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Distribution and Antimicrobial Susceptibility of Gram-Positive and Gram-Negative Pathogens Isolated from Patients Hospitalized in a Tertiary Teaching Hospital in Southwestern China

Lingling Xu [1], Zhangrui Zeng [1], Yinhuan Ding [1], Min Song [1], Kui Yang [1] and Jinbo Liu [1,*]

[1]The Affiliated Hospital of Southwest Medical University, Luzhou, Sichuan Province, China

[*]*Corresponding author*: Department of Laboratory Medicine, The Affiliated Hospital of Southwest Medical University, Luzhou Province, China. Email: liulab2019@163.com

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Abstract

Background: Bacteria are the most common causes of clinical infectious diseases. The distribution and antimicrobial resistance (AMR) rates of bacteria provide important guidelines for clinical antibacterial treatment; however, the information in this region is still missing.

Objectives: This study aimed to evaluate the changes in the distribution and AMR rates of clinical isolates from inpatients.

Methods: We conducted a retrospective cross-sectional analysis of the distribution and antimicrobial susceptibility of all non-duplicate Gram-negative bacterial (GNB) and Gram-positive bacterial (GPB) isolates collected from January 1, 2013, to December 31, 2018, in our hospital.

Results: In total, 56,535 and 3,518 non-repetitive isolates were detected in the whole hospital and intensive care units (ICUs), respectively. The isolates included GPB (26.3% and 18.4%, respectively) and GNB (73.7% and 81.6%, respectively). The five dominant bacteria were the same in the whole hospital and ICUs, but *Escherichia coli*, *Klebsiella pneumoniae*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Acinetobacter baumannii* percentages were different. The detection rates of all isolates and five dominant bacteria were significantly different between the ICUs and the whole hospital ($P < 0.05$). The detection rate of extended-spectrum β-lactamase (ESBL)-*E. coli* (54.1%) was significantly higher than that of *K. pneumoniae* (26.1%). The detection rates of carbapenem-resistant (CR) and extensively drug-resistant (XDR)-*A. baumannii* were the highest in both the ICUs (87.1% and 21.8%, respectively) and the whole hospital (65.5% and 12.9%, respectively). The methicillin-resistant *S. aureus* (MRSA) detection rate was high (26.5%) but showed a significant decreasing trend ($P < 0.05$). The detection rates of ESBL and XDR-*E. coli*, CRAB, and XDR-*S. aureus* were significantly different between the ICUs and the whole hospital ($P < 0.05$). Gram-negative bacteria were highly susceptible to amikacin (> 90%) and tigecycline (> 98%). *Staphylococcus aureus* showed 100% susceptibility to vancomycin and linezolid. *Acinetobacter baumannii* had the highest resistance to imipenem (62.8%) and meropenem (64.0%). Except for *A. baumannii* and *E. coli* ($P < 0.05$), the AMR levels and the trends of the other isolates were similar between the ICUs and the whole hospital ($P > 0.05$).

Conclusions: Currently, the appropriate antimicrobial agents in our hospital include amikacin and tigecycline for the treatment of GNB infections and vancomycin and linezolid for the treatment of GPB infections. Moreover, it is still necessary to monitor AMR in the ICUs and the whole hospital simultaneously.

Keywords: Antimicrobial Resistance, Intensive Care Unit, Gram-Positive Bacteria, Gram-Negative Bacteria

1. Background

Bacterial resistance to antibiotics is becoming a global threat to human health. An alarming increase in antimicrobial resistance (AMR) among both Gram-positive and Gram-negative pathogens has been observed in China (1) and Europe (2) in recent decades. In recent years, however, the prevalence of many resistant Gram-positive bacteria (GPB) has remained relatively stable or declined. Besides, the prevalence of methicillin-resistant *Staphylococcus aureus* (MRSA) has begun to decrease in some countries in recent years (2). Gram-negative bacteria (GNB) are more concerning than GPB, as the levels of AMR in many important pathogens, including *Escherichia coli*, *Pseudomonas aeruginosa*, *Acinetobacter baumannii*, and *Klebsiella pneumoniae*, have increased in China (3) and other areas of the world (4). It has been reported that epidemiological surveillance of antimicrobial agents' resistance levels can provide useful information for clinical prevention efforts, effective antibiotic therapy administration, and optimized antibiotic use,

which has become one of the most important components of AMR control.

Although the AMR levels are published by China antimicrobial surveillance network (CHINET) researchers every year, the AMR levels are obtained from a small amount of hospital data in large cities of China and do not fully represent the AMR levels in all regions of China (34 provinces or cities). According to the CHINET (5), the resistance rates of *E. coli* isolates to cefepime and imipenem in 2011 to 2014 were 40.7 to 28.1% and 1.0 to 0.9%, respectively. However, the resistance rates of *E. coli* isolates to cefepime and imipenem in Zhengzhou city, China, from 2011 to 2014 were 49.7 to 38.4% and 0.9 to 1.3%, respectively (6). There were significant differences in the distributions of resistance levels in different geographical locations. According to another national surveillance program (7), except for carbapenem-resistant (CR) *E. coli* (CREC), which did not differ greatly by region, the prevalence of carbapenem-resistant *K. pneumoniae* (CRKP) and extensively drug-resistant *P. aeruginosa* (XDRPA) and *A. baumannii* (XDRAB) strains varied significantly across regions.

2. Objectives

We evaluated the antimicrobial susceptibility patterns of GPB and GNB isolated from hospitalized patients (ICUs and the whole hospital) in a regional tertiary teaching hospital in southwestern China.

3. Methods

3.1. Study Design and Setting

In this surveillance study, we recorded and analyzed data from bacterial cultures and antimicrobial susceptibility tests performed on both GPB and GNB causing nosocomial infections in all wards at the Affiliated Hospital of Southwest Medical University from January 2013 to December 2018. The study setting is a 3200-bed tertiary teaching hospital and the largest hospital in southern Sichuan province, China. The hospital offers health care services to more than 1.8 million outpatients and 130,000 inpatients per year for patients living in the four provinces and cities (Sichuan province, Yunnan province, Guizhou province, and Chongqing city, approximately 40 million persons). Data were collected from all wards [including 39 general wards and three ICUs (general intensive care unit, neonatal ICU, and coronary CU)]. The study protocol was approved by the ethics committee of the hospital.

3.2. Isolate Collection

The isolates were collected in our hospital from January 1, 2013, to December 31, 2018. The isolates were cultured from all sample sources (e.g., bloodstream, respiratory tract, urinary tract, secretions, cerebrospinal fluid, other sterile body fluids, feces, genital tract, and others). The identification of these bacteria was performed with a MicroScan WalkAway 96 Plus System (Siemens, Germany) and a Microflex LT (Bruker Diagnostics Inc., USA) matrix-assisted laser desorption/ionization time-of-flight mass spectroscopy (MALDI-TOF MS) system.

3.3. Susceptibility Testing

Antimicrobial susceptibility tests were performed by using modified broth microdilution tests with the MicroScan System (Siemens, Germany). The tests were performed according to the manufacturer's recommendations, and the results were interpreted according to the Clinical Laboratory and Standards Institute (CLSI) breakpoints for the respective years (CLSI document M100-S23-28, Wayne, PA: CLSI, 2013-2018) (8-13). The US Food and Drug Administration (FDA) breakpoints were used for tigecycline. The MRSA and extended-spectrum β-lactamase (ESBL) isolates were identified by a MicroScan WalkAway 96 Plus System according to the manufacturer's instructions. Methicillin-resistant *S. aureus* and ESBL-producing *E. coli* and *K. pneumoniae* were determined according to the CLSI guidelines. The control bacterial strains were *S. aureus* ATCC 25923, *E. coli* ATCC 25922, *K. pneumoniae* ATCC 700603, *P. aeruginosa* ATCC 27853, and *A. baumannii* ATCC 19606.

3.4. Statistical Analysis

The chi-square or Fisher's exact tests were used to compare categorical data, and Student's *t*-tests or the Mann-Whitney U test to compare continuous data. The trend was analyzed by linear regression analysis. All of the data were analyzed using SPSS 24.0 (IBM Corporation, Armonk, NY). Probability values of $P < 0.05$ were considered statistically significant.

4. Results

4.1. Distribution and Culture-Positive Rate of Specimens

From 2013 to 2018, a total of 275,944 and 11,335 nonrepetitive specimens were collected from all wards and ICUs in our hospital, respectively. The total culture-positive rates of the specimens in the whole hospital and ICUs were 14.8% and 18.0%, respectively. The distribution and culture-positive rates of these specimens in all wards were as follows: Sputum/endotracheal aspirates (34.3 and 17.5%), blood (28.4 and 4.9%), secretions (12.6 and 35.4%), urine (12.4

and 18.1%), sterile body fluid (8.6 and 7.7%), and other specimens (3.8 and 2.2%). The distribution and culture-positive rates of these specimens in the ICUs were as follows: Sputum/endotracheal aspirates (55.3 and 23.6%), blood (26.4 and 5.6%), sterile body fluid (6.8 and 18.3%), urine (5.5 and 12.1%), secretions (4.3 and 35.9%), and other specimens (1.6 and 1.6%). The detailed data are shown in Figure 1.

4.2. Detection Rate of Bacteria

From 2013 to 2018, the total detection rates were 20.5% (56535/275944) in the whole hospital and 31.0% (3518/11335) in the ICU wards ($P < 0.001$), which included 14,872 isolates of GPB (26.3%) and 41,663 isolates of GNB (73.7%) in the whole hospital and 646 isolates of GPB (18.4%) and 2,872 isolates of GNB (81.6%) in the ICUs. The five dominant bacteria were *E. coli* (20.3%), *K. pneumoniae* (12.2%), *S. aureus* (11.4%), *P. aeruginosa* (8.1%), and *A. baumannii* (6.0%) in the whole hospital, and *A. baumannii* (17.6%), *P. aeruginosa* (11.4%), *K. pneumoniae* (9.6%), *E. coli* (8.2%) and *S. aureus* (5.3%) in the ICUs. The five dominant species accounted for 54.8 to 60.1% of all isolates in the whole hospital and 48.1 to 57.7% of all isolates in the ICUs. The detailed data are shown in Table 1. The non-dominant bacterial populations are shown in Appendix.

4.3. Patterns of Antimicrobial Resistance

In the whole hospital, the pooled resistance levels of ESBL-*E. coli*, CR-*A. baumannii* (CRAB), and XDRAB isolates were highest (54.1, 65.5, and 12.9%, respectively), and XDRAB showed a marked linear increase from 2.5 to 25.9% ($P < 0.05$). Besides, CR-*P. aeruginosa* (CRPA) showed a marked increase from 8.7 to 22.4%. However, ESBL-*E. coli* showed a linearly decreasing trend ($P < 0.05$), and MRSA showed a linear decrease from 29.8 to 21.3% ($P < 0.05$). The rates of XDR isolates of *E. coli* (XDREC) and *K. pneumoniae* (XDRKP) were low (less than 1.0%) but showed a linear increase ($P < 0.05$). In the ICUs, the detection rates of CRAB and XDRAB were more than 80% and 20%, respectively. Also, ESBL-*E. coli* and -*K. pneumoniae* and XDRAB showed marked increases from 56.3 to 70.0%, 17.8 to 25.5%, and 2.3 to 23.2%, respectively ($P < 0.05$). The detection rate of MRSA showed a marked decrease from 40.7 to 12.9% ($P < 0.05$). No XDR strains were found for *E. coli*, *K. pneumoniae*, and *S. aureus*. The detection rates of ESBL- and XDR-*E. coli*, CRAB, and XDR-*S. aureus* showed significant differences between the ICUs and the whole hospital ($P < 0.05$). The detailed data are shown in Table 2.

4.4. Trends in Antimicrobial Resistance

4.4.1. Escherichia coli

The resistance rate of cephem antibiotics was over 50% in the ICUs and the whole hospital. The resistance rates of penicillin in the ICUs and the whole hospital were more than 90 and 80%, respectively. Amikacin, piperacillin/tazobactam, cefoperazone/sulbactam, imipenem, meropenem, ertapenem, and tigecycline were still highly active against *E. coli* in the ICUs and the whole hospital (resistance rate < 5%). All the *E. coli* strains (100%) were susceptible to imipenem, meropenem, and tigecycline in the ICUs. The resistance levels of penicillin and cephems, imipenem, meropenem, tetracycline, and tigecycline were different between the ICUs and the whole hospital ($P < 0.05$). *E. coli* was first found to be resistant to tigecycline in 2017 in our hospital. The detailed data are shown in Table 3.

4.4.2. Klebsiella pneumoniae

There were marked increases in resistance to cefoperazone/sulbactam, imipenem, and meropenem, from 0.0 to 7.4%, 0.1 to 4.0%, and 0.5 to 3.5%, respectively, in the whole hospital and to piperacillin, cefoperazone/sulbactam, tetracycline, and tigecycline, from 35.6 to 98.2%, 0.0 to 9.1%, 20.0 to 29.1%, and 0.0 to 5.5%, respectively, in the ICUs. However, resistance to amikacin, cefuroxime, cefoxitin, and ertapenem decreased from 6.7 to 0.0%, 40.0 to 30.9%, 24.4 to 10.9%, and 6.7 to 1.8%, respectively. Imipenem and meropenem resistance rates essentially fluctuated by approximately 1.6 and 2.2%, respectively. The antimicrobial agent resistance levels did not significantly differ between the ICUs and the whole hospital ($P > 0.05$). *Klebsiella pneumoniae* was first found to be resistant to tigecycline in 2017, and the resistance is gradually increasing. The detailed data are shown in Table 4.

4.4.3. Pseudomonas aeruginosa

There were marked decreases in resistance to amikacin, gentamicin, ciprofloxacin, and levofloxacin, from 11.8 to 3.7%, 32.0 to 5.7%, 30.8 to 18.5%, and 30.6 to 19.0% in the whole hospital, and from 12.1 to 2.6%, 51.5 to 6.1%, 36.4 to 17.4%, and 45.5 to 14.8% in the ICUs, respectively. Cefoperazone/sulbactam, ticarcillin/clavulanic acid, imipenem, and meropenem resistance levels showed marked increases, from 0.0 to 5.9%, 20.4 to 42.2%, 12.5 to 22.4%, and 5.8 to 19.3% in all wards, respectively. *P. aeruginosa* was still highly sensitive to amikacin, cefoperazone/sulbactam, and cefepime (resistance rates < 10%). The AMR levels did not significantly differ between the ICUs and the whole hospital ($P > 0.05$). The detailed data are shown in Table 5.

