Retrospective Clinical Research Report

Journal of INTERNATIONAL MEDICAL RESEARCH

Journal of International Medical Research
50(2) 1–10

DOI: 10.1177/03000605221079761
journals.sagepub.com/home/imr
SAGE

Prevalence and antibiotic resistance of *Klebsiella pneumoniae* in a tertiary hospital in Hangzhou, China, 2006–2020

Zhezhe Lin[1], Jianhua Yu[2], Shourong Liu[2] and Mingli Zhu[1]

Abstract

Objective: This study analyzed the characteristics and tendencies of resistance to common antibiotics for *Klebsiella pneumoniae* to provide a basis for clinical treatment and prevention.

Methods: A total of 71,743 isolates were collected from hospital clinical specimens following standard procedures from 2006 to 2020. Statistical analyses were conducted on laboratory test results.

Results: A total of 3054 isolates of *K. pneumoniae* were mainly isolated from sputum (53.77%), urine (14.70%), and blood (8.42%). Isolation rates of strains in the AIDS, hepatology, and intensive care wards were 9.72%, 12.52%, and 16.45%, respectively. Resistance rates of imipenem, cefazolin, gentamicin, tobramycin, ciprofloxacin, and ceftazidime respectively increased from 2.33%, 27.91%, 16.28%, 13.95%, 18.60%, and 9.30% to 12.83%, 40.82%, 21.57%, 25.07%, 44.61%, and 17.78%, while piperacillin–tazobactam resistance decreased from 13.95% to 13.70%. Differences in resistance rates to seven antibiotics were significant among specimen types. Detection rates of carbapenem-resistant *K. pneumoniae* were significantly different among blood, sputum, and urine specimens, and between wards.

Conclusions: The prevalence and drug resistance of *K. pneumoniae* showed an upward trend over time, and resistance varied according to ward and specimen source. The prevention of nosocomial infections and rational drug use must be emphasized to reduce antimicrobial resistance.

[1]Department of Open Laboratory Medicine, Hangzhou Xixi Hospital Affiliated to Zhejiang Chinese Medical University, Hangzhou, China
[2]Hangzhou Xixi Hospital Affiliated to Zhejiang Chinese Medical University, Hangzhou, China

Corresponding author:
Mingli Zhu, Department of Open Laboratory Medicine, Hangzhou Xixi Hospital Affiliated to Zhejiang Chinese Medical University, No. 2 Hengbu Street, Hangzhou 310023, China.
Email: mlzhhz@163.com

Keywords
Klebsiella pneumoniae, antimicrobial resistance, tertiary hospital, prevalence, clinical specimen, nosocomial infection

Date received: 16 August 2021; accepted: 21 January 2022

Introduction

Klebsiella pneumoniae (*K. pneumoniae*), as a common opportunistic pathogen, is a main cause of nosocomial infections, which affect the lung, bloodstream, and urinary tract.[1] *K. pneumoniae* is second only to *Escherichia coli* for the highest detection rate among Gram-negative bacteria in China.[2] *E. coli* was the most isolated bacterium from blood and urine samples in major hospitals in China during 2018, and showed serious drug resistance,[3] while that of *K. pneumoniae* is also increasing in severity.

Hu et al.[3] found that the resistance rates of *K. pneumoniae* to imipenem and meropenem increased more than eight-fold from 2005 to 2018 (from 3.0%–25% and from 2.9%–26.3%, respectively), while those to ceftazidime and ciprofloxacin increased from 19.7% to 21.7% and from 17.3% to 22.4%, respectively, from 2014 to 2019.[2] The resistance mechanism of *K. pneumoniae* mainly includes the production of β-lactