

Distribution Features and Antimicrobial Resistance Trends of Clinical Pathogens: A Retrospective Study in a Tertiary Teaching Hospital in East China (2020–2024)

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Purpose: To examine the distribution of clinical pathogens and their antimicrobial resistance trends in a hospital in East China to provide evidence for rational antibiotic use and infection control.

Methods: We conducted a retrospective study of bacterial isolates from January 2020 to December 2024. Bacterial identification and antimicrobial susceptibility testing were performed using the VITEK 2 system. WHONET 5.6 and R software were used for data analysis. Statistical analyses included chi-square tests and trend tests.

Results: A total of 8680 pathogenic isolates were collected. Gram-negative bacteria predominated (74.7%) over Gram-positive bacteria (25.3%). The primary specimens were urine (33.7%), sputum (25.3%), and secretions (19.4%). The leading pathogens were *E. coli* (28.4%), *K. pneumoniae* (12.8%), and *P. aeruginosa* (11.5%). The carbapenem resistance rate was less than 1.9% in *Escherichia coli* strains over five years. The rate for carbapenem resistant *K. pneumoniae* (CRKP) showed a significant increasing trend, rising from 9.4% in 2022 to 16.7% in 2024 ($p < 0.05$). CRKP rates were lower than national CHINET data. The imipenem resistance rate of *Pseudomonas aeruginosa* exhibited an upward trend from 2020 (24.2%) to 2023 (34.1%) ($p < 0.05$). *A. baumannii* maintained high resistance to imipenem (>73%), exceeding national levels. The proportion of methicillin-resistant *Staphylococcus aureus* (MRSA) fluctuated over the course of the five years (26.9–44.8%). No vancomycin-resistant *Enterococcus* (VRE) was detected.

Conclusion: *E. coli*, *K. pneumoniae*, and *P. aeruginosa* were the predominant pathogens in this hospital. The rising and high resistance rates of CRKP and CRAB highlight the urgent need for enhanced antimicrobial stewardship. B-lactamase, β -lactamase inhibitor combination preparations and carbapenems were recommended for susceptible strains of *E. coli* and *K. pneumoniae*. For CRKP infections and CRAB infections, tigecycline and colistin are recommended. Continuous surveillance and infection control are crucial to combat the evolving threat of multidrug-resistant organisms.

Keywords: bacterial resistance surveillance, multi-drug resistant organism, rational application of antibiotics, hospital associated infection

Introduction

Antimicrobial resistance (AMR) is increasingly acknowledged as a big global danger to health in the 21st century. A systematic analysis of AMR from 1990 to 2021, with forecasts extending to 2050, underscores the escalating threat posed by AMR, projecting millions of deaths attributable to resistant infections if current trends continue.¹ Moreover, AMR's impact is not confined to high-income countries. It poses a significant threat to countries with low to moderate

income levels, where the burden of bacterial infections is high, and healthcare systems are often under-resourced.² In China, the challenge of AMR is particularly acute, characterized by high prevalence rates of multi-drug resistant organisms (MDRO) that complicate treatment. The public health implications of AMR in China are profound, with projections indicating that by 2050, AMR could be associated with over 769,000 deaths in the country, with the most lethal infections being bloodstream infections attributed to bacterial causes. For instance, carbapenem-resistant *Acinetobacter baumannii* (CRAB) and methicillin-resistant *Staphylococcus aureus* (MRSA), which have shown increasing resistance trends over the past decades.³ A multicentre, retrospective cohort study in 2021 demonstrated that in 2017, the financial burden of antibiotic resistance on communities was estimated at \$77 billion, representing 0.37% of China's annual gross domestic product (GDP), with \$57 billion associated with MDROs.⁴ This points out the demand for precise interventions, including robust surveillance and antimicrobial stewardship, to address the unique challenges posed by AMR in immunocompromised populations.

The primary organizations overseeing national bacterial resistance monitoring are China Antimicrobial Resistance Surveillance System (CARSS) and China Antimicrobial Surveillance Network (CHINET). Spread of bacteria and drug resistance patterns in key referral hospitals are tracked by CHINET. CARSS is responsible for observing bacterial resistance to medications throughout various autonomous regions and different provinces. CHINET surveillance data revealed that vancomycin-resistant *Enterococcus* (VRE) was not commonly found, and the rate of carbapenem-resistant *Pseudomonas aeruginosa* (CPRAE) and MRSA demonstrated decreasing trends in 2005–2022. Carbapenem-resistant *Klebsiella pneumoniae* (CRKP) exhibited a significant rising pattern from 2.9% (2005) to 25.0% (2018), and then slightly decreased to 22.6% (2022).⁵

Study of distribution patterns of pathogens and the trend of antimicrobial resistance of Chinese hospitals revealed a severe form of resistance that is both alarming and complex. The prevalence of MDROs such as MRSA, CRAB, and carbapenem-resistant *Enterobacterales* (CRE) underscores the critical challenge posed by antimicrobial resistance (AMR) in China.⁶ The emergence of CRKP strains, particularly in southern China, further highlights the geographic variability and the need for targeted interventions.⁷ The dispersion of pathogens and their resistance patterns vary significantly across different regions and healthcare settings in China. For instance, in the Sichuan region, *Escherichia coli* (*E. coli*), *Enterococcus faecium* (*E. faecium*), and *Klebsiella pneumoniae* (*K. pneumoniae*) are the predominant uropathogens, with *E. coli* showing strong resistance to numerous antibiotics.⁸ Similarly, in burn wards, pathogens such as *Staphylococcus aureus* and *Acinetobacter baumannii* are prevalent, with high resistance to common antibiotics.⁹ The widespread presence of strains capable of producing extended-spectrum beta-lactamase (ESBL) of *K. pneumoniae* and *E. coli* further complicates treatment options.¹⁰ The results emphasize the requirement of continuous surveillance and tailored antimicrobial management programs to address the regional and pathogen-specific resistance patterns.¹¹

