

Predominance of Gram-negative Bacteria in Orthopaedic Implant Infections: A Hospital-Based Cross-Sectional Study in Western Kenya

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ABSTRACT

Background: Orthopaedic implant infections remain a major clinical challenge, often complicated by biofilm formation that impairs antibiotic penetration and delays healing. Globally, the infection rate is about 13% in primary implantation and 40% in revision surgeries. In Kenya, the infection rate is about 13.8%. Gram-negative bacteria are increasingly recognised as key pathogens, yet data from Kenya remain limited.

Materials and Methods: This cross-sectional study was conducted at Kakamega County Teaching and Referral Hospital (KCTRH) between January 2023 and March 2024. A total of 191 patients with clinically suspected orthopaedic implant infections were enrolled in the study. Purposive sampling was used to recruit participants. Specimens (wound swabs) were inoculated on blood, MacConkey, and chocolate agar and incubated aerobically at 37°C for 24–48 hours. Bacterial identification and antimicrobial susceptibility testing were performed using standard biochemical tests and the VITEK 2 Compact system (bioMérieux, France). Sample size was estimated using Fisher's formula, assuming an expected prevalence of 20%, a 5% margin of error, and a 95% confidence interval.

Results: Overall, the most prevalent Gram-negative species were *Klebsiella pneumoniae* (29.3%), *Escherichia coli* (17.9%), *Pseudomonas aeruginosa* (16.9%), and *Citrobacter freundii* (10.3%). Other Gram-negatives, including *Proteus mirabilis*, *Providencia stuartii*, *Raoultella ornithinolytica*, and *Klebsiella oxytoca*, were detected in <2.2% of cases. *Staphylococcus aureus* (14.9%) and *Staphylococcus epidermidis* (2.1%) were the only Gram-positive species. Infections occurred mainly in the early (47.67%) and delayed (50.78%) phases, with *Klebsiella pneumoniae* predominating in both phases. High resistance was observed to ampicillin, penicillin, vancomycin, and several cephalosporins, while amikacin and piperacillin-tazobactam showed the highest sensitivity.

Conclusion: Gram-negative bacteria, predominantly *Klebsiella pneumoniae*, were a major causative agent of orthopaedic implant infections, suggesting a shift from *Staphylococcus aureus*. The resistance patterns emphasise the need for routine, individualised AST to guide effective therapy.

BACKGROUND

Orthopaedic implant infections remain a serious postoperative complication in modern surgical practice, often resulting in prolonged hospitalisation, increased costs, and poor functional outcomes.¹ Globally, the infection rate in primary implant placement is about 13% and considerably higher after surgical revision (up to 40%).² In Kenya, the infection rate is about 13.8%, probably underestimated since there are no protocols in place for recognising implant infection. These infections occur when microorganisms adhere to the surface of implants and form biofilms, which make them resistant to host immune responses and antibiotic therapy.³ The incidence of implant-associated infections ranges from 1% to 5%, depending on the type of surgery and patient-related factors.⁴ In developing countries, this

burden may be higher due to limited infection control measures, delayed diagnosis, and inappropriate antibiotic use.⁵

The pathogenesis of orthopaedic implant infections involves a complex interaction between bacterial virulence, biofilm formation, and host immune response.⁶ Once established, biofilms act as protective barriers, allowing bacteria to persist even under high antibiotic concentrations.³ Consequently, infections often become chronic and recurrent, sometimes necessitating implant removal to achieve complete resolution.⁷

Traditionally, Gram-positive bacteria such as *Staphylococcus aureus* and coagulase-negative staphylococci have been the main aetiologic agents.⁸ However, recent studies indicate a growing shift toward Gram-negative organisms, including *Escherichia*

Escherichia coli, *Klebsiella* spp., and *Pseudomonas aeruginosa*.^{8,9} This emerging pattern raises concern because Gram-negative bacteria exhibit multiple resistance mechanisms, including β -lactamase production, efflux pumps, and porin mutations.⁹

In Kenya, information on the microbial aetiology of orthopaedic implant infections remains limited, and local antimicrobial resistance profiles are poorly characterised.¹⁰ which include penicillins, cephalosporins, monobactams and carbapenems, exert their antibacterial activity by inhibiting the bacterial cell wall synthesis and have a global positive impact in treating serious bacterial infections. Today, β -lactam antibiotics are the most frequently prescribed antimicrobial across the globe. However, due to the widespread use and misapplication of β -lactam antibiotics in fields such as human medicine and animal agriculture, resistance to this superlative drug class has emerged in the majority of clinically important bacterial pathogens. This heightened antibiotic resistance prompted researchers to explore novel strategies to restore the activity of β -lactam antibiotics, which led to the discovery of β -lactamase inhibitors (BLIs). Most existing studies have focused on general wound infections or post-traumatic surgical infections, leaving a gap in knowledge about implant-related infections.¹¹ Most health facilities rely on empirical treatment approaches without culture-based evidence, which suggests the use of broad-based antibiotics like amikacin, cefazolin, rifampicin, clindamycin, methicillin, amoxicillin and clavulanic acid.¹²

Orthopaedic implant-associated infections are typically classified based on the time of onset into early (<2 weeks post-surgery), delayed (2–10 weeks), and late infections (>10 weeks).¹³ However, there is ambiguity regarding whether this timing refers to the time interval from the initial injury, the implant fixation, or the onset of clinical symptoms and which, if any, is clinically relevant. This classification is widely adopted, though, as it is likely to influence treatment decisions.¹⁴ Recent analysis of the bacteriological aetiology in fracture-related infections and prosthetic joint infections suggests that a similar bacterial profile may be present across all three phases.¹⁵ Therefore, this study aimed to determine the bacterial species involved, their profiles across different phases of infection, and the antimicrobial resistance patterns among patients with orthopaedic implant infections at Kakamega County Teaching and Referral Hospital (KCTRH) in Western Kenya.

