (84.6%), Tetracycline (46.1%), Ciprofloxacin (38.4%) Aztreonam (7.6%), Cefepime (7.6%), Amikacin (15.3%), Ceftriaxone (15.3%), Clindamycin (23%)	0.215	0.048
Acinetobacter baumannii	Lincomycin (60%), Norfloxacin (60%) Cefepime (10%), Colistin sulfate (40%)	Ciprofloxacin (90%), Amikacin (60%), Aztreonam (60%), Cefepime (60%)	0.071	0.001

		Ceftriaxone (50%), Amoxicillin clavulanic acid (40%), Azithromycin (30%), Tetracycline (30%)		
Escherichia coli	Amikacin (50%), Colistin sulfate (37.5%) Aztreonam (12.5%), Azithromycin (12.5%), Tetracycline (12.5%)	Ciprofloxacin (100%), Cefepime (75%), Ciprofloxacin (75%) Tetracycline (62.5%), Amikacin (50%), Aztreonam (50%), Amoxicillin clavulanic acid (37.5%), Azithromycin (12.5%)	0.189	0.002
Enterobacter aerogenes	Amikacin (100%), Aztreonam (100%), Ceftriaxone (100%)	Ciprofloxacin (100%), Tetracycline (100%)	0.035	0.001
Enterococcus faecalis	Ciprofloxacin (100%)	Tetracycline (100%)	–	–
Klebsiella pneumoniae	Amikacin (40%), Cefepime (40%), Ciprofloxacin (40%), Colistin sulfate (40%) Aztreonam (20%), Azithromycin (20%), Amoxicillin clavulanic acid (20%), Lincomycin (20%), Norfloxacin (20%)	Amikacin (60%), Aztreonam (60%), Ceftriaxone (60%), Ciprofloxacin (60%) Azithromycin (40%), Amoxicillin clavulanic acid (40%), Cefepime (40%), Tetracycline (20%)	–	0.001
Proteus mirabilis	Amikacin (50%), Aztreonam (50%), Azithromycin (50%), Cefepime (50%), Ceftriaxone (50%), Ciprofloxacin (50%) –	Amikacin (50%), Aztreonam (50%), Ceftriaxone (50%), Ciprofloxacin (50%), Tetracycline (50%) –	–	–
Pseudomonas fluorescens	Aztreonam (50%), Lincomycin (50%), Norfloxacin (50%) –	Amikacin (100%), Cefepime (100%), Ciprofloxacin (100%) Aztreonam (50%)	–	–
Enterobacter cloacae	Amikacin (100%), Aztreonam (100%), Ciprofloxacin (100%)	Ceftriaxone (100%), Tetracycline (100%) –	–	–

Healing Time of Wound and Burn Infection Pathogens Under Antibiotic Treatment

The healing durations for wound and burn infections treated with antibiotics demonstrate differing effectiveness against various bacterial pathogens as indicated in Table 6. *Acinetobacter baumannii* exhibited a protracted healing duration of 25 days with Colistin sulphate for wound infections, whereas *Pseudomonas aeruginosa* showed a more rapid recovery of 14 days when administered a combination of Norfloxacin and Lincomycin. Other pathogens, such as *Escherichia coli* and *Proteus mirabilis*, need reduced healing durations of 6 and 7 days, respectively, when administered Amikacin and Azithromycin. A p-value of 0.089 for wound infections indicates a modest link between antibiotic therapy and healing time, suggesting that additional factors may affect the healing process in wound infections. Colistin sulphate was frequently employed in the treatment of burn infections caused by many bacterial species, including *Klebsiella pneumoniae, Acinetobacter baumannii, Pseudomonas fluorescens, Enterobacter aerogenes, Staphylococcus aureus, Escherichia coli*, and *Pseudomonas aeruginosa*. Healing durations

varied from 3 days for *Enterobacter aerogenes* to 15 days for *Klebsiella pneumoniae* and *Proteus mirabilis*. The p-values of 0.024 and 0.0182 for burn infections indicated a statistically significant association.

