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Bacterial Profile and Antimicrobial Susceptibility Patterns of Postoperative Wound Isolates in Selected Hospitals in Eastern Libya

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الملف البكتيري وأنماط الحساسية للمضادات الحيوية للعزلات الجراحية بعد العمليات الجراحية في مستشفيات مختارة في شرق ليبيا

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Abstract:

Background: Surgical site infections (SSIs) represent major complications associated with surgical procedures, leading to increased morbidity, prolonged hospitalization, elevated healthcare costs, and amplified antimicrobial resistance worldwide. The microbiological spectrum of SSI pathogens and their resistance profiles vary significantly across geographical regions, healthcare facilities, patient cohorts, and local infection control practices. **Objective**: This study aimed to identify bacterial pathogens associated with postoperative surgical site infections among patients across selected healthcare facilities in Al-Marj, Tocra, Taknis, and Benghazi, Eastern Libya, and to determine their antimicrobial susceptibility patterns. **Methods**: A multicenter cross-sectional study was conducted between April and July 2026, examining 100 clinical wound specimens and bacterial isolates from patients with suspected postoperative SSIs. Isolates were processed using conventional microbiological methods, Gram staining, and phenotypic biochemical tests, while antimicrobial susceptibility was evaluated via the Kirby-Bauer disk diffusion method. Data were analyzed using SPSS version 18, utilizing descriptive statistics and chi-square tests with significance set at $P < 0.05$. **Results**: Gram-negative bacteria accounted for 58.0% of isolates, while Gram-positive bacteria comprised 42.0%. The most prevalent isolates were Escherichia coli and Staphylococcus aureus (23.0% each), followed by Staphylococcus epidermidis (21.0%), Pseudomonas aeruginosa (19.0%), and Klebsiella spp. (14.0%). Bacterial distributions and Gram-stain classifications varied significantly among hospitals ($P < 0.001$ and $P = 0.002$, respectively). Significant associations with bacterial species were observed for susceptibility to ampicillin ($P < 0.001$), gentamicin ($P = 0.001$), and ceftazidime ($P = 0.046$). **Conclusion**: The findings reveal considerable bacterial diversity and varying antimicrobial resistance profiles among

postoperative wound infections in Eastern Libya, underscoring the critical need for continuous surveillance, standardized susceptibility testing, and robust antimicrobial stewardship programs.

Keywords: Surgical site infections; bacterial pathogens; antimicrobial susceptibility; wound microbiology; Eastern Libya.

الملخص

الخلفية: تمثل التهابات موضع الجراحة مضاعفات رئيسية مرتبطة بالتدخلات الجراحية، مما يؤدي إلى زيادة معدلات المراضة، وإطالة فترة الإقامة بالمستشفى، وارتفاع تكاليف الرعاية الصحية، وتفاقم مقاومة مضادات الميكروبات على مستوى العالم. يختلف الطيف الميكروبي لمسببات التهابات موضع الجراحة وملامح مقاومتها بشكل ملحوظ عبر المناطق الجغرافية، ومرافق الرعاية الصحية، وفئات المرضى، وممارسات مكافحة العدوى المحلية. **الهدف**: هدفت هذه الدراسة إلى تحديد مسببات الأمراض البكتيرية المرتبطة بالتهابات موضع الجراحة بعد العملية لدى المرضى في مرافق صحية مختارة في المرج، وتوكرة، والتكنية، وبنغازي في شرق ليبيا، وتحديد أنماط حساسيتها للمضادات الحيوية. **الطريقة**: أجريت دراسة مقطعية متعددة المراكز بين أبريل ويوليو 2026، شملت 100 عينة جروح سريرية وعزلة بكتيرية من مرضى يعانون من اشتباه التهابات موضع الجراحة. تمت معالجة العزلات باستخدام الطرق الطحلبية التقليدية، وتلوين جرام، والاختبارات الكيميائية الحيوية المظهرية، بينما تم تقييم الحساسية للمضادات الحيوية عبر طريقة انتشار قرص كيربي-باور. تم تحليل البيانات باستخدام برنامج الحزم الإحصائية للعلوم الاجتماعية (SPSS) الإصدار 18، باستخدام الإحصاء الوصفي واختبار كاي تربيع مع اعتبار مستوى الدلالة $P < 0.05$. **النتائج**: شكلت البكتيريا سالبة الجرام 58.0% من العزلات، بينما بلغت نسبة البكتيريا موجبة الجرام 42.0%. كانت العزلات الأكثر شيوعاً هي الإشريكية القولونية والمكورات العنقودية الذهبية (23.0% لكل منهما)، تليها المكورات العنقودية البشروية (21.0)، والزائفة الزنجارية (19.0%)، وأنواع الكلبسيلا (14.0%). تباينت التوزيعات البكتيرية وتصنيفات صبغة جرام بشكل ملحوظ بين المستشفيات ($P < 0.001$ و $P = 0.002$ على التوالي). لوحظت ارتباطات ذات دلالة إحصائية مع الأنواع البكتيرية لكل من الحساسية للأبيسيلين ($P < 0.001$)، والجنتاميسين ($P = 0.001$)، وسيفتازيديم ($P = 0.046$). **الاستنتاج**: تُظهر النتائج تنوعاً بكتيرياً معتبراً وملامح مقاومة متباينة لمضادات الميكروبات بين التهابات الجروح بعد العملية الجراحية في شرق ليبيا، مما يؤكد الحاجة الملحة للترصد المستمر، واختبارات الحساسية القياسية، وبرامج الإشراف الصارم على مضادات الميكروبات.

الكلمات المفتاحية: التهابات موضع الجراحة؛ مسببات الأمراض البكتيرية؛ الحساسية للمضادات الحيوية؛ ميكروبيولوجيا الجروح؛ شرق ليبيا.

1.Introduction

Wounds are disruptions in the normal integrity of the skin and underlying tissues that may result from accidental, deliberate, or surgical procedures. Since the skin represents the body's first line of defense against microbial invasion, any disruption of its protective function provides an opportunity for pathogenic microorganisms to colonize and multiply, potentially leading to wound infection (Bowler et al., 2001; Mahon and Manuselis, 1995; Stephan and Landis, 2008). Microbial invasion stimulates an inflammatory response characterized by redness, heat, swelling, and pain, with the accumulation of defensive cells and inflammatory exudate at the site of infection (Abdul Hafeez et al., 1996).

