History of Medicine, 2026, 12(1): 389-397
DOI: 10.48047/HM. V12.I1.2026.389-397

A Study to Detect Carbapenemase Production by Phenotypic Method in Carbapenem-Resistant Enterobacteriaceae and Its Effect on Antimicrobial Susceptibility Pattern in a Tertiary Care Hospital, Rajasthan

Dr. Shivani Nigam[1], Dr. Preeti Srivastava[2]

[1]PG Resident, Department of Microbiology, JNUIMSRC, Jaipur, Rajasthan, India
[2]Professor, Department of Microbiology, JNUIMSRC, Jaipur, Rajasthan, India

Abstract

Background: Carbapenem-resistant Enterobacterales (CRE) have emerged as a **critical global public health threat**, with mortality rates in CRE bloodstream infections ranging from **40–50%**. Carbapenems serve as last-resort antibiotics; their compromise by **carbapenemase-producing organisms** severely limits therapeutic options. The present study was undertaken to detect carbapenemase production by phenotypic method (**mCIM**) in carbapenem-resistant Enterobacteriaceae and to determine its effect on the antimicrobial susceptibility pattern in a tertiary care hospital in Rajasthan, India.

Methodology: This **prospective, laboratory-based observational study** was carried out in the Bacteriology Laboratory, Department of Microbiology, Jaipur National University Institute for Medical Sciences and Research Centre, Jaipur, Rajasthan. A total of **355 Enterobacterales isolates** obtained from clinical specimens including urine, pus, blood, sputum and endotracheal secretions were included. Identification was performed by culture characteristics, Gram staining and biochemical tests. Antimicrobial susceptibility testing was performed by **Kirby-Bauer disk diffusion method** on Mueller-Hinton agar as per **CLSI 2023 guidelines**. Carbapenemase production was detected by **modified carbapenem inactivation method (mCIM)**.

Results: Of 355 isolates, *Escherichia coli* was predominant (224; **63.1%**), followed by *Klebsiella pneumoniae* (118; 33.2%) and *Enterobacter aerogenes* (13; 3.7%). The majority of patients belonged to the 21–40 years age group (37.7%), with a male preponderance (55.2%). Urine was the most common specimen source (48.7%). All isolates showed **100% resistance to meropenem**; resistance to imipenem and ertapenem was 89.0% and 87.9%, respectively. Extensive multidrug resistance was observed across all antibiotic classes including β-lactams, fluoroquinolones and aminoglycosides. Carbapenemase production was detected by mCIM in **253 of 355 isolates (71.3%)**. Species-wise, mCIM positivity was 72.3% in *E. coli*, 67.8% in *K. pneumoniae* and 84.6% in *Enterobacter aerogenes*. No statistically significant association was found between sample type and carbapenemase production ($p = 0.61$).

Conclusion: CRE represents a **formidable therapeutic challenge** in tertiary care settings, with **carbapenemase-mediated resistance** being the dominant mechanism (71.3% by mCIM). The widespread multidrug resistance pattern leaves very limited treatment options, with **fosfomycin and nitrofurantoin** retaining comparative utility only in urinary isolates. Early phenotypic detection of carbapenemase production using mCIM is essential to guide therapy, implement infection control measures and support antimicrobial stewardship programs.

Keywords: Carbapenem-resistant Enterobacterales (CRE); Carbapenemase production; Modified Carbapenem Inactivation Method (mCIM); Antimicrobial susceptibility; Multidrug resistance; *Klebsiella pneumoniae*; *Escherichia coli*; Tertiary care hospital; Rajasthan

Introduction

The bacterial family **Enterobacterales** is widely distributed in nature and forms part of the normal intestinal microbiota of humans and animals. These are Gram-negative, rod-shaped, non-spore-forming facultative anaerobes that ferment carbohydrates. They cause a wide range of infections, most commonly **urinary tract**

infections, followed by pneumonia, wound, bloodstream and CNS infections, and are major contributors to hospital-acquired infections such as catheter-associated UTIs and ventilator-associated pneumonia [1]. *Escherichia coli* is a dominant intestinal facultative anaerobe present in most healthy individuals. It is commonly associated with community-acquired urinary tract infections and can also cause diarrhea, meningitis, septicemia, pneumonia and intra-abdominal infections. *Klebsiella* species are widely present in feces and the environment and are important causes of nosocomial infections, particularly device-associated infections [2].