METHODS

Study Design and Study Area

A cross-sectional study was conducted at Kakamega County Teaching and Referral Hospital between August 2024 and March 2025. This Level 5 hospital serves as the primary referral centre for Kakamega County and neighbouring regions. Baseline hospital data shows that approximately 600 orthopaedic surgeries are conducted within three months. Patients are managed both outpatient and inpatient in the orthopaedic department. Motorcycle accidents are a major cause of trauma-related injuries in this area, contributing significantly to the burden of orthopaedic cases.¹⁶

Study Population and Sample Size

The study population included patients with implant-related surgical site infections (SSI) following orthopaedic procedures at KCTRH. The sample size was calculated using Fisher's formula (1999) for estimating proportions in cross-sectional studies¹⁷: $n = (Z^2 \times p \times (1 - p)) / d^2$, where $Z = 1.96$ for a 95% confidence interval, $P = .20$ (estimated prevalence from local data), and $d = .05$ (margin of error). For populations over 10,000, the calculated sample size was 245. Since the study population was 600, the sample was adjusted using $nf = 245 / (1 + 245/600)$, giving 174 patients. To account for potential non-response, 10% was added¹⁸, resulting in a final sample size of 191 patients.

Sampling

A purposive sampling technique was used to recruit all consecutive patients meeting the inclusion criteria during the study period. Eligible participants included those with clinical signs of infection at the implant site confirmed by a consultant orthopaedic surgeon. Patients of all age groups and both sexes diagnosed with implant infections and those with both internally and externally fixed implants. Patients with skin conditions at the surgical incision site as well as those whose implantation was done through an already infected wound were excluded, as the pre-existing infection could introduce pathogens. Data was collected at the orthopaedic outpatient clinic and inpatient wards, as well as intraoperatively during surgical interventions from consecutive patients with implant-related surgical site infections.

Data Collection Procedures

Data was collected using a structured questionnaire to obtain baseline demographic information. Pus swabs were collected after cleaning the infection site with normal saline to remove necrotic tissue, dry exudates and dressing residues. The samples were immediately transferred to the hospital's microbiology laboratory using Amies transport medium in a cooler box. Direct smears were prepared for Gram staining.

Bacteria Identification and Antibiotic Susceptibility Testing

Standard culturing was performed on blood agar and chocolate agar (aerobically in a 5–10% CO₂ atmosphere at 37°C for 24 hours) and MacConkey agar with crystal violet (incubated aerobically at 37°C for 24 hours) (media from Oxoid (Thermo Fisher Scientific), Basingstoke, the United Kingdom). Purity plating was carried out on the same media to obtain pure isolates. Bacteria identification and antimicrobial susceptibility testing were carried out using the VITEK 2 system (bioMérieux, Marcy-l'Étoile, France). Stock cultures of *Staphylococcus aureus* ATCC 25923 and *Escherichia coli* ATCC 25922 were used as control strains.

Data Management and Analysis

The data was organised and managed using Epi Info version 3.4.3 (Centers for Disease Control and Prevention, Atlanta, GA, USA). Statistical analysis was performed using SPSS version 25 (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to summarise data on bacterial isolates and antimicrobial susceptibility patterns. Results were presented using frequencies and percentages.

Ethical Approval and Considerations.

Ethical approval for this study was obtained from Kakamega County Teaching and Referral Hospital Ethics and Research Committee (KCTRH ERC/260/08/2024) and the Maseno University Ethics Review Committee (MUERC/01385/24). A research permit was granted by the National Commission for Science, Technology and Innovation (NACOSTI/P/24/38713). Informed consent was obtained from all adult participants, and assent was obtained from minors. The consent and assent forms were provided in both English and Kiswahili to ensure participant understanding. Access to participant data was restricted to the principal investigator, and coded identifiers were used to ensure confidentiality and protect participant privacy.

RESULTS

Demographic Characteristics of Participants

The study involved 191 participants, as shown in Table 1. The distribution of age goes up to 90 years, clustered based on generational cohorts, and the majority were male (66.0%, n = 126), while females accounted for 34.0% (n = 65). Most participants (65.4%) had no known comorbid conditions. Among those with underlying illnesses, hypertension (16.7%) and diabetes mellitus (16.2%) were the most frequent. A few participants reported other health conditions, including alcohol use, combined diabetes and hypertension, and hypertension with a history of prostatectomy, each occurring in about 0.5% of cases. Fractures were the leading type of injury among participants. Femur fractures (37.7%) were most common, followed by tibia fractures (34.0%), ulna fractures (15.7%), and pelvic fractures (10.5%). Fibular (1.6%) and humerus (0.5%) fractures were relatively uncommon. Regarding implant use, external fixation devices (37.2%) were the most frequently applied, followed by pins and wires (35.1%) and plates (25.7%). Implant removal was rarely performed, observed in only 2.1% of cases. Table 1 provides participants demographic characteristics including age, sex, comorbidities, type of injury, and orthopaedic implant used at (KCTRH).

