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ORIGINAL ARTICLE

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Bacteriological Profile and Antibiotic Susceptibility Patterns of Wound Infections at a Public Tertiary Hospital in Sana'a Governorate, Yemen

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ABSTRACT

Background: Wound infections are a leading cause of morbidity and mortality globally, representing one of the most prevalent nosocomial infections. The etiological agents vary by geographic region, and there is a growing incidence of antibiotic resistance among these pathogens. This study retrospectively analyzed the bacterial species isolated from patients with wound infections and their antibiotic susceptibility patterns at a public tertiary hospital in Sana'a Governorate, Yemen.

Methods: A retrospective cross-sectional study was conducted to identify the bacterial species causing wound infections and their antibiotic susceptibility patterns among patients admitted to the 48 Model Hospital in Sana'a Governorate from January 2020 to December 2020. This study included all patients diagnosed with wound infections and undergoing culture and antibiotic susceptibility testing during the study period.

Results: Of the 386 patients with wound swab cultures, 290 (75.1%) had infections caused by a single bacterial species, most frequently among males (98.6%). Among the isolates, Gram-negative bacilli accounted for 61.4%, while Gram-positive cocci comprised 38.6%. *Staphylococcus aureus* was the most frequently isolated bacterial species (38.3%), followed by *Pseudomonas aeruginosa* (36.6%) and *Klebsiella* spp. (11.7%). Vancomycin showed the highest efficacy against Gram-positive isolates (100% sensitivity), followed by moxifloxacin (90.9%), linezolid (86.2%), and methicillin (68.5%), whereas amoxicillin/clavulanic acid and amoxicillin showed the lowest activity. Among Gram-negative isolates, imipenem demonstrated the highest activity (90.4%), followed by ceftriaxone/tazobactam (80.2%), amikacin (78.1%), and gentamicin (77.1%). However, cefotaxime, ceftazidime, and cefuroxime showed limited efficacy. For *P. aeruginosa*, imipenem remained the most effective agent (90.5%), followed by amikacin (78.6%) and tazobactam/piperacillin (70%).

Conclusion: Wound infections are predominantly caused by Gram-negative bacilli, particularly *P. aeruginosa* and *Klebsiella* spp., with *S. aureus* being the most common Gram-positive isolate. The majority of infections occur among male patients. While high levels of resistance to commonly used antibiotics are observed, vancomycin remains fully effective against Gram-positive isolates, and imipenem demonstrates the highest efficacy against Gram-negative bacteria, including *P. aeruginosa*. The

high level of antibiotic resistance of bacterial species isolated from wound infections emphasizes the need for evidence-based empirical treatment guided by local susceptibility patterns.

Keywords: Wound infection ▪ Bacterial isolates ▪ Antibiotic susceptibility ▪ Yemen

1. Introduction

Postsurgical wound infections are one of the most common hospital-acquired infections and have increased the morbidity and mortality rates worldwide,[1] with causative agents having different profiles by geographic region. Gram-negative bacterial isolates from wound swabs have shown high levels of antimicrobial resistance to multiple antibiotics.[2] In recent decades, the prevalence of multidrug-resistant (MDR) bacterial strains, including *Acinetobacter baumannii, Escherichia coli, Klebsiella pneumoniae, Pseudomonas aeruginosa*, and methicillin-resistant *Staphylococcus aureus* (MRSA), has risen notably in hospital-acquired infections. Resistance to extended-spectrum antibiotics, such as third-generation cephalosporins, is often mediated by extended-spectrum beta-lactamases (ESBLs), and the prevalence of ESBL-producing Gram-negative bacteria has been increasing in recent years.[3-5]

The excessive and improper use of antibiotics has contributed to the emergence of MDR bacterial strains.[6] Hospital admissions increase the risk of acquiring treatment-related infections and disseminating MDR pathogens, leading to an overuse of antibiotics.[7] The rapid development and spread of antibiotic resistance among pathogenic bacteria pose significant challenges to public health worldwide.[8]

