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Research Article

Bacterial Profile, Antimicrobial Susceptibility Patterns, and Associated Factors in Wound Infection Patients at Wad Medani, Sudan: A Four-year, Laboratory-based, Retrospective, Cross-sectional Study

Yousif B. Hamadalneel[1]*, Osama A. Idris[2], Hifa O. Ahmed[1], Marwa F. Alamin[3], Samira M. Fageer[4], Yassen M. Abualgasim[5], Alaaeldeen M. Attaallah[6], and Mohammed A. Taha[5]

[1]Department of Clinical Pharmacy & Pharmacy Practice, Faculty of Pharmacy, University of Gezira, Wad Medani, Sudan
[2]Department of Internal Medicine, Faculty of Medicine, National Ribat University, Khartoum, Sudan
[3]Department of Molecular Biology, Institute of Endemic Disease, Khartoum University, Khartoum, Sudan
[4]Department of Microbiology, College of Medical Laboratory Science, Sudan International University, Khartoum, Sudan
[5]Pathology Center for Diagnosis and Research, Faculty of Medicine, University of Gazira, Wad Medani, Sudan
[6]Department of Internal Medicine, Faculty of Medicine, University of Gezira, Wad Medani, Sudan

Corresponding Author: Yousif B. Hamadalneel; email: Yousefbekhet2020@gmail.com

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Abstract

Background: Wound infections increase the risk of disarticulation and amputation and have significant economic repercussions. Therefore, this study aimed to identify the bacterial profiles of wound infections, patterns of antibiotic resistance, and associated factors.

Methods: This was a laboratory-based, retrospective, cross-sectional study. The study included all wound specimens for culture and drug sensitivity that were routinely obtained for diagnostic purposes at the Pathology Center for Diagnosis and Research (PCDR), University of Gezira, Sudan, from January 1, 2020, to October 15, 2023. Data were manually collected from the registries (a paper-based record) of the PCDR. Data analysis was performed using the Statistical Package for Social Sciences version 27.0.

Results: Overall, 642 wound specimens were investigated, with 450 (70.1%) cultures positive for bacterial growth. A total of 230 (51.1%) male patients had positive wound cultures. Among those with positive growth, 291(64.7%) were gram-negative bacteria (GNB) (95% CI; *P*-value 0.332). The most commonly isolated bacteria were *Staphylococcus aureus* 147 (32.7%) and *Escherichia coli* 145 (32.2%). Vancomycin 93.3% (43/45) and linezolid 83.7% (82/98) were the drugs most susceptible to gram-positive bacteria (GPB), while amikacin 88.7% (228/257) and gentamicin 70.6% (108/153) were the most susceptible to GNB. Univariate logistic regression revealed that only age (95% CI; *P*-value 0.004) had a statistical association with wound culture growth.

Conclusion: This study reported a high rate of bacterial growth. The most frequently isolated bacteria were *S. aureus* and *E. coli*. The drugs that showed the highest susceptibility to GPB were vancomycin and linezolid, while amikacin and gentamicin were the most effective against GNB. Age had a statistically significant association with wound culture growth. The high resistance rate of isolated bacteria, particularly GNB, necessitates immediate and significant modifications to their antimicrobial prescription policy for safe, rational, and effective antimicrobial administration. Additionally, antimicrobial agents should be used based on the susceptibility of specific microorganisms.

Keywords: bacterial profile, antimicrobial susceptibility, wound infections, Sudan

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1. Introduction

Antimicrobial resistance poses a significant public health challenge, contributing to an estimated 4.95 million deaths in 2019, in addition to directly causing 1.27 million deaths worldwide [1, 2]. This resistance arises from adaptive changes in bacteria that make them resistant to currently effective antimicrobial drugs, resulting in illnesses that are difficult to cure [3].

Three forms of wound infections can be distinguished: deep incisional wounds, organ-specific infections, and incisional surgical wounds, which are significant consequences of surgery [4]. The prevalence of wound infections in developed countries ranges from 3% to 11%, while in developing countries, it is about 40% [5–7]. Wound infections increase the risk of disarticulation, amputation, slow healing, and lengthen hospital stays, leading to significant economic consequences [8, 9].

Studies worldwide have revealed that gram-negative bacteria (GNB) constitute the majority of wound infections. Among these, the most prevalent are *Pseudomonas aeruginosa, Escherichia coli, Proteus mirabilis,* and *Klebsiella pneumoniae*. Additionally, the most frequently isolated gram-positive bacteria (GPB) are *Staphylococcus aureus,* which is also the most antibiotic-resistant bacterium [10–14].