Carbapenem-resistant Enterobacterales (CRE) have rapidly spread worldwide and represent a major global health threat. They are associated with high mortality in bloodstream infections and are mainly driven by **plasmid-mediated horizontal gene transfer** [3,4]. The COVID-19 era further accelerated the emergence and spread of carbapenem resistance. Healthcare-associated transmission, including patient-to-patient spread and healthcare worker carriage, plays a major role, highlighting the importance of strict infection control measures such as hand hygiene, isolation, cohorting and surveillance [5].

Carbapenems are last-line broad-spectrum antibiotics used for severe multidrug-resistant infections. Increasing resistance to other β-lactams has led to greater reliance on agents such as imipenem, meropenem, doripenem and ertapenem [6,7]. Carbapenem resistance occurs through **reduced permeability, efflux mechanisms, enzymatic degradation and carbapenemase production**. These mechanisms contribute to multidrug resistance and therapeutic failure [8-10]. Carbapenemases are classified into **Class A, Class B metallo-β-lactamases and Class C (AmpC-related enzymes)**. These enzymes differ in structure, mechanism and inhibition profiles [11,12].

Detection of carbapenem resistance involves screening methods such as disk diffusion, MIC testing and automated systems, with confirmatory tests including **Modified Hodge Test, Carba NP, mCIM and MALDI-TOF MS** [13-16]. Phenotypic detection remains essential in routine laboratories due to its **affordability and practicality**, especially in resource-limited settings. Although molecular methods are more precise, phenotypic methods remain crucial for timely detection and guiding appropriate antimicrobial therapy in multidrug-resistant infections.

Materials and Methods

A **prospective, laboratory-based observational study** was conducted at the Bacteriology Laboratory, Department of Microbiology, Jaipur National University Institute of Medical Sciences and Research Center (JNUIMSRC), Jaipur, Rajasthan. The study was carried out over a period of **one year** following approval from the **Institutional Ethics Committee**. Clinical specimens were received from both inpatient (IPD) and outpatient (OPD) departments, including urine, pus, blood, sputum, endotracheal aspirates and cerebrospinal fluid (CSF). A total of **355 Enterobacterales isolates** were included. Only one isolate per patient was included in the study. Patients already taking antibiotics were excluded.

Specimen Processing and Bacterial Identification

All specimens were processed by **direct microscopy (Gram staining)** and aerobic culture. Pus, blood, sputum and endotracheal aspirates were inoculated onto Blood agar and MacConkey agar; urine specimens were inoculated onto HiCrome UTI agar; CSF onto Chocolate agar and Blood agar. Plates were incubated aerobically at **35°C ± 2°C for 18–24 hours**. Presumptive identification of Gram-negative rods was based on colony morphology, Gram staining and a comprehensive **biochemical panel** including the indole test, methyl red (MR) test, Voges-Proskauer (VP) test, citrate utilization, urease, triple sugar iron (TSI) agar, oxidase, catalase, mannitol motility and nitrate reduction tests.

Antimicrobial Susceptibility Testing (AST)

Antimicrobial susceptibility testing was performed using the **Kirby-Bauer disk diffusion method** on Mueller-Hinton agar (MHA). Bacterial suspensions were adjusted to **0.5 McFarland turbidity**. Antibiotic discs were placed with adequate spacing and plates were incubated at 35°C for 18–24 hours. Zone diameters were measured

in millimetres (mm) and interpreted according to **CLSI 2023 guidelines**. A total of **22 antibiotics** were tested, including ampicillin, amoxicillin-clavulanate, cefazolin, ceftriaxone, cefotaxime, piperacillin-tazobactam, gentamicin, ciprofloxacin, levofloxacin, cotrimoxazole, cefuroxime, cefepime, meropenem, imipenem, ertapenem, amikacin, tetracycline, ceftazidime-avibactam, ceftazidime, colistin (MIC only), nitrofurantoin (urine isolates only) and fosfomycin (urine isolates only).

