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Antimicrobial resistance profile of clinical isolates from hospitals across China: CHINET 2024 surveillance report

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Abstract

This study aimed to monitor clinical isolate susceptibility to antimicrobial agents in healthcare facilities in 31 provinces or cities of China in 2024. Antimicrobial susceptibility of clinical isolates from 74 hospitals was tested using disc diffusion automated systems. The data were interpreted using the 2024 Clinical and Laboratory Standards Institute breakpoints. A total of 458,271 clinical isolates were collected, of which 28.3% were Gram-positive and 71.7% were Gram-negative. Methicillin-resistant *Staphylococcus aureus*, *S. epidermidis,* and other coagulase-negative *Staphylococcus* strain prevalence was 28.4%, 76.5%, and 70.2%, respectively. No vancomycin-resistant clinical *Staphylococcus* spp. were found. *Enterococcus faecalis* had significantly lower resistance rates to most antimicrobial agents tested than *E. faecium*, with a few vancomycin-resistant strains of both identified. The prevalence of penicillin-susceptible *Streptococcus pneumoniae* was 97.5% in isolates from children and 96.1% in those from adults. The carbapenem resistance rate was < 15.0% for most *Enterobacterales* species except *Klebsiella*; 22.6% and 23.4% of *Klebsiella* were resistant to imipenem and meropenem, respectively. Most *Enterobacterales* were highly susceptible to tigecycline (≤ 3.1%) and colistin (≤ 4.2%). *Pseudomonas aeruginosa* imipenem and meropenem resistance rates were 21.3% and 17.3%, respectively; those of *Acinetobacter baumannii* were 64.5% and 64.7%, respectively. In 2024, antimicrobial resistance in clinically isolated bacteria in major regions of China remained high. Antimicrobial agents must be rationally selected based on monitoring to effectively control the development of bacterial resistance.

Keywords CHINET, Antimicrobial susceptibility testing, Carbapenem, Resistant Gram, Negative bacilli, Methicillin, Resistant *S. aureus*, Penicillin, Resistant *Streptococcus pneumoniae*

Introduction

The widespread presence of multidrug-resistant bacteria, including carbapenem-resistant Gram-negative bacilli and methicillin-resistant *Staphylococcus aureus*, in healthcare facilities poses a significant threat to global public health [1]. Antimicrobial susceptibility testing is essential for the precise and effective treatment of multidrug-resistant bacterial infections. It plays a key role in promptly identifying new multidrug-resistant bacteria and developing new antimicrobial agents. China's antimicrobial resistance surveillance program is in line with international efforts. The Chinese government and social

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organizations have made significant efforts to curb bacterial resistance in China. With the support of the World Health Organization Western Pacific Region and the Chinese Ministry of Health, the Antimicrobial Resistance Surveillance Network was formally established in Beijing and Shanghai in 1988. By 2005, these networks had expanded to cover the whole country and included the Centre for Antibacterial Surveillance, the China Antimicrobial Resistance Surveillance System and the China Antimicrobial Surveillance Network (CHINET). The former two are led by the National Health Commission, while the latter is led by Huashan Hospital, Fudan University [2].

Since 2005, the CHINET network has provided scientific references to help to understand changes in important drug-resistant bacteria and the emergence and prevalence of new resistance mechanisms. It has also promoted the rational use of clinical antimicrobial agents by releasing surveillance report every year. Since 2017, CHINET has conducted an active surveillance study, collecting important drug-resistant clinical strains and transporting them to the central laboratory. There, the minimum inhibitory concentration of antimicrobial agents is determined and second-generation sequencing analysis is performed on drug-resistant strains to clarify the mechanism of antimicrobial resistance. At present, it contains 74 members from 31 provinces, municipalities, and autonomous regions, including 55 general hospitals and 19 children's hospitals, of which 61 are tertiary hospitals and 13 are secondary hospitals. This article reports the 2024 CHINET Surveillance Network results.

Results

Bacterial distribution

A total of 458,271 clinical isolates were collected in 2024, with Gram-positive and Gram-negative bacteria accounting for 28.3% (129,690) and 71.7% (328,581), respectively; isolates from inpatients and outpatients accounted for 88.7% (406,486) and 11.3% (51,785), respectively. Isolates from adult patients made up 74.3% (340,665), and those from paediatric patients (0–18 years) made up 25.7% (117,606). Overall, 42.5% were from respiratory samples; 18.4% were from the urinary tract, 12.8% were from blood, 5.6% were from wound pus, 5.0% were from sterile body fluids (such as cerebrospinal fluid), 1.3% were from genital tract, 1.2% were from feces, and 13.2% were from other samples. The top five species were *Escherichia coli* (18.2%), *Klebsiella* spp. (15.9%), *S. aureus* (9.1%), *Acinetobacter* spp. (8.0%) and *Enterococcus* spp. (8.0%). The distribution of bacterial species is shown in Table 1.