Data on the epidemiology of bacterial infections and the sensitivity patterns of isolated bacteria are essential for guiding empirical treatment [15]. In sub-Saharan Africa, including Sudan, current treatment guidelines emphasize the empiric treatment of infections. However, a recent World Health Organization (WHO) report on antimicrobial resistance surveillance revealed a lack of local data on antibiotic resistance and an absence of information on the most prevalent pathogens, such as *MRSA*. However, this approach may worsen patient outcomes and increase bacterial resistance [16, 17]. In Sudan, few studies have examined the issues related to bacterial resistance and susceptibility patterns or aimed to develop an antibiogram to guide antibiotic use [18]. Therefore, this study seeks to identify the bacterial profiles of wound infections, patterns of antibiotic sensitivity, and associated factors to provide better guidance on the selection of initial empirical antibiotics that will adequately cover the common local organisms in Wad-Medani, Gazira State, Sudan.

2. Methods

2.1. Study setting and period

The study was conducted from January 2020 to October 2023, utilizing laboratory data routinely collected for diagnostic purposes at the Pathology Center for Diagnosis and Research (PCDR), University of Gezira, Wad Medani, Sudan. The PCDR functions as the reference laboratory and serves all hospital settings in Wad-Medani, which includes six university teaching hospitals, two military hospitals, and one police hospital. Wad-Medani is the capital of Gezira State, covering a total area of 65 km^2 and has a population of 515,230 according to the 2008 census.

2.2. Study design

This study is a laboratory-based, retrospective, and cross-sectional investigation.

2.3. Data sources

Data were collected manually from the registries (a paper-based record) of the PCDR. The registries contain descriptions of microbiological procedures and anonymous patient information, which includes the patient's code number, date of birth, age, sex, type of clinical sample, type of bacterial strain, and results of tested antibiotics. At the end of data collection, investigators conducted checks for data quality and completeness.

2.4. Inclusion criteria

The study included all wound specimens that were analyzed for culture and drug sensitivity at the PCDR from January 1, 2020, to October 15, 2023.

2.5. Exclusion criteria

Below are the study's exclusion criteria:

(i) Fungal elements,

(ii) Multiple bacteria,

(iii) Antimicrobials that were not tested for ≥80% of isolated bacteria [19], and

(iv) Antimicrobials that are not recommended by the Clinical and Laboratory Standard Institute (CLSI) guidelines [20].

2.6. Laboratory methods and sampling process

2.6.1. Sampling process

The PCDR applies the standard microbiological methods for sample collection. Prior to sample collection, the wound edges were cleaned, and any remaining exudate was removed by washing with a physiological saline solution. Samples were collected based on the type of wound. Specifically, when the wound was superficial, a sample was obtained from the lesion using a swab, moving in a zigzag pattern across the wound within a 1 cm^2 area from the center to the edge without touching the surrounding skin. The swab was then placed in a tube containing Nuova Aptaca SRL, the transport medium used for this purpose. If the wound had an abscess or deep lesions, after applying the physiological saline solution, at least 0.5–1 mL of material from the deepest area of the lesion was aspirated using a sterile syringe needle and subsequently placed in blood culture medium. After collection, the sample was transferred to the microbiology department in the PCDR laboratory for further culture analysis.

2.6.2. Isolated organism identification

MacConkey agar and blood agar plates were used to inoculate the collected samples. Cultures were incubated for 24 hours in an aerobic environment at 37 °C. After 24 hrs, all plates were first checked for growth, and those that showed no growth were incubated for an additional 48 hrs. For all positive cultures, identification of the isolated bacteria was performed through morphological characteristics, Gram staining, and confirmatory biochemical tests.

The catalase reaction, coagulase test, bacitracin test, optochin test, and hemolytic activity test on blood agar were performed to identify the GPB. In contrast, inoculation on MacConkey agar plates, followed by biochemical tests such as indole production, H2S production, urease tests, citrate/carbohydrate utilization, and oxidase tests, was utilized to identify the GNB [21].

2.6.3. Antimicrobial susceptibility

The susceptibilities of the isolated bacteria were determined according to the 2020 CLSI guidelines using Mueller–Hinton agar plates (Oxoid, England) with the Kirby–Bauer disk diffusion method [20].

The following antimicrobials were used to test the GPB isolates: vancomycin (30 µg), cotrimoxazole

(1.25/23.75 μg), cefotaxime (30 μg), tetracycline (30 μg), ciprofloxacin (5 μg), gentamicin (10 μg), linezolid (30 μg), levofloxacin (5 μg), chloramphenicol (30 μg), ceftriaxone (30 μg), erythromycin, and clindamycin [20].

GNB isolates were tested against ampicillin/sulbactam (10/10 μg), cotrimoxazole (1.25/23.75 μg), gentamicin (10 μg), ampicillin (10 μg), ciprofloxacin (5 μg), levofloxacin (5 μg), chloramphenicol (30 μg), ceftriaxone (30 μg), tetracycline (30 μg), ofloxacin (5 μg), piperacillin/tazobactam (100/10 μg), amikacin (30 μg), cefuroxime (30 μg), and cefotaxime (30 μg) [20]. The zone diameters' interpretations were based on the CLSI 2020 guideline breakpoints [20].

2.6.4. Variable definition

Coliform: Comprised of bacterial species from genera without *Klebsiella* and *E. coli* (e.g., *Citrobacter, Enterobacter, Serratia*, etc.).

2.6.5. Quality control

To guarantee the authenticity of the results, quality control techniques were employed as standard practices throughout the entire laboratory work process. Before use, the staining reagents, antibiotic discs, and culture media were examined for their normal shelf life [22]. Following preparation and autoclaving for 15 minutes at 121°C, all culture plates and antibiotic discs were stored at the recommended refrigeration temperature. The standard reference of the bacterial isolates was investigated on agar plates with biochemical assays and antibiotic discs serving as a positive control [22]. The samples were processed cautiously by highly qualified microbiologists.

2.7. Statistical analysis

Data analysis was conducted using the Statistical Package for Social Sciences (SPSS) version 27.0. Frequencies and percentages were used to present categorical data. After verifying the applicability conditions, the Pearson chi-squared test and Fisher's exact test were employed to compare categorical data. The factors associated with wound infection were identified through univariate binary logistic regression analysis. The findings are presented as odds ratios with 95% confidence intervals (CIs), and a statistically significant difference was considered at a P-value $\leq$ 0.05. Age, year, and sex were identified as independent variables, while a positive wound culture was considered the dependent variable in this study.

3. Results

3.1. Sociodemographic characteristics

Overall, 642 wound specimens were studied over four years: 332 (51.7%) were male patients, while female patients accounted for 310 (48.3%) (95% CI; P-value < 0.111; Table **1**). The majority of the specimens, 196 (30.5%), were collected in 2023, followed by 170 (26.5%) in 2020 (Table **1**). Additionally, 233 (36.5%) patients were aged 19–45 years, while 152 (23.5%) were aged between 46 and 60 years. Patients aged ≤1 year and those between 2 and 5 years were the smallest group, comprising 27 (4.2%).

3.2. Bacterial profile

Overall, 450 (70.1%) of the wound samples exhibited bacterial growth, with the majority, 291 (64.7%), being GNB, while GPB accounted for 159 (35.3%) (95% CI; P-value < 0.332) (Table **1**). Male patients accounted for 230 (51.1%) of those with positive wound cultures, whereas females comprised 220 (48.9%). The highest percentage of positive wound cultures, 133 (29.6%), occurred in 2023, followed by 127 (28.2%) in 2020 (95% CI; *P*-value < 0.240) (Table **1**). Additionally, patients aged 19–45 years had the highest rate of positive wound culture at 163 (36.2%), followed by those aged 46–60 years at 112 (24.9%), while those aged ≤1 year had the lowest at 12 (2.7%) positive wound cultures. The distribution of bacteria isolated from infected wounds, stratified by age group, is summarized in Table **2**.

Table 1: Characteristics of the sample, categorized by the survey years.

Characteristics	2020 *N* (%)	2021 *N* (%)	2022 *N* (%)	2023 *N* (%)	Total *N* (%)	*P*-value*
Sample	170 (26.5)	144 (22.4)	132 (20.5)	196 (30.5)	642	
Sex						0.111
Male	81 (24.4)	67 (20.2)	70 (21.1)	114 (34.3)	332 (51.7)	
Female	89 (28.7%)	77 (24.8%)	62 (20%)	82 (26.5%)	310 (48.3)	
Bacterial growth						0.240
Yes	127 (28.2)	94 (20.9%)	96 (21.3%)	133 (29.6%)	450 (70.1%)	
No	43 (22.4%)	50 (26%)	36 (18.8%)	63 (32.8%)	192 (29.9%)	
Gram stain						0.332
GPB	49 (30.8%)	29 (18.2%)	39 (24.5%)	42 (26.4%)	159 (35.3%)	
GNB	78 (26.8%)	65 (22.3%)	57 (19.6%)	91 (31.3%)	291 (64.7%)	

*Pearson's Chi-squared and Fisher's exact test.
N (%), number (percentage); GPB, gram-positive bacteria; GNB, gram-negative bacteria

Table 2: Distribution of isolated bacteria from infected wounds stratified by age group.

Isolated bacteria	≤ 1 *N* (%)	2–5 *N* (%)	6–12 *N* (%)	13–18 *N* (%)	19–45 *N* (%)	46–60 *N* (%)	>60 *N* (%)	Total *N* (%)
GNB	8 (2.7)	12 (4.1)	14 (4.8)	22 (7.6)	95 (32.6)	76 (26.1)	64 (22)	291 (64.7)
E. coli	5 (3.4)	6 (4.1)	11 (7.6)	8 (5.5)	48 (33.1)	36 (24.8)	31 (21.4)	145 (32.2)
Kleb. Spp	0	0	0	1 (14.3)	3 (42.9)	3 (42.9)	0	7 (1.6)
Coliform*	1 (5.9)	0	0	0	6 (35.7)	7 (41.2)	3 (17.6)	17 (3.8)
P. aerug	2 (2.9)	3 (4.3)	1 (1.4)	11 (15.7)	21 (30)	17 (24.3)	15 (21.4)	70 (15.6)
Prot. Spp	0	3 (5.8)	2 (3.8)	2 (3.8)	17 (32.7)	13 (25)	15 (18.8)	52 (11.6)
GPB	4 (2.5)	2 (1.9)	5 (3.1)	12 (7.5)	68 (42.8)	36 (22.6)	31 (19.5)	159 (35.3)
S. aureus	4 (2.7)	3 (2)	5 (3.4)	11 (7.5)	62 (42.2)	35 (23.8)	27 (18.4)	147 (32.7)
Strep. Spp	0	0	0	1 (8.3)	6 (50)	1 (8.3)	4 (33.3)	12 (2.7)
Total	12 (2.7%)	15 (3.3%)	19 (4.2%)	34 (7.6%)	163 (36.2%)	112 (24.9%)	95 (21.1%)	450

*Bacterial species of genera without *Klebsiella and E. coli* (*Citrobacter, Enterobacter, Serratia*, etc.).
N (%), number(percentage); *E. coli*, *Escherichia coli*; *Kleb.* Spp, *Klebsiella species; P. aerug*, *Pseudomonas aeruginosa*; *Prot.* Spp, *Proteus* species; *S. aureus*, *Staphylococcus aureus*; *Strep.* Spp, *Streptococcus* species; GNB, gram-negative bacteria; GPB, gram-positive bacteria

Staphylococcus aureus was the most frequently isolated bacterium, accounting for 147 cases (32.7%), with the highest frequency of 42 (33.1%) occurring in 2020 and the lowest frequency of 28

(29.85%) in 2021 (Table **3**). *E. coli* was the second most commonly isolated bacterium, accounting for 145 (32.2%) of the isolates. Its highest isolation rate of 45 (33.8%) occurred in 2023, while the lowest isolation rate of 37 (28.9%) was in 2021 (Table **3**). The lowest percentage of isolated bacteria was *Klebsiella* species (spp.) at 7 (1.6%), with all being isolated in 2023 at 5 (3.8%) and in 2021 at 2 (2.1%) (Table **3**). Regarding GPB, the analyzed data indicated that *S. aureus* was the most isolated bacterium, while among GNB, *E. coli* was the most commonly isolated bacterium (Table **3**).

3.3. Antimicrobial susceptibility patterns

The investigated samples revealed that 16 drugs were examined. The results indicated that vancomycin was the most susceptible to GPB, with a rate of 93.3% (43/45), followed by linezolid at 83.7% (82/98) and chloramphenicol at 83% (49/59). In contrast, cefotaxime showed the lowest susceptibility, at 14.3% (1/7) (Figure **1**).

In particular, *S. aureus* was the most sensitive to vancomycin at 92.9% (39/42), and linezolid at 83.7% (77/92), while erythromycin at 42.9% (18/42) was the drug that was the least sensitive (Table **4**). In addition, *Streptococcus* spp. exhibited total sensitivity of 100% to vancomycin (3/3), ciprofloxacin (8/8), levofloxacin (8/8), and chloramphenicol (6/6), and the least sensitivity to cefotaxime at 14.3% (1/7) (Table **4**).

Our data showed that amikacin at 88.7% (228/257), gentamicin at 70.6% (108/153), and levofloxacin at 69.6% (103/148) were the drugs most susceptible to GNB. In comparison, cefuroxime at 6.5% (6/92) and ampicillin at 6% (6.100) were the drugs least susceptible to GNB (Figure **2**).

In particular, a remarkable result showed that amikacin was the most effective drug against *E. coli, P. aeruginosa, Klebsiella* spp., and *Proteus* spp. At the same time, piperacillin-tazobactam proved to be the most effective against coliform bacteria (Table **5**). Other notable findings indicated that the least effective drug among all isolated GNB was ampicillin, except for *P. aeruginosa* (Table **5**).

3.4. Factors associated with positive wound culture

Table **6** provides a summary of the univariate logistic regression analysis examining factors related to positive wound culture results. The analysis revealed that only the age group factor exhibited a statistically significant relationship with positive wound cultures (95% CI; *P*-value = 0.004). Specifically, the following age groups demonstrated decreased incidence of positive wound culture compared to the ≤1 year age group: 13–18 years (crude odds ratio [COR] 0.118; 95% CI 0.035–0.393; *P*-value < 0.001), 19–45 years (COR 0.341; 95% CI 0.152–0.767; *P*-value 0.009), 46–60 years (COR 0.279; 95% CI 0.120–0.647; *P*-value 0.003), and >60 years (COR 0.312; 95% CI 1.133–0.728; *P*-value 0.007).

Table 3: Distribution of isolated bacteria from infected wounds categorized by years.

Isolated bacteria	2020 *N* (%)	2021 *N* (%)	2022 *N* (%)	2023 *N* (%)	Total *N* (%)
Gram-negative					
E. coli	37 (28.9)	30 (31.9)	33 (34.4)	45 (33.8)	145 (32.2)
Klebsiella Spp	0	2 (2.1)	0	5 (3.8)	7 (1.6)
Coliform*	3 (2.4)	6 (6.4)	3 (3.1)	5 (3.8)	17 (3.8)

Table 3: Continued.

Isolated bacteria	**2020 *N* (%)**	**2021 *N* (%)**	**2022 *N* (%)**	**2023 *N* (%)**	**Total *N* (%)**
P. aeruginosa	21 (16.4)	16 (17)	11 (11.5)	22 (16.5)	70 (15.5)
Proteus Spp	17 (13.4)	11 (11.7)	10 (10.4)	14 (10.5)	52 (11.6)
Gram-positive					
S. aureus	42 (33.1)	28 (29.8)	38 (39.6)	39 (29.3)	147 (32.7)
Streptococcus Spp	7 (5.5)	1 (1.1)	1 (1)	3 (2.3)	12 (2.7)
Total	127 (28.2%)	94 (20.9%)	96 (21.3%)	133 (29.6%)	450

*Bacterial species of genera without *Klebsiella and E. coli* (*Citrobacter, Enterobacter, Serratia*, etc.).
N (%), number (percentage); *S. aureus*, *Staphylococcus aureus*; *P. aeruginosa*, *Pseudomonas aeruginosa*; *E. coli*, *Escherichia coli*; Spp, species.

Table 4: Antimicrobial sensitivity patterns of Gram-positive bacteria.

Antibiotic	***S. aureus***	***Streptococcus* Spp**
Vancomycin	92.9% (39/42)	100% (3/3)
Cotrimoxazole	44.8% (47/105)	37.55 (3/8)
Tetracycline	52.1% (74/142)	27.3% (3/11)
Cefotaxime	NA	14.3% (1/7)
Ciprofloxacin	64.2% (68/106)	100% (8/8)
Levofloxacin	72% (72/100)	100% (8/8)
Linezolid	83.7% (77/92)	83.3% (5/6)
Gentamycin	77.6% (76/98)	85.7% (6/7)
Chloramphenicol	81.1% (43/53)	100% (6/6)
Clindamycin	71.4% (25/35)	NA
Ceftriaxone	NA	62.5% (5/8)
Erythromycin	42.9% (18/42)	66.7% (2/3)

S. aureus: Staphylococcus aureus; NA, not applicable; Spp, species

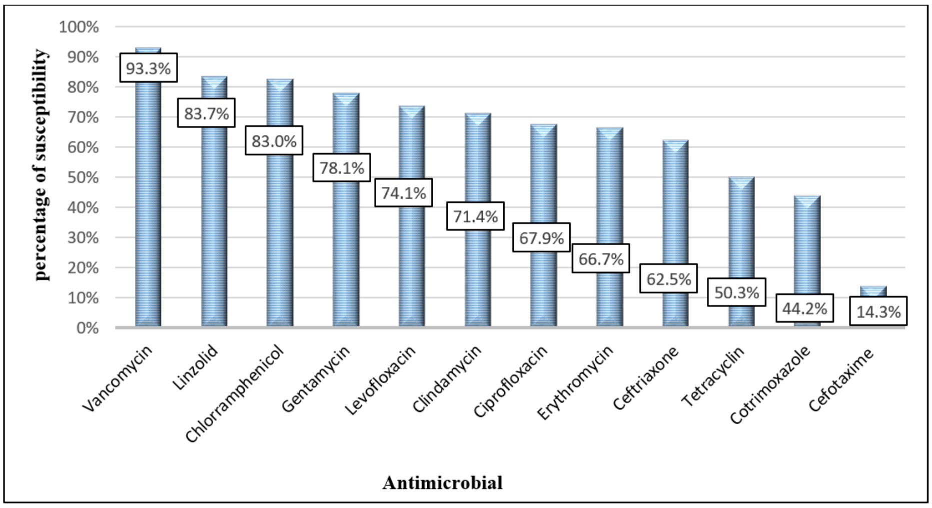

Figure 1: Antimicrobial sensitivity patterns of isolated Gram-positive bacteria.

Table 5: Antimicrobial sensitivity patterns of Gram-negative bacteria.