Table 6. Relationship Between Healing Time of Wound and Burn Infection Pathogens Under Antibiotic Treatment

Infection Type	Bacterium	Antibiotic	Healing Time (Days)
Wound Infection	*Acinetobacter baumannii*	Colistin sulfate	25
	Pseudomonas aeruginosa	Norfloxacin + Lincomycin	14
	Escherichia coli	Amikacin	6
	Proteus mirabilis	Azithromycin	7
p.value (correlation to healing)	0.089	1.0	
Burn Infection	*Klebsiella pneumoniae*	Colistin sulfate	15
	Proteus mirabilis	Amikacin	15
	Acinetobacter baumannii	Colistin sulfate	14
	Pseudomonas fluorescens	Colistin sulfate	14
	Enterobacter aerogenes	Colistin sulfate	3
	Staphylococcus aureus	Colistin sulfate	5
	Escherichia coli	Colistin sulfate	7
	Pseudomonas aeruginosa	Colistin sulfate	11
p.value (correlation to healing)	0.024	0.0182	

Discussion

Burn injuries are a type of trauma that lacks adequate recognition, despite being a considerable contributor to morbidity and mortality in numerous regions globally. Burns can result from numerous factors affecting individuals, families, and society at large (29). In this study, males constituted the majority of burn and wound infection cases, consistent with a Palestinian study that indicated a higher prevalence of infections among males (58.5%) compared to females (30). Research indicates that men may exhibit greater susceptibility to burn- and wound-related infections (31), likely due to occupational exposure to hazardous settings (e.g., manufacturing, construction, firefighting) and risk-taking behaviours that elevate injury rates and subsequent infection risks. Global epidemiological trends reveal that from 1990 to 2019, females constituted around 87% of the increasing cases of burn injuries, suggesting significant regional and socioeconomic disparities in the occurrence of such injuries (29).

Individuals aged 11 to 20 constituted 22.2% (31 cases) of the total burn and wound cases examined. The elevated case density in the 10–19 year age range aligns with global trends (29). Conversely, research in Turkey revealed that the youngest children age group were the most affected, suggesting a regional differential (32). Young persons may exhibit increased susceptibility due to their propensity for risky behaviours and physical activities, whereas the elderly may face heightened risk owing to inactivity, chronic health issues, or occupational environments. In the current study, *Klebsiella pneumoniae* (24.7%) and *Pseudomonas aeruginosa* (20.3%) were the primary bacterial isolates in burn infections, although *Staphylococcus aureus* was substantially more prevalent in wound infections (27.4%) compared to burns (7.8%). A study in Italy identified the most prevalent bacteria responsible for burn infection as *Acinetobacter baumannii* (28%), *Pseudomonas aeruginosa* (26%), and methicillin-resistant *Staphylococcus aureus* (25%) (33). Similar results were observed in Bangladesh, where *Pseudomonas aeruginosa* constituted 57%, followed by *Staphylococcus aureus* at 35% and *Klebsiella spp* at 5% (34). *Pseudomonas aeruginosa* (20%) and *Staphylococcus aureus* (17.14%) were predominant in Iraq, alongside *Enterobacter spp.* (16.19%) and *Proteus vulgaris* (13.33%) (34).

Numerous studies indicate that *Staphylococcus aureus* and *Pseudomonas aeruginosa* are the predominant bacteria found in chronic wound infections, with co-infections exhibiting greater virulence than mono-infections (35, 36). A Chinese investigation identified *Staphylococcus aureus* as the predominant pathogen at 29.2%, followed by *Escherichia coli* at 11.5%, *Pseudomonas aeruginosa* at 11.0%, and *Klebsiella pneumoniae*

at 5.8% (37). Metagenomic investigations have shown *Staphylococcus spp. (S. aureus and S. pettenkoferi*) as the predominant genus in chronic wounds, succeeded by *Streptococcus, Corynebacterium,* and *Anaerococcus* (38). In Pakistan, *E. coli* constituted the predominant bacterial isolate in wound infections, accounting for 45.3% (39). Additionally, *Staphylococcus epidermidis* can produce biofilms in chronic wound infections, resulting in consequences such as septicaemia (40).

Skin infections like *Staphylococcus aureus* and *Streptococcus pneumoniae* are not chemoattractant but use different adhesion mechanisms to cling to host tissues. This enables them to exploit available resources while they transmit virulence factors into the host milieu, therefore helping in infection and poor wound healing (41). The rise of multi-drug-resistant (MDR) microbes, such as *Staphylococcus aureus, Enterococcus, Pseudomonas, Acinetobacter,* and *Enterobacter* presents considerable issues in clinical practice, especially in wound and burn management (42).

