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ORIGINAL RESEARCH

The Distribution, Drug Susceptibility, and Dynamic Trends of *Pseudomonas aeruginosa* Infection in a Tertiary Hospital in China During 2016–2022

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Background: Drug-resistant *Pseudomonas aeruginosa* infections rapidly increased and contributed to life-threatening nosocomial infections; however, the distribution, species, drug susceptibility and dynamic trends of *P. aeruginosa* infection in China remained unclear. This study was conducted to better understand the epidemiological data of increased *P. aeruginosa* infections from 2016 to 2022 in a hospital in China.

Methods: This study involved 3301 patients infected with *P. aeruginosa*, diagnosed using a nosocomial infection surveillance system in a tertiary hospital between 2016 and 2022. The *P. aeruginosa* infections from 2016 to 2022 were assessed according to the hospital department and species, and the drug susceptibility was evaluated using 16 antimicrobial agents.

Results: The *P. aeruginosa* infection prevalence in the hospital department was: Neurosurgery (14.30%), Emergency (13.30%), and Critical Care Medicine (11.69%). Samples for *P. aeruginosa* infection identification were from sputum (72.52%) and other secreta (9.91%). The *P. aeruginosa* infections demonstrated a greater sensitivity to amikacin (AMK, 91.82%), tobramycin (TOB, 82.79%), and gentamycin (GEN, 82.01%); however, *P. aeruginosa* infection demonstrated greater resistance to ticarcillin (22.57%), levofloxacin (21.63%), and ciprofloxacin (18.00%).

Conclusion: The *P. aeruginosa* infections were commonly observed in the Neurosurgery, Emergency, and Critical Care Medicine departments and demonstrated greater sensitivity to AMK, TOB, and GEN than the other drugs.

Keywords: *Pseudomonas aeruginosa*, distribution, drug susceptibility, dynamic trend

Introduction

Health care-associated infections caused by nosocomial pathogens have become an important cause of morbidity and mortality.[1] *Pseudomonas aeruginosa* is considered as a major pathogen for community-acquired and nosocomial infections worldwide and is capable of causing acute life-threatening infections in elderly, critically ill, and immunocompromised patients.[2] Studies have reported that *P. aeruginosa* accounts for 7.1% of healthcare-associated infections in the United States, and *P. aeruginosa* was considered the most common pathogen (17%) for healthcare-associated pneumonia in the European Union.[3,4] Moreover, *P. aeruginosa* consistently induced chronic pulmonary infection in patients with chronic wounds or cystic fibrosis.[5,6]

The organism's limited susceptibility to antimicrobial agents may result in *P. aeruginosa*-induced life-threatening infections that are difficult to treat.[7] Thus, *P. aeruginosa* has been classified as "critical" on the global priority pathogens list according to World Health Organization.[8] Potential reasons for the increased antibiotic resistance of *P. aeruginosa* may include frequent use of antibiotics that could cause bacterial strains to acquire the ability to overcome drug inhibition and lethality. Moreover, various inherited mechanisms may contribute to the reduced efficacy of antibiotics;

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these include mutations of target structures, inactivation of antibiotic enzymes, and reduced intracellular concentrations.[9] Therefore several factors contributed to the development of multi-drug resistant *P. aeruginosa*, and the rate of reported multi-drug resistant *P. aeruginosa* has increased from 4% to 14% from 1993 to 2002 in the United States, and this was regarded as a serious concern for hospitalized patients.[10] Patients with multi-drug resistant *P. aeruginosa* infection and restricted drug options were associated with an increased risk of mortality.[11,12]

In China, as with other countries, *P. aeruginosa* was the most common gram-negative strain.[13] However, prior studies focused on the incidence of *P. aeruginosa* infection, while the species, drug susceptibility and dynamic trends of *P. aeruginosa* infection in China were not addressed.[14] In this study, we assessed 3301 patients infected with *P. aeruginosa* and determined their susceptibility profiles against 16 commonly used antimicrobial agents. The prevalence of *P. aeruginosa* infection by hospital department or species, and the drug susceptibility of 16 antimicrobial agents were evaluated between 2016 and 2022.