Bacterial Species Responsible for Orthopaedic Implant Infections

As shown in Table 2, a wide range of bacterial species were isolated from patients with implant-related infections. Gram-negative bacteria predominated, with *Klebsiella pneumoniae* being the most frequently isolated organism (29.3%). Other common Gram-negative species included *Escherichia coli* (17.9%) and *Pseudomonas aeruginosa* (16.9%). *Citrobacter freundii* (10.3%) and *Proteus mirabilis* (4.1%) were also notable contributors to infection. Less frequently encountered Gram-negative bacteria included *Providencia stuartii*, *Raoultella ornithinolytica*, and *Klebsiella oxytoca*, each representing less than 2.0% of the total isolates.

Among Gram-positive organisms, only *Staphylococcus aureus* (14.9%) and *Staphylococcus epidermidis* (2.1%) were identified. Polymicrobial infections were observed in four participants, indicating the presence of more than one bacterial species in the same sample. Specifically, two cases involved co-infection with *Klebsiella pneumoniae* and *S. aureus*, while the remaining two cases showed a combination of *Escherichia coli* and *Pseudomonas*

aeruginosa. Additionally, 1.0% of the samples demonstrated no detectable bacterial growth. Details on the frequency and percentage distribution of bacterial isolates are provided in Table 2.

TABLE 1: Demographic and Clinical Characteristics of Participants

| Variables | Frequency (n=191) | Percentage (%) |
|--------------------------------|-------------------|----------------|
| Age (years) | | |
| ≤ 18 | 10 | 5.2% |
| 19-29 | 40 | 20.9% |
| 30-40 | 60 | 31.4% |
| 41-51 | 50 | 26.2% |
| 52-62 | 25 | 13.1% |
| ≥ 73 | 6 | 3.1% |
| Sex | | |
| Male | 126 | 66.0% |
| Female | 65 | 34.0% |
| Comorbidities | | |
| Diabetes and Hypertension | 1 | 0.5% |
| Hypertension and Prostatectomy | 1 | 0.5% |
| Alcoholism | 1 | 0.5% |
| Diabetes | 31 | 16.2% |
| Hypertension | 32 | 16.7% |
| None | 125 | 65.4% |
| Injury Type | | |
| Humerus fracture | 1 | 0.5% |
| Fibular fracture | 3 | 1.6% |
| Pelvic fracture | 20 | 10.5% |
| Ulna fracture | 30 | 15.7% |
| Tibia fracture | 65 | 34.0% |
| Femur fracture | 72 | 37.8% |
| Implants | | |
| Implant removal | 4 | 2.1% |
| Plate | 49 | 25.7% |
| Pins and wires | 67 | 35.1% |
| Exofix | 71 | 37.2% |

TABLE 2: Bacterial Profiles in Orthopaedic Implant-Associated Infections

| BACTERIA ISOLATED | Frequency | Percentage (%) |
|-----------------------------------|-----------|----------------|
| <i>Klebsiella pneumoniae</i> | 57 | 29.3 |
| <i>E.Coli</i> | 35 | 17.9 |
| <i>P. aeruginosa</i> | 33 | 16.9 |
| <i>Staphylococcus aureus</i> | 29 | 14.9 |
| <i>Citrobacter freundii</i> | 20 | 10.3 |
| <i>Proteus mirabilis</i> | 8 | 4.1 |
| <i>S. epidermidis</i> | 4 | 2.1 |
| <i>Providencia stuartii</i> | 3 | 1.5 |
| <i>Raoultella ornithinolytica</i> | 2 | 1.0 |
| <i>Klebsiella oxytoca</i> | 2 | 1.0 |
| No bacteria growth | 2 | 1.0 |
| Total | 195 | 100 |

Bacterial Profile at the Various Phases of Implant Infection

As shown in Table 3, the distribution of bacterial species varied across the early, delayed, and late phases of implant-related infections. *Klebsiella pneumoniae* was the most frequently isolated pathogen, occurring mainly during the early (38.6%) and delayed (61.4%) phases. *Escherichia coli* was also common, with 54.3% of isolates detected in the early phase, 40.0% in the delayed phase, and 5.7% in the late phase. Similarly, *Pseudomonas aeruginosa* was recovered in both early (39.4%) and delayed (60.6%) infections. *Citrobacter freundii* was predominantly associated with early infections (75.0%) and appeared less frequently in the delayed phase (25.0%). *Proteus mirabilis* followed a similar trend, with 62.5% of isolates from early and 37.5% from delayed infections. Among the less common species, *Providencia stuartii* occurred mainly in delayed (66.7%) and late (33.3%) phases, while *Klebsiella oxytoca* and *Raoultella ornithinolytica* were isolated exclusively from early and delayed infections, respectively. The late phase of infection showed limited bacterial recovery, with only two isolates, one *Escherichia coli* and one *Providencia stuartii*.

Antibiotic Response Patterns Associated with Orthopaedic Implant Infections

Table 4 summarises the antimicrobial susceptibility profiles of bacterial isolates recovered from orthopaedic implant infections. The responses were categorised as Resistant (R), Intermediate (I), or Sensitive (S) based on standard interpretive criteria. Overall, susceptibility

testing revealed extensive multidrug resistance to commonly prescribed antibiotics. All isolates (100%) were resistant to penicillin, while high resistance rates were also observed for ceftriaxone (97.9%), cefazolin (96%), cefotaxime (88.2%), ampicillin (85%), and vancomycin (84.6%). These findings underscore the limited effectiveness of β -lactam antibiotics, including first- and second-generation cephalosporins, as well as vancomycin, in managing implant-associated infections in this setting. In contrast, amikacin exhibited the highest activity, with 98% of isolates remaining susceptible. Meropenem (84.1%) and piperacillin-tazobactam (69.2%) also showed promising efficacy. Moderate resistance levels were observed for ciprofloxacin (49.7%), clindamycin (48.2%), and gentamicin (28.7%), indicating partial retention of activity compared with β -lactam agents.

