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Original Article

Clinical characteristics, infection sites, and mortality risk factors in community-acquired hypermucoviscous Klebsiella pneumoniae infections

Hongkui Sun[1], Li Lei[2], Wenqing Lai[1], Qingbiao Liang[3], Miaolian Chen[1]

[1] *Intensive Care Unit Department, Zhongshan City People's Hospital, Guangdong Province, China*
[2] *Department of Respiratory Medicine, Zhongshan City People's Hospital, Guangdong Province, China*
[3] *Intensive Care Unit Department, Zhongshan Huangpu People's Hospital, Guangdong Province, China*

Abstract

Objective: We aim to investigate the clinical, laboratory, and biological characteristics of patients with hypermucoviscous *Klebsiella pneumoniae* (hmKp) infections across various community settings to inform early screening of high-risk patients and improve treatment success rates.

Methods: Patients were categorized into hmKp and non-hmKp groups. We analyzed the clinical presentation, laboratory findings, infection sites, and drug-sensitivity test results of the clinical isolates to identify mortality risk factors associated with hmKp infections.

Results: The mortality rate for patients with multisite infection involving the lungs and bloodstream was as high as 76% in hmKp group, surpassing that in the non-hmKp group, although this difference was not statistically significant ($p = 0.055$). Invasive infections most frequently occurred concurrently with infections of the liver, lungs, and bloodstream. The resistance and mortality rates for hmKp infection were both 17%. Notably, nearly 18% of the patients had concurrent intracranial infections, which had the highest mortality risk of 100% for hmKp. Although both hmKp and non-hmKp strains were sensitive to most antibiotics, the non-hmKp strains exhibited higher antibiotic resistance. Multivariate regression analysis identified advanced age (OR: 1.04; 95% CI: 1.01-1.08; $p = 0.024$) and high SOFA (OR: 1.49; 95% CI: 1.21-1.83, $p = 0.000$) and APACHE II scores (OR: 1.10; 95% CI: 1.00-1.20, $p = 0.049$) as independent mortality risk factors for patients with hmKp.

Conclusions: HmKp infections at varied anatomical locations exhibit significant prognostic differences. Invasive infections pose a particularly high mortality risk. Timely treatment escalation may improve prognosis among older patients with high SOFA and APACHE II scores.

Key words: *Klebsiella pneumoniae*; liver abscess; multidrug resistance; risk factor; septicemia.

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Introduction

Klebsiella pneumoniae (Kp) is a major pathogen that poses a threat to human health and life, causing various infections, including pneumonia, liver abscess, and bloodstream infections [1,2]. Kp is classified into two distinct clonal groups: classical *K. pneumoniae* (cKp) and hypervirulent *K. pneumoniae* (hvKp) [2]. HvKp is often associated with severe invasive infections, which are characterized by specific bacterial phenotypes, including high viscosity and the K1/2 capsule serotype, affecting multiple organs [3]. Despite this distinction, definitive clinical features or molecular markers for diagnosis are yet to be identified. In clinical settings, *K. pneumoniae* is typically classified as either hypermucoviscous (hmKp) or non-hypermucoviscous (non-hmKp). Due to the high viscosity of hmKp, the "string test", in which a single bacterial colony on an agar plate is stretched for > 5 mm using a needle, serves as the gold standard to differentiate hmKp from non-hmKp [4]. HmKp has clinical specificity, often causing severe invasive and migratory community-acquired infections. Despite ideal drug sensitivity, these infections commonly result in poor prognosis and high mortality rates, significantly endangering human health and life [4].

Nonetheless, the impact of hmKp infections at various sites and their prognosis has garnered significant attention. Currently, the most frequently reported infection site is Kp liver abscess, followed by community-acquired Kp bacteremia [3-5]. Studies indicate that the proportion of bacteremia in among patients with community-acquired Kp infections in Taiwan can reach 75% [5]. In contrast, the incidence in Europe and the United States ranges from 17% to 43% [6]. Notably, community-acquired Kp pneumonia complicated by bacteremia has attracted considerable interest because of its high morbidity and mortality. In Mainland China, the incidence of bacteremia pneumonia attributed to hmKp in communities is 23.21%, with a mortality rate of 55.1% [7,8]. In addition, metastatic infections associated with hmKp are increasingly recognized [9]. However, invasive infections across multiple sites often lead to misdiagnosis or missed diagnosis. Furthermore, limited

information is available on the infection characteristics, treatment options, and potential mortality differences associated with these pathogens at various sites. An in-depth investigation of site-specific infection characteristics is essential to develop more effective treatment strategies. Therefore, in this study, we aimed to examine the clinical, laboratory, and biological characteristics of patients infected with hmKp across various community sites, thereby establishing a basis for early screening of high-risk patients and enhancing treatment outcomes.

Methods

Patients

This retrospective study was conducted at Zhongshan City People's Hospital and included 326 patients diagnosed with Kp infection in the community between January 2019 and February 2024. Based on the string test results, patients were classified into the following two groups: hmKp (positive result) and non-hmKp (negative result). Clinical and laboratory characteristics, infection sites, and bacteriological profiles of these patients were also analyzed. All data collected in this study were anonymous and retrospective. This study was approved by the Clinical Research and Animal Experiment Ethics Committee of Zhongshan City People's Hospital (No. 2024-098).

Inclusion criteria

Patients were eligible for inclusion in this study if they met the following conditions: (1) confirmed Kp infection acquired in the community, with the isolation and identification of Kp from clinical samples such as blood, alveolar lavage fluid, midstream urine, or drainage fluid, and (2) the availability of complete case data.

Exclusion criteria

Patients were excluded if they met any of the following: (1) concurrent infection with multiple pathogens; (2) age < 18 years or being pregnant or lactating; (3) non-compliance with prescribed treatment.

Definition

Invasive infection was defined as the simultaneous involvement of two or more tissues and/or organs, excluding bloodstream infections.

Pathogen identification and drug sensitivity test

Pathogen identification and antimicrobial susceptibility testing were conducted using the

Table 1. Clinical characteristics of the patients in the hmKp and non-hmKp groups.

Parameters	HmKp (N = 192)	Non-hmKp (N = 134)	Test Statistic (t/χ^2)	df	*p*
Age, years	61.29 ± 15.49	65.01 ± 14.61	-1.827	324	0.062
Gender			0.155	1	0.694
Male	141 (73.4%)	101 (75.4%)			
Female	51 (26.6%)	33 (24.6%)			
Basic diseases					
Hypertension	29 (15.1%)	23 (17.2%)	0.250	1	0.617
Diabetes	77 (40.1%)	55 (41.0%)	0.029	1	0.865
Cerebrovascular disease	32 (16.7%)	29 (21.6%)	1.284	1	0.257
Chronic kidney disease	11 (5.7%)	11 (8.2%)	0.771	1	0.380
Liver and gallbladder diseases	14 (7.3%)	7 (5.2%)	0.560	1	0.454
Tumors	16 (8.3%)	17 (12.7%)	1.644	1	0.263
Healthy patients	52 (27.1%)	34 (25.4%)	0.119	1	0.730
Septicemia	133 (69.3%)	73 (54.5%)	7.425	1	**0.006***
Drainage of liver abscess	73 (38.0%)	26 (19.4)	12.937	1	**0.000***
Septic shock	65 (33.9%)	33 (24.6%)	3.196	1	0.074
Antibiotic exposure	20 (10.4%)	18 (13.4%)	0.697	1	0.404
Invasive infection	34 (17.7%)	11 (8.2%)	5.986	1	**0.014***
Drug sensitivity results			**9.139**	**1**	**0.003***
Drug resistance	41 (21.4%)	49 (36.6%)			
Drug sensitivity	151 (78.6%)	85 (63.4%)			
MDRB	14 (7.3%)	22 (16.4%)	6.691	1	**0.010***
MODS	73 (38%)	36 (26.9%)	4.792	1	**0.036***
Disease severity					
APACHE II	15.08 ± 0.607	16.15 ± 0.758	-1.116	256	0.309
SOFA	5.76 ± 0.335	4.77 ± 0.319	1.928	324	0.055
Treatment			**0.217**	**1**	**0.642**
Monotherapy	160 (83.3%)	109 (81.3%)			
Double-drug therapy	32 (16.7%)	25 (18.7%)			
Result					
Dead	58 (30.2%)	30 (22.4%)	2.449	1	0.118

MDRB: multidrug-resistant bacteria; MODS: multiple organ dysfunction syndrome; APACHE: Acute physiology and chronic health evaluation; SOFA: sequential organ failure score.

MicroScan WalkAway 96 Plus system (Siemens, Germany). Confirmation of pathogen identification was achieved through MALDI-TOF mass spectrometry (Brooke, Germany), and all strains were further verified using the string test. The tested antibiotics included ampicillin (AMP), amikacin (AMK), aztreonam (ATM), ciprofloxacin (CIP), cefotetan (CEF), ceftriaxone (CRO), ertapenem (ETP), cefepime (CPM), nitrofurantoin (NIT), gentamicin (GEN), imipenem (IPM), levofloxacin (LVX), cefoperazone/sulbactam (CSL), trimethoprim-sulfamethoxazole (SXT), ceftazidime (CAZ), tigecycline (TGC), tobramycin (TOB), piperacillin/tazobactam (TZP), cefuroxime (CXM), and ceftazidime-avibactam (CAZ/AVI). Multidrug-resistant bacteria (MDRB) were classified as strains resistant to at least three distinct classes of antibiotics [10].

Data collection

Patient data were retrieved from the information system during hospitalization, after applying the study inclusion and exclusion criteria.

Results

Clinical characteristics of patients

A total of 326 patients were included in this study, comprising of 192 with hmKp and 134 with non-hmKp. The mean age was 62.51±16.06 years (Table 1), with a gender ratio of 2.9:1 (male:female = 242:84). Diabetes was the most common underlying disease in Kp infection (132/326, 40.5%) (Table 1), with similar proportions in both groups (40.1% vs. 41.0%) (Table 1). Bacteremia was reported in 63.2% of the patients (206/326), and its incidence was significantly higher in the hmKp group than in the non-hmKp group (69.3% vs. 54.5%, $p = 0.006$) (Table 1). The incidence of shock was higher in hmKp group, though not statistically significant (33.9% vs. 24.6%, $p = 0.074$) (Table 1). Furthermore, the incidence of multiple organ dysfunction syndrome (MODS) was higher in the hmKp group than in the non-hmKp group ($p = 0.036$), whereas the prognosis between the two groups did not differ significantly ($p = 0.118$) (Table 1).

In the case of therapeutic aspects, all patients received antibiotic treatment, with 17.5% (57/326) receiving combination antibiotic therapy (Table 1). The most common regimens included carbapenems, carbapenem ± LVX, or third-generation cephalosporins. No significant differences were found between the two groups in terms of age, underlying disease, disease severity, shock, or treatment (all $p > 0.05$) (Table 1). The mortality rate was higher in the hmKp group than in the non-hmKp group (30.2% vs 22.4%; Table 1), although this difference was not statistically significant ($p > 0.05$) (Table 1).

