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ORIGINAL RESEARCH

# Antimicrobial Resistance Patterns of Pathogens Isolated from Patients with Wound Infection at a Teaching Hospital in Vietnam

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**Purpose:** At a teaching Hospital in Vietnam, the persistently high incidence of diagnosed wound infection poses ongoing challenges to treatment. This study seeks to explore the causative agents of wound infection and their antimicrobial and multidrug resistance patterns.

**Methods:** A cross-sectional study was conducted at the Department of Microbiology, Military Hospital 103, Vietnam. Data on microorganisms that caused wound infection and their antimicrobial resistance patterns was recorded from hospitalized patients from 2014 to 2021. Using the chi-square test, we analyzed the initial isolation from wound infection specimens collected from individual patients.

**Results:** Over a third (34.9%) of wound infection samples yielded bacterial cultures. *Staphylococcus aureus* was the most prevalent bacteria, followed by *Pseudomonas aeruginosa*. Worryingly high resistance rates were observed for several antibiotics, particularly among Gram-negative bacteria. Ampicillin displayed the highest resistance (91.9%), while colistin and ertapenem remained the most effective. In Gram-positive bacteria, glycopeptides like teicoplanin and vancomycin (0% and 3.3% resistance, respectively) were most effective, but their use was limited. Clindamycin and tetracycline showed decreasing effectiveness. Resistance rates differed between surgical and non-surgical wards, highlighting the complex dynamics of antimicrobial resistance within hospitals. Multidrug resistance (MDR) was substantial, with Gram-negative bacteria exhibiting a 63.6% MDR rate. *Acinetobacter baumannii* showed the highest MDR rate (88.0%).

**Conclusion:** This study investigated wound infection characteristics, antibiotic resistance patterns of common bacteria, and variations by hospital ward. *S. aureus* was the most prevalent bacteria, and concerning resistance rates were observed, particularly among Gram-negative bacteria. These findings highlight the prevalence of multidrug resistance in wound infections, emphasizing the importance of infection control measures and judicious antibiotic use.

**Keywords:** wound infection, multidrug resistance, antimicrobial resistance, AMR in Vietnam

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## Introduction

Antimicrobial resistance (AMR) is a growing threat to public health, especially in developing countries. Multiple factors, including incomplete treatment courses, poor supply chain management, unregulated over-the-counter availability of antibiotics, and irrational prescribing practices, fuel its rise.[1] The consequences are dire: in the US, antibiotic-resistant infections claim over 35,000 lives annually.[2] By 2050, projections suggest a frightening 10 million deaths per year worldwide.[3]

Among the many implications of AMR, one of the most prevalent is its impact on wound infection, which are highly common in settings with poor infection prevention and control (IPC) measures.[4] Wound infection with AMR bacteria contributes to higher mortality rates, prolonged patient debility, extended hospital stays, and increased healthcare costs, especially in developing countries where irrational antibiotic use is prevalent.[5,6] Inadequate management of wound infection in settings with poor IPC measures also poses a risk of pathogens spreading to other patients and healthcare providers, emphasizing the need for improved in-hospital management.[7]

The skin, providing an ideal medium for pathogenic bacteria to proliferate, increases the likelihood of skin wound infection, impeding natural healing.[8] The origin of wounds, whether postsurgical, posttraumatic, or chronic, further compounds the risk of infection.[9] The alarming increase in multidrug resistance bacteria exacerbates the threat of antibiotic failure and raises mortality rates.[10] More than 90% resistance of *Staphylococcus aureus* to penicillin remains a global concern, with MRSA strains exhibiting rapid expansion within healthcare facilities.[11,12] Unwise administration of broad-spectrum antibiotics in developing countries, where dispensing antibiotics without a medical prescription is common, accelerates the emergence of resistant bacteria.[13–15] At a teaching Hospital in Vietnam, the high incidence of diagnosed wound infection continues to strain the treatment process. This study aims to investigate the causative agents of wound infection and their patterns of AMR and MDR. The findings will provide valuable information to enhance the effectiveness of treatment, reduce hospitalization time, lower treatment costs, and target MDR strains associated with wound infection in Vietnam.

## Materials and Methods

### Study Design and Setting

This cross-sectional study occurred at the Microbiology Department of Military Hospital 103 in Vietnam from January 2014 to December 2021.

### Patients

Inclusion criteria for this study encompassed patients diagnosed with a wound infection exhibiting at least one of the following signs and symptoms: redness, swelling, purulent exudate, odor, and pain. Pus swabs or pus collected by sterilized syringe were collected during initial wound cleaning from admitted patients. The study focused on the initial isolates (first occurrence) of bacterial species from wound specimens collected from each patient during the study period. Conversely, exclusion criteria ruled out bacteria isolated from wound specimens determined to be contaminants. Duplicate negative or positive cultures of wound specimens from the same patient were removed during the study period.