Antibiogram Analysis

Figure 1 illustrates the antibiotic resistance patterns observed among the bacterial species isolated from orthopaedic implant infections. High resistance rates were noted for ampicillin, penicillin, vancomycin, and cephalosporins, including cefazolin, cefixime, ceftriaxone, and ceftazidime. *Klebsiella pneumoniae* demonstrated broad resistance across multiple antibiotic classes. In contrast, the resistance rate was low for piperacillin-tazobactam, amikacin, and meropenem, indicating their potential efficacy in this clinical setting.

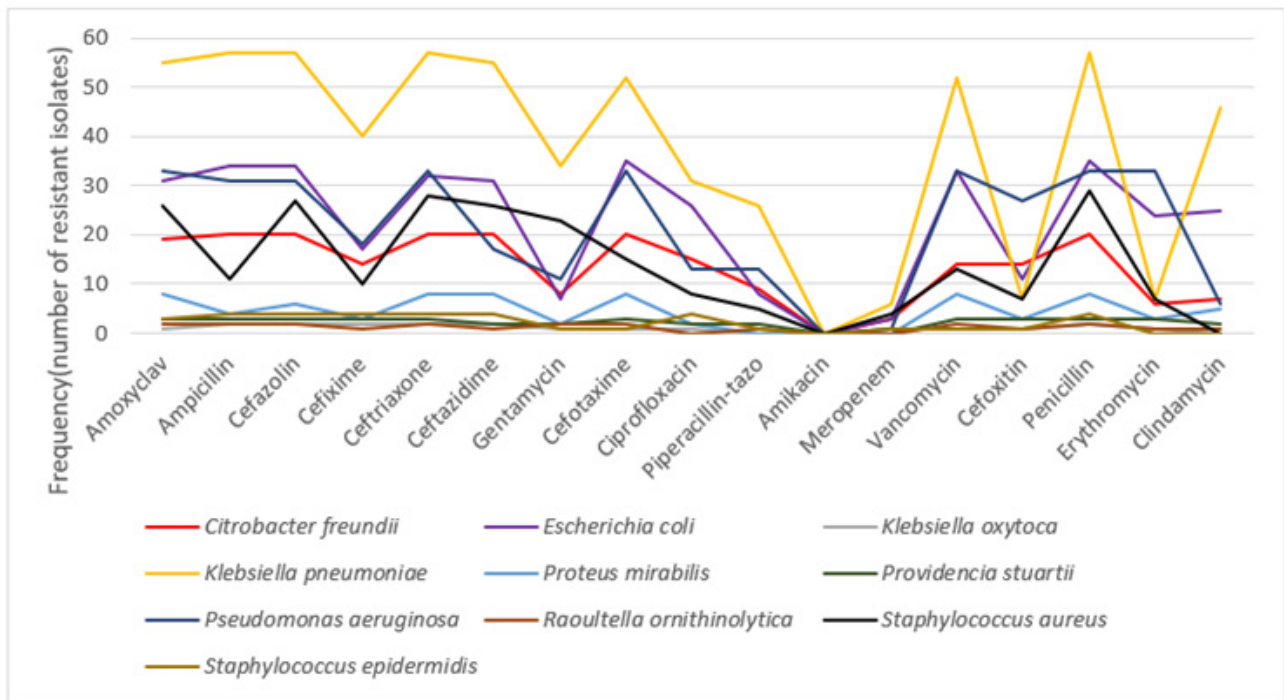
TABLE 3: Distribution of Bacteria Isolated Across Phases of Implant-Related Infection

| BACTERIA ISOLATED | PHASE OF INFECTION | | | Total |
|-----------------------------------|--------------------|-------------|-----------|-------|
| | Early | Delayed | Late | |
| <i>Klebsiella pneumoniae</i> | 22 (38.6%) | 35 (61.4%) | 0 (0%) | 57 |
| <i>Escherichia coli</i> | 19 (54.3%) | 14 (40%) | 2 (5.7%) | 35 |
| <i>Pseudomonas aeruginosa</i> | 13 (39.4%) | 20 (60.6%) | 0 (0%) | 33 |
| <i>Staphylococcus aureus</i> | 12 (41.4%) | 17 (58.6%) | 0 (0%) | 29 |
| <i>Citrobacter freundii</i> | 15 (75%) | 5 (25%) | 0(0%) | 20 |
| <i>Proteus mirabilis</i> | 5 (62.5%) | 3 (37.5%) | 0 (0%) | 8 |
| <i>Staphylococcus epidermidis</i> | 4 (100%) | 0 (0%) | 0 (0%) | 4 |
| <i>Providencia stuartii</i> | 0 (0%) | 2 (66.7%) | 1 (33.3%) | 3 |
| <i>Klebsiella oxytoca</i> | 2 (100%) | 0 (0%) | 0 (0%) | 2 |
| <i>Raoultella ornithinolytica</i> | 0 (0%) | 2 (100%) | 0 (0%) | 2 |
| Total | 92 (47.67%) | 98 (50.78%) | 3 (1.55%) | 193 |

