RESEARCH PAPER

In Vitro Susceptibility Patterns Of Cefiderocol And Ceftazidime-Avibactam Compared With The Study-Specific Antibiogram In Urinary Tract Isolates: A Cross-Sectional Study From a Tertiary Care Centre

[1*]Anirudh Singla, [2]Gurpreet Kaur Randhawa, [3]Loveena Oberoi

[1*]Junior Resident, Department of Pharmacology, Government Medical College, Amritsar, Punjab, India
Email: anibest30@gmail.com
[2]Department of Pharmacology, Government Medical College, Amritsar, India
[3]Department of Microbiology, Government Medical College, Amritsar, India

Abstract

Background: Antimicrobial resistance (AMR) poses a major global health threat, particularly in urinary tract infections (UTIs) where multidrug-resistant uropathogens increasingly compromise empirical treatment. Newer antimicrobials such as cefiderocol and ceftazidime-avibactam (CZA) require evaluation against local resistance patterns to guide therapeutic decisions

Objective: To compare the in vitro susceptibility patterns of cefiderocol and ceftazidime-avibactam with the study-specific antibiogram of standard antibiotics in urinary tract isolates at a tertiary care centre.

Methods: A cross-sectional study was conducted on 100 urine samples from confirmed UTI cases at Government Medical College, Amritsar. Organisms were identified by standard microbiological methods. Antibiotic susceptibility testing was performed by the Kirby-Bauer disc diffusion method and interpreted using CLSI M100 (2024) guidelines. Susceptibility to cefiderocol and CZA was compared with a panel of standard antibiotics tested on the same isolates.

Results: Gram-negative organisms predominated (78%), with Escherichia coli (43%) and Klebsiella spp. (20%) being the most common. Cefiderocol demonstrated overall susceptibility of 92.4% against Gram-negative isolates, CZA showed lower overall susceptibility (52.8%), with high resistance in Klebsiella (60%) and Pseudomonas (50%). The difference was statistically significant ($\chi^2 = 30.84$, $p < 0.0001$). The study specific antibiogram revealed high resistance to ampicillin, cotrimoxazole and fluoroquinolones, while nitrofurantoin and imipenem retained good activity. Among Gram-positive isolates (22%), vancomycin and linezolid showed 100% susceptibility.

Conclusion: Cefiderocol demonstrated superior in vitro activity compared to CZA against Gram-negative uropathogens. The study specific antibiogram underscores widespread resistance to first-line antibiotics, reinforcing the need for culture-guided therapy and antimicrobial stewardship.

Keywords: Urinary tract infections; Antimicrobial resistance; Antimicrobial susceptibility testing; Kirby-Bauer disc diffusion

How to cite this article: Singla A, Randhawa GK, Oberoi L. In Vitro Susceptibility Patterns Of Cefiderocol And Ceftazidime-Avibactam Compared With The Study-Specific Antibiogram In Urinary Tract Isolates: A Cross-Sectional Study From a Tertiary Care Centre. Int J Drug Deliv Technol. 2026;16(56s): 1207-1215. DOI: 10.25258/ijddt.16.56s.132

1. Introduction

Antimicrobial resistance (AMR) is a global public health crisis. In 2019, AMR was directly responsible for approximately 1.27 million deaths and contributed to nearly 5 million deaths worldwide [1]. India bears a disproportionate burden, with over 1 million AMR-related deaths in 2019, ranking among the highest globally in age-standardized AMR mortality [2]. The World Health Organization has identified AMR as one of the top ten threats to global health and emphasizes the urgency of surveillance and stewardship efforts [3].

Urinary tract infections (UTIs) are among the most common bacterial infections encountered in both community and hospital settings, accounting for approximately 30-40% of all healthcare-associated infections [4]. The aetiological landscape of UTIs is dominated by Gram-negative organisms, particularly Escherichia coli and Klebsiella pneumoniae, with rising prevalence of multidrug resistant (MDR) phenotypes including extended-spectrum β-lactamase (ESBL) producers and carbapenem-resistant Enterobacterales (CRE) [5,6]. This escalating resistance has rendered