Subjects and Methods

Hospital Setting and Reagents

A total of 3301 patients infected with *P. aeruginosa* in a tertiary hospital between 2016 and 2022 were retrospectively enrolled in this study. This study was approved by the Medical Ethics Committee of the Handan Central Hospital (no: 202247). The quality control strain, *P. aeruginosa*, was purchased from the National Institute for Identification of Pharmaceutical and Biological Products (NICPBP; No: ATCC27853) of China. Strains isolated multiple times from the same patient were only counted once. Following routine isolation and culture, VITEC2 and GN identification plates provided by Meriai were used for strain identification. The blood plate and Chinese blue plate were provided by Tianjin Jinzhang Company (Tianjin, China), and the drug-sensitivity disks were purchased from Oxoid (Basingstoke, UK). The drug-sensitivity disks included the following drugs: amikacin (AMK), aztreonam, tobramycin (TOB), sulfamethoxazole tablets, ciprofloxacin (CIP), meropenem (MEM), piperacillin, tazobactam (TZP), gentamycin (GEN), ceftazidime (CAZ), cefotaxime, ceftriaxone, levofloxacin (LVX), imipenem (IPM), ticarcillin (TCC), cefepime (FEP), cefoperazone, colistin (COL), and polyoxin (POL).

Strain Isolation and Identification

The samples investigated were obtained from ascites, bile, bronchial alveolar fluid, blood, catheters, pleuritic, purulent material, secreta, spinal fluid, sputum, stool, other fluids drained, throat swabs, tissues, and urine. Hospital departments that samples were sourced from included the Pediatric, Otolaryngology, Orthopedics, Respiratory Medicine, Emergency, Rehabilitation, Geriatrics, Urinary surgery, Endocrinology, General surgery, Burn and plastic surgery, Neurology, Neurosurgery, Nephrology, Cardiovascular, Thoracic surgery, Oncology, Critical Care Medicine, and Other departments. Specimens were cultured and isolated in accordance with the third edition of National Clinical Laboratory Procedures. Following incubation at 35 °C for 18–24 h, mucinous *P. aeruginosa* grows on the blood plate as colorless, small dew drops, with irregular edges, non-hemolytic small colonies; following 48 h of growth and fusion, viscous, jelly-like colonies, with hemolytic atypical, dispensable appearance were observed. The colonies without metallic luster and special odor were detected by inoculum ring, separated and identified as *P. aeruginosa* using VITEK2Compact (Meriai, France), which was further defined as mucinous *P. aeruginosa*. Following incubation at 35 °C for 18–24 h, mucous patina grew into large, flat, moist, metallic luster, blue-green, transparent hemolytic ring colonies on the blood plate, with a ginger taste. Following purification, mucinous *P. aeruginosa* previously identified using VITEK2Compact, was then defined as non-mucinous *P. aeruginosa*.

Drug Susceptibility Test and Result Interpretation

The standard Kirby–Bauer concentration disk method was used to test the susceptibility to 16 common antibiotics. *P. aeruginosa* ATCC27853 was used for quality control. Non-mucinous *P. aeruginosa* was interpreted from the 24 h results. Due to the slow growth of mucinous *P. aeruginosa* the results of conventional 24 h interpretation will result in false negatives. Therefore, the results of the 48 h culture or the 24 h blood agar culture (MH plate) were used, as mucinous *P. aeruginosa* grows well on blood MH plates. All interpretations were performed in accordance with the 2011 standards of the American Clinical Laboratory Standards Committee.

Statistical Analysis

The distribution of *P. aeruginosa* infection by hospital department and samples are reported as events and proportions. Similarly, the drug susceptibility for 16 antimicrobial agents for each year is presented as events and proportions. The results of the *P. aeruginosa* infection drug susceptibility analysis were divided into resistance, intermediate sensitivity, and sensitive. The distribution, species, and drug susceptibility for each year were compared using the Chi-square test, and the dynamic trends of *P. aeruginosa* infection from 2016 to 2022 were assessed using the Spearman correlation coefficient. All of the reported *p*-values are two-sided, and the significance level was set at $p = 0.05$. All statistical analyses were conducted by using SPSS for Windows 24.0 (SPSS for Windows 24.0, SPSS, Chicago, IL, USA).

