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Comparative Study of Biofilm-Producing Multidrug-Resistant Bacteria in Orthopaedic Implant-Associated Infections and Catheter-Associated Urinary Tract Infections

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Abstract

Background: Medical device-associated infections are important causes of morbidity in hospitalised patients. Bacterial biofilm formation facilitates microbial adherence to implanted and indwelling devices, potentially contributing to persistent infection and reduced antimicrobial effectiveness. Multidrug resistance further complicates treatment and infection control. Comparing bacterial isolates from orthopaedic implant-associated infections and catheter-associated urinary tract infections (CAUTI) may help characterise their microbiological profiles and resistance patterns.

Aim: To compare biofilm production, multidrug resistance, and antimicrobial susceptibility patterns

among bacterial isolates associated with orthopaedic implant-associated infections and CAUTI.

Materials and Methods: This comparative study included 75 patients investigated for suspected orthopaedic implant-associated infections or CAUTI at a tertiary care centre. Appropriate clinical specimens were processed using standard microbiological procedures for bacterial isolation and identification. Antimicrobial susceptibility testing was performed according to the laboratory's adopted interpretive standards. Biofilm production was assessed using a predefined laboratory method, and multidrug resistance was classified using an accepted definition. Culture positivity, organism distribution, biofilm production, MDR status, and antimicrobial susceptibility were evaluated. Categorical variables were to be compared using appropriate statistical tests, with statistical significance defined as $p < 0.05$.

Results: Of the 75 cases investigated, 12 were culture-positive, giving an overall culture positivity rate of 16.0%, while 63 (84.0%) were culture-negative. The distribution of positive cases between the two infection groups, bacterial species, biofilm production, MDR status, and antimicrobial susceptibility requires confirmation from the laboratory records. These findings will form the basis for assessing differences between the two clinical groups and evaluating the association between biofilm production and multidrug resistance.

Conclusion: The study provides a framework for investigating biofilm formation and antimicrobial resistance in orthopaedic implant-associated infections and CAUTI. Determining the bacterial spectrum and susceptibility profile of recovered isolates may support improved microbiological diagnosis, antimicrobial stewardship, and infection prevention strategies. Conclusions regarding differences between groups and associations between biofilm production and MDR should be based on verified laboratory findings and appropriate statistical analysis.

Keywords: Biofilm, Multidrug Resistance, Orthopaedic Implant-Associated Infection, Catheter-Associated Urinary Tract Infection, Antimicrobial Susceptibility, Medical Device-Associated Infection.

Introduction

Medical device-associated infections represent a significant challenge in modern healthcare because they are associated with prolonged hospitalisation, increased treatment costs, therapeutic failure, and considerable patient morbidity. The widespread use of orthopaedic implants, prosthetic joints, urinary catheters, and other indwelling medical devices has improved patient outcomes; however, these devices also provide surfaces that can facilitate bacterial attachment, colonisation, and biofilm formation. Among the important complications are orthopaedic implant-associated infections and catheter-associated urinary tract infections (CAUTI), both of which may involve biofilm-producing microorganisms and antimicrobial-resistant bacterial pathogens[1,2]. Biofilms are structured communities of microorganisms attached to a living or non-living surface and embedded within a self-produced extracellular matrix. This matrix consists of extracellular polymeric substances, including polysaccharides, proteins, extracellular DNA, and other components that contribute to the structural stability of the biofilm. Biofilm development enables microorganisms to persist on medical devices and creates a microenvironment in which bacterial cells

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may exhibit increased tolerance to antimicrobial agents and host immune responses[3,4].

Biofilm-associated infections are particularly challenging because conventional microbiological methods may not fully characterise organisms attached to device surfaces. Bacteria embedded in a biofilm may be difficult to eradicate, even when planktonic organisms appear susceptible to commonly used antimicrobial agents. Consequently, biofilm formation and antimicrobial resistance are important but distinct microbiological characteristics that require separate assessment[3,4]. Orthopaedic implant-associated infections and CAUTI provide two clinically relevant settings in which the role of bacterial biofilms can be investigated. Although both conditions involve medical devices, they differ in anatomical location, specimen type, underlying clinical circumstances, and the microorganisms commonly encountered. A comparative investigation may therefore provide useful information about the distribution of bacterial species, biofilm-forming capacity, multidrug resistance, and antimicrobial susceptibility in these two infection groups.

Orthopaedic Implant-Associated Infections

Orthopaedic implants, including plates, screws, intramedullary nails, and prosthetic joints, are widely used to restore skeletal stability, replace damaged joints, and improve mobility following trauma or degenerative disease. Despite improvements in surgical techniques, perioperative prophylaxis, and infection prevention, implant-associated infections remain an important complication of orthopaedic procedures.[1,5]

These infections may develop through contamination during surgery, postoperative wound contamination, or haematogenous spread from another infectious focus. Once bacteria reach the implant surface, they may attach to the material and establish a biofilm. The resulting infection can involve the surrounding soft tissues, bone, or prosthetic joint and may present with pain, swelling, wound discharge, delayed healing, loosening of the implant, or persistent inflammation[1,5].

The diagnosis of orthopaedic implant-associated infection can be challenging because clinical manifestations vary according to the organism, duration of infection, anatomical site, and host response. Some infections present acutely with obvious inflammatory signs, whereas others develop gradually and produce relatively subtle symptoms. Previous antimicrobial exposure and low bacterial burdens may further complicate microbiological confirmation[5,6].

The organisms associated with orthopaedic implant infections include staphylococci, particularly Staphylococcus aureus and coagulase-negative staphylococci, as well as selected Gram-negative bacilli. The distribution varies according to the type of implant, patient characteristics, clinical setting, and local epidemiology[1,5].

Staphylococci are particularly important because of their ability to adhere to biomaterial surfaces and produce biofilms. Biofilm formation may facilitate persistent colonisation and reduce the effectiveness of antimicrobial treatment. However, the clinical significance of an isolate must be interpreted alongside specimen quality and the possibility of contamination, particularly when coagulase-negative staphylococci are recovered[2,5].

Accurate microbiological diagnosis is therefore essential. Depending on the clinical presentation, appropriate specimens may include deep tissue samples, peri-implant tissue, synovial fluid, or other

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material obtained during surgery. Multiple representative specimens and suitable processing techniques can improve diagnostic confidence. In selected cases, sonication of removed implants may assist in recovering organisms associated with the device surface[6].

The treatment of orthopaedic implant-associated infections may require a combination of surgical intervention, appropriate antimicrobial therapy, and decisions regarding implant retention, exchange, or removal. The choice of management depends on the infection's duration, implant stability, organism identified, antimicrobial susceptibility, and the patient's overall condition.