Phenotypic Detection of Carbapenemase Production: mCIM

The **Modified Carbapenem Inactivation Method (mCIM)** was performed as per CLSI guidelines. A 1 µL loopful of bacteria from an overnight blood agar culture was emulsified in 2 mL tryptic soy broth (TSB) and a 10 µg meropenem disk was added. The tubes were incubated at 35°C ± 2°C in ambient air for **4 hours ± 15 minutes**. Simultaneously, a 0.5 McFarland suspension of *E. coli ATCC 25922* was prepared and used to inoculate MHA plates (indicator lawn). The exposed meropenem disk was then placed onto the inoculated MHA plate and incubated at 35°C for 18–24 hours. mCIM was interpreted as **carbapenemase positive** when the zone diameter was 6–15 mm or when pinpoint colonies were present within a 16–18 mm zone; as **carbapenemase negative** when the zone diameter was ≥19 mm with a clear zone and no colonies; and as **indeterminate** when the zone diameter was 16–18 mm, or ≥19 mm with pinpoint colonies inside the zone.

Results

A total of **355 patients** were included in the study. The predominant age group was **21–40 years (134 patients; 37.7%)**, followed by 41–60 years (119; 33.5%), 61–80 years (50; 14.1%), ≤20 years (31; 8.7%) and >80 years (21; 5.9%). Male patients constituted **196 cases (55.2%)** and female patients 159 cases (44.8%), reflecting a **male preponderance**.

Characteristic	Number (n)	Percentage (%)
Age group		
≤ 20 years	31	8.7
21–40 years	134	37.7
41–60 years	119	33.5
61–80 years	50	14.1
> 80 years	21	5.9
Gender		
Male	196	55.2
Female	159	44.8
Department / Area		
General Medicine	75	21.1
ICU	71	20.0
General Surgery	63	17.7
OPD	40	11.3
Respiratory Medicine	30	8.5
Obstetrics and Gynaecology	29	8.2
Emergency	17	4.8
Pediatrics	16	4.5
Orthopedics	13	3.7

Characteristic	Number (n)	Percentage (%)
Dermatology	1	0.3
Sample		
Urine	173	48.7
Pus culture	99	27.9
Blood	55	15.5
Sputum	19	5.4
ET secretion	9	2.5
Organism		
Escherichia coli	224	63.1
Klebsiella pneumoniae	118	33.2
Enterobacter aerogenes	13	3.7

Table 1. Demographic and Patient Characteristics of Study Population and Isolates

The largest proportion of isolates was from the **General Medicine ward (75; 21.1%)**, followed by ICU (71; 20.0%) and General Surgery (63; 17.7%). **Urine samples** were the predominant specimen source (173; 48.7%), followed by pus cultures (99; 27.9%), blood (55; 15.5%), sputum (19; 5.4%) and endotracheal secretions (9; 2.5%). *Escherichia coli* was the most common isolate (224; 63.1%), followed by *Klebsiella pneumoniae* (118; 33.2%), with *Enterobacter aerogenes* constituting the smallest proportion (13; 3.7%).

Analysis of carbapenem susceptibility among the 355 isolates revealed an **alarmingly high level of resistance**. All isolates were resistant to **meropenem (100%)**. Resistance to imipenem was observed in 316 isolates (89.0%), with only 39 isolates (11.0%) remaining sensitive. Similarly, ertapenem resistance was detected in 312 isolates (87.9%), while sensitivity was noted in 43 isolates (12.1%).

Carbapenem	Resistant n (%)	Susceptible n (%)
Meropenem	355 (100.0)	0 (0.0)
Imipenem	316 (89.0)	39 (11.0)
Ertapenem	312 (87.9)	43 (12.1)

Table 2. Carbapenem Resistance Pattern (n = 355)

The antimicrobial susceptibility profile of CRE isolates showed **extensive multidrug resistance**. Very high resistance was observed against β-lactams including ampicillin (98.8%), amoxicillin-clavulanic acid (93.2%), cefazolin (99.7%), ceftriaxone/cefotaxime/cefuroxime (95.5%), cefepime (91.3%) and ceftazidime (95.8%). **Fluoroquinolones** also showed poor activity with high resistance to ciprofloxacin (98.9%) and levofloxacin (97.5%), while piperacillin-tazobactam resistance was 91.3%. **Aminoglycosides** showed limited sensitivity (amikacin 29.3%, gentamicin 26.5%). Cotrimoxazole (15.8%) and tetracycline (20.0%) showed low sensitivity, and **ceftazidime-avibactam** had limited activity (7.0%). Among urinary isolates, **nitrofurantoin** showed the highest susceptibility (57.2%), followed by **fosfomycin** (35.5%).