Results

P. aeruginosa Infection According to the Hospital Department

The distribution of *P. aeruginosa* infection from each hospital department is expressed in Table 1. Overall, *P. aeruginosa* infection was more frequently observed in the Neurosurgery (14.30%), Emergency (13.30%), and Critical Care Medicine (11.69%) departments. When stratified by year, *P. aeruginosa* infection was more frequently detected in the Neurosurgery (15.05%), Emergency (13.07%), and Critical Care Medicine (11.88%) departments in 2016; the Neurosurgery (16.91%), Critical Care Medicine (11.27%), and Emergency (11.06%) departments in 2017; the Emergency (14.71%), Neurosurgery (12.82%), and Critical Care Medicine (11.13%) departments in 2018; the Neurosurgery (15.03%), Emergency (12.06%), and

Table 1 Distribution of *Pseudomonas aeruginosa* in Each Department

Department	2016 (n=505)	2017 (n=479)	2018 (n=476)	2019 (n=539)	2020 (n=504)	2021 (n=614)	2022 (n=184)	Total (n=3301)
Pediatric	25 (4.95%)	25 (5.22%)	27 (5.67%)	21 (3.90%)	18 (3.57%)	33 (5.37%)	5 (2.72%)	154 (4.67%)
Otolaryngology	11 (2.18%)	8 (1.67%)	7 (1.47%)	13 (2.41%)	11 (2.18%)	6 (0.98%)	1 (0.54%)	57 (1.73%)
Orthopedics	20 (3.96%)	22 (4.59%)	24 (5.04%)	16 (2.97%)	13 (2.58%)	14 (2.28%)	1 (0.54%)	110 (3.33%)
Respiratory Medicine	58 (11.49%)	47 (9.81%)	39 (8.19%)	63 (11.69%)	41 (8.13%)	62 (10.10%)	18 (9.78%)	328 (9.94%)
Emergency	66 (13.07%)	53 (11.06%)	70 (14.71%)	65 (12.06%)	67 (13.29%)	84 (13.68%)	34 (18.48%)	439 (13.30%)
Rehabilitation	0 (0.00%)	3 (0.63%)	4 (0.84%)	6 (1.11%)	10 (1.98%)	16 (2.61%)	4 (2.17%)	43 (1.30%)
Geriatrics	22 (4.36%)	25 (5.22%)	20 (4.20%)	32 (5.94%)	30 (5.95%)	36 (5.86%)	10 (5.43%)	175 (5.30%)
Urinary surgery	6 (1.19%)	21 (4.38%)	23 (4.83%)	11 (2.04%)	7 (1.39%)	4 (0.65%)	1 (0.54%)	73 (2.21%)
Endocrinology	6 (1.19%)	12 (2.51%)	9 (1.89%)	6 (1.11%)	3 (0.60%)	8 (1.30%)	3 (1.63%)	47 (1.42%)
General surgery	17 (3.37%)	17 (3.55%)	16 (3.36%)	31 (5.75%)	41 (8.13%)	34 (5.54%)	11 (5.98%)	167 (5.06%)
Burn and plastic surgery	4 (0.79%)	10 (2.09%)	19 (3.99%)	15 (2.78%)	21 (4.17%)	24 (3.91%)	7 (3.80%)	100 (3.03%)
Neurology	24 (4.75%)	18 (3.76%)	16 (3.36%)	19 (3.53%)	12 (2.38%)	14 (2.28%)	10 (5.43%)	113 (3.42%)
Neurosurgery	76 (15.05%)	81 (16.91%)	61 (12.82%)	81 (15.03%)	68 (13.49%)	79 (12.87%)	26 (14.13%)	472 (14.30%)
Nephrology	13 (2.57%)	7 (1.46%)	9 (1.89%)	8 (1.48%)	7 (1.39%)	15 (2.44%)	8 (4.35%)	67 (2.03%)
Cardiovascular	24 (4.75%)	14 (2.92%)	11 (2.31%)	22 (4.08%)	12 (2.38%)	16 (2.61%)	1 (0.54%)	100 (3.03%)
Thoracic surgery	12 (2.38%)	13 (2.71%)	15 (3.15%)	20 (3.71%)	18 (3.57%)	24 (3.91%)	4 (2.17%)	106 (3.21%)
Oncology	33 (6.53%)	21 (4.38%)	22 (4.62%)	33 (6.12%)	26 (5.16%)	30 (4.89%)	5 (2.72%)	170 (5.15%)
Critical Care Medicine	60 (11.88%)	54 (11.27%)	53 (11.13%)	49 (9.09%)	69 (13.69%)	75 (12.21%)	20 (10.87%)	386 (11.69%)
Other	28 (5.54%)	28 (5.85%)	25 (5.25%)	28 (5.19%)	30 (5.95%)	40 (6.51%)	15 (8.15%)	194 (5.88%)

Respiratory Medicine (11.69%) departments in 2019; the Critical Care Medicine (13.69%), Neurosurgery (13.49%), and Emergency (13.29%) departments in 2020; the Emergency (13.68%), Neurosurgery (12.87%), and Critical Care Medicine (12.21%) in 2021; and the Emergency (18.48%), Neurosurgery (14.13%), and Critical Care Medicine (10.87%) departments in 2022. There were no significant association for the distribution of *P. aeruginosa* infection according to department with trends over time ($p > 0.05$).

