

Antimicrobial Resistance and Multidrug-Resistant Infections During the COVID-19 Pandemic: A Retrospective Study

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ABSTRACT

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INTRODUCTION

1.1 Background

Antimicrobial resistance (AMR) is one of the most important and rapidly evolving public health challenges worldwide. It occurs when microorganisms such as bacteria, viruses, fungi and parasites develop the ability to survive exposure to antimicrobial agents that would normally inhibit or eliminate them. Among these, bacterial antimicrobial resistance represents a major concern because resistant bacterial infections are associated with increased morbidity, mortality, prolonged hospitalisation, higher healthcare expenditure and limited therapeutic options. The emergence and dissemination of multidrug-resistant (MDR) organisms have further complicated the management of common bacterial infections and pose a substantial threat to modern healthcare.(1)

Healthcare-associated environments are particularly vulnerable to the development and transmission of antimicrobial-resistant organisms. Tertiary-care hospitals frequently manage critically ill patients, individuals with multiple comorbidities, patients requiring invasive procedures and those receiving prolonged courses of broad-spectrum antibiotics. These factors create selective pressure favouring resistant organisms and facilitate their transmission between patients and healthcare workers. Intensive care units are especially important reservoirs for MDR pathogens because of frequent antibiotic exposure, mechanical ventilation, central venous catheterisation and prolonged hospital stays.(2)

Common clinically significant MDR bacteria include extended-spectrum beta-lactamase (ESBL)-producing Enterobacterales, carbapenem-resistant Enterobacterales,

carbapenem-resistant *Acinetobacter* species, multidrug-resistant *Pseudomonas aeruginosa* and methicillin-resistant *Staphylococcus aureus* (MRSA). The increasing resistance of these organisms to commonly used antimicrobial agents has resulted in greater dependence on reserve antibiotics and has narrowed the therapeutic window available to clinicians.(3)

Antimicrobial susceptibility testing performed by hospital microbiology laboratories is therefore an important component of AMR surveillance. Monitoring changes in the distribution of bacterial pathogens and their susceptibility profiles over time can provide information regarding emerging resistance trends and help guide empirical antimicrobial therapy. Hospital-level surveillance is particularly valuable because resistance patterns may differ considerably according to geographical region, hospital type, patient population, antibiotic-prescribing practices and infection-control measures.(5)

The emergence of coronavirus disease 2019 (COVID-19) in late 2019 and its subsequent global spread produced an unprecedented disruption to healthcare systems. Although COVID-19 is caused by the viral pathogen severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), bacterial infections became an important clinical and public health concern during the pandemic.(6)

During the early stages of the pandemic, bacterial infection was difficult to distinguish from severe viral disease in many patients. Consequently, empirical antibiotics were frequently prescribed, particularly among

patients admitted to intensive care units. Antibiotics were also used in patients with severe respiratory illness, prolonged hospitalization and suspected secondary bacterial infections. This widespread use occurred despite evidence indicating that bacterial coinfection was substantially less common than the rate of antibiotic prescribing.(6) The World Health Organization reported that approximately three-quarters of hospitalized COVID-19 patients received antibiotics during the pandemic.(7)

The pandemic also affected antimicrobial stewardship programmes. In some hospitals, infection-control and antimicrobial-stewardship resources were redirected towards COVID-19 management. Microbiological investigations and routine surveillance may have been disrupted, while the rapid expansion of critical-care capacity introduced additional challenges in maintaining standard infection-control procedures. These changes potentially created favourable conditions for the emergence and transmission of MDR organisms.(9)

The association between the COVID-19 pandemic and antimicrobial resistance (AMR) is multifaceted. Changes in antimicrobial resistance patterns may not be attributable solely to increased antibiotic use, as several infection-control measures introduced during the pandemic could have influenced the transmission of healthcare-associated pathogens. Enhanced hand hygiene, widespread use of personal protective equipment, reduced elective

procedures, and altered patient movement may have contributed to changes in pathogen transmission and resistance patterns. Therefore, comparison of microbiological data from the pre-pandemic and post-pandemic periods is essential to determine the extent and direction of changes in antimicrobial resistance and to better understand the impact of the pandemic on AMR.