Table 1 Distribution of bacterial species

Organism	No. of strains	%
Escherichia coli	83,632	18.2
Klebsiella spp.	72,674	15.9
Staphylococcus aureus	41,890	9.1
Acinetobacter spp.	36,802	8.0
Enterococcus spp.	36,485	8.0
Pseudomonas aeruginosa	35,055	7.6
Coagulase-negative *Staphylococcus*[a]	19,392	4.2
Haemophilus influenzae	25,541	5.6
β-hemolytic *Streptococcus*	13,813	3.0
Enterobacter spp.	12,551	2.7
Stenotrophomonas maltophilia	12,976	2.8
Streptococcus pneumoniae	*11,802*	*2.6*
Moraxella catarrhalis	10,616	2.3
Proteus spp.	8478	1.8
Serratia spp.	5295	1.2
S. viridans[a]	4596	1.0
Salmonella spp.	4578	1.0
Citrobacter spp.	3978	0.9
Burkholderia cepacia	2932	0.6
Morganella spp.	2260	0.5
Pseudomonas spp. excluding *P. aeruginosa*	1479	0.3
Aeromonas spp.	1457	0.3
Achromobacter xylosoxidans	720	0.2
Providencia spp.	580	0.1
Elizabethkingia meningosepticum	528	0.1
Chryseobacterium indologenes	478	0.1
Neisseria gonorrhoeae	352	0.1
Others [b]	7331	1.6
Total	458,271	100.0

[a] From blood, cerebrospinal fluid, or other sterile body fluids

[b] Including *Aeromonas*, *Pantoea* spp., *Comamonas* spp., *Bordetella* spp., *Brevundimonas* spp., *Vibrio* spp., and other genera

Sensitivity and resistance rates of Gram-positive cocci to antimicrobial agents

Among the 129,690 Gram-positive strains, the most common were *S. aureus* (32.3%), *Enterococcus* spp. (28.1%), *Streptococcus* spp. (23.3%), and coagulase-negative *Staphylococci* (15.0%). The antimicrobial resistance of these bacteria is described as follows.

Staphylococcus spp.

The detection rate of methicillin-resistant *S. aureus* (MRSA) was 28.4%; that of methicillin-resistant *S. epidermidis* (MRSE) was 76.5%, with other methicillin-resistant strains (MRCNS) (excluding *S. pseudointermediate* and *S. schleiferi*) making up 70.2%. MRSA, MRSE, and other MRCNS were significantly more

resistant to erythromycin, clindamycin, gentamicin, rifampicin, and levofloxacin than methicillin-sensitive *Staphylococcus*. However, the resistance rate to sulfamethoxazole-trimethoprim was lower in MRSA (6.7%) than in MSSA (11.9%). Resistance rates to sulfamethoxazole-trimethoprim were significantly higher in MRSE (49% and 32%) than in MRSA (6.7%), but significantly lower to clindamycin (38.3% and 47.8%) than in MRSA (53.8%). No vancomycin-resistant *Staphylococcus* spp. strains were found. A few methicillin-resistant coagulase-negative staphylococci were resistant to linezolid (*S. capitis*, *S. epidermidis*, and *S. hominis*). Details are shown in Table 2.

Enterococcus spp.

42.1% and 49.1% of the *Enterococcus* spp. were *E. faecalis* and *E. faecium*, respectively; 8.8% were other *Enterococci*. *E. faecalis* had a significantly lower resistance rate to most of the antimicrobial agents than *E. faecium*; its resistance rates to ampicillin, nitrofurantoin, and fosfomycin were 1.6%, 1.1%, and 2.2%, respectively, whereas *E. faecium* had higher resistance rates to both ampicillin and nitrofurantoin at 91.4% and 45.6%, respectively. Both were sensitive to tigecycline, with resistance rates of 0% and 0.3%, and their resistance rates to high concentrations of gentamicin (≥512 μg/mL) were 36.6% and 39.7%, respectively. A few vancomycin-, tigecycline-, and linezolid-resistant strains were found for both *E. faecalis* and *E. faecium*. Linezolid-resistant strains of *E. faecalis* (4.4%) outnumbered *E. faecium* (0.7%), while vancomycin-resistant strains of *E. faecium* (5.1%) outnumbered *E. faecalis* (0.1%). Details are shown in Table 3.

Table 3 Susceptibility of *Enterococcus* species to antimicrobial agents (%)

Antimicrobial agent	*E. faecalis* (*n* = 15,344)		*E. faecium* (*n* = 17,929)	
	R	S	R	S
Ampicillin	1.6	98.4	91.4	8.6
Gentamicin-High	36.6	63.1	39.7	60.1
Vancomycin	0.1	99.8	5.1	94.8
Teicoplanin	0.2	99.8	4.4	95.3
Linezolid	4.4	94.4	0.7	99
Tigecycline	0	99.6	0.3	98.7
Levofloxacin	34.6	63.9	86.2	10
Nitrofurantoin	1.1	98	45.6	28.7
Fosfomycin [a]	2.2	95.9	NA	NA

NA not available, *R* Resistant, *S* Susceptible

[a] For urinary tract isolates only

Streptococcus spp.

In pediatric patients, there were 8484 non-meningeal *Streptococcus pneumoniae* strains, with detection rates of penicillin-susceptible *S. pneumoniae* (PSSP), penicillin-intermediate *S. pneumoniae* (PISP), penicillin-resistant *S. pneumoniae* (PRSP) of 97.5% (8271), 2.4% (201), and 0.1% (12), respectively. In adult patients, there were 1732 non-meningeal *S. pneumoniae* strains, with detection rates of PSSP, PISP, and PRSP of 96.1% (1664), 2.9% (51), and 1.0% (17), respectively (Table 4). The resistance

Table 2 Susceptibility of *Staphylococcus* strains to antimicrobial agents (%)