Several studies have investigated the prevalence and antibiotic susceptibility patterns of bacterial isolates from wound infections in different regions and healthcare settings. In Yemen, high rates of antibiotic resistance have been reported among bacterial isolates from various clinical specimens.[3-5, 9, 10] A recent large-scale study in Sana'a hospitals reported a high resistance rate.[11] However, limited information is available regarding wound infections, particularly in Sana'a Governorate hospitals. Therefore, this study aimed to bridge this knowledge gap by retrospectively analyzing the bacterial isolates and their antibiotic susceptibility patterns among patients with infected wounds at the 48 Model Hospital in the governorate.

2. Methods

2.1. Study design, population and setting

A retrospective cross-sectional study was conducted to identify bacterial isolates and assess their antibiotic susceptibility patterns among patients with wound infections admitted to the 48 Model Hospital in Sana'a, Yemen. This hospital is one of the main tertiary care facilities in Sana'a and serves as a referral hospital for patients from various Yemeni cities, including the capital city of Sana'a and its surrounding areas. This study included 386 patients diagnosed with wound infections and undergoing wound swab cultures and antibiotic susceptibility testing from January 2020 to December 2020.

2.2. Data collection

Data were retrieved from patients' medical records using a structured data collection form, which included information on patient demographics, results of wound swab cultures, and antibiotic susceptibility profiles. According to the recorded laboratory data, wound swabs had been cultured on three types of media: blood agar, MacConkey agar, and mannitol salt agar. After 24 hours of incubation at 37°C, bacterial species were identified and antibiotic susceptibility testing was determined according to well-established standards.

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2.3. Data analysis

Descriptive statistics, including the frequency and percentage of bacterial isolates and their antibiotic susceptibility patterns, were calculated using Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA).

3. Results

3.1. Wound infection rate by gender

Among the patients who underwent wound swab cultures, 75.1% (290/386) were infected with a single bacterial species. Of these culture-positive patients, 286 (98.6%) were males and 4 (1.4%) were females.

3.2. Distribution of bacterial species isolated from wound swabs

Table 1 shows that, among the bacterial isolates from patients with wound infections, 61.4% (178/290) were Gram-negative bacilli, while 38.6% (112/290) were Gram-positive cocci. *S. aureus* was the most predominant bacterial isolate (38.3%; 111/290), followed by *Pseudomonas* spp. (36.6%) and *Klebsiella* spp. (11.7%). However, *E. coli* (7.2%), *Proteus* spp. (5.2%), *Acinetobacter* spp. (0.7%), and coagulase-negative staphylococci (CoNS) (0.3%) were the least frequent bacterial isolates (Table 1).

3.3. Antibiotic susceptibility patterns of Gram-positive bacterial isolates

Table 2 shows that vancomycin was the most effective antibiotic against Gram-positive bacterial isolates from wound infections, with 100% of the 97 isolates showing sensitivity. This was followed by moxifloxacin (90.9%), linezolid (86.2%), methicillin (68.5%), and ampicillin/sulbactam (64.3%). In contrast, lower sensitivity rates were observed for azithromycin (50.9%) and ceftriaxone (50%), while oxacillin (37.8%), penicillin (33.3%), amoxicillin (22.6%), and amoxicillin/clavulanic acid (15.8%) were among the least effective antibiotics.

Table 1: Distribution of bacterial species isolated from patients with wound infections at 48 Model Hospital in Sana'a Governorate, Yemen (2020)*

Bacterial species	*n*	(%)
S. aureus	111	**(38.3)**
P. aeruginosa	106	**(36.6)**
Klebsiella spp.	34	**(11.7)**
E. coli	21	**(7.2)**
Proteus spp.	15	**(5.2)**
Acinetobacter spp.	2	**(0.7)**
CoNS	1	**(0.3)**

* The total number of culture-positive patients was 290. CoNS, coagulase-negative staphylococci.