Postoperative wound infections are important healthcare-associated complications. Microorganisms may originate from the patient's own skin and tissues or from external sources, including healthcare workers, contaminated surfaces, instruments, and the hospital

environment (Oguntibeju and Nwobu, 2004). The occurrence of surgical site infections (SSIs) may be influenced by inadequate sterilization, poor hand hygiene, contaminated surgical instruments, inappropriate disinfection, operating-room contamination, and insufficient environmental control (Murray et al., 2004). Patients with compromised immunity, including those affected by cancer, diabetes, or AIDS, or those receiving immunosuppressive medications such as corticosteroids, may be at increased risk of postoperative infection (Bailey and Love, 2004). The prevalence and bacterial etiology of SSIs also differ between geographical regions and healthcare settings, making local surveillance important for developing appropriate infection-control strategies and empirical antimicrobial treatment (WHO, 2016).

Surgical practice has developed considerably from ancient procedures such as trepanation, which were performed without modern anesthesia or effective sterilization, to modern surgery based on anesthesia, aseptic techniques, advanced instruments, and improved postoperative care (Ellis, 2001). The introduction of anesthesia represented an important milestone in surgical development, while the antiseptic principles introduced by Joseph Lister substantially reduced postoperative infections (Lister, 1867). Modern surgery encompasses several specialties, including general, plastic, cardiac, orthopedic, neurosurgical, and abdominal surgery. Improvements in surgical techniques have been accompanied by advances in wound management, including sterile wound cleaning, appropriate dressings, continuous monitoring, and prophylactic antibiotic use when indicated (Mangram et al., 1999).

Surgical infections may occur at different anatomical sites and include surgical site infections, postoperative pneumonia, urinary tract infections, and gastrointestinal infections (Nicholas, 2001). SSIs are particularly important because they may cause localized inflammation, wound discharge, delayed healing, and, in severe cases, systemic infection. Common bacterial pathogens associated with surgical wound infections include *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella* spp., *Enterococcus* spp., and *Proteus* spp. (Mangram et al., 1999; Cheadle, 2006; Talaro and Park, 2005; Collee, 1989; Arora, 2003; Bell and Kyriakides, 2002; Bagnasco et al., 1988). These organisms may originate from different reservoirs and reach surgical wounds through the patient's normal flora, contaminated hands, instruments, hospital surfaces, medical equipment, or other environmental sources. Their clinical importance is increased by the emergence of resistant strains, including methicillin-resistant *Staphylococcus aureus* (MRSA), extended-spectrum β-lactamase (ESBL)-producing Enterobacterales, carbapenemase-producing *Klebsiella*, and vancomycin-resistant enterococci (VRE).

Several factors contribute to the development and persistence of postoperative bacterial infections. Hospital and environmental contamination can facilitate the transmission of pathogens, particularly *S. aureus* and *P. aeruginosa* (Kampf et al., 2019). Inadequate wound care and poor hygiene may promote bacterial multiplication and increase the risk of complications such as cellulitis and sepsis (Smith et al., 2020). Immunosuppression increases susceptibility to infection and may contribute to more severe outcomes (Lee et al., 2018). In addition, bacterial virulence factors, including toxin production, tissue invasion, immune evasion, and biofilm formation, can delay wound healing and make infections more difficult to eradicate (Roberts et al., 2021). Antibiotic resistance, particularly MRSA and other multidrug-resistant organisms, further complicates treatment and increases the risk of prolonged infection and healthcare-associated transmission (Gonzalez et al., 2019).

The diagnosis of wound infection is primarily clinical and is based on signs and symptoms such as pain, heat, swelling, redness, ulceration, dermatitis, fever, and purulent discharge. Microbiological investigations are important for identifying causative organisms and determining their antimicrobial susceptibility. However, wound cultures should generally be obtained when there is clinical evidence or strong suspicion of infection because wounds may

normally be contaminated or colonized by microorganisms (Woods et al., 2018). Diagnostic investigations may include microbiological, blood, and radiological examinations to identify pathogens, guide antimicrobial treatment, assess systemic effects, and detect complications such as sepsis, osteomyelitis, or deeper collections (Miller et al., 2019). Common specimen types include superficial wound swabs, pus samples, and tissue biopsies or wound scrapings (Foster et al., 2021).

Prevention and management of SSIs require a combination of surgical, antimicrobial, and infection-control measures. Reducing the microbial burden through appropriate preoperative skin preparation is an important preventive strategy (Dumville et al., 2015). Perioperative antibiotic prophylaxis can reduce the risk of SSIs, particularly in procedures such as total joint arthroplasty (Garvin and Hanssen, 1995). Other important measures include careful handling of soft tissues, minimizing tissue trauma and tension, and selecting appropriate incision sizes (Soballe et al., 1992; Masini et al., 2011). Shortening operative duration is also important because prolonged surgery is associated with an increased risk of SSI (Cheng et al., 2017). Minimizing blood loss and unnecessary allogeneic blood transfusion may further reduce the risk of SSIs and periprosthetic joint infections (Cizmic et al., 2019).

Environmental and intraoperative measures are also essential. Reducing unnecessary operating-room traffic can limit airborne contamination and microbial exposure (Persson, 2019). Appropriate antiseptic irrigation may assist in tissue debridement and reduction of microbial contamination (Siddiqi et al., 2021). Proper sterilization of surgical instruments and implants is essential for preventing SSIs and implant-associated infections (Manea et al., 2018). Finally, appropriate wound closure techniques and suitable postoperative dressings contribute to reducing infection risk and promoting wound healing (DeSimone et al., 2020).

In the Libyan context, investigating the bacterial causes and antimicrobial susceptibility patterns of postoperative SSIs is particularly important because bacterial profiles and resistance patterns may vary between healthcare facilities and geographical areas. Therefore, the present study focuses on secondary-care hospitals in Al-Marj, Tocra, and Taknis, together with Benghazi Medical Centre (BMC), a major tertiary referral center in Eastern Libya. Comparing these different healthcare settings may provide useful information about the distribution of bacterial pathogens and their antimicrobial susceptibility patterns and may contribute to improving empirical antimicrobial selection, infection-control practices, and postoperative outcomes (El-Khabri and Ahmaida, 2020).

Accordingly, this descriptive cross-sectional study was conducted from April to July 2026 and included 100 wound specimens/bacterial isolates. The study aimed to isolate and identify bacterial pathogens associated with postoperative SSIs, determine the frequency and distribution of the identified pathogens in Al-Marj, Tocra, Taknis, and Benghazi, and evaluate their antimicrobial susceptibility patterns against selected antimicrobial agents.

2. Materials and Methods

2.1 Study Design

A descriptive cross-sectional laboratory-based study was conducted to investigate bacterial pathogens associated with postoperative surgical site infections (SSIs) and to determine their antimicrobial susceptibility patterns. The study focused on bacterial isolates recovered from postoperative wound specimens collected from patients attending selected hospitals in Eastern Libya.

2.2 Study Area

The study was conducted in four healthcare facilities located in Eastern Libya: Al-Marj Hospital, Benghazi Medical Centre/Hospital, Taknis Hospital, and Tocra Hospital. These healthcare facilities represent different geographical and healthcare settings, including hospitals located within and outside Benghazi.