Research of bacterial distribution patterns and resistance trends of hospitals in eastern China is a critical area of study; however, reports on this topic remain limited. A study on the genomic epidemiology of ST11 CRKP clone strains in eastern and central China reveals alarming resistance rates exceeding 90% to several antibiotic classes, including fluoroquinolones and β -lactams.¹² The study of CRAB isolates in multiple areas of China highlights widespread distribution of resistant isolates, particularly the CC92 clonal complex, which is prevalent in hospitals across eastern China.¹³ These studies collectively illustrate the pressing need for detailed reports and analyses of bacterial distribution and AMR trends in hospitals in eastern China to inform public health strategies and mitigate the spread of resistant pathogens. Our hospital is a large general hospital located in East China that integrates medical treatment, teaching, scientific research, and health management. Drug resistance in bacteria has several unique characteristics: high detection rate of multi-drug resistant bacteria; strong environmental adaptability and dissemination capabilities of strains. This study aims to address the surveillance gap in East China by providing comprehensive resistance data from our hospital, which serves as a representative tertiary teaching hospital in the region, to inform regional antimicrobial stewardship programs. This document compiles data on bacterial resistance monitoring in hospital from 2020 to 2024, investigates the pattern of distribution and drug-sensitive data regarding the bacteria found, and exhibits trends of antimicrobial resistance patterns of pathogens. We aimed to provide a reference for the hospital divisions to compose relevant policies and clinical uses for antibiotics.

Materials and Methods

The Origin of Isolates

From January 1, 2020, to December 31, 2024, 8680 bacterial strains were clinically isolated at this hospital, with duplicate strains from the same site and patient being excluded. Sample collection procedures: Specimens were collected following standard sterile techniques from various departments including ICU, Urology Surgery, Neurosurgery, Orthopedics, Pediatrics, Respiratory, Emergency, and other clinical units. The specimens were processed according to standard microbiological procedures.

Equipment, Susceptibility test cards

VITEK2-Compact (Bio-Merieux, France) was utilized along with the system-compatible drug sensitivity cards AST-P639, AST-N334 and AST-N335.

Bacteria Identification, Drug Resistance Testing, and Reference Strain

The whole isolates were determined by the VITEK 2 automated system. Drug sensitivity experiments adhered to the procedure recommended by the Clinical and Laboratory Standards Institute (CLSI). Drug sensitivity interpretation was conducted using the automated instrument method along with the Kirby-Bauer (KB) method. Standard strains such as *Escherichia coli* (*E. coli*) ATCC25922 were used. Incubation conditions: All isolates were cultured at 35°C for 18–24 hours under appropriate atmospheric conditions. Criteria for excluding duplicates: Strains from the same patient and same site within 30 days were excluded. The experiment was conducted in a biosafety cabinet. The strains used in the experiment were sterilized under high pressure and then disposed of as infectious medical waste.

Analysis of Drug Sensitivity and Data

Results of drug sensitivity tests were interpreted in line with the CLSI standard guidelines, and annual data analysis was performed using WHONET 5.6 software. R Software (Version 3.5.3) was applied for statistical analysis. Chi-square tests were used to compare resistance rates between groups. Cochran-armitage trend test was used to analyze trends over time. P-value less than 0.05 indicated statistical significance.

Results

Yearly Allocation of Pathogenic Bacteria [n (%)]

From 2020 to 2024, 8680 bacterial isolates were obtained, encompassing 6487 isolates of Gram-negative bacteria (74.7%) and 2193 isolates of Gram-positive bacteria (25.3%). The majority of strains were sourced from urine (33.7%), sputum (25.3%), secretions (19.4%), and blood (16.6%) (Table 1).

Table 1 The Source of Bacterial Specimens

	2020 (n=1496)		2021 (n=1750)		2022 (n=1732)		2023 (n=1839)		2024 (n=1863)		Total (n=8680)	
	n	%	n	%	n	%	n	%	n	%	n	%
Sputum	433	28.9	432	24.7	507	29.3	429	23.3	395	21.2	2196	25.3
Urine	433	28.9	581	33.2	571	33	684	37.2	658	35.3	2927	33.7
Secretions	306	20.5	345	19.7	276	15.9	362	19.7	399	21.4	1688	19.4
Blood	228	15.2	312	17.8	289	16.7	289	15.7	321	17.2	1439	16.6
Others*	96	6.4	80	4.6	89	5.1	75	4.1	90	4.8	430	5.0
Total	1496	100.0	1750	100.0	1732	100.0	1839	100.0	1863	100.0	8680	100.0

Note: *Specimen other than the list.

Abbreviation: n, the number of strains.

The top five Gram-negative bacilli were *E. coli* (2464, 28.4%), *K. pneumoniae* (1115, 12.8%), *P. aeruginosa* (1000, 11.5%), *A. baumannii* (632, 7.3%), and *Proteus mirabilis* (*P. mirabilis*) (338, 3.9%). The leading four Gram-positive bacteria were 743 isolates of *Staphylococcus aureus* (*S. aureus*) (8.6%), 743 strains of coagulase-negative *Staphylococcus* (CNS) (8.6%), 430 isolates of *E. faecium* (5.0%), and 202 isolates of *E. faecalis* (2.3%) (Table 2).

Non-ICU strains were dominated by *E. coli* (31.1%), whereas ICU isolates were dominated by *A. baumannii* (19.0%), *K. pneumoniae* (17.7%), and *P. aeruginosa* (16.9%). The proportions of *A. baumannii* and *P. aeruginosa* strains were significantly higher in the ICU (19.0%, 16.9%) than in the non-ICU (5.1%, 10.5%) ($p < 0.05$) (Table 3). Over the five-year period, the ICU, Urology Surgery, and Neurosurgery were the leading clinical areas for pathogen detection (Table 4).

Resistance Levels of Gram-Positive Isolate to Antimicrobial Drugs MRSA and MSSA

During the five-year period, no *S. aureus* strains that showed resistance to daptomycin, vancomycin, linezolid, teicoplanin, or tigecycline emerged. MRSA exhibited greater resistance when compared with methicillin-sensitive *S. aureus* (MSSA) to penicillin G, clindamycin, erythromycin, moxifloxacin, and rifampicin each year (Table 5). Statistical comparison between MRSA and MSSA resistance rates was performed using chi-square tests, and most comparisons were statistically significant ($p < 0.05$).