Table 2: Antibiotic susceptibility pattern of Gram-positive bacterial isolates from patients with wound infections at 48 Model Hospital in Sana'a Governorate, Yemen (2020)

Antibiotics	*N*	Susceptibility pattern					
		Sensitive		Intermediate		Resistant	
		n	(%)	*n*	(%)	*n*	(%)
Amoxicillin	31	7	**(22.6)**	5	**(16.1)**	19	**(61.3)**
Amoxicillin/clavulanic acid	76	12	**(15.8)**	9	**(11.8)**	55	**(72.4)**
Ampicillin/sulbactam	28	18	**(64.3)**	4	**(14.3)**	6	**(21.4)**
Azithromycin	53	27	**(50.9)**	2	**(3.8)**	24	**(45.3)**
Ceftriaxone	96	48	**(50.0)**	8	**(8.3)**	40	**(41.7)**
Linezolid	29	25	**(86.2)**	2	**(6.9)**	2	**(6.9)**
Methicillin	111	76	**(68.5)**	0	**(0.0)**	35	**(31.5)**
Moxifloxacin	88	80	**(90.9)**	4	**(4.5)**	4	**(4.5)**
Oxacillin	111	42	**(37.8)**	6	**(5.4)**	63	**(56.8)**
Penicillin	105	35	**(33.3)**	12	**(11.4)**	58	**(55.2)**
Vancomycin	97	97	**(100.0)**	0	**(0.0)**	0	**(0.0)**

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3.4. Antibiotic susceptibility patterns of Gram-negative bacterial isolates

Table 3 shows that imipenem was the most effective antibiotic against Gram-negative bacterial isolates from wound infections, with 90.4% of the 177 isolates being sensitive. This was followed by ceftriaxone/tazobactam (80.2%), amikacin (78.1%), gentamicin (77.1%), ceftriaxone/sulbactam (71.3%), and levofloxacin (68.6%). In contrast, lower sensitivity rates were observed for ceftriaxone (50%) and cefoperazone (43.8%), while cefotaxime (35.4%), ceftazidime (30.2%), and cefuroxime (26.1%) were the least effective antibiotics.

Table 3: Antibiotic susceptibility pattern of Gram-negative bacterial isolates from patients with wound infections at 48 Model Hospital in Sana'a Governorate, Yemen (2020)

Antibiotics	*N*	Susceptibility pattern		
		Sensitive	Intermediate	Resistant
		n (%)	*n* (%)	*n* (%)
Amikacin	155	121 (**78.1**)	6 (**3.9**)	28 (**18.1**)
Cefoperazone	32	14 (**43.8**)	8 (**25.0**)	10 (**31.2**)
Cefotaxime	99	35 (**35.4**)	3 (**3.0**)	61 (**61.6**)
Ceftazidime	116	35 (**30.2**)	15 (**12.9**)	66 (**56.9**)
Ceftriaxone	176	88 (**50.0**)	12 (**6.8**)	76 (**43.2**)
Ceftriaxone/tazobactam	111	89 (**80.2**)	6 (**5.4**)	16 (**14.4**)
Ceftriaxone/sulbactam	108	77 (**71.3**)	8 (**7.4**)	23 (**21.3**)
Cefuroxime	111	29 (**26.1**)	5 (**4.5**)	77 (**69.4**)
Gentamicin	105	81 (**77.1**)	0 (**0.0**)	24 (**22.9**)
Imipenem	177	160 (**90.4**)	8 (**4.5**)	9 (**5.1**)
Levofloxacin	153	105 (**68.6**)	19 (**12.4**)	29 (**18.9**)

3.4. Antibiotic susceptibility patterns of *P. aeruginosa* isolates

Table 4 shows that imipenem was the most effective antibiotic against *P. aeruginosa* isolates from wound infections, with 90.5% of the 105 isolates being sensitive. This was followed by amikacin (78.6%), tazobactam/piperacillin (70%), meropenem (69.8%), and levofloxacin (68.9%). Moderate sensitivity was observed for piperacillin (55%), while lower rates were noted for cefepime (44.3%) and ceftazidime (32.1%).