Antimicrobial agent	MRSA (*n* = 11,750)		MSSA (*n* = 29,589)		MRSE (*n* = 5706)		MSSE (*n* = 1752)		MRCNS (*n* = 7484)		MSCNS (*n* = 3172)	
	R	S	R	S	R	S	R	S	R	S	R	S
Penicillin G	100	0	86.9	13.1	100	0	79.3	20.7	100	0	72.3	27.7
Oxacillin	100	0	0	100	100	0	0	100	100	0	0	100
Gentamicin	12.3	86.2	5.4	91.9	21.7	67.6	7.5	87.4	24	65.6	1.2	96.4
Clindamycin	53.8	45.8	16.3	82.9	38.3	60.7	15.7	83.1	47.8	51	14.5	84.4
Erythromycin	76.4	23	50.3	48.3	76.2	22.2	63.5	35.2	90.3	8.9	61.1	37.7
Vancomycin	0	100	0	100	0	100	0	100	0	100	0	100
Linezolid	0	100	0	100	1.9	98.2	0	100	3.1	96.9	0.1	99.9
Tigecycline	0	100	0	100	0	100	0	100	0	100	0	100
Rifampin	2.1	96	0.4	99	8.8	90.4	1.5	98.3	14.1	85.3	0.5	99.1
Levofloxacin	26.9	65.8	9.1	83.6	63.5	33.6	26.8	67.8	77.1	18.9	12.8	79.1
Trimethoprim-sulfamethoxazole	6.7	93.3	11.9	88.1	49	50.8	35.2	67.5	32	68	10.4	89.6

MRSA methicillin-resistant *S. aureus, MSSA* methicillin-susceptible *S. aureus, MRSE* methicillin-resistant *Staphylococcus epidermidis, MSSE* methicillin-susceptible *S. epidermidis, MRCNS* methicillin-resistant coagulase-negative *Staphylococcus, MSCNS* methicillin-susceptible coagulase-negative *Staphylococcus, R* Resistant, *S* Susceptible

Table 4 The distribution of nonmeningitis *S. pneumoniae* isolates from children and adults

Strains	Isolates from children						Isolates from adults					
	2022		2023		2024		2022		2023		2024	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
PSSP	6819	94.4	9990	93.1	8271	97.5	1354	95.4	1874	95.9	1664	96.1
PISP	379	5.2	642	6.0	201	2.4	48	3.4	62	3.2	51	2.9
PRSP	24	0.3	96	0.9	12	0.1	17	1.2	18	0.9	17	1.0
Total	7222	100.0	10,728	100.0	8484	100.0	1419	100.0	1954	100.0	1732	100.0

PSSP penicillin-susceptible *S. pneumoniae, PISP* penicillin-intermediate *S. pneumoniae, PRSP* penicillin-resistant *S. pneumoniae*

rates of non-meningeal strains from children and adults to erythromycin, clindamycin, and trimethoprim-sulfamethoxazole were all ≥ 58.3%. Among non-meningeal isolates, 4.7% and 2.1% of adult PSSP strains were resistant to levofloxacin and moxifloxacin, respectively; the resistance rates of pediatric PSSP strains to these two drugs were low, with a levofloxacin resistance rate of only 0.4%, and no resistant strains to moxifloxacin were found. No strains resistant to vancomycin and linezolid were detected (Table 5).

There were 75 strains of *S. pneumoniae* isolated from cerebrospinal fluid specimens, 68 of which had complete antimicrobial susceptibility records. Among them, there were 30 adult strains; the detection rates of PSSP and PRSP were 26.7% (8/30) and 73.3% (22/30), respectively. There were 38 pediatric strains, with detection rates of PSSP and PRSP being 2.6% (1/38) and 97.4% (37/38), respectively. The resistance rates of pediatric PRSP strains to chloramphenicol and cefotaxime were 9.1% and 19%, respectively, which were higher than the resistance rates of adult PRSP strains (8.3% and 6.7%) (Table 6). The groups of β-*Streptococcus haemolyticus* were very susceptible to penicillin, cefotaxime, and ceftriaxone, with no non-β-lactam-sensitive strains. Among 2916 strains of viridans streptococci isolated from sterile body fluid specimens such as blood and cerebrospinal fluid, the resistance rates to penicillin and other β-lactams were ≤ 8%. This bacterium showed high resistance rates to erythromycin and clindamycin at 64.5% and 56.1%, respectively, and a resistance rate of 13.9% to levofloxacin. No vancomycin- or linezolid-resistant *Streptococcus* spp. were found (Table 7).

Sensitivity and resistance rates of Gram-negative bacilli to antimicrobial agents

Enterobacterales

The resistance rate of *E. coli* to ceftriaxone was 52.2%, with 2.0% and 2.3% resistant to imipenem and meropenem, respectively; > 50.0% were resistant to piperacillin, sulfamethoxazole-trimethoprim, ciprofloxacin, and levofloxacin. *Klebsiella* spp. had resistance rates of 39.6%, 21.3%, and 22.1% to ceftriaxone, imipenem, and meropenem, respectively. Except for *Morganella*ceae (including genera *Proteus*, *Morganella*, *Providencia*), other *Enterobacterales* mostly had carbapenem resistance rates < 8.9%. Except for resistance rates of *Enterobacter*, *Citrobacter*, and *Providencia* to ceftazidime-avibactam (19.8%, 18%, and 36.3%, respectively), other Enterobacterales were

Table 5 Susceptibility of non-meningitis *S. pneumoniae* isolates from children and adults to antimicrobial agents (%)