Laboratory results

Table 2 presents a comparison of the laboratory results between the hmKp and non-hmKp groups. Compared with the patients in the non-hmKp group, those in the hmKp group demonstrated significantly elevated levels of PLT, PCT, CRP, TB, and IL-6 (all $p < 0.05$). However, no significant differences were observed in other laboratory parameters.

Susceptibility and resistance rates for each medication

Figure 1 illustrates the drug sensitivity results across various patient isolates. Of the 90 patients with resistant strains (Table 1), 38 had prior antibiotic exposure (Table 1). Specifically, 78.6% of the hmKp strains showed sensitivity, whereas 7.3% were classified as MDRB strains (Table 1). Conversely, in the non-hmKp group, 63.4% were sensitive strains and 16.4% were MDRB strains (Table 1). Both the hmKp and non-hmKp strains had general sensitivity to most antibiotics, although the highest resistance rates were recorded against SXT (Figure 1).

Table 2. Laboratory characteristics of the patients in the hmKp and non-hmKp groups.

Parameters	HmKp (N = 192)	Non-hmKp (N = 134)	Test Statistic (Z)	*p*
WBC	12.63 (7.70 to 17.40)	11.37 (6.12 to 16.95)	-0.674	0.500
PLT	132 (70 to 206.25)	158 (107.25 to 261.75)	**-2.60**	**0.009***
PCT	11.19 (2.07 to 43.87)	5.59 (1.10 to 29.57)	**-2.573**	**0.010***
CRP	171 (94.43 to 250)	131.4 (63.75 to 217)	**-2.51**	**0.012***
TB	19.00 (11.70 to 42.30)	14.00 (9.10 to 27.60)	**-2.493**	**0.013***
Lac	2.00 (1.39 to 3.42)	1.82 (1.23 to 3.50)	-0.847	0.397
Cr	102.00 (69.00 to 181.25)	98.00 (75.00 to 169.00)	0.226	0.821
CK	87.00 (36.00 to 324.75)	78.00 (37.75 to 240.50)	-0.498	0.618
CK-MB	15.00 (10.40 to 24.00)	14.00 (9.00 to 23.00)	-1.468	0.142
TNT	35.00 (14.00 to 43.00)	40.00 (18.50 to 49.50)	-1.186	0.236
IL-6	265.50 (73.75 to 3481.50)	165.00 (61.56 to 678.35)	**-2.364**	**0.018***
D-dimer	3.63 (1.50 to 7.40)	2.95 (1.40 to 4.90)	-1.365	0.172

WBC: white blood cells; PLT: platelets; PCT: procalcitonin; CRP: C-reactive protein; TB: total bilirubin; Lac: Lactic acid; Cr: creatinine; CK: creatine kinase; CK-MB: creatine kinase-MB isoenzyme; TNT: Troponin T; IL-6: interleukin-6. * $p \leq 0.05$ is considered significant.

Figure 1. Susceptibility and resistance rates for each medication in hmKp and non-hmKp groups.