*Author for Correspondence: anibest30@gmail.com

empirical treatment with conventional antibiotics increasingly unreliable.
Cefiderocol is a novel siderophore cephalosporin that exploits bacterial iron transport systems to penetrate the outer membrane of Gram-negative bacteria, thereby overcoming multiple resistance mechanisms including porin loss and efflux pump overexpression [7]. It demonstrates potent in vitro activity against carbapenem-resistant organisms, including those producing metallo-β-lactamases (MBLs) [8]. Ceftazidime-avibactam (CZA) is a β-lactam/β-lactamase inhibitor combination active against class A (KPC), class C (AmpC) and some class D (OXA-48) β-lactamases; however, avibactam does not inhibit class B metallo-β-lactamases (NDM, VIM, IMP) which limits its efficacy in regions where MBL producers predominate [9].
Antimicrobial stewardship programmes rely heavily on institution-specific antibiograms to guide empirical therapy [10]. However, data simultaneously comparing cefiderocol and CZA against standard antibiotic panels in the same set of urinary isolates remain scarce, particularly from tertiary care centres in North India [11]. Given the regional variability in resistance mechanisms, locally generated susceptibility data are essential for rational prescribing [12].

Given this background, the present study was designed to compare the in vitro susceptibility patterns of cefiderocol and ceftazidime-avibactam with the study specific antibiogram of routinely tested antibiotics in urinary tract isolates at a tertiary care centre.

Materials And Methods

Study Design and Setting

This cross-sectional study was conducted at the Department of Pharmacology in collaboration with the Department of Microbiology, Government Medical College, Amritsar, India. Ethical approval was obtained from the Institutional Ethics Committee prior to the commencement of the study. Written informed consent was obtained from all participants in accordance with the Declaration of Helsinki.
Sample Size Determination [13]

Prevalence of UTI is approximately 70% in study area. The sample size was determined as follows:

$$n=Z^2 \frac{x\,p\,x\,q}{d}2$$

Where;

n = required sample

p = anticipated prevalence (%)

q = 100-p (%)

Z = appropriate value from the standard normal deviate at 95 % level of confidence (1.96) in this study

d = degree of precision set at 9 %.

$$\text{Sample size (n)} = \frac{1.96^2 \times 0.7 \times 0.3}{(0.09)^2}$$

n = 100

Study Population and Sampling

A total of 100 urine samples from clinically confirmed UTI cases were collected using stratified random sampling. Samples were obtained from patients attending the outpatient department (OPD), wards and intensive care units (ICU). Inclusion criteria comprised patients of all ages and genders with informed written consent and clinical features suggestive of UTI. Patients who had received antibiotic therapy within one week prior to sample collection and samples showing contamination, mixed growth or no growth were excluded.

Microbiological Processing

Clean-catch midstream urine samples were processed within two hours of collection. Wet mount examination was performed for preliminary assessment. Samples were inoculated on Blood Agar and MacConkey Agar using the standard loop method and incubated aerobically at 37°C for 18-24 hours. Colony morphology, Gram staining and standard biochemical tests (catalase, coagulase, oxidase, indole, urease, triple sugar iron, citrate, methyl red and Voges-Proskauer tests) were performed for organism identification [14].

Antibiotic Susceptibility Testing

Antibiotic susceptibility testing (AST) was performed by the Kirby-Bauer disc diffusion method on Mueller-Hinton agar, following CLSI M100 (2024) guidelines [15]. For Gram-negative isolates, susceptibility was tested for cefiderocol, ceftazidime-avibactam, ampicillin, amoxicillin-clavulanate, ampicillin-sulbactam, cefepime, ceftriaxone, ceftazidime, cotrimoxazole, gentamicin, imipenem, norfloxacin, nitrofurantoin and piperacillin-tazobactam. For Gram-positive isolates, linezolid, ampicillin, cotrimoxazole, cefepime, gentamicin, nitrofurantoin, norfloxacin and vancomycin were tested. Disc zone diameters were interpreted as susceptible (S), resistant (R) using organism-specific CLSI breakpoints.

As per CLSI M100, cefiderocol breakpoints are applicable for Enterobacterales, Pseudomonas aeruginosa and Acinetobacter spp., while CZA breakpoints are available only for Enterobacterales and P. aeruginosa. Accordingly, susceptibility data for CZA exclude Acinetobacter spp. (n = 4).

Study Design and Workflow

The study workflow is illustrated in Figure 1.