The inclusion of hospitals from different geographical locations was intended to provide a broader assessment of the distribution of bacterial pathogens associated with postoperative wound infections and to identify possible differences in bacterial profiles among healthcare facilities.

2.3 Study Period

The study was conducted from April to July 2026.

2.4 Study Population and Sample Size

The study population consisted of patients who developed postoperative wound infections and from whom wound specimens were collected for microbiological examination.

A total of 100 wound specimens/bacterial isolates were included in the study. The samples were distributed according to the participating hospitals as follows:

- Al-Marj Hospital: 31 samples (31.0%)
- Tocra Hospital: 30 samples (30.0%)
- Benghazi Hospital: 21 samples (21.0%)
- Taknis Hospital: 18 samples (18.0%)

The sample distribution was intended to include specimens from different healthcare facilities and geographical locations.

2.5 Inclusion Criteria

Patients were eligible for inclusion when they met the following criteria:

1. Patients who had undergone a surgical procedure.
2. Patients who developed clinical signs suggestive of postoperative wound infection.
3. Patients from whom a wound specimen could be collected for microbiological examination.
4. Specimens that were appropriately collected and submitted to the laboratory for bacterial investigation.

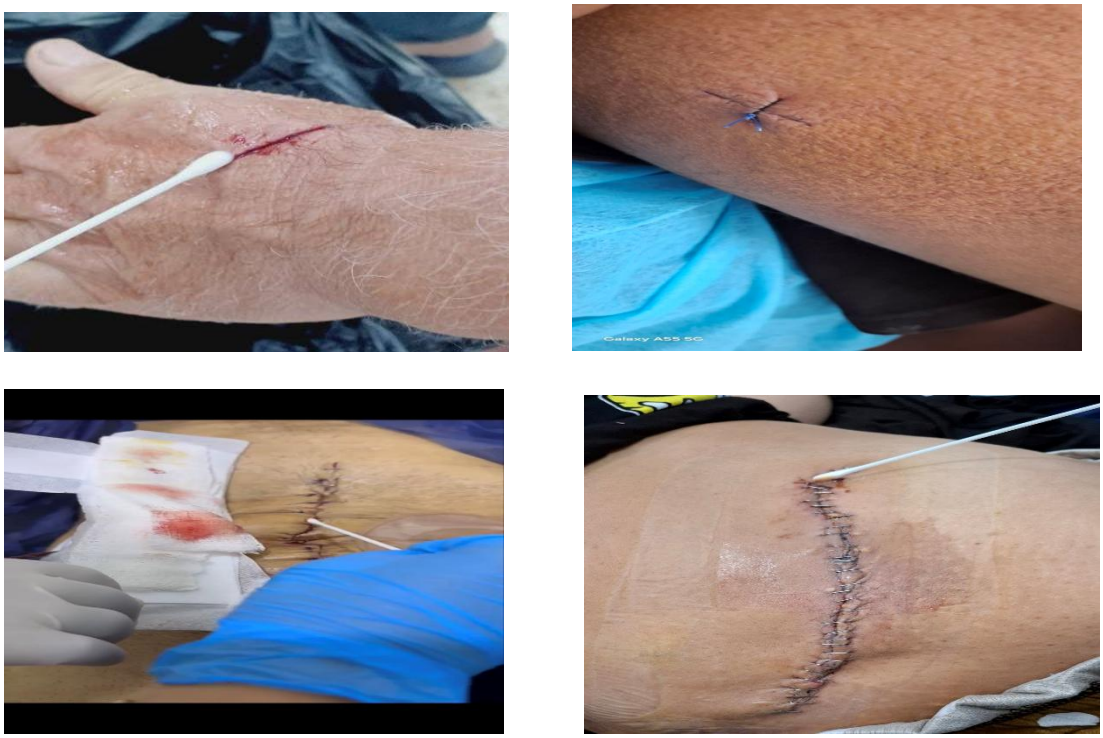

Figure 1: Collection of a clinical wound swab specimen from a patient.

2.6 Exclusion Criteria

The following specimens were excluded from the study:

1. Specimens that were improperly collected or inadequately labeled.
2. Specimens that were contaminated during collection or transportation.
3. Specimens that were insufficient for microbiological examination.
4. Specimens from patients who did not meet the study criteria.

2.7 Ethical Considerations

The study was conducted in accordance with the principles of ethical research involving human participants. Permission to collect clinical specimens was obtained from the relevant healthcare facilities and/or responsible authorities.

Patient information was treated confidentially, and specimens were processed using coded identifiers rather than personal identifying information. The results were used exclusively for scientific and research purposes.

2.8 Collection of Wound Specimens

Wound specimens were collected from patients with suspected postoperative surgical site infections using standard aseptic procedures.

Before specimen collection, the wound was assessed clinically, and superficial contamination was removed when appropriate. A sterile swab was used to collect material from the infected area, particularly from areas showing evidence of purulent discharge or active infection.

The collected specimens were placed in appropriate sterile transport containers and transported to the microbiology laboratory as soon as possible for processing.

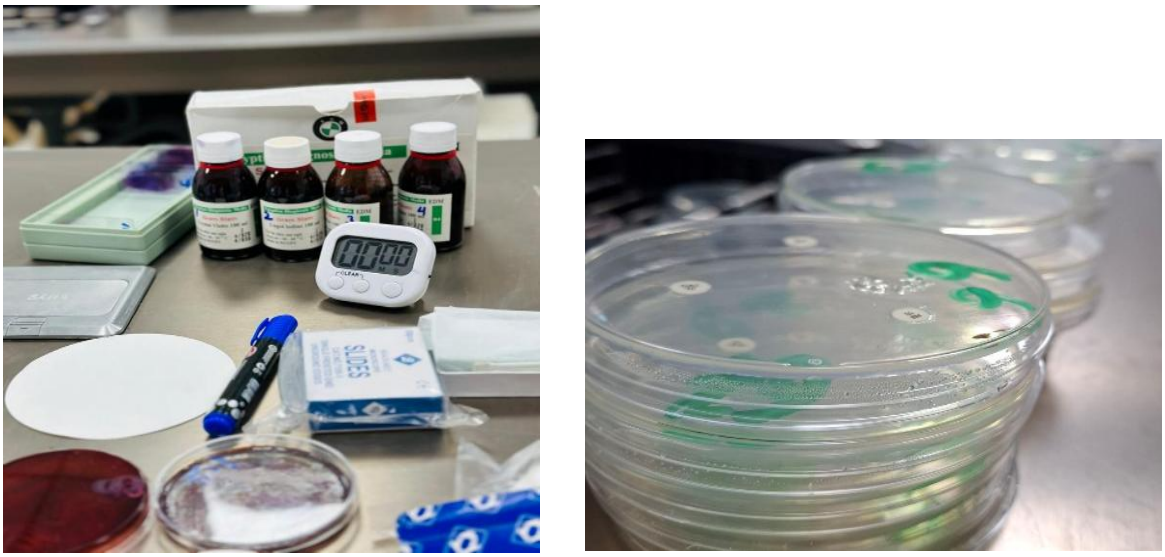

Figure 2: Laboratory preparation of culture media for bacterial isolation.