### Laboratory Procedure

Patients who met the inclusion criteria were considered to have wound infection.[16] Specimens were collected from open wounds using sterile swabs after thorough rinsing with sterile saline. For closed wounds, pus or aspirates were collected from disinfected areas (70% alcohol, 10% povidone-iodine, followed by sterile saline) using a sterilized syringe according to standard guidelines.[17] Specimens were inoculated onto blood agar, MacConkey agar (Oxoid, UK), and brain heart infusion broth (Oxoid, UK) using a 4-quadrant streaking method. Blood agar was incubated at 35°C with 5% CO2, while MacConkey agar and broth were incubated at 35°C for at least 3 days. According to the manufacturer's instructions, colonies of suspected bacterial pathogens were identified using conventional methods and the Vitek 2 automated system (BioMérieux, France).[17] Susceptibility testing was conducted using the Vitek 2 system (BioMérieux, France), and minimum inhibitory concentration (MIC) testing was performed via Etest (BioMérieux, France). Nine drug

classes, including aminoglycosides (amikacin, gentamycin, tobramycin), penicillin (ampicillin, piperacillin), beta-lactams /inhibitors (amoxicillin/ clavulanic acid, piperacillin/tazobactam, ticarcillin/clavulanic acid), cephalosporins (cefepime, cefotaxime, ceftazidime, ceftriaxone), fluoroquinolones (ciprofloxacin, levofloxacin, norfloxacin), monobactams (aztreonam), carbapenems (ertapenem, imipenem, meropenem), folate pathway antagonists (trimethoprim/sulfamethoxazole) and lipopeptides (colistin) were used for the susceptibility test of common Gram-negative bacteria. Regarding susceptibility tests for Gram-positive bacteria, 11 drug classes were performed as described previously.[18] Interpretation of antimicrobial susceptibility followed the Clinical and Laboratory Standards Institute 2014 guidelines, updated annually.[19] Colistin MIC testing was performed in microplates according to the European Committee on Antimicrobial Susceptibility Testing (EUCAST) 2013.[20] Intermediate resistance was considered sensitivity. Considering the clinical efficacy observed in intermediate cases and the limitation of available antibiotics in the growing antimicrobial resistance, we categorized it as sensitive to reflect a more conservative approach to treatment decisions.[21,22] Multidrug resistance strains were defined as resistant to at least one antimicrobial drug in three or more antimicrobial classes. *Escherichia coli* ATCC 25922 and *Pseudomonas aeruginosa* ATCC 27853 served as control strains. Samples with Gram-negative or Gram-positive bacteria frequency below 2% were excluded from the dataset to focus on the most clinically significant pathogens. This exclusion criterion might have led to underestimating the laboratory positivity rate for wound infection, as samples with low-frequency pathogens were not included in the final analysis.

### Statistical Analysis

To analyze the data, we employed R software version 4.3.2, utilizing the "tidyverse" package for Chi-square tests. A significance level of $P < 0.05$ was applied to all statistical analyses. We analyzed the demographic characteristics of the admitted patients, including age, sex, bacterial isolates obtained from wound cultures, and antimicrobial susceptibility test results.

## Results

### Epidemiological Characteristics of Wound Infection Samples and Patient Demographics

A total of 2748 samples with various wound infections were analyzed; 959 (34.9%) were positive for common pathogens. Gram-positive bacteria comprised the most isolates (63.3%), with *Staphylococcus aureus* being the most prevalent. Gram-negative bacteria accounted for 36.7% of the isolates, with *P. aeruginosa* being the most common. Among these organisms, *S. aureus* was the most predominant bacteria, accounting for 59.6% of the isolates, followed by *P. aeruginosa* (12.4%), *E. coli* (10.8%), *Klebsiella pneumoniae* (8.2%), *Acinetobacter baumannii* (5.2%), and *Enterococcus* spp. (3.6%). Positive pathogens were predominant in the surgical wards, accounting for 76.1%, followed by the Internal medicine ward (12.0%), Infectious disease ward (6.0%), and ICU (5.8%) (Table 1).

Regarding age distribution among patients, adults between 41 and 65 years old constituted the most significant proportion of cases (40.5%), followed closely by those aged 16 to 40 (39.2%). Patients older than 66 accounted for 17.8% of the cases, whereas those in the 0 to 15 age group represented only 2.5%. The analysis of pus swab samples revealed a difference in the distribution of cases by gender. Males (64.8%) accounted for a higher proportion of positive cultures than females (35.2%) (Table 1).