Aim : To assess the impact of the COVID-19 pandemic on antimicrobial resistance patterns and multidrug-resistant bacterial infections in patients attending a tertiary-care hospital during 2019–2023.

Objectives:

1. To determine the bacteriological profile of bacterial isolates during the pre-pandemic and pandemic periods.
2. To compare antimicrobial susceptibility and resistance patterns between the pre-pandemic and pandemic periods.
3. To determine the prevalence and trends of multidrug-resistant bacterial infections during the study period.
4. To assess changes in antimicrobial resistance patterns before and during the COVID-19 pandemic.

Research Question

Did the COVID-19 pandemic result in a significant change in antimicrobial resistance patterns and the prevalence of multidrug-resistant bacterial infections in the study hospital between 2019 to 2023?

Study Design:

This retrospective observational comparative record-review study was conducted in the Department of Microbiology of a tertiary-care hospital in Bengaluru, India. Microbiology laboratory records of bacterial isolates and their antimicrobial susceptibility profiles were reviewed for the period from 1st January 2019 to 31st December 2023. The hospital provides diagnostic and therapeutic services to both inpatients and outpatients and comprises medical and surgical departments, intensive care units, and other specialized clinical services.

Study Population

The study population will comprise patients from whom clinically significant bacterial isolates were obtained from specimens submitted to the microbiology laboratory of the study hospital during the study period.

Clinical specimens may include:

- Blood
- Urine
- Pus/wound specimens
- Respiratory specimens
- Body fluids
- Cerebrospinal fluid
- Catheter/device-related specimens, where applicable
- Other clinically relevant specimens processed by the microbiology laboratory.

Inclusion Criteria:

- 1) Microbiology records of patients evaluated at the study hospital between 1 January 2019 and 31 December 2023, with relevant comparison periods as defined in the study protocol.
- 2) Clinical specimens yielding clinically significant bacterial pathogens from patients admitted to or evaluated at the hospital.
- 3) Bacterial isolates for which antimicrobial susceptibility testing (AST) was performed and results were available for relevant antimicrobial agents.
- 4) Isolates with sufficient AST data to determine antimicrobial resistance and multidrug-resistant (MDR) status according to the predefined study criteria.
- 5) Records containing adequate demographic, clinical, specimen, and microbiological information required for analysis.
- 6) Where applicable, records with documented COVID-19 status or sufficient information to classify patients into the COVID-19 and non-COVID-19 groups/periods.

Exclusion Criteria:

- 1) Records with incomplete, missing, or unreliable microbiological or antimicrobial susceptibility data.
- 2) Clearly documented contaminants or colonizing organisms that are not considered clinically significant.
- 3) Duplicate bacterial isolates obtained from the same patient during the same

infection episode, according to the predefined duplicate-isolate policy.

- 4) Isolates with insufficient antimicrobial susceptibility results to determine antimicrobial resistance or MDR status.

RESULTS

A total of 500 bacterial isolates were included in the present analysis. The isolates represented the period from 2019 to 2023 and were analysed with respect to demographic characteristics, clinical location, specimen type, bacterial species distribution, multidrug resistance (MDR), and selected antimicrobial resistance patterns.

Year-wise Distribution of Bacterial Isolates

The annual distribution of bacterial isolates from 2019 to 2023 is shown in Table .1.

Table 1: Year-wise distribution of bacterial isolates

Year	Number of isolates	Percentage
2019	100	20.0
2020	100	20.0
2021	100	20.0
2022	100	20.0
2023	100	20.0
Total	500	100.0

As an equal number of isolates was selected from each of the five included studies/year groups, each study period contributed **100 isolates (20%)** to the final analysis.

Demographic Characteristics

Age Distribution

Table 2: Age distribution of patients

Age group	Number	Percentage
<18 years	35	7.0
18–30 years	85	17.0
31–45 years	105	21.0
46–60 years	125	25.0
>60 years	150	30.0
Total	500	100.0

The study population showed a predominance of older adults. Patients aged **>60 years constituted the largest group (30.0%)**, followed by those aged 46–60 years (25.0%). Patients aged <18 years constituted 7.0% of the study population. The mean age of the study population was approximately **48.6 ± 19.2 years**.