2.9 Laboratory Processing of Specimens

Upon arrival at the microbiology laboratory, each specimen was processed using standard bacteriological techniques. The specimens were examined for bacterial growth and subsequently subjected to phenotypic and biochemical tests for preliminary identification.

The laboratory investigation included:

- Primary bacterial isolation.
- Assessment of colony morphology.
- Gram staining.
- Mannitol fermentation testing.
- Hemolysis testing.
- Plasma coagulase testing.
- Enterococcus-related testing.

- Identification of bacterial species based on the combination of cultural, microscopic, and biochemical characteristics.
- Antimicrobial susceptibility testing.

2.10 Bacterial Isolation and Identification

Clinical wound specimens were inoculated onto appropriate bacteriological culture media under aseptic conditions. Following incubation under the laboratory's standard conditions, bacterial growth was examined macroscopically.

Individual colonies were evaluated according to their:

- Size.
- Shape.
- Color.
- Texture.
- Colony elevation.
- Pigmentation.
- Hemolytic characteristics, where applicable.

Distinct colonies were subcultured when necessary to obtain pure cultures before further identification.

Figure 3: Laboratory preparation of culture media, sterilization, and agar plate pouring for bacterial isolation.

2.11 Gram Staining

Gram staining was performed to differentiate bacterial isolates into Gram-positive and Gram-negative groups and to assess their cellular morphology.

A bacterial smear was prepared from a pure colony, air-dried, heat-fixed, and subjected to the Gram-staining procedure. The stained preparations were examined microscopically using the appropriate magnification.

Based on Gram-staining characteristics, the isolates were classified as either Gram-positive or Gram-negative bacteria.

2.12 Mannitol Fermentation Test

The mannitol fermentation test was performed as a biochemical test to assess the ability of bacterial isolates to ferment mannitol.

The test was interpreted according to the observed color reaction of the culture medium. A yellow reaction was considered indicative of mannitol fermentation, whereas a pink reaction was interpreted as a negative fermentation reaction according to the laboratory procedure used.

In the present study, 61.0% of the isolates demonstrated a pink reaction, while 39.0% demonstrated a yellow reaction.

2.13 Hemolysis Test

Hemolytic activity was determined by observing the appearance of bacterial growth on blood-containing culture medium.

The isolates were classified according to their hemolytic pattern as follows:

- Alpha (α) hemolysis: partial hemolysis characterized by a greenish discoloration around colonies.
- Beta (β) hemolysis: complete hemolysis characterized by a clear zone around colonies.
- Gamma (γ) hemolysis: absence of detectable hemolysis.

The hemolysis results were recorded for each bacterial isolate and subsequently analyzed according to bacterial species.

2.14 Plasma Coagulase Test

The plasma coagulase test was performed to detect coagulase-producing bacteria. The test was particularly useful for the phenotypic differentiation of *Staphylococcus aureus* from coagulase-negative staphylococci.

The test was recorded as positive when coagulation or clot formation was observed and negative when no coagulation occurred according to the laboratory protocol.

In the overall study sample, 57.0% of isolates were positive for the plasma coagulase test, while 43.0% were negative.

2.15 Enterococcus Test

An Enterococcus-related identification test was performed as part of the biochemical characterization of the bacterial isolates.

The results were categorized as:

- Enterococcus positive.
- Enterococcus negative.
- No definitive result.

Because a considerable proportion of specimens produced no definitive result, these observations were retained as a separate category during statistical analysis rather than being excluded.

2.16 Identification of Bacterial Species

Bacterial identification was based on the combination of Gram-staining characteristics, colony morphology, hemolysis pattern, mannitol fermentation, plasma coagulase results, Enterococcus-related testing, and other routine laboratory characteristics used during bacterial identification.

The principal bacterial species identified in the study were:

- *Escherichia coli*
- *Klebsiella* spp.
- *Pseudomonas aeruginosa*
- *Staphylococcus aureus*
- *Staphylococcus epidermidis*

The identified organisms represented both Gram-negative and Gram-positive bacteria.

2.17 Antimicrobial Susceptibility Testing

Antimicrobial susceptibility testing was performed on the identified bacterial isolates to determine their responses to selected antimicrobial agents.

The tested antimicrobial agents included:

- Vancomycin (VA)
- Ceftazidime (CAZ)
- Amoxicillin/Clavulanate (AMC)
- Ampicillin (AMP)
- Gentamicin (CN)
- Ceftriaxone (CRO)

The Kirby–Bauer disk diffusion method was used for antimicrobial susceptibility testing. Standardized bacterial suspensions were prepared from fresh pure cultures and inoculated onto the appropriate susceptibility-testing medium. Antimicrobial discs were then applied to the inoculated agar surface and incubated under standardized laboratory conditions.

Following incubation, inhibition zones were measured in millimeters and interpreted according to the applicable antimicrobial susceptibility guidelines.

The antimicrobial susceptibility results were categorized as:

- R: Resistant
- I: Intermediate
- S: Susceptible

2.18 Quality Control

Quality-control procedures were applied throughout specimen processing, bacterial identification, and antimicrobial susceptibility testing to improve the reliability and reproducibility of laboratory findings.

These procedures included the use of appropriate sterile materials, aseptic techniques, verification of culture purity, proper handling of bacterial isolates, and adherence to standardized laboratory procedures.

2.19 Data Collection and Statistical Analysis

Data obtained from the laboratory investigations were recorded in a structured data sheet and subsequently entered into a statistical analysis program.

Descriptive statistics were used to summarize the data, including frequencies and percentages for categorical variables.

The following variables were analyzed:

- Hospital.
- Geographic location of hospital.
- Gram-stain reaction.
- Mannitol fermentation reaction.
- Hemolysis pattern.
- Plasma coagulase result.
- Enterococcus test result.
- Identified bacterial species.
- Antimicrobial susceptibility pattern.

The chi-square (χ^2) test was used to assess associations between categorical variables, including:

- Hospital and bacterial species.
- Bacterial species and Gram-stain reaction.
- Bacterial species and mannitol fermentation.
- Bacterial species and alpha hemolysis.
- Bacterial species and beta hemolysis.
- Bacterial species and gamma hemolysis.
- Bacterial species and plasma coagulase test.
- Bacterial species and Enterococcus test results.
- Hospital and Gram-stain reaction.
- Hospital and Enterococcus test results.
- Bacterial species and antimicrobial susceptibility patterns.