Table 2 The Distribution and Proportion of Pathogenic Bacteria

	2020 (n=1496)		2021 (n=1750)		2022 (n=1732)		2023 (n=1839)		2024 (n=1863)		Total (n=8680)	
	n	%	n	%	n	%	n	%	n	%	n	%
Pathogenic bacteria												
Gram-negative bacterium	1104	73.8	1330	76	1340	77.4	1387	75.4	1326	71.2	6487	74.7
<i>Escherichia coli</i>	398	26.6	461	26.3	481	27.8	560	30.5	564	30.3	2464	28.4
<i>Pseudomonas aeruginosa</i>	182	12.2	184	10.5	219	12.6	211	11.5	204	11.0	1000	11.5
<i>Klebsiella pneumoniae</i>	188	12.6	225	12.9	203	11.7	265	14.4	234	12.6	1115	12.8
<i>Acinetobacter baumannii</i>	124	8.3	153	8.7	205	11.8	68	3.7	82	4.4	632	7.3
<i>Proteus mirabilis</i>	57	3.8	75	4.3	59	3.4	84	4.6	63	3.4	338	3.9
<i>Enterobacter cloacae</i>	43	2.9	73	4.2	38	2.2	66	3.6	52	2.8	272	3.1
<i>Stenotrophomonas maltophilia</i>	31	2.1	42	2.4	33	1.9	41	2.2	20	1.1	167	1.9
<i>Serratia marcescens</i>	24	1.6	41	2.3	46	2.7	27	1.5	19	1.0	157	1.8
<i>Enterobacter aerogenes</i>	16	1.1	31	1.8	27	1.6	23	1.3	18	1.0	115	1.3
Others*	41	2.7	45	2.6	29	1.7	42	2.3	70	3.8	227	2.6
Gram-positive Bacterium	392	26.2	420	24	392	22.6	452	24.6	537	28.8	2193	25.3
<i>Staphylococcus aureus</i>	145	9.7	145	8.3	128	7.4	134	7.3	191	10.3	743	8.6
Coagulase negative staphylococcus	130	8.7	160	9.1	129	7.4	137	7.4	187	10.0	743	8.6
<i>Enterococcus faecium</i>	72	4.8	69	3.9	98	5.7	106	5.8	85	4.6	430	5.0
<i>Enterococcus faecalis</i>	34	2.3	28	1.6	28	1.6	48	2.6	64	3.4	202	2.3
Others*	11	0.7	18	1	9	0.5	27	1.5	10	0.5	75	0.9
Total	1496	100.0	1750	100.0	1732	100.0	1839	100.0	1863	100.0	8680	100.0

Note: *Bacteria other than the list.

Abbreviation: n, the number of strains.

Table 3 Distribution of Bacteria Isolates in ICU and Non-ICU

Pathogenic Bacteria	n	ICU		Non-ICU	
		n	%	n	%
Gram-negative bacterium	6487	1111	80.7	5376	73.6
<i>Escherichia coli</i>	2464	194	14.1	2270	31.1
<i>Pseudomonas aeruginosa</i>	1000	232	16.9	768	10.5
<i>Klebsiella pneumoniae</i>	1115	243	17.7	872	11.9
<i>Acinetobacter baumannii</i>	632	262	19.0	370	5.1
<i>Proteus mirabilis</i>	338	47	3.4	291	4.0
<i>Enterobacter cloacae</i>	272	18	1.3	254	3.5
<i>Stenotrophomonas maltophilia</i>	167	52	3.8	115	1.6
<i>Serratia marcescens</i>	157	19	1.4	138	1.9
<i>Enterobacter aerogenes</i>	115	16	1.2	99	1.4
Others	227	28	2.0	199	2.7
Gram-positive Bacterium	2193	265	19.3	1928	26.4
<i>Staphylococcus aureus</i>	743	54	3.9	689	9.4
Coagulase negative staphylococcus	743	100	7.3	643	8.8
<i>Enterococcus faecium</i>	430	87	6.3	343	4.7
<i>Enterococcus faecalis</i>	202	18	1.3	184	2.5
Others*	75	6	0.4	69	0.9
Total	8680	1376	100.0	7304	100.0

Note:*Bacteria other than the list.

Enterococcus

Over a period of five years, *E. faecium* and *E. faecalis* isolates showed complete sensitivity to vancomycin, tigecycline, linezolid and teicoplanin. From 2020 to 2024, *E. faecium* strains exhibited significantly greater resistance to ampicillin, penicillin G, erythromycin, and levofloxacin compared to *E. faecalis* strains ($p < 0.05$). *E. faecium* exhibited a resistance rate of over 70% to ampicillin, penicillin G, erythromycin and levofloxacin, while *E. faecalis* was generally sensitive to most antibiotics (Table 6).

The Resistance of Gram-Negative Strains to Antimicrobial Drugs

Enterobacteriaceae

The percentages of resistance of *E. coli* and *K. pneumoniae* to cephalosporins belonging to the second and third generations ranged from 19.7% to 55.2%. *K. pneumoniae*, *E. coli* and *P. mirabilis* were highly sensitive to piperacillin/tazobactam, cefoperazone/sulbactam, amoxicillin-clavulanic acid, amikacin, ertapenem, imipenem, and tigecycline, with resistance rates <31.8%. The highest resistance rates to carbapenems were 1.9%, 16.7%, 3.5%, and 30.1% for *E. coli*, *K. pneumoniae*, *P. mirabilis* and *Enterobacter cloacae* (*E. cloacae*) respectively. In 2021, the resistance rates of *Serratia marcescens* (*S. marcescens*) to ertapenem and meropenem were 88.9% and 80%, respectively (Table 7).

