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Original Article

Clinical characteristics and risk factors for *Klebsiella pneumoniae* bloodstream infection in 152 immunocompetent patients

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Abstract

Objective: To investigate the clinical characteristics and prognostic risk factors for *Klebsiella pneumoniae* bloodstream infections in immunocompetent patients.

Methods: The study included patients with *K. pneumoniae* bloodstream infection treated in Zhongda Hospital from June 2016 to June 2021. Clinical data and antibiotic susceptibility test results were retrospectively collected and analyzed. Independent risk factors for mortality were screened using the chi-square test and multivariate logistic regression.

Results: A total of 152 patients were included in the analysis. In our cohort, 77.6% of patients were older than 60 years, and 80.9% of them had community-acquired infections. The most common complications were type 2 diabetes, hypertension, and stroke sequelae. The proportion of patients with septic shock or abscesses was 34.9% and 25.7%, respectively. There were significant differences in the site of infection, septic shock, and serum levels of procalcitonin, hypersensitive C-reactive protein, D-dimer, creatinine, and lactic acid between survivors and non-survivors ($p < 0.05$). Multivariate regression analysis showed that hospital-acquired infections, septic shock, length of hospital stay, and creatinine levels were independent risk factors for mortality. Antibiotic susceptibility test results indicated that clinical outcomes varied depending on bacterial sensitivity to ampicillin/sulbactam.

Discussion: *Klebsiella pneumoniae* is a common community-acquired and hospital-acquired bacteria and usually infects older people with complications such as diabetes. Nosocomial infections, length of stay, septic shock, and renal insufficiency are potentially associated with poor prognosis. Bacterial susceptibility to ampicillin/sulbactam affects prognosis.

Key words: *Klebsiella pneumoniae*; bloodstream infection; clinical features; antibiotic resistance; risk factors.

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Introduction

Klebsiella pneumoniae (KP) is a common pathogenic bacillus that causes infections in community and hospital settings. The 2019 China Antimicrobial Surveillance Network (CHINET) report revealed that the rate of isolation of KP in respiratory specimens was 20.6%, higher than that of all other bacterial species [1]. The detection rate of KP in blood samples was 16.5%, second to *Escherichia coli*. KP is classified into hypervirulent and classic according to virulence. Hypervirulent KP (hvKP) is characterized by high invasiveness and potential migration to the liver, lung, kidney, and eyeball [2,3]. The mortality rate from KP infections complicated with septic shock was 50-77% in the United States [4]. According to the European Antimicrobial Resistance Surveillance Network, the number of deaths caused by carbapenem-resistant KP (CRKP) increased six-fold from 2007 to 2015 [5], representing the highest increase in the rate of mortality among all drug-resistant bacterial infections. Since then, CRKP infections have become a global public health problem. To provide clinical evidence for the rational use of antibiotics and reduce mortality and bacterial resistance to antibiotics, this study retrospectively analyzed clinical characteristics and risk factors associated with KP bloodstream infections in a cohort admitted to our hospital from June 2016 to June 2021.

Methods

General information

This study was conducted from June 2016 to June 2021 in Zhongda Hospital of Southeast University, Jiangsu Province, China. The inclusion criteria were patients older than 18 years with positive blood cultures of KP and symptoms of infection (fever and abnormal leukocyte count). The exclusion criteria were (1) patients with incomplete medical or follow-up records, (2) patients with hematological diseases within 3 months before enrollment, (3) patients undergoing

chemotherapy due to cancer, (4) patients with acquired immune deficiency syndrome, and (5) patients with asymptomatic bacteremia. This study was approved by the Research Ethics Committee of Zhongda Hospital of Southeast University (Approval Number 2018ZDSYLL092-P01) and was registered in the Chinese Clinical Trial Registry (Registration Number ChiCTR1800019036).

Diagnostic criteria for bloodstream infections [6]

KP was isolated from blood cultures of patients with any of the following symptoms or signs: (1) body temperature > 38 ℃ or < 36 ℃ accompanied by chills; (2) invasion of the portal system or disseminated infections; (3) systemic infection but no detectable infection foci; (4) systolic blood pressure < 90 mmHg (1 mmHg = 0.133 kPa) or more than 40 mmHg lower than the systolic blood pressure before admission in patients with septic shock.