Antibiotic	*E. coli*	*P. aeruginosa*	*Klebsiella* Spp	*Proteus* Spp	Coliform*
AMC	7.7% (5/65)	NA	25%(1/4)	18.8% (6/32)	0 (0/7)
COT	25.2% (34/135)	NA	0 (0/7)	29.2% (14/48)	33.3% (5/15)
TE	41.2% (54/131)	NA	0 (0/6)	18% (9/50)	43.8% (7/16)
CTX	27.4%(37/135)	NA	14.3% (1/7)	39.1% (18/46)	37.5% (6/16)
CIP	36.5% (27/74)	68.3% (28/41)	40% (2/5)	72.7% (24/33)	66.7% (4/6)
LE	54.5% (36/66)	76.9% (30/39)	75% (3/4)	87.55% (28/32)	85.7% (6/7)
GM	68.6% (48/70)	71.8% (28/39)	100% (4/4)	69.7% (23/33)	71.45% (5/7)
TZP	41.9% (26/62)	56.8% (21/37)	50% (2/4)	75% (21/28)	100% (6/6)
CH	64.1% (41/64)	NA	100% (4/4)	64.3% (18/28)	50% (4/8)
OF	33.9% (20/59)	63.9 (23/36)	50% (2/4)	72.4% (21/29)	28.6% (2/7)
AK	90.2% (119/132)	91.9% (57/62)	100% (5/5)	77.8% (35/45)	92.3% (12/13)
AMP	5.6% (4/72)	NA	0 (0/3)	6.3% (1/16)	11.1% (1/9)
CXM	6.2% (4/65)	NA	0 (0/2)	6.3% (1/16)	11.1% (1/9)
CTR	15.45 (10/65)	NA	0 (0/4)	46.7% (14/30)	28.6% (2/7)

*Bacterial species of genera without *Klebsiella and E. coli* (*Citrobacter, Enterobacter, Serratia*, etc.).
P. aeruginosa, *Pseudomonas aeruginosa*; Spp, species; *E. coli*, *Escherichia coli*; AMC, ampicillin/sulbactam; COT, cotrimoxazole; TE, tetracycline; CTX, cefotaxime; CIP, ciprofloxacin; LE, levofloxacin; GM, gentamycin; TZP, piperacillin/tazobactam; CH, chloramphenicol; OF, ofloxacin; AK, amikacin; AMP, ampicillin; CXM, cefuroxime; CTR, ceftriaxone.

Table 6: Univariate logistic regression of factors associated with positive wound culture at PCDR from January 2020 to October 2023.

Characteristic	COR (95% CI)	*P*-value
Sex		
Male	Reference	——-
Female	0.918 (0.655 – 1.288)	0.621
Age (yrs)		
≤1	Reference	——-
2–5	0.460 (0.219–1.872)	0.415
6–12	0.589 (0.211–1.645)	0.313
13–18	0.118 (0.035–0.393)	<0.001
19–45	0.341 (0.152–0.767)	0.009
46–60	0.279 (0.120–0.647)	0.003
Year		0.228
2020	Reference	——-
2021	1.538 (0.937–2.576)	0.064
2022	1.423 (1.013–1.971)	0.676
2023	1.410 (0.892–2.228)	0.141

PCDR, Pathology Center for Diagnosis and Research; COR, crude odds ratio; CI, confidence interval.

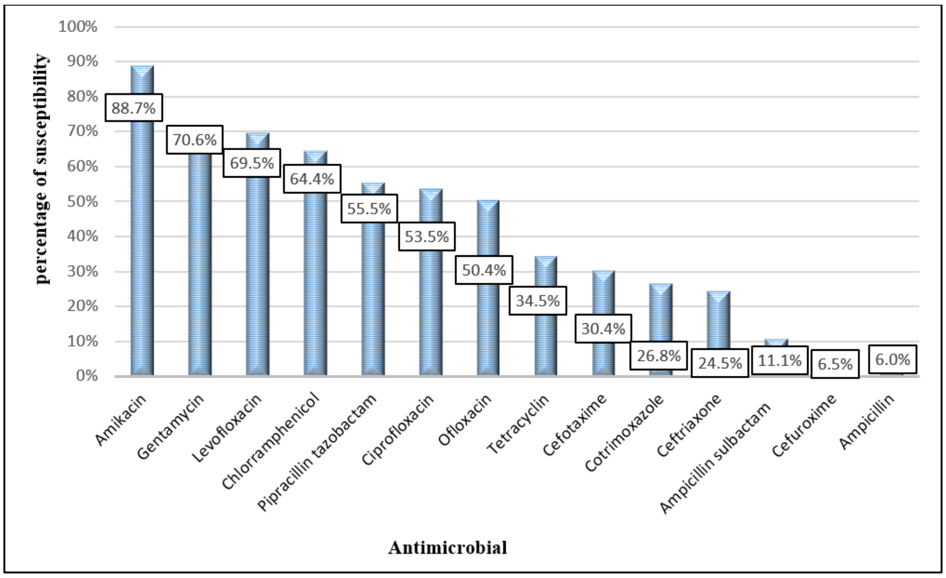

Figure 2: Antimicrobial sensitivity patterns of isolated Gram-negative bacteria.