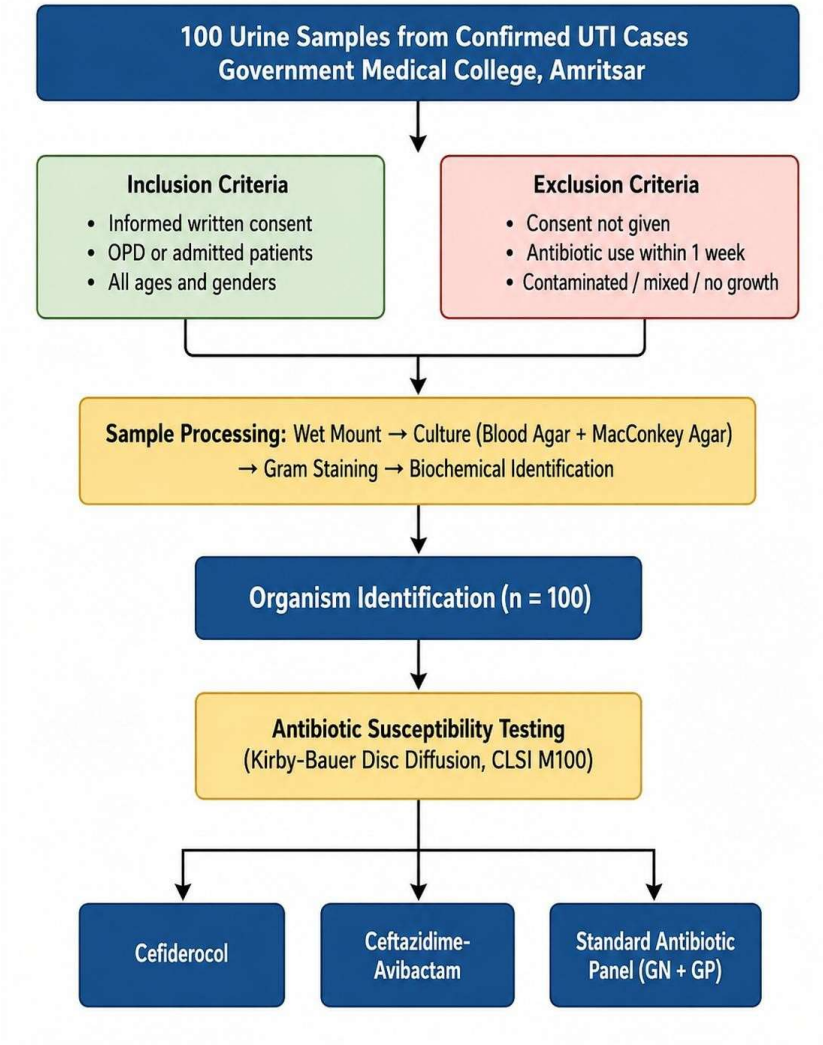

Figure 1. Study flow diagram showing sample processing, organism identification, antibiotic susceptibility testing workflow and overall susceptibility results. CZA = Ceftazidime-Avibactam.

Statistical Analysis

Data were entered and managed using Microsoft Excel. Categorical variables were expressed as frequencies and percentages. The chi-square test was used to compare susceptibility rates between cefiderocol and CZA. P less than 0.05 was considered statistically significant.

Results

Demographic And Clinical Profile

Of the 100 study participants, the majority were in the 31-40-year age group (39%), followed by 21-30 years (33%). Females constituted 79% of cases. Sixty percent of samples were collected from OPD patients, 32% from wards and 8% from ICU settings. Urinary catheterisation was present in 13% of patients (Table 1).

Table 1. Demographic and Clinical Profile of Study Participants (n = 100). Data represented as n (%).

Variable	Category	n (%)
Age Group	0-10 years	1 (1.0)
	11-20 years	5 (5.0)
	21-30 years	33 (33.0)
	31-40 years	39 (39.0)
	41-50 years	17 (17.0)
	51+ years	5 (5.0)
Gender	Female	79 (79.0)
	Male	21 (21.0)
Sample Source	OPD	60 (60.0)
	Ward	32 (32.0)
	Ward-ICU	8 (8.0)
Urinary Catheter	Yes	13 (13.0)
	No	87 (87.0)

Microbiological Profile

Gram-negative organisms constituted 78% and Gram-positive organisms 22% of all isolates. Among Gram-negative isolates, E. coli was the most prevalent uropathogen (43%), followed by Klebsiella spp. (20%), Pseudomonas spp. (8%), Acinetobacter spp. (4%) and Proteus spp. (3%). Among Gram-positive isolates, MRSA accounted for 9%, MRCONS 8% and Enterococcus spp. 5% (Table 2).