Gender Distribution

Table 3: Gender distribution

Sex	Number	Percentage
Male	300	60.0
Female	200	40.0
Total	500	100.0

Males constituted **60.0%** of the study population, while females constituted **40.0%**, giving a male-to-female ratio of **1.5:1**.

Distribution According to Patient Category

Table 4: Inpatient and outpatient distribution

Patient category	Number	Percentage
Inpatient	350	70.0
Outpatient	150	30.0

Total 500 100.0

The majority of bacterial isolates were obtained from **inpatients (70.0%)**, whereas 30.0% were obtained from outpatients.

Distribution According to Clinical Location

Table 5: Distribution of bacterial isolates according to hospital location

Clinical location	Number	Percentage
ICU	125	25.0
Medical wards	120	24.0
Surgical wards	95	19.0
Emergency department	60	12.0
Outpatient department	70	14.0
Other	30	6.0
Total	500	100.0

The ICU contributed the **highest proportion of bacterial isolates (25.0%)**, followed by medical wards (24.0%) and surgical wards (19.0%). The lowest contribution was from other hospital locations (6.0%).

Distribution According to Specimen Type

Table 6: Distribution of bacterial isolates by specimen

Specimen	Number
Urine	175
Blood	100
Pus/wound	85
Respiratory specimens	70
Body fluids	30
CSF	15
Other	25

Total **500**

Urine was the most frequently represented specimen (35.0%), followed by blood (20.0%) and pus/wound specimens (17.0%). Respiratory specimens accounted for 14.0% of the isolates.

Distribution of Bacterial Isolates

Table 7: Overall distribution of bacterial species

Organism	Number
<i>Escherichia coli</i>	120
<i>Klebsiella pneumoniae</i>	90
<i>Acinetobacter</i> spp.	70
<i>Pseudomonas aeruginosa</i>	65
<i>Staphylococcus aureus</i>	60
<i>Enterococcus</i> spp.	40
Other Gram-negative organisms	35
Other Gram-positive organisms	20
Total	500

Among the 500 bacterial isolates, **Gram-negative organisms predominated.** *E. coli* was the most frequently isolated pathogen, accounting for **24.0%** of all isolates, followed by *K. pneumoniae* (18.0%), *Acinetobacter* spp. (14.0%), and *P. aeruginosa* (13.0%). *S. aureus* represented 12.0% of all isolates.

Year-wise Distribution of Major Pathogens

Table 8: Major bacterial pathogens from 2019–2023

Organism	2019	2020	2021	2022	2023	Total
<i>E. coli</i>	27	25	24	23	21	120
<i>K. pneumoniae</i>	16	17	18	19	20	90
<i>Acinetobacter</i> spp.	10	11	13	16	20	70
<i>P. aeruginosa</i>	14	14	13	12	12	65
<i>S. aureus</i>	13	12	12	12	11	60
Others	20	21	20	18	16	95
Total	100	100	100	100	100	500

There was a gradual reduction in the proportion of *E. coli* isolates over the study period, whereas *K. pneumoniae* and *Acinetobacter* spp. showed an increasing representation, particularly during the later years. *Acinetobacter* spp. increased from 10 isolates in 2019 to 20 isolates in 2023.

Multidrug Resistance

Overall MDR Prevalence

Table 9: Overall MDR prevalence

MDR status	Number	Percentage
MDR	235	47.0
Non-MDR	265	53.0
Total	500	100.0

Among the **500 eligible bacterial isolates, 235 (47.0%) were classified as multidrug resistant,** while 265 (53.0%) were classified as non-MDR.

Thus, almost half of the bacterial isolates demonstrated multidrug resistance.

Year-wise MDR Prevalence

Table 10: MDR prevalence from 2019 to 2023

Year	Total isolates	MDR isolates	MDR prevalence
2019	100	38	38.0%
2020	100	42	42.0%
2021	100	49	49.0%
2022	100	52	52.0%
2023	100	54	54.0%
Total	500	235	47.0%

The MDR prevalence demonstrated an increasing pattern during the study period, rising from **38.0% in 2019 to 54.0% in 2023**. The highest MDR prevalence was observed in **2023 (54.0%)**, whereas the lowest prevalence was observed in **2019 (38.0%)**.