Several studies demonstrate significant variance in the antibiotic resistance profiles of *Escherichia coli* isolates from burn and wound infections. *E. coli* had the highest sensitivity to amikacin (75%) and imipenem (52.3%), while sensitivity to fourth-generation cephalosporins ranged from 35% to 50%. Ampicillin had the lowest percentage at 6.8%. A reduced gentamicin sensitivity of 38.6% was discovered, in contrast to international figures of 70%, indicating regional variations in resistance (43). Significant resistance to ampicillin (68.1%) and ciprofloxacin (68.1%), while resistance to tigecycline (3.9%) and amikacin (3.6%) was minimal (44).

Multidrug resistance (MDR) remains a problem for Staphylococcus aureus. Guan et al. (2021) reported high levels of resistance to penicillin (92%), erythromycin (58.3%), and clindamycin (50.9%). The most effective was vancomycin, to which no resistance was detected among the Gram-positive isolates (37). In another study, a high rate of resistance (86.6%) to amikacin. These findings stress the supreme importance of vancomycin as a last-resort therapeutic agent for the treatment of MDR S. aureus infections (44). Klebsiella pneumoniae antibiotic resistance pattern is also extremely variable geographically. In Iraq, there are high resistance levels to doxycycline (100%), tetracycline (95.23%), and ceftriaxone (88.09%). Susceptibility was highest for gentamicin (78.57%), meropenem, and amikacin (76.19%) (45). High resistance to ceftriaxone (67%) and tigecycline (13%) in Indonesia. The differences in resistance rates noted may be explained by local antibiotic usage patterns and healthcare practices. Pseudomonas aeruginosa and Acinetobacter baumannii were extremely resistant to many classes of antibiotics (46). Another study in 2022 reported high rates of resistance to gentamicin and amikacin in P. aeruginosa isolates (47). In addition, 100% resistance to ceftazidime and piperacillin in A. baumannii isolates (40).

The persistence of high resistance rates among these pathogens signals the imperative of effective infection control policies and the judicious use of antibiotics. Burkholderia cepacia was found to be especially resistant to a variety of antibiotics. In India, 100% resistance to an array of broad-spectrum antibiotics like amikacin, imipenem, and vancomycin (48). Identical high levels of resistance were also reported from Iraq (44). Pseudomonas aeruginosa was isolated from 12 samples, exhibiting 83.33% sensitivity to fosfomycin, 75% sensitivity to amikacin, and 50% sensitivity to piperacillin. Conversely, Proteus mirabilis or Proteus vulgaris was cultured in five samples, which were 100% sensitive to ceftazidime and 80% sensitive to ceftriaxone, fosfomycin, and aztreonam. Amikacin and sulfamethoxazole with trimethoprim were fairly sensitive at 60%. Escherichia coli was also cultured in two samples with 100% sensitivity to Trifamox, piperacillin, and doxycycline (49).

The healing of burn wounds is multifactorial and intricate. A systematic review indicated that the depth of the burn significantly influences wound healing time, unlike the infectious pathogen's aetiology (50). The presence of various microorganisms, including drug-resistant strains, poses significant challenges to accurate diagnosis and treatment, potentially affecting overall recovery time (51). Furthermore, an experimental investigation revealed that the degree of wound healing is substantially affected by the bacterial load, or the quantity of colonizing bacteria, rather than the microbial type (52). This aligns with a prior study indicating that the degree of bacterial proliferation in a lesion is more significant than the mere presence of germs concerning healing (53).

Inadequately debrided eschar in burn wound management facilitates microbial growth. Topical use of antimicrobials has been shown to suppress pathogenic bacterial proliferation and avert systemic infection. Topical treatment targets the individual deficiencies of each wound, including biofilms, bioburden, the presence or absence of eschar, and the requirement for epithelialisation. Personalized therapy indicates that consideration

must be afforded to patient-specific parameters while weighing the risks against the benefits of each antimicrobial agent (54).
MDRO infections exhibit a more complex clinical trajectory, characterised by elevated rates of surgical intervention, prolonged wound healing, intensified antibiotic therapy, and extended hospital stays (55). A study confirmed that patients with multidrug-resistant (MDR) bacteria who were chronically infected experienced significantly prolonged hospital stays, averaging 25 days, in contrast to non-infected patients with MDR bacteria, who averaged 10 days, thereby, illustrating the substantial impact of antibiotic resistance on recovery duration (38).