Antimicrobial agent	Isolates from children						Isolates from adults					
	PSSP (*n* = 8271)		PISP (*n* = 201)		PRSP (*n* = 12)		PSSP (*n* = 1664)		PISP (*n* = 51)		PRSP (*n* = 17)	
	R	S	R	S	R	S	R	S	R	S	R	S
Penicillin G	0	100	0	0	100	0	0	100	0	0	100	0
Vancomycin	0	100	0	100	0	100	0	100	0	100	0	100
Linezolid	0	100	0	100	0	100	0	100	0	100	0	100
Erythromycin	99	0.7	100	0	100	0	94.6	4.5	98	2	100	0
Clindamycin	96.5	2.8	98.9	1.1	85.7	14.3	91.8	7.5	100	0	100	0
Trimethoprim-sulfamethoxazole	60.4	25.5	81.8	10.2	72.7	9.1	58.3	30.8	70	12	70.6	11.8
Levofloxacin	0.4	99.3	0.5	99.5	11.1	88.9	4.7	94.4	8	90	35.3	64.7
Moxifloxacin	0	100	0.5	99.5	0	100	2.1	96.8	2.4	97.6	17.6	76.5
Chloramphenicol	9	91	3	97	0	100	13.7	86.3	16.2	83.8	12.5	87.5

Table 6 Susceptibility of meningitis *S. pneumoniae* isolates from children and adults to antimicrobial agents (%)

Antimicrobial agent	Isolates from children				Isolates from adults			
	PSSP (*n* = 1*)		PRSP (*n* = 37)		PSSP (*n* =8*)		PRSP (*n* = 22)	
	R	S	R	S	R	S	R	S
Penicillin G	0	1	100	0	0	8	100	0
Ceftriaxone	0	1	10.7	50.0	0	4	15.4	76.9
Cefotaxime	0	1	19	33.3	0	4	6.7	80.0
Meropenem	0	1	7.4	59.3	0	6	10.5	47.4
Vancomycin	0	1	0	100	0	7	0	100
Linezolid	0	1	0	100	0	6	0	100
Erythromycin	1	0	100	0	6	0	100	0
Clindamycin	1	0	100	0	2	2	80	20
Trimethoprim-sulfamethoxazole	1	0	48.5	39.4	2	3	76.5	11.8
Levofloxacin	0	1	0	100	0	4	0	100
Moxifloxacin	0	1	0	100	0	4	0	100
Chloramphenicol	0	1	9.1	90.9	1	3	8.3	91.7

* Number of strains

Table 7 Susceptibility of *Streptococcus* species to antimicrobial agents (%)

Antimicrobial agent	Group A		Group B		Group C		Group F		Group G		*S. viridans* [a]	
	(*n* = 5309)		(*n* = 7208)		(*n* = 479)		(*n* = 46)		(*n* = 54)		(*n* = 2916)	
	R	S	R	S	R	S	R	S	R	S	R	S
Penicillin G	0	100	0	100	0	100	0	100	0	100	4.7	63.3
Erythromycin	96.3	2.3	76.3	19.2	69.7	24.3	80.4	17.4	75.9	18.5	64.5	25.8
Clindamycin	94.4	4	62.9	35.3	60	36.4	92.1	93.5	83.3	16.7	56.1	40.5
Cefotaxime	0	100	0	100	0	100	0	100	0	100	6.6	89.5
Ceftriaxone	0	100	0	100	0	100	0	100	0	100	8	87.6
Vancomycin	0	100	0	100	0	100	0	100	0	100	0	100
Linezolid	0	100	0	100	0	100	0	100	0	100	0	100
Levofloxacin	0.5	99.3	45.6	54	1	98.1	0	100	0	100	13.9	84.8

[a] Isolates from blood, cerebrospinal fluid, or other sterile body fluids

sensitive to it, with resistance rates ≤ 7.8% (Table 8). The annual changes in the resistance rates of *K. pneumoniae* to imipenem and meropenem are shown in Fig. 1. Apart from intrinsically resistant strains, other *Enterobacterales* bacteria were sensitive to tigecycline and colistin, with resistance rates ≤ 4.2%.

Table 9 shows that *Salmonella typhimurium* and *S. enteritidis* had high resistance rates to ampicillin (≥ 85.4%); resistance rates to ceftriaxone were ≤ 31.2%, and they were sensitive to ciprofloxacin, with resistance rates ≤ 9%. The resistance rates of *S. enteritidis* to trimethoprim-sulfamethoxazole and chloramphenicol (9.6% and 3.1%, respectively) were lower than those of *S. typhimurium* (53.2% and 64.1%, respectively). The resistance and sensitivity rates of *Enterobacterales* to commonly used antimicrobial agents are shown in Table 10.

Non-fermenting Gram-negative bacilli

The isolation rate of 103,739 non-fermenting Gram-negative bacilli among the total monitored strains was 22.6%, with *Acinetobacter* spp. (35.5%), *Pseudomonas aeruginosa* (33.8%), and *Stenotrophomonas maltophilia* (12.5%) being the most common. *P. aeruginosa* showed a decreasing trend in resistance, with resistance rates of 21.3% and 17.3% to imipenem and meropenem, respectively, and 13.7% and 17.9% to ciprofloxacin and aztreonam. In addition, the resistance rates to colistin, amikacin, and ceftazidime-avibactam were ≤ 5.8%, and those to piperacillin-tazobactam, cefoperazone-sulbactam, gentamicin,

Table 8 Susceptibility of *Enterobacterales* to antimicrobial agents (%)