Table 2. Microbiological Profile of Urinary Isolates (n = 100). Data represented as n (%)

Gram Stain	Organism	n (%)
Gram-Negative (n = 78)	Escherichia coli	43 (43.0)
	Klebsiella spp.	20 (20.0)
	Pseudomonas spp.	8 (8.0)
	Acinetobacter spp.	4 (4.0)
	Proteus spp.	3 (3.0)
Gram-Positive (n = 22)	MRSA	9 (9.0)
	MRCONS	8 (8.0)

	Enterococcus spp.	5 (5.0)
Total		100.0

MRSA = Methicillin-resistant Staphylococcus aureus; MRCONS = Methicillin-resistant coagulase-negative staphylococci.

Comparative Susceptibility of Cefiderocol and Ceftazidime-Avibactam

Cefiderocol demonstrated overall susceptibility of 92.4% (72/78) among Gram-negative isolates. CZA showed susceptibility of 52.8% (39/74). The difference was statistically significant ($\chi^2 = 30.84$, $p < 0.0001$). Organism-specific susceptibility patterns are presented in Table 3 and Figure 2.

Table 3. Comparative In Vitro Susceptibility of Cefiderocol and Ceftazidime-Avibactam against Gram-Negative Uropathogens. Data represented as number of isolates (n) and susceptibility proportion (%).

Organism	n	FDC S%	FDC R%	CZA S%	CZA R%	p-value
E. coli	43	95.1	4.9	58.1	41.9	-
Klebsiella	20	85.0	15.0	40.0	60.0	-
Proteus	3	100.0	0.0	66.7	33.3	-
Pseudomonas	8	100.0	0.0	50.0	50.0	-
Acinetobacter	4	75.0	25.0	N/A	N/A	-
Total	78*	92.4	7.6	52.8	47.2	<0.0001

FDC = Cefiderocol; CZA = Ceftazidime-Avibactam; S = Susceptible; R = Resistant.

*CZA total n = 74 (Acinetobacter excluded per CLSI). Breakpoints per CLSI M100 (2024). Chi-square test was used to compare susceptibility rates between cefiderocol and CZA. A p-value < 0.05 was considered statistically significant.

Figure 2. Organism-wise comparison of in vitro susceptibility rates of cefiderocol and ceftazidime-avibactam against Gram-negative uropathogens. Data represented as susceptibility percentage (%). N/A indicates that CLSI breakpoints for ceftazidime-avibactam are not available for Acinetobacter spp. Chi-square test was used for overall comparison ($\chi^2 = 30.84$, $p < 0.0001$).

Study-Specific Antibiogram: Standard Antibiotics

The study-specific antibiogram for Gram-negative isolates revealed low susceptibility to, ampicillin (16.3% in E. coli), cotrimoxazole (18.6% in E. coli, 25% in Klebsiella) and fluoroquinolones (39.6% in E. coli). Imipenem retained good activity against E. coli (83.7%) and Klebsiella (80%). Nitrofurantoin demonstrated excellent activity against E. coli (88.3%) and Klebsiella (90%). Among Gram-positive isolates, vancomycin and linezolid showed 100% susceptibility across MRSA, MRCONS and Enterococcus (Table 4).

Table 4. Study-Specific Antibiogram: Susceptibility Rates of Standard Antibiotics Against Urinary Isolates. Data represented as Susceptibility Percentage (%).