### Antimicrobial Resistance Patterns of Common Gram-Negative Bacteria

Overall, nine drug classes, including aminoglycosides, penicillin, beta-lactamase inhibitors, cephalosporins, fluoroquinolones, monobactam, carbapenems, folate pathway antagonists, and lipopeptides were used for the susceptibility test of common Gram-negative bacteria. Ampicillin displayed the highest resistance rate (91.9%), followed by ceftriaxone (70.3%), levofloxacin (68.8%), and ticarcillin/clavulanic acid (68.0%). Conversely, meropenem (35.8%), imipenem (33.0%), colistin (7.6%), and ertapenem (7.4%) were the most effective antibiotics. Among Gram-negative bacteria tested, *A. baumannii* showed 100% resistance to several antimicrobials, including amoxicillin/clavulanic acid, ceftriaxone, levofloxacin, and aztreonam. Similarly, almost maximum resistance patterns were observed in *E. coli* and

**Table 1** Demographics and Distribution of Pathogens Among Hospitalized Patients with Wound Infections at a Teaching Hospital in Vietnam

| | Number of Isolates | Percentage (%) |
|---|---|---|
| **Gender** | | |
| Males | 621 | 64.8 |
| Females | 338 | 35.2 |
| Total | 959 | 100 |
| **Hospital ward** | | |
| ICU | 56 | 5.8 |
| Infectious Disease | 58 | 6 |
| Internal medicine | 115 | 12 |
| Surgical | 730 | 76.1 |
| Total | 959 | 100 |
| **Pathogens** | | |
| **Gram-Negative Bacteria** | **352** | **36.7** |
| *Acinetobacter baumannii* | 50 | 5.2 |
| *Escherichia coli* | 104 | 10.8 |
| *Klebsiella pneumoniae* | 79 | 8.2 |
| *Pseudomonas aeruginosa* | 119 | 12.4 |
| **Gram-Positive Bacteria** | **607** | **63.3** |
| *Enterococcus* spp. | 35 | 3.6 |
| *Staphylococcus aureus* | 572 | 59.6 |
| Total | 959 | 100 |
| **Age Group** | | |
| 0–15 | 24 | 2.5 |
| 16–40 | 376 | 39.2 |
| 41–65 | 388 | 40.5 |
| ≥ 66 | 171 | 17.8 |
| Total | 959 | 100 |

*K. pneumoniae* against ampicillin, with 90.7% and 96.9% resistance rates, respectively. Meanwhile, *P. aeruginosa* displayed the highest resistance to trimethoprim/sulfamethoxazole (95.0%). All three bacteria remained susceptible to colistin, with resistance rates lower than 10%. The remaining Gram-negative bacteria, such as *E. coli*, showed susceptibility to ertapenem, imipenem, and meropenem (ranging from 1.3% to 3.3%). The susceptibility testing revealed a significant difference ($P < 0.05$) in resistance rate to 19/20 of tested antibiotics except for colistin among the Gram-negative bacteria (Table 2).

## Antimicrobial Resistance Patterns of Common Gram-Positive Bacteria

Overall, 11 drug classes, including aminoglycosides, macrolides, cephamycin, fluoroquinolones, tetracyclines, glycopeptides, oxazolidinones, streptogramins, ansamycins, lincosamides, and folate pathway antagonists were used for the susceptibility test of common Gram-positive bacteria. Erythromycin demonstrated the highest resistance rate among the tested antibiotics, with 87.9% of Gram-positive bacteria exhibiting resistance to this agent. This was followed by clindamycin and azithromycin, with resistance rates of 85.3% and 85.1%, respectively. Tetracycline displayed reduced effectiveness against Gram-positive bacteria, with a substantial resistance rate of 74.4%. Among the fluoroquinolones, ciprofloxacin and levofloxacin showed moderate resistance rates of 25.5% and 25.9%, respectively, while moxifloxacin exhibited a slightly lower resistance rate of 20.8%, indicating better efficacy compared to other fluoroquinolones tested. Teicoplanin and vancomycin (glycopeptides antibiotic) demonstrated low resistance rate of 0% and 3.3%,

**Table 2** Antimicrobial Resistance Patterns of Gram-Negative Bacteria Isolated from Wound Infection Patients at a Teaching Hospital in Vietnam