Antimicrobial agent	*E. coli*		*Klebsiella* spp.		*Enterobacter* spp.		*Proteus* spp.		*Serratia* spp.		*Citrobacter* spp.		*Morganella* spp.		*Providencia* spp.	
	(*n* = 83,632)		(*n* = 72,674)		(*n* = 12,551)		(*n* = 8478)		(*n* = 5295)		(*n* = 3978)		(*n* = 2260)		(*n* = 580)	
	R	S	R	S	R	S	R	S	R	S	R	S	R	S	R	S
Amikacin	1.8	97.7	15.5	84.2	1.3	98.3	3	96.1	1.4	97.9	1.3	98.5	1.8	97.9	8.7	89.3
Gentamicin	32.9	66.1	25.3	73.3	11.3	87.4	21.9	63.1	6	93.4	13.7	84.9	19.1	76.9	23.6	63.9
Imipenem	2	97.8	21.3	78.1	8.9	88.2	15.1	60.4	5.9	90.6	7.9	90.8	24.7	36.9	21.5	59.7
Meropenem	2.3	97.5	22.1	77.6	8.6	90.6	2.5	96.8	5.3	94.5	7.9	91.8	1.6	98.1	17.5	81.1
Cefepime	26.5	64.2	31.3	66.2	15.3	79.5	8.5	83.4	6.5	89.5	12.1	83.8	3.8	91.1	15.4	75.6
Ceftazidime	22	69.7	32.4	64.8	32.7	65.5	8.5	89.9	5.2	93.7	27.8	70.3	12.6	83.1	31.9	65.9
Ceftazidime-avibactam	5.1	94.9	7.8	92.2	19.8	80.2	5.2	94.8	5.9	94.1	18	82	3.4	96.6	36.3	63.1
Ceftriaxone	52.2	47.4	39.6	59.9	37.6	60.9	32.4	65.3	14	84.7	35.8	63.6	13.4	81.3	31.5	63.5
Cefoperazone-sulbactam	5.3	88.3	24.7	70.8	13.9	78.8	1.9	96.3	6.3	89.3	11.9	81.5	2.4	92.2	15.2	80.3
Cefoxitin	10.7	84.1	24.2	73.3	92.5	6.3	6.8	87.5	21.5	37.6	47.1	47.1	13.9	50.6	16.5	80.5
Cefuroxime	54.4	42.6	42.4	55.4	44.1	43.5	49.4	49.2	86	2.9	36.9	58.2	81.3	8.3	41.1	54.9
Cefazolin	71.5	14.2	45.4	54	88.4	10.6	55.5	43.8	96.3	2.7	62.6	36.7	99.5	0.1	75.9	23.3
Piperacillin	71	21.7	45.3	47.7	32.3	60.8	21.7	62.6	11.4	85.7	35.2	50.8	17.2	66.7	25.9	61
Piperacillin-tazobactam	5.8	90.4	25.3	70.6	19.9	70.9	2.1	96.3	5.1	91.4	13.8	77.6	4.9	92.8	14.7	82
Ampicillin-sulbactam	34.7	41.4	41.4	52.1	56.9	36.6	30.4	64.5	70.8	16.3	36.6	60.9	51.9	41.3	54.2	30
Ciprofloxacin	62.8	28.2	41.6	51.1	23.1	69.3	46.7	47.4	12	83	28.5	63.9	42.3	50.9	56.3	38.1
Levofloxacin	54.8	28.5	31.3	55.9	16.3	71.4	34.2	56	7.8	85.1	21	66.9	25.7	59.1	53.7	38.5
Trimethoprim-sulfamethoxazole	51.6	48.3	32.4	67.5	18.2	81.8	55.7	44.2	3.1	96.9	22.1	77.8	39.4	60.5	53.4	46.5
Tigecycline	0.7	99	3.1	91.7	2.4	94.1	12.9	36.9	0.4	95.3	1.1	96.8	9.9	72.4	23.8	39
Colistin	1.1	98.9	4.2	95.8	3.4	96.6	96.7	1.9	83.9	12.8	1.5	98.5	91.2	7.1	94.7	2.6

ceftazidime, cefepime, and piperacillin were all ≤ 14.2%. Of the 36,802 *Acinetobacter* spp. strains, 88.6% were *A. baumannii*. The resistance rates of *Acinetobacter* spp. to tigecycline, colistin, and minocycline were 1.7%, 1.8%, and 15.0%, respectively. The resistance rate of *Acinetobacter* spp. to other antimicrobial agents, including β-lactams, aminoglycosides, and quinolones, was high (≥ 43%). The resistance rates of imipenem and meropenem were as high as 64.5% and 64.7%, respectively. The resistance rates of *S. maltophilia* to sulfamethoxazole-trimethoprim, minocycline, and levofloxacin were 6.5%, 1.4%, and 8.4%, respectively. The resistance rates of *Burkholderia cepacia* to meropenem, ceftazidime, minocycline, and sulfamethoxazole-trimethoprim were 11.6%, 6.6%, 3.3%, and 4%, respectively, and 19% were resistant to levofloxacin (Table 11).

Other Gram-negative bacilli

Haemophilus influenzae and Moraxella catarrhalis

Of the 22,553 *H. influenzae* strains, 77.5% (17,488) and 22.5% (5065) were isolated from children and adults, respectively. The detection rate of β-lactamase in isolates from children and adults was 80.2% and 71.1%, respectively. The ampicillin resistance rates of *H. influenzae* isolated from children and adults were 78.9% and 69.1%, respectively. Most *H. influenzae* were susceptible to ceftriaxone and meropenem, with a low non-susceptibility rate of ≤ 0.5%; the non-susceptibility rate to levofloxacin was 15.6%. Additionally, the resistance rate to chloramphenicol was also low at 0.2%. The resistance rates of pediatric isolates to ampicillin, cefuroxime, trimethoprim-sulfamethoxazole, azithromycin, and levofloxacin were higher than those of adult strains (Table 12).