4.4.4. Acinetobacter baumannii

Except for cefoperazone/sulbactam and tigecycline, to which *A. baumannii* was highly susceptible, other antimicrobial agents in the ICUs and the whole hospital

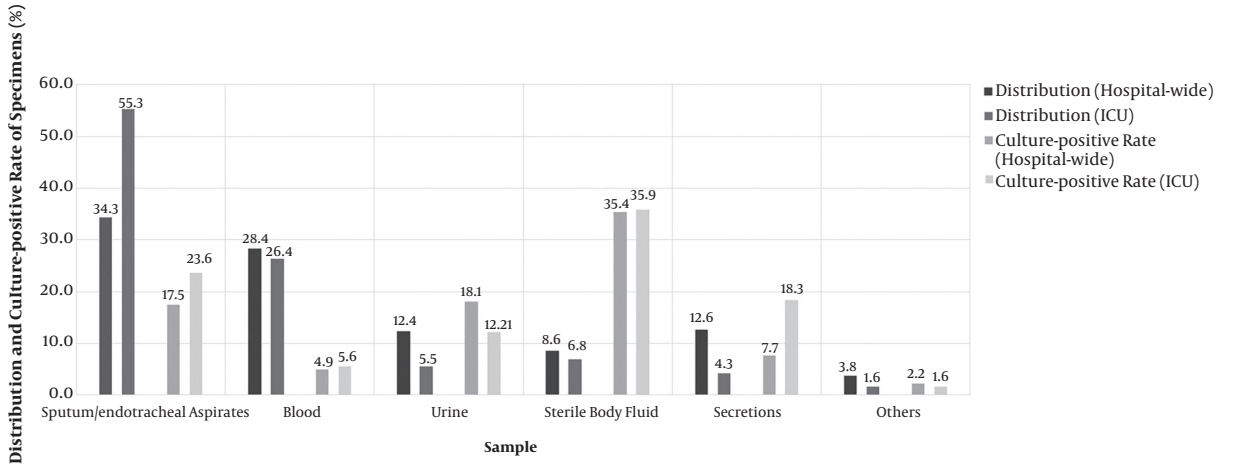

Figure 1. Annual percentage of distribution and culture-positive rate of specimens in ICUs and the whole hospital; Others include ducts, tissues, bile, prostatic fluid, drainage fluid, feces, etc.

Table 1. Percentage of Five Targeted Species Among Total Number of Reported Isolates [a]

Bacterial Species/Wards	Total	2013	2014	2015	2016	2017	2018	2018 - 2013, % Change	P-Value [b]	P-Value [c]
All isolates										< 0.001
Whole hospital	56535 (20.5)	7429 (21.6)	8754 (19.3)	9389 (20.9)	10309 (20.7)	10752 (20.0)	10082 (18.0)	-3.6	0.147	
ICU	3518 (31.0)	412 (40.8)	344 (30.1)	398 (30.2)	673 (27.0)	920 (28.2)	771 (33.7)	-7.1	0.344	
Escherichia coli										< 0.001
Whole hospital	11486 (20.3)	1602 (21.6)	1927 (22.0)	1868 (19.9)	2025 (19.6)	1972 (18.3)	2092 (20.7)	-0.9	0.189	
ICU	289 (8.2)	32 (7.8)	40 (11.6)	30 (7.5)	50 (7.4)	49 (5.3)	88 (11.4)	3.6	0.968	
Klebsiellapneumoniae										0.066
Whole hospital	6897 (12.2)	1097 (14.8)	1109 (12.7)	1177 (12.5)	1292 (12.5)	1148 (10.7)	1074 (10.7)	-4.1	0.007	
ICU	337 (9.6)	45 (10.9)	38 (11.0)	53 (13.3)	64 (9.5)	82 (8.9)	55 (7.1)	-3.8	0.097	
Staphylococcus aureus										< 0.001
Whole hospital	6452 (11.4)	788 (10.6)	1007 (11.5)	1012 (10.8)	1310 (12.7)	1111 (10.3)	1224 (12.1)	0.7	0.521	
ICU	187 (5.3)	27 (6.6)	16 (4.7)	12 (3.0)	48 (7.1)	53 (5.8)	31 (4.0)	-2.6	0.719	
Pseudomonas aeruginosa										0.130
Whole hospital	4573 (8.1)	519 (7.0)	568 (6.5)	695 (7.4)	744 (7.2)	934 (8.7)	1113 (11.0)	4.0	0.031	
ICU	401 (11.4)	33 (8.0)	40 (11.6)	21 (5.3)	70 (10.4)	122 (13.3)	115 (14.9)	6.9	0.137	
Acinetobacterbaumannii										< 0.001
Whole hospital	3410 (6.0)	367 (4.9)	477 (5.4)	587 (6.3)	697 (6.8)	730 (6.8)	552 (5.5)	0.6	0.294	
ICU	620 (17.6)	88 (23.4)	45 (13.1)	86 (21.6)	156 (23.2)	163 (17.7)	82 (10.6)	-12.8	0.337	
Total percentage of five targeted species										0.005
Whole hospital	32818 (58.0)	4373 (58.9)	5088 (58.1)	5339 (56.9)	6068 (58.9)	5895 (54.8)	6055 (60.1)	-1.2	0.919	
ICU	1834 (52.1)	257 (54.6)	179 (52.0)	202 (50.8)	388 (57.7)	469 (51.0)	371 (48.1)	-6.5	0.363	

[a] Values are expressed as No. (%) unless otherwise indicated.
[b] $P < 0.05$, the annual detection rate of bacteria showed a linear change between 2013 and 2018.
[c] $P < 0.05$, there was a significant difference in the annual detection rate of bacteria between the ICUs and the whole hospital.

Table 2. Annual Proportions of MRSA, ESBLs- *Escherichia coli*, and *Klebsiella pneumoniae*, CR Gram-Negative Bacilli, and XDR Gram-Positive and Gram-Negative Bacteria Causing Intensive Care Unit and Hospital-wide Infections