Table 1. General data and clinical characteristics of 152 *Klebsiella pneumoniae* patients.

Clinical and demographic characteristics	n (%)
Sample size	152 (100)
Gender	
Male	100 (65.8)
Female	52 (34.2)
Age (years)	
< 60	34 (22.4)
≥ 60	118 (77.6)
Onset place	
Community acquired	123 (80.9)
Hospital acquired	29 (19.1)
Initial lesion of infection	
Digestive system	61 (40.1)
Urinary system	36 (23.7)
Respiratory system	31 (20.4)
Skin soft tissue	6 (3.9)
Musculoskeletal system	4 (2.6)
Catheter-related	3 (2.0)
Neurological infection	3 (2.0)
Peritoneal cavity infection	2 (1.3)
Unknown location	7 (4.6)
Underlying disease	
Diabetes	65 (42.8)
Hypertension	63 (41.4)
Sequelae of stroke	29 (19.1)
Coronary heart disease	21 (13.8)
Malignant solid tumor	15 (9.9)
Renal insufficiency	12 (7.9)
Hematological diseases	9 (5.9)
Autoimmunity diseases	7 (4.6)
Admission Department	
Emergency ward	42 (27.6)
Intensive care unit	33 (21.7)
Department of general practice	15 (9.9)
Geriatric department	13 (8.6)
Intervention department	11 (7.2)
Department of Gastroenterology	10 (6.6)
Department of general surgery	10 (6.6)
Department of urological surgery	7 (4.6)
Department of nephrology	5 (3.3)
Other department	6 (3.9)
Viscera abscess	39 (25.7)
Septic shock	53 (34.9)
Prognosis after 28 days	
Survival	121 (79.6)
Fatal	31 (20.4)

Antibiotic susceptibility tests

Bacterial culture and identification were carried out in accordance with National Clinical Examination Procedures (fourth edition). Pathogenic bacteria were identified using the BioMérieux Vitek 2 Compact automatic bacterial identification and drug sensitivity analysis system. The results were interpreted according to the 30th edition of the Clinical and Laboratory Standards Institute (ClSI-M100) [7].

Data collection

Clinical and laboratory data of patients with positive blood culture for KP were collected, including (1) general information: gender, age, underlying diseases, initial infection site, other sites of infection, length of hospital stay, complications, and prognosis; (2) laboratory examinations: leukocyte count, platelet count, procalcitonin (PCT), hypersensitive C-reactive protein (hs-CRP), prothrombin time, activated partial thrombin time, D-dimer, albumin, alanine aminotransferase, aspartate aminotransferase, total bilirubin, and creatinine; (4) antibiotic susceptibility test results. The cohort was divided into two groups—survivors and non-survivors—according to 28-day mortality.

Statistical analysis

All statistical analyses were performed using SPSS version 22.0. Normally distributed and non-normally distributed continuous variables were described as means and standard deviations or medians and interquartile ranges, respectively. Non-normally distributed continuous variables were compared using Student's *t*-test or Mann–Whitney U test. Categorical variables were compared using the chi-square test and expressed as numbers and percentages. The baseline characteristics of survivors and non-survivors at admission were compared by one-way repeated-measures analysis of variance. Independent risk factors were identified by multiple logistic regression. A p value of less than 0.05 was considered statistically significant.