Antibiotic	Susceptible n (%)	Resistant n (%)
Ampicillin	4 (1.12)	351 (98.8)
Amoxicillin-Clavulanic acid	24 (6.8)	331 (93.2)
Cefazolin	1 (0.3)	354 (99.7)

Antibiotic	Susceptible n (%)	Resistant n (%)
Ceftriaxone	16 (4.5)	339 (95.5)
Cefotaxime	16 (4.5)	339 (95.5)
Piperacillin-Tazobactam	31 (8.7)	324 (91.3)
Gentamicin	94 (26.5)	261 (73.5)
Ciprofloxacin	4 (1.1)	351 (98.9)
Levofloxacin	9 (2.5)	346 (97.5)
Cotrimoxazole	56 (15.8)	299 (84.2)
Cefuroxime	15 (4.2)	340 (95.5)
Cefepime	31 (8.7)	324 (91.3)
Meropenem	0 (0.0)	355 (100.0)
Imipenem	39 (11.0)	316 (89.0)
Ertapenem	43 (12.1)	312 (87.9)
Amikacin	104 (29.3)	251 (70.7)
Tetracycline	71 (20.0)	284 (80.0)
Ceftazidime	15 (4.2)	340 (95.8)
Ceftazidime-Avibactam	25 (7.0)	315 (88.7)
Nitrofurantoin (Urine; n=173)	99 (57.2)	74 (42.7)
Fosfomycin (Urine; n=134)	126 (35.5)	8 (2.3)

Table 3. Antimicrobial Susceptibility Pattern in CRE (n = 355)

Species-Wise Antimicrobial Susceptibility

***Escherichia coli* (n = 224):** The antimicrobial susceptibility pattern of 224 *Escherichia coli* isolates showed high-level multidrug resistance, with very high resistance to β-lactams (ampicillin 97.8%, cefazolin 99.6%, ceftriaxone 94.6%) and fluoroquinolones (98.7% resistance to ciprofloxacin and levofloxacin). Carbapenem resistance was high (meropenem 100%, imipenem 85.7%, ertapenem 83.0%). Among urinary isolates (n = 134), **fosfomycin** demonstrated the highest effectiveness with **94.0% sensitivity**, while nitrofurantoin showed moderate sensitivity (65.6%).

***Klebsiella pneumoniae* (n = 118):** This species showed **extensive multidrug resistance**, with universal resistance (100%) to ampicillin, cefazolin, cefuroxime and meropenem. Aminoglycoside activity was limited (gentamicin 10.2%, amikacin 20.3% sensitivity), and carbapenem resistance was high (imipenem 94.9%, ertapenem 95.8%). Among urinary isolates (n = 39), nitrofurantoin showed limited effectiveness (28.2% sensitivity).

***Enterobacter aerogenes* (n = 13):** Complete resistance (100%) was observed to ampicillin, amoxicillin-clavulanic acid, cefazolin, ceftriaxone, cefotaxime, cefuroxime, ciprofloxacin, levofloxacin, meropenem, ertapenem and ceftazidime. Imipenem also showed poor activity, with only **7.7% sensitivity**.

Species-wise analysis of carbapenemase-producing organisms by **mCIM** showed that among *Escherichia coli* isolates (n = 224), 162 (72.3%) were positive; among *Klebsiella pneumoniae* (n = 118), 80 (67.8%) were positive; and *Enterobacter aerogenes* showed the highest proportion, with 11 of 13 isolates (84.6%) testing positive. Overall, carbapenemase production was detected in **253 isolates (71.3%)**.

History of Medicine, 2026, 12(1): 389-397
DOI: 10.48047/HM. V12.I1.2026.389-397

Organism	mCIM Positive n (%)	mCIM Negative n (%)	Total
Escherichia coli	162 (72.3)	62 (27.7)	224
Klebsiella pneumoniae	80 (67.8)	38 (32.2)	118
Enterobacter aerogenes	11 (84.6)	2 (15.4)	13
Total	**253 (71.3)**	**102 (28.7)**	**355**

Table 4. Species-Wise Carbapenemase Production by mCIM

The association between sample type and carbapenemase production showed that among urine samples, 124 of 174 isolates were positive; in pus samples, 68 of 100; in blood, 43 of 55; and in respiratory/other samples, 18 of 26. Overall, **no significant association was observed between sample type and carbapenemase production (p = 0.61)**.