Bacterial Species/Resistance Level/Wards	Pooled	2013	2015	2016	2017	2018	2018 - 2013, % Change	P-Value [a]	P-Value [b]
E. coli									
ESBLs									0.001
Whole hospital	54.1	57.1	57.1	53.8	51.2	50.9	-6.2	0.012	
ICU	67.4	56.3	66.7	70.0	63.3	70.0	13.7	0.433	
CR									0.948
Whole hospital	1.1	2.2	0.4	1.4	0.6	1.4	-0.8	0.54	
ICU	1.3	0.0	3.3	0.0	0.0	3.3	3.3	0.414	
XDR									0.014
Whole hospital	0.1	0.00	0.05	0.10	0.20	0.19	0.19	0.003	
ICU	0.0	0	0	0	0	0	0	-	
K. pneumoniae									
ESBLs									0.369
Whole hospital	26.1	24.8	25.5	24.6	25.9	29.7	4.9	0.204	
ICU	24.9	17.8	28.3	28.1	28.0	25.5	7.7	0.114	
CR									0.552
Whole hospital	1.9	2.0	1.0	1.7	1.0	5.0	3	0.263	
ICU	2.7	6.7	1.9	6.3	0.0	1.8	-4.9	0.486	
XDR									0.092
Whole hospital	0.1	0.0	0.0	0.2	0.2	0.5	0.47	0.022	
ICU	0.0	0	0	0	0	0	0	-	
P. aeruginosa									
CR									0.95
Whole hospital	17.4	8.7	12.1	15.7	26.0	22.4	13.7	0.01	
ICU	25.5	15.2	19.1	24.4	40.2	20.0	4.8	0.191	
XDR									0.444
Whole hospital	1.8	1.7	2.7	1.6	1.3	1.3	-0.4	0.217	
ICU	2.0	0.0	0.0	2.9	2.5	2.6	2.6	0.031	
A. baumannii									
CR									< 0.001
Whole hospital	65.5	69.5	70.7	61.5	61.1	73.7	4.2	0.774	
ICU	87.1	87.5	89.5	83.3	87.7	86.6	-0.9	0.377	
XDR									0.182
Whole hospital	12.9	2.5	9.0	12.3	13.8	25.9	23.4	0.013	
ICU	21.8	2.3	16.0	33.0	24.5	23.2	20.9	0.12	
S. aureus									
MRSA									0.098
Whole hospital	26.5	29.8	29.2	24.9	26.2	21.3	-8.5	0.013	
ICU	36.9	40.7	41.7	50.0	30.2	12.9	-27.8	0.103	
XDR									< 0.001
Whole hospital	0.5	0.5	0.7	0.3	0.3	0.4	-0.1	0.197	
ICU	0.0	0	0	0	0	0	0	-	

Abbreviations: ESBLs, extended-spectrum β-lactamase; MRSA, methicillin-resistant *S. aureus*; CR, carbapenem-resistant; XDR, extensively drug-resistant.
[a] $P < 0.05$, the resistance level of bacteria showed a linear change between 2013 and 2018.
[b] $P < 0.05$, there was a significant difference in the resistance level of bacteria between the ICUs and the whole hospital.

Table 3. Resistance Rates (%) of *Escherichia coli* to Antimicrobial Agents in the Whole Hospital and Intensive Care Units

Antimicrobial Agent/Wards	Pooled	2013	2014	2015	2016	2017	2018	2018 - 2013, % Change	P-Value [a]	P-Value [b]
AMP										< 0.001
Whole hospital	84.0	85.8	84.5	83.5	83.5	83.6	83.5	-2.3	0.050	
ICU	91.0	87.5	92.5	90.0	90.0	89.8	93.3	5.8	0.274	
AMK										0.988
Whole hospital	2.8	2.8	3.3	2.2	1.9	2.9	3.5	0.7	0.743	
ICU	3.4	3.2	2.5	0.0	0.0	4.1	6.7	3.5	0.352	
GEN										0.484
Whole hospital	42.2	44.2	45.7	42.6	41.7	40.8	39.1	-5.1	0.008	
ICU	45.7	46.9	40.0	46.7	48.0	32.7	53.3	6.4	0.381	
PIP										0.023
Whole hospital	81.4	82.2	80.7	80.0	80.3	79.2	85.9	3.7	0.543	
ICU	91.7	81.3	90.0	83.3	88.0	100.0	96.7	15.4	0.049	
TZP										0.944
Whole hospital	2.9	3.9	2.2	3.5	3.1	2.3	2.5	-1.4	0.262	
ICU	2.7	3.3	4.0	3.7	2.0	2.0	2.3	-1	0.079	
CRO										0.001
Whole hospital	55.7	58.9	56.7	57.9	54.2	52.9	54.6	-4.3	0.037	
ICU	67.4	59.4	75.0	66.7	70.0	65.3	66.7	7.3	0.835	
CFZ										0.007
Whole hospital	63.1	67.6	64.4	66.1	61.4	58.5	61.8	-5.8	0.047	
ICU	72.2	65.6	82.5	73.3	74.0	69.4	70.0	4.4	0.771	
CXM										0.008
Whole hospital	58.8	63.5	60.5	61.8	57.5	55.4	55.3	-8.2	0.005	
ICU	68.4	59.4	77.5	66.7	70.0	69.4	66.7	7.3	0.790	
CTX										0.003
Whole hospital	55.0	58.4	56.5	57.8	54.2	52.1	52.0	-6.4	0.008	
ICU	66.7	56.3	75.0	66.7	70.0	63.3	66.7	10.4	0.746	
CAZ										0.027
Whole hospital	54.9	58.4	56.3	58.0	54.0	51.6	51.9	-6.5	0.012	
ICU	62.3	56.3	72.5	66.7	70.0	63.3	53.3	-3	0.596	
FEP										0.004
Whole hospital	54.9	58.4	56.6	57.5	54.2	51.7	52.0	-6.4	0.006	
ICU	65.7	56.3	75.0	66.7	70.0	63.3	63.3	7	0.960	
SCF										0.603
Whole hospital	3.5	3.4	2.9	4.2	4.2	5.1	1.5	-1.9	0.816	
ICU	3.5	4.3	3.9	4.8	5.3	6.3	0.0	-4.3	0.511	
FOX										0.924
Whole hospital	12.9	15.1	12.4	14.3	12.7	11.5	11.9	-3.2	0.075	
ICU	12.0	9.4	7.5	23.3	12.0	14.3	10.0	0.6	0.830	
IMP										0.039
Whole hospital	0.4	0.0	0.2	0.1	0.3	0.5	1.0	1	0.014	
ICU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	-	
MEM										0.014
Whole hospital	0.3	0.1	0.2	0.1	0.5	0.3	0.8	0.7	0.045	
ICU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	-	
ETP										0.914
Whole hospital	1.2	2.2	1.0	0.4	1.2	0.6	1.7	-0.5	0.662	
ICU	1.3	0.0	0.0	3.3	0.0	0.0	3.3	3.3	0.414	
LEV										0.433
Whole hospital	45.8	47.7	45.4	43.6	47.5	43.3	47.6	-0.1	0.887	
ICU	48.1	46.9	35.0	56.7	56.0	55.1	43.3	-3.6	0.625	
CIP										0.515
Whole hospital	49.9	51.2	49.6	49.0	51.5	47.2	51.0	-0.2	0.727	
ICU	51.6	56.3	37.5	56.7	62.0	55.1	46.7	-9.6	0.908	
SXT										0.136
Whole hospital	56.5	58.1	59.8	57.8	55.1	55.7	53.4	-4.7	0.020	
ICU	62.5	65.6	67.5	60.0	66.0	46.9	66.7	1.1	0.510	
TET										0.048
Whole hospital	65.4	66.8	67.0	65.0	65.8	66.9	61.5	-5.3	0.155	
ICU	76.6	71.9	82.5	76.7	74.0	57.9	87.5	15.6	0.988	
TGC										-
Whole hospital	0.05			0.0	0.0	0.1	0.1	0.1	0.067	
ICU	0.0			0.0	0.0	0.0	0.0	0	-	

Abbreviations: AMP, ampicillin; AMK, amikacin; GEN, gentamicin; PIP, piperacillin; TZP, piperacillin/tazobactam; CRO, ceftriaxone; CFZ, cefazolin; CXM, cefuroxime; CTX, cefotaxime; CAZ, ceftazidime; FEP, cefepime; SCF, cefoperazone/sulbactam, FOX, cefoxitin; IPM, imipenem; MEM, meropenem; ETP, ertapenem; LEV, levofloxacin; CIP, ciprofloxacin; SXT, trimethoprim-sulfamethoxazole; TET, tetracycline; TGC, tigecycline.