A total of 10,616 *M. catarrhalis* strains were identified, predominantly from children (9369), with 97.3% β-lactamase detection. The susceptibility rate to amoxicillin-clavulanic acid and cefuroxime was > 91.6%; the erythromycin and azithromycin non-susceptibility rates were 48.2% and 52.4%, respectively, while the sulfamethoxazole-trimethoprim susceptibility rate was 84%.

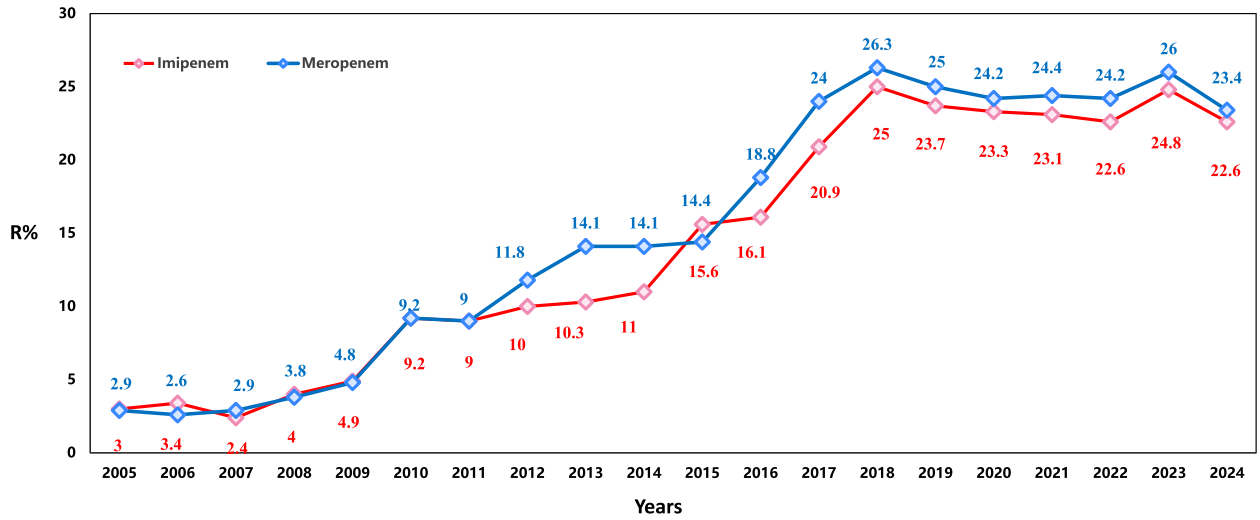

Fig. 1 Changing resistance rates of *K. pneumoniae* strains to imipenem and meropenem in CHINET antimicrobial resistance surveillance program, 2005–2024

Discussion

Compared with previous results [3], the 2024 CHINET surveillance results show that the total number of strains collected was 458,271, an increase of 2.9% from 445,199 in 2023. The top five species remained essentially unchanged as *E. coli* (18.2%), *Klebsiella* spp. (15.9%), *S. aureus* (9.1%), *Acinetobacter* spp. (8.0%), and *Enterococcus* spp. (8.0%). The detection rate of MRSA among staphylococci decreased from 29.6% in 2023 to 28.4%; the detection rate of MRSE decreased from 81.9% in 2023 to 76.5%, and the detection rate of MRCNS decreased from 78.5% in 2023 to 70.2%. *K. pneumoniae* imipenem and meropenem resistance rates increased from 3.0% and 2.9% in 2005 to 25% and 26.3% in 2018, respectively, with high resistance (~22%) maintained until 2024. *P. aeruginosa* resistance to both imipenem and meropenem decreased for the 6th consecutive year, from 27.5% and 23.5% in 2019 to 21.3% and 17.3% in 2024, respectively. *A. baumannii* resistance to imipenem and meropenem also decreased for the 4th consecutive year, from 77.7% and 79.0% in 2019 to 71.2% and 71.9% in 2022, respectively; it increased to 73.4% and 73.7% in 2023 before decreasing to 64.5% and 64.7% in 2024.

Throughout the year, the main sources of clinical isolates were from the respiratory tract (42.5%), urine (18.4%), and blood (12.8%), indicating that the respiratory and urinary systems remain high-incidence areas. The top five bacteria showed little change, consistent with trends over the past decade, highlighting the need to continue focusing on the control of antibiotic resistance in these dominant genera. The detection rates of methicillin-resistant strains (MRSA, MRCNS, and MRSE) have decreased to 28.4%, 76.5%, and 70.2% respectively, representing a decline of 1.2% to 8.3% compared with 2023. This trend indicates the effectiveness of national special rectification measures in controlling the drug resistance of gram-positive bacteria in recent years, and may also be directly related to the reduction in the intensity of antibiotic use. Research from the Centers for Disease Control in the United States also indicates that limiting the prophylactic use of broad-spectrum antibiotics in hospitals led to a 17.1% annual decrease in MRSA bloodstream infection rates from 2005 to 2012 [4]. MRSA remains highly sensitive to vancomycin and linezolid, preserving critical treatment options for clinical use. Hospital transmission is the primary route for MRSA spread, and strict infection control measures such as hand hygiene, personal protective equipment, contact isolation, and environmental cleaning have significantly interrupted the transmission chain of resistant bacteria. Despite the overall positive trend, there are still significant regional differences in MRSA detection rates. In East China, where medical resources are concentrated and there are many critically ill patients, the MRSA isolation rate is as high as 44.6%, while in Northeast China, it is only 15.4% [5].