Sample group	Positive	Negative	Total
Urine	124	50	174
Pus	68	32	100
Blood	43	12	55
Respiratory / Other	18	8	26
Total	**253**	**102**	**355**

Table 5. Association of Sample Type with Carbapenemase Production (mCIM)

Discussion

Carbapenem-resistant Enterobacterales have emerged as a **formidable clinical and public health challenge** globally, with the rapid dissemination of carbapenemase genes through horizontal gene transfer significantly narrowing treatment options. The present study provides a comprehensive analysis of the epidemiology, antimicrobial susceptibility and carbapenemase production patterns among CRE isolates from a tertiary care hospital in Jaipur, Rajasthan. The majority of patients (37.7%) belonged to the 21–40 years age group, with male predominance (55.2%), mirroring findings by **Patidar et al. (2021) [17]**, who similarly reported the highest CRE proportion in the 21–40 years group (36%). In contrast, studies by **Abhishek et al. (2022) [18]** and **Khare et al. (2022) [19]** found a shift toward older patient cohorts (>60 years), possibly reflecting ICU-predominant study populations with greater comorbidity burden. The male preponderance is consistent with **Sahin et al. (2015) [20]** (65.1% male) and **Aishwarya et al. (2021) [21]** (60% male).

Urine was the predominant specimen source (48.7%), consistent with **Mulla et al. (2016) [22]** and **Chanda et al. (2024) [23]**. Conversely, pus-dominant distributions have been reported by **Parate et al. (2017) [24]** and **Aishwarya et al. (2021) [21]**, while endotracheal secretion-dominant patterns were noted by **Vamsi et al. (2022) [25]** in ICU-enriched cohorts — highlighting how study population and clinical setting substantially influence specimen distribution. Department-wise, General Medicine (21.1%) and ICU (20.0%) contributed most isolates, aligning with **Patidar et al. (2021) [17]** and **Abhishek et al. (2022) [18]**.

Escherichia coli was the predominant isolate (63.1%), followed by *K. pneumoniae* (33.2%), agreeing with **Abhishek et al. (2022) [18]** (E. coli 55%, K. pneumoniae 34%) and **Patidar et al. (2021) [17]**. Some studies, including **Aishwarya et al. (2021) [21]** and **Sahin et al. (2015) [20]**, reported K. pneumoniae as the dominant organism, particularly in ICU and bloodstream settings, suggesting organism predominance is influenced by clinical context and specimen mix.

The extensive multidrug resistance documented in this study — near-universal resistance to β-lactams and fluoroquinolones — reflects the severe co-resistance phenotype typical of CRE. **Universal meropenem resistance (100%)** across all isolates is a defining feature of clinically significant CRE. Fluoroquinolone resistance exceeded 97% for both ciprofloxacin and levofloxacin, mirroring **Chavan et al. (2024) [26]** (ciprofloxacin 93.9%, levofloxacin 97.4%). Aminoglycoside susceptibility (amikacin 29.3%, gentamicin 26.5%) was limited but represented a relative pocket of remaining activity, consistent with **Silva et al. (2017) [27]**. Ceftazidime-avibactam sensitivity was low (7.0%), indicating that even newer β-lactam/β-lactamase inhibitor combinations face significant resistance pressure. Notably, **fosfomycin retained high activity (94.0%)** among urinary E. coli isolates, consistent with its established role as a valuable oral salvage option for CRE urinary tract infections.

The **mCIM positivity rate of 71.3%** confirms carbapenemase-mediated resistance as the dominant mechanism among CRE isolates in this tertiary care hospital. This rate is broadly concordant with **Giri et al. (2021) [28]** (67.9% in Maharashtra) and **Khare et al. (2022) [19]** (~70%). *Enterobacter aerogenes* showed the highest carbapenemase production rate (84.6%), likely reflecting intrinsic AmpC activity compounded by acquired carbapenemases. The **28.7% of mCIM-negative CRE isolates** suggest that non-carbapenemase mechanisms — such as porin loss combined with AmpC/ESBL overexpression, or efflux pump upregulation — also contribute significantly to carbapenem resistance, necessitating complementary testing (e.g., eCIM for MBL differentiation). The absence of a statistically significant association between sample type and carbapenemase production ($p = 0.61$) demonstrates that carbapenemase-producing CRE are **not restricted to any particular anatomical or infection site**, underscoring the need for systematic surveillance and universal infection control precautions.