[a] $P < 0.05$, the resistance rate of antimicrobial agents showed a linear change between 2013 and 2018.

[b] $P < 0.05$, there was a significant difference in the resistance rate of antimicrobial agents between the ICUs and the whole hospital.

Table 4. Resistance Rates (%) of *Klebsiella pneumoniae* to Antimicrobial Agents in the Whole Hospital and Intensive Care Units

Antimicrobial Agent/Wards		Pooled	2013	2014	2015	2016	2017	2018	2018 - 2013, % Change	P-Value [a]	P-Value [b]
AMK											0.654
	Whole hospital	2.9	2.6	2.4	2.2	2.3	2.2	6.2	3.6	0.218	
	ICU	2.4	6.7	0.0	3.8	1.6	2.4	0.0	-6.7	0.213	
GEN											0.627
	Whole hospital	17.7	17.1	17.9	16.1	17.2	18.4	19.5	2.4	0.156	
	ICU	17.5	13.3	7.9	18.9	23.4	19.5	16.4	3.1	0.269	
PIP											0.525
	Whole hospital	52.2	52.9	47.9	52.0	55.7	59.8	43.7	-9.2	0.902	
	ICU	62.3	35.6	28.9	58.5	59.4	73.2	98.2	62.6	0.004	
TZP											0.292
	Whole hospital	6.2	7.1	8.6	4.7	5.5	4.4	7.4	0.3	0.509	
	ICU	4.7	6.7	2.6	7.5	7.8	2.4	1.8	-4.9	0.349	
CRO											0.265
	Whole hospital	27.8	26.9	29.2	26.3	25.3	28.7	31.1	4.2	0.352	
	ICU	26.1	22.2	15.8	28.3	29.7	29.3	25.5	3.3	0.229	
CFZ											0.389
	Whole hospital	35.0	37.9	36.7	34.1	32.5	34.0	35.4	-2.5	0.202	
	ICU	33.5	35.6	18.4	34.0	35.9	37.8	32.7	-2.9	0.502	
CXM											0.579
	Whole hospital	33.1	35.2	34.7	32.2	30.7	31.8	34.5	-0.7	0.449	
	ICU	34.4	40.0	28.9	34.0	37.5	34.1	30.9	-9.1	0.506	
CTX											0.281
	Whole hospital	27.4	26.9	29.0	26.3	25.2	27.4	30.0	3.1	0.59	
	ICU	25.8	22.2	15.8	28.3	29.7	28.0	25.5	3.3	0.248	
CAZ											0.305
	Whole hospital	27.5	26.9	29.2	26.6	25.9	27.1	30.0	3.1	0.597	
	ICU	26.1	24.4	15.8	28.3	29.7	28.0	25.5	1.1	0.358	
FEP											0.386
	Whole hospital	27.2	26.7	28.8	26.2	25.3	27.1	29.8	3.1	0.561	
	ICU	26.1	22.2	15.8	28.3	31.3	28.0	25.5	3.3	0.266	
SCF											0.942
	Whole hospital	4.6	0.0	1.2	3.8	3.3	11.8	7.4	7.4	0.035	
	ICU	5.7	0.0	0.8	1.9	4.7	12.2	9.1	9.1	0.015	
FOX											0.8
	Whole hospital	16.1	18.9	18.2	14.8	13.5	14.6	17.1	-1.8	0.3	
	ICU	16.3	24.4	15.8	17.0	20.3	12.2	10.9	-13.5	0.059	
IMP											0.3
	Whole hospital	1.0	0.1	0.1	0.3	0.5	1.0	4.0	3.9	0.055	
	ICU	0.3	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.805	
MEM											0.822
	Whole hospital	1.0	0.5	0.6	0.4	0.7	0.9	3.5	3.0	0.104	
	ICU	0.9	2.2	0.0	1.9	1.6	0.0	0.0	-2.2	0.232	
ETP											0.564
	Whole hospital	1.9	1.9	0.9	1.1	1.9	1.5	4.6	2.7	0.176	
	ICU	2.7	6.7	0.0	1.9	6.3	0.0	1.8	-4.9	0.485	
LEV											0.635
	Whole hospital	11.8	11.2	10.5	12.1	11.4	11.8	14.1	2.9	0.079	
	ICU	11.9	2.2	5.3	13.2	12.5	22.0	7.3	5.1	0.242	
CIP											0.365
	Whole hospital	16.6	15.6	14.5	16.1	16.3	17.1	20.3	4.7	0.034	
	ICU	20.2	20.0	7.9	18.9	20.3	25.6	21.8	1.8	0.236	
SXT											0.636
	Whole hospital	26.6	26.0	25.6	26.7	26.5	27.0	27.8	1.8	0.013	
	ICU	26.4	26.7	10.5	26.4	28.1	31.7	27.3	0.6	0.322	
TET											0.417
	Whole hospital	31.7	29.2	33.3	28.7	30.7	34.8	34.0	4.8	0.184	
	ICU	30.3	20.0	18.4	22.6	28.1	48.8	29.1	9.1	0.135	
TGC											0.33
	Whole hospital	0.3	-	-	0.0	0.0	0.3	0.8	0.8	0.068	
	ICU	1.6	-	-	0.0	0.0	1.2	5.5	5.5	0.123	

Abbreviations: AMK, amikacin; GEN, gentamicin; PIP, piperacillin; TZP, piperacillin/tazobactam; CRO, ceftriaxone; CFZ, cefazolin; CXM, cefuroxime; CTX, cefotaxime; CAZ, ceftazidime; FEP, cefepime; SCF, cefoperazone/sulbactam; FOX, cefoxitin; IPM, imipenem; MEM, meropenem; ETP, ertapenem; LEV, levofloxacin; CIP, ciprofloxacin; SXT, trimethoprim-sulfamethoxazole; TET, tetracycline; TGC, tigecycline.

[a] $P < 0.05$, the resistance rate of antimicrobial agents showed a linear change between 2013 and 2018.

[b] $P < 0.05$, there was a significant difference in the resistance rate of antimicrobial agents between the ICUs and the whole hospital.