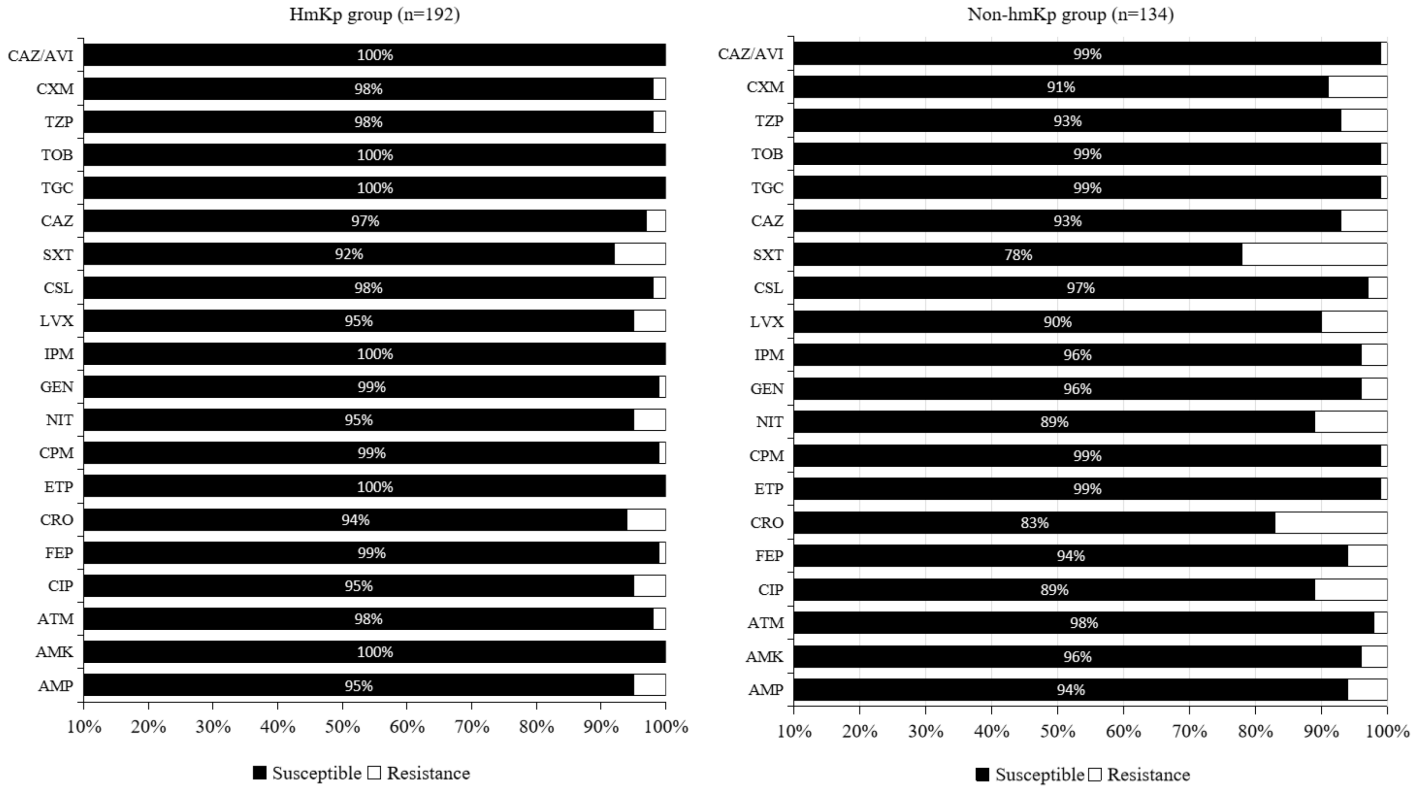
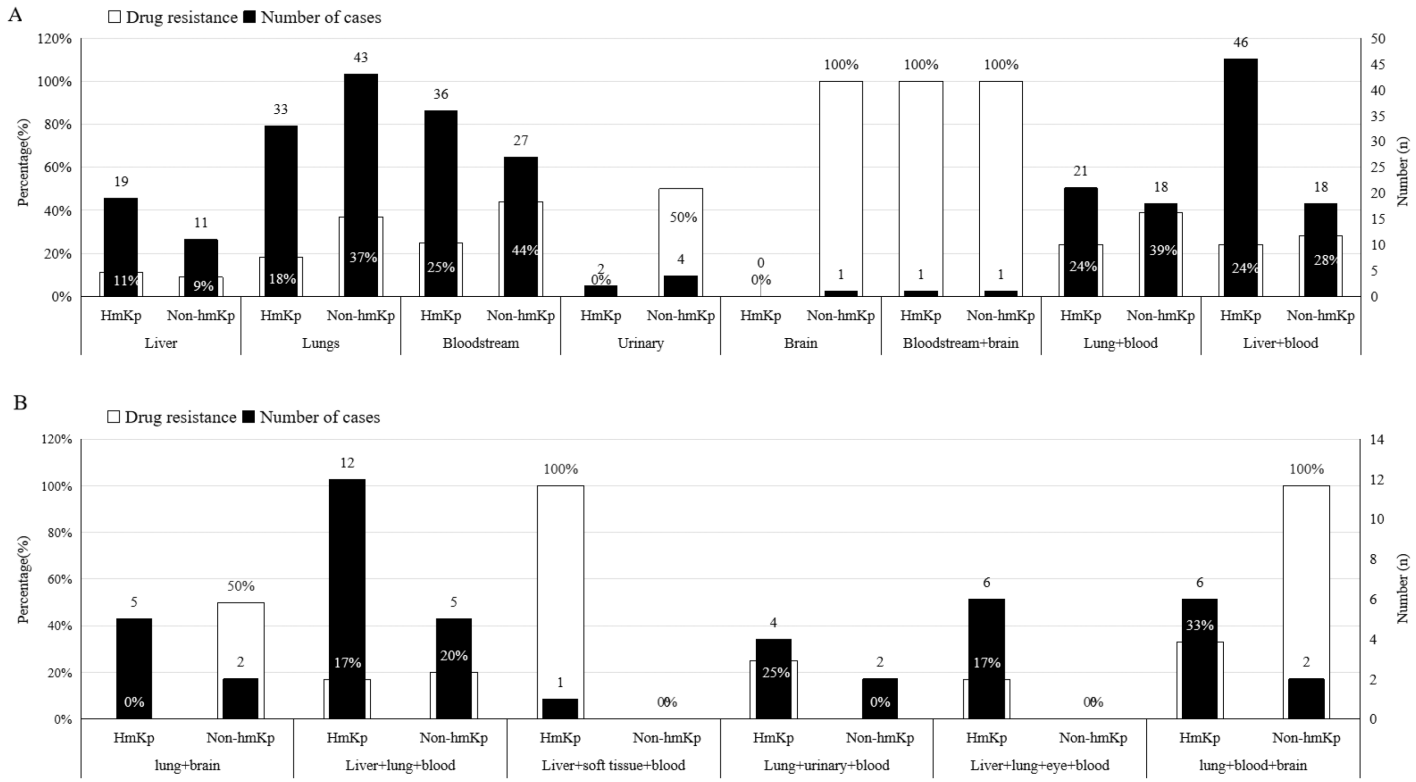


Figure 2 A. Different types of infections and their drug resistance in two groups of non-invasive infections; **B.** Different types of infections and their drug resistance in two groups of invasive infections.



Moreover, the antibiotic resistance rate in the non-hmKp strains was significantly higher than that in the hmKp strain (p = 0.003) (Table 1), with an elevated MDRB resistance rate (p = 0.01; Table 1). In addition, two carbapenemase-resistant Kp strains were identified from the sputum samples of patients with non-hmKp (data not shown).

Resistance profiles of the hmKp and non-hmKp groups for different types of infections

In non-invasive infections, the resistance rate of non-hmKp infections generally exceeded that of hmKp infections (Figure 2A). Except for simple liver abscesses, non-hmKp infections demonstrated a slightly higher resistance rate than hmKp infections (Figure 2A). Intracranial infections, either alone or in combination with bloodstream infections, were limited to three cases, all involving resistant strains (Figure 2A). The resistance rate among patients with simple pulmonary infections, bloodstream infections, or combined pulmonary and bloodstream infections was relatively high, ranging from 18% to 25% for hmKp strains and from 37% to 44% for non-hmKp strains (Figure 2A).