Results

General information

A total of 152 patients (100 males [65.8%] and 52 females [34.2%]) with KP bloodstream infections were included in the study. The age of the cohort ranged from

21 to 96 years, 118 (77.6%) patients were older than 60 years, and 123 (80.9%) of these patients acquired infections from community settings. The most common complications were type 2 diabetes (65, 42.8%), hypertension (63, 41.4%), and stroke sequelae (29, 19.1%). Infections were more common in the digestive system (61, 40.1%), urinary tract (36, 23.7%), respiratory tract (31, 20.4%), biliary tract (26, 17.1%), and gastrointestinal tract (3, 2.0%). Affected patients were admitted to emergency departments (42, 27.6%), intensive care units (33, 21.7%), or general practice departments (15, 9.9%). Fifty-three patients (34.9%) had septic shock. Thirty-nine patients (25.7%) had abscesses in different organs, including the liver (32 cases), liver and lung (two cases), liver and brain (one case), lung and brain (one case), lung and kidney (one case), liver + lung + prostate (one case), and liver + lung + eyes (one case). Only 18 (11.8%) patients with abscesses underwent surgery or interventional therapy. The number of survivors and non-survivors was 121 and 31, respectively, with a 28-day mortality rate of 20.4%. The demographic and clinical characteristics of our patients are shown in Table 1.

Prognosis of infections by the chi-square test

Clinical outcomes varied depending on the site of infection ($\chi^2 = 4.381$, $p = 0.036$) and the development of septic shock ($\chi^2 = 7.914$, $p = 0.005$). Furthermore, the

Table 2. Comparison of risk factors in survival and death groups.

	Survival	Fatal	χ^2/z	*p*
Age (years)	71.77 ± 16.16	73.23 ± 12.14	0.172	0.864
Length of stay	17.66 ± 12.01	6.1 ± 9.53	5.999	0.000
Gender			0.464	0.496
Male	78 (78.0%)	22 (22.0%)		
Female	43 (82.7%)	9 (17.3%)		
Onset place			4.381	0.036
Community	102 (83.0%)	21 (17.1%)		
Hospital	19 (67.9%)	10 (32.1%)		
Initial lesion of infection			7.002	0.587
Digestive system	50 (82.0%)	11 (18.0%)		
Urinary system	31 (86.1%)	5 (13.9%)		
Respiratory system	23 (74.2%)	8 (25.8%)		
Skin soft tissue	4 (66.7%)	2 (33.3%)		
Musculoskeletal system	4 (100.0%)	0 (0.0%)		
Catheter-related	3 (75.0%)	1 (25.0%)		
Neurological infection	2 (66.7%)	1 (33.3%)		
Peritoneal cavity infection	2 (100.0%)	0 (0.0%)		
Multiple abscess	5 (71.4%)	2 (28.6%)		
unknown location	5 (71.4%)	2 (28.6%)		
Underlying disease				
Diabetes	56 (86.2%)	9 (13.8%)	3.000	0.083
Sequelae of stroke	21 (72.4%)	8 (27.6%)	1.142	0.285
Malignant solid tumor	11 (73.3%)	4 (26.7%)	0.089	0.766
Hypertension	51 (81.0%)	12 (19.0%)	0.120	0.729
Coronary heart disease	17 (81.0%)	4 (19.0%)	0.027	0.869
Renal insufficiency	9 (75.0%)	3 (25.0%)	0.002	0.969
Hematological diseases	5 (55.6%)	4 (44.4%)	2.015	0.156
Autoimmunity diseases	5 (71.4%)	2 (28.6%)	0.005	0.845
Septic shock	34 (66.7%)	17 (33.3)	7.914	0.005
MDR KP	19 (82.6%)	4 (17.4%)	0.068	0.795
Lab examination				
WBC	11.5 (7.32~15.68)	11.12 (5.53~14.16)	0.718	0.473
PCT	10.53 (2.74~30.52)	26.0 (5.9~54.0)	2.054	0.040
CRP	165.2 (115.9~226.5)	107.2 (11.84~247)	2.115	0.034
IL-6	102 (58.5~153.5)	348 (308~368)	7.628	0.000
PLT	145 (91.5~192.5)	125 (50~196)	1.125	0.261
PT	13.7 (12.25~14.9)	14.9 (12.4~18.8)	2.124	0.034
APTT	29.6 (27.5~32.5)	30.7 (27.4~35.6)	1.441	0.150
D-Dimer	1171 (612~3145)	2286 (909~6749)	1.962	0.049
Cr	88 (69~128.5)	117 (78~181)	2.387	0.017
Lac	2.4 (1.5~3.55)	3.2 (1.8~6.8)	2.116	0.034
Tbil	16.8 (9.95~27.35)	16.4 (9.2~50.5)	0.494	0.621
ALT	37 (21.5~87)	38 (27~106)	0.873	0.382
AST	43 (28.5~95.5)	47 (32~187)	1.107	0.268
ALB	35.5 (31.5~38.2)	32.8 (29.3~37.1)	1.630	0.103
Glu	9.1 (7.29~13.68)	8.18 (6.6~13.67)	0.844	0.399