Table 5. Resistance Rates (%) of *Pseudomonas aeruginosa* to Antimicrobial Agents in the Whole Hospital and Intensive Care Units

Antimicrobial Agent/Wards		Pooled	2013	2014	2015	2016	2017	2018	2018 - 2013, % Change	P-Value [a]	P-Value [b]
AMK											0.892
	Whole hospital	6.2	11.8	11.4	6.2	5.1	3.7	3.7	-8.1	0.006	
	ICU	5.7	12.1	10.0	4.8	12.9	1.6	2.6	-9.5	0.122	
GEN											0.857
	Whole hospital	15.1	32.0	24.1	21.7	11.8	9.1	5.7	-26.3	< 0.001	
	ICU	13.7	51.5	27.5	4.8	20.0	4.1	6.1	-45.4	0.049	
PIP											0.076
	Whole hospital	22.1	26.6	22.7	26.6	17.9	13.6	26.9	0.3	0.516	
	ICU	29.9	42.4	27.5	23.8	22.9	27.9	34.8	-7.6	0.6	
TZP											0.388
	Whole hospital	10.8	8.7	10.9	15.8	9.5	8.9	11.1	2.5	0.999	
	ICU	11.0	9.1	22.5	19.0	17.1	4.9	8.7	-0.4	0.388	
SCF											0.69
	Whole hospital	5.3	0.0	0.0	4.7	7.1	9.6	5.9	5.9	0.038	
	ICU	6.2	0.0	0.0	9.5	11.4	7.4	5.2	5.2	0.25	
TIM											0.159
	Whole hospital	28.8	20.4	22.4	26.0	22.6	28.6	42.2	21.8	0.041	
	ICU	40.1	33.3	32.5	28.6	35.7	27.0	63.5	30.1	0.246	
CAZ											0.865
	Whole hospital	11.5	7.5	10.7	16.8	9.9	11.1	11.9	4.4	0.583	
	ICU	9.5	12.1	15.0	14.3	8.6	8.2	7.8	-4.3	0.062	
FEP											0.052
	Whole hospital	9.9	6.6	9.7	11.8	9.4	9.3	11.1	4.6	0.237	
	ICU	8.0	6.1	5.0	4.8	10.0	8.2	8.7	2.6	0.124	
ATM											0.424
	Whole hospital	22.1	18.9	18.3	23.3	20.2	24.4	24.2	5.3	0.051	
	ICU	23.2	27.3	22.5	19.0	22.9	19.7	27.0	-0.3	0.857	
IMP											0.302
	Whole hospital	16.7	12.5	9.2	10.8	10.5	26.0	22.4	9.8	0.088	
	ICU	24.4	18.2	10.0	19.0	17.1	40.2	20.0	1.8	0.297	
MEM											0.215
	Whole hospital	13.3	5.8	7.9	6.2	8.2	22.9	19.3	13.5	0.043	
	ICU	20.9	12.1	10.0	19.0	17.1	35.2	14.8	2.7	0.295	
CIP											0.737
	Whole hospital	25.0	30.8	24.5	29.5	20.8	30.0	18.5	-12.3	0.257	
	ICU	26.2	36.4	17.5	14.3	8.6	46.7	17.4	-19.0	0.93	
LEV											0.988
	Whole hospital	24.4	30.6	21.8	28.3	19.6	29.9	19.0	-11.7	0.393	
	ICU	26.2	45.5	17.5	14.3	12.9	44.3	14.8	-30.7	0.625	

Abbreviations: AMK, amikacin; GEN, gentamicin; PIP, piperacillin; TZP, piperacillin/tazobactam; SCF, cefoperazone-sulbactam; TIM, ticarcillin/clavulanic acid; CAZ, ceftazidime; FEP, cefepime; ATM, aztreonam; IPM, imipenem; MEM, meropenem; CIP, ciprofloxacin; LEV, levofloxacin.

[a] $P < 0.05$, the resistance rate of antimicrobial agents showed a linear change between 2013 and 2018.

[b] $P < 0.05$, there was a significant difference in the resistance rate of antimicrobial agents between the ICUs and the whole hospital.

showed high resistance levels of over 80 and 60%, respectively. Sulfamethoxazole/trimethoprim and cefoperazone/sulbactam resistance rates showed marked increases, from 31.6 to 51.1% and 0 to 21.7% in the whole hospital and 27.3 to 35.4% and 0 to 18.3% in the ICUs ($P < 0.05$), but the others showed decreasing trends, and amikacin, tobramycin, and piperacillin/tazobactam resistance levels showed marked linear declines ($P < 0.05$). Except for cefoperazone/sulbactam, sulfamethoxazole/trimethoprim, and tigecycline, the resistance rates of the other antimicrobial agents were significantly different between the ICUs and the whole hospital ($P < 0.05$), but all of them showed high resistance levels and the same change trends with time. *A. baumannii* was first found to be resistant to tigecycline in 2014. The detailed data are shown in Table 6.

4.4.5. *Staphylococcus aureus*

No isolate was found to be resistant to vancomycin and linezolid. *Staphylococcus aureus* showed high susceptibility to sulfamethoxazole/trimethoprim, clindamycin, erythromycin, and penicillin, but the susceptibility rates showed marked decreasing trends with time ($P < 0.05$). The other AMR levels showed marked decreasing trends with time ($P < 0.05$) in the ICUs and the whole hospital from 2013 to 2018, and rifampicin, levofloxacin, ciprofloxacin, gentamicin, and tetracycline resistance levels showed marked linear declines ($P < 0.05$). Except for levofloxacin and ciprofloxacin resistance levels, which were significantly different between the ICUs and the whole hospital ($P < 0.05$), the other AMR levels were not significantly different between the ICUs and the whole hospital ($P > 0.05$). The detailed data are shown in Table 7.

5. Discussion

Microbial resistance to antimicrobial agents (AMR) has been a major challenge. The main cause of AMR is the overuse and misuse of antimicrobial agents in healthcare settings and by the general public. The containment of AMR is an urgent priority, both in China and worldwide (14). Monitoring AMR is the most effective means to provide useful information for prevention and help clinicians prescribe effective antibiotic therapy.

Our study showed that only the percentages of sputum/endotracheal aspirate specimens were higher in the ICUs than in the whole hospital. Moreover, the culture-positive rates of sputum/endotracheal aspirates in the ICUs were higher than those in the whole hospital. The reason may be that ICU-acquired pneumonia and ventilator-associated pneumonia (VAP) were the most common types of healthcare-associated infections in ICU patients, and ICU-acquired pneumonia and VAP are major causes of morbidity and mortality in ICU patients (15, 16). It was similar to those from Tanzania (17). Additionally, this study showed that most of the isolates were recovered from sputum/endotracheal aspirates from the whole hospital (40.4%) and ICUs (72.5%), similar to reports from CHINET surveillance in China (18, 19) (40.0% in 2017 and 41.6% in 2016) for the whole hospital and in Iran (20) (70.63%) for ICUs. The distributions of the other specimens with isolates were different in the ICUs and the whole hospital. The sources of isolates in the whole hospital were significantly different from those in the ICUs. Therefore, it was necessary to analyze the distribution and detection rate of specimens in different areas.

This study showed that the percentages of GPB and GNB in the whole hospital were similar to those reported by CHINET surveillance in China (19) (GPB, 29.2% and GNB, 70.8%) and Greece (21) (GPB, 31.8% and GNB, 68.2%) and different from those reported in China (22) (GPB, 20.25% and GNB, 79.75%) and southern Ethiopia (23) (GPB, 37.23% and GNB, 62.77%). In the ICUs, the percentages of bacteria were 18.4% for GPB and 81.6% for GNB, different from those reported in Poland (24) (GPB, 21.6% and GNB, 71.6%) and similar to those reported in Saudi Arabia (25) (GPB, 15.9% and GNB, 81.0%) and Greece (21) (GPB, 18.5% and GNB, 81.5%). The percentage of GNB was significantly higher in the whole hospital than in the ICUs ($P < 0.05$). This study found that there were differences in the percentages of isolates between different cities, but we could still refer to the national data of CHINET surveillance in China.