A P-value < 0.05 was considered statistically significant.

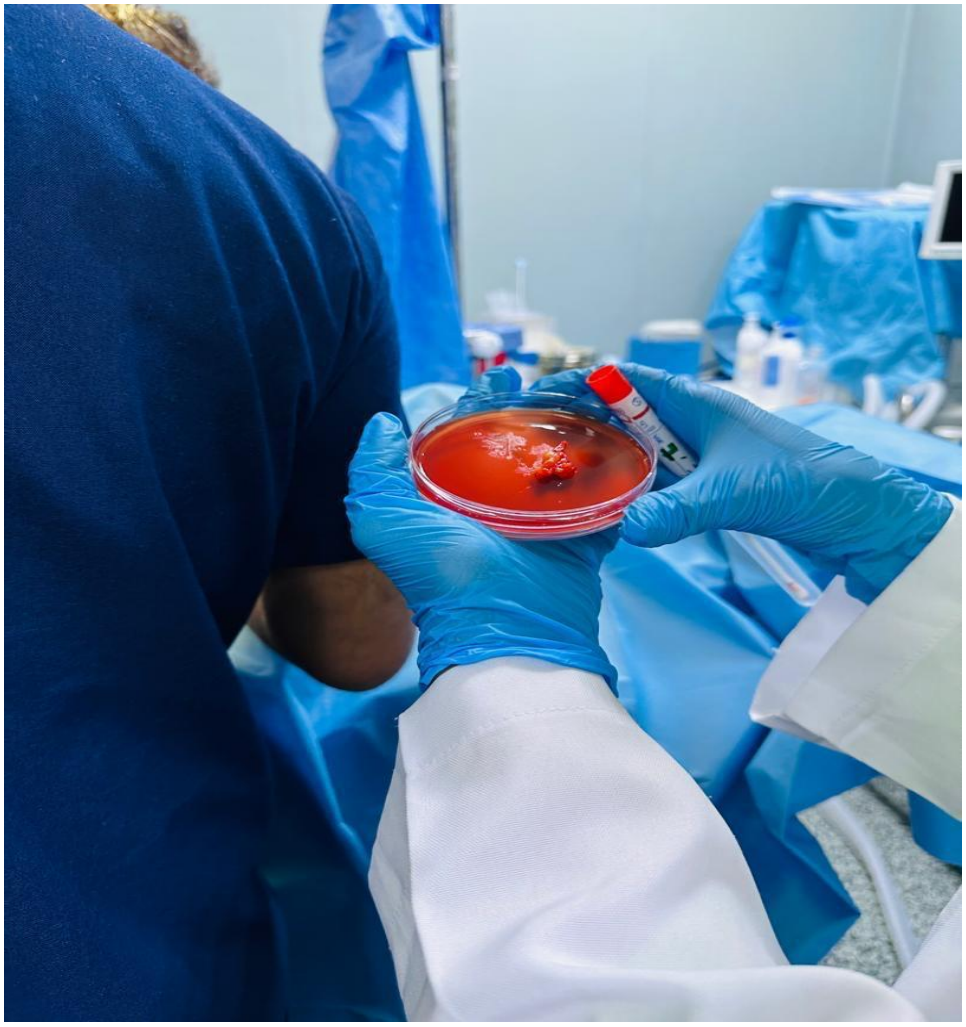

Figure 4: Bacterial culture procedures for diagnosis.

2.20 Presentation of Results

The results were presented using frequency and percentage tables. Associations between categorical variables were presented with the corresponding chi-square value, degrees of freedom, and P-value.

The antimicrobial susceptibility results were presented separately for each tested antimicrobial agent, with bacterial species categorized according to resistant, intermediate, and susceptible responses.

Table 1. General Distribution of Bacterial Isolates and Identification Results

Variable	Category	Frequency, n (%)
Hospital	Al-Marj	31 (31.0)
	Benghazi	21 (21.0)
	Taknis	18 (18.0)
	Tocra	30 (30.0)
Geographic location	Outside Benghazi	79 (79.0)
	Inside Benghazi	21 (21.0)
Gram stain	Gram-negative	58 (58.0)
	Gram-positive	42 (42.0)
Mannitol test	Pink	61 (61.0)
	Yellow	39 (39.0)
Hemolysis	Alpha	33 (33.0)
	Beta	44 (44.0)
	Gamma	23 (23.0)
Plasma coagulase	Positive	57 (57.0)
	Negative	43 (43.0)
Bacterial species	*Escherichia coli*	23 (23.0)
	Klebsiella pneumoniae	14 (14.0)
	Pseudomonas aeruginosa	19 (19.0)
	Staphylococcus aureus	23 (23.0)
	Staphylococcus epidermidis	21 (21.0)
Enterococcus test	Entero	12 (12.0)
	Non	40 (40.0)
	No result	48 (48.0)
Total		100 (100.0)

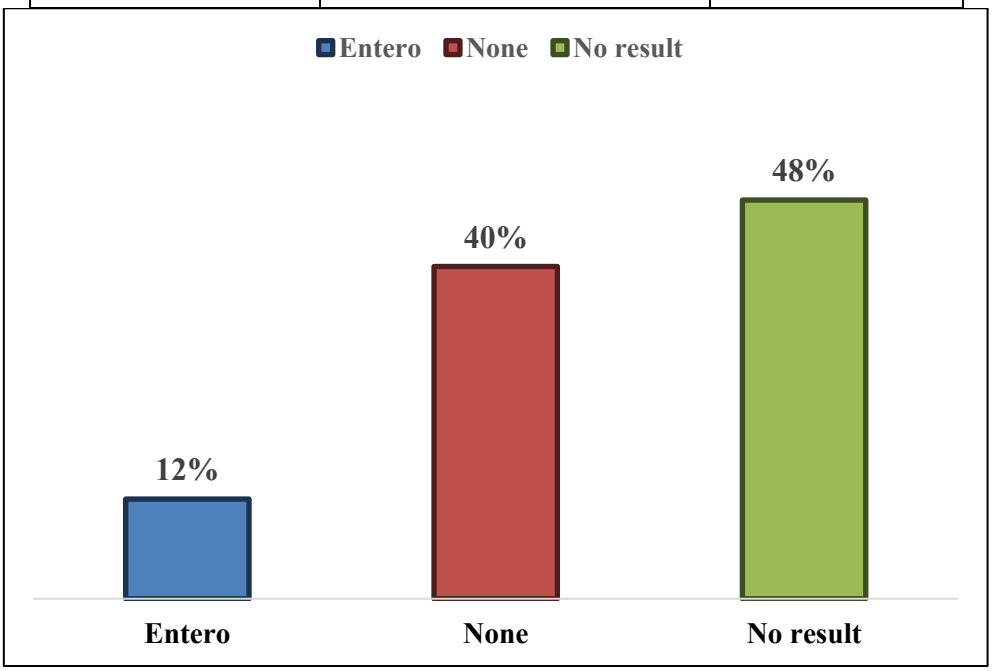

Figure (1) Distribution of Enterococcus Test Results.