TABLE 4: Patterns of Antibiotic Resistance, Sensitivity, and Intermediate Responses among Isolates (N = 193)

| Antibiotic | Resistant | % | Response/ percentage Sensitive | % | Intermediate | % |
|-------------------|-----------|------|--------------------------------|------|--------------|------|
| Penicillin | 193 | 100 | 0 | 0 | 0 | 0 |
| Ceftriaxone | 189 | 97.9 | 0 | 0 | 4 | 2.1 |
| Cefazolin | 186 | 96 | 4 | 2 | 3 | 2 |
| Amoxyclav | 181 | 93.7 | 4 | 2.1 | 8 | 4.2 |
| Cefotaxime | 170 | 88.2 | 23 | 11.8 | 0 | 0 |
| Ceftazidime | 166 | 85.1 | 27 | 14.9 | 0 | 0 |
| Ampicillin | 166 | 85 | 27 | 15 | 0 | 0 |
| Vancomycin | 163 | 84.6 | 30 | 15.4 | 0 | 0 |
| Cefixime | 119 | 61 | 66 | 33.9 | 8 | 5.1 |
| Ciprofloxacin | 97 | 49.7 | 88 | 46.1 | 8 | 4.1 |
| Clindamycin | 92 | 48.2 | 99 | 50.8 | 2 | 1 |
| Erythromycin | 92 | 48.2 | 99 | 50.8 | 2 | 1 |
| Cefoxitin | 75 | 38.5 | 118 | 61.5 | 0 | 0 |
| Piperacillin-tazo | 60 | 30.8 | 133 | 69.2 | 0 | 0 |
| Gentamycin | 56 | 28.7 | 112 | 58.4 | 25 | 12.8 |
| Meropenem | 19 | 10.7 | 164 | 84.1 | 10 | 5.1 |
| Amikacin | 0 | 0 | 189 | 98 | 4 | 2 |

FIGURE 1: Antibiotic Resistance Profiles of Bacterial Isolates from Orthopedic Implant Infections



DISCUSSION

This study characterised bacteria causing orthopaedic implant infections, their profile on the various phases of infection and determined their antimicrobial susceptibility patterns. The key findings of this study indicate that a diverse range of bacterial species are responsible for orthopaedic implant infections in the region, with *Klebsiella pneumoniae* (29.3%) being most responsible for the implant infections. Further, it is revealed that all participants had fractures as the source of injury, and exofix (37.2%) was the commonest implant used. Additionally, infections occurred mainly in the early (47.67%) and delayed (50.78%) phases. The results also revealed that bacteria isolated are of varying susceptibility patterns, with penicillin (100%) and ceftriaxone (97.9%) showing the highest resistance patterns, while amikacin (98%) and meropenem (84.1%) had the highest susceptibility.

A total of 191 participants were enrolled in the study, with a predominance of males and individuals aged 31–50 years, consistent with global orthopaedic trauma trends and likely reflecting greater exposure to occupational and high-risk physical activities.¹⁵ This demographic profile may explain the increased risk of fractures and subsequent implant-related infections, while the lower representation of females likely reflects differences in activity patterns and injury exposure; similar male predominance has been reported in other studies.¹⁹ Comorbidities such as diabetes (16.2%) and hypertension (16.7%) were present in a notable proportion of participants and may have contributed to increased infection risk and delayed healing, as conditions like diabetes are known to impair immune function and bone regeneration.²⁰ These findings emphasise the importance of preoperative optimisation and tailored perioperative care in high-risk patients. Additionally, the predominance of external fixation and pins or wires reflects fracture management practices in resource-limited settings, where implant choice, surgical exposure, and postoperative care demands can significantly influence infection risk.²¹ This observation suggests that implant selection and surgical technique remain critical determinants of infection prevention. Collectively, these observations underscore the critical role of patient risk profiling, implant selection, and surgical technique in preventing orthopaedic implant infections.

This study revealed the presence of diverse Gram-negative bacterial species among participants with orthopaedic implant infections. *Klebsiella pneumoniae* was the most frequently isolated pathogen, although other bacterial species also played a role. This Gram-negative enterobacterium is increasingly associated with severe infections and high mortality rates.²² The distribution of these organisms is influenced by a variety of epidemiological factors, including host-related conditions and perioperative practices.²³ Other contributing factors may include delayed fracture healing, post-surgical trauma, sepsis and contamination at the surgical sites.²⁴ Our findings are consistent with studies showing an upward trend in Gram-negative bacterial involvement in orthopaedic implant-related infections. For instance, a study in Russia reported an increase in Gram-negatives isolates from 25% to 33%.²⁵ Similar trends were observed in Sweden and Lithuania, where

Gram-negative pathogens dominated implant-related infections.²⁴ Studies in West Africa²⁶ and India⁹ also reported a higher prevalence of Gram-negative bacteria compared to Gram-positive. In our study, *Pseudomonas aeruginosa* was also isolated in 16.9% of cases, aligning with previously reported prevalence rates ranging from 7% to 28.8%.¹⁵ This suggests an increasing role for *P. aeruginosa* in orthopaedic implant infections, meriting further investigation into its specific risk factors.

Analysis of bacterial profiles across early, delayed, and late phases highlights the dynamic nature of implant infections. These findings are consistent with a study conducted in the UK²⁷ that reported no significant differences in bacterial species across infection phases. The presence of *K. pneumoniae* and *E. coli* in both early and delayed phases suggest their ability to persist despite host defences and postoperative antibiotics. Notably, *E. coli* has been shown to form biofilms on orthopaedic implants, contributing to chronic infections and treatment resistance.²⁸ Consistent with prior research, highly virulent organisms tend to dominate early infections,^{26,30} while less virulent bacteria are more common in delayed phases.²⁹ Clinically, this distinction is important as early-phase infections may require aggressive, targeted therapy, whereas delayed-phase infections may benefit from combined surgical and antibiotic strategies to eradicate persistent pathogens. Understanding phase-specific pathogen dynamics allows clinicians to optimise both the timing of interventions and antibiotic selection.