4. Discussion

The bacterial pattern appears to change geographically and temporally; some may be endemic to particular regions, while others are rare [1]. Overall, the study's results showed that 70.1% of the wound samples tested positive for bacterial growth. Our findings are similar to those of a laboratory-based study conducted in Pescara, Italy (72.6%) [23] and a hospital-based study conducted in Debre Markos, Ethiopia (69.5%) [24]. Our results reflect a higher percentage than those found in a previous hospital-based study conducted in Saudi Arabia (56.1%) [25] and a laboratory-based study conducted in Bahir Dar, Ethiopia (61.6%) [26], but lower than those reported in hospital-based studies carried out in Nigeria (95%) [27], Tanzania (91.4%) [10], Gondar, and India (83.72%) [28], as well as an inpatient and outpatient study conducted in Ethiopia (83.9%) [29]. These variations could be attributed to differences in the study populations and study areas, supporting the idea that strict adherence to microbiological evaluation prior to therapy is essential. Additionally, this variation could be associated with the fact that countries have distinct approaches to infection prevention and control, such as regular monitoring of antibiotic resistance, and they also have varied regulations and policies governing the use of antibiotics. Furthermore, these differences may be related to variations in the study setting, such as community versus hospital settings.

According to the present study, positive wound cultures were isolated from both females and males with nearly comparable bacterial growth rates. These results are similar to those found in Saudi Arabia [25] and Debre Markos, Ethiopia [24].

The current study revealed that patients aged 19 to 45 years experienced the most positive wound culture results, a finding similar to those documented in Nepal, where infections were most prevalent in the 21- to 40-year age group [30]. In contrast, the incidence of microbial wound infections was noticeably higher in individuals aged 60 years or older in Saudi Arabia [25]. Furthermore, the rate of wound infection was significantly high among those aged 55 to 64 years in Debre Markos, Ethiopia [24].

In this study, a higher percentage of GNB compared to GPB confirmed the findings of the majority of studies worldwide [10, 11, 13, 31]. This may be because most patients with wound infections were hospitalized, and GNP was more common in the hospital setting than GPB. In contrast, more than half of the GPB were found in Bahir Dar, Ethiopia [26].

Over the past few decades, *S. aureus* has become one of the most significant human pathogens, contributing significantly to hospital- and community-acquired infections [32]. Our current findings align with those of other studies worldwide, where *S. aureus* was the most commonly isolated bacterium [10, 23–25, 29, 31, 33]. Additionally, *E. coli* was the second most common isolate, followed by *Klebsiella* spp. This arrangement of predominant bacteria is consistent with findings in Saudi Arabia [34] and Nepal [30]. This similarity can be explained by the fact that the majority of microbial isolates are commonly found in gut flora and skin, and can easily disseminate through cuts or fractures in either the skin or soft tissue.

In this study, among the GPB, the most susceptible drugs were vancomycin, followed by linezolid. These results align with research conducted in central Italy, which showed that all GPB strains were susceptible to vancomycin and linezolid [23]. In Debre Markos, Ethiopia, ciprofloxacin was the most effective antimicrobial agent, followed by gentamicin and then ceftriaxone [24]. Furthermore, in this study, cefotaxime and cotrimoxazole were the least susceptible drugs. In Gondor, Ethiopia, GPB strains exhibited resistance to ampicillin (86.4%), followed by amoxicillin (83%), penicillin (81.3%), oxacillin (74.6%), and finally tetracycline (59.4%) [29]. This difference may stem from variations in the frequency of antibiotic use across regions, as well as the regulations governing antibiotic usage.

Specifically, in this study, S. *aureus* was found to be most sensitive to vancomycin, followed by linezolid, while erythromycin was identified as the least sensitive drug against *S. aureus.* This finding aligns with a study conducted in India, where *S. aureus* showed maximum susceptibility (100%) to linezolid and vancomycin [28]. Additionally, all strains of *S. aureus* in Gondar, Ethiopia, were sensitive to vancomycin but exhibited significant resistance levels to amoxicillin (87.2%), penicillin (84.6%), oxacillin (76.9%), tetracycline (64.1%), and erythromycin (61.5%) [29]. The results of this study contradict those reported in Saudi Arabia, which demonstrated that *S. aureus* exhibited high sensitivity to clindamycin (96.8%) and comparative sensitivity to oxacillin, followed by erythromycin, then ciprofloxacin and trimethoprim-sulfamethoxazole [25]. In Nepal, *S. aureus* isolates collected postoperatively showed high resistance levels to piperacillin (41.66%), oxacillin (41.66%), and cotrimoxazole (33.33%) [33]. Moreover, *S. aureus* displayed significant resistance to amoxicillin (61.9%) in northern Tanzania [10]. These variations may relate to differences in antibiotic disc availability and usage in each study.