Among the 100 bacterial isolates, Al-Marj Hospital contributed the largest proportion (31.0%), followed by Tocra (30.0%), Benghazi (21.0%), and Taknis (18.0%). Most isolates were obtained from hospitals outside Benghazi (79.0%). Gram-negative bacteria predominated (58.0%). Beta hemolysis was the most common hemolytic pattern (44.0%). *E. coli* and *S. aureus* were the most frequently identified species (23.0% each). The Enterococcus test was positive in 12.0% of isolates, while 48.0% produced no definitive result

Table 2. Distribution of Bacterial Species According to Hospital

Bacterial species	Al-Marj n (%)	Benghazi n (%)	Taknis n (%)	Tocra n (%)	Total
Escherichia coli	0 (0.0)	0 (0.0)	0 (0.0)	23 (100.0)	23
Klebsiella pneumoniae	0 (0.0)	6 (42.9)	8 (57.1)	0 (0.0)	14
Pseudomonas aeruginosa	19 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	19
Staphylococcus aureus	2 (8.7)	4 (17.4)	10 (43.5)	7 (30.4)	23
Staphylococcus epidermidis	10 (47.6)	11 (52.4)	0 (0.0)	0 (0.0)	21
Total	31	21	18	30	100

Chi-square = 153.527; df = 12; P < 0.001

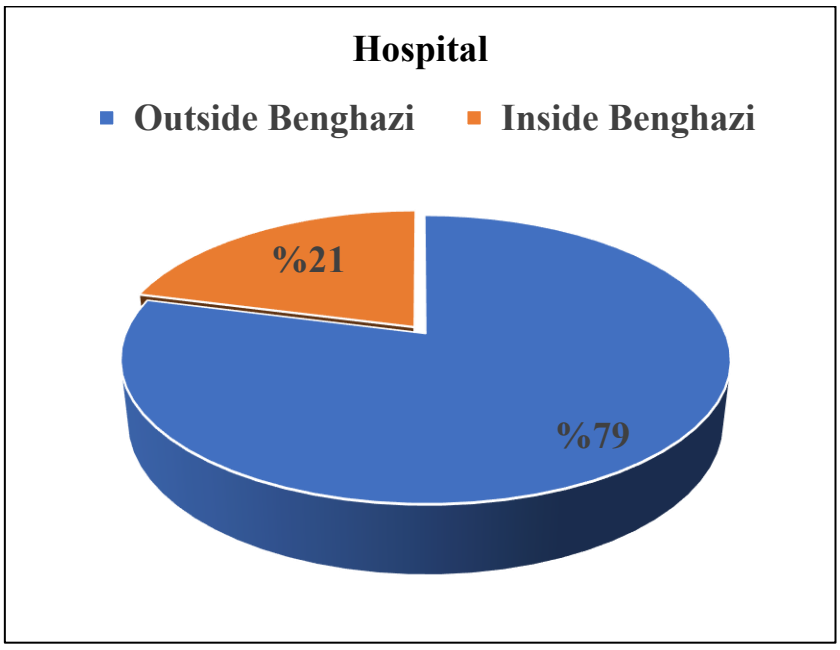

Figure (2) Distribution of the Study Sample by Hospital Geographic Location

A statistically significant association was observed between hospital and bacterial species (χ^2 = 153.527, df = 12, P < 0.001). All *E. coli* isolates were obtained from Tocra Hospital, while all *P. aeruginosa* isolates were obtained from Al-Marj. *K. pneumoniae* was identified in Benghazi and Taknis, accounting for 42.9% and 57.1% of its isolates, respectively. *S.*

aureus was distributed among all four hospitals, whereas *S. epidermidis* was detected only in Al-Marj and Benghaz

Table 3. Distribution of Bacterial Species According to Gram-Stain, Mannitol Fermentation, Hemolysis, and Plasma Coagulase Results

Bacterial species	Gram-negative n (%)	Gram-positive n (%)	Pink n (%)	Yellow n (%)	Alpha n (%)	Beta n (%)	Gamma n (%)	Coagulase positive n (%)	Coagulase negative n (%)
Escherichia coli	23 (100.0)	0 (0.0)	12 (52.2)	11 (47.8)	7 (30.4)	16 (69.6)	0 (0.0)	11 (47.8)	12 (52.2)
Klebsiella pneumoniae	14 (100.0)	0 (0.0)	4 (28.6)	10 (71.4)	14 (100.0)	0 (0.0)	0 (0.0)	14 (100.0)	0 (0.0)
Pseudomonas aeruginosa	19 (100.0)	0 (0.0)	5 (26.3)	14 (73.7)	0 (0.0)	12 (63.2)	7 (36.8)	13 (68.4)	6 (31.6)
Staphylococcus aureus	0 (0.0)	23 (100.0)	19 (82.6)	4 (17.4)	5 (21.7)	16 (69.6)	2 (8.7)	15 (65.2)	8 (34.8)
Staphylococcus epidermidis	2 (9.5)	19 (90.5)	21 (100.0)	0 (0.0)	7 (33.3)	0 (0.0)	14 (66.7)	4 (19.0)	17 (81.0)

Statistical significance: Gram stain, $\chi^2 = 92.572$, df = 4, $P < 0.001$; Mannitol fermentation, $\chi^2 = 34.490$, df = 4, $P < 0.001$; Alpha hemolysis, $\chi^2 = 39.171$, df = 4, $P < 0.001$; Beta hemolysis, $\chi^2 = 42.532$, df = 4, $P < 0.001$; Gamma hemolysis, $\chi^2 = 38.375$, df = 4, $P < 0.001$; Plasma coagulase, $\chi^2 = 25.337$, df = 4, $P < 0.001$.