On May 17, 2024, the World Health Organization (WHO) released an updated version of the "2024 List of Priority Pathogens," designating carbapenem-resistant *Enterobacterales* and *A. baumannii* as critical priorities, while carbapenem-resistant *P. aeruginosa* was adjusted to high priority [6]. The resistance status of carbapenem-resistant Gram-negative bacteria has become a significant challenge in healthcare. According to historical monitoring data, the imipenem and meropenem resistance

rates of *K. pneumoniae* have fluctuated, increasing during 2005–2018 and 2023, while decreasing in 2019 and 2024. These fluctuations may be related to various factors, including the intensity of carbapenem antibiotic use, the types of antibiotics used, and the implementation of infection control measures during different periods. The instability in resistance rates indicates the need for continuous monitoring of key drugs and dynamic adjustments to control strategies [7–10].

According to active monitoring data from the CHINET monitoring network, the detection rates of KPC-type carbapenemases in *E. coli*, *K. pneumoniae*, and *Enterobacter* species were 21.6%, 85.8%, and 10%, respectively, highlighting the need to strengthen the graded management and rational application of carbapenem antibiotics. Resistance rates of *P. aeruginosa* to imipenem and meropenem have decreased for 6 consecutive years, while those of *A. baumannii* have decreased for 4 consecutive years. Although there was an increase in 2023, the rates dropped again in 2024, indicating that reasonable use of antibiotics and strengthened infection control measures have achieved some effectiveness. However, continuous attention to resistance trends is necessary to prevent a rebound in resistance rates.

The growing problem of bacterial resistance has fueled enthusiasm for the development of new antimicrobial agents to meet the clinical needs, including ceftazidime-avibactam, imipenem-relabactam, aztreonam-avibactam, meropenem-vaborbactam, ceftolozane-tazobactam, cefiderocol, and sulbactam-durlobactam. While accelerating the launch of new antibacterial drugs domestically, there is often a need to rely on existing antibiotics to conduct synergy tests to assist clinicians in formulating precise multi-drug combination treatment plans. It is recommended that clinical microbiology laboratories select appropriate synergy testing methods [11], such as the broth microdilution checkerboard method, the broth disk elution method, and the disk diffusion method, to screen effective multidrug combination regimens. To advance the clinical application of antimicrobial synergy testing, the Clinical and Laboratory Standards Institute 2024 recommended the broth disk elution method for determining the susceptibility of metalloenzyme-producing *Enterobacterales* and *S. maltophilia* to the combination of ceftazidime-avibactam combined with aztreonam [12]. Based on this method, an improved broth microdilution method using "cefoperazone-sulbactam (with increased sulbactam dosage)" [13] was developed specifically for carbapenem-resistant *A. baumannii*. This method serves as a convenient and reliable way to test the sensitivity of *A. baumannii* to cefepime-sulbactam, with the results providing valuable reference for clinicians considering the use of high-dose sulbactam in treating *A. baumannii*-related infections.

The results of CHINET antimicrobial resistance surveillance in 2024 show that the resistance of common clinically isolated bacteria has changed. The detection rates of some important antimicrobial-resistant bacteria have decreased, but there are still fluctuations and challenges. To curb the further spread of drug-resistant bacteria, multi-centre molecular epidemiological studies on drug-resistant bacteria must be conducted to clarify their epidemiological characteristics so that effective infection prevention and control measures can be formulated. To improve bacterial drug resistance monitoring in China, it is necessary to establish a national reference laboratory for antimicrobial susceptibility testing that can be used to guide laboratories to perform well in testing new antimicrobial agents, antimicrobial synergy testing, and multicenter scientific research, to lay the foundation for the performance standards of antimicrobial susceptibility testing in China.

Table 9 Susceptibility of *Salmonella* species to antimicrobial agents (%)

Antimicrobial agent	*S. typhimurium* (*n* = 905)		*S. enteritidis* (*n* = 498)	
	R	S	R	S
Ampicillin	87.9	12	85.4	13.9
Ampicillin-sulbactam	28.3	58	30.7	40.6
Ceftriaxone	31.2	68.7	22.6	77.4
Ciprofloxacin	7.4	21.7	9	15.9
Trimethoprim-sulfamethoxazole	53.2	46.4	9.6	89.8
Chloramphenicol	64.1	35.9	3.1	96.4

Table 10 Overall susceptibility of *Enterobacterales* isolates to antimicrobial agents (%)

Antimicrobial agent	No. of strains	R	S
Colistin	28,075	0.3	96
Tigecycline	12,053	1.8	95.5
Amikacin	183,925	6.7	92.9
Ceftazidime-avibactam	45,116	7.6	92.4
Meropenem	176,589	10.2	89.5
Imipenem	184,196	10.5	87.6
Cefoperazone-sulbactam	162,518	12.9	81.7
Piperacillin-tazobactam	187,892	13.9	81.7
Cefepime	189,212	18.7	75.2
Ceftazidime	189,043	25.5	69.6
Ciprofloxacin	149,115	47.4	43.8

Table 11 Susceptibility of non-fermentative Gram-negative bacilli to antimicrobial agents (%)