WBC: white blood cell; PCT: procalcitonin; CRP: C-reactive protein; IL-6: interleukin-6; PLT: platelet; PT: prothrombin time; APTT: activated partial thromboplastin time; Cr: creatinine; Lac: lactic acid; Tbil: total bilirubin; ALT: glutamic-pyruvic transaminase; AST: glutamic oxalacetic transaminase; ALB: albumin; Glu: glucose.

Table 3. Multiple logistic analysis of risk factors of fatal outcome.

Risk factor	B	S.E	Wals	*p*	OR	95% (CI)
Septic shock	1.836	0.585	9.865	0.002	6.27	1.99~19.73
Hospital acquired infection	1.483	0.668	4.933	0.026	4.405	1.19~16.30
Length of stay	-0.198	0.044	20.489	0.000	0.82	0.75~0.89
Creatinine	0.004	0.002	3.970	0.046	1.004	1.00~1.008

levels of PCT (χ^2 = 2.054, p = 0.004), hs-CRP (χ^2 = 2.115, p = 0.034), D-dimer (χ^2 = 1.962, p = 0.049), creatinine (χ^2 = 2.387, p = 0.017), and lactic acid (χ^2 = 2.116, p = 0.034) differed significantly between survivors and non-survivors (Table 2).

Prognosis of infections by regression analysis

The parameters with statistical significance in the univariate analysis were included in the multivariate logistic regression model. Independent risk factors for mortality in KP bloodstream infections were septic shock (OR: 6.27, 95% CI: 1.99-19.73), hospital-acquired infections (OR: 4.405, 95% CI: 1.19-16.30), and creatinine levels (OR: 1.004, 95% CI: 1.00-1.008). Length of hospital stay (OR: 0.82, 95% CI: 0.75-0.89) might be a protective factor (Table 3 and Figure 1).

Antibiotic susceptibility test results

Among 152 strains, 15 (9.9%) were extended-spectrum β-lactamase (ESBL) producers, 23 (15.1%) were multidrug-resistant, 16 (10.5%) were carbapenem-resistant, and 10 (6.6%) were pan-resistant. These strains were completely resistant to ampicillin. The rate of resistance to cefazolin, furantoin, and ampicillin/sulbactam was 25.9%, 23.3%, and 22.6%, respectively. The rate of resistance to cotrimoxazole, aztreonam, ceftriaxone, ceftazidime, ciprofloxacin, and levofloxacin ranged from 15% to 20%. The rate of resistance to piperacillin/tazobactam, cefotetan, cefepime, gentamicin, tobramycin, and imipenem/cilastatin was approximately 10%.

Figure 1. Multiple logistic analysis of risk factors of fatal outcome.

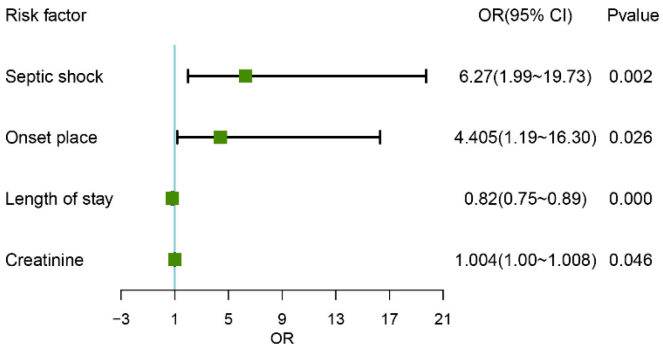

Figure 2. Antibiotics resistance and sensitivity of 152 strains of *Klebsiella pneumoniae*.