A statistically significant association was observed between bacterial species and Gram-stain results, mannitol fermentation, all three hemolysis patterns, and plasma coagulase results ($P < 0.001$). All *E. coli*, *K. pneumoniae*, and *P. aeruginosa* isolates were Gram-negative, whereas all *S. aureus* isolates were Gram-positive. Pink mannitol reactions were most frequent among *S. epidermidis* (100.0%) and *S. aureus* (82.6%). Alpha hemolysis was observed in all *K. pneumoniae* isolates, while beta hemolysis was most frequent among *E. coli* and *S. aureus* (69.6% each). Gamma hemolysis was most frequent among *S. epidermidis* (66.7%). Plasma coagulase positivity was highest among *K. pneumoniae* (100.0%), followed by *P. aeruginosa* (68.4%) and *S. aureus* (65.2%

Table 4. Distribution of Enterococcus Test Results According to Bacterial Species and Hospital

Category	Entero n (%)	Non n (%)	No result n (%)
Bacterial species			
Escherichia coli	3 (13.0)	5 (21.7)	15 (65.2)
Klebsiella pneumoniae	2 (14.3)	11 (78.6)	1 (7.1)
Pseudomonas aeruginosa	2 (10.5)	7 (36.8)	10 (52.6)
Staphylococcus aureus	4 (17.4)	14 (60.9)	5 (21.7)

Staphylococcus epidermidis	1 (4.8)	3 (14.3)	17 (81.0)
Hospital			
Al-Marj	3 (9.7)	8 (25.8)	20 (64.5)
Benghazi	5 (23.8)	6 (28.6)	10 (47.6)
Taknis	0 (0.0)	18 (100.0)	0 (0.0)
Tocra	4 (13.3)	8 (26.7)	18 (60.0)

Bacterial species: $\chi^2 = 29.167$; df = 8; $P < 0.001$ Hospital: $\chi^2 = 35.867$; df = 6; $P < 0.001$.

The Enterococcus test was significantly associated with both bacterial species and hospital ($P < 0.001$). Enterococcus-positive results were most frequent among *S. aureus* (17.4%) and least frequent among *S. epidermidis* (4.8%). The highest proportion of negative results was observed among *K. pneumoniae* (78.6%). No Enterococcus-positive result was recorded in Taknis Hospital, where all isolates were negative. No definitive result was obtained for 81.0% of *S. epidermidis* and 65.2% of *E. coli* isolates.

Table 5. Antimicrobial Susceptibility Patterns of the Identified Bacterial Species

Antimicrobial agent	Bacterial species	Resistant, n (%)	Intermediate, n (%)	Susceptible, n (%)
Vancomycin (VA)	*Escherichia coli* (n=23)	6 (26.1)	7 (30.4)	10 (43.5)
	Klebsiella pneumoniae (n=14)	6 (42.9)	1 (7.1)	7 (50.0)
	Pseudomonas aeruginosa (n=7)	3 (42.9)	3 (42.9)	1 (14.3)
	Staphylococcus aureus (n=17)	3 (17.6)	3 (17.6)	11 (64.7)
	Staphylococcus epidermidis (n=7)	2 (28.6)	2 (28.6)	3 (42.9)
Ceftazidime (CAZ)	*Escherichia coli* (n=23)	18 (78.3)	1 (4.3)	4 (17.4)
	Klebsiella pneumoniae (n=14)	10 (71.4)	0 (0.0)	4 (28.6)
	Pseudomonas aeruginosa (n=7)	6 (85.7)	0 (0.0)	1 (14.3)
	Staphylococcus aureus (n=17)	7 (41.2)	2 (11.8)	8 (47.1)
	Staphylococcus epidermidis (n=7)	2 (28.6)	1 (14.3)	4 (57.1)
Amoxicillin/Clavulanate (AMC)	*Escherichia coli* (n=23)	9 (39.1)	0 (0.0)	14 (60.9)
	Klebsiella pneumoniae (n=14)	10 (71.4)	0 (0.0)	4 (28.6)
	Pseudomonas aeruginosa (n=7)	2 (28.6)	0 (0.0)	5 (71.4)

	Staphylococcus aureus (n=17)	5 (29.4)	2 (11.8)	10 (58.8)
	Staphylococcus epidermidis (n=7)	3 (42.9)	1 (14.3)	3 (42.9)
Ampicillin (AMP)	*Escherichia coli* (n=23)	22 (95.7)	0 (0.0)	1 (4.3)
	Klebsiella pneumoniae (n=14)	14 (100.0)	0 (0.0)	0 (0.0)
	Pseudomonas aeruginosa (n=7)	7 (100.0)	0 (0.0)	0 (0.0)
	Staphylococcus aureus (n=17)	6 (35.3)	4 (23.5)	7 (41.2)
	Staphylococcus epidermidis (n=7)	1 (14.3)	0 (0.0)	6 (85.7)
Gentamicin (CN)	*Escherichia coli* (n=23)	9 (39.1)	0 (0.0)	14 (60.9)
	Klebsiella pneumoniae (n=14)	0 (0.0)	1 (7.1)	13 (92.9)
	Pseudomonas aeruginosa (n=7)	6 (85.7)	1 (14.3)	0 (0.0)
	Staphylococcus aureus (n=17)	3 (17.6)	2 (11.8)	12 (70.6)
	Staphylococcus epidermidis (n=7)	0 (0.0)	2 (28.6)	5 (71.4)
Ceftriaxone (CRO)	*Escherichia coli* (n=23)	10 (43.5)	2 (8.7)	11 (47.8)
	Klebsiella pneumoniae (n=14)	4 (28.6)	1 (7.1)	9 (64.3)
	Pseudomonas aeruginosa (n=7)	1 (14.3)	0 (0.0)	6 (85.7)
	Staphylococcus aureus (n=17)	4 (23.5)	3 (17.6)	10 (58.8)
	Staphylococcus epidermidis (n=7)	5 (71.4)	1 (14.3)	1 (14.3)

Statistical significance: Vancomycin: $\chi^2 = 9.619$, df = 10, P = 0.474; Ceftazidime: $\chi^2 = 18.604$, df = 10, P = 0.046; Amoxicillin/Clavulanate: $\chi^2 = 12.187$, df = 10, P = 0.273; Ampicillin: $\chi^2 = 52.189$, df = 10, P < 0.001; Gentamicin: $\chi^2 = 29.170$, df = 10, P = 0.001; Ceftriaxone: $\chi^2 = 13.840$, df = 10, P = 0.180.

Antimicrobial susceptibility varied across bacterial species. Statistically significant associations were observed for ceftazidime (P = 0.046), ampicillin (P < 0.001), and gentamicin (P = 0.001), whereas no significant associations were observed for vancomycin (P = 0.474), amoxicillin/clavulanate (P = 0.273), or ceftriaxone (P = 0.180). The highest resistance to ceftazidime was observed among *P. aeruginosa* (85.7%), followed by *E. coli* (78.3%) and *K. pneumoniae* (71.4%). Ampicillin resistance was particularly high among *K. pneumoniae* and *P. aeruginosa* (100.0% each) and *E. coli* (95.7%). For gentamicin, resistance was highest among *P. aeruginosa* (85.7%), whereas *K. pneumoniae* showed the highest susceptibility (92.9%). For ceftriaxone, susceptibility was highest among *P. aeruginosa* (85.7%), while *S. epidermidis* showed the highest resistance (71.4%).