| Antimicrobials Class | Antimicrobial Agents | *Acinetobacter baumannii* | | *Escherichia coli* | | *Klebsiella pneumoniae* | | *Pseudomonas aeruginosa* | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | R (%) | N | R (%) | N | R (%) | N | R (%) | N | R (%) | P |
| **Aminoglycosides** | **Amikacin** | 26 | 46.20 | 96 | 7.30 | 67 | 14.90 | 103 | 34.00 | 292 | 21.90 | < 0.0001 |
| | **Gentamycin** | 43 | 86.00 | 75 | 33.30 | 59 | 30.50 | 101 | 46.50 | 278 | 45.70 | < 0.0001 |
| | **Tobramycin** | 29 | 89.70 | 7 | 71.40 | NA | NA | 100 | 49.00 | 136 | 58.80 | 0.0004 |
| **Penicillin** | **Ampicillin** | 7 | 71.40 | 86 | 90.70 | 64 | 96.90 | 3 | 66.70 | 160 | 91.90 | 0.0324 |
| | **Piperacillin** | 29 | 89.70 | 4 | 75.00 | NA | NA | 86 | 20.90 | 119 | 39.50 | < 0.0001 |
| **Beta-Lactamase Inhibitors** | **Amoxicillin/clavulanic acid** | 8 | 100.00 | 96 | 33.30 | 75 | 36.00 | NA | NA | 179 | 37.40 | 0.0009 |
| | **Piperacillin/tazobactam** | 34 | 91.20 | 9 | 33.30 | 59 | 30.50 | 20 | 25.00 | 122 | 46.70 | < 0.0001 |
| | **Ticarcillin/clavulanic acid** | 24 | 95.80 | 3 | 33.30 | NA | NA | 95 | 62.10 | 83 | 68.00 | 0.0028 |
| **Cephalosporins** | **Cefepime** | 41 | 87.80 | 93 | 37.60 | 66 | 40.90 | 106 | 38.70 | 306 | 45.40 | < 0.0001 |
| | **Cefotaxime** | 21 | 85.70 | 93 | 62.40 | 74 | 43.20 | NA | NA | 188 | 57.40 | 0.001 |
| | **Ceftazidime** | 42 | 90.50 | 96 | 44.80 | 72 | 41.70 | 105 | 38.10 | 315 | 47.90 | < 0.0001 |
| | **Ceftriaxone** | 10 | 100.00 | 15 | 80.00 | 10 | 30.00 | 2 | 50.00 | 37 | 70.30 | 0.0045 |
| **Fluoroquinolones** | **Ciprofloxacin** | 42 | 92.90 | 90 | 67.80 | 70 | 41.40 | 110 | 60.90 | 312 | 62.80 | < 0.0001 |
| | **Levofloxacin** | 31 | 100.00 | 15 | 80.00 | 8 | 25.00 | 103 | 61.20 | 157 | 68.80 | < 0.0001 |
| | **Norfloxacin** | 4 | 75.00 | 79 | 53.20 | 64 | 40.60 | 15 | 80.00 | 162 | 51.20 | 0.031 |
| **Monobactams** | **Aztreonam** | 12 | 100.00 | 17 | 76.50 | 11 | 27.30 | 53 | 54.70 | 93 | 61.30 | 0.0014 |
| **Carbapenems** | **Ertapenem** | NA | NA | 79 | 1.30 | 56 | 16.10 | NA | NA | 135 | 7.40 | 0.0013 |
| | **Meropenem** | 47 | 89.40 | 92 | 3.30 | 69 | 27.50 | 105 | 45.70 | 313 | 35.80 | < 0.0001 |
| | **Imipenem** | 41 | 87.80 | 93 | 3.20 | 67 | 29.90 | 96 | 40.60 | 297 | 33.00 | < 0.0001 |
| **Folate Pathway Antagonists** | **Trimethoprim/sulfamethoxazole** | 37 | 51.40 | 82 | 73.20 | 62 | 45.20 | 40 | 95.00 | 221 | 65.60 | < 0.0001 |
| **Lipopeptides** | **Colistin** | 21 | 4.80 | NA | NA | 2 | 0.00 | 69 | 8.70 | 92 | 7.60 | 0.77 |

**Notes**: N, number of tested isolates; R, Resistance. P-value was calculated by the Chi-square test.
**Abbreviation**: NA, Not applicable.

respectively, highlighting their effectiveness against Gram-positive bacteria. Similarly, linezolid exhibited a low resistance rate of 0.9%, indicating its efficacy in combating these pathogens. Notably, tigecycline displayed a meager resistance rate of only 0.30%, suggesting its effectiveness as an alternative therapeutic option against Gram-positive bacteria. Among the Gram-positive pathogens tested, *Enterococcus* spp. showed a limited efficacy to macrolides, with 100% and 79.3% for azithromycin and clindamycin, respectively. The clindamycin resistance rate was also observed to be high, with 87.5% of isolates showing resistance to this antibiotic. On the other hand, the most effective antibiotic against *Enterococcus* spp. was tigecycline, with all *Enterococcus* spp. isolates being sensitive to this microbial agent. For *S. aureus*, the highest resistance rate was observed with erythromycin, with 88.7% of isolates being resistant to this antibiotic. In contrast, the most effective antibiotic against *S. aureus* was teicoplanin and linezolid, with a resistance rate of only 0% and 0.70%, respectively. The susceptibility testing revealed that *Enterococcus* spp. had significantly high resistance to ciprofloxacin, levofloxacin, vancomycin, quinupristin/dalfopristin, and doxycycline compared to *S. aureus* ($p < 0.001$). (Table 3).