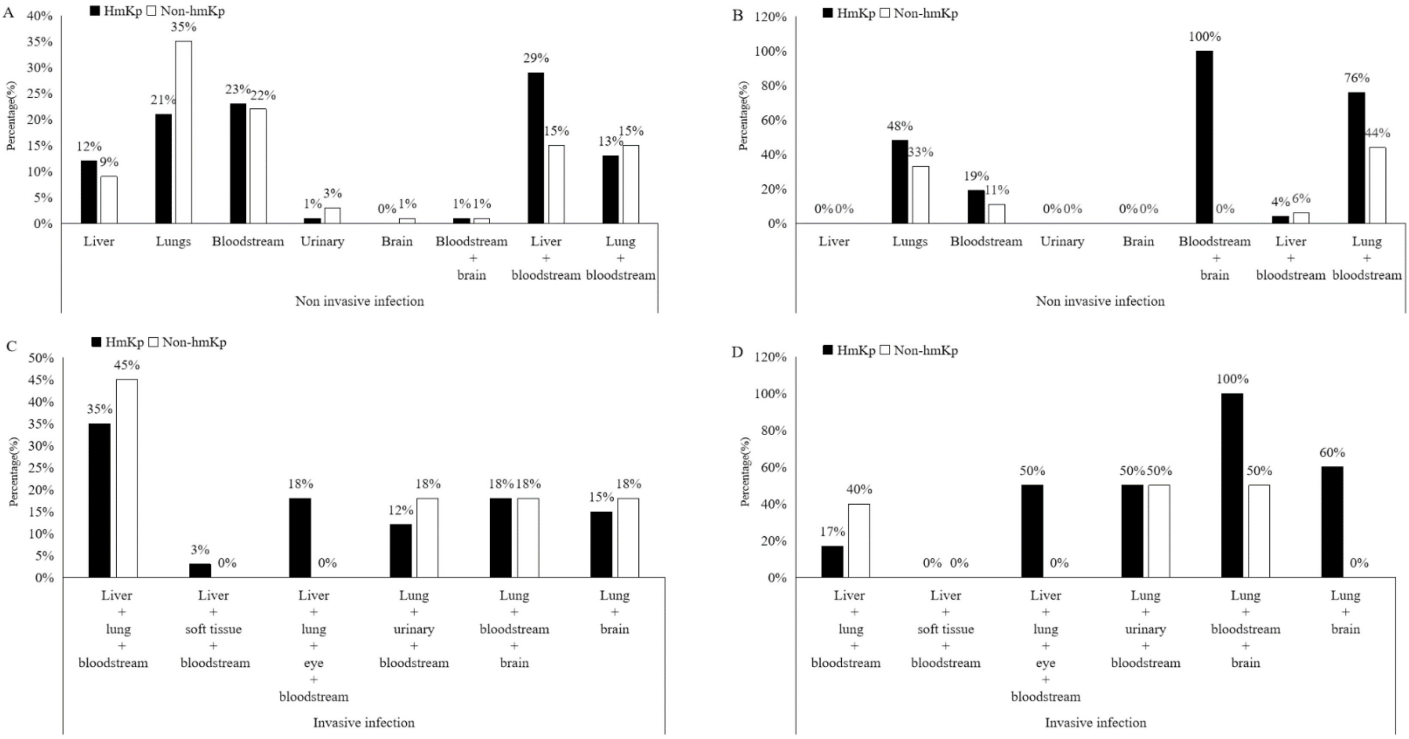
In invasive infections, multisite infection involving the liver, lungs, and bloodstream was the most prevalent (Figure 2B). Compared with hmKp strains, non-hmKp strains exhibited a marginally higher drug resistance rate (Figure 2B). Furthermore, a 100% drug resistance rate was noted in two types of infections: one involving hmKp strains with concurrent liver, soft tissue, and bloodstream infections and the other involving non-hmKp strains with multisite infections of the lungs, bloodstream, and brain. However, only one case of the former and two cases of the latter were observed (Figure 2B).

Incidence rates and proportion of deaths of each type of infection

Kp infections showed significant variability across various anatomical sites within the community. Among the non-invasive infections, the lungs were the most common site of single-site infection, followed by the bloodstream and liver (Figure 2A, 3A). Notably, pulmonary or bloodstream infections were associated with a higher risk of death, with mortality rates of 76% for hmKp and 44% for non-hmKp infections (Figure 3B).

Invasive infections were more prevalent in hmKp cases than in non-hmKp cases (Table1). Concurrent infection involving the liver, lungs, and bloodstream exhibit the highest incidence rates, with hmKp at 35% and non-hmKp at 45% (Figure 3C). Corresponding mortality rates were 17% and 40%, respectively.

Figure 3 A. Incidence rates of each type of non-invasive infection; **B.** Proportion of patients who died according to the type of non-invasive infection; **C.** Incidence rates of each type of invasive infection; **D.** Proportion of patients who died according to the type of invasive infection.



Notably, intracranial infections were observed in approximately 18% of patients (Figure 3C), with mortality rates reaching 100% for hmKp and 50% for non-hmKp (Figure 3D).

Risk factors for mortality: hmKp and non-hmKp

Tables 3 and 4 summarized the outcomes of the univariate and multivariate logistic regression analyses that assessed the impact of independent variables on clinical mortality.