5. Discussion

5.1 Bacterial Isolation Rates

The results of the present study demonstrate considerable microbial diversity among postoperative surgical site infections across Al-Marj, Tocra, Taknis, and Benghazi. The isolated pathogens included Gram-positive bacteria, particularly *Staphylococcus aureus* and *Staphylococcus epidermidis*, as well as Gram-negative bacteria, including *Escherichia coli*, *Pseudomonas aeruginosa*, and *Klebsiella* species.

In the present study, Gram-negative bacteria accounted for 58.0% of the isolates, while Gram-positive bacteria accounted for 42.0%. *E. coli* and *S. aureus* were the most frequently isolated organisms, each representing 23.0% of the total isolates. This finding demonstrates the mixed bacterial etiology of postoperative SSIs in the participating healthcare facilities.

The relatively high frequency of Gram-negative organisms may be associated with the types of surgical procedures performed, particularly gastrointestinal and emergency procedures, as well as possible environmental contamination within hospital wards and operating theaters. In addition, differences in patient characteristics, hospital practices, wound-care procedures, and antimicrobial exposure may contribute to variation in bacterial profiles between healthcare facilities.

At the same time, the substantial contribution of Gram-positive organisms, particularly *Staphylococcus* species, is consistent with the established importance of skin flora in postoperative wound infections. *S. aureus* can enter surgical wounds through the patient's endogenous flora or through contaminated hands, equipment, and healthcare environments. The distribution of bacterial species also differed significantly between hospitals, suggesting that local factors may influence the bacterial profile of postoperative SSIs.

The marked differences observed between hospitals are particularly important. *P. aeruginosa* accounted for the largest proportion of isolates in Al-Marj Hospital, whereas *E. coli* predominated in Tocra Hospital. *S. epidermidis* was the predominant isolate in Benghazi Hospital, while *S. aureus* was the most frequent organism in Taknis Hospital. These differences emphasize the importance of facility-specific microbiological surveillance.

5.2 Antimicrobial Susceptibility Patterns

The antimicrobial susceptibility findings demonstrated substantial variation among bacterial species and antimicrobial agents. Significant associations were observed between bacterial species and susceptibility to ceftazidime, ampicillin, and gentamicin, whereas no statistically significant associations were observed for vancomycin, amoxicillin/clavulanate, or ceftriaxone.

Ampicillin showed the strongest statistical association with bacterial species ($\chi^2 = 52.189$, df = 10, $P < 0.001$). The highest proportion of resistant isolates was observed among *E. coli*, followed by *K. pneumoniae* and *P. aeruginosa*. This finding is consistent with the widespread resistance to older beta-lactam antimicrobial agents that has been reported among Gram-negative bacteria in many healthcare settings.

Ceftazidime also demonstrated a statistically significant association with bacterial species ($\chi^2 = 18.604$, df = 10, $P = 0.046$). *E. coli* accounted for the largest proportion of resistant isolates. The observed resistance may reflect the circulation of resistant Gram-negative organisms, although the present study did not perform specific phenotypic or molecular tests to confirm ESBL or carbapenemase production. Therefore, such mechanisms should not be inferred solely from the susceptibility results.

Gentamicin demonstrated a statistically significant association with bacterial species ($\chi^2 = 29.170$, df = 10, $P = 0.001$). Although *E. coli* accounted for the largest proportion of resistant isolates, a substantial proportion of isolates were susceptible to gentamicin. This finding indicates that gentamicin may retain useful activity against some of the bacterial isolates included in the study. However, antimicrobial therapy should be guided by individual

susceptibility results, clinical considerations, and local antimicrobial stewardship policies rather than by aggregate susceptibility patterns alone.

No statistically significant association was observed between bacterial species and vancomycin susceptibility (P = 0.474), amoxicillin/clavulanate susceptibility (P = 0.273), or ceftriaxone susceptibility (P = 0.180). These findings indicate that differences observed among species for these antimicrobial agents did not reach the predefined threshold for statistical significance.

Overall, the susceptibility findings highlight the importance of routine antimicrobial susceptibility testing for postoperative wound infections. Empirical antimicrobial therapy should be reviewed and adjusted according to microbiological results whenever possible.

Furthermore, the spectrum of bacterial pathogens isolated from surgical site infections in this study aligns with broader epidemiological trends of nosocomial and community-acquired infections reported across various healthcare sectors in Libya. For instance, the predominance of Gram-negative bacilli and Staphylococcus aureus as primary etiological agents mirrors the findings of Ben Hsin et al. (2025), who investigated bacterial profiles in urinary tract infections across Libyan clinical laboratories. This consistent pattern of pathogenic distribution across different clinical conditions underscores a shared challenge of microbial persistence and antimicrobial resistance in local healthcare settings, emphasizing the urgent need for standardized infection control protocols, continuous surveillance, and judicious antimicrobial stewardship.

6. Recommendations

1. The efficiency of operating rooms and surgical instruments should be regularly evaluated to ensure patient safety and quality of healthcare. This should include periodic assessment of sterilization equipment and disinfectants and strict adherence to appropriate hand-hygiene practices by healthcare personnel.
2. Periodic microbiological surveillance of the hospital environment should be conducted when indicated, including isolation and identification of bacterial organisms and assessment of their antimicrobial susceptibility patterns.
3. Hospitals should develop and implement antimicrobial stewardship strategies that promote appropriate antimicrobial use, reduce unnecessary antibiotic exposure, and encourage selection of antimicrobial agents based on susceptibility-testing results whenever clinically appropriate.
4. A specialized infection prevention and control committee should be established or strengthened within healthcare facilities. The committee should conduct regular surveillance of healthcare-associated infections and develop effective strategies to reduce infection and environmental contamination.
5. Awareness and health-education programs should be provided for healthcare workers, patients, and visitors regarding the risks of healthcare-associated infections and the principles of infection prevention and transmission control.
6. Periodic research and surveillance studies should be encouraged to investigate hospital contamination, postoperative infections, bacterial pathogens, and antimicrobial resistance.
7. Sterile instruments and appropriately prepared disinfectants should be used during wound dressing and postoperative wound care in accordance with established infection-control procedures.
8. Healthcare personnel should receive regular training on current infection-prevention, diagnostic, wound-care, and antimicrobial-stewardship practices.
9. Patients should be appropriately followed after surgery to facilitate early detection and management of postoperative wound infections.

10. Rapid and reliable diagnostic techniques should be considered to shorten the time required for identification of bacterial pathogens and determination of antimicrobial susceptibility.
11. Further research should investigate the causes, mechanisms, and epidemiological determinants of antimicrobial resistance among bacterial pathogens associated with surgical site infections in Libya.
12. Healthcare facilities should implement appropriate occupational-health and infection-control procedures for healthcare workers who are identified as carriers of clinically important pathogens, in accordance with applicable guidelines and institutional policies, to minimize the risk of transmission to patients.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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