ORIGINAL RESEARCH

Analysis on Bacterial Distribution and Change of Drug Resistance Rate in ICUs Across Southwest China from 2018 to 2022

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Purpose: To analyze the distribution of bacteria and their drug resistance changes in Intensive Care Units (ICUs) across Southwest China from 2018 to 2022 and establish the antibiogram in this region to provide a basis for early empirical antimicrobial use.

Methods: Non-repetitive pathogens isolated from 109 member units with qualified data were obtained from the Antimicrobial Resistance Surveillance System in Sichuan Province, southwest China. The results obtained were interpreted with reference to CLSI M100-31th, and analyzed with WHONET 5.6 software.

Results: A total of 46,728 clinical isolates in ICUs were collected from 2018 to 2022, of which gram-negative organisms accounted for 76.1%, and gram-positive were 23.9%. The top 5 were *Klebsiella pneumoniae, Acinetobacter baumannii, Escherichia coli, Pseudomonas* aeruginosa and *Staphylococcus aureus*, respectively. From 2018 to 2022, the resistance rates of *Klebsiella pneumoniae* to imipenem and meropenem changed from 14.5% and 17.8% to 14.0% and 14.4%, showing a steady downward trend. *Escherichia coli* was always highly sensitive to carbapenems, with a total resistance rate of 3.8%. Among non-fermented gram-negative bacteria, the resistance rates of *Pseudomonas aeruginosa* to imipenem and meropenem decreased significantly, changed from 25.3% and 22.9% in 2018 to 20.0% and 15.1% in 2022. However, *Acinetobacter baumannii* showed high resistance rates of 76.2% and 76.9% to imipenem and meropenem, respectively. MRSA and MRCNS accounted for 31.7% and 82.7%, respectively. No vancomycin and linezolid-resistant *Staphylococcus aureus* was isolated. *Enterococcus faecalis* maintained high activity to vancomycin, teicoplanin, and linezolid; no vancomycin or teicoplanin-resistant *Enterococcus faecium* strains were detected.

Conclusion: From 2018 to 2022, the isolated bacteria in ICU were mainly gram-negative bacteria, and the growth of some multidrug-resistant bacteria was effectively controlled. All levels of medical institutions should continue to strengthen bacterial resistance surveillance, promote the establishment of antimicrobial stewardship program, and enhance restrictions on outpatient antimicrobial use.

Keywords: intensive care unit, bacterial resistance surveillance, multidrug-resistant bacteria, change of drug-resistant rate

Introduction

Antibiotic resistance, a growing global health problem, is one of the most important determinants of outcomes in patients with severe infections.[1–3] The World Health Organization (WHO) has warned that the misuse of antibiotics has resulted in a new elevation in the global antibiotic resistant rate, which further exacerbates the depletion of antibiotics.[4] Due to the emergence of drug-resistant bacteria, the treatment of clinical infectious diseases has faced more severe challenges, and meanwhile, the frequency of nosocomial infections is gradually increasing. Of the more than 700,000 medical-associated infections in the United States each year, more than half were caused by drug-resistant bacteria, and nearly half of the infections caused by drug-resistant bacteria were derived from intensive care unit (ICU).[5] Carbapenemase-resistant Enterobacteriaceae (CRE) bacteria has been spreading rapidly in Europe.[6,7] Methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococci* (VRE), carbapenem-resistant *Acinetobacter baumannii* (CRAB) and carbapenem-resistant *Pseudomonas*

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aeruginosa (CRPA) have contributed to multidrug-resistant (MDR), extensively drug-resistant (XDR), and pandrug-resistant (PDR), which has further provoked an increase in related infections within medical institutions.[8] As the rate of antibiotic resistance continues to rise, so do the morbidity, mortality, and treatment costs associated with infection among patients in healthcare settings, especially in the ICU setting.[9]

Initial appropriate antibiotic therapy (IAAT) is a key determinant of severe infection outcome,[10] and the Surviving Sepsis Guidelines highly recommended that patients receive timely and appropriate antibiotic therapy to reduce mortality.[11] However, not all serious infections are caused by drug-resistant bacteria, clinicians must develop strategies to determine which patients are candidates for broad-spectrum antibiotic therapy. Antimicrobial stewardship program (ASP) has been shown to be effective in reducing unnecessary antibiotic use and improving patient outcomes,[10,12] the difficulty lies in how to balance the need for IAAT to improve patient outcomes with the need to avoid unnecessary antibiotic use to reduce resistance emergence. ASP in ICU should include expected effect and feedback of antimicrobial prescription, treatment course monitoring, prescribing restriction and use of the regional antibiogram.[13,14] The establishment of a regional antibiogram facilitates the improvement of the success rate of early empiric antibiotic treatment.

Therefore, we conducted a systematic analysis to the bacterial species distribution and their drug resistance rates in ICU across 109 medical institutions of Southwest China from 2018 to 2022, hoping to provide data support for the early empirical antibiotic use in intensive care units of this region, effectively control the epidemic of multidrug-resistant bacteria, and further improve the application of antimicrobial drugs and the construction of bacterial resistance surveillance network in medical institutions.

Materials and Methods

Bacterial Origin

After data review, isolated strains of ICUs (including respiratory and internal medicine intensive care units, emergency intensive care units, geriatric intensive care units, etc) from 109 medical institutions in member units of Sichuan Bacterial Resistance Monitoring Network from 2018 to 2022 were included in the final analysis, and duplicate strains were eliminated in principle of retaining the first strain of the same bacteria in the same patient.

Bacterial Identification and Susceptibility Testing

BIOMERIEUX VITEK 2 drug susceptibility system, BD Phoenix 100 automatic analysis system, DL96 detection system, Beckman Coulter MicroScan Autoscan-4 semi-automatic microbial system, TDR identification drug susceptibility system, Meihua Medical MA120 microbial identification drug susceptibility analysis system and BIOMERIEUX MOLDI-TOF mass spectrometry system were used for bacterial identification. Antibiotic susceptibility testing was performed with reference to the minimum inhibitory concentration (MIC) test, Kirby–Bauer method (K-B) and E-test method recommended by the 2022 Clinical Laboratory Standard Institute (CLSI) guidelines.[15,16] The medicinal paper pieces came from Binhe Hangzhou, Kangtai Wenzhou and Oxoid, etc.