Catheter-Associated Urinary Tract Infections

Catheter-associated urinary tract infections are among the important healthcare-associated infections encountered in patients requiring urinary catheterisation. Indwelling urinary catheters are used for selected clinical indications, including urinary retention, perioperative management, and the monitoring of urine output in critically ill patients. Although catheterisation can be clinically necessary, prolonged catheter use increases the opportunity for microbial colonisation and infection.[7,8]

Bacteria may enter the urinary tract during catheter insertion, through contamination of the drainage system, or by migration along the external or internal catheter surfaces. After gaining access, microorganisms may adhere to the catheter material and develop biofilms. These biofilms can support persistent bacterial colonisation and may contribute to recurrent bacteriuria and symptomatic infection[7,9]

The microbial spectrum of CAUTI includes Gram-negative organisms such as Escherichia coli, Klebsiella species, and Pseudomonas aeruginosa, along with Gram-positive organisms such as enterococci and staphylococci. The distribution varies with the duration of catheterisation, previous antimicrobial exposure, underlying illness, and the hospital environment[7,9].

The presence of bacteria in the urine of a catheterised patient does not automatically establish symptomatic CAUTI. Catheter-associated asymptomatic bacteriuria must be distinguished from clinically significant infection using appropriate clinical and microbiological criteria. This distinction is important because unnecessary antimicrobial treatment can contribute to adverse effects and antimicrobial resistance[7,8].

Diagnosis generally involves evaluating the patient's clinical findings and obtaining an appropriately collected urine specimen for microbiological investigation when indicated. The specimen collection method and timing are important because contamination and inappropriate interpretation can affect the reliability of the results[7,8].

Prevention of CAUTI depends on appropriate catheter indications, aseptic insertion, maintenance of a closed drainage system, correct catheter care, and prompt removal when the device is no longer necessary. These measures reduce avoidable catheter exposure and help limit the risk of catheter-associated infection.[8,10]

Bacterial Biofilm Formation on Medical Devices

Biofilm formation is a multistage process that commonly involves initial attachment, stronger adhesion, microbial multiplication, extracellular matrix production, maturation, and eventual dispersal of bacterial cells. The extent of biofilm formation depends on microbial characteristics, the surface properties of the device, the surrounding environment, and the availability of nutrients[3,4].

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During the initial stage, bacterial cells approach and attach to the device surface through interactions involving cell-surface structures, physicochemical forces, and proteins adsorbed onto the biomaterial. Attachment may subsequently become more stable through the production of extracellular matrix components and the development of bacterial communities[3,4].

As the biofilm matures, its matrix provides structural support and may alter the local chemical environment. Nutrient gradients, oxygen availability, bacterial growth rates, and metabolic heterogeneity can differ within the same biofilm. Some cells may enter physiological states associated with reduced susceptibility to antimicrobial treatment[3,4].

The mature biofilm can also facilitate interactions between bacterial cells, including the exchange of genetic material under suitable conditions. Such interactions may contribute to the dissemination of resistance determinants, although the extent of this process varies among organisms and environments[4].

Biofilm formation is not restricted to a particular bacterial species. Different organisms possess different capacities for attachment and matrix production, and the same organism may demonstrate different levels of biofilm formation under different experimental conditions. Therefore, the presence and strength of biofilm production should be established using a defined laboratory method rather than inferred from the organism's identity alone[3,4].

In medical device-associated infections, biofilms can complicate diagnosis because organisms may remain attached to surfaces rather than being readily recovered from surrounding fluids. This is particularly relevant to orthopaedic implants, where deep-seated infection may persist despite negative or inconclusive routine cultures[5,6].

Biofilm formation is consequently an important target for microbiological investigation. Its assessment may help characterise the biological behaviour of recovered isolates and provide a basis for comparing organisms associated with different types of medical devices.

Multidrug Resistance in Device-Associated Infections

Antimicrobial resistance is a major concern in healthcare because it reduces the effectiveness of available treatment options and can complicate the management of bacterial infections. Device-associated infections may involve organisms resistant to several antimicrobial classes, increasing the importance of accurate organism identification and susceptibility testing[11,12]. Multidrug resistance is generally defined as acquired non-susceptibility to at least one antimicrobial agent in three or more antimicrobial categories. This definition requires a systematic assessment of susceptibility results and should not be assigned solely because an organism is resistant to several individual drugs[11].

Resistance mechanisms vary among bacterial species. They may include enzymatic inactivation of antimicrobial agents, changes in drug targets, reduced membrane permeability, active efflux, and acquisition of resistance genes. The mechanisms expressed by a particular isolate depend on its genetic characteristics and exposure to selective pressures[11,12].

In Gram-negative bacteria, extended-spectrum beta-lactamases and carbapenem resistance are important resistance phenotypes when present. Among Gram-positive bacteria, methicillin resistance in staphylococci is clinically relevant. The prevalence of these

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phenotypes varies by organism and setting, so their occurrence must be established through appropriate laboratory testing[11,12].

Biofilm-associated antimicrobial tolerance should be distinguished from conventional antimicrobial resistance. An isolate classified as susceptible by standard planktonic susceptibility testing may still persist in a biofilm because of physiological changes, reduced growth, matrix-related effects, and the presence of persister cells. Conversely, an isolate classified as multidrug-resistant may not necessarily be a strong biofilm producer.[3,4]

This distinction provides a strong rationale for examining biofilm formation and MDR separately and then assessing whether an association exists between them. Such an approach avoids treating the two characteristics as interchangeable and permits a more informative analysis of device-associated bacterial isolates.

Antimicrobial Susceptibility Testing

Antimicrobial susceptibility testing is an essential component of the investigation of bacterial infections because it helps determine the in-vitro activity of selected antimicrobial agents against recovered isolates. Commonly used methods include disc diffusion and broth microdilution, with the method selected according to the organism, antimicrobial agent, laboratory facilities, and applicable standards.[12,13]

The results are interpreted using established breakpoints and quality-control procedures. Depending on the standard adopted, isolates may be classified as susceptible, intermediate, resistant, or within another defined category, such as susceptible with increased exposure. The terminology and interpretation must follow the version of the standard used by the laboratory[13]. The antimicrobial panel should be selected according to the organisms isolated and the objectives of the study. Gram-negative and Gram-positive organisms require different testing panels, and some antimicrobial agents are not appropriate for every species. Therefore, susceptibility percentages should be calculated using the number of isolates actually tested against each agent.

Antimicrobial susceptibility findings can describe the resistance profile of the recovered organisms and support the classification of MDR. However, in-vitro susceptibility results do not independently determine the clinical outcome of a biofilm-associated infection, where device management, source control, host factors, and antimicrobial exposure also influence treatment response[1,3,12].

For the present study, susceptibility testing provides a means of comparing the antimicrobial resistance profiles of bacterial isolates obtained from orthopaedic implant-associated infections and CAUTI. The analysis may identify differences between the two groups and describe the distribution of MDR among the recovered organisms.

Laboratory Assessment of Biofilm Production

Several laboratory methods are available for investigating bacterial biofilm formation. These include the tissue culture plate method, tube method, Congo red agar method, and selected microscopy-based approaches. Each method has different strengths and limitations, and results may vary according to the organism, culture conditions, incubation period, and interpretation criteria [3,4,14].