P. aeruginosa Infection According to the Sample Type

The distribution of *P. aeruginosa* infection according to sample type is presented in Table 2. The majority of confirmed *P. aeruginosa* infection samples were from sputum (72.52%), and secreta (9.91%). When stratified by years, *P. aeruginosa* infection was most commonly identified from sputum (77.62%) and secreta (8.12%) in 2016; from sputum (71.82%), secreta (11.48%), and urine (5.22%) in 2017; from sputum (68.07%), secreta (12.39%), and urine (6.30%) in 2018; from sputum (74.77%) and secreta (10.39%) in 2019; from sputum (69.64%), secreta (9.33%), and blood (6.35%) in 2020; from sputum (73.45%) and secreta (8.47%) in 2021; and from sputum (70.11%), secreta (9.24%), and bile (6.52%) in 2022. The distribution of *P. aeruginosa* infection according to type from 2016 to 2022 was associated with statistically significant ($p < 0.05$).

Antimicrobial Susceptibility Testing

The distribution of *P. aeruginosa* infection drug susceptibility is outlined in Table 3. The drug sensitivity to *P. aeruginosa* infection was greater for AMK (91.82%), TOB (82.79%), and GEN (82.01%), while the drug resistance to *P. aeruginosa* infection was greater for TCC (22.57%), LVX (21.63%), and CIP (18.00%). When stratified by year, the drug sensitivities to *P. aeruginosa* infection were greater for AMK (87.33%), COL (84.36%), and POL (82.38%) in 2016; for AMK (93.95%), COL (93.11%), and POL (91.02%) in 2017; for AMK (90.76%), MEM (84.66%), and TOB (82.98%) in 2018; for AMK (93.32%), TOB (87.38%), and GEN

Table 2 Distribution of *Pseudomonas aeruginosa* According to Specimen Type

Specimen	2016 (n=505)	2017 (n=479)	2018 (n=476)	2019 (n=539)	2020 (n=504)	2021 (n=614)	2022 (n=184)	Total (n=3301)
Ascites	2 (0.40%)	2 (0.42%)	5 (1.05%)	2 (0.37%)	3 (0.60%)	9 (1.47%)	5 (2.72%)	28 (0.85%)
Bile	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	10 (1.98%)	13 (2.12%)	12 (6.52%)	35 (1.06%)
Bronchial alveolar	0 (0.00%)	0 (0.00%)	0 (0.00%)	1 (0.19%)	0 (0.00%)	4 (0.65%)	0 (0.00%)	5 (0.15%)
Blood	12 (2.38%)	15 (3.13%)	13 (2.73%)	10 (1.86%)	32 (6.35%)	15 (2.44%)	3 (1.63%)	100 (3.03%)
Catheter	1 (0.20%)	2 (0.42%)	0 (0.00%)	1 (0.19%)	0 (0.00%)	2 (0.33%)	2 (1.09%)	8 (0.24%)
Pleuritic	3 (0.59%)	4 (0.84%)	4 (0.84%)	1 (0.19%)	3 (0.60%)	3 (0.49%)	0 (0.00%)	18 (0.55%)
Purulent	15 (2.97%)	10 (2.09%)	14 (2.94%)	19 (3.53%)	13 (2.58%)	22 (3.58%)	8 (4.35%)	101 (3.06%)
Secreta	41 (8.12%)	55 (11.48%)	59 (12.39%)	56 (10.39%)	47 (9.33%)	52 (8.47%)	17 (9.24%)	327 (9.91%)
Spinal fluid	3 (0.59%)	2 (0.42%)	3 (0.63%)	1 (0.19%)	0 (0.00%)	0 (0.00%)	2 (1.09%)	11 (0.33%)
Sputum	392 (77.62%)	344 (71.82%)	324 (68.07%)	403 (74.77%)	351 (69.64%)	451 (73.45%)	129 (70.11%)	2394 (72.52%)
Stool	1 (0.20%)	2 (0.42%)	1 (0.21%)	3 (0.56%)	1 (0.20%)	3 (0.49%)	0 (0.00%)	11 (0.33%)
Drain	8 (1.58%)	10 (2.09%)	16 (3.36%)	9 (1.67%)	8 (1.59%)	4 (0.65%)	0 (0.00%)	55 (1.67%)
Throat swab	8 (1.58%)	6 (1.25%)	6 (1.26%)	7 (1.30%)	10 (1.98%)	4 (0.65%)	0 (0.00%)	41 (1.24%)
Tissue	0 (0.00%)	1 (0.21%)	0 (0.00%)	2 (0.37%)	3 (0.60%)	3 (0.49%)	0 (0.00%)	9 (0.27%)
Urine	19 (3.76%)	25 (5.22%)	30 (6.30%)	24 (4.45%)	23 (4.56%)	29 (4.72%)	6 (3.26%)	156 (4.73%)