Interpretation of Results and Quality Control

The MIC value and inhibition circle diameter results were interpreted according to the CLSI M100 31st edition guideline standard.[17] When the results of quality control strains were under control, the results of the study strains could be included in the data analysis.

Antibiotic susceptibility testing of quality control strains was performed once a week as a routine quality control procedure. MH agar medium was used for common bacterial susceptibility testing, HTM medium was used for *Haemophilus influenzae* susceptibility testing, and 5% sheep blood MH agar medium was used for *Streptococcus pneumoniae* and Streptococcus β-hemolyticus. Quality control strains included but were not limited to *Staphylococcus aureus* ATCC25923, *Escherichia coli* ATCC25922, *Klebsiella pneumoniae* ATCC700603, *Pseudomonas aeruginosa* ATCC27853, *Enterobacter cloacae* ATCC700323, *Streptococcus pneumoniae* ATCC49619 and *Haemophilus influenzae* ATCC49247.

Statistical Processing

All data were statistically analyzed by WHONET 5.6 software after removing duplicate strains.

Results

Specimen Origin and Bacterial Distribution

A total of 46,728 bacterial strains were isolated in Intensive Care Units from 2018 to 2022, and the top five specimen types were sputum (60.8%), blood (13.2%), urine (9.0%), bronchoalveolar lavage fluid (4.6%) and pus (2.6%), respectively (Figure 1).

Among them, 35,549 strains of gram-negative bacteria were accounting for 76.1%, and 11,179 strains of gram-positive bacteria accounting for 23.9%. The top three isolation rates among gram-negative bacteria were *Klebsiella pneumoniae* (9623, 20.6%), *Acinetobacter baumannii* (6353, 13.6%) and *Escherichia coli* (5684, 12.2%), respectively. The first isolation rate among gram-positive bacteria was *Staphylococcus aureus*, with a total of 3099 strains accounting for 6.6%, followed by *Enterococcus faecium* (2210, 4.7%) and *Staphylococcus epidermidis* (1127, 2.6%) (Table 1). The detection trends of top 10 isolates from 2018 to 2022 are shown in Figure 2.
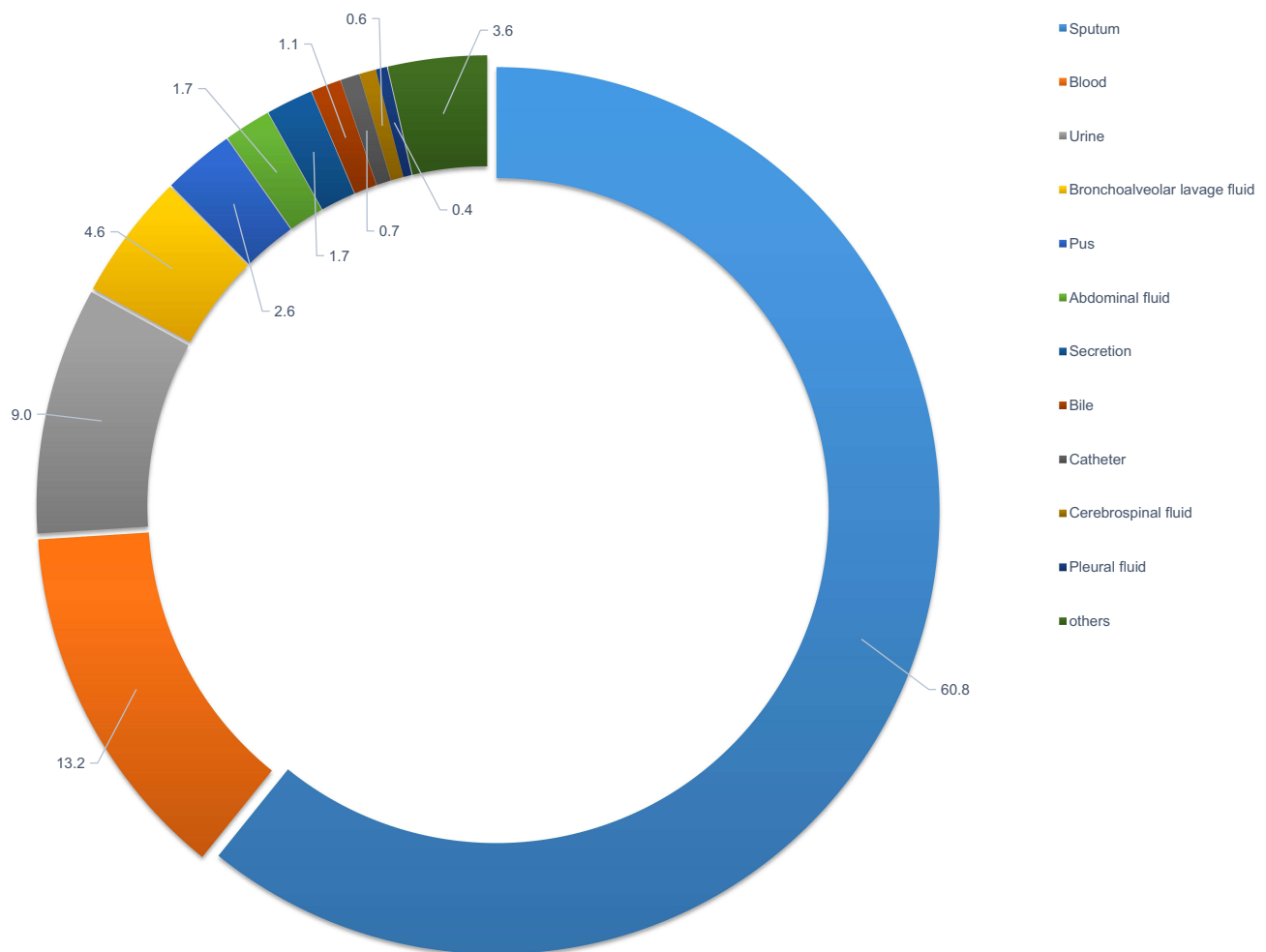

Figure 1 Percentage distribution of specimen sources.