## Resistance Rate of Pathogens in Patients Admitted to Surgical and Non-Surgical Wards

This study found that wound infection caused by Gram-negative bacteria exhibited higher resistance rates to certain antibiotics in non-surgical wards compared to surgical wards. In the non-surgical wards, the resistance rates were generally higher compared to the surgical wards for most antimicrobial agents. Notably, antibiotics or antimicrobial classes like gentamycin, tobramycin, piperacillin, amoxicillin/clavulanic acid, piperacillin/tazobactam, cefepime, cefotaxime, ceftazidime, ciprofloxacin, norfloxacin, carbapenems, trimethoprim/sulfamethoxazole and colistin showed higher resistance rates in the non-surgical wards compared to the surgical wards. Conversely, some antibiotics displayed higher resistance rates among patients in the surgical ward, including amikacin, ampicillin, ticarcillin/clavulanic acid, ceftriaxone, levofloxacin, and aztreonam. The statistical analysis using the p-values indicates significant differences in resistance rates between the surgical

**Table 3** Antimicrobial Resistance Patterns of Gram-Positive Bacteria Isolated from Wound Infection Patients at a Teaching Hospital in Vietnam

| Antimicrobials Class | Antimicrobial Agents | *Enterococcus* spp. | | *S. aureus* | | Total | | |
|---|---|---|---|---|---|---|---|---|
| | | N | R (%) | N | R (%) | N | R (%) | P |
| **Aminoglycosides** | **Gentamycin** | NA | NA | 439 | 21.9 | 439 | 21.9 | NA |
| **Macrolides** | **Azithromycin** | 5 | 100.0 | 256 | 84.8 | 261 | 85.1 | 0.3449 |
| | **Erythromycin** | 29 | 79.3 | 293 | 88.7 | 322 | 87.9 | 0.1384 |
| **Cephamycins** | **Cefoxitin** | NA | NA | 131 | 59.3 | 131 | 59.3 | NA |
| **Fluoroquinolones** | **Ciprofloxacin** | 31 | 61.3 | 503 | 23.3 | 534 | 25.5 | < 0.0001 |
| | **Levofloxacin** | 28 | 60.7 | 485 | 23.9 | 513 | 25.9 | < 0.0001 |
| | **Norfloxacin** | 10 | 40.0 | 83 | 27.7 | 93 | 29.0 | 0.4211 |
| | **Moxifloxacin** | 4 | 25.0 | 395 | 20.8 | 399 | 20.8 | 0.8355 |
| | **Ofloxacin** | NA | NA | 223 | 25.6 | 223 | 25.6 | NA |
| **Tetracyclines** | **Tetracyclin** | 26 | 88.5 | 337 | 73.3 | 363 | 74.4 | 0.0882 |
| | **Doxycycline** | 18 | 61.1 | 222 | 9.0 | 240 | 12.9 | < 0.0001 |
| | **Tigecycline** | 20 | 0.0 | 324 | 0.3 | 344 | 0.3 | 0.8038 |
| **Glycopeptides** | **Teicoplanin** | 9 | 0.0 | 83 | 0.0 | 92 | 0.0 | NA |
| | **Vancomycin** | 32 | 18.8 | 418 | 2.2 | 450 | 3.3 | < 0.0001 |
| **Oxazolidinones** | **Linezolid** | 24 | 4.2 | 417 | 0.7 | 441 | 0.9 | 0.0836 |
| **Streptogramins** | **Quinupristin/dalfopristin** | 26 | 46.2 | 350 | 0.6 | 376 | 3.7 | < 0.0001 |
| **Ansamycins** | **Rifampicin** | NA | NA | 359 | 5.0 | 359 | 5.0 | NA |
| **Lincosamides** | **Clindamycin** | 7 | 87.5 | 355 | 85.5 | 376 | 85.3 | 0.6505 |
| **Folate pathway antagonists** | **Trimethoprim/sulfamethoxazole** | NA | NA | 448 | 15.8 | 448 | 15.8 | NA |

**Notes**: N, number of tested isolates; R, Resistance. P-value was calculated by the Chi-square test.
**Abbreviation**: NA, Not applicable.

and non-surgical wards for some antibiotics, such as meropenem and imipenem. However, the p-values suggest no significant difference in resistance rates for other antibiotics between the two types of hospital wards (Figure 1).

Our results indicated that the resistance rates of Gram-positive bacteria causing wound infection to most tested antibiotics were higher in non-surgical wards than in surgical wards. Antibiotics such as amikacin, cefoxitin, fluoroquinolones,