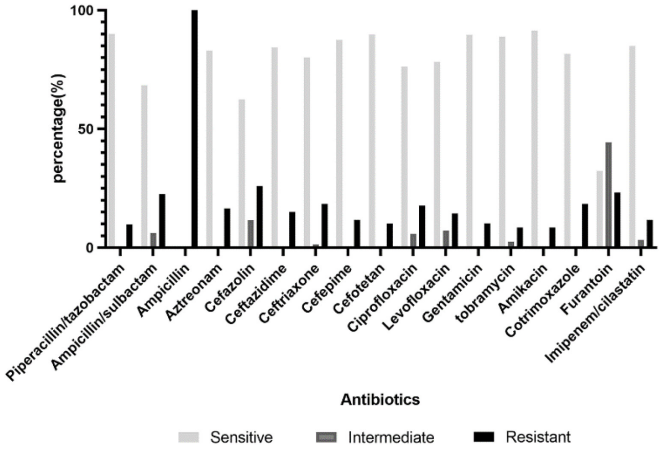

Table 4. Antibiotical resistance and sensitivity of 152 strains of *Klebsiella pneumoniae.*

Antibiotics	S (%)	I (%)	R (%)	
Piperacillin/tazobactam	137 (90.1)	0 (0)	15 (9.9)	103
Ampicillin/sulbactam	104 (68.4)	9 (6.2)	33 (22.6)	84
Ampicillin	0 (0)	0 (0)	147 (100)	
Aztreonam	126 (82.9)	0 (0)	25 (16.6)	96
Cefazolin	70 (62.5)	13 (11.6)	29 (25.9)	103
Ceftazidime	128 (84.3)	1 (0.6)	23 (15.1)	75
Ceftriaxone	117 (80.1)	2 (1.4)	27 (18.5)	106
Cefepime	133 (87.5)	1 (0.6)	18 (11.8)	103
Cefotetan	132 (89.8)	0 (0)	15 (10.2)	78
Ciprofloxacin	116 (76.3)	9 (5.9)	27 (17.8)	58
Levofloxacin	119 (78.3)	11 (7.2)	22 (14.5)	12
Gentamicin	131 (89.7)	0 (0)	15 (10.3)	69
Tobramycin	135 (88.8)	4 (2.6)	13 (8.6)	19
Amikacin	139 (91.4）	0 (0)	13 (8.6)	32
Cotrimoxazole	124 (81.6)	0 (0)	28 (18.4)	
Furantoin	43 (32.3)	59 (44.4)	31 (23.3)	17
Imipenem/cilastatin	129 (84.9)	5 (3.3)	18 (11.8)	16

The rate of resistance to amikacin and tobramycin was 8.6% (Table 4 and Figure 2). Univariate analysis showed that clinical outcomes varied depending on bacterial susceptibility to ampicillin/sulbactam (χ^2 = 12.151, p = 0.002) but not to other antibiotics (Table 5).

Discussion

KP is a Gram-negative bacillus commonly found in clinical infection. The infection of pathogenic enterobacteria causes pneumonia, liver abscesses, urinary and bloodstream infections, and other infectious diseases in community and hospital settings. The Blood Bacterial Resistant Investigation Collaborative System (BRICS) reported that the rate of detection of KP increased from 9.9% in 2014 to 18.4% in 2020 [8]. A systematic review showed that the rate of mortality from bloodstream infections due to KP was 54.30% [9], much higher than that reported in our study (23%).

Table 5. Comparison of antibiotics sensitivity in survival and death groups.