The study employed mCIM **without confirmation by eCIM** for all isolates, which precludes definitive classification of carbapenemase class (MBL vs. serine carbapenemase). **Molecular methods** (PCR for bla-NDM, bla-KPC, bla-OXA-48) were not performed, limiting characterization of specific carbapenemase genes. The **single-center design** limits generalizability to other regions and hospital types.

Conclusion

This study highlights a substantial burden of CRE in a tertiary care hospital setting, predominantly affecting young and middle-aged adults with male preponderance. Most isolates were recovered from urine and pus samples, indicating **urinary tract and wound-related infections** as major sources, while medical wards, intensive care units and surgical departments were the main contributing areas. *Escherichia coli* was the most frequently isolated organism, followed by *Klebsiella pneumoniae*, whereas *Enterobacter aerogenes* constituted a smaller proportion. Antimicrobial susceptibility testing showed **extensive multidrug resistance** across all species, with very high resistance to beta-lactams, fluoroquinolones and carbapenems, including universal meropenem resistance. **Fosfomycin and nitrofurantoin** showed comparatively better activity among urinary isolates, although their usefulness remained limited to specific clinical contexts. Phenotypic testing by mCIM demonstrated carbapenemase production in **more than two-thirds of isolates**, confirming carbapenemase-mediated resistance as a major mechanism. High carbapenemase positivity across major species and the absence of significant association with sample type suggest widespread distribution across different clinical specimens. Overall, the findings emphasize the serious therapeutic challenges posed by CRE and support the need for strengthened **antimicrobial stewardship, routine phenotypic detection, continuous resistance surveillance, judicious use of last-line antibiotics and strict infection prevention measures** in tertiary care hospitals.

References

1. Gupta N, Limbago BM, Patel JB, Kallen AJ. Carbapenem-resistant Enterobacteriaceae: epidemiology and prevention. Clin Infect Dis. 2011;53(1):60-67.

2. Baek MS, Kim JH, Park JH, Kim TW, Jung HI, Kwon YS. Comparison of mortality rates in patients with carbapenem-resistant Enterobacterales bacteremia according to carbapenemase production: a multicenter propensity-score matched study. Sci Rep. 2024 Jan 5;14(1):597.

3. Nordmann P, Naas T, Poirel L. Global spread of carbapenemase-producing Enterobacteriaceae. Emerg Infect Dis. 2011;17(10):1791-1798.

4. van Duin D, Doi Y. The global epidemiology of carbapenemase-producing Enterobacteriaceae. Virulence. 2017;8(4):460-469.

5. Sakagianni A, Koufopoulou C, Koufopoulos P, Feretzakis G, Koumaki V. The impact of COVID-19 on the epidemiology of carbapenem resistance. Antibiotics. 2025 Sep 11;14(9):916.

6. Hawkey PM, Livermore DM. Carbapenem antibiotics for serious infections. BMJ. 2012;344:e3236.

7. Patel G, Bonomo RA. 'Stormy waters ahead': global emergence of carbapenemases. Front Microbiol. 2013;4:48.

8. Codjoe FS, Donkor ES. Carbapenem resistance: a review. Med Sci (Basel). 2017 Dec 21;6(1):1.

9. Sawa T, Kooguchi K, Moriyama K. Molecular diversity of extended-spectrum β-lactamases and carbapenemases and antimicrobial resistance. J Intensive Care. 2020 Jan 28;8:13.

10. Jeon JH, Lee JH, Lee JJ, Park KS, Karim AM, Lee CR, Jeong BC, Lee SH. Structural basis for carbapenem-hydrolyzing mechanisms of carbapenemases conferring antibiotic resistance. Int J Mol Sci. 2015 Apr 29;16(5):9654-9692.

11. Nordmann P, Poirel L. Epidemiology and diagnostics of carbapenem resistance in gram-negative bacteria. Clin Infect Dis. 2019 Nov 13;69(Suppl 7):S521-528.