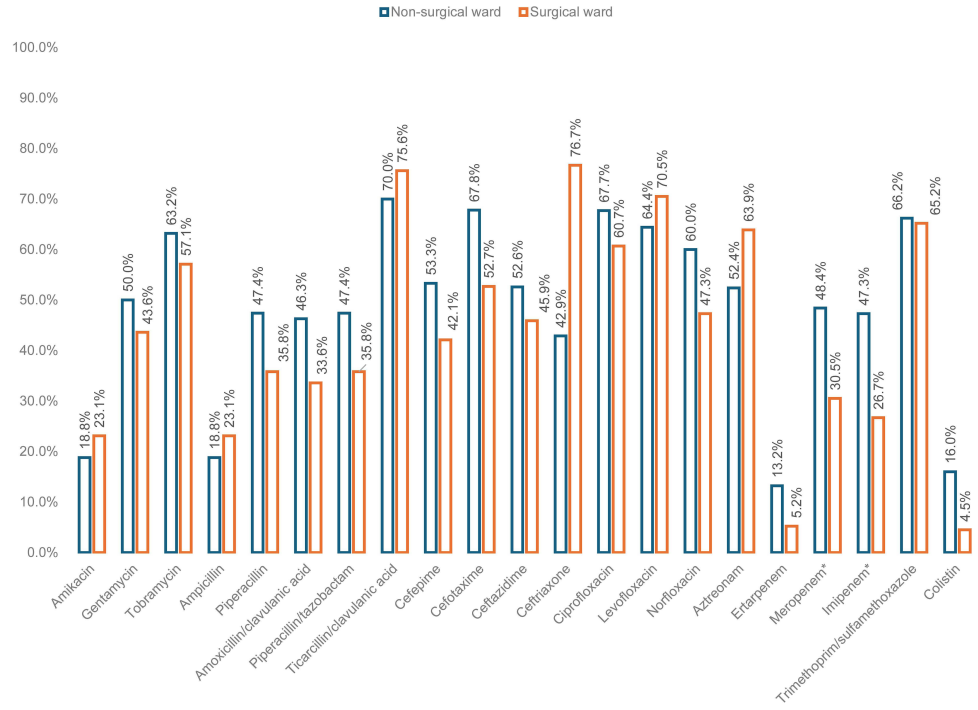


**Figure 1** Antimicrobial resistance to selected antibiotics of Gram-negative bacteria among hospital wards. *P < 0.05, chi-square test.

tetracyclines, quinupristin/dalfopristin, rifampicin, and trimethoprim/sulfamethoxazole exhibited higher resistance rates in the non-surgical wards compared to the surgical wards. However, some antibiotics showed slightly higher resistance rates in the surgical ward, including macrolides, tigecycline, glycopeptides, linezolid, and clindamycin (Figure 2).

## Multidrug Resistance Rate of Gram-Positive and Gram-Negative Bacteria

Multidrug resistance, defined as resistance to three or more classes of antibiotics, varies among different bacterial species. Gram-negative bacteria exhibited an MDR rate of 63.6%. Of which, *A. baumannii* showed the highest multidrug resistance rate at 88.0%, followed by *E. coli* at 73.1% and *P. aeruginosa* at 60.5%. *Klebsiella pneumoniae* showed a relatively lower but significant MDR rate of 40.5%. For Gram-positive bacteria, the MDR was observed at 57.3%. Among these bacteria, *Enterococcus* spp. displayed the highest multidrug resistance rate at 62.9%, followed closely by *S. aureus* at 57.0% (Figure 3).