Table 4 The Top Ten Departments of Pathogen Detection

Ranking of Strains	2020 (n=1496)			2021 (n=1750)			2022 (n=1732)			2023 (n=1839)			2024 (n=1863)		
	Clinical Department	n	%	Clinical Department	n	%	Clinical Department	n	%	Clinical Department	n	%	Clinical Department	n	%
1	ICU	268	17.9	ICU	376	21.5	Neurosurgery Dept	362	20.9	Urology Surgery	306	16.6	ICU	289	15.5
2	Urology Surgery	218	14.6	Urology Surgery	325	18.6	ICU	358	20.7	ICU	305	16.6	Urology Surgery	277	14.9
3	Neurosurgery Dept	206	13.8	Neurosurgery Dept	250	14.3	Urology Surgery	280	16.2	Neurosurgery Dept	262	14.2	Neurosurgery Dept	177	9.5
4	General Surgery Dept	151	10.1	Department of Pediatrics	122	7	Emergency Dept	94	5.4	Emergency Dept	106	5.8	General Surgery Dept	127	6.8
5	Department of Orthopedic	83	5.5	General Surgery Dept	114	6.5	Department of Neurology	88	5.1	Department of Orthopedic	95	5.2	Department of Orthopedic	105	5.6
6	Emergency Dept	77	5.1	Respiratory Dept	96	5.5	Department of Pediatrics	87	5	General Surgery Dept	95	5.2	Department of Pediatrics	99	5.3
7	Department of Nephrology	65	4.3	Department of Orthopedic	92	5.3	General Surgery Dept	83	4.8	Respiratory Dept	93	5.1	Respiratory Dept	92	4.9
8	Respiratory Dept	62	4.1	Emergency Dept	77	4.4	Department of Orthopedic	79	4.6	Department of Neurology	92	5	Department of rehabilitation medicine	89	4.8
9	Department of Pediatrics	58	3.9	Department of Neurology	74	4.2	Respiratory Dept	69	4	Department of Pediatrics	81	4.4	Emergency Dept	85	4.6
10	Endocrine Dept	44	2.9	Rheumatology Immunology Department	59	3.4	Department of Nephrology	65	3.8	Department of rehabilitation medicine	70	3.8	Department of Neurology	79	4.2

Abbreviation: n, the number of strains.

Table 5 The Resistance Rate of *Staphylococcus* Strains to Antimicrobial Agents (%)

Antibiotics	MRSA					MSSA				
	2020 (n=39)	2021 (n=65)	2022 (n=45)	2023 (n=40)	2024 (n=77)	2020 (n=106)	2021 (n=80)	2022 (n=83)	2023 (n=95)	2024 (n=122)
Penicillin G	100	100	100	100	100	94.3	83.8	90.4	89.5	93.2
Oxacillin	100	100	100	100	100	0	0	0	0	0
Clindamycin	69.2	63.1	71.1	70	58.4	43.4	45	34.9	44.2	36.9
Erythromycin	69.2	61.5	66.7	70	50.6	48.1	47.5	30.1	47.4	37.7
Moxifloxacin	20.5	12.3	11.1	15	14.3	17.9	10	6	8.4	11.5
Levofloxacin	17.9	13.8	15.6	25	16.9	20.8	15	13.3	11.6	16.4
Sulfamethoxazole	15.4	4.6	20	5	4.7	6.6	7.5	2.4	10.5	7.4
Rifampicin	7.7	4.6	6.7	2.5	6.5	4.7	2.5	2.4	1.1	1.6
Gentamicin	5.1	4.6	4.4	2.5	3.9	2.8	2.5	0	4.2	4.1
Daptomycin	0	0	0	0	0	0	0	0	0	0
Linezolid	0	0	0	0	0	0	0	0	0	0
Vancomycin	0	0	0	0	0	0	0	0	0	0
Teicoplanin	0	0	0	0	0	0	0	0	0	0
Tigecycline	0	0	0	0	0	0	0	0	0	0

Abbreviations: MRSA, Methicillin-resistant *Staphylococcus aureus*; MSSA, methicillin-sensitive *Staphylococcus aureus*.

Table 6 The Resistance Rate of *E. Faecalis* and *E. Faecium* to Antimicrobial Agents (%)

Antibiotics	<i>E. faecium</i>					<i>E. faecalis</i>				
	2020 (n=72)	2021 (n=69)	2022 (n=98)	2023 (n=106)	2024 (n=85)	2020 (n=34)	2021 (n=28)	2022 (n=28)	2023 (n=48)	2024 (n=64)
Penicillin G	100	89.9	98	93.3	92.1	11.8	3.6	14.3	8.3	10.4
Ampicillin	98.2	88.4	96.9	92.4	86.9	4.8	3.6	14.3	2.1	6.2
Levofloxacin	97.2	81.2	90.8	89.5	71.8	32.4	25	32.1	39.6	51.6
Erythromycin	91.7	94.2	89.8	88.6	83.5	64.7	64.3	78.6	68.8	65.6
Gentamicin-high	42.8	44.5	33.8	37.7	41.2	35	41.2	46.4	41.7	43.8
Linezolid	0	0	0	0	0	0	0	0	0	0
Vancomycin	0	0	0	0	0	0	0	0	0	0
Teicoplanin	0	0	0	0	0	0	0	0	0	0
Tigecycline	0	0	0	0	0	0	0	0	0	0

Nonfermentative Bacteria

P. aeruginosa exhibited minimal resistance to the majority of antimicrobial agents. Most antibiotics were ineffective against *A. baumannii* isolates, except for tigecycline and colistin (Table 8).

Table 7 The Resistance Rate of *Enterobacteriaceae* to Antimicrobial Agents (%)