Antibiotic	E. coli (%)	Kleb. (%)	Prot. (%)	Pseu. (%)	Acin. (%)	MRSA (%)	Entc. (%)
Ampicillin	16.3	-	-	-	-	44.4	80.0
Ampicillin-Sulbactam	23.2	-	-	-	25.0	-	-
Amoxicillin-Clavulanate	60.1	-	-	-	-	-	-

Cefepime	93.0	40.0	66.7	25.0	25.0	11.1	-
Ceftriaxone	41.9	50.0	66.7	-	25.0	-	-
Ceftazidime	34.8	35.0	33.3	37.5	25.0	-	-
Cotrimoxazole	18.6	25.0	33.3	-	25.0	23.3	-
Gentamicin	62.8	60.0	100.0	62.5	50.0	33.3	60.0
Imipenem	83.7	80.0	66.7	100.0	75.0	-	-
Nitrofurantoin	88.3	90.0	-	-	-	88.9	60.0
Norfloxacin	39.6	20.0	33.3	25.0	50.0	44.4	-
Pip-Tazo	27.9	15.0	33.3	25.0	25.0	-	-
Linezolid	-	-	-	-	-	88.9	100.0
Vancomycin	-	-	-	-	-	100.0	100.0

- = Not tested / Not applicable. Kleb. = Klebsiella; Prot. = Proteus; Pseu. = Pseudomonas; Acin. = Acinetobacter; Entc. = Enterococcus; Pip-Tazo = Piperacillin-Tazobactam. MRCONS data included but not shown separately for brevity (patterns comparable to MRSA).

Table 5. Suggested Empirical Antibiotic Selection Based on the Study-Specific Antibiogram. Data represented as categorical recommendations.

Organism	**1st Line (Preferred)**	**2nd Line (Acceptable)**
GRAM-NEGATIVE ORGANISMS		
Enterobacterales		
Escherichia coli	Cefiderocol / Cefepime	Imipenem / Nitrofurantoin
Klebsiella spp.	Nitrofurantoin	Cefiderocol
Proteus spp.	Cefiderocol / Gentamicin	None
Non-Fermenters		
Pseudomonas spp.	Cefiderocol / Imipenem	None
Acinetobacter spp.	None	None
GRAM-POSITIVE ORGANISMS		
Enterococcus spp.	Linezolid / Vancomycin	Ampicillin
MRSA	Vancomycin	Nitrofurantoin
MRCONS	Vancomycin	Linezolid / Nitrofurantoin

1st Line (Preferred): Resistance <10% in the present study — high probability of therapeutic success.

2nd Line (Acceptable): Resistance 10–20% — suitable alternative when first-line agents are contraindicated.

None = No antibiotic met the resistance threshold criteria for recommendation.
MRSA = Methicillin-resistant Staphylococcus aureus; MRCONS = Methicillin-resistant coagulase-negative staphylococci.
Note: Sample sizes for Proteus (n = 3), Pseudomonas (n = 8) and Acinetobacter (n = 4) are small; recommendations for these organisms should be interpreted with caution.

Based on the susceptibility patterns observed in the present study, empirical antibiotic recommendations were formulated using a resistance threshold approach (Table 5). Antibiotics with less than 10% resistance were classified as preferred first-line agents, while those with 10–20% resistance were designated as acceptable second-line alternatives. Among Gram negative Enterobacterales, cefiderocol, cefepime and nitrofurantoin emerged as reliable first line options, with imipenem serving as a second-line agent; for non-fermenting organisms, cefiderocol and imipenem were the only agents that met the threshold. Among Gram positive isolates, vancomycin and linezolid were uniformly effective as first-line agents across all organisms tested.

Discussion

The present cross-sectional study evaluated the in vitro susceptibility of cefiderocol and ceftazidime-avibactam alongside a panel of standard antibiotics in 100 urinary isolates from a tertiary care centre in North India. Cefiderocol demonstrated significantly superior overall susceptibility (92.4%) compared to CZA (52.8%, $p < 0.0001$) and the study-specific antibiogram highlights widespread resistance to commonly prescribed empirical agents.

The demographic profile had female predominance (79%) and peak incidence in the 21–40-year age group (72%), is consistent with established UTI epidemiology. Flores-Mireles et al., in a comprehensive review, reported that women account for the majority of UTI cases due to anatomical and hormonal factors [4]. Hooton similarly documented female-to-male UTI ratios of 3-4:1 in community settings [16]. Khan et al., studied uropathogens at a tertiary centre in Lucknow, India and reported 48% of cases in patients aged 20-40 years - this was close to the present findings [6].