Table 4: Antibiotic susceptibility pattern of *P. aeruginosa* isolates from patients with wound infections at 48 Model Hospital in Sana'a Governorate, Yemen (2020)

Antibiotics	*N*	Susceptibility pattern		
		Sensitive	Intermediate	Resistant
		n (%)	*n* (%)	*n* (%)
Amikacin	103	81 (**78.6**)	5 (**4.9**)	17 (**16.5**)
Cefepime	106	47 (**44.3**)	11 (**10.4**)	48 (**45.3**)
Ceftazidime	106	34 (**32.1**)	10 (**9.4**)	62 (**58.5**)
Imipenem	105	95 (**90.5**)	5 (**4.8**)	5 (**4.8**)
Meropenem	106	74 (**69.8**)	8 (**7.5**)	24 (**22.6**)
Piperacillin	40	22 (**55.0**)	6 (**15.0**)	12 (**30.0**)
Tazobactam/piperacillin	90	63 (**70.0**)	11 (**12.2**)	16 (**17.8**)
Levofloxacin	106	73 (**68.9**)	11 (**10.4**)	22 (**20.8**)

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4. Discussion

Wound infections can lead to extended hospital stays and raise mortality rates by up to 80%.[12] The clinical management of these infections relies on two key components: antibiotic therapy and proper wound care.[13] However, the empirical use of antibiotics may foster the emergence of antimicrobial-resistant pathogens.[14]

In this study, a wound infection prevalence of 75.1% was observed, which is consistent with rates reported from Ethiopia (72.6%) and Uganda (68.8%).[15, 16] However, lower rates were reported from Nepal (60.2%) and India (52.4%),[17, 18] and higher rates were reported from Iraq (84%) and Tanzania (96%).[19, 20] The variation in observations may stem from differences in the types of bacterial infections and the specific sources of wound samples. Moreover, disparities in infection control practices and the use of antibiotic prophylaxis across countries can greatly impact bacterial growth. Additionally, the limited growth of certain bacteria could be due to their requirement for complex or specialized culture media.[5] On the other hand, the prevalence of infections may be influenced by several factors, including inadequate sterilization during surgical procedures, substandard hygiene practices, and poor living conditions within communities. Additionally, the absence of effective post-discharge surveillance systems for patients can hinder early detection and management of infections, thereby exacerbating the issue.

The current study identified *S. aureus* (38.3%) and *P. aeruginosa* (36.6%) as the most prevalent bacterial species, with CoNS being the least common, accounting for only 0.3% of isolates. These findings are consistent with reports from various countries, including Italy, Ethiopia, Tanzania, India, Ghana, and Saudi Arabia,[16, 20-25] where *S. aureus* and *P. aeruginosa* were the most frequently predominant pathogens in wound infections. Notably, *S. aureus* is commonly found in the normal body flora and *P. aeruginosa* is common in the environment, suggesting that wound infections may originate from endogenous sources or environmental contamination. The variation in their prevalence can be attributed to differences in healthcare practices, environmental factors, and the prevalence of multidrug-resistant organisms.

In our study, Gram-positive bacteria exhibited high resistance rates to penicillin, amoxicillin-clavulanic acid, and azithromycin. Conversely, these bacteria demonstrated notable sensitivity to methicillin, moxifloxacin, and vancomycin. These findings align with reports from Ethiopia, Nepal, India, and Italy,[21, 23, 26, 27] which have documented similar antimicrobial resistance patterns among Gram-positive pathogens. On the other hand, Gram-positive bacteria in the present study exhibited high susceptibility to both vancomycin and linezolid, two antibiotics commonly employed in clinical settings. However, vancomycin resistance was observed among 35% of *S. aureus* isolates from patients with wound infections in Tanzania.[20] This elevated resistance may be attributed to factors such as inadequate infection control measures and the irrational or inappropriate use of antimicrobial agents. The prevalence of MRSA among patients with wound infections in the present study was 31.5%, aligning with findings from studies conducted in Bangladesh and India.[28, 29] However, lower rates have been documented in Eritrea, Brazil, and Italy.[21, 30, 31] The occurrence of MRSA infections is influenced by multiple factors, including the presence of comorbidities, the specific site of infection, the duration of surgical procedures, and the inappropriate use of antibiotics. Understanding these risk factors is essential for implementing effective prevention and management strategies against MRSA infections.