Antimicrobial agent	*P. aeruginosa* (*n* = 35,055)		*Acinetobacter* (*n* = 36,802)		*S. maltophilia* (*n* = 12,976)		*B. cepacia* (*n* = 2932)	
	R	S	R	S	R	S	R	S
Amikacin	3.4	95.3	49.5	49.3	NA	NA	NA	NA
Gentamicin	7.4	88.5	61.4	36.1	NA	NA	NA	NA
Imipenem	21.3	76.6	64.5	35	NA	NA	NA	NA
Meropenem	17.3	78.1	64.7	34.6	NA	NA	11.6	82.8
Cefepime	8.7	83.8	59.3	34.6	NA	NA	NA	NA
Ceftazidime	12.7	82.9	64.7	33.6	38.5	36.8	6.6	89.5
Ceftazidime-avibactam	5.8	94.2	NA	NA	NA	NA	NA	NA
Cefoperazone-sulbactam	12.8	76.9	48.9	38.4	NA	NA	NA	NA
Aztreonam	17.9	67.6	NA	NA	NA	NA	NA	NA
Piperacillin	14.2	76.7	65.8	28.8	NA	NA	NA	NA
Piperacillin-tazobactam	11.3	79.9	66.7	31.5	NA	NA	NA	NA
Ampicillin-sulbactam	NA	NA	61.1	34.9	NA	NA	NA	NA
Ciprofloxacin	13.7	78	64.5	34.6	NA	NA	NA	NA
Levofloxacin	NA	NA	NA	NA	8.4	88.4	19	63.7
Trimethoprim-sulfamethoxazole	NA	NA	43	56.8	6.5	92.8	4	95.3
Colistin	1.4	98.6	1.8	98.2	NA	NA	NA	NA
Tigecycline	NA	NA	1.7	91.4	NA	NA	NA	NA
Minocycline	NA	NA	15	63.3	1.4	95.6	3.3	88.3
Chloramphenicol	NA	NA	NA	NA	15.6	42.3	8.9	77.6

Table 12 Susceptibility of *H. influenzae* to antimicrobial agents (%)

Antimicrobial agent	Total (*n* = 22,553)		Isolates from children (*n* = 17,488)		Isolates from adults (*n* = 5065)	
	R	S	R	S	R	S
Ampicillin	76.3	18.8	78.9	16.2	69.1	26.2
Amoxicillin-clavulanic acid	1.2	95.4	1.0	95.8	2.5	93.5
Ampicillin-sulbactam	7.8	84.4	7.6	85.0	8.7	82.5
Cefuroxime	36.9	41.3	37.5	36.4	35.2	57.9
Ceftriaxone	0.5*	98.6	0.2*	99.3	1.3*	96.2
Meropenem	0.3*	94.8	0.1*	95.6	0.7*	91.8
Chloramphenicol	0.2	98.6	0.1	99.1	0.2	97.3
Levofloxacin	15.6*	82.2	18.6	80.2	2.4*	91.0
Azithromycin	53.6*	36.9	57.6*	32.0	40.0*	53.4
Trimethoprim-sulfamethoxazole	61.2	35.3	63.3	32.5	53.9	45.0

* Nonsusceptible (only has susceptable breakpoint)

Conclusions

Increasing resistance to commonly used antimicrobial agents is still observed in clinical bacterial isolates. However, the prevalence of important carbapenem-resistant organisms such as *K. pneumoniae*, *P. aeruginosa*, and *A. baumannii* has decreased in recent years after increasing for many years. This suggests that close surveillance of bacterial resistance is important to cope with and prevent the development of antimicrobial resistance. A major limitation of this study is that the current results are based on passive surveillance data analysis. This method is less likely to include newly marketed antimicrobials, and does not incorporate epidemiological investigations of important resistance mechanisms.

Materials and methods

Clinical strains

Clinical isolates from 74 hospitals (55 general and 19 children's specialty hospitals; 61 tertiary and 13 secondary hospitals) in 31 provinces, cities, or autonomous regions in China were collected from January 1 to December 31, 2024. Antimicrobial susceptibility testing was performed according to the uniform technical protocols of CHINET to exclude duplicate isolates from the same patient, as well as coagulase-negative staphylococci and viridans streptococci isolated from non-sterile body fluid specimens.

Antimicrobial susceptibility testing

Antimicrobial susceptibility testing was performed using an automated antimicrobial susceptibility testing machine and disk diffusion as recommended by CLSI M100 34th ED 2024 [12]. The quality control strains included *S. aureus* ATCC 25923, *S. aureus* ATCC 29213, *E. coli* ATCC 25922, *P. aeruginosa* ATCC 27853, *S. pneumoniae* ATCC 49619, and *H. influenzae* ATCC 49247. Results were interpreted according to the 2024 CLSI breakpoints for all agents except for tigecycline, for which CLSI criteria are not available; tigecycline MICs were interpreted using US Food and Drug Administration breakpoints for *Enterobacterales* (2024 version) [14]. The criteria for fosfomycin apply to the separation of *E. coli* and *E. faecalis* from urine specimens; the criteria for polymyxins are based on the standards outlined in the "Expert Consensus on Polymyxin Drug Susceptibility Testing and Clinical Interpretation" document [15].

Definition of carbapenem-resistant strains

According to the definition, carbapenem-resistant organisms refer to those that are resistant to carbapenem antibiotics, including *Enterobacterales*, *P. aeruginosa*, and *A. baumannii*.

Data analysis

Data were statistically analyzed using WHONET 5.6.

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Authors' contributions

F.H., Y.G., D.Z., and F.W. designed the study. Y.G., L.D., S.W., R.H., D.Y., and Y.Y. performed the experiments and wrote the manuscript. All authors contributed to the article and approved the submitted version.

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Data availability
The datasets used or analyzed during the current study are available in CHINET, www.chinets.com.

Declarations

Ethics approval and consent to participate
The study protocol was approved by the Institutional Review Board of Huashan Hospital, Fudan University (no. 2022–700).

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests. Author Fupin Hu is a member of the Editorial Board for *One Health Advances*, and he was not involved in the journal's review of, or decisions related to this manuscript.

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