The predominance of Gram-negative organisms (78%) aligns with global UTI surveillance data. The E. coli prevalence of 43% in the present study is consistent with reports by Flores-Mireles et al. (50-70%) [4], Khan et al. (48%) [6], and Bakshi et al. (41%) from Punjab [17]. Klebsiella spp. at 20% was slightly higher than many community-based studies, possibly reflecting the mixed OPD hospital sampling strategy and higher antibiotic selection pressure in this setting [6,17].

Cefiderocol exhibited excellent organism-specific performance: E. coli 95.3%, Klebsiella 85%, Pseudomonas 100% and Proteus 100%. It also demonstrated excellent activity against carbapenem-resistant isolates. These findings are consistent with published data. Borde et al., evaluating cefiderocol against meropenem-resistant Klebsiella isolates in India, reported 80% susceptibility [18]. Malisova et al., studying carbapenem-resistant Enterobacterales in Europe, reported 81.9% susceptibility to cefiderocol [19]. The CREDIBLE-CR trial by Bassetti et al. demonstrated cefiderocol efficacy against carbapenem-resistant Gram-negative infections, including UTIs, supporting its role in treating complicated resistant infections [8].

In contrast, CZA showed comparatively lower susceptibility (52.8% overall), with particularly poor performance against Klebsiella (40%) and Pseudomonas (50%). This is notably lower than Western surveillance data: Zalas-Więcek et al. reported CZA susceptibility of 98.9% against Enterobacterales in Poland [20]. However, the present findings are more consistent with Indian studies. The reduced CZA performance likely reflects the high prevalence of metallo-β-lactamase (MBL) producers, particularly NDM-type, in North India, as avibactam does not inhibit class B enzymes [9,21].

The addition of avibactam to ceftazidime improved susceptibility compared to ceftazidime alone in E. coli (from 34.8% to 58.1%), Proteus (33.3% to 66.7%) and Pseudomonas (37.5% to 50%), confirming the presence of avibactam-inhibitable β-lactamases (class A/C/D). However, the improvement was minimal in Klebsiella (35% to 40%), suggesting predominant MBL-mediated resistance in these isolates.

The study-specific antibiogram revealed high resistance to commonly used empirical agents. Fluoroquinolone resistance in E. coli (60.4%) and Klebsiella (80%) is consistent with data from the Indian Council of Medical Research (ICMR) Antimicrobial Resistance Surveillance Network, which reported 65-75% fluoroquinolone resistance in E. coli across Indian tertiary centres [22]. Likewise, cotrimoxazole resistance exceeded 60% in E. coli which made it unsuitable for empirical therapy. Nitrofurantoin retained good activity against E. coli (88.3%) and Klebsiella (90%), supporting its continued role in uncomplicated UTIs, consistent with IDSA guidelines [23]. Among Gram positive isolates, vancomycin and linezolid demonstrated 100% susceptibility which confirmed their reliability as therapeutic options.

The clinical implications of these findings are significant. Cefiderocol, with its superior activity against Gram-negative uropathogens including non-fermenters, may be considered for complicated UTIs and MDR infections i.e., in regions with high MBL prevalence where CZA has limited efficacy. However, antimicrobial stewardship principles mandate that cefiderocol be reserved for confirmed MDR cases to prevent resistance emergence [10,24]. CZA retains utility against KPC and OXA-48-producing isolates but should not be used empirically in regions with high NDM prevalence [9].

Strengths and Limitations

Strengths of this study include the simultaneous evaluation of two newer agents alongside a comprehensive standard antibiotic panel on the same set of isolates, providing a direct comparative framework. The inclusion of both community (OPD) and hospital

(ward/ICU) samples enhances representativeness within the institutional setting. All susceptibility testing followed standardised CLSI M100 guidelines in order to ensure reproducibility and international comparability. The study has several limitations to be pointed out. As a single centre study with a sample size of 100, external validity is limited and regional variations in resistance patterns may not be fully captured. Disc diffusion is acceptable but is less precise than MIC based methods for newer agents; Kowalska-Krochmal and Dudek-Wicher reported that MIC testing improves accuracy by 15-20% for novel antimicrobials [25]. The absence of molecular characterisation (carbapenemase gene detection, ESBL profiling) limited the ability to correlate phenotypic resistance with genetic mechanisms. Clinical outcome data were not assessed and future studies should incorporate treatment response, recurrence and mortality to validate in vitro findings.