Univariate regression analysis identified age, MODS, SOFA and APACHE II scores, and shock as risk factors for mortality among patients with hmKp. Multivariate analysis further determined that age (OR: 1.04; 95% CI: 1.01-1.08), SOFA scores (OR: 1.49; 95% CI: 1.21-1.83), and APACHE II scores (OR: 1.10; 95% CI: 1.00-1.20) were independent mortality risk factors for patients with hmKp (Table 3). In the case of the patients with non-hmKp, univariate regression analysis highlighted MODS, SOFA and APACHE II scores, age, gender, and shock as mortality risk factors. Subsequent multivariate regression revealed age (OR:1.09; 95% CI: 1.04-1.51) and SOFA scores (OR:1.41; 95% CI:1.05-1.90) as independent mortality risk factors for patients with non-hmKp (Table 4). Finally, ROC analysis demonstrated fair diagnostic efficacy for both logistic models (area under the ROC curve values of 0.876 and 0.914, respectively) (Figure 4).

Discussion

The incidence of hmKp infection has been consistently increasing annually, drawing significant attention from clinicians globally owing to the associated high mortality rates. In this study, we examined the clinical and microbiological characteristics of patients with hmKp infections across various sites in Zhongshan, Guangdong, South China over recent years. To our knowledge, this study is the first comparative analysis of hmKp infection characteristics across varied anatomical sites in patients.

Table 3. Risk factors for mortality among patients with hmKp.

Parameters	Univariate analysis		Multivariate analysis	
	OR (95% CI)	*p*	OR (95% CI)	*p*
Age, years	0.98 (0.96 to 0.98)	**0.06***	1.04 (1.01 to 1.08)	**0.024***
Gender				
Male	ref.	-		
Female	0.63 (0.30 to 1.32)	0.228		
Basic diseases				
Cardiovascular disease	0.69 (0.28 to 1.74)	0.441		
Diabetes	0.71 (0.37 to 1.34)	0.297		
Cerebrovascular disease	2.05 (0.94 to 4.47)	0.071		
Chronic kidney disease	0.49 (0.10 to 2.37)	0.380		
Liver and gallbladder diseases	0.61 (0.16 to 2.27)	0.461		
Tumors	1.90 (0.67 to 5.39)	0.224		
MODS	9.93 (4.86 to 20.30)	**< 0.001***		
SOFA	1.47 (1.31 to 1.64)	**< 0.001***	1.49 (1.21 to 1.83)	**0.000***
APACHE II	1.20 (1.11 to 1.29)	**< 0.001***	1.10 (1.00 to 1.20)	**0.049***
Shock	4.21 (2.18 to 8.09)	**< 0.001***		

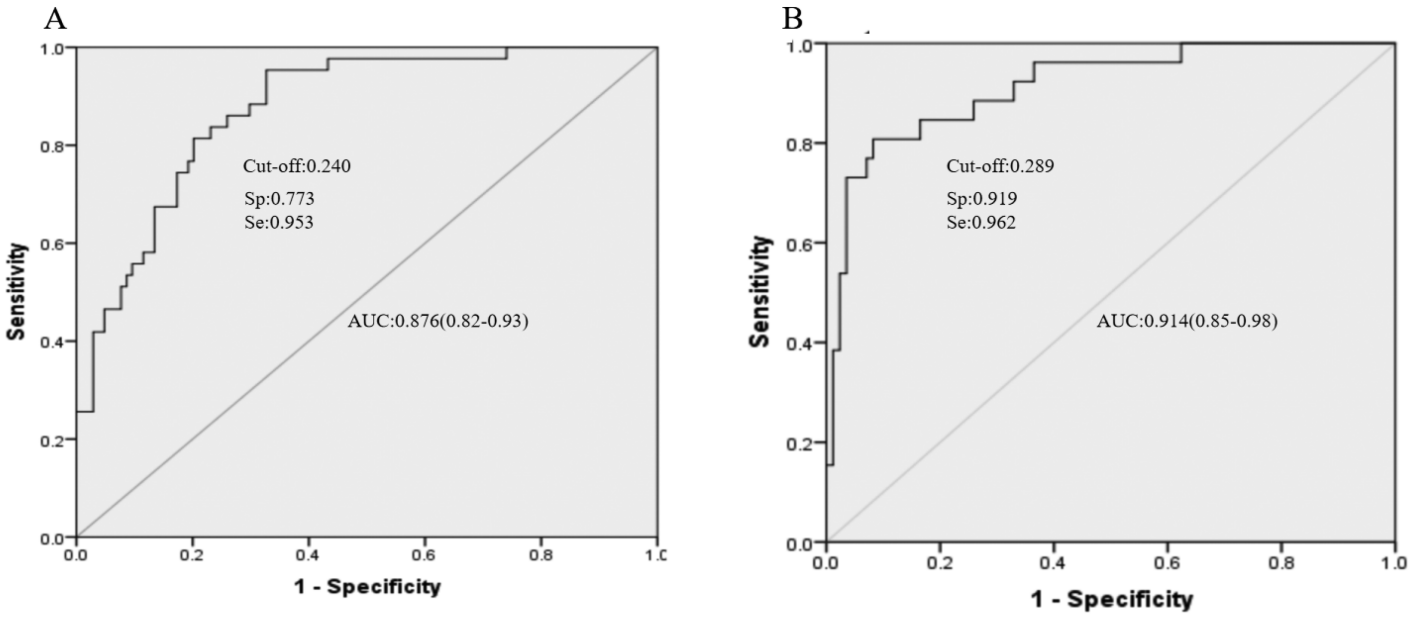
MODS: multiple organ dysfunction syndrome; SOFA: sequential organ failure score; APACHE: Acute physiology and chronic health evaluation. *$p \leq 0.05$ is considered significant.