Table 1 Distribution of Bacterial Species from 2018 to 2022

Organism	No. of Strains	%
Klebsiella pneumoniae	9623	20.6
Acinetobacter baumannii	6353	13.6
Escherichia coli	5684	12.2
Pseudomonas aeruginosa	4391	9.4
Staphylococcus aureus	3099	6.6
Enterococcus faecium	2210	4.7
Stenotrophomonas maltophilia	1844	3.9
Enterobacter cloacae	1528	3.3
Staphylococcus epidermidis	1227	2.6
Haemophilus influenzae	1065	2.3
Streptococcus pneumoniae	1027	2.2
Serratia marcescens	727	1.6
Staphylococcus hominis ss. hominis	701	1.5
Staphylococcus haemolyticus	660	1.4
Klebsiella aerogenes	607	1.3
Klebsiella oxytoca	566	1.2
Enterococcus faecalis	508	1.1
Burkholderia cepacia	403	0.9
Others*	4505	9.6
Total	46,728	100.0

Notes:*Bacteria other than the list.

Sensitivity and Resistance Rates of Gram-Negative Bacteria to Antimicrobials
Enterobacteriaceae

Klebsiella pneumoniae and *Escherichia coli* ranked first and third in the overall detection rate. From 2018 to 2022, the resistance rates of *Klebsiella pneumoniae* to imipenem and meropenem changed from 14.5% and 17.8% to 14.0% and 14.4%, showing a steady downward trend (Figure 3). The resistance rates of *Escherichia coli* to piperacillin, ceftriaxone, ciprofloxacin, levofloxacin, and trimethoprim–sulfamethoxazole were greater than 50%, while the resistance rates to carbapenems were always highly sensitive, with a total resistance rate of 3.8%. The total resistance rates of major Enterobacteriaceae to commonly used antimicrobials are shown in Table 2.

Non-Fermented Gram-Negative Bacilli

The resistance rates of *Acinetobacter baumannii* to most of the tested drugs were higher than 50%, and the resistance rates to imipenem and meropenem were 76.2% and 76.9%, respectively. It was highly sensitive to polymyxin B, colistin and tigecycline with resistance rates of 2.5%, 0.6% and 1.8%. The resistance rates of *Pseudomonas aeruginosa* to cefoperazone/sulbactam, piperacillin/tazobactam, ceftazidime, cefepime, gentamicin, ciprofloxacin, and levofloxacin were lower than 19.1%, and they were highly sensitive to polymyxin B, colistin and amikacin with resistance rates of 1.1%, 1.3% and 1.7%, respectively. The resistance rates of *Pseudomonas aeruginosa* to imipenem and meropenem decreased significantly, changed from 25.3% and 22.9% in 2018 to 20.0% and 15.1% in 2022 (Figure 4). The total resistance rates and susceptibility of major non-fermented gram-negative bacteria to commonly used antimicrobials are shown in Table 3.

Other Gram-Negative Bacilli

A total of 1065 strains of *Haemophilus influenzae* were isolated, adult isolates and child isolates accounted for 59.5% and 40.5%, respectively. The resistance rate of *Haemophilus influenzae* to ampicillin was more than 50%. Most *Haemophilus influenzae* were highly sensitive to ceftriaxone, meropenem, levofloxacin and chloramphenicol, while a few non-susceptible strains had appeared to the latter three. In comparison, isolates from children were more resistant to ampicillin, cefuroxime, and trimethoprim–sulfamethoxazole than those from adults (Table 4).
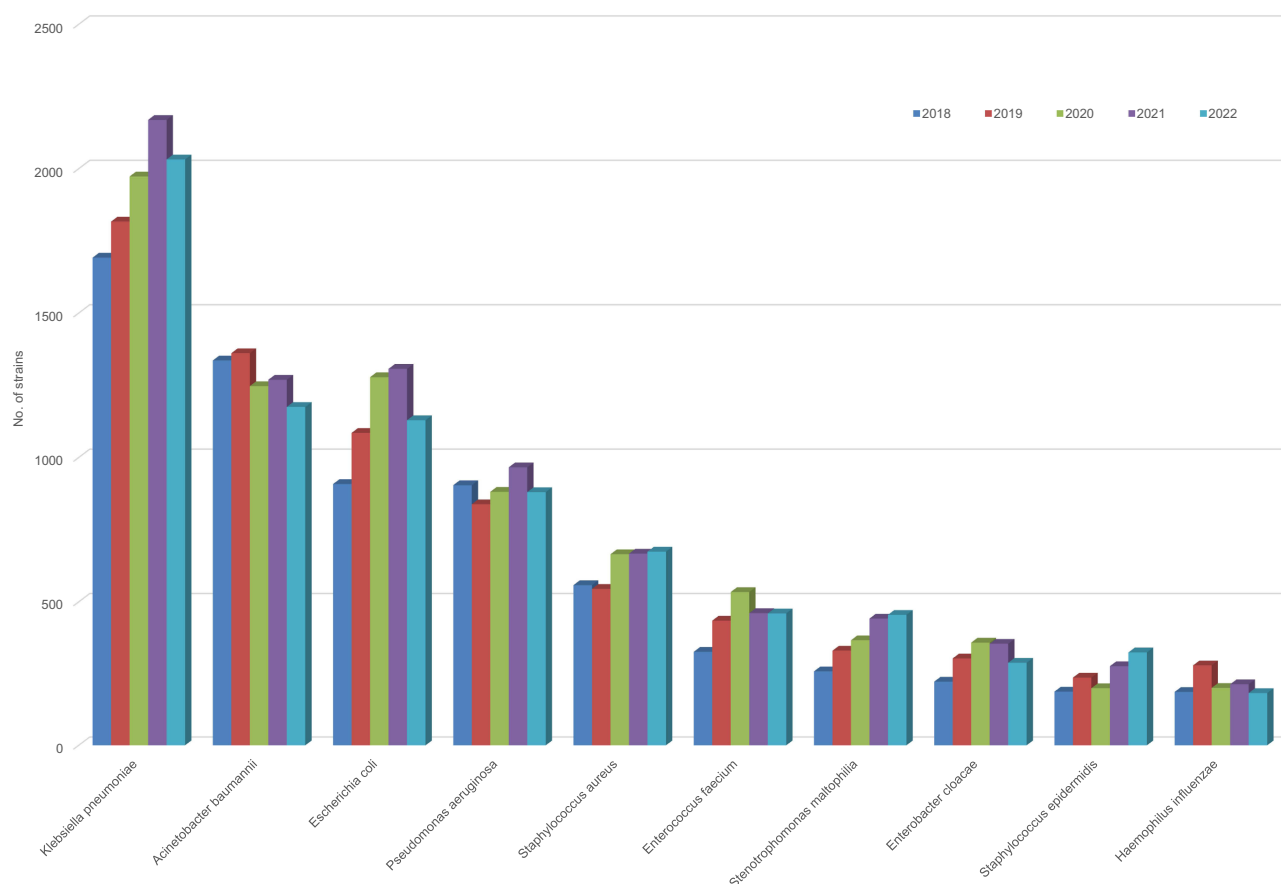
Figure 2 Detection trends of top 10 isolates from 2018 to 2022.