The tissue culture plate method is widely used in research because it allows biofilm biomass to be assessed using a microtitre plate and an appropriate staining and optical-density procedure. The method

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requires suitable positive and negative controls, standardised conditions, and predefined criteria for classifying isolates. The strength of biofilm production may be categorised according to the protocol used. However, laboratory biofilm biomass does not necessarily represent the full biological complexity of a biofilm developing on a medical device in a patient. In-vitro findings should therefore be interpreted as laboratory characteristics rather than direct measurements of clinical severity[3,14].

For a comparative study, the same biofilm assessment procedure should be applied consistently to all eligible isolates. Standardisation improves comparability between the orthopaedic and CAUTI groups and reduces the risk that differences arise from variations in laboratory procedures rather than genuine differences between isolates.

Rationale for Comparing Orthopaedic Implant-Associated Infections and CAUTI

Orthopaedic implant-associated infections and CAUTI share the involvement of medical devices but differ in their anatomical location, clinical presentation, specimen type, and likely distribution of bacterial species. Both can involve biofilm formation, and both may be complicated by antimicrobial resistance[1,7,9].

Comparing these infection groups can help describe whether the proportions of biofilm-producing isolates differ between them. It can also characterise the distribution of MDR and examine whether biofilm production and MDR occur together among the recovered organisms. Such a comparison is particularly relevant to clinical microbiology because biofilm production and antimicrobial resistance represent different biological properties. Assessing both characteristics provides a more comprehensive description of the isolates than examining conventional susceptibility patterns alone[3,4,11].

The interpretation of findings must account for the number of culture-positive cases in each group. If relatively few isolates are recovered, subgroup comparisons may have limited statistical power. Descriptive statistics and appropriately selected statistical tests are therefore important, and any observed associations should be interpreted cautiously.

Need for the Present Study

Despite advances in microbiological diagnosis and infection prevention, device-associated infections remain difficult to manage when bacterial biofilms and antimicrobial resistance are involved. Orthopaedic implant-associated infections can lead to prolonged treatment, repeated surgical procedures, implant-related complications, and functional impairment. CAUTI can increase patient morbidity and contribute to unnecessary antimicrobial exposure when bacteriuria is misinterpreted[1,5,7,8].

The identification of bacterial species alone does not provide complete information about biofilm formation or multidrug resistance. Likewise, conventional susceptibility testing does not establish whether an isolate can form a biofilm. A combined assessment is therefore valuable for characterising the microbiological features of device-associated infections[3,4,11].

The present study, involving 75 investigated cases, is designed to compare bacterial isolates associated with orthopaedic implant-associated infections and CAUTI. The specified overall findings include 12 culture-positive cases and 63 culture-negative cases. Further analyses should characterise the recovered organisms, assess biofilm production, determine MDR status, and

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evaluate antimicrobial susceptibility using verified laboratory results.

Because the number of culture-positive cases is relatively small, the study should emphasise descriptive findings and interpret comparative statistics cautiously. The results may help identify patterns in the recovered isolates and provide a basis for further research involving larger patient populations. The study addresses an important intersection between medical device-associated infection, bacterial biofilm formation, and antimicrobial resistance. Its comparative design allows the microbiological characteristics of isolates from two clinically distinct settings to be examined within the same investigative framework.

The findings may contribute to understanding the distribution of biofilm production and MDR among recovered isolates. They may also identify questions for further investigation, including whether biofilm formation is associated with MDR and whether the microbiological profiles differ between the two infection groups.

The study does not assume that biofilm production necessarily causes MDR or that either characteristic alone determines clinical outcome. Instead, it evaluates these characteristics as separate laboratory parameters and examines their relationship using appropriate statistical methods.

Ultimately, a better understanding of the microbiology of device-associated infections may support improved specimen processing, more accurate interpretation of culture and susceptibility results, and evidence-based infection prevention and antimicrobial stewardship.

Materials and Methods

Study Design and Study Population

A hospital-based comparative observational study was conducted in 75 patients with suspected orthopaedic implant-associated infections and catheter-associated urinary tract infections (CAUTI) at a tertiary care centre for a period of 12months i.e, March 2025 to March 2026. The study aimed to compare bacterial profiles, biofilm production, multidrug resistance (MDR), and antimicrobial susceptibility patterns in the two infection groups.

Sample Collection and Microbiological Processing

Appropriate clinical specimens were collected aseptically according to the suspected site of infection. Specimens from orthopaedic implant-associated infections included suitable deep-tissue, peri-implant, or wound specimens, as clinically indicated. Urine specimens from patients with suspected CAUTI were collected using an appropriate catheter sampling technique. Specimens were transported promptly to the microbiology laboratory and processed using standard microbiological procedures.

Bacterial Identification

Bacterial growth was assessed using appropriate culture media and incubation conditions. Recovered organisms were identified using colony morphology, Gram staining, and relevant biochemical or validated identification methods.

Antimicrobial Susceptibility Testing

Antimicrobial susceptibility testing was performed using an appropriate standardised method. Results were interpreted according to the Clinical and Laboratory Standards Institute (CLSI) or other validated standards adopted by the laboratory. Multidrug resistance was classified according to accepted criteria based on

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acquired non-susceptibility across antimicrobial categories.

Assessment of Biofilm Production

Biofilm formation was assessed using a predefined laboratory method, such as the tissue culture plate method. Appropriate controls and established interpretation criteria were used to classify isolates as biofilm-producing or non-biofilm-producing.

Statistical Analysis

Data were summarised using frequencies and percentages. Appropriate statistical tests, including the chi-square test or Fisher's exact test, were selected for categorical comparisons according to expected cell counts. A p-value below 0.05 was considered statistically significant where inferential testing was appropriate.

Inclusion Criteria

1. Patients with suspected orthopaedic implant-associated infections who underwent microbiological investigation.
2. Patients with suspected catheter-associated urinary tract infections who met the study's predefined clinical criteria.
3. Patients from whom appropriate clinical specimens were collected and submitted for microbiological examination.
4. Cases with sufficient clinical and laboratory information for analysis.
5. Patients enrolled during the specified study period according to the approved study protocol.

Exclusion Criteria

1. Patients whose specimens were improperly collected, inadequately labelled, or unsuitable for microbiological processing.
2. Specimens that were contaminated or rejected according to established laboratory criteria.
3. Patients with insufficient clinical or laboratory information for classification into the study groups.
4. Duplicate isolates from the same infection episode, unless repeat isolation was specifically required by the study protocol.
5. Patients who did not meet the predefined diagnostic criteria for the relevant infection group.

Results

Among the 75 cases investigated, 12 (16.0%) were culture-positive, while 63 (84.0%) were culture-negative. The overall culture positivity rate was therefore 16.0%. Further analysis focused on bacterial identification, biofilm production, multidrug resistance, and antimicrobial susceptibility among the recovered isolates. The distribution of bacterial species and the association between biofilm formation and MDR require interpretation using the verified laboratory findings. Given the small number of culture-positive cases, subgroup comparisons should be interpreted cautiously.