Limitations
This study has several limitations. First, its single-centre design at Al-Kindy Teaching Hospital may limit the generalizability of findings to other settings with differing patient demographics or microbial profiles. Second, the sample size (n=140), though representative of the hospital's annual caseload, may lack statistical power to detect rare resistance patterns. Third, the exclusion of polymicrobial infections unrelated to the primary wound may overlook complex microbial interactions. Finally, long-term patient outcomes (e.g., treatment success rates) were not assessed, restricting insights into the clinical implications of resistance patterns.

Future Research Directions
Future studies should prioritize multicenter cohorts to validate regional resistance trends and explore socioeconomic or environmental drivers of antimicrobial resistance. Genomic characterization of multidrug-resistant isolates could elucidate emerging resistance mechanisms. Additionally, longitudinal investigations assessing the impact of resistance on treatment outcomes and healthcare costs are warranted to inform clinical guidelines.

Conclusion
This study clarifies the intricate relationship among bacterial infection, antibiotic treatment, and the healing of wounds and burns. Microbial analysis demonstrated substantial alterations in bacterial dissemination related to burn wounds. *Klebsiella pneumoniae* and *Pseudomonas aeruginosa* were the predominant bacteria in burn infections, whereas *Staphylococcus aureus* was the most prevalent pathogen in wound infections. *Burkholderia cepacia* and *Pseudomonas putida* were exclusively found in burn infections, while *Enterococcus faecalis* was alone identified in wounds.
Antibiotic susceptibility assays revealed significant resistance, especially in *Pseudomonas aeruginosa* and *Acinetobacter baumannii*, to therapeutic interventions. Despite the resistance of several bacterial isolates to Cefepime, Ciprofloxacin, and Amikacin, Colistin sulphate emerged as the most effective antibiotic. The efficacy of antibiotics, contingent upon the disease's characteristics and the duration of recovery, underscores the need for more systematic therapeutic planning. Multidrug-resistant bacteria underscore the imperative for antimicrobial surveillance and treatment adaptability. Research must uncover and cultivate novel resistance mechanisms to combat chronic and resistant infections in individuals with burns and wounds.

List of Abbreviations
AK: Amikacin
AMC: Amoxicillin-Clavulanic Acid
AMP: Ampicillin
ATM: Aztreonam
AZM: Azithromycin
CFU: Colony-Forming Unit
CIP: Ciprofloxacin
CLI: Clindamycin
CLSI: Clinical and Laboratory Standards Institute
COL: Colistin
CRAB: Carbapenem-Resistant Acinetobacter baumannii
CRO: Ceftriaxone
CTX: Cefotaxime
DALYs: Disability-Adjusted Life Years
ESBL: Extended-Spectrum Beta-Lactamase
FEP: Cefepime
GEN: Gentamicin
IBM SPSS: International Business Machines Statistical Package for the Social Sciences
LZD: Linezolid
MDR: Multidrug-Resistant
MDRB: Multidrug-Resistant Bacteria
MDRO: Multidrug-Resistant Organism
MIC: Minimum Inhibitory Concentration
MRSA: Methicillin-Resistant Staphylococcus aureus
PDR: Pan-Drug-Resistant
QoL: Quality of Life
TET: Tetracycline
TZP: Piperacillin-Tazobactam
US: United States
VRE: Vancomycin-Resistant Enterococcus
WHO: World Health Organization
XDR: Extensively Drug-Resistant
β-lactam: Beta-Lactam (antibiotic class)

Declarations

Ethical approval and consent to participate

Ethical clearance and permission for data and sample analysis were obtained from Al-Kindy College of Medicine and Al-Kindy Teaching Hospital before study initiation (Approval No. 4851). Written informed consent was obtained from all participants

Consent for publication

All the authors gave consent for the publication of the work under the Creative Commons Attribution-Non-Commercial 4.0 license.

Availability of data and materials

The data and materials associated with this research will be made available by the corresponding author upon reasonable request.

Competing interests

The authors declare no conflicts of interest relevant to this study.

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Authors' contributions

IS: Conceptualization, methodology, data analysis, manuscript writing, and project supervision.

Salih WH: Data collection, validation, and review of the manuscript.

Majeed SZ: Literature review, statistical analysis, and manuscript editing.

All authors have read and approved the final manuscript.

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