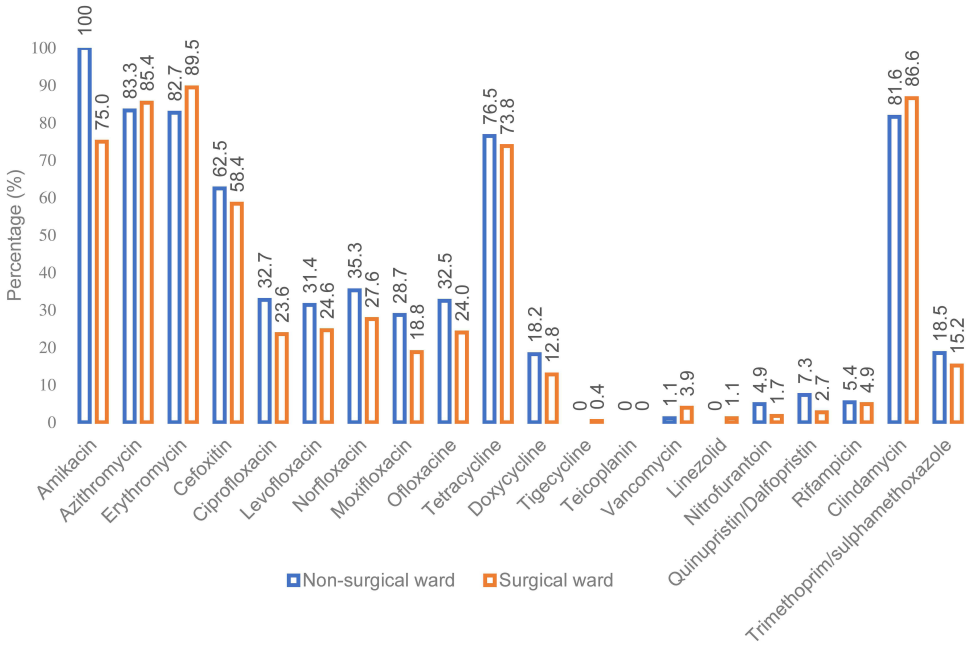


**Figure 2** Antimicrobial resistance to selected antibiotics of Gram-positive bacteria among hospital wards.

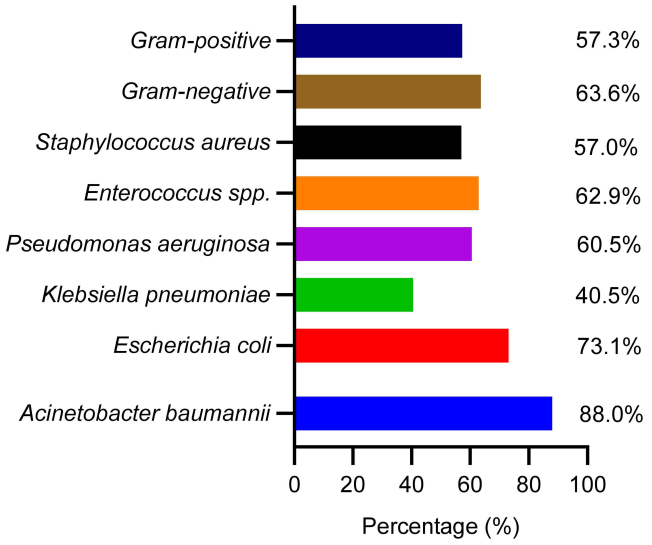


**Figure 3** Multidrug resistance rate of bacteria isolated from patients with wound infection admitted to a teaching hospital.

## Discussion

This study investigated the characteristics of wound infection, antibiotic resistance patterns of common bacteria isolated from wound infection, and variations according to hospital wards. We identified wound infections in 34.9% of the collected samples. These wound infections exhibited signs and symptoms such as redness, swelling, purulent exudate, odor, and pain. The proportion of samples yielding positive cultures for bacterial pathogens (34.9%) was significantly lower than those reported in studies conducted in Tanzania (93,1% in 2014) and Myanmar (58.0% in 2018).[6,23] This discrepancy might be attributed to several factors specific to our study design and patient population compared to the referenced studies. Variations in the patient population could be a contributing factor. For instance, our study might have included more patients with wounds that are less likely to harbor bacteria, such as clean surgical wounds, compared to the studies in Tanzania and Myanmar, which might have focused more on chronic or open wounds.[6,23] Additionally, wound types can significantly impact bacterial colonization. Differences in the types of wounds included in our study compared to the references could explain the observed variation in positive culture rates.[24] Lastly, diagnostic techniques might have played a role. Variations in wound swab collection techniques or culture media used could have affected the sensitivity of detecting bacterial presence.[24] Furthermore, excluding isolates with a frequency below 2% from our analysis could have resulted in underestimating the true diversity of bacteria in wound infection.

Our study found *S. aureus* as the most prevalent bacteria, followed by *P. aeruginosa*, which aligns with previous findings in wound infection, where these bacteria are among the most common.[8,25,26] The higher frequency of positive cultures in surgical wards aligns with the expectation of more invasive procedures being conducted in those areas. Adults between 41 and 65 constituted the most significant proportion of cases, with males exhibiting a higher incidence of positive cultures than females. These demographic trends warrant further investigation to explore potential underlying biological or behavioral factors that might contribute to the observed differences.

Our study revealed concerning resistance rates for several commonly used antibiotics, particularly among Gram-negative bacteria. Ampicillin exhibited the highest resistance rate, which aligned with a rate reported as high as more than 90% in a previous study on wound infection used by Gram-negative bacteria.[27] Ceftriaxone resistance followed ampicillin, with rates of 70.3%. However, according to studies, ceftriaxone rates can range from 29% to 98% in wound infection.[27,28] Levofloxacin resistance in our study is a growing concern, as it was much higher than reported in a study conducted in Bangladesh.[25] Conversely, colistin displayed among the most effectiveness across Gram-negative bacteria, indicating their potential as a last-resort treatment option. However, the judicious use of these last-line antibiotics is crucial to preserve their efficacy for future use.[29] Imipenem and ertapenem followed colistin as another choice for treating wound infection caused by Gram-negative bacteria. Other considerations may include amikacin.

Regarding the treatment for Gram-positive bacteria-caused wound infection, the most effective were the glycopeptides groups, in which teicoplanin and vancomycin showed 0% and 3.3%, respectively, resistance to *Enterococcus* spp. and *S. aureus*. These antibiotics are considered the gold standard for treating severe infections caused by methicillin-resistant *Staphylococcus aureus* (MRSA) and other resistant Gram-positive bacteria.[30–32] However, glycopeptides are typically reserved as a last-line therapy due to their potential for serious side effects and the risk of selecting even more resistant strains.[33] Surprisingly, tigecycline followed teicoplanin with 0.3% resistance to *S. aureus*. This was aligned with a study conducted by Zeng et al 2022, which found that the tigecycline resistance rate to *S. aureus* was lower than 1%.[34] Linezolid, quinupristin/dalfopristin, and rifampicin were followed tigecycline with a resistance rate to Gram-positive bacteria under or equal to 5%. Even though these antibiotics were effective against various Gram-positive bacteria, their use is limited by potential side effects and emerging resistance.[35–37] In contrast, our analysis of clindamycin and tetracycline showed less effective Gram-positive bacterial treatment. Due to increasing resistance rates, these antibiotics are becoming less effective against some Gram-positive bacteria, particularly *S. aureus*.[38–41]