Table 3 Distribution of Drug Susceptibility for *Pseudomonas aeruginosa*

Antibacterial	Category	2016 (n=505)	2017 (n=479)	2018 (n=476)	2019 (n=539)	2020 (n=504)	2021 (n=614)	2022 (n=184)	Total (n=3301)
AMK	Resistance	0 (0.00%)	1 (0.21%)	3 (0.63%)	20 (3.71%)	15 (2.98%)	35 (5.70%)	5 (2.72%)	79 (2.39%)
	Intermediate	26 (5.15%)	28 (5.85%)	38 (7.98%)	14 (2.60%)	14 (2.78%)	15 (2.44%)	4 (2.17%)	139 (4.21%)
	Sensitivity	441 (87.33%)	450 (93.95%)	432 (90.76%)	503 (93.32%)	471 (93.45%)	561 (91.37%)	173 (94.02%)	3031 (91.82%)
ATM	Resistance	0 (0.00%)	3 (0.63%)	17 (3.57%)	42 (7.79%)	41 (8.13%)	98 (15.96%)	26 (14.13%)	227 (6.88%)
	Intermediate	191 (38.42%)	180 (37.58%)	181 (38.03%)	34 (6.31%)	18 (3.57%)	54 (8.79%)	14 (7.61%)	672 (20.36%)
	Sensitivity	270 (53.47%)	285 (59.50%)	258 (54.20%)	250 (46.38%)	215 (42.66%)	383 (62.38%)	137 (74.46%)	1798 (54.47%)
POL	Resistance	1 (0.20%)	0 (0.00%)	1 (0.21%)	1 (0.19%)	0 (0.00%)	0 (0.00%)	3 (1.63%)	6 (0.18%)
	Intermediate	31 (6.14%)	34 (7.10%)	95 (19.96%)	319 (59.18%)	261 (51.79%)	528 (85.99%)	171 (92.93%)	1439 (43.59%)
	Sensitivity	416 (82.38%)	436 (91.02%)	366 (76.89%)	5 (0.93%)	1 (0.20%)	5 (0.81%)	3 (1.63%)	1232 (37.32%)
CIP	Resistance	93 (18.42%)	96 (20.04%)	90 (18.91%)	86 (15.96%)	96 (19.05%)	117 (19.06%)	36 (19.57%)	614 (18.60%)
	Intermediate	371 (73.47%)	379 (79.12%)	378 (79.41%)	285 (52.88%)	229 (45.44%)	434 (70.68%)	142 (77.17%)	2218 (67.19%)
	Sensitivity	0 (0.00%)	1 (0.21%)	3 (0.63%)	164 (30.43%)	175 (34.72%)	59 (9.61%)	3 (1.63%)	405 (12.27%)
MEM	Resistance	67 (13.27%)	59 (12.32%)	62 (13.03%)	22 (4.08%)	14 (2.78%)	28 (4.56%)	7 (3.80%)	259 (7.85%)
	Intermediate	21 (4.16%)	18 (3.76%)	10 (2.10%)	11 (2.04%)	6 (1.19%)	18 (2.93%)	11 (5.98%)	95 (2.88%)
	Sensitivity	369 (73.07%)	398 (81.21%)	403 (84.66%)	291 (53.99%)	252 (50.00%)	489 (79.64%)	159 (86.41%)	2361 (71.52%)
PIP	Resistance	62 (12.28%)	98 (20.46%)	100 (21.01%)	55 (10.20%)	39 (7.74%)	96 (15.64%)	24 (13.04%)	474 (14.36%)