Table 4. Risk factors for mortality among patients with non-hmKp.

Parameters	Univariate analysis		Multivariate analysis	
	OR (95% CI)	*p*	OR (95% CI)	*p*
Age, years	1.06 (1.02 to 1.10)	**0.001***	1.09 (1.04 to 1.51)	**0.001***
Gender				
Male	ref.	-		
Female	3.21 (1.34 to 7.67)	**0.009***		
Basic diseases				
Cardiovascular disease	1.67 (0.61 to 4.54)	0.313		
Diabetes	1.34 (0.59 to 3.04)	0.478		
Cerebrovascular disease	1.80 (0.71 to 4.52)	0.211		
Chronic kidney disease	1.33 (0.33 to 5.37)	0.686		
Liver and gallbladder diseases	1.41 (0.26 to 7.76)	0.688		
Tumors	2.11 (0.71 to 6.29)	0.179		
MODS	7.16 (2.94 to 17.44)	**< 0.001***		
SOFA	1.35 (1.17 to 1.55)	**< 0.001***	1.41 (1.05 to 1.90)	**0.002***
APACHE II	1.15 (1.08 to 1.24)	**< 0.001***		
Shock	3.91 (1.63 to 9.37)	**0.002***		

MODS: multiple organ dysfunction syndrome; SOFA: sequential organ failure score; APACHE: Acute physiology and chronic health evaluation. *$p \leq 0.05$ is considered significant.

Figure 4. ROC results of multivariate models for patients with hmKp (**A**) and non-hmKp (**B**).



Kp is the leading pathogen in community-acquired infections, with diabetes being the predominant risk factor [11,12]. In our study, 40% of the patients had diabetic comorbidities, constituting the highest proportion. Bacteremia was observed in 206 (63.2%) patients, aligning with a multicenter study in Taiwan by Ko *et al.*, which reported a 68% incidence of Kp bacteremia [6]. Conversely, lower proportions have been reported in other regions, including 43% in the United States, 39% in Australia, 34% in South Africa, 22% in Europe, and 17% in Argentina. The reasons for these geographical discrepancies remain unclear; however, some researchers [6] hypothesize that the origin of Kp bacteremia is geographically unique. A prospective study by Zhang *et al.* indicated that these geographical differences in pathogens were linked to variations in pathogen gene sequences [13]. Our study revealed that the bacteremia proportion in the hmKp group was 69.3%, significantly higher than the 24%–31.4% reported in other regions of China [7,14] and the 6% incidence (53/878) observed in a Spanish study by Cubero *et al.* [15]. These regional variations in Kp infection likely result from a combination of bacterial factors, host factors, socioeconomic conditions, and genetic susceptibility among various ethnic groups. A notably higher incidence of bacteremia and MODS was found in hmKp patients with hmKp than in those with non-hmKp, with no significant difference in mortality between the groups. Similarly, Rafat *et al.* reported a higher rate of multiple organ failure in patients with hmKp but no significant difference in mortality [16]. A prior study in France supported these findings, noting that patients with hmKp, despite appropriate treatment, had a longer duration of positive blood cultures than those with non-hmKp (73.5 vs. 50.7 days, $p = 0.04$) [17]. This prolonged duration may be attributed to biofilm formation by the pathogen [18]. In our study, septic shock incidence was higher in the hmKp group than in the non-hmKp group, although this difference did not reach statistical significance. This result corresponds with a report by Togawa [19], suggesting a potential link between the genetic and highly viscous phenotypes. The increased incidence of MODS and shock associated with hmKp may be related to a more severe systemic inflammatory response (PCT and CRP levels) and invasive infections (multisite simultaneous infections). This perspective is supported by Liu *et al.* [20]. Therefore, identifying the prognostic risk factors of Kp infection in the community is clinically significant for physicians. Chen *et al.* [21] found no significant correlation between carbapenem resistance in pathogenic bacteria and patient mortality. However, host factors, disease severity, and timely and appropriate treatment were identified as primary prognostic determinants. Our study identified age and SOFA and APACHE II scores as prognostic risk factors for hmKp infection, whereas age and SOFA scores were indicated as risk factors for non-hmKp infection, which was in line with previous research findings [21]. All these findings underscore the need for clinicians to closely monitor these risk factors.