Sensitivity and Resistance Rates of Gram-Positive Bacteria to Antimicrobials
Staphylococcus spp

Staphylococcus aureus owned the highest detection rate among gram-positive bacteria, with a total of 3099 isolated. The detection rates of MRSA and methicillin-resistant coagulase-negative *Staphylococcus* (MRCNS) respectively were 31.7% and 82.7%, and their resistance rates to antimicrobials such as aminoglycosides, quinolones, and macrolides were significantly higher than those of methicillin-sensitive strains (MSSA and MSCNS). However, the resistance rate of MRSA to trimethoprim-sulfamethazole was below that of MSSA (10.5% versus 19.1%). No vancomycin-resistant strain had been identified in *Staphylococcus* species, and a very small number of linezolid-resistant MRCNS were isolated with a rate of 0.7% (Table 5).

Enterococcus Genus

The detection rate of *Enterococcus faecium* (2210, 4.7%) was significantly higher than that of *Enterococcus faecalis* (508, 1.1%). The sensitivity to most of the tested antibacterial drugs of *Enterococcus faecium* was significantly lower than that of *Enterococcus faecalis*. The resistance rates of the two to high concentrations of gentamicin were 36.0% and 47.5%, respectively. No vancomycin and teicoplanin-resistant *Enterococcus faecium* strains was detected, while a few vancomycin and teicoplanin-resistant strains (both 1.3%) were detected in *Enterococcus faecalis*, and more linezolid-resistant *Enterococcus faecium* strains (2.1%) than *Enterococcus faecalis* (0.4%). The total susceptibility and resistance rates of major *Enterococcus genus* to commonly used antimicrobials are shown in Table 6.

Other Gram-Positive Coccus

A total of 1027 strains of *Streptococcus pneumoniae* were isolated. The detection rates of PSSP, PISP, and PRSP were 98.5%, 1.5%, and 0.0% for 82 strains isolated from children, and 96.4%, 2.5%, and 1.1% for 945 strains isolated from
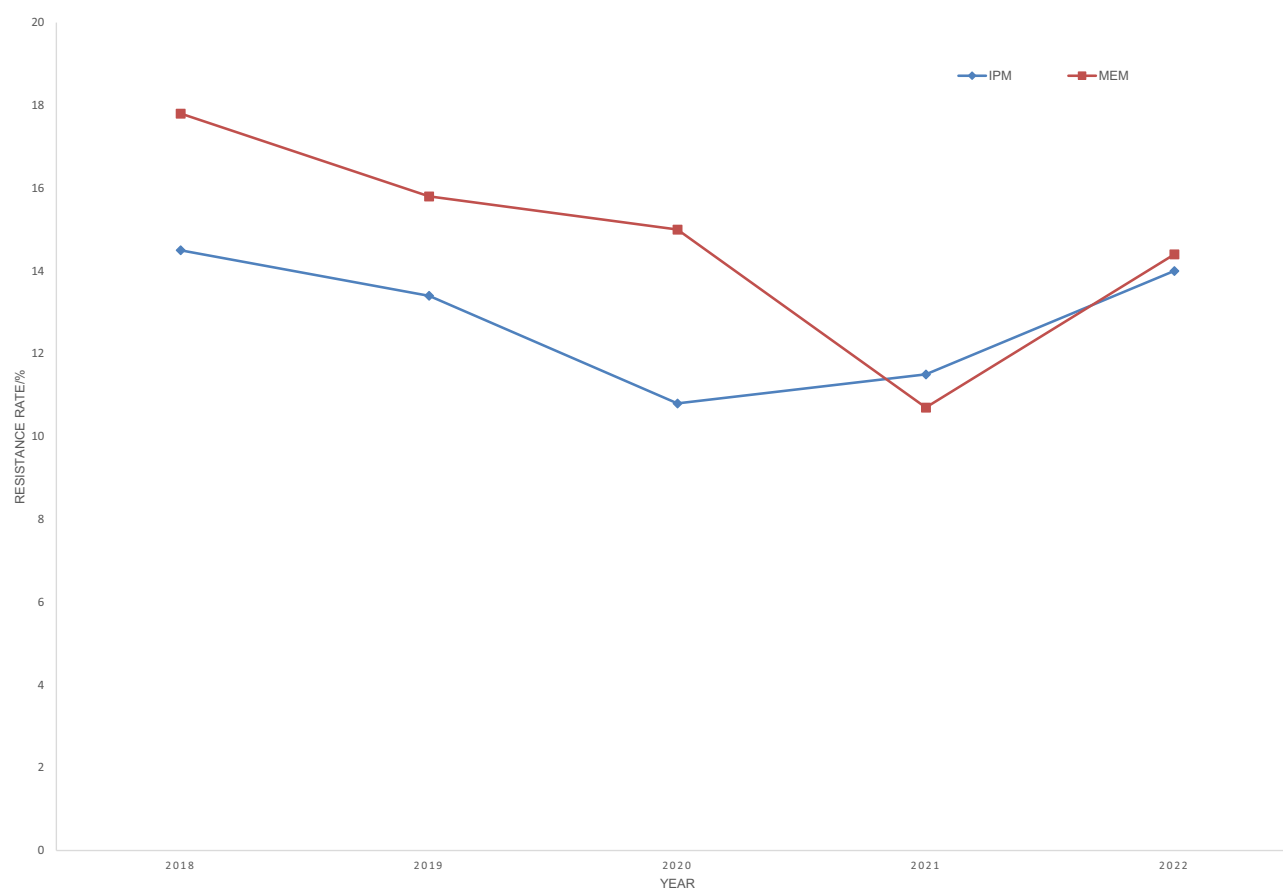
Figure 3 Changes in the resistance rate in *Klebsiella pneumoniae* to imipenem and meropenem from 2018 to 2022.