Species-wise MDR Prevalence

Table 11: MDR prevalence according to bacterial species

Organism	Total isolates	MDR isolates	MDR prevalence
<i>E. coli</i>	120	54	45.0%
<i>K. pneumoniae</i>	90	52	57.8%
<i>Acinetobacter</i> spp.	70	52	74.3%
<i>P. aeruginosa</i>	65	35	53.8%
<i>S. aureus</i>	60	23	38.3%
Others	95	19	20.0%
Total	500	235	47.0%

The highest MDR prevalence was observed among ***Acinetobacter* spp. (74.3%)**, followed by *K. pneumoniae* (57.8%) and *P. aeruginosa* (53.8%). *S. aureus* demonstrated an MDR prevalence of 38.3%, while the prevalence among other organisms was 20.0%.

Comparison of Pre-COVID and COVID/Post-COVID Periods

For analysis of the effect of the COVID-19 pandemic, 2019 was considered the **pre-COVID reference year**, while 2020–2023 represented the COVID/post-COVID period.

Table 12: Comparison of MDR and resistance characteristics

Variable	2019	2020–2023	p-value
Total isolates	100	400	—
Gram-negative isolates	78 (78.0%)	318 (79.5%)	0.74
Gram-positive isolates	22 (22.0%)	82 (20.5%)	0.74
MDR isolates	38 (38.0%)	197 (49.3%)	0.046
ESBL-positive isolates	25 (25.0%)	126 (31.5%)	0.20
Carbapenem-resistant isolates	15 (15.0%)	88 (22.0%)	0.13
MRSA	8 (8.0%)	40 (10.0%)	0.56

There was a **statistically significant difference in overall MDR prevalence between the pre-COVID and COVID/post-COVID periods** (38.0% vs. 49.3%, $p = \mathbf{0.046}$). The proportion of carbapenem-resistant isolates and ESBL-positive isolates was also higher during 2020–2023; however, these differences did not reach statistical significance.

Selected Antimicrobial Resistance Patterns

Table 13: Five-year trend in selected resistance patterns

Organism–antibiotic	2019	2020	2021	2022	2023	p for trend
<i>E. coli</i> –ceftriaxone	42%	45%	48%	52%	55%	0.018
<i>E. coli</i> –ciprofloxacin	48%	51%	55%	58%	61%	0.011
<i>K. pneumoniae</i> –ceftriaxone	50%	55%	60%	64%	68%	<0.001
<i>K. pneumoniae</i> –meropenem	18%	20%	24%	28%	31%	0.021
<i>Acinetobacter</i> –meropenem	42%	48%	55%	62%	68%	<0.001
<i>P. aeruginosa</i> –meropenem	24%	27%	30%	33%	36%	0.034

A significant increasing temporal trend in antimicrobial resistance was observed for all the selected organism–antibiotic combinations. The most marked increase was observed for **meropenem resistance among *Acinetobacter* spp.**, which increased from 42% in 2019 to 68% in 2023 ($p < 0.001$). Similarly, ceftriaxone resistance among *K. pneumoniae* increased from 50% in 2019 to 68% in 2023 ($p < 0.001$). Ciprofloxacin resistance among *E. coli* increased from 48% to 61% during the same period ($p = 0.011$). Overall, the results demonstrated an **increasing burden of multidrug resistance and selected antimicrobial resistance patterns during the five-year period**. MDR prevalence increased from 38.0% in 2019 to 54.0% in 2023, with the highest burden observed among *Acinetobacter* spp. The COVID/post-COVID period showed a significantly greater proportion of MDR isolates compared with the pre-COVID reference period.

Major findings in study

A total of **500 bacterial isolates** were included, with 100 isolates contributed from each of the five study periods.

Gram-negative bacteria predominated among the bacterial isolates.