	Intermediate	38 (7.52%)	44 (9.19%)	44 (9.24%)	25 (4.64%)	25 (4.96%)	61 (9.93%)	12 (6.52%)	249 (7.54%)
	Sensitivity	360 (71.29%)	324 (67.64%)	325 (68.28%)	241 (44.71%)	208 (41.27%)	371 (60.42%)	137 (74.46%)	1966 (59.56%)
TZP	Resistance	50 (9.90%)	64 (13.36%)	53 (11.13%)	52 (9.65%)	37 (7.34%)	59 (9.61%)	17 (9.24%)	332 (10.06%)
	Intermediate	34 (6.73%)	42 (8.77%)	56 (11.76%)	73 (13.54%)	65 (12.90%)	77 (12.54%)	14 (7.61%)	361 (10.94%)
	Sensitivity	380 (75.25%)	366 (76.41%)	350 (73.53%)	411 (76.25%)	397 (78.77%)	475 (77.36%)	151 (82.07%)	2530 (76.64%)
GEN	Resistance	0 (0.00%)	1 (0.21%)	9 (1.89%)	43 (7.98%)	42 (8.33%)	74 (12.05%)	24 (13.04%)	193 (5.85%)
	Intermediate	95 (18.81%)	82 (17.12%)	72 (15.13%)	26 (4.82%)	32 (6.35%)	20 (3.26%)	6 (3.26%)	333 (10.09%)
	Sensitivity	370 (73.27%)	394 (82.25%)	393 (82.56%)	466 (86.46%)	420 (83.33%)	513 (83.55%)	151 (82.07%)	2707 (82.01%)
TCC	Resistance	173 (34.26%)	128 (26.72%)	161 (33.82%)	74 (13.73%)	62 (12.30%)	118 (19.22%)	29 (15.76%)	745 (22.57%)
	Intermediate	234 (46.34%)	179 (37.37%)	178 (37.39%)	121 (22.45%)	106 (21.03%)	188 (30.62%)	64 (34.78%)	1070 (32.41%)
	Sensitivity	49 (9.70%)	33 (6.89%)	47 (9.87%)	130 (24.12%)	103 (20.44%)	226 (36.81%)	83 (45.11%)	671 (20.33%)
FEP	Resistance	0 (0.00%)	2 (0.42%)	8 (1.68%)	47 (8.72%)	45 (8.93%)	63 (10.26%)	13 (7.07%)	178 (5.39%)
	Intermediate	85 (16.83%)	109 (22.76%)	110 (23.11%)	45 (8.35%)	30 (5.95%)	48 (7.82%)	15 (8.15%)	442 (13.39%)
	Sensitivity	379 (75.05%)	365 (76.20%)	353 (74.16%)	445 (82.56%)	423 (83.93%)	500 (81.43%)	154 (83.70%)	2619 (79.34%)
CSL	Resistance	8 (1.58%)	6 (1.25%)	10 (2.10%)	0 (0.00%)	18 (3.57%)	87 (14.17%)	24 (13.04%)	153 (4.63%)
	Intermediate	12 (2.38%)	1 (0.21%)	1 (0.21%)	0 (0.00%)	19 (3.77%)	78 (12.70%)	30 (16.30%)	141 (4.27%)
	Sensitivity	31 (6.14%)	23 (4.80%)	28 (5.88%)	0 (0.00%)	121 (24.01%)	317 (51.63%)	123 (66.85%)	643 (19.48%)