12. Walther-Rasmussen J, Høiby N. Class A carbapenemases. J Antimicrob Chemother. 2007 Sep;60(3):470-482.

13. Calderaro A, Chezzi C. MALDI-TOF MS: a reliable tool in the real life of the clinical microbiology laboratory. Microorganisms. 2024 Feb 3;12(2):322.

14. Schuetz AN, Ferrell A, Hindler JA, Humphries R, Bobenchik AM. Overview of changes in the Clinical and Laboratory Standards Institute performance standards for antimicrobial susceptibility testing: M100 32nd and 33rd editions. J Clin Microbiol. 2025 Sep 10;63(9):e01623-23.

15. Pandurangan S, BegumEsak S, Narayanasamy A. Phenotypic detection methods of carbapenemase production in Enterobacteriaceae. Int J Curr Microbiol Appl Sci. 2015;4(06):547-552.

16. Dobhal S, Sen M, Agarwal J, Das A, Chandra A, Srivastava A, Nath SS. Carbapenemase detection methods for carbapenem-resistant Enterobacterales: which to choose? MGM J Med Sci. 2023 Apr 1;10(2):218-224.

17. Patidar N, Vyas N, Sharma S, Sharma B. Phenotypic detection of carbapenemase production in carbapenem-resistant Enterobacteriaceae by modified hodge test and modified strip carba NP test. J Lab Physicians. 2021 Mar;13(01):014-021.

18. Abhishek S, Naik SS, Leela KV, Maheswary D. Genotypic distribution and antimicrobial susceptibilities of carbapenemase-producing Enterobacteriaceae isolated in tertiary care hospital in South India. J Pure Appl Microbiol. 2022 Dec 1;16(4).

19. Khare AP, Gopinathan A, Leela KV, Naik S. Comparison of three phenotypic methods of carbapenemase enzyme detection to identify carbapenem-resistant Enterobacterales. J Pure Appl Microbiol. 2022 Dec 1;16(4):2679-2687.

20. Sahin K, Tekin A, Ozdas S, Akin D, Yapislar H, Dilek AR, Sonmez E. Evaluation of carbapenem resistance using phenotypic and genotypic techniques in Enterobacteriaceae isolates. Ann Clin Microbiol Antimicrob. 2015 Oct 6;14(1):44.

21. Aishwarya JR, Illamani V. Prevalence and antimicrobial susceptibility pattern of carbapenemase producing gram-negative bacterial isolates. J Res Med Dent Sci. 2021;9(6):140-149.

22. Mulla S, Charan J, Rajdev S. Antibiotic sensitivity pattern in blaNDM-1-positive and carbapenemase-producing Enterobacteriaceae. Int J Appl Basic Med Res. 2016;6(1):14-17.

23. Chanda P, Gupta S, Chattopadhyay S, Bose S. Phenotypic detection of carbapenem-resistant Enterobacterales and carbapenem-resistant Pseudomonas aeruginosa by mCIM and eCIM in a tertiary care hospital in Eastern India. Asian J Med Sci. 2024;15(8):79-84.

24. Parate A, Karyakarte R, Ambhore N. Phenotypic detection of carbapenemase production and difference in antimicrobial susceptibility pattern in clinical isolates of Klebsiella pneumoniae. Indian J Microbiol Res. 2017;4(3):253-258.

25. Vamsi SK, Moorthy RS, Hemiliamma MN, Reddy RB, Sirikonda S. Phenotypic and genotypic detection of carbapenemase production among gram negative bacteria isolated from hospital-acquired infections. Saudi Med J. 2022;43(3):236.

26. Chavan SS, Angadi KM, Dave RP. Occurrence and types of carbapenamase enzymes amongst enterobacterales and Pseudomonas spp. using automated phenotypic method. IP Int J Med Microbiol Trop Dis. 2024;10(2):138-144.

27. Silva DD, Rampelotto RF, Lorenzoni VV, Santos SO, Damer J, Hörner M, Hörner R. Phenotypic methods for screening carbapenem-resistant Enterobacteriaceae and assessment of their antimicrobial susceptibility profile. Rev Soc Bras Med Trop. 2017 Mar;50:173-178.

28. Giri S, Sen S, Lall M. Descriptive study for detection of carbapenem-resistant Enterobacteriaceae by the Modified Carbapenem Inactivation Method in a tertiary care hospital of Western Maharashtra. J Evid Based Med Healthc. 2021;8(05):261-266.