The study highlights a concerning prevalence of multidrug resistance, particularly among *K. pneumoniae* and *P. aeruginosa*. High resistance to commonly used agents such as penicillin, vancomycin, and cephalosporins aligns with reports from a regional tertiary hospital.³¹ High resistance rates were observed for ampicillin, penicillin, Vancomycin, and cephalosporins, including cefazolin, cefixime, ceftriaxone, and ceftazidime, indicating that these antibiotics are largely ineffective against many of the isolates, including *Klebsiella pneumoniae* and *Klebsiella oxytoca*, highlighting their multidrug-resistant nature. For example, high vancomycin resistance has been associated with its lack of ability to pass the outer membrane of Gram-negative bacteria.²³ These findings were consistent with a study conducted at Kenyatta National Hospital, which also reported resistance to vancomycin, ampicillin, and cephalosporins such as ceftriaxone among organisms causing orthopaedic implant-related infections.³² Kenya lacks a national surveillance system and guidelines in the use of antibiotic, perhaps leading to antibiotics misuse resulting in an emerging antibiotic resistance trend.³³

In contrast, amikacin, meropenem and piperacillin-tazobactam demonstrated the highest sensitivity rates across multiple bacterial isolates, suggesting they are among the most effective antibiotics for treating implant-related infections. These findings align with those of a previous study that identified these three antibiotics as the most effective for managing prosthetic joint infections (PJIs) and fracture-related infections (FRIs).²⁶ Similarly, their use has also been supported as part of standard clinical practice in the treatment of orthopaedic implant infections.³² High resistance rates among Gram-negative organisms in orthopaedic implant infections have been reported, highlighting the need for alternative treatment

strategies.³¹ Similarly, antimicrobial resistance in orthopaedic surgeries has been shown to pose significant challenges, contributing to increased infection rates and poorer treatment outcomes.³⁴

Mechanistically, resistance among Gram-negative organisms is often mediated by plasmids, transposons, and biofilm formation.³⁵ *P. aeruginosa*'s resilience is enhanced by virulence factors, environmental survival, and host immunosuppression.¹⁵ High frequencies of *Klebsiella pneumoniae* in orthopaedic implant infections in this study may be attributed to the emergence of multi-drug-resistant (MDR) strains. These strains have been linked to hospital outbreaks and are recognised as an urgent threat to public health.³⁶ Their resistance mechanisms primarily have been known to involve production of extended-spectrum β -lactamases (ESBLs) and the expression of carbapenemases.⁸ Multidrug-resistant *P. aeruginosa* strains have been associated with rapid bone destruction in orthopaedic infections, underscoring the severity of infections caused by resistant bacteria.³⁷ Additionally, high carbapenem resistance rates have been reported³⁸ among *P. aeruginosa* isolates, highlighting the global challenge of treating infections caused by this pathogen. *Escherichia coli* also demonstrated resistance to several antibiotics, particularly cephalosporins. Studies have shown that *Escherichia coli* promotes osteoclastic activity while inhibiting osteoblast differentiation, thus making it a challenging pathogen to eliminate. As a result, effective management often requires implant removal.³⁹ The study reinforces the importance of local antibiograms and stewardship programs, as indiscriminate empiric therapy may promote further resistance and compromise implant survival.

Limitations of the Study

Considering the cross-sectional design of the study, some of the limitations experienced include challenges in accurately determining preoperative status and maintaining long-term follow-up of participants, and the findings may not fully reflect regional variations in pathogen distribution and resistance patterns.

CONCLUSION

This study provides valuable insight into the dominance of Gram-negative bacteria as major causative agents of orthopaedic implant infections. This trend may indicate a shift from the traditionally predominant *Staphylococcus aureus*, which could be attributed to the current practices of managing orthopaedic surgical wounds postoperatively.

The findings highlight the importance of understanding the local bacterial ecology in orthopaedic implant infection, as a broad spectrum of pathogens was identified. The similarity in bacterial profiles across different phases of infection suggests that phase-specific diagnosis may not be necessary. Furthermore, the varied antibiotic response patterns underscore the need for routine, individualised antibiotic sensitivity testing in all patients with orthopaedic implant infections to guide effective and targeted antibiotic selection and ultimately improve clinical outcomes.

Recommendations for Research

Future research should focus on investigating the rising

prevalence of Gram-negative bacteria in orthopaedic implant infections, with particular attention to region-specific patterns in Kenya. Additionally, further studies are needed to evaluate the efficacy of targeted antibiotic regimens, such as amikacin, piperacillin-tazobactam, and meropenem, in the management of postoperative implant infections, in order to inform more effective and context-specific treatment strategies.