adults. The drug sensitivity test results showed that both children's and adult strains had high resistance rates to trimethoprim–sulfamethoxazole, erythromycin and clindamycin, and no vancomycin- and linezolid-resistant strains were detected (Table 7).

Table 2 Resistance Rates of Enterobacteriaceae Strains to Antimicrobial Agents

Antimicrobial Agent	KPN (n=9623)		ECO (n=5684)		ECL (n=1528)		SMA (n=727)		PMI (n=383)		CFR (n=240)		MMO (n=141)	
	R	S	R	S	R	S	R	S	R	S	R	S	R	S
Ampicillin	–[a]	–	86.7	11.9	–	–	–	–	64.9	32.9	–	–	–	–
Piperacillin	41.1	50.4	84.5	13.2	49.2	49.2	7.0	92.6	44.2	45.3	52.1	43.8	27.0	64.9
Cefoperazone–sulbactam	17.9	76.5	11.5	75.6	24.0	65.4	1.7	95.8	1.0	95.8	17.9	72.4	4.9	92.6
Ampicillin–sulbactam	33.3	61.3	51.2	28.6	–	–	–	–	42.2	49.4	–	–	64.8	9.0
Piperacillin–tazobactam	16.1	80.0	8.6	86.1	27.3	63.7	2.6	94.8	0.5	98.6	22.9	64.7	3.7	94.8
Cefazolin	42.1	45.7	72.5	17.2	–	–	–	–	59.3	25.0	–	–	–	–
Cefuroxime	33.6	63.5	60.2	36.1	63.3	23.6	–	–	46.9	50.2	–	–	–	–
Ceftazidime	21.8	76.5	30.4	66.7	43.4	55.5	4.3	95.1	6.8	91.6	44.2	54.5	15.2	78.0
Ceftriaxone	30.9	68.9	59.6	40.2	48.6	50.4	10.9	86.8	40.8	57.0	47.8	51.3	16.9	77.9
Cefepime	19.2	77.3	24.4	66.7	23.2	69.3	3.3	93.8	10.4	73.9	17.1	78.2	5.4	90.8
Cefoxitin	20.8	77.1	14.4	80.0	–	–	–	–	4.2	93.2	–	–	18.6	60.5
Ertapenem	9.0	90.9	2.9	96.9	15.3	83.1	2.9	96.8	1.0	97.9	7.9	91.5	2.8	97.2
Imipenem	12.6	86.7	3.4	96.4	16.3	81.5	5.8	84.1	25.0[b]	50.0 [b]	10.0	87.3	NA	NA

(*Continued*)

Table 2 (Continued).

Antimicrobial Agent	KPN (n=9623)		ECO (n=5684)		ECL (n=1528)		SMA (n=727)		PMI (n=383)		CFR (n=240)		MMO (n=141)	
	R	S	R	S	R	S	R	S	R	S	R	S	R	S
Meropenem	14.1	85.6	3.6	96.1	14.1	85.1	2.4	97.1	0.9	98.3	10.8	88.6	2.3	97.7
Amikacin	9.8	90.0	2.7	96.9	2.5	96.0	0.3	99.3	1.9	97.3	1.3	98.7	4.3	95.7
Gentamicin	18.6	80.3	34.9	63.3	18.0	76.9	2.2	97.2	20.0	56.0	17.3	81.0	21.8	72.2
Ciprofloxacin	21.1	76.6	52.5	45.1	20.3	75.0	1.7	97.7	42.4	51.0	25.3	70.6	20.5	68.2
Levofloxacin	18.7	78.8	50.3	46.6	18.3	77.0	1.0	98.1	25.2	64.1	20.1	75.1	9.0	81.3
Trimethoprim–sulfamethoxazole	24.5	75.5	52.7	47.2	25.9	74.1	2.8	97.2	54.9	45.1	25.0	75.0	37.0	63.0
Polymyxin B	0.8	95.1	2.3	97.7	0.0	90.9	–	–	–	–	0.0	100.0	–	–
Tigecycline	1.8	96.7	0.2	99.8	2.0	95.7	0.3	98.7	–	–	1.0	98.0	–	–
Nitrofurantoin	30.8	28.3	3.1	88.4	17.2	33.4	–	–	–	–	3.9	92.2	–	–
Fosfomycin	NA	NA	2.0[c]	96.0[c]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Notes: [a]Intrinsic resistance; [b]Results by Kirby–Bauer method only; [c]For urinary tract isolates only.
Abbreviations: NA, not available; KPN, *Klebsiella pneumonia*; ECO, *Escherichia coli*; ECL, *Enterobacter cloacae*; SMA, *Serratia marcescens*; PMI, *Proteus mirabilis*; CFR, *Citrobacter freundii*; MMO, *Morganella morganii*.