Antibiotics	<i>E. coli</i>					<i>Klebsiella pneumoniae</i>					<i>Proteus mirabilis</i>					<i>Enterobacter cloacae</i>					<i>Serratia marcescens</i>				
	2020	2021	2022	2023	2024	2020	2021	2022	2023	2024	2020	2021	2022	2023	2024	2020	2021	2022	2023	2024	2020	2021	2022	2023	2024
	(n=398)	(n=461)	(n=481)	(n=560)	(n=564)	(n=188)	(n=225)	(n=203)	(n=265)	(n=234)	(n=57)	(n=75)	(n=59)	(n=84)	(n=63)	(n=43)	(n=73)	(n=38)	(n=66)	(n=52)	(n=24)	(n=41)	(n=46)	(n=27)	(n=19)
Ceftriaxone	54.5	51.5	47.5	45.7	51.9	46	50.2	32.2	40.8	41.6	41.1	38.7	23.1	40.2	37.1	NA	NA	NA	NA	NA	50	88.9	66.7	53.8	NA
Levofloxacin	53.4	50.8	47.5	48.5	57.2	23.8	29.8	14.3	24	25.6	28.1	29.3	15.3	29.8	16.1	4.7	30.1	7.9	21.5	26.9	45.5	78	50	25.9	36.8
Cefuroxime	53.3	49.9	46.9	47.1	55.2	42.9	52.6	35.3	45.4	45.7	47.1	37.3	27.6	43.9	41.9	45.8	52.9	41.7	58.1	65.4	100	100	NA	80.8	94.7
Cefuroxime axetil	53.3	49.9	46.9	47.1	55.2	42.9	52.6	35.3	45.7	45.7	47.1	37.3	27.6	43.9	41.9	45.8	52.9	41.7	58.1	65.4	100	100	NA	80.8	94.7
Sulfame thoxazole	51.4	48.4	43.3	47.2	50.4	39.5	44.9	28.1	31.8	32.5	52.6	54.7	40.7	47.6	59.7	23.3	23.3	21	28.8	36.5	3.3	9.8	4.3	3.7	5.3
Cefepime	34.4	29.5	27	23.4	36.5	29.7	36.9	23.2	30	33.3	14	9.3	3.4	14.3	9.7	11.6	38.4	15.8	28.8	29.4	19.5	36.6	21.7	11.1	10.5
Cefazidime	25.1	25.6	21.9	19.7	24.5	29.9	38.7	24.1	34.2	31.6	0	2.7	6.8	14.3	6.5	30.2	50.7	35.1	47	46.2	14.3	26.8	15.2	18.5	21.1
Amoxicillin-clavulanic acid	6.6	7.7	10	9	11.7	14.3	26.8	17.1	31.8	30.1	0	0	0	0	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Piperacillin/Tazobactam	6.4	7.2	8.5	6.7	7.1	21.1	28.9	19.2	24.6	22.1	0	0	3.4	1.2	4.8	23.3	43.8	31.6	39.4	32.7	NA	NA	NA	NA	NA
Cefopera zone/Sulbactam	6.3	6.5	5.4	4.3	3.4	14.6	18.7	10.8	19.1	18.5	0	0	0	0	0	11.6	39.7	26.3	30.8	30.8	50	85.4	58.7	29.6	31.6
Amikacin	1.8	2.6	2.9	1.4	1.4	3.3	8.4	5.9	14.1	13.4	1.8	0	0	1.2	0	2.4	2.7	0	4.5	3.9	12.5	0	0	3.7	0
Ertapenem	0.8	0.9	1.8	NA	NA	6.3	12.4	8.8	NA	NA	1.8	0	4	NA	NA	15.8	30	18.8	NA	NA	50	88.9	47.6	NA	NA
Imipenem	0.8	0.9	1.9	1.1	0.9	6.4	12.4	9.4	15.8	16.7	3.5	0	0	0	3.2	13.6	30.1	13.2	25.8	23.1	NA	NA	NA	NA	NA
Meropenem	NA	NA	NA	1.4	0.7	NA	NA	NA	15.8	13.7	0	0	0	0	0	NA	NA	NA	27.3	21.2	30	80	80.8	37	27.8
Tigecycline	0.3	0	0	0.9	0.2	0	0	0	0	0.5	NA	NA	NA	2.4	4.8	0	0	0	0	0	0	0	0	0	0

Abbreviation: NA, not available.

Table 8 The Resistance Rate of Non-Fermentative Gram-Negative Bacilli to Antimicrobial Agents (%)

Antibiotics	<i>Pseudomonas aeruginosa</i>					<i>Acinetobacter baumannii</i>				
	2020 (n=182)	2021 (n=184)	2022 (n=219)	2023 (n=211)	2024 (n=204)	2020 (n=124)	2021 (n=153)	2022 (n=205)	2023 (n=68)	2024 (n=82)
Tigecycline	NA	NA	NA	NA	NA	3.2	3.9	6.3	2.9	2.4
Ticarcillin-clavulnic acid	48.4	43.4	47.7	50.2	45.0	86.9	86.8	93.2	76.5	68.9
Imipenem	24.2	29.3	33.3	34.1	29	81.5	83.7	93.7	73.5	73.2
Cefoperazone/Sulbactam	23.6	19.3	21	22.1	23.5	77.4	56.2	70.7	51.5	48.8
Meropenem	22.5	24.7	30.9	28.4	28.7	89.5	85.3	93.7	75	72
Levofloxacin	18.3	17.7	17	22.7	21.9	79.8	81	73.2	36.8	24.4
Ceftazidime	15.9	21	16.4	23.2	27.5	87	85	94.1	73.5	74.4
Ciprofloxacin	14.7	14.9	13.8	18.3	21.2	88.4	88.1	93.1	75	70.7
Colistin	6.2	5.1	7.8	3.8	4.6	3.5	3.3	0	0	8.5
Tobramycin	5.6	8.6	8.3	14.9	18.2	74.2	82.8	87.7	61.8	64.6
Cefepime	5	6.6	8.2	8.3	11.3	74.8	62.7	62.7	52.9	65.9
Amikacin	2.8	6.1	5.9	9.1	9.5	NA	NA	NA	NA	NA
Piperacillin/Tazobactam	0	0.7	0	0	2.3	86.9	88	94.6	75	75.6

Trends of Multi-Drug Resistant Bacteria

Among MDRO strains detected in 2020–2024, carbapenem-resistant *E. coli* (CRECO) ranged at a low level (0.8%–1.9%). CRKP showed an upward trend in 2022–2024 (9.4%–16.7%, $p < 0.05$). CRAB was maintained at a very high level of detection (>73%) and exhibited an upward trend followed by a downward trend. Carbapenem-resistant *P. aeruginosa* (CRPA) has demonstrated an increasing trend from 2020 to 2023 and a declining trend in 2024 for the first time ($p < 0.05$). MRSA fluctuated over five years. VRE has not been detected in the past five years (Figure 1 and Table 9).

Evaluation of Data from Bacterial Surveillance of CHINET and the Hospital

The proportions of Gram-negative bacteria found in this hospital were slightly higher than CHINET over five years. The detection rates of CRAB and carbapenem-resistant *Pseudomonas aeruginosa* (CRPAE) are higher than those of CHINET from 2020 to 2024. Detection frequencies for carbapenem-resistant *Klebsiella pneumoniae* (CRKPN) were lower than those of CHINET during this five-year period. The detection rates of MRSA have been higher than those of CHINET in the last four years (2021–2024) (Table 10).