Among the GNB, the most sensitive drugs were amikacin, followed by gentamicin and levofloxacin, while ampicillin and cefuroxime were the least susceptible. These findings align with two studies from Italy in which amikacin was the most active drug against GNB [11, 23]. Different studies revealed varied resistance patterns. In a study conducted in Debre Markos, Ethiopia, tetracycline, ampicillin, and amoxicillin (also known as Augmentin) were found to be the least effective antibiotics among GNB [24]. In Tanzania, most GNB strains exhibited 100% resistance to cotrimoxazole and 66.7% resistance to amoxicillin/clavulanate [10]. Moreover, in Gondor, Ethiopia, GNB strains displayed high resistance to amoxicillin (97.4%) and ampicillin (94.8%) [29].

In particular, amikacin was the most effective drug against *E*. coli, *P. aeruginosa*, *Klebsiella* spp., and *Proteus* spp., while ampicillin was found to be the least effective drug among all applicable GNB, except for *P. aeruginosa*. In Pescara, Italy, *E. coli* were 100% susceptible to amikacin; conversely, 28.3% of *P. aeruginosa* strains were resistant to amikacin, while isolates displayed high resistance to ampicillin in these studies [23]. In Gondar, Ethiopia, most *E. coli* isolates were sensitive to gentamicin, followed by ceftriaxone, then chloramphenicol and ciprofloxacin. The isolates of *P. aeruginosa* were responsive to ciprofloxacin and gentamicin. *Klebsiella* spp. were only sensitive to gentamicin, and *E. coli* and *Klebsiella pneumoniae* exhibited the highest resistance rates to augmentin and ampicillin, respectively [27]. In India, *E. coli* showed the greatest susceptibility to ciprofloxacin (75.7%) and gentamicin (54.5%). For *P. aeruginosa,* maximum susceptibility was observed with piperacillin (100%) and tobramycin (71.4%) [28]. In Debre Markos, Ethiopia, *P. aeruginosa* exhibited the highest resistance to piperacillin and gentamicin, while meropenem and ciprofloxacin were reported to be relatively effective antibiotics [24]. Additionally, a study from Saudi Arabia showed that most *E. coli* strains were resistant to ciprofloxacin [25]. These variations could be attributed to differences in the type of wound, study population, and study area, as well as variations in antibiotic disc availability and usage among the studies.

In this study, several variables were tested as risk factors for a positive wound culture, and only the age group showed a significant association. This association with positive wound culture differed from that found in Bahir Dar, where a significant association existed between the patient's sex and wound infection, but no significant correlation was found with age [26].

4.1. Strengths and limitations

The strengths of this research study include the data analyses from four consecutive years, which provide an accurate representation of the bacteriological profile and antibiotic resistance patterns of infected wounds. Additionally, the data were pooled from PCDR, which encompasses all Wad-Medani hospital settings and serves as the reference laboratory for this study.

Some limitations were identified in the current study. First, a fully documented patient profile was unavailable due to the retrospective nature of the study, specifically regarding the patient's setting, which was incomplete. Second, there is no information available regarding the pathologies and comorbidities that the study's patients may have, as well as any antimicrobials administered, since the study samples were collected for diagnostic purposes, independent of the study. Lastly, in addition to the lack of facilities in the microbiology laboratory, anaerobic microorganisms could not be included.

5. Conclusion

This study reported a high rate of bacterial growth. The most frequently isolated bacteria were *S. aureus* and *E. coli*. Vancomycin and linezolid were the most effective drugs against GPB, while amikacin and gentamicin were the most effective drugs against GNB. Positive wound cultures were statistically associated with age. The high resistance rates of isolated bacteria, particularly GNB, to the most commonly used fluoroquinolone and beta-lactam antibiotics necessitate immediate and significant changes to their antimicrobial prescription policy for safe, rational, and effective antimicrobial use. Additionally, antimicrobial agents should be selected based on the susceptibility of specific microorganisms. The findings presented in this study could assist medical professionals in developing protocols and guidelines to choose an appropriate antimicrobial regimen for treating wound infections and preventing the emergence of multidrug-resistant strains.

Declarations

Acknowledgments

None.

Ethical Considerations

The study was approved by the Gezira State Ministry of Health Ethical Committee, Sudan, on September 7, 2023. Patient informed consent was waived because samples were obtained independently of this study for diagnostic purposes. Therefore, informed patient consent was not applicable since the data were provided anonymously.

Competing Interests

The authors declare that they have no conflicts of interest.

Availability of Data and Material

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Abbreviations and Symbols

PCDR: Pathology Center for Diagnosis and Research

GNB: Gram-negative bacteria

GPB: Gram-positive bacteria

WHO: World Health Organization

CLSI: Clinical and Laboratory Standard Institute

SPSS: Statistical Package for Social Sciences

CIs: Confidence intervals

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