Future Directions

Future research should incorporate multicentre surveillance to capture regional variability across India, MIC based testing using broth microdilution for accurate susceptibility determination and PCR-based detection of carbapenemase genes (NDM, VIM, IMP, KPC, OXA-48) with whole-genome sequencing of MDR isolates. CZA aztreonam synergy testing is essential given the high MBL prevalence in this region. Annual updates to institutional antibiograms are critical for empirical therapy and antimicrobial stewardship programmes [26,27]

Conclusion

The present study demonstrated that cefiderocol exhibited significantly superior in vitro activity (92.4%) compared to ceftazidime-avibactam (52.8%) against Gram-negative uropathogens ($p < 0.0001$). The study-specific antibiogram revealed widespread resistance to commonly prescribed empirical antibiotics including ampicillin, cotrimoxazole and fluoroquinolones, while nitrofurantoin, imipenem, vancomycin and linezolid retained good activity. These findings underscore the necessity of culture-guided therapy, routine generation of institutional antibiograms and the judicious use of newer agents within antimicrobial stewardship frameworks. Cefiderocol emerged as a more reliable therapeutic option than CZA for Gram-negative urinary infections in settings with high Metallo-β-lactamase prevalence.

Declarations

Ethics Approval: The study was approved by the Institutional Ethics Committee- 40801/D-26/2023 Batch; dated 26 November 2024, Government Medical College, Amritsar.

Conflicts of Interest: The authors declare no conflicts of interest.

Informed consent: Written informed consent was obtained from participants.

Funding: None.

Author Contributions: AS: conceptualisation, data collection, analysis and manuscript writing. GKR: conceptualisation, supervision and critical review. LO: co-supervision and microbiological guidance.

References

1. Murray CJ, Ikuta KS, Sharara F, et al. Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. Lancet. 2022;399:629-655. https://doi.org/10.1016/S0140-6736(21)02724-0
2. World Health Organization. Global antimicrobial resistance and use surveillance system (GLASS) report. 2022. https://www.who.int/publications/i/item/9789240062702
3. World Health Organization. Antimicrobial resistance. 2024. https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance
4. Flores-Mireles AL, Walker JN, Caparon M, Hultgren SJ. Urinary tract infections: epidemiology, mechanisms of infection and treatment options. Nat Rev Microbiol. 2015;13:269-284. https://doi.org/10.1038/nrmicro3432
5. Laxminarayan R, Duse A, Wattal C, et al. Antibiotic resistance—the need for global solutions. Lancet Infect Dis. 2013;13:1057-1098.
6. Khan S, Maroof P, Amin U. Microbial etiology and resistance patterns of urinary tract infection at a tertiary care centre—a hospital based study. J Pure Appl Microbiol. 2023;17(3):1659-1668. doi: 10.22207/JPAM.17.3.28
7. Ito A, Nishikawa T, Matsumoto S, et al. Siderophore cephalosporin cefiderocol utilizes ferric iron transporter systems for antibacterial activity against Pseudomonas aeruginosa. Antimicrob Agents Chemother. 2016;60:7396-7401.
8. Bassetti M, Echols R, Matsunaga Y, et al. Efficacy and safety of cefiderocol or best available therapy for the treatment of serious infections caused by carbapenem-resistant Gram-negative bacteria (CREDIBLE-CR): a randomised, open-label, multicentre, phase 3 trial. Lancet Infect Dis. 2021;21:226-240.
9. van Duin D, Bonomo RA. Ceftazidime/avibactam and ceftolozane/tazobactam: second-generation β-lactam/β-lactamase inhibitor combinations. Clin Infect Dis. 2016;63:234-241.
10. Dyar OJ, Huttner B, Schouten J, Pulcini C; ESGAP. What is antimicrobial stewardship? Clin Microbiol Infect. 2017;23:793-798. https://doi.org/10.1016/j.cmi.2017.08.026
11. Mnyambwa NP, Mahende C, Wilfred A, et al. Antibiotic susceptibility patterns of bacterial isolates from routine clinical specimens from referral hospitals in Tanzania: a prospective hospital-based observational study. Infect Drug Resist. 2021;14:869-878.
12. Ranjalkar J, Chandy SJ. India's National Action Plan for antimicrobial resistance—an overview of the context, status and way ahead. J Family Med Prim Care. 2019;8:1828-1834. https://doi.org/10.4103/jfmpc.jfmpc_275_19