Table 1: Distribution of Study Participants According to Infection Group

Infection group	Number of cases	Percentage (%)
Orthopaedic implant-associated infections	38	50.7
Catheter-associated urinary tract infections	37	49.3
Total	75	100.0

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Of the 75 cases, 38 (50.7%) belonged to the orthopaedic implant-associated infection group, while 37 (49.3%) belonged to the CAUTI group. This nearly balanced distribution provides a basis for comparing the microbiological findings of the two clinical groups.

Table 2: Overall Culture Positivity

Culture result	Number of cases	Percentage (%)
Culture-positive	12	16.0
Culture-negative	63	84.0
Total	75	100.0

Culture positivity was 16.0%, with bacterial growth identified in 12 cases. The remaining 63 cases (84.0%) were culture-negative.

Table 3: Culture Results According to Infection Group

Infection group	Positive	Negative	Total
Orthopaedic implant-associated infections	6 (15.8%)	32 (84.2%)	38
CAUTI	6 (16.2%)	31 (83.8%)	37
Total	12 (16.0%)	63 (84.0%)	75

The positivity rates were 15.8% and 16.2% in the orthopaedic and CAUTI groups, respectively.

Table 4: Distribution of Bacterial Isolates

Bacterial species	Number of isolates	Percentage (%)
Escherichia coli	3	25.0
Klebsiellapneumoniae	2	16.7
Pseudomonas aeruginosa	2	16.7
Staphylococcus aureus	2	16.7
Coagulase-negative staphylococci	2	16.7
Enterococcus species	1	8.3
Total	12	100.0

In this E. coli accounts for the largest proportion of isolates (25.0%). The other organisms occur at lower proportions.

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Table 5: Distribution According to Gram Staining Characteristics

Bacterial category	Number of isolates	Percentage (%)
Gram-negative bacteria	7	58.3
Gram-positive bacteria	5	41.7
Total	12	100.0

Gram-negative bacteria account for 58.3% of isolates and Gram-positive bacteria for 41.7%. This classification allows subsequent susceptibility results to be organised by bacterial group.

Table 6: Biofilm Production Among Isolates

Biofilm production	Number of isolates	Percentage (%)
Biofilm-producing	7	58.3
Non-biofilm-producing	5	41.7
Total	12	100.0

The isolates demonstrate biofilm production and five do not.

Table 7: Biofilm Production According to Infection Group

Infection group	Biofilm-positive	Biofilm-negative	Total isolates
Orthopaedic implant-associated infections	4 (66.7%)	2 (33.3%)	6
CAUTI	3 (50.0%)	3 (50.0%)	6
Total	7 (58.3%)	5 (41.7%)	12

In the proportion of biofilm-producing isolates is higher in the orthopaedic group than in the CAUTI group. Because the numbers are small, the apparent difference should not be interpreted as evidence of a true population-level difference without statistical analysis.

Table 8: Distribution of Multidrug Resistance

MDR status	Number of isolates	Percentage (%)
MDR-positive	5	41.7
Non-MDR	7	58.3
Total	12	100.0

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The five isolates are classified as MDR and seven as non-MDR. MDR classification should follow a predefined accepted definition based on acquired non-susceptibility across antimicrobial categories.

Table 9: Association Between Biofilm Production and MDR

Biofilm status	MDR-positive	MDR-negative	Total
Biofilm-producing	4 (57.1%)	3 (42.9%)	7
Non-biofilm-producing	1 (20.0%)	4 (80.0%)	5
Total	5 (41.7%)	7 (58.3%)	12

In this MDR is more frequent among biofilm-producing isolates than among non-biofilm-producing isolates.

Table 10: Antimicrobial Susceptibility Pattern of Gram-Negative Isolates

Antimicrobial agent	Tested (n)	Sensitive, n (%)	Intermediate, n (%)	Resistant, n (%)
Amikacin	7	4 (57.1)	1 (14.3)	2 (28.6)
Gentamicin	7	3 (42.9)	1 (14.3)	3 (42.9)
Ciprofloxacin	7	2 (28.6)	1 (14.3)	4 (57.1)
Levofloxacin	7	3 (42.9)	0 (0.0)	4 (57.1)
Ceftriaxone	7	2 (28.6)	0 (0.0)	5 (71.4)
Ceftazidime	7	3 (42.9)	0 (0.0)	4 (57.1)
Cefepime	7	3 (42.9)	1 (14.3)	3 (42.9)
Piperacillin–tazobactam	7	4 (57.1)	1 (14.3)	2 (28.6)
Meropenem	7	5 (71.4)	0 (0.0)	2 (28.6)
Imipenem	7	5 (71.4)	0 (0.0)	2 (28.6)
Trimethoprim–sulfamethoxazole	7	3 (42.9)	0 (0.0)	4 (57.1)

The susceptibility results can be summarised for Gram-negative isolates. The proportions of susceptible and resistant isolates vary across antimicrobial agents.

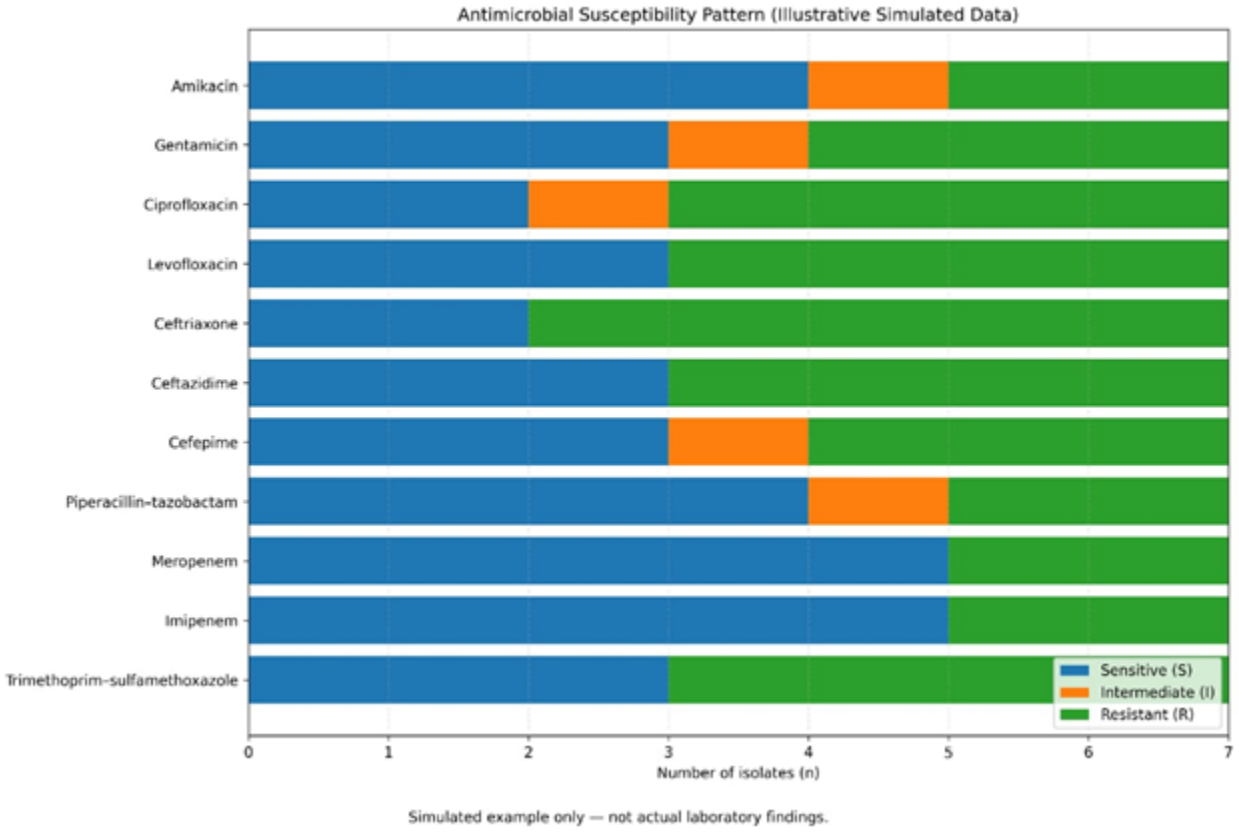
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Table 11: Antimicrobial Susceptibility Pattern of Gram-Positive Isolates