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Gram-negative bacteria in the present study exhibited high susceptibility to antibiotics such as imipenem, ceftriaxone/tazobactam, amikacin, gentamicin, ceftriaxone/sulbactam, and levofloxacin, which is consistent with studies conducted in India and Nepal.[29, 32-34] However, in Egypt, a higher resistance to imipenem has been reported among Gram-negative isolates,[35] indicating regional variations in antimicrobial susceptibility. Conversely, Gram-negative bacteria in this study demonstrated increased resistance to cephalosporins lacking β-lactamase inhibitors, including ceftriaxone, cefoperazone, cefotaxime, ceftazidime, and cefuroxime. This resistance pattern aligns with observations from Egypt.[35] The rising resistance to penicillin and cephalosporin antibiotics may be attributed to their overuse and the prevalence of organisms producing ESBLs, which confer resistance to a broad range of β-lactam antibiotics.

In this study, *P. aeruginosa* isolates demonstrated high susceptibility to imipenem, amikacin, piperacillin /tazobactam, meropenem, and levofloxacin, while they exhibited significant resistance to β-lactam antibiotics lacking β-lactamase inhibitors. These findings align with reports from Saudi Arabia, Iraq, Italy, India, Nigeria, and Pakistan.[21, 36-40] Such resistance can be primarily attributed to the production of beta-lactamases through resistance genes and mutational processes. Variations in resistance rates across studies may be due to factors such as population hygiene, the type of clinical specimens examined, and antibiotic exposure.

This study has several limitations. First, the retrospective design of the study at one tertiary hospital in Sana'a may affect the generalizability of the findings to broader populations or other healthcare settings in Yemen. Additionally, the absence of detailed demographic and clinical data, such as patient age, comorbidities, or length of hospital stay, limits the ability to assess contributing factors and clinical outcomes of wound infections. Information on the prior use of antibiotics by patients, which could influence the observed resistance patterns, was also not available. The study relied exclusively on traditional culture-based techniques for pathogen identification and antimicrobial susceptibility testing, without incorporating molecular diagnostics that could offer more accurate detection and resistance profiling. Additionally, differences in infection control practices during the study period were not accounted for, which may have influenced infection prevalence and resistance trends. Future investigations that address these gaps could offer a more in-depth understanding of the epidemiology and management of wound infections.

5. Conclusion

Wound infections are predominantly caused by Gram-negative bacilli, particularly *P. aeruginosa* and *Klebsiella* spp., with *S. aureus* being the most common Gram-positive isolate. The majority of infections occur among male patients. While high levels of resistance to commonly used antibiotics are observed, vancomycin remains fully effective against Gram-positive isolates, and imipenem demonstrates the highest efficacy against Gram-negative bacteria, including *P. aeruginosa*. The high level of antibiotic resistance of bacterial species isolated from wound infections emphasizes the need for evidence-based empirical treatment guided by local susceptibility patterns.

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Ethical approval and consent

This study was approved by the Research Ethics Committee of the Faculty of Medicine and Health Sciences, University of Science and Technology, Sana'a, Yemen (Ethical Clearance No. 1446/0053/UREC/UST). In

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addition, permission was obtained from the administration of the 48 Model Hospital. Informed consent was waived because of the retrospective nature of the study. The privacy and confidentiality of data were ensured.

Conflict of Interest

The authors declare no conflict of interest associated with this article.

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