While surgical wards often exhibit higher antibiotic use compared to non-surgical wards, our analysis reveals a different dynamic within our hospital setting.[42,43] We observed generally elevated resistance rates across various antimicrobial agents among patients in non-surgical wards compared to the surgical wards. This finding suggests a complex interplay of factors, including the prevalence of chronic conditions and potentially compromised immune systems, contributing to increased resistance in non-surgical patient populations.[44,45] Notably, in the hospital setting in

Vietnam, antibiotics commonly overprescribed or self-medication such as gentamicin, norfloxacin, and ciprofloxacin, showed significantly higher resistance rates in the non-surgical wards, indicating potential overuse or misuse of these agents in this patient population.[46–48] In addition, certain antibiotics, including carbapenems, displayed higher resistance rates among patients in the non-surgical wards, possibly due to selective pressure from prior antibiotic use or increased exposure to resistant pathogens in non-surgical settings. The significant differences in resistance rates for antibiotics like meropenem and imipenem underscore the importance of tailoring antimicrobial therapy based on the specific patient population and clinical context. These findings emphasize the need for targeted antimicrobial stewardship efforts to optimize antibiotic use and minimize the emergence of resistance, particularly in high-risk hospital wards. Similar trends were observed in Gram-positive bacteria, with higher resistance rates seen in the non-surgical wards for antibiotics like tetracyclines, rifampicin, and trimethoprim/sulfamethoxazole. Conversely, antibiotics like macrolides, except for amikacin and glycopeptides, exhibited slightly higher resistance rates in the surgical wards, possibly due to differences in patient demographics, underlying conditions, or healthcare practices. Understanding the drivers of resistance and implementing targeted interventions, such as antimicrobial stewardship programs and infection control measures, is essential for preserving the effectiveness of antibiotics and minimizing the impact of multidrug resistance infections in surgical and non-surgical patient populations.

The multidrug resistance results among different bacterial species present a concerning picture of the prevalence of antimicrobial resistance in the studied population. Gram-negative bacteria exhibited a substantial MDR rate of 63.6%, indicating resistance to three or more classes of antibiotics. Among these, *Acinetobacter baumannii* displayed the highest MDR rate at 88.0%, highlighting the challenge posed by this pathogen in clinical settings. *E. coli* and *P. aeruginosa* also exhibited significant MDR rates at 73.1% and 60.5%, respectively, underscoring the broad resistance spectrum of these bacteria. Although *Klebsiella pneumoniae* showed a relatively lower MDR rate at 40.5%, it still represents a significant proportion of MDR cases among Gram-negative bacteria. The observed MDR rates among Gram-positive bacteria were also notable, with an overall MDR rate of 57.3%. *Enterococcus* spp. They have demonstrated the highest MDR rate within this group at 62.9%, indicating widespread resistance to multiple antibiotic classes. *S. aureus* followed closely with an MDR rate of 57.0%, further highlighting the challenge of combating multidrug resistance in Gram-positive pathogens. Our analysis of MDR among common pathogens isolated from wound infection patients agrees with a study conducted by Alam et al, which found that MDR in Gram-negative patients was more prevalent than in Gram-positive patients.[28] However, our study showed slightly lower rates of both Gram-negative and Gram-positive MDR bacteria compared to that study by Alam et al[28] These findings underscore the urgent need for comprehensive antimicrobial stewardship programs, infection control measures, and the development of alternative treatment strategies to address the growing threat of multidrug resistance. Effective surveillance, prudent antibiotic use, and the promotion of new antimicrobial agents are essential in mitigating the impact of multidrug resistance and preserving the efficacy of existing antibiotics for future generations.

## Conclusion

In conclusion, this study sheds light on the significant burden of wound infection, the alarming prevalence of antibiotic resistance, and the variations observed across hospital wards in a teaching hospital in Vietnam. These findings highlight the urgent need for enhanced infection control measures, optimized antibiotic prescribing practices, and the development of targeted treatment strategies for wound infection. The substantial rates of multidrug resistance, particularly among Gram-negative bacteria, pose a significant public health threat. Implementing stricter antibiotic stewardship programs and robust infection control measures is crucial to curb the further expansion of resistance and ensure the continued effectiveness of antibiotics. This study's insights serve as a call to action for healthcare professionals, policymakers, and stakeholders to collaborate in addressing this pressing global health challenge.

## Data Sharing Statement

Data can be made available upon request to the corresponding author.

## Ethical Statement

This study was submitted for approval to the Ethical Committee of Military Hospital 103 (Approval No. 35/CNChT-HĐĐĐ). The Ethical Committee of Military Hospital 103 waived the requirement of patients' informed consent because the study was retrospective data. Patients' information was anonymized before being analyzed. The study completely followed the principle of the Declaration of Helsinki.

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## Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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