Our results showed that the species of the five dominant bacteria were consistent with those reported in studies in other regions, including the CHINET for China (5), Zhengzhou (China) (6), Nanjing (China) (26), Seoul (Korea) (27), Somalia (28), and Greece (21), but the proportions of the five dominant bacteria were different. Therefore, it was necessary to analyze the proportions of bacteria in different areas. This study found that the detection rates of MRSA, ESBL-*E. coli*, CRPA, CRAB, and XDRAB in the whole hospital were lower than those in the ICUs, similar to other reports from China (Wuhan) (29); however, the detection rates of ESBL-*K. pneumoniae*, CREC, CRKP, and XDRPA in the ICUs and the whole hospital were similar, while the detection rates of XDREC, XDRKP, and XDRSA in the ICUs were lower than those in the whole hospital. These results were different from reports in New Jersey (the USA) (30). Besides, MRSA showed a decreasing trend in both the ICUs and the whole hospital, similar to that reported by CHINET surveillance (5). The detection rates of XDRPA and XDRAB were similar to those reported by CHINET surveillance, but the rate of XDRKP was lower than that reported by CHINET surveillance (5). Therefore, it is necessary to monitor the

Table 6. Resistance Rates (%) of *Acinetobacter baumannii* to Antimicrobial Agents in the Whole Hospital and Intensive Care Units

Antimicrobial Agent/Wards		Pooled	2013	2014	2015	2016	2017	2018	2018 - 2013, % Change	P-Value [a]	P-Value [b]
AMK											0.001
	Whole hospital	58.4	71.9	54.7	62.2	52.2	54.0	62.1	-9.8	0.382	
	ICU	79.8	93.2	86.7	86.0	71.2	80.4	70.7	-22.5	0.026	
GEN											0.001
	Whole hospital	65.3	76.3	60.2	69.0	59.0	63.3	69.2	-7.1	0.572	
	ICU	85.3	95.5	86.7	89.5	76.3	89.0	79.3	-16.2	0.155	
TOB											0.002
	Whole hospital	61.7	74.7	56.2	66.8	56.4	56.0	66.7	-8.0	0.497	
	ICU	81.6	94.3	86.7	89.5	73.7	81.0	73.2	-21.1	0.028	
PIP											0.001
	Whole hospital	71.7	75.5	63.5	74.1	67.6	66.0	86.6	11.1	0.486	
	ICU	90.5	94.3	97.8	91.9	84.0	92.0	90.2	-4.1	0.280	
TZP											0.002
	Whole hospital	66.5	74.4	61.6	70.5	62.1	60.8	73.9	-0.5	0.835	
	ICU	84.7	92.0	91.1	88.4	84.6	84.7	69.5	-22.5	0.020	
SCF											0.816
	Whole hospital	9.0	0.0	9.6	6.3	8.2	6.6	21.7	21.7	0.082	
	ICU	7.6	0.0	8.9	4.7	6.4	8.6	18.3	18.3	0.050	
CAZ											< 0.001
	Whole hospital	67.9	73.3	63.1	71.7	63.6	64.7	74.3	1.0	0.978	
	ICU	88.4	89.8	95.6	90.7	84.0	89.6	86.6	-3.2	0.255	
FEP											< 0.001
	Whole hospital	67.7	74.7	62.5	71.0	63.7	64.2	73.4	-1.3	0.874	
	ICU	87.4	93.2	97.8	90.7	83.3	84.0	86.6	-6.6	0.072	
IMP											< 0.001
	Whole hospital	62.8	66.2	56.2	69.2	60.3	60.1	66.5	0.3	0.930	
	ICU	84.0	86.4	88.9	84.9	82.7	86.5	75.6	-10.8	0.104	
MEM											< 0.001
	Whole hospital	64.0	67.3	54.5	69.5	60.7	60.4	73.4	6.1	0.562	
	ICU	86.3	86.4	91.1	89.5	82.1	87.7	85.4	-1.0	0.461	
CIP											< 0.001
	Whole hospital	68.0	75.7	61.0	70.7	64.7	64.8	74.6	-1.1	0.998	
	ICU	88.1	94.3	95.6	88.4	81.4	89.6	86.6	-7.7	0.159	
LEV											< 0.001
	Whole hospital	63.1	68.9	56.6	67.5	59.1	57.9	72.1	3.2	0.187	
	ICU	85.0	89.8	95.6	82.6	79.5	86.5	84.1	-5.6	0.262	
SXT											0.601
	Whole hospital	47.4	31.6	37.1	40.2	49.5	63.3	51.1	19.5	0.026	
	ICU	56.3	27.3	53.3	41.9	59.0	88.3	35.4	8.1	0.431	
TGC											0.198
	Whole hospital	1.5		3.4	2.4	1.0	0.5	1.6	-1.8	0.146	
	ICU	2.6		6.7	4.7	1.9	1.2	2.4	-4.3	0.076	

Abbreviations: AMK, amikacin; GEN, gentamicin; TOB, tobramycin; PIP, piperacillin; TZP, piperacillin/tazobactam; SCF, cefoperazone/sulbactam; CAZ, ceftazidime; FEP, cefepime; IPM, imipenem; MEM, meropenem; CIP, ciprofloxacin; LEV, levofloxacin; SXT, trimethoprim-sulfamethoxazole; TGC, tigecycline.

[a] $P < 0.05$, the resistance rate of antimicrobial agents showed a linear change between 2013 and 2018.

[b] $P < 0.05$, there was a significant difference in the resistance rate of antimicrobial agents between the ICUs and the whole hospital.

patterns of AMR in this area, and this study provides reference data for the prevention and control of super-resistant bacteria in this area.

The trends of most antimicrobial resistance levels among *E. coli* and *K. pneumoniae* were stable in the ICUs and the whole hospital. For *P. aeruginosa*, a decrease in resistance with time was observed for amikacin, gentamicin, ciprofloxacin, and levofloxacin, and an increase in resistance was observed for ticarcillin/clavulanic acid, cefoperazone/sulbactam, cefepime, imipenem, and meropenem in both the ICUs and the whole hospital. For *A. baumannii*, a decrease in resistance with time was observed for amikacin, gentamicin, tobramycin, piperacillin/tazobactam, ciprofloxacin, imipenem, and

Table 7. Resistance Rates (%) of *Staphylococcus aureus* to Antimicrobial Agents in the Whole Hospital and Intensive Care Units