Discussion

The monitoring results showed that a total of 46,728 bacterial strains were isolated from ICU across 109 medical institutions in Western China from 2018 to 2022, and the main sources of specimens were sputum, blood, urine,
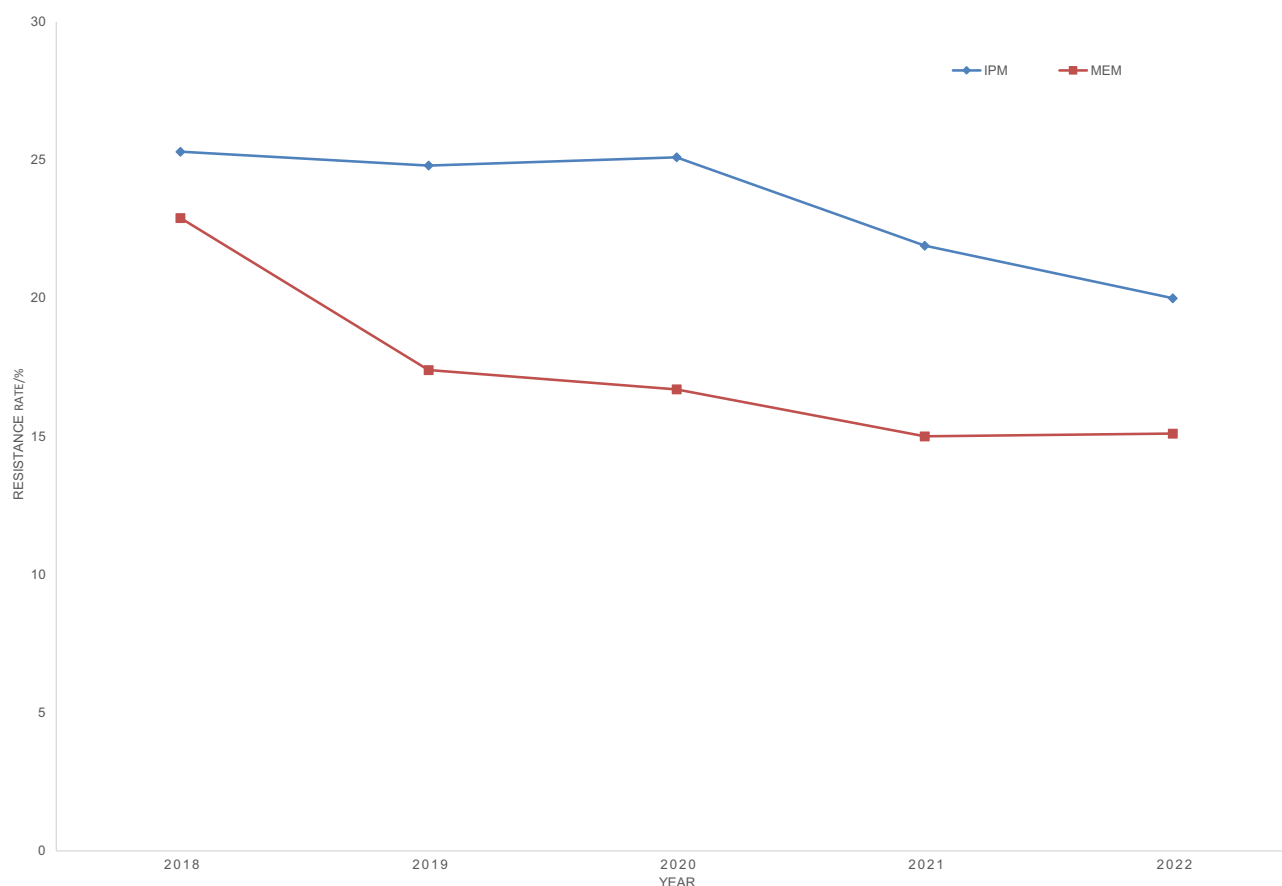

Figure 4 Changes in the resistance rate in *Pseudomonas aeruginosa* to imipenem and meropenem from 2018 to 2022.

Table 3 Resistance Rates of Non-Fermentative Gram-Negative Bacilli to Antimicrobial Agents

Antimicrobial Agent	ABA (n=6353)		PAE (n=4391)		PMA (n=1844)		PCE (n=403)	
	R	S	R	S	R	S	R	S
Piperacillin	86.2	11.6	22.8	62.9	–	–	–	–
Cefoperazone–sulbactam	53.4	33.3	15.9	67.4	21.4	62.7	28.4	48.6
Ampicillin–sulbactam	64.9	28.0	–	–	–	–	–	–
Piperacillin–tazobactam	72.9	22.9	15.8	68.6	–	–	38.6	50.3
Ceftazidime	74.3	23.0	19.1	71.4	38.1	50.2	13.7	81.3
Cefepime	74.2	23.5	12.3	79.3	81.8	7.3	38.1	24.4
Aztreonam	– *	–	25.1	54.4	–	–	75.4	19.8
Imipenem	76.2	23.1	23.1	72.7	–	–	89.4	7.5
Meropenem	76.9	22.1	16.5	78.7	–	–	13.1	81.4
Amikacin	57.0	40.0	1.7	96.9	–	–	NA	NA
Gentamicin	67.1	31.1	5.6	90.3	–	–	83.6	12.1
Ciprofloxacin	76.1	23.5	13.1	81.5	23.0	49.2	14.2	67.6
Levofloxacin	60.6	26.3	14.1	77.5	7.9	88.1	14.0	77.8
Trimethoprim–sulfamethoxazole	44.7	55.1	–	–	8.5	91.4	11.6	88.1
Colistin	1.1	98.9	2.0	98.0	82.2	17.8	–	–
Polymyxin B	2.5	97.5	1.1	97.2	33.3	37.5	–	–
Minocycline	17.9	60.3	–	–	1.7	95.6	12.5	84.4
Tigecycline	1.8	88.9	–	–	7.4	87.0	16.3	66.3

Notes: *Intrinsic resistance.
Abbreviations: NA, not available; ABA, *Acinetobacter baumannii*; PAE, *Pseudomonas aeruginosa*; PMA, *Stenotrophomonas maltophilia*; PCE, *Burkholderia cepacia*.