		Survival	Fatal	χ^2/z	*p*
Amikacin	S	113	26	2.858	0.091
	I	0	0		
	R	8	5		
Piperacillin/Tazobactam	S	110	27	0.403	0.525
	I	0	0		
	R	11	4		
Ampicillin/Sulbactam	S	92	16	12.151	**0.002**
	I	4	6		
	R	25	7		
Aztreonam	S	103	24	1.066	0.302
	I	0	0		
	R	18	7		
Ceftazidime	S	103	25	0.774	0.679
	I	1	0		
	R	17	6		
Cefazolin	S	88	21	0.121	0.941
	I	10	3		
	R	23	6		
Ciprofloxacin	S	94	22	0.673	0.714
	I	7	2		
	R	20	7		
Ceftriaxone	S	98	23	0.632	0.729
	I	2	0		
	R	21	6		
Cefotetan	S	110	26	0.484	0.487
	I	0	0		
	R	11	4		
Macrodantin	S	43	8	0.95	0.622
	I	53	13		
	R	25	8		
Cefepime	S	107	26	0.919	0.632
	I	1	0		
	R	13	5		
Gentamicin	S	110	24	1.631	0.202
	I	0	0		
	R	11	5		
Imipenem	S	110	26	1.94	0.379
	I	1	0		
	R	10	5		
Levofloxacin	S	95	24	0.111	0.946
	I	9	2		
	R	17	5		
Cotrimoxazole	S	99	25	0.023	0.881
	I	0	0		
	R	22	6		
Tobramycin	S	108	27	1.9	0.387
	I	4	0		
	R	9	4		
Ertapenem	S	109	26	1.525	0.467
	I	1	0		
	R	11	5		
Ampicillin/sulbactam	S	0	0	NA	NA
	I	0	0		
	R	121	30		

S: sensitive; I: intermediate; R: resistant; *p*: *p* value.

Moreover, mortality increased two-fold in patients receiving inappropriate empirical treatment (95% CI: 1.1-3.4, $p = 0.02$) [10]. Therefore, clinicians should pay attention to bloodstream infections due to KP because of the high morbidity and mortality.

In our study, 77.6% of patients were older than 60 years, and the major sites of infection were the digestive and urinary systems. Thirty-one patients (20.4%) had liver abscesses, leading to infections in distant tissues and organs, including the brain, eye, and lung. In addition, the prevalence of underlying diseases such as diabetes, stroke sequelae, and malignant tumors was high in these patients, consistent with previous findings [11]. Older patients are more likely to have poor nutritional status, immune dysfunctions, and comorbidities. Moreover, invasive surgeries involving indwelling gastric tube and catheter placement require the use of broad-spectrum antibiotics, increasing susceptibility to KP infections [12]. The processes by which KP enters the bloodstream are unclear. Some studies have shown that KP colonizes the intestinal tract and invades the bloodstream by gastrointestinal translocation through the endothelial and intestinal barrier [13,14]. In our cohort, diabetes was the most common complication , accounting for 42.8% of cases, and the prevalence of diabetes was significantly higher in survivors than in non-survivors; nonetheless, there was no significant intergroup difference in this variable in the univariate analysis ($p = 0.083$). It was shown that 50.0% of patients with bloodstream infections due to HvKP had diabetes, and 77.8% of patients with septic shock had diabetes [15]. Clinical studies have demonstrated that capsular polysaccharide (CPS) is an important virulence factor of KP, and environmental glucose may increase the biosynthesis of CPS [16,17]. High glucose levels due to poor glycemic control stimulate CPS biosynthesis and CPS gene expression in hvKP, increasing resistance to phagocytosis and contributing to the development of invasive syndrome. Therefore, diabetes may be a risk factor for the development of bloodstream infections caused by hvKP isolates.

Patients with KP bloodstream infections were divided into survivors and non-survivors according to 28-day mortality. The results of multivariate analysis showed that hospital-acquired infection, septic shock, length of hospital stay, and creatinine level were independent risk factors for bloodstream infections. The proportion of patients older than 60 years was 77.6%, most of whom had multiple underlying diseases. Moreover, most patients with hospital-acquired infections were in critical condition and had received appropriate treatment before outpatient and emergency treatment, especially the long-term use of antibiotics, resulting in the emergence of multidrug- and pandrug-resistant strains [18,19]. Septic shock is an independent risk factor for acute kidney injury (AKI) [20]. The prevalence of AKI is proportional to the severity of infection; for instance, the prevalence of AKI in patients with severe infection or septic shock was approximately 23% and 51%, respectively [21]. Moreover, the advanced AKI stages are associated with worse prognosis [22]. Our results showed that the incidence of septic shock was high in patients with KP bloodstream infections, and AKI increased the risk of death. Therefore, more attention should be paid to the occurrence of AKI in patients with hospital-acquired bloodstream infections due to KP.