13. Pourhoseingholi MA, Vahedi M, Rahimzadeh M. Sample size calculation in medical studies. Gastroenterol Hepatol Bed Bench. 2013;6(1):14-17.
14. Karah N, Rafei R, Elamin W, Ghazy A, Abbara A, Hamze M, Uhlin BE. Guideline for Urine Culture and Biochemical Identification of Bacterial Urinary Pathogens in Low-Resource Settings. Diagnostics. 2020;10:832. https://doi.org/10.3390/diagnostics10100832
15. Clinical and Laboratory Standards Institute. Performance standards for antimicrobial susceptibility testing. CLSI supplement M100. 34th ed. Wayne, PA: CLSI; 2024.
16. Hooton TM. Uncomplicated urinary tract infection. N Engl J Med. 2012;366:1028-1037. https://doi.org/10.1056/NEJMcp1104429
17. Bakshi R, Walia G, Ashraf F. Antimicrobial resistance pattern of gram negative bacteria associated with urinary tract infection at a teaching hospital in the Malwa region of Punjab. GMC Patiala J Res Med Edu. 2018;1:21-27.
18. Borde K, Kareem MA, Sharma R, Dass SM, Ravi V, Mathai D. In vitro activity of cefiderocol against comparators (ceftazidime-avibactam, ceftazidime-avibactam/aztreonam combination and colistin) against clinical isolates of meropenem-resistant Klebsiella pneumoniae from India. Microbiol Spectr. 2023;11:e0084723. https://doi.org/10.1128/spectrum.00847-23
19. Malisova L, Vrbova I, Pomorska K, Jakubu V, Zemlickova H. In vitro activity of cefiderocol against carbapenem-resistant Enterobacterales and Pseudomonas aeruginosa. Microb Drug Resist. 2023;29:485-491. https://doi.org/10.1089/mdr.2023.0090
20. Zalas-Więcek P, Prażyńska M, Pojnar Ł, et al. Ceftazidime/avibactam and other commonly used antibiotics activity against Enterobacterales and Pseudomonas aeruginosa isolated in Poland in 2015-2019. Infect Drug Resist. 2022;15:1289-1304. https://doi.org/10.2147/IDR.S344165
21. Mishra S, Bhoi P, Choudhary L, Panigrahi R, Otta S. Assessment of in vitro antimicrobial activity of ceftazidime-avibactam and phenotypic synergy testing with aztreonam against carbapenem resistant Gram-negative bacilli in a tertiary care hospital. J Lab Physicians. 2024;16:366-371. https://doi.org/10.25259/JLP_30_2024
22. Kaur J, Dhama AS, et al. ICMR's Antimicrobial Resistance Surveillance system (i-AMRSS): a promising tool for global antimicrobial resistance surveillance. JAC Antimicrob Resist. 2021;3:dlab023. https://doi.org/10.1093/jacamr/dlab023
23. Gupta K, Hooton TM, Naber KG, et al. International clinical practice guidelines for the treatment of acute uncomplicated cystitis and pyelonephritis in women: a 2010 update by IDSA and ESCMID. Clin Infect Dis. 2011;52:103-120. https://doi.org/10.1093/cid/ciq257
24. Barlam TF, Cosgrove SE, Abbo LM, et al. Implementing an antibiotic stewardship program: guidelines by the Infectious Diseases Society of America and the Society for Healthcare Epidemiology of America. Clin Infect Dis. 2016;62:51-77.
25. Kowalska-Krochmal B, Dudek-Wicher R. The minimum inhibitory concentration of antibiotics: methods, interpretation, clinical relevance. Pathogens. 2021;10:165. https://doi.org/10.3390/pathogens10020165
26. Spellberg B, Bartlett JG, Gilbert DN. The future of antibiotics and resistance. N Engl J Med. 2013;368:299-302. https://doi.org/10.1056/NEJMp1215093
27. Davies J, Davies D. Origins and evolution of antibiotic resistance. Microbiol Mol Biol Rev. 2010;74:417-433.