Table 4 Resistance Rates of *Haemophilus influenzae* to Antimicrobial Agents

Antimicrobial Agent	Total (n=1065)		Isolates from Adults (n=431)		Isolates from Children (n=634)	
	R	S	R	S	R	S
Ampicillin	64.9	31.2	59.6	35.7	68.7	27.9
Amoxicillin–clavulanic acid	12.7	87.3	13.3	86.7	12.3	87.7
Ampicillin–sulbactam	27.0	73.0	22.1	77.9	30.6	69.4
Cefuroxime	31.0	66.6	28.4	68.9	32.5	65.2
Ceftriaxone	0.0*	100.0	0.0*	100.0	0.0*	100.0
Meropenem	1.4*	98.6	1.1*	98.9	1.6*	98.4
Levofloxacin	1.2*	98.8	0.9*	99.1	1.5*	98.5
Trimethoprim–sulfamethoxazole	47.5	40.9	43.0	44.1	50.8	38.6
Azithromycin	28.6*	71.4	29.6*	70.4	27.8*	72.2
Chloramphenicol	3.9	95.7	3.9	95.8	3.8	95.6

Notes: *Insensitivity rate, sensitive breakpoints only.

bronchoalveolar lavage fluid, pus, etc. Among them, the isolation rate of gram-negative bacteria was 76.1%, and the top three were *Klebsiella pneumoniae, Acinetobacter baumannii* and *Escherichia coli*, respectively. The isolation rate of gram-positive bacteria was 23.9%, with *Staphylococcus aureus* being the most, followed by *Enterococcus faecium* and *Staphylococcus epidermidis*.

Klebsiella pneumoniae and *Escherichia coli* ranked the top 2 gram-negative bacteria, and the number of isolates displayed an upward trend from 2018 to 2022 (Figure 2). Over a five-year period, the resistance rates of *Klebsiella pneumoniae* to imipenem and meropenem exhibited a steady downward trend. The sensitivity of *Escherichia coli* to carbapenems was stable overall, with a total resistance rate of only 3.8%. Among non-fermented gram-negative bacteria,

Table 5 Resistance Rates of *Staphylococcus* spp. to Antimicrobial Agents

Antimicrobial Agent	MRSA (n=982)		MSSA (n=2117)		MRCNS (n=2717)		MSCNS (n=570)	
	R	S	R	S	R	S	R	S
Penicillin G	100.0	0.0	90.0	10.0	100.0	0.0	74.5	25.5
Oxacillin	100.0	0.0	0.0	100.0	100.0	0.0	0.0	100.0
Gentamicin	26.5	68.6	14.2	81.8	31.7	59.2	3.0	94.0
Rifampin	16.6	82.8	0.3	99.2	16.7	82.9	1.0	98.8
Levofloxacin	38.8	60.3	11.3	88.2	73.7	23.9	12.5	86.0
Trimethoprim–sulfamethoxazole	10.5	89.5	19.1	80.9	49.3	50.7	27.9	72.1
Clindamycin	60.4	39.5	26.7	72.9	47.8	50.7	11.4	86.7
Erythromycin	79.3	18.7	48.2	49.3	85.2	13.2	55.4	43.1
Nitrofurantoin	1.0	98.5	0.0	99.4	0.7	98.8	0.0	100.0
Linezolid	0.0	100.0	0.0	100.0	0.7	99.3	0.0	100.0
Vancomycin	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
Teicoplanin	0.0	95.8	0.0	97.5	0.0	100.0	0.0	100.0

Abbreviations: MRSA, methicillin-resistant *Staphylococcus aureus*; MSSA, methicillin-sensitive *Staphylococcus aureus*; MRCNS, methicillin-resistant coagulase-negative *Staphylococcus*; MSCNS, methicillin-sensitive coagulase-negative *Staphylococcus*.

Table 6 Resistance Rates of *E. faecium* and *E. faecalis* to Antimicrobial Agents

Antimicrobial Agent	EFM (n=2210)		EFA (n=508)	
	R	S	R	S
Penicillin G	95.2	4.8	13.2	86.6
Ampicillin	93.8	6.2	9.7	90.3
Gentamicin-high	47.5	52.5	36.0	64.0
Streptomycin-high	30.7	69.3	28.5	71.5
Rifampin	76.1	13.4	48.5	34.3
Levofloxacin	93.7	4.6	28.0	68.8
Moxifloxacin	96.0	3.0	25.9	69.1
Nitrofurantoin	53.1	21.1	8.2	85.8
Linezolid	0.4	98.6	2.1	95.3
Vancomycin	1.3	98.7	0.0	100.0
Teicoplanin	1.3	98.7	0.0	100.0

Abbreviations: EFM, *Enterococcus faecium*; EFA, *Enterococcus faecalis*.