The prevalence of drug-resistant KP, especially carbapenem-resistant strains, is increasing with the widespread use of antibiotics. Previous literature suggested that the hypervirulence and antibiotic resistance of KP would not overlap [23]. Nonetheless, nosocomial carbapenem-resistant hvKP strains were isolated in a tertiary hospital in Beijing, reducing the efficacy of treatment [24]. CHINET showed that resistance rate of KP strains to imipenem increased from 14.1% in 2014 to 24.2% in 2020 [25]. However, resistance to commonly used antibiotics in our samples was low, and the rate of resistance to imipenem was 11.8%, significantly lower than that reported by CHINET. This discrepancy may be related to two reasons: first, 87.7% of KP strains evaluated by CHINET were isolated from inpatients, and the incidence of CRKP in ICU patients was 23.0%. In turn, 82.2% of KP infections in our cohort were community-acquired, resulting in lower carbapenem selective pressure; second, the samples analyzed in CHINET were obtained from respiratory secretions (36.2%), urine (20.8%), and blood (15.0%). In contrast, all our samples were obtained from blood, and the rate of contamination was low.

In China, the BRICS 2018-2019 showed that the resistance rate of KP isolates to cephalosporins (first, second, and third generations), quinolones, and sulfamethoxazole was higher than 30%, that to cefepime, cefoxitin, piperacillin, and tazobactam was 20-30%, and that to amikacin was 14.6%; in turn, these isolates were highly sensitive to polymyxin and tigecycline [26]. Our antibiotic susceptibility results were similar to those of BRICS; however, antibiotic resistance rates were significantly lower than those reported by BRICS. These rates were lower than 20% for all evaluated antibiotics, except for cefazolin,

furantoin, and ampicillin/sulbactam, and the resistance to amikacin was the lowest. This result may be because most patients in our cohort had community-acquired infections. Moreover, the small sample size may lead to sampling errors.

Our results showed that the susceptibility of KP to carbapenem, cefepime, cefotetan, piperacillin-tazobactam, and amikacin was 84.2%, 87.3%, 89.5%, 89.5%, and 91.4%. KP produces ESBLs, AmpC β-lactamases, and carbapenemases through drug resistance genes to hydrolyze β-lactams. In this respect, the KPC-producing enzyme was resistant to carbapenem and other β -lactams [27,28]. Although serotyping was not conducted in this study, the resistance rate to imipenem/cilastatin was higher than that to piperacillin/tazobactam, probably because of the excessive use of carbapenem in patients with nosocomial infections, underscoring the need to limit the excessive use of this antimicrobial agent.

Conclusions

KP is highly prevalent and causes severe infections, reducing treatment efficacy. KP bloodstream infections are particularly concerning, especially in older patients with diabetes complicated by liver abscesses. Septic shock and elevated serum creatinine levels were independent risk factors for KP bloodstream infections and mortality. Carbapenems, enzyme inhibitors, fourth-generation cephalosporins, and aminoglycosides should be rationally used as first-line antibiotics for empirical treatment based on drug resistance data. Moreover, drug susceptibility testing is essential to adjust treatment and reduce antibiotic exposure, antimicrobial resistance, and mortality.

Ethical Approval

This research was approved by the Research Ethics Committee of Zhongda Hospital, Southeast University.

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Authors' contributions

Qun Zhang designed and conceptualized the study and wrote the manuscript. Pan Wang and Menghuan Shen collected and analyzed data and wrote the manuscript. Chun Shan collected and analyzed data. All authors approved the final version of the manuscript.

Availability of data and materials

The datasets used or analyzed in this study are available from the corresponding author upon reasonable request.

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