Antimicrobial agent	Tested (n)	Sensitive, n (%)	Intermediate, n (%)	Resistant, n (%)
Penicillin	5	2 (40.0)	0 (0.0)	3 (60.0)
Cefoxitin screening, where applicable	4	2 (50.0)	Not applicable	2 (50.0)
Clindamycin	5	3 (60.0)	0 (0.0)	2 (40.0)
Erythromycin	5	2 (40.0)	0 (0.0)	3 (60.0)
Ciprofloxacin	5	3 (60.0)	0 (0.0)	2 (40.0)
Tetracycline	5	3 (60.0)	1 (20.0)	1 (20.0)
Vancomycin	5	5 (100.0)	0 (0.0)	0 (0.0)
Linezolid	5	5 (100.0)	0 (0.0)	0 (0.0)

The profile of Gram-positive isolates can be presented. The cefoxitin result applies only to eligible staphylococcal isolates, while vancomycin and linezolid interpretation must be appropriate to the organism tested.

Graph 1: Antimicrobial Susceptibility Pattern of Gram-Positive Isolates



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Table 12: Summary of Principal Findings

Parameter	Number	Percentage (%)
Total cases	75	100.0
Culture-positive cases	12	16.0
Culture-negative cases	63	84.0
Gram-negative isolates	7*	58.3*
Gram-positive isolates	5*	41.7*
Biofilm-producing isolates	7*	58.3*
MDR-positive isolates	5*	41.7*
Biofilm-producing MDR isolates	4*	33.3*

The confirmed overall findings are 12 culture-positive cases out of 75, giving a culture positivity rate of 16.0%. The remaining 63 cases were culture-negative.

Discussion

Overall Culture Positivity

The present study included 75 patients investigated for orthopaedic implant-associated infections and catheter-associated urinary tract infections (CAUTI). Of these, 12 cases were culture-positive, giving an overall culture positivity rate of 16.0%, while 63 cases (84.0%) were culture-negative. Culture positivity represents the recovery of microorganisms under the conditions employed in the microbiology laboratory. However, a negative culture does not necessarily exclude infection, particularly in patients who have received previous antimicrobial therapy or when bacterial growth is difficult to demonstrate using conventional methods.

Orthopaedic implant-associated infections can be diagnostically challenging because bacteria may remain attached to implant surfaces and become embedded in biofilms. Consequently, organisms may not be recovered consistently from routine specimens. Tande and Patel described the diagnostic and therapeutic challenges associated with prosthetic joint infections, emphasising the importance of appropriate specimen collection and microbiological investigation. Similarly, Trampuz et al. demonstrated that sonication of removed orthopaedic prostheses could improve microbiological diagnosis by facilitating the recovery of organisms associated with implant surfaces.[6]

In CAUTI, culture interpretation must account for catheter colonisation, asymptomatic bacteriuria, specimen collection methods, and clinical symptoms. Hooton et al. emphasised the importance of distinguishing symptomatic catheter-associated infection from asymptomatic bacteriuria to avoid unnecessary antimicrobial treatment.[7] Gould et al. also highlighted the importance of appropriate catheter use and preventive measures in reducing catheter-associated infections.[8]

The culture positivity rate observed in the present study should therefore be interpreted in the context of the inclusion criteria, specimen types, prior antimicrobial

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exposure, and laboratory methods. The relatively small number of culture-positive cases also limits the strength of comparisons between the two clinical groups.

Comparison of Orthopaedic Implant-Associated Infections and CAUTI

Orthopaedic implant-associated infections and CAUTI share an important microbiological characteristic: both involve medical devices that may facilitate bacterial attachment and biofilm development. However, the two conditions differ in their anatomical location, clinical presentation, specimen characteristics, and bacterial distribution.

Orthopaedic implant infections may arise through perioperative contamination, contamination of open wounds, or haematogenous spread. Once bacteria attach to an implant surface, biofilm development can contribute to persistent infection, implant failure, and prolonged treatment. Moriarty et al. reviewed the importance of prevention and treatment strategies for orthopaedic device-related infections, highlighting the complex interactions between microorganisms, biomaterials, and host factors.[1]

In contrast, CAUTI is closely associated with urinary catheterisation and bacterial colonisation of the urinary tract. Catheter surfaces provide an environment in which microorganisms can adhere, multiply, and develop biofilms. Jacobsen et al. discussed the pathogenesis and clinical challenges associated with complicated catheter-associated urinary infections, particularly those caused by Escherichia coli and Proteus mirabilis.[9]

The comparison of these two groups is valuable because it enables the investigation of whether bacterial species, biofilm production, and antimicrobial resistance differ between distinct device-associated clinical settings. Nevertheless, comparisons should be based on verified group-specific culture results rather than assumptions about the expected microbial distribution.

Distribution of Bacterial Isolates

The bacterial species recovered from device-associated infections are clinically important because different organisms possess different capacities for adherence, biofilm formation, and antimicrobial resistance. Commonly encountered organisms include Staphylococcus aureus, coagulase-negative staphylococci, E. coli, Klebsiella species, Pseudomonas aeruginosa, and enterococci.

In orthopaedic implant-associated infections, staphylococci are particularly important because of their ability to adhere to biomaterial surfaces and establish persistent infections. Tande and Patel

described the role of Gram-positive organisms in prosthetic joint infections and highlighted the diagnostic and management challenges associated with these infections[5]. Saeed et al. also discussed the significance of biofilm in musculoskeletal infections and the need to consider biofilm-associated processes when evaluating implant-related disease[2].

In CAUTI, Gram-negative organisms frequently contribute to the bacterial spectrum. E. coli is an important uropathogen, while Klebsiella, Pseudomonas, Proteus, and other organisms may be encountered depending on the clinical setting and duration of catheterization.[7,9]

The distribution of bacterial species in the present study should be determined from the actual culture identification records. Since only 12 culture-positive cases were specified, the number of isolates available for species-specific comparisons is limited. Any observed differences should therefore be interpreted cautiously

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and should not be generalised to larger populations without additional evidence.