REFERENCES

- Ronin D, Boyer J, Alban N, Natoli RM, Johnson A, Kjellerup BV. Current and novel diagnostics for orthopedic implant biofilm infections: a review. *APMIS*. 2022 Feb;130(2):59-81. doi: [10.1111/apm.13197](https://doi.org/10.1111/apm.13197).
- Sciolla S, Martuscelli G, Nappi F, et al. Trends in Managing Cardiac and Orthopaedic Device-Associated Infections by Using Therapeutic Biomaterials. *Polymers*. 2021;13(10). doi: [10.3390/polym13101556](https://doi.org/10.3390/polym13101556)
- Akay S, Yagmur A. Recent Advances in Antibacterial Coatings to Combat Orthopedic Implant-Associated Infections. *Molecules*. 2024;29(5):1172. doi: [10.3390/molecules29051172](https://doi.org/10.3390/molecules29051172)
- Tokarski A, Courtney PM, Deirmengian C, Kwan S, McCahon J, Deirmengian GK. Systemic Manifestation of Periprosthetic Joint Infection Is Associated With Increased In-Hospital Mortality. *Cureus*. 2023;15(3):e36572. doi: [10.7759/cureus.36572](https://doi.org/10.7759/cureus.36572)
- Bunduki GK, Masoamphambe E, Fox T, Musaya J, Musicha P, Feasey N. Prevalence, risk factors, and antimicrobial resistance of endemic healthcare-associated infections in Africa: a systematic review and meta-analysis. *BMC Infect Dis*. 2024;24(1):158. doi: [10.1186/s12879-024-09038-0](https://doi.org/10.1186/s12879-024-09038-0)
- Dibartola AC, Swearingen MC, Granger JF, Stoodley P, Dusane DH. Biofilms in orthopedic infections: a review of laboratory methods. *APMIS*. 2017;125(4):418-428. doi: [10.1111/apm.12671](https://doi.org/10.1111/apm.12671)
- Advancing the management of prosthetic joint infections: a review of randomized controlled trials and emerging evidence | *Antimicrobial Agents and Chemotherapy*. Accessed March 18, 2026. <https://journals.asm.org/doi/10.1128/aac.00338-25>
- Sarkar K, Mullan S, Menon H. Exploring Drug Resistance: Microbial Profiles, Antibiotic Sensitivity, and Biofilm Development in Orthopedic Implant Infections. *Cureus*. 2024;16(10):e70938. doi: [10.7759/cureus.70938](https://doi.org/10.7759/cureus.70938)
- Chebli D, Dhaif F, Ridha A, Schade A, Khatri C. A meta-analysis of the incidence of infections following open tibia fractures and the microorganisms that cause them in high-, middle- and low-income countries. *Trop Doct*. 2024;54(3):272-281. doi: [10.1177/00494755241232171](https://doi.org/10.1177/00494755241232171)
- Narendrakumar L, Chakraborty M, Kumari S, Paul D, Das B. β -Lactam potentiators to re-sensitize resistant pathogens: Discovery, development, clinical use and the way forward. *Front Microbiol*. 2023;13. doi: [10.3389/fmicb.2022.1092556](https://doi.org/10.3389/fmicb.2022.1092556)
- Drobish IC, Barasa IK, Otieno G, et al. Prevalence of Antimicrobial Resistance and Association with Patient Outcomes in a Rural Kenyan Hospital. *Am J Trop Med*