Discussion

In 2015, the United Nations' World Health Assembly approved the World Health Organization's Global Action Plan. And several nations are dedicating substantial resources to strengthen their surveillance infrastructure for antimicrobial resistance, including the creation and growth of networks. Antimicrobial resistance (AMR) is a great health risk in countries with low to moderate income levels and will lead to substantial economic and health impacts.² Since 2016, our hospital, as part of China CARSS, has been involved in this initiative, providing quarterly reports on antimicrobial resistance data to all medical personnel and CARSS. Even during the COVID-19 pandemic from 2020 to 2022, the observation of bacteria was maintained. From 2020 to 2024, clinical samples resulted in the isolation of 8680 strains. The

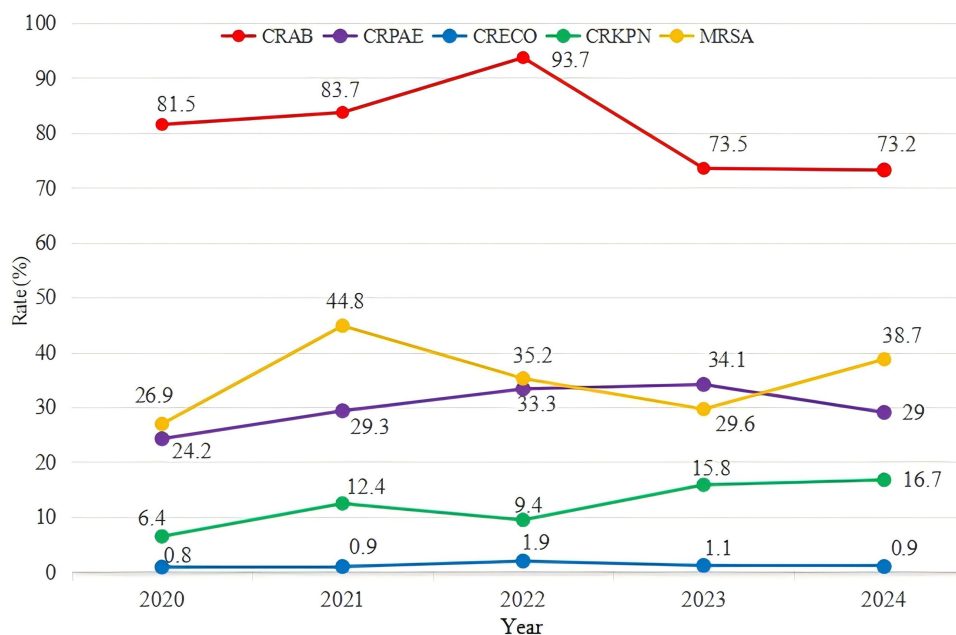


Figure 1 Distribution of multidrug-resistant organisms from 2020 to 2024.

Abbreviations: CRAB, Carbapenem-resistant *Acinetobacter baumannii*; CRPAE, Carbapenem-resistant *Pseudomonas aeruginosa*; CRECO, Carbapenem-resistant *Escherichia coli*; CRKPN, Carbapenem-resistant *Klebsiella pneumoniae*; MRSA, Methicillin-resistant *Staphylococcus aureus*.

leading three Gram-negative pathogenic microorganisms were *E. coli* (28.4%), *K. pneumoniae* (12.8%), *P. aeruginosa* (11.5%), and the Gram-positive isolates were dominated by *S. aureus* (8.6%), *CNS* (8.6%), *E. faecium* (5.0%) (Table 2).

During the five-year timeframe, 74.7% of the isolates were identified as Gram-negative, and 25.3% as Gram-positive. In 2020–2024, the percentage of Gram-negative bacteria was marginally greater than CHINET for each year. Over the last five years, the proportion of Gram-negative bacteria to Gram-positive cocci was about 7 to 3, which is consistent with the reports of CARSS and CHINET during the past years.^{5,14,15} The 1376 strains (15.9%) isolated from ICU patients were dominated by *A. baumannii* (19.0%), *K. pneumoniae* (17.7%), and *P. aeruginosa* (16.9%). This indicates that non-fermentative bacteria maintained high activity compared to other bacteria in the ICU for a long time. A recent study reported that the most frequent pathogen within the intensive care unit of a recently constructed hospital was *A. baumannii* (30.77%).¹⁶ The 7304 strains (84.1%) collected from patients not admitted to the ICU were dominated by *E. coli* (31.1%), which was slightly lower than the data of bloodstream infection in Sichuan Province in Southwest China (36.8%).¹⁷ The detection ratio of *CNS* in non-ICU patients was 8.8%, whereas that of ICU was 7.3%, as it was an adult ICU. In East China, *CNS* was the leading pathogen responsible for bloodstream infections in hospitalized children, accounting for 47.1%.¹⁸

In 1959, methicillin was brought into use to combat infections from penicillin-resistant *S. aureus*, but strains resistant to methicillin emerged soon after. Throughout the next decade, MRSA established itself as one of the most widespread

Table 9 Detection Rate of MDRO Strains in Hospital From 2020 to 2024 [n(%)]

Pathogenic Bacteria	2020	2021	2022	2023	2024	χ^2	P
CRAB	101(81.5)	128(83.7)	192(93.7)	50(73.5)	60(73.2)	27.570	0
CRPAE	44(24.2)	54(29.3)	73(33.3)	72(34.1)	60(29)	27.906	0
CRECO	3(0.8)	4(0.9)	9(1.9)	6(1.1)	5(0.9)	3.169	0.53
CRKPN	12(6.4)	28(12.4)	19(9.4)	42(15.8)	39(16.7)	14.635	0.006
MRSA	39(26.9)	65(44.8)	45(35.2)	40(29.6)	77(38.7)	13.138	0.011