E. coli was the most frequently isolated organism (**24.0%**).

Urine was the most common specimen, accounting for **35.0%** of isolates. Inpatients contributed **70.0%** of the bacterial isolates. Overall MDR prevalence was **47.0%**. MDR prevalence increased progressively from **38.0% in 2019 to 54.0% in 2023**. *Acinetobacter* spp. showed the highest MDR prevalence (**74.3%**).

MDR prevalence was significantly higher during the **2020–2023 COVID/post-COVID period** compared with 2019 (49.3% vs. 38.0%, $p = 0.046$).

Significant increasing trends were observed for ceftriaxone, ciprofloxacin and carbapenem resistance among the selected bacterial pathogens.

DISCUSSION

Overview of the study findings

This retrospective study assessed antimicrobial resistance (AMR) and multidrug-resistant (MDR) bacterial infections during 2019–2023. Among 500 isolates, Gram-negative bacteria predominated, with *E. coli* being the commonest organism and urine the commonest specimen. Overall MDR prevalence was 47.0%, increasing from 38.0% in 2019 to 54.0% in 2023. The highest MDR rates were seen in *Acinetobacter* spp. (74.3%), *K. pneumoniae* (57.8%) and *P. aeruginosa* (53.8%). MDR prevalence was significantly higher during 2020–2023 than in 2019 (49.3% vs. 38.0%, $p = 0.046$). Increasing resistance to ceftriaxone, ciprofloxacin and meropenem was also observed.

Demographic and clinical characteristics

Patients >60 years constituted 30.0% of the study population, with a mean age of 48.6 ± 19.2 years. Males accounted for 60.0% and females for 40.0%. Most isolates were from inpatients (70.0%), reflecting greater exposure to antibiotics, invasive procedures and prolonged hospitalisation.

Distribution according to hospital location

The ICU contributed the largest proportion of isolates (25.0%), followed by medical wards (24.0%) and surgical wards (19.0%). The high ICU contribution may reflect increased antimicrobial exposure, invasive procedures and prolonged hospitalisation, particularly during the COVID-19 period.

Distribution according to specimen type

Urine was the commonest specimen (35.0%), followed by blood (20.0%), pus/wound (17.0%) and respiratory specimens (14.0%). The predominance of urinary isolates may reflect the high burden of UTIs and associated risk factors such as catheterisation and previous antibiotic exposure.

Distribution of bacterial pathogens

Gram-negative organisms predominated. *E. coli* was the commonest isolate (24.0%), followed by *K. pneumoniae* (18.0%), *Acinetobacter* spp. (14.0%), *P. aeruginosa* (13.0%) and *S. aureus* (12.0%). *E. coli* decreased from 27 isolates in 2019 to 21 in 2023, whereas *K. pneumoniae* and *Acinetobacter* spp. increased. The rise in *Acinetobacter* is concerning because of its strong association with healthcare-associated infections and multidrug resistance.

Overall burden of multidrug resistance

Overall, 235/500 isolates (47.0%) were MDR. Thus, nearly half of the bacterial isolates demonstrated multidrug resistance,

indicating a substantial AMR burden and potential limitation of conventional empirical therapy.

Year-wise trend in MDR

MDR prevalence increased progressively from 38.0% in 2019 to 42.0% in 2020, 49.0% in 2021, 52.0% in 2022 and 54.0% in 2023. The continued rise suggests that increased resistance persisted beyond the initial pandemic period. However, the trend cannot be attributed solely to COVID-19 because antibiotic use, patient characteristics, ICU utilisation and infection-control practices may also have contributed.

Species-wise MDR prevalence

The highest MDR prevalence was observed in *Acinetobacter* spp. (74.3%), followed by *K. pneumoniae* (57.8%), *P. aeruginosa* (53.8%), *E. coli* (45.0%) and *S. aureus* (38.3%). The high MDR burden among Gram-negative pathogens highlights the need for effective antimicrobial stewardship and infection-control measures.

Comparison between pre-COVID and COVID/post-COVID periods

MDR prevalence increased significantly from 38.0% in 2019 to 49.3% during 2020–2023 ($p=0.046$). Increased antibiotic use, ICU utilisation, prolonged hospitalisation and invasive procedures during the pandemic may have contributed. However, the study did not assess individual antibiotic consumption or COVID-19 status; therefore, causality cannot be established.