Community-acquired Kp infections exhibit a

marked discrepancy between optimal drug sensitivity and poor prognosis, with substantial variations in the incidence and outcomes across different community sites. Therefore, comprehending the characteristics of community-acquired Kp infection at varied community sites is critical. A previous research study [22] indicated that the urinary system is the primary site for community-acquired Kp infections, followed by the lungs. These results differed from those found in our investigation. In non-invasive infections, the lungs were the most commonly affected organ, followed by the bloodstream and liver. In contrast, the highest incidence of invasive infections was observed with concurrent involvement of the liver, lungs and bloodstream. These discrepancies may be attributed to variations in the study populations and regional factors. A prior study indicated that patients with pulmonary involvement had the poorest prognosis for community-acquired Kp infections, followed by those with sepsis [21]. Our observations were consistent with that finding. The earlier study also revealed that among patients with non-invasive infections, those with concurrent pulmonary and bloodstream infections had the poorest prognosis, with mortality rates of 76% for hmKp infections and 44% for non-hmKp infections. In Taiwan, researchers found that bacteremic pneumonia caused by hmKp was associated with a comparatively higher mortality rate (60.2%) [21], a trend also observed in our study. This result could be related to the anti-phagocytic properties of hmKp capsular polysaccharides (CPS), lipopolysaccharides (LPS), and outer membrane proteins (OMP) [23]. A French study reported a higher mortality rate associated with hmKp infections than with non-hmKp infections (50% vs. 35%, p = 0.71), although this difference was not statistically significant [16]. This result is consistent with our findings (30.2% vs. 22.4%, p = 0.118); however, the mortality rates for both hmKp and non-hmKp infections in our cohort were relatively lower. This disparity may be because the previous studies had focused solely on ICU patients and the sample size was smaller (n = 59), which significantly influenced the outcome differences. Among patients with invasive infections, those presenting with concurrent infections in the lungs, bloodstream, and brain had the highest mortality rates, with that for hmKp reaching 100% and for non-hmKp reaching 50%. The small sample size in this subgroup (n = 8) may have resulted in an overestimation of the mortality rate, an issue not previously reported in the literature. Previous studies indicate a higher propensity for hmKp infections to present as invasive infections [24], with our research also yielding consistent results. The incidence of invasive infection in patients with hmKp was 17.7%, whereas the reported incidence in medical centers ranges from 9% to 37% [24,25], possibly due to variations in bacterial serotypes [3,26], and regional differences. Yu *et al.* [12] analyzed 455 patients across eight countries (China, South Africa, Australia, Belgium, the United States, Argentina, and Turkey), revealing regional discrepancies in Kp infections. In addition, liver abscesses and metastatic infections caused by Kp are more prevalent in Asian countries [11,27,28] than in Europe and the United States [29,30]. However, the exact mechanism driving these regional differences, such as ethnic or genetic factors of the pathogenic bacteria, remains unknown. Previous studies indicated that hmKp has a greater likelihood of causing encephalitis, purulent endophthalmitis, and soft-tissue infections [3,25]. This trend was also observed in our study, along with the finding that multisite infections involving the liver, lungs, and bloodstream were more prevalent in hmKp cases than in non-hmKp cases. Nevertheless, these results appear contradictory because different Kp serotypes infect distinct sites more frequently [26]. Furthermore, limited data necessitate further research to elucidate these inconsistencies. Clinically, hmKp presents distinct challenges because it is more likely to trigger severe systemic inflammatory responses, MODS, and invasive infections than non-hmKp. This finding highlights the necessity for clinicians to exercise heightened vigilance and conduct comprehensive evaluations to avoid missed diagnoses, particularly in older patients and those with comparatively higher SOFA scores.

Previous research has reported that compared with patients with non-hmKp, those with hmKp have elevated levels of WBC, CRP, PCT, and IL-6 [31,32], although these differences lacked statistical significance. Similar trends were also observed in our study, but with statistically significant increases in specific indicators for patients with hmKp. These discrepancies might stem from the differences in the definitions of hmKp and sample sizes.

Moreover, antibiotic resistance poses a global challenge. Our study found that both hmKp and non-hmKp strains were generally sensitive to most antibiotics, although their resistance levels varied. The antibiotic resistance rate and the proportion of MDRB in non-hmKp strains were significantly higher, consistent with previous studies [20]. However, the proportion of multidrug resistance in hmKp strains was 7.3%, which was lower than earlier reported values [33]. This difference may be explained by the regional

epidemiological differences of the pathogenic bacteria and the varying management practices across different medical centers. Antibiotic resistance also differed by infection site, with bloodstream infections showing the highest resistance rates among non-invasive infection cases. Although drug-resistant bacteria have been identified across diverse invasive infections, the limited number of such cases restricts the generalizability of resistance rates across different infection types, ultimately preventing an accurate reflection of the broader population. The high drug resistance rate observed in blood cultures also remains unexplained. This phenomenon may be linked to the different sources of pathogens. Clinically, Kp in the bloodstream primarily originates from the intestinal tract or urinary system, both of which exhibit relatively high drug resistance compared with other sites. Among the studied antibiotics, the highest resistance rate was against SXT. Moreover, efforts should be directed toward enhancing the rational use and monitoring of antibiotics to standardize antimicrobial management, thereby delaying or reducing the emergence of drug-resistant strains. The incidence of carbapenemase-producing Kp is also on the rise [33]. In our study, two non-hmKp isolates were resistant to carbapenemases, whereas no carbapenemase-resistant hmKp strains were detected. The ongoing emergence of carbapenemase-resistant Kp isolates presents unprecedented challenges for preventing and controlling drug-resistant bacterial infections and ensuring optimal clinical treatment.

This study has several limitations that should be considered. First, we focused exclusively on Kp in the Zhongshan community, Guangdong Province, China. Second, selection bias may be present due to the study ’s retrospective design. Finally, the strain’s genome was not analyzed due to constraints.

Conclusions

HmKp exhibits clinical particularities and significance. Compared to non-hmKp, hmKp is more likely to induce severe systemic inflammatory responses and lead to MODS and invasive infections. Patients with hmKp intracranial infection or bacteremic pneumonia have high mortality rates. Finally, drug resistance rates are higher in bloodstream infections than in other sites, necessitating increased vigilance from clinicians.

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Ethics approval and consent to participate

This study was approved by the Clinical Research and Animal Experiment Ethics Committee of Zhongshan City People's Hospital (No.:2024-098).

Availability of data and materials

The data and materials used in this study are available from the corresponding authors upon request.

Authors' contributions

MC and QL conducted the research and design. WL and LL conducted the data collection. HS conducted the data analysis and wrote the manuscript. All authors reviewed the final manuscript.

Corresponding Author

Miaolian Chen
People's Hospital of Zhongshan City, No. 2
Sunwen East Road East, Zhongshan City
Guangdong Province, China
Email: franken2005@126.com

Conflict of interest

No conflict of interest is declared.

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