Table 10 Comparison of Bacterial Surveillance Data of Anqing Hospital and CHINET

Parameter	Anqing Hospital					CHINET				
	2020	2021	2022	2023	2024	2020	2021	2022	2023	2024
Gram-positive bacteria	26.2	24	22.6	24.3	25.3	28.1	28.6	29	29	28.3
Gram-negative bacteria	73.8	76	77.4	75.7	74.7	71.9	71.4	71	71	71.7
MRSA	26.9	44.8	35.2	29.6	38.7	31	30	28.7	29.6	29.2
CRAB	81.5	83.7	93.7	73.5	73.2	68.1	65.6	71.2	73.4	64.5
CRPAE	24.2	29.3	33.3	34.1	29	23.2	23	22.1	21.9	21.3
CRECO	0.8	0.9	1.9	1.1	0.9	2	1.8	1.9	1.9	2.0
CRKPN	6.4	12.4	9.4	15.8	16.7	21.5	20.8	22.6	24.8	22.6
Resistance rate of <i>Enterobacter cloacae</i> to imipenem	13.6	30.1	13.2	25.8	23.1	9.4	9.4	NA	NA	NA
Resistance rate of <i>Proteus mirabilis</i> to imipenem	3.5	0	0	0	3.2	4.4	7.1	NA	NA	NA
Resistance rate of <i>Serratia marcescens</i> to meropenem	30	80	80.8	37	27.8	6.4	5.2	NA	NA	NA
Resistance rate of <i>E. faecium</i> to vancomycin	0	0	0	0	0	1.1	1.4	2.2	3.2	5.1
Resistance rate of <i>E. faecalis</i> to vancomycin	0	0	0	0	0	0.1	0.1	0.1	0.1	0.1

Abbreviations: CRECO, Carbapenem-resistant *Escherichia coli*; CRKPN, Carbapenem-resistant *Klebsiella pneumoniae*; CRAB, Carbapenem-resistant *Acinetobacter baumannii*; CRPAE, Carbapenem-resistant *Pseudomonas aeruginosa*; MRSA, Methicillin-resistant *Staphylococcus aureus*.

strains around the world.¹⁹ MRSA constitutes a serious health risk to humans as the strain can become resistant to any antibacterial drugs to which it is faced. Various mutations and SNPs in the genome of MRSA strains enable it to acquire resistance against long-used antibiotics for treatment, such as vancomycin and daptomycin, etc.²⁰ This study observed a rapid increase in the MRSA detection rate, going from 26.9% to 44.8% in the period of 2020–2021, and then decreased to 29.6% in 2022–2023, and demonstrated a rising trend in 2024 (38.7%) (Figure 1). The MRSA ratios were higher than those at the national level by 2021, 2022, and 2024 (Table 10). The proportion of multidrug-resistant *S. aureus* has reached 57.1% in Nepal in 2021, which was much higher than the data in this study.²¹ MRSA demonstrated a greater resistance rate compared to MSSA for the majority of antibiotics. Penicillin G resistance was absolute in MRSA strains, and MSSA strains exhibited considerable resistance to this antibiotic in five years (94.3%, 83.8%, 90.4%, 89.5%, and 93.2%). Oxacillin was recommended as the first-line drug for MSSA infections. Sulfamethoxazole was suitable for MSSA and MRSA infections. For MRSA infections, vancomycin, teicoplanin, sulfamethoxazole, linezolid, daptomycin and tigecycline were optional (Table 5). *S. aureus* is frequently responsible for surgical site infections (SSIs) in patients undergoing orthopedic surgery. A systematic review in Africa demonstrated that hospitalized patients and healthcare workers had the highest MRSA colonization rates of 12.9% and 13.6%, respectively.²² A single-center study showed that the incidence of MSSA and MRSA of nasal colonization percentages were 26.3% and 7.7%, respectively.²³ Regulating antibiotic use in communities and strengthening infection control programs such as hand hygiene in hospitals are important strategies to diminish MRSA and MSSA colonization rates, thus reducing the spread and the total infection load.

E. faecium exhibited resistance to almost 50% of the antibiotics tested, whereas *E. faecalis* demonstrated a lower resistance to the same drugs. By contrast, they exhibited complete sensitivity to teicoplanin, tigecycline and linezolid (Table 6). Vancomycin-resistant *Enterococcus* strains were not detected. Enterococci was considered an “ancient” bacterium. As animals transitioned to living on land, enterococci have undergone evolution. Hospitals provide a suitable environment for enterococci to thrive due to their adaptations.²⁴ Despite there being 58 species of enterococci, *E. faecium* and *E. faecalis* cause the majority of human infections.²⁵ The antimicrobial response and physiological features of *E. faecalis* are not the same as those of numerous other typical human pathogens.²⁶ Healthcare-associated

infections are often caused by enterococci that have developed resistance to vancomycin. The rise of antibiotic resistance is making it harder to treat infections. Due to their genomic flexibility and resilience, VRE have robustly adapted to various drug-resistance factors.²⁷ A new meta-analysis found that bloodstream infections caused by VRE faecium have an increased rate of mortality in comparison to those triggered by vancomycin-sensitive *Enterococcus faecium*, and vancomycin resistance, regardless of the VRE species, might be linked to increased mortality.²⁸ Although the VRE strains were not detected in this research, we need to be vigilant about the emergence of VRE strains.

The predominant pathogen found in this study was *E. coli*, similar with other studies in Central China and the CHINET data.^{5,29} The resistance levels of *E. coli* to ceftriaxone, cefuroxime, cefuroxime axetil, and sulfamethoxazole drugs were higher than 43.3%. Resistance rate to third-generation cephalosporins was much greater than that reported in Romania.³⁰ The level of resistance in *E. coli* to quinolones was greater than 47.5%. Ceftazidime, amoxicillin-clavulanic acid, piperacillin/tazobactam and cefoperazone/sulbactam were applicable for *E. coli* infections (Table 7). *Enterobacteriaceae* is widespread in various environments. The *Enterobacteriaceae* family comprises *E. coli*, *K. pneumoniae*, *Enterobacter cloacae*, *Serratia marcescens*, among others. Carbapenem-resistant isolates are known as carbapenem-resistant *Enterobacteriaceae* (CRE). CRE has emerged as a significant public health threat in recent years.³¹ These species cause infections that are linked to high rates of death and disease.³² Carbapenems are highly effective against *E. coli*, with a resistance rate of less than 1.9% from this study. The hypervirulent carbapenem resistant *E. coli* ST410 clone has recently become a significant world wide health issue, particularly in China.³³