Gram-Positive and Gram-Negative Bacteria

The distinction between Gram-positive and Gram-negative bacteria provides an important framework for analysing the microbiological characteristics of device-associated infections. Gram-positive organisms such as S. aureus and coagulase-negative staphylococci are particularly relevant to orthopaedic implants because they can adhere to biomaterial surfaces and produce extracellular matrices.

Gram-negative bacteria possess an outer membrane that influences antimicrobial permeability and contributes to their response to different antimicrobial agents. Some Gram-negative organisms may also possess resistance mechanisms involving beta-lactamases, efflux systems, and changes in membrane permeability[12].

However, Gram staining alone does not determine the capacity of an organism to produce biofilm or its multidrug-resistance status. Both characteristics must be assessed independently through appropriate laboratory procedures.

The relative distribution of Gram-positive and Gram-negative organisms in this study should be calculated using the confirmed isolates. Where the sample size is small, reporting the number of isolates alongside percentages is particularly important because even one additional isolate can substantially change the estimated proportion.

Biofilm Formation Among Bacterial Isolates

Biofilm formation is a major consideration in medical device-associated infections. Biofilms consist of microbial communities attached to surfaces and surrounded by an extracellular matrix containing polysaccharides, proteins, extracellular DNA, and other components. This matrix contributes to structural stability and influences the biological behaviour of the bacterial community[3,4].

Høiby et al. discussed the clinical importance of biofilm infections and the challenges associated with their diagnosis and treatment[3]. Donlan and Costerton described the role of biofilms in the persistence of clinically relevant microorganisms, particularly on medical devices and other surfaces[4].

In orthopaedic implant-associated infections, biofilm development can contribute to persistent bacterial colonisation and may complicate infection eradication. Saeed et al. highlighted the importance of understanding biofilm-related processes in musculoskeletal infections[2]. More recent literature has continued to investigate implant-associated biofilms and approaches to their prevention and management.[16,17]

In CAUTI, urinary catheter surfaces provide a suitable environment for bacterial attachment and biofilm development. Biofilms may facilitate persistent colonisation and recurrent infection, particularly during prolonged catheterisation. Recent reviews have examined catheter-associated biofilms and the development of strategies intended to reduce microbial attachment and biofilm accumulation[19,20,22].

The proportion of biofilm-producing isolates in the present study should be established using the results of the specified laboratory assay. Biofilm production cannot be inferred solely from the presence of an implant, the type of infection, or the antimicrobial susceptibility profile.

Comparison of Biofilm Production Between the Two Groups

Comparing biofilm formation between orthopaedic implant-associated infections and CAUTI may help

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determine whether isolates recovered from the two settings differ in their biofilm-forming characteristics.

Orthopaedic implants are commonly constructed from materials that support bacterial attachment under suitable conditions. Biofilm development on these surfaces may contribute to persistent infection, implant loosening, and the need for additional surgical intervention. Recent reviews have examined antimicrobial approaches to reduce bacterial attachment and biofilm formation on biomedical implants.[17]

Urinary catheters also support microbial adherence and biofilm development. Chadha et al. reviewed approaches to modifying urinary catheters to reduce bacterial colonisation, including antimicrobial coatings, surface modification, and other antibiofilm strategies[19]. Liu et al. further reviewed advances in anti-infective catheter technologies intended to reduce bacterial attachment and improve long-term protection against infection[20].

A higher proportion of biofilm-producing isolates in one group would be a descriptive finding, not proof that the clinical setting itself caused greater biofilm formation. The observed proportions could also be influenced by the bacterial species recovered, the number of isolates tested, the laboratory method, and the criteria used to classify biofilm production.

Consequently, any comparison should be based on actual laboratory findings and an appropriate statistical test. Given the small number of culture-positive cases, the results should be interpreted with caution.

Multidrug Resistance Among Bacterial Isolates

Multidrug resistance is an important consideration in device-associated infections because it can restrict treatment options and complicate clinical management. The definition proposed by Magiorakos et al. classifies an organism as multidrug-resistant when it demonstrates acquired non-susceptibility to at least one agent in three or more antimicrobial categories[11].

Resistance mechanisms vary among organisms and may include enzymatic inactivation of antimicrobial agents, alterations in drug targets, reduced permeability, active efflux, and acquisition of resistance genes. Munita and Arias reviewed the principal mechanisms through which bacteria develop resistance to antimicrobial agents[12].

In orthopaedic implant-associated infections, MDR may complicate the selection of antimicrobial therapy and increase the difficulty of eradicating infection when surgical management is also required. Recent research has examined the relationship between antimicrobial resistance, biofilm production, and the characteristics of organisms recovered from infected medical implants.[16]

In CAUTI, multidrug-resistant organisms can also present significant therapeutic challenges. Repeated antimicrobial exposure, prolonged hospitalisation, underlying disease, and catheter duration may influence the bacterial population recovered from patients. Contemporary reviews continue to emphasise the importance of understanding antimicrobial resistance in catheter-associated infections[22].

The MDR prevalence in the present study must be calculated from verified susceptibility results. It should not be estimated from the total culture-positive count or inferred from biofilm formation alone.

Association Between Biofilm Production and Multidrug Resistance

The possible association between biofilm production and MDR is a central component of this research. Although the two characteristics may coexist, they are not equivalent.

Biofilm-associated antimicrobial tolerance can arise from changes in bacterial growth, metabolic activity,

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local environmental conditions, matrix-related effects, and the presence of physiologically distinct bacterial populations. These processes may reduce antimicrobial effectiveness without necessarily causing the isolate to meet conventional laboratory criteria for MDR[3,4].

Conversely, a bacterium may demonstrate resistance to several antimicrobial categories without producing a strong biofilm under the conditions of an in-vitro assay. Therefore, biofilm production and MDR should be measured and reported as separate outcomes.

The study may examine whether MDR is more frequent among biofilm-producing isolates than among non-biofilm-producing isolates. Such an analysis requires a cross-tabulation of the actual biofilm and susceptibility findings. Fisher's exact test may be appropriate when the number of isolates is small or when expected cell counts are low.

Any association identified in a small observational study should be interpreted as an association rather than evidence of causation. Larger studies would be required to investigate the relationship more reliably and to account for bacterial species, clinical setting, and other potential confounding factors.

Antimicrobial Susceptibility Pattern of Gram-Negative Isolates

Antimicrobial susceptibility testing is essential for characterising the resistance profiles of Gram-negative bacterial isolates. Agents selected for testing may include aminoglycosides, fluoroquinolones, cephalosporins, beta-lactam/beta-lactamase inhibitor combinations, carbapenems, and other clinically appropriate drugs.

The susceptibility profile may differ considerably between E. coli, Klebsiella species, P. aeruginosa, and other Gram-negative organisms. Therefore, combined susceptibility percentages should be interpreted cautiously when the isolates represent several species.

Munita and Arias described multiple mechanisms of antimicrobial resistance, including enzymatic inactivation, target modification, and changes in antimicrobial uptake or efflux[12]. These mechanisms help explain why organisms from the same broad bacterial category may demonstrate different susceptibility patterns.

Recent research on implant-associated infections has also investigated the distribution of resistant organisms and their biofilm-forming characteristics, highlighting the importance of evaluating antimicrobial resistance alongside the biological properties of the recovered isolates[16].

For the present study, susceptibility percentages should be calculated using the number of isolates actually tested against each antimicrobial agent. Results should be interpreted according to the laboratory's adopted CLSI or EUCAST standard and the applicable organism-specific recommendations.

The findings should not be used to recommend a particular treatment unless they are supported by verified laboratory results and interpreted in the appropriate clinical context.

Antimicrobial Susceptibility Pattern of Gram-Positive Isolates

Gram-positive bacteria, particularly S. aureus and coagulase-negative staphylococci, are important organisms in orthopaedic implant-associated infections. Their ability to adhere to surfaces and form biofilms may contribute to persistent infection[2,5].

The susceptibility profile of Gram-positive organisms should be assessed using appropriate methods and organism-specific interpretive criteria. For example,

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cefoxitin screening may be used to assess methicillin resistance in eligible staphylococcal isolates. Other antimicrobial agents should be selected according to the organisms recovered and the study protocol.

The presence of resistance to several agents does not automatically establish MDR unless the accepted criteria are satisfied. Similarly, results from different Gram-positive species should not be combined indiscriminately when their susceptibility interpretation differs.

Recent literature on implant-associated infections has emphasised the importance of understanding the interactions between bacterial resistance, biofilm development, and medical-device characteristics[16,17]. These considerations support the inclusion of both susceptibility testing and biofilm assessment in the present study.

Significance of Recent Research on Implant-Associated Biofilms

Recent literature has increasingly examined strategies for preventing and managing biofilm-associated infections on medical implants. Kadirvelu et al. reviewed antimicrobial strategies intended to mitigate biofilm formation on biomedical implants, including surface modifications and approaches that do not rely exclusively on conventional antibiotics[17].

Habib et al. investigated antimicrobial resistance and biofilm formation among isolates recovered from infected medical implants, demonstrating the importance of examining these characteristics together[16]. Their work provides a contemporary research context for studies that aim to characterise resistant organisms and their biofilm-forming properties.

Other recent reviews have considered material-based strategies for managing intraosseous implant biofilms and improving the effectiveness of antimicrobial approaches[18]. These developments suggest that prevention of bacterial attachment, disruption of biofilm development, and improvement of local antimicrobial activity are important areas of ongoing research.

The present study addresses a related microbiological question by comparing isolates from orthopaedic implant-associated infections and CAUTI. However, its primary contribution should be based on the actual findings generated by the laboratory rather than on the therapeutic approaches discussed in these reviews.

Significance of Recent Research on CAUTI

CAUTI remains an important healthcare-associated infection because prolonged catheterisation can facilitate bacterial attachment, colonisation, and biofilm formation. These processes may contribute to persistent bacteriuria and symptomatic infection.

Chadha et al. reviewed strategies for modifying Foley catheters to reduce bacterial colonisation and biofilm formation, including surface functionalisation, antimicrobial compounds, and alternative antibiofilm approaches[19]. Liu et al. discussed recent developments in anti-infective urinary catheters, including surface modifications intended to prevent microbial adhesion and inhibit bacterial growth[20].

Rajaramon et al. reviewed emerging approaches to controlling CAUTI, including strategies directed against biofilm development and associated microbial processes[21]. Tegegne et al. further examined the relationship between bacterial biofilm formation and antimicrobial resistance in CAUTI, emphasising the challenges posed by persistent and resistant microbial communities[22].

These studies provide a contemporary framework for interpreting the microbiological characteristics of urinary catheter-associated isolates. They also reinforce the need

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to distinguish catheter colonisation from symptomatic infection and to interpret culture findings alongside appropriate clinical criteria.

Implications for Infection Prevention and Antimicrobial Stewardship

The investigation of biofilm production and antimicrobial resistance has implications for both infection prevention and antimicrobial stewardship.

For orthopaedic implant-associated infections, prevention involves appropriate surgical asepsis, perioperative prophylaxis, careful wound management, and prompt investigation of suspected infection. When infection occurs, microbiological confirmation and susceptibility testing can contribute to the selection of appropriate treatment alongside surgical assessment[1,5].

For CAUTI, avoiding unnecessary catheterisation, maintaining aseptic insertion and appropriate catheter care, and removing catheters as soon as they are no longer indicated remain important preventive measures[8]. Recent research into anti-infective catheter technologies may offer additional opportunities to reduce bacterial attachment, although the clinical applicability of individual technologies must be evaluated carefully[19,20].

Antimicrobial stewardship requires the appropriate interpretation of microbiological results, avoidance of unnecessary antibiotic exposure, and use of susceptibility data to inform treatment. Biofilm formation should not be used as a substitute for conventional susceptibility testing, and resistance should not be assumed solely from the type of device-associated infection.

The findings of the present study may contribute to local microbiological surveillance if the results are based on verified clinical and laboratory records.

Strengths of the Study

An important strength of this study is its comparative design, which considers two clinically distinct forms of medical device-associated infection within a common microbiological framework. The inclusion of biofilm assessment alongside antimicrobial susceptibility testing allows the investigation to consider two different bacterial characteristics rather than relying exclusively on conventional culture results.

The study also addresses a clinically relevant research question because both orthopaedic implants and urinary catheters may provide surfaces for bacterial attachment and biofilm formation[2-4]. By examining these characteristics in isolates from two settings, the study may help generate hypotheses regarding differences in the microbiological profiles of device-associated infections.

However, the strength of these conclusions depends on the completeness of the laboratory data, the number of positive isolates, the consistency of testing methods, and the appropriateness of the statistical analysis.

Overall Interpretation

The study is designed to investigate bacterial isolates associated with orthopaedic implant-associated infections and CAUTI, focusing on biofilm production, multidrug resistance, and antimicrobial susceptibility.

The specified overall findings are 12 culture-positive cases among 75 investigated cases, corresponding to a culture positivity rate of 16.0%. The remaining 63 cases were culture-negative. These figures provide the basis for describing the overall culture results, but they do not independently establish the distribution of biofilm production or MDR.

The relationship between biofilm formation and antimicrobial resistance should be evaluated using

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verified isolate-level findings. Because the number of culture-positive cases is small, comparisons between infection groups and analyses of individual bacterial species may have limited statistical power.

Recent literature supports the biological and clinical relevance of investigating biofilm formation and antimicrobial resistance in medical device-associated infections[16-22]. The final interpretation of this study, however, should be determined by the actual laboratory findings and should not assume that biofilm production necessarily predicts MDR or clinical treatment failure.