Table 7 Resistance Rates of *Streptococcus pneumonia* to Antimicrobial Agents

Antimicrobial Agent	Total (n=1027)		Isolates from Adults (n=945)		Isolates from Children (n=82)	
	R	S	R	S	R	S
Penicillin G	1.0	96.7	1.1	96.4	0.0	98.5
Ceftriaxone	6.7	89.8	6.3	90.4	10.1	84.1
Cefotaxime	4.6	89.6	4.2	90.5	7.1	81.4
Meropenem	7.0	68.3	6.9	69.1	7.2	58.0
Levofloxacin	2.5	97.0	2.7	96.7	0.0	100.0
Moxifloxacin	1.5	98.0	1.4	98.1	2.9	97.1
Trimethoprim–sulfamethoxazole	56.6	30.5	56.0	30.6	66.2	27.0
Clindamycin	87.7	11.1	87.4	11.5	90.3	6.5
Erythromycin	93.4	5.3	93.6	5.2	92.9	5.7
Vancomycin	0.0	100.0	0.0	100.0	0.0	100.0

the resistance rates of *Acinetobacter baumannii* to most of the tested drugs were more than 50%, and the resistance rates to imipenem and meropenem respectively were 76.2% and 76.9%, which were significantly higher than those of the national level (65.8% and 66.6%).[18] The overall resistance rates of *Pseudomonas aeruginosa* to imipenem and meropenem were 23.1% and 16.5%, performing a significant decrease trend from 2018 to 2022. The overall downward trend of the drug resistance rate is inseparable from the following two points. First of all, the national policy system has made the legalization and institutionalization of antimicrobial drug management on track, raised the awareness of medical workers on the hierarchical use of antimicrobial drugs and the public's awareness of the drug resistance's crisis, and greatly promoted the rational use of antimicrobial drugs. Secondly, the gradual improvement of the bacterial resistance monitoring network provides a useful reference for the administrative department to adjust management policies in a timely manner, and for medical institutions to rationally select antibacterial drugs.

The increasing incidence and epidemic of carbapenem-resistant gram-negative bacilli (CRGNB) has become a global public health issue, with mortality rates as high as 6.6% to 20%.[19,20] WHO has classified CRE, CRAB, and CRPA as the pathogens of critical threat in the global priority list.[4] CRGNB usually exhibit the characteristics of broad drug resistance or even total drug resistance due to the prevalence of resistance genes to other antibacterial drugs,[21] making clinical anti-infection treatment difficult. Ceftazidime/avibactam, tigecycline, and polymyxin are considered the most effective antimicrobials for the treatment of infections caused by CRGNB.[22–24] Laboratories should conduct susceptibility testing of other antimicrobials as much as possible while using mentioned above antimicrobials, and if necessary, combined susceptibility testing could be applied to screen out more effective anti-infective regimens.[25] Carbapenemase-producing is the most important resistance mechanism of CRE,[26] different types of carbapenemase need to be targeted with carbapenem inhibitor combinations. Therefore, it is recommended that laboratories should carry out the detection of carbapenemase phenotype or genotype as advocated[27] and report to the clinical.

Among the gram-positive bacteria isolated in this surveillance, staphylococci and enterococci were the main ones. The detection rates of MRSA and MRCNS were 31.7% and 82.7%, respectively, which were higher than those of the national level (28.7% and 78.2%).[18,28] During 5 years, *Staphylococcus aureus* has always maintained a high sensitivity to linezolid, vancomycin and teicoplanin, vancomycin still is introduced as a drug of choice for treating serious infections due to MRSA. However, due to the overuse of vancomycin, non-sensitive strains began to emerge. Vancomycin-resistant *Staphylococcus aureus* (VRSA) strains have been reported in the United States, Iran, and India.[29–32] Increased antibiotic resistance in MRSA isolates is becoming one of the most serious health problems worldwide. The good news is that new agents such as Travancin, Dabavancin, Olitavan Cin and Tedizolid have recently been licensed to treat infections caused by MRSA. In addition, as a normal colonizing flora of human skin and mucous membranes, with the increase in invasive operations, such as indwelling catheters, endotracheal intubation and implantation of medical devices, *Staphylococcus epidermis* is necessary to exclude contamination caused by improper operation and define whether it is the real pathogenic bacteria.

During 5 years, *Enterococcus faecium* and *Enterococcus faecalis* remained highly sensitive to linezolid, vancomycin, and tecoplanin. Temporarily, no vancomycin-resistant *Enterococcus faecium* strains were detected, and a few vancomycin-resistant strains were detected in *Enterococcus faecalis*. Together with MRSA, WHO identified VRE as Priority 2 drug-resistant bacterium in the "Global Priority List of Antibiotic-Resistant Bacteria".[4] Although high-dose daptomycin and linezolid could be applied for the treatment of VRE infections, emerging antibiotic resistance to these agents limits potential available therapies.

Conclusion

From 2018 to 2022, the bacteria infection in intensive care units of Southwest China was mainly gram-negative bacteria, and the growth rate of major multidrug-resistant bacteria was significantly higher than that of the national level. Given the rising prevalence of MDR/XDR/PDR bacteria in ICU, the establishment and execution of ASP is particularly critical. ASP has been shown to be effective in reducing antibiotic resistance, duration of ventilation, days of antibiotic use, and healthcare costs in critically ill patients. Because of these benefits, antibiotic stewardship should be implemented in all intensive care units as a core competency of intensive care physicians. On top of ASP, rapid and accurate diagnostics play a crucial role in striking the right balance between providing timely and appropriate antibiotic therapy in the ICU while

minimizing the unnecessary use of antibiotics. Advanced diagnostics empower healthcare professionals to make informed decisions promptly, ensuring optimal patient care and preserving the effectiveness of antibiotics.

Ethics Approval

The study was approved by the Ethics Committee of Sichuan Provincial People's Hospital, University of Electronic Science and Technology of China, Chengdu, China (No. 2023324). The ethics committee waived the need for written informed consent provided by participants due to the retrospective nature of this study. Patients' anonymous information was provided from the microbiology hospital laboratory, which isolated the strains. The study completely followed the principles outlined in the Declaration of Helsinki.

Disclosure

The authors report no conflicts of interest in this work.

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