In the five-year period of this study, the percentage of resistance of *K. pneumoniae* to imipenem varied from 6.4% to 16.7% ($p < 0.05$), and the level of CRKP detection in 2020–2021 showed an upward trend (6.4% to 12.4%), decreasing to 9.4% in 2022 and increasing again to 16.7% in 2024 (Table 9). The CRKP ratio for each year was lower than that of the CHINET level during 2020 to 2024 (Table 10). The significant increasing trend of CRKP was consistent with national surveillance data. According to the CHINET surveillance program, carbapenem resistance in *K. pneumoniae* has shown a concerning upward trajectory across China, rising from 2.9% in 2005 to over 20% in recent years.³⁴ This pattern highlights the rapid dissemination of carbapenem resistance mechanisms among *Enterobacteriaceae* in healthcare settings nationwide. Levofloxacin, amoxicillin-clavulanic acid, cefoperazone/sulbactam, piperacillin/tazobactam, amikacin and imipenem were recommend for sensitive *K. pneumoniae* infections. Tigecycline was recommended for CRKP infections (Table 7). A recent retrospective analysis showed that combining carbapenems with quinolones and aminoglycosides may not be a successful treatment for CRKP infections.³⁵ *K. pneumoniae* strains that are hypervirulent and resistant to carbapenems have appeared as a worldwide public health risk in recent years.³⁶ Carbapenem-resistant and hypervirulent *K. pneumoniae* (CR-hvKP), which predominantly spread through plasmids, has spread widely across China, leading to severe hospital infections, but there are limited effective treatments.³⁷ The prevalence of carbapenemase-producing hypervirulent *K. pneumoniae* (HvKP) in Anhui province in East China, particularly the elevated mortality rate associated with HvKP, warrants increased attention.³⁸ Substantial efforts are required to explore and devise strategies to stop the spread of *K. pneumoniae* virulence plasmids and/or carbapenem resistance within the borders of China.

The opportunistic pathogen, *A. baumannii*, demonstrates strong resistance to most antimicrobial agents. Resistance of *A. baumannii* to imipenem and meropenem remained at very high levels (73.2%–93.7% and 72%–93.7%) in the five-year period. The level of resistance to the majority of antibiotics was greater than 60%. Imipenem or meropenem can be applied for *A. baumannii* infections only when susceptibility testing confirms sensitivity. For CRAB strains, polymyxin and tigecycline were recommended (Table 8). The rate of CRAB in each year was much higher than that at the national level, especially significantly revealed in 2020–2022 (Table 10). The persistently high CRAB resistance rates (>73%) throughout our study period reflect the challenging epidemiology of this pathogen in Chinese hospitals. A nationwide study documented the clonal dissemination of carbapenem-resistant *A. baumannii* across multiple provinces, nearly 70% of the ICUs are contaminated by CRAB isolates in China, with certain high-risk clones demonstrating remarkable persistence in the hospital environment.³⁹ Our findings reinforce the need for enhanced environmental cleaning and strict contact precautions, particularly in intensive care settings where *A. baumannii* transmission risk is highest.

The imipenem resistance rate of *P. aeruginosa* in this study ranged from 24.2% to 34.1%. *P. aeruginosa* was nearly 50% resistant to ticarcillin-clavulanic acid and showed high susceptibility to the majority of antibiotics (<25%). Aminoglycosides, β -lactams, fluoroquinolones and carbapenems were applicable for *P. aeruginosa* infections (Table 8). The CRPA ratio for

each year was higher than the CHINET level, especially in 2022 and 2023 (Table 10). A downward trend was observed from 2023 to 2024 (Figure 1). Notably, the significant decline in CRPA from 34.1% in 2023 to 29.0% in 2024 ($p < 0.05$) may reflect the cumulative impact of our hospital's antimicrobial stewardship initiatives. International research has highlighted variations in clinical characteristics and results of individuals suffering from CRPA infections across different areas, and patients with infections from carbapenemase-producing CRPA strains had an increased 30-day mortality rate even when confounders were considered.⁴⁰ The presence of carbapenemase is common in China, and it is important to monitor the hypervirulent ST463 carbapenem-resistant *P. aeruginosa* and ceftazidime- and avibactam-resistant *K. pneumoniae* carbapenemase-producing *P. aeruginosa* to prevent significant clinical issues.^{41,42} The combination of phenotypic and genotypic methods can notably reduce the time to effective treatment and enhance outcomes for patients with CRPA infections.⁴³

This study has several limitations. First, it is a single-center study, which may limit the generalizability of the findings. Second, we did not include molecular methods to characterize resistance mechanisms, which would provide deeper insights into the resistance patterns. Future studies should incorporate molecular epidemiology to better understand the transmission and evolution of resistance and to guide precise therapy.

Conclusion

The pathogenic bacteria identified in this study were chiefly occupied by *E. coli*, *K. pneumoniae* and *P. aeruginosa*. Constant and dynamic observation of the growth trends of multidrug-resistant bacteria is crucial, particularly for CRE, CRAB, CRPA, MRSA, and VRE. Based on our susceptibility data, we recommend the following: for *E. coli* and *K. pneumoniae* infections, β -lactamase, β -lactamase inhibitor combination preparations and carbapenems are preferred for susceptible strains; tigecycline should be considered for CRKP; for *P. aeruginosa*, piperacillin-tazobactam retains excellent activity; for *A. baumannii*, colistin-based combinations are recommended; and for *S. aureus*, vancomycin is the cornerstone for MRSA infections. The significant increase in CRKP ($p < 0.05$) and the high burden of CRAB in our hospital call for enhanced infection control measures and antimicrobial stewardship programs. Comprehensive measures must be implemented to prevent MDRO, thereby decreasing the production of harmful bacteria and the occurrence of infections acquired in hospitals.

Ethics Statement

This research received approval from the Medical Ethics Committee at Anqing First People's Hospital of Anhui Province (AQYY–YXLL–LWLL–51). This research was conducted retrospectively and followed only the susceptibility of bacteria to medications information of the specimens, the request to ethically exempt from informed consent was waived. This research was carried out following the guidelines of the Declaration of Helsinki.

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Disclosure

The authors confirm that they do not have any conflicts of interest.

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