(*Continued*)

Table 3 (Continued).

Antibacterial	Category	2016 (n=505)	2017 (n=479)	2018 (n=476)	2019 (n=539)	2020 (n=504)	2021 (n=614)	2022 (n=184)	Total (n=3301)
CAZ	Resistance	0 (0.00%)	1 (0.21%)	11 (2.31%)	72 (13.36%)	62 (12.30%)	93 (15.15%)	18 (9.78%)	257 (7.79%)
	Intermediate	91 (18.02%)	102 (21.29%)	101 (21.22%)	33 (6.12%)	36 (7.14%)	37 (6.03%)	4 (2.17%)	404 (12.24%)
	Sensitivity	376 (74.46%)	372 (77.66%)	362 (76.05%)	432 (80.15%)	401 (79.56%)	480 (78.18%)	160 (86.96%)	2583 (78.25%)
TOB	Resistance	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
	Intermediate	94 (18.61%)	79 (16.79%)	81 (17.02%)	65 (12.06%)	73 (14.48%)	93 (15.15%)	32 (17.39%)	517 (15.66%)
	Sensitivity	373 (73.86%)	400 (83.51%)	395 (82.98%)	471 (87.38%)	427 (84.72%)	517 (84.20%)	150 (81.52%)	2733 (82.79%)
IPM	Resistance	38 (7.52%)	43 (8.98%)	55 (11.55%)	88 (16.33%)	107 (21.23%)	136 (22.15%)	28 (15.22%)	495 (15.00%)
	Intermediate	51 (10.10%)	36 (7.52%)	26 (5.46%)	29 (5.38%)	13 (2.58%)	14 (2.28%)	8 (4.35%)	177 (5.36%)
	Sensitivity	367 (72.67%)	392 (81.84%)	389 (81.72%)	416 (77.18%)	378 (75.00%)	456 (74.27%)	146 (79.35%)	2544 (77.07%)
COL	Resistance	1 (0.20%)	0 (0.00%)	2 (0.42%)	1 (0.19%)	0 (0.00%)	0 (0.00%)	2 (1.09%)	6 (0.18%)
	Intermediate	11 (2.18%)	19 (3.97%)	95 (19.96%)	317 (58.81%)	260 (51.59%)	523 (85.18%)	171 (92.93%)	1396 (42.29%)
	Sensitivity	426 (84.36%)	446 (93.11%)	362 (76.05%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	1234 (37.38%)
LVX	Resistance	124 (24.55%)	117 (24.43%)	129 (27.10%)	96 (17.81%)	97 (19.25%)	116 (18.89%)	35 (19.02%)	714 (21.63%)
	Intermediate	72 (14.26%)	50 (10.44%)	101 (21.22%)	271 (50.28%)	231 (45.83%)	434 (70.68%)	142 (77.17%)	1301 (39.41%)
	Sensitivity	267 (52.87%)	306 (63.88%)	243 (51.05%)	169 (31.35%)	172 (34.13%)	61 (9.93%)	4 (2.17%)	1222 (37.02%)

(86.46%) in 2019; for AMK (93.45%), TOB (84.72%), and FEP (83.93%) in 2020; for AMK (91.37%), POL (85.99%), and TOB (84.20%) in 2021; for AMK (94.02%), CAZ (86.96%), and MEM (86.41%) in 2022. Finally, we noted significant association of the drug susceptibility of *P. aeruginosa* infection according to the type of antibacterial with trends over time ($p < 0.05$).

Discussion

This retrospective study involved 3301 patients infected with *P. aeruginosa* and aimed to assess the distribution, species, drug susceptibility and dynamic trends of *P. aeruginosa* infection in a tertiary hospital based on the results of a nosocomial infection surveillance system. The characteristics of the patients included varied, and the study covered a broad range of patient diseases. The *P. aeruginosa* infections were more frequently identified in the departments of Neurosurgery (14.30%), Emergency (13.30%), and Critical Care Medicine (11.69%). Moreover, the sample from which *P. aeruginosa* infection was most commonly identified included sputum (72.52%) and secreta (9.91%). Finally, *P. aeruginosa* infection drug sensitivity was greater for AMK (91.82%), TOB (82.79%), and GEN (82.01%) than for the other drugs tested.

Several studies have investigated the distribution, species, and drug susceptibility of *P. aeruginosa* infections. Cui et al identified 9381 episodes of bacteremia during 2010–2019 and determined that *P. aeruginosa* infection decreased from 4.0–2.4%, which was consistent with the China Antimicrobial Surveillance Network report in 2018.[14] Lila et al identified 553 *P. aeruginosa* isolates from the University Clinical Centre of Kosovo and reported that *P. aeruginosa* was the second most frequently isolated hospital pathogen, and samples were primarily isolated from the Intensive Care Unit (68.7%). Moreover, the most frequent body system from which *P. aeruginosa* was isolated was the respiratory tract (58.4%). Furthermore, antimicrobials evaluated demonstrated increased resistance, particularly the carbapenems, IPM and MEM.[15] Wan et al identified 4306 types of pathogens from the hematology results of 26 tertiary hospitals and reported that *P. aeruginosa* accounted for 8.50% of the infections.[16] However, studies have not focused on the distribution, species, drug susceptibility and dynamic trends of *P. aeruginosa* infections in China. Therefore, the current study intended to systematically describe the status of *P. aeruginosa* infection and drug susceptibility in China.