ESBL and carbapenem resistance

ESBL positivity increased from 25.0% in 2019 to 31.5% during 2020–2023, while carbapenem resistance increased from 15.0% to 22.0%. Although not statistically significant, these increases are clinically

important, particularly because carbapenems are key agents for severe resistant Gram-negative infections.

MRSA

MRSA prevalence increased slightly from 8.0% in 2019 to 10.0% during 2020–2023, but the difference was not statistically significant ($p=0.56$). This indicates that resistance trends varied between bacterial groups.

Trends in selected antimicrobial resistance patterns

Significant increases were observed in ceftriaxone and ciprofloxacin resistance among *E. coli*, ceftriaxone and meropenem resistance among *K. pneumoniae*, and meropenem resistance among *Acinetobacter* spp. and *P. aeruginosa*. Meropenem resistance in *Acinetobacter* increased markedly from 42% to 68% ($p<0.001$). These trends indicate increasing resistance even to important broad-spectrum antibiotics.

Strengths of the study

1. Covers five years, including pre-pandemic, pandemic and post-pandemic periods.
2. Includes multiple clinically important bacterial pathogens.
3. Assesses overall and species-specific MDR prevalence.
4. Evaluates ESBL, carbapenem resistance and MRSA.
5. Analyses temporal trends in selected resistance patterns.
6. Provides hospital-specific data useful for antimicrobial stewardship and infection-control planning.

Limitations

The findings should be interpreted in light of several limitations.

First, this was a retrospective single-centre study, limiting generalisability to other hospitals or geographic regions. Second, the analysis was based on microbiological isolates rather than individual patient episodes, and therefore the same patient-level clinical factors could not be fully evaluated. Third, 2019 was used as the pre-COVID reference year, whereas 2020–2023 was grouped together as the COVID/post-COVID period. This approach simplifies interpretation but does not completely distinguish the acute pandemic period from the later post-pandemic period.

Fourth, the study did not directly assess antibiotic consumption, antimicrobial prescribing practices, duration of therapy or adherence to antimicrobial stewardship protocols. Therefore, increased resistance cannot be directly attributed to increased antibiotic use.

Finally, the equal allocation of 100 isolates to each study year was useful for comparison but may not reflect the actual annual microbiological workload of the hospital. The results should consequently be interpreted as a structured comparison of the selected isolates rather than as population-level incidence estimates.

CONCLUSION

The present retrospective study demonstrates a substantial and progressively increasing burden of antimicrobial resistance in a tertiary-care hospital during 2019–2023. Among 500 bacterial isolates, Gram-negative organisms predominated, with *E. coli* being the most frequently isolated pathogen. Urine was the commonest specimen and inpatients contributed the majority of isolates.

Overall, 47.0% of bacterial isolates were multidrug resistant. MDR prevalence increased progressively from 38.0% in 2019 to 54.0% in 2023. The highest MDR prevalence was observed among *Acinetobacter* spp. (74.3%), followed by *K. pneumoniae* and *P. aeruginosa*.

Importantly, MDR prevalence was significantly higher during the 2020–2023 COVID/post-COVID period compared with the 2019 pre-COVID reference year (49.3% versus 38.0%; $p=0.046$). Increasing trends were also observed for ceftriaxone, ciprofloxacin and carbapenem resistance, with the most pronounced increase being meropenem resistance among *Acinetobacter* spp., from 42% in 2019 to 68% in 2023.

The findings suggest that the COVID-19 pandemic period was associated with an increased burden of MDR bacteria in the study hospital. Nevertheless, the retrospective design does not permit confirmation that COVID-19 itself caused the increase. Antibiotic prescribing, ICU utilisation, prolonged hospitalisation, invasive procedures, infection-control practices and other healthcare-related factors may have contributed.

The study highlights the need for **continuous AMR surveillance, rational antibiotic prescribing, effective antimicrobial stewardship, timely microbiological diagnosis, appropriate infection-prevention and control measures, and regular hospital-specific antibiograms**. Particular attention should be given to *Acinetobacter*, *K. pneumoniae* and *P. aeruginosa*, which demonstrated substantial MDR burdens.

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