Antimicrobial Agent/Wards	Pooled	2013	2014	2015	2016	2017	2018	2018 - 2013, % Change	P-Value [a]	P-Value [b]
VAN										-
Whole hospital	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	
ICU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	
LZD										-
Whole hospital	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	
ICU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	
RD										0.378
Whole hospital	7.3	16.1	10.3	6.8	4.7	6.2	3.3	-12.7	0.015	
ICU	11.8	37.0	31.3	0.0	10.4	0.0	6.5	-30.6	0.064	
SXT										0.623
Whole hospital	6.0	6.5	6.5	7.7	5.9	6.3	3.9	-2.6	0.154	
ICU	5.9	0.0	12.5	25.0	2.1	9.4	0.0	0.0	0.738	
LEV										0.019
Whole hospital	13.9	20.2	16.0	12.5	12.8	13.6	10.6	-9.6	0.026	
ICU	28.3	44.4	50.0	33.3	35.4	15.1	12.9	-31.5	0.009	
CIP										0.011
Whole hospital	16.3	22.5	19.3	15.5	15.5	15.8	12.0	-10.5	0.008	
ICU	33.2	51.9	50.0	33.3	41.7	18.9	19.4	-32.5	0.012	
GEN										0.369
Whole hospital	24.3	36.5	31.2	23.3	21.1	21.3	17.5	-19.0	0.005	
ICU	27.3	59.3	50.0	41.7	14.6	20.8	12.9	-46.4	0.005	
DA										0.706
Whole hospital	60.0	65.5	68.5	59.9	59.2	59.9	50.3	-15.2	0.022	
ICU	55.6	55.6	68.8	75.0	58.3	60.4	29.0	-26.5	0.218	
ERY										0.768
Whole hospital	60.8	65.1	69.7	61.0	59.5	61.1	51.6	-13.5	0.037	
ICU	56.1	51.9	68.8	83.3	60.4	60.4	29.0	-22.8	0.336	
PEN										0.843
Whole hospital	93.3	95.3	95.7	94.9	95.6	95.0	84.6	-10.7	0.145	
ICU	93.0	88.9	93.8	100.0	100.0	96.2	77.4	-11.5	0.546	
OXA										0.098
Whole hospital	26.5	29.8	29.9	29.2	24.9	26.2	21.3	-8.4	0.013	
ICU	36.9	40.7	56.3	41.7	50.0	30.2	12.9	-27.8	0.103	
TET										0.526
Whole hospital	30.0	37.9	34.1	28.8	28.2	30.2	24.2	-13.7	0.015	
ICU	32.1	59.3	62.5	25.0	25.0	24.5	19.4	-39.9	0.028	

Abbreviations: VAN, vancomycin; LZD, linezolid; RD, rifampin; SXT, trimethoprim-sulfamethoxazole; LEV, levofloxacin; CIP, ciprofloxacin; GEN, gentamicin; DA, clindamycin; ERY, erythromycin; PEN, penicillin; OXA, oxacillin; TET, tetracycline.

[a] $P < 0.05$, the resistance rate of antimicrobial agents showed a linear change between 2013 and 2018.

[b] $P < 0.05$, there was a significant difference in the resistance rate of antimicrobial agents between the ICUs and the whole hospital.

tigecycline in the ICUs, while an increase in resistance was observed for cefoperazone/sulbactam in both the ICUs and the whole hospital. The resistance rates of *S. aureus* to all the antimicrobial agents showed decreasing trends, especially in the ICUs, similar to other reports (Wuhan) (29).

The results of the present study showed that the resistance levels to carbapenems, β-lactam-containing agents, and tigecycline in *E. coli* were higher than those in *K. pneumoniae*; however, *E. coli* and *K. pneumoniae* maintained high sensitivity to all the agents. In this study, the resistance rates of *E. coli* to all the antimicrobial agents in the whole hospital and the ICUs were higher than those reported in other areas, including by CHINET surveillance (5) and in Nanjing (26), Zhengzhou (6), and Greece (31). However, the resistance levels of *K. pneumoniae* to most of the antimicrobial agents were lower than those reported in these areas. For *P. aeruginosa*, we found that it was more sensitive to all the antimicrobial agents than *A. baumannii*. However, *A. baumannii* had a high sensitivity to only cefoperazone/sulbactam and tigecycline, while it had a high resistance rate to all the other antimicrobial agents.

In the whole hospital and ICUs, the resistance rates of *A. baumannii* to ceftazidime, cefepime, imipenem, and meropenem were higher than those reported by CHINET

surveillance (5) and those in Zhengzhou (6) and Kazakhstan (32) but lower than those reported in Nanjing and Lebanon. However, in the whole hospital and ICUs, the resistance rates of *P. aeruginosa* to all the antimicrobial agents were lower than those reported by CHINET surveillance (5) and those in Zhengzhou (6), Nanjing (26), and Greece (21). We also found that *P. aeruginosa* was more sensitive to ceftazidime and cefepime than to imipenem and meropenem in our study. This may be related to the mechanism of carbapenem resistance caused by the deletion of outer membrane proteins and the overexpression of efflux pump genes in *P. aeruginosa*. For *S. aureus*, the resistance rate to most of the antimicrobial agents in the whole hospital was lower than that reported by CHINET surveillance (5) and those in Zhengzhou (6), Nanjing (26), and North Korea (27), but higher than that reported in Dongguan (33). In the ICUs, the resistance rates of *S. aureus* to most of the antimicrobial agents were lower in our study than those in Greece (21) and higher than those in Kazakhstan (32). The difference in resistance of these bacteria to different antibiotics may be related to the distribution of patients in the region and the management of antibiotic use.

The results of the present study showed that the susceptibility of *A. baumannii* to tigecycline began in 2014, with resistance rates of 3.4% (hospital-wide) and 6.7% (ICUs). However, resistance to tigecycline showed a decreasing trend with time. The resistance level of *E. coli* to tigecycline (< 0.05) has remained stable since 2015, but it was higher than those reported in Africa (0), North America (0), and South America (0) and lower than those reported in Asia (0.3%) and Europe (0.1%) (34). The resistance levels of *K. pneumoniae* to tigecycline showed an increasing trend with time, which was higher than those reported in Africa (0) and North America (0) but lower than those reported in Asia (1.3%), South America (0.9%), and Europe (0.7%) (34). However, bacterial isolates were still highly sensitive to tigecycline in vitro in our study (susceptibility > 99%).

This study has two limitations. First, it was a single-center study. Since susceptibility rates vary among hospitals and units in different regions, the results may not be representative of and generalizable to other institutions, especially primary health care institutions. Second, incubation periods may vary according to the type of the pathogen or a patient's underlying condition, and it was difficult to distinguish between cases of ICU-acquired infections and pre-existing colonization on ICU admission. Therefore, we will conduct a separate and more detailed study of cases of ICU-acquired infections and pre-existing colonization on ICU admission in future studies.

5.1. Conclusions

The distribution of clinical samples, the detection rate, and the sensitivity of clinical isolates varied with time and region. The susceptibility rates of *E. coli* and *A. baumannii* to antimicrobial agents were significantly higher than those in other areas. Besides, *K. pneumoniae* and *P. aeruginosa* had higher susceptibility to antimicrobial agents in our study than those reported in other regions, and the resistance of *S. aureus* to antimicrobial agents gradually decreased over time. Between the ICUs and the whole hospital, the resistance rates to antimicrobial agents were significantly different for *A. baumannii* and slightly different for *E. coli*, but there was no difference for *K. pneumoniae*, *S. aureus*, and *P. aeruginosa*. These data provide important useful information for the treatment and prevention of clinical infections.

Supplementary Material

Supplementary material(s) is available here [To read supplementary materials, please refer to the journal website and open PDF/HTML].

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Footnotes

Authors' Contribution: LLX, ZRZ, and JBL designed the study and drafted the manuscript. ZRZ, YHD, MS, and KY collected the data. ZRZ and LLX analyzed the data; LLX and ZRZ wrote the paper. LLX and ZRZ contributed equally to this work and share the first authorship. All authors have read and approved the final manuscript.

Conflict of Interests: The authors declare that there is no conflict of interest in this study.

Ethical Approval: The study protocol was approved by the Ethics Committee of the Affiliated Hospital of Southwest Medical University (project no. K2020043). This is a retrospective study. The need for informed consent was waived by the Clinical Research Ethics Committee.

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