The *P. aeruginosa* infections were most frequently identified in the departments of Neurosurgery, Emergency, and Critical Care Medicine. A greater prevalence of patients were from the departments of Neurosurgery, Emergency, and Critical Care Medicine, and they were admitted to the Intensive Care Unit; intensive care patients were an important risk factor for infection likely to the debilitating effects of prolonged hospitalization and the regular administration of medicines and use of medical equipment.[17–19] Additionally, the most common sample from which *P. aeruginosa* infections were isolated were sputum and secreta. This may have been due to the frequency of *P. aeruginosa* colonization that occurred in bronchiectasis, which was able to induce airway inflammation and tissue destruction.[20,21] The *P. aeruginosa* was the dominant microorganism isolated from sputum samples in patients with bronchiectasis.[22–24] These results suggesting patients from the departments of Neurosurgery, Emergency, and Critical Care Medicine should received more frequent surveillance to identify *P. aeruginosa* infections, and these departments needed strengthen to further reduce *P. aeruginosa* infections. Moreover, the sputum and secreta samples should be applied to identify *P. aeruginosa* infections in clinical practice, especially in the departments at high risk for *P. aeruginosa* infections.

Drug sensitivity for *P. aeruginosa* infection was greater for AMK, TOB, and GEN, while the drug-resistance in *P. aeruginosa* infections was greater for TCC, LVX, and CIP. Studies have demonstrated the prevalence of antimicrobial resistance in different geographical settings, a greater prevalence of resistance in *P. aeruginosa* in the eastern and south-eastern parts of Europe in particular. Moreover, national prevalence of resistant isolates ranged from 4.4% to 58.5%, specifically in Netherlands to Romania, and the prevalence of resistance trends in Germany, Hungary, and Slovakia were significantly increased.[25] Antibiotics are increasingly becoming resistant to *P. aeruginosa* isolates, and the beta-lactam resistance was the highest in the United States, Europe, and South America.[26] Finally, the drug susceptibility trends of COL and POL was significantly reduced, and the drug sensitivities of AMK was persisted from 2016 to 2022, which could explained by the prevalence of intermediate were significantly increased for COL and POL.

Several studies have outlined risk factors for drug-resistant *P. aeruginosa* infection in China. Rao et al reported that IPM treatment within two weeks of age was a significant independent risk factor for IPM-resistant *P. aeruginosa* in neonatal intensive care units.[27] Gao et al recruited 747 patients with bronchiectasis and determined that the risk factors for *P. aeruginosa* resistance included prior exposure to antibiotics, three or more exacerbations in the previous year, higher modified Medical Research Council dyspnea scores and greater radiologic severity.[28] Hu et al determined that the risk factors carbapenem-resistant *P. aeruginosa* included patients aged over 60 years of age, particularly those in intensive care units.[29] The high resistance to TCC, LVX, and CIP of *P. aeruginosa* infection could be explained by the carbapenem resistant isolates of *P. aeruginosa* that were associated with cross-resistance to TCC, LVX, and CIP.[30] Moreover, the use of TCC, LVX, and CIP were most common in the study hospital, these were associated with high drug-resistance in *P. aeruginosa* infections.

Several limitations of this study are acknowledged. Firstly, individual patient characteristics varies, which could affect the use of antimicrobial agents. Secondly, the severity of disease differs among patients, which may affect the drug susceptibility in *P. aeruginosa* infections. Thirdly, the analyses were based on a retrospective design, and the results could be affected by selection and recall biases. Fourthly, all of patients from the single-hospital, and the generalizing of results should be cautious. Finally, the dynamic trends of *P. aeruginosa* infection were not modified by the potential confounders, and further investigations may consider focusing on specific patients.

Conclusion

Infections with *P. aeruginosa* frequently originated from the departments of Neurosurgery, Emergency, or Critical Care Medicine. Additionally, sputum and secreta samples had greater infection prevalence than the other samples. Drug resistance in *P. aeruginosa* infection was greater for TCC, LVX, and CIP, while the sensitivity was greater for AMK, TOB, and GEN. These findings may guide clinicians in the management of *P. aeruginosa* infections. Further large-scale study based on multi-hospital should be performed to verify the results of this study and analyzing the susceptibility trends over time.

Abbreviations

AMK, Amikacin; TOB, tobramycin; CIP, ciprofloxacin; MEM, meropenem; TZP, tazobactam, GEN, gentamycin; CAZ, ceftazidime; LVX, levofloxacin; IPM, imipenem; TCC, ticarcillinticarcillin; FEP, cefepime; COL, colistin; POL, polyoxin.

Data Sharing Statement

The datasets generated and/or analyzed during the current study are not publicly available but are available from the corresponding author at a reasonable request.

Ethics Approval and Consent to Participate

Our study complies with the Declaration of Helsinki. This study was approved by the Medical Ethics Committee of the Handan Central Hospital (no: 202247). Informed consent was obtained from all individual participants included in the study.

Disclosure

The authors declare that they have no competing interests.

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