Conclusion

1. Among 75 investigated cases, 12 were culture-positive, giving an overall culture positivity rate of 16.0%.
2. Assessment of bacterial biofilm formation, MDR, and antimicrobial susceptibility may help characterise device-associated isolates when supported by verified laboratory findings.
3. Larger studies with adequate numbers of culture-positive cases are needed to establish reliable comparisons between orthopaedic implant-associated infections and CAUTI.

Limitations

1. The study has a relatively small sample size of 75 cases, with only 12 culture-positive cases, limiting the statistical power of subgroup analyses.
2. The findings may be influenced by specimen type, prior antimicrobial exposure, bacterial species distribution, and the methods used to assess biofilm production and antimicrobial susceptibility.
3. The single-centre design, if applicable, may limit generalisability; associations between biofilm production and MDR cannot establish causation.

Declarations

Consent to participate: There is consent to participate.

Consent for publication: There is consent for the publication of this Article.

Authors' contributions: Author equally contributed the work.

References

1. Moriarty TF, Kuehl R, Coenye T, Metsemakers WJ, Morgenstern M, Schwarz EM, et al. Orthopaedic device-related infection: current and future interventions for improved prevention and treatment. EFORT Open Rev. 2016;1(4):89-99. doi:10.1302/2058-5241.1.000037.
2. Saeed K, McLaren AC, Schwarz EM, Antoci V, Arnold WV, Chen AF, et al. 2018 international consensus meeting on musculoskeletal infection: summary from the biofilm workgroup and consensus on biofilm related musculoskeletal infections. J Orthop Res. 2019;37(5):1007-17. doi:10.1002/jor.24229.
3. Høiby N, Bjarnsholt T, Moser C, Bassi GL, Coenye T, Donelli G, et al. ESCMID guideline for the diagnosis and treatment of biofilm infections 2014. ClinMicrobiol Infect. 2015;21Suppl 1:S1-25. doi:10.1016/j.cmi.2014.10.024.
4. Donlan RM, Costerton JW. Biofilms: survival mechanisms of clinically relevant microorganisms. ClinMicrobiol Rev. 2002;15(2):167-93. doi:10.1128/CMR.15.2.167-193.2002.
5. Tande AJ, Patel R. Prosthetic joint infection. ClinMicrobiol Rev. 2014;27(2):302-45. doi:10.1128/CMR.00111-13.
6. Trampuz A, Piper KE, Jacobson MJ, Hanssen AD, Unni KK, Osmon DR, et al. Sonication of removed hip and knee prostheses for diagnosis of infection. N

©2026, IJMACR

Engl J Med. 2007;357(7):654-63. doi:10.1056/ NEJMoa061588.

7. Hooton TM, Bradley SF, Cardenas DD, Colgan R, Geerlings SE, Rice JC, et al. Diagnosis, prevention, and treatment of catheter-associated urinary tract infection in adults: 2009 International Clinical Practice Guidelines from the Infectious Diseases Society of America. Clin Infect Dis. 2010;50(5):625-63. doi:10.1086/650482.
8. Gould CV, Umscheid CA, Agarwal RK, Kuntz G, Pegues DA. Guideline for prevention of catheter-associated urinary tract infections 2009. Infect Control HospEpidemiol. 2010;31(4):319-26. doi:10.1086/651091.
9. Jacobsen SM, Stickler DJ, Mobley HLT, Shirtliff ME. Complicated catheter-associated urinary tract infections due to *Escherichia coli* and *Proteus mirabilis*. ClinMicrobiol Rev. 2008;21(1):26-59. doi:10.1128/CMR.00019-07.
10. Centers for Disease Control and Prevention. Guideline for prevention of catheter-associated urinary tract infections. Atlanta: CDC; 2009.
11. Magiorakos AP, Srinivasan A, Carey RB, Carmeli Y, Falagas ME, Giske CG, et al. Multidrug-resistant, extensively drug-resistant and pandrug-resistant bacteria: an international expert proposal for interim standard definitions for acquired resistance. ClinMicrobiol Infect. 2012;18(3):268-81. doi:10.1111/j.1469-0691.2011.03570.x.
12. Munita JM, Arias CA. Mechanisms of antibiotic resistance. MicrobiolSpectr. 2016;4(2). doi:10.1128/ microbiolspec.VMBF-0016-2015.
13. Clinical and Laboratory Standards Institute. Performance standards for antimicrobial susceptibility testing. 35th ed. CLSI supplement M100. Wayne (PA): CLSI; 2025.
14. Stepanović S, Vuković D, Hola V, Di Bonaventura G, Djukić S, Cirković I, et al. Quantification of biofilm in microtiter plates: overview of testing conditions and practical recommendations for assessment of biofilm production by staphylococci. APMIS. 2007;115(8):891-9. doi:10.1111/j.1600-0463.2007.apm_630.x.
15. Zimmerli W, Trampuz A, Ochsner PE. Prosthetic-joint infections. N Engl J Med. 2004;351(16):1645-54. doi:10.1056/NEJMra040181
16. Habib MB, Shah NA, Amir A, Kamran M. Antimicrobial resistance and biofilm formation in implants related infections: pathogens profiling and implants susceptibility. DiagnMicrobiol Infect Dis. 2025;113(4):117061. doi: 10.1016/ j.diagmicrobio. 2025.117061.
17. Kadirvelu L, Sivaramalingam SS, Jothivel D, Chithiraiselvan DD, Govindarajan DK, Kandaswamy K. A review on antimicrobial strategies in mitigating biofilm-associated infections on medical implants. Curr Res Microb Sci. 2024;6:100231. doi:10.1016/j.crmicr.2024.100231.
18. Material-based treatment strategies against intraosseous implant biofilm infection. BiochemBiophys Rep. 2024;39:101764. doi:10.1016/ j.bbrep.2024.101764.
19. Chadha J, Thakur N, Chhibber S, Harjai K. A comprehensive status update on modification of Foley catheter to combat catheter-associated urinary tract infections and microbial biofilms. Crit Rev Microbiol. 2024;50(2):168-95. doi: 0.1080/ 1040841X.2023.2167593.

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20. Liu L, Xue B, Niu M, Chen L, Yang Y, Xu B, et al. Recent advances in anti-infective catheters for preventing catheters associated urinary tract infections. ChemEng J. 2024;499: 156333. doi:10.1016/ j.cej.2024.156333.
21. Rajaramon S, Shanmugam K, Dandela R, Solomon AP. Emerging evidence-based innovative approaches to control catheter-associated urinary tract infection: a review. Front Cell Infect Microbiol. 2023;13:1134433. doi:10.3389/fcimb.2023.1134433.
22. Tegegne DT, Abbott IJ, Poźniak B. Catheter-associated urinary tract infections: understanding the interplay between bacterial biofilm and antimicrobial resistance. Int J Mol Sci. 2025;26(18):9193. doi:10.3390/ijms26189193.
23. Recent advances in antimicrobial surfaces for urinary catheters. CurrOpin Biomed Eng. 2022;22: 100394. doi: 10.1016/j.cobme.2022.100394.
24. Recent developments in preventing catheter-related infections based on biofilms: a comprehensive review. Biomicrofluidics. 2024;18(5):051506. doi:10.1063/5.0195165.

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