- Hyg. 2023;108(6):1227-1234. doi:10.4269/ajtmh.22-0311
12. Aleign D, Tena T, Tadesse D, et al. Bacteriological Profiles, Antimicrobial Susceptibility Patterns, and Associated Factors in Patients Undergoing Orthopedic Surgery with Suspicion of Surgical Site Infection at Arba Minch General Hospital in Southern Ethiopia. *Infect Drug Resist.* 2022;15:2427-2443. doi:10.2147/IDR.S367510
 13. Silva R, Salles MC, Matosa R, Ayres B, Dias V, Caetano LM. Orthopedic-Implant Associated Infection due to Gram-Negative Bacilli: The Worrisome Impact of *Acinetobacter baumannii* Multidrug Resistance in a Brazilian Center. *Open Forum Infect Dis.* 2017;4(Suppl 1):S111-S112. doi:10.1093/ofid/ofx163.121
 14. Baertl S, Walter N, Engelstaedter U, et al. What Is the Most Effective Empirical Antibiotic Treatment for Early, Delayed, and Late Fracture-Related Infections? *Antibiotics.* 2022;11(3):287. doi:10.3390/antibiotics11030287
 15. Lumbe H. Prevalence and Risk Factors Associated with Implant Infections in Orthopedic Surgeries at Songea Regional Referral Hospital, Tanzania. 7(11).
 16. Khanbhai M, Lutomia MBL. Motorcycle Accident injuries seen at Kakamega Provincial Hospital in Kenya. Published online July 31, 2012. Accessed October 14, 2025. <http://hdl.handle.net/1807/52930>
 17. Pourhoseingholi MA, Vahedi M, Rahimzadeh M. Sample size calculation in medical studies. *Gastroenterol Hepatol Bed Bench.* 2013 Winter;6(1):14-17. PMID: 24834239; PMCID: PMC4017493.
 18. Egbuchulem, K.I., 2023. The basics of sample size estimation: an editor's view. *Annals of Ibadan postgraduate medicine*, 21(1), 5-10
 19. Albavera-Gutierrez RR, Espinosa-Ramos MA, Rebolledo-Bello E, et al. Prevalence of *Staphylococcus aureus* Infections in the Implantation of Orthopedic Devices in a Third-Level Hospital: An Observational Cohort Study. *Pathogens.* 2024;13(8):620. doi:10.3390/pathogens13080620
 20. Aleign D, Tena T, Tadesse D, et al. Bacteriological Profiles, Antimicrobial Susceptibility Patterns, and Associated Factors in Patients Undergoing Orthopedic Surgery with Suspicion of Surgical Site Infection at Arba Minch General Hospital in Southern Ethiopia. *Infect Drug Resist.* 2022;15:2427-2443. doi:10.2147/IDR.S367510
 21. Galasso O, Crinisio A, Bartoli A, Moretti B. Advances and Challenges in Orthopedic Implant-Associated Infections. *Healthcare (Basel).* 2024;12(18):1819. doi:10.3390/healthcare12181819
 22. Kasimova AR, Рашидовна КА, Tufanova OS, et al. Twelve-Year Dynamics of Leading Pathogens Spectrum Causing Orthopedic Infection: A Retrospective Study. *Traumatology and Orthopedics of Russia.* 2024;30(1):1. doi:10.17816/2311-2905-16720
 23. Masson E. Letter in response to article in journal of infection: "The microbiology of chronic osteomyelitis: Changes over ten years." *EM-Consulte.* Accessed June 14, 2025. <https://www.em-consulte.com/article/1491000/letter-in-response-to-article-in-journal-of-infect>
 24. van Groesen E, Slingerland CJ, Innocenti P, Mihajilovic M, Masereeuw R, Martin NI. Vancomyxins: Vancomycin-Polymyxin Nonapeptide Conjugates That Retain Anti-Gram-Positive Activity with Enhanced Potency against Gram-Negative Strains. *ACS Infect Dis.* 2021;7(9):2746-2754. doi:10.1021/acsinfectdis.1c00318
 25. Sebastian S, Sezgin EA, Stučinskas J, et al. Different microbial and resistance patterns in primary total knee arthroplasty infections - a report on 283 patients from Lithuania and Sweden. *BMC Musculoskelet Disord.* 2021;22(1):800. doi:10.1186/s12891-021-04689-5
 26. Rupp M, Baertl S, Walter N, Hitzenbichler F, Ehrenschwender M, Alt V. Is There a Difference in Microbiological Epidemiology and Effective Empiric Antimicrobial Therapy Comparing Fracture-Related Infection and Periprosthetic Joint Infection? A Retrospective Comparative Study. *Antibiotics (Basel).* 2021;10(8):921. doi:10.3390/antibiotics10080921
 27. Mengesha MG, Rajasekaran S, Ramachandran K, et al. Orthopedic postoperative infection profile and antibiotic sensitivity of 2038 patients across 24 countries - Call for region and institution specific surgical antimicrobial prophylaxis. *J Orthop.* 2024;55:97-104. doi:10.1016/j.jor.2024.04.018
 28. Crémet L, Broquet A, Brulin B, et al. Pathogenic potential of *Escherichia coli* clinical strains from orthopedic implant infections towards human osteoblastic cells. *Pathog Dis.* 2015;73(8):ftv065. doi:10.1093/femspd/ftv065
 29. Walter N, Baertl S, Engelstaedter U, et al. Letter in response to article in journal of infection: "The microbiology of chronic osteomyelitis: Changes over ten years." *J Infect.* 2021;83(6):709-737. doi:10.1016/j.jinf.2021.09.006
 30. Lu Y, Cai W jie, Ren Z, Han P. The Role of Staphylococcal Biofilm on the Surface of Implants in Orthopedic Infection. *Microorganisms.* 2022;10(10):1909. doi:10.3390/microorganisms10101909
 31. Li B, Webster TJ. Bacteria antibiotic resistance: New challenges and opportunities for implant-associated orthopedic infections. *J Orthop Res.* 2018;36(1):22-32. doi:10.1002/jor.23656
 32. Sheikh MA. Prevalence, Risk Factors, and Microbiological Profile of Early Surgical Site Infection Following Orthopaedic Implant Surgery at Kenyatta National Hospital. Thesis. University of Nairobi; 2022. Accessed June 14, 2025. <http://erepository.uonbi.ac.ke/handle/11295/161914>
 33. Mekuria LA, de Wit TF, Spieker N, et al. Analyzing data from the digital healthcare exchange platform for surveillance of antibiotic prescriptions in primary care in urban Kenya: A mixed-methods study. *PLoS One.* 2019;14(9):e0222651. doi:10.1371/journal.pone.0222651
 34. Lakhani A, Jindal K, Khatri K. Antimicrobial resistance (AMR) in Orthopaedic surgeries: A Complex issue and global threat. *Journal of Orthopaedic Reports.* 2025;4(4):100466. doi:10.1016/j.jorep.2024.100466
 35. Patel KH, Gill LI, Tisingh EK, et al. Microbiological Profile of Fracture Related Infection at a UK Major Trauma Centre. *Antibiotics (Basel).* 2023;12(9):1358. doi:10.3390/antibiotics12091358

36. Wyres KL, Holt KE. Klebsiella Pneumoniae as a Key Trafficker of Drug Resistance Genes from Environmental to Clinically Important Bacteria. PeerJ Inc.; 2018. doi:[10.7287/peerj.preprints.26852v1](https://doi.org/10.7287/peerj.preprints.26852v1)
37. Yang SC, In Y, AlShammari SM, Kim MS. Rapid bone destruction caused by multidrug-resistant Pseudomonas aeruginosa septic arthritis: A case report. Medicine (Baltimore). 2024;103(36):e39462. doi:[10.1097/MD.00000000000039462](https://doi.org/10.1097/MD.00000000000039462)
38. Harris F, Phoenix DA, Dennison SR. Antimicrobial Peptides from Frogs of the Glandirana Genus. Biologics. 2024;4(4):444-507. doi:[10.3390/biologics4040027](https://doi.org/10.3390/biologics4040027)
39. Oche DA, Oyegoke PI, Akpudo MO, Olayinka BO. Antibiotics Resistance Pattern of Staphylococcus aureus Isolated From In-patients of an Orthopaedic Hospital in North-Western Nigeria. IntJ Epidemiol Res. 2021;8(4):160-166. doi:[10.34172/ijer.2021.29](https://doi.org/10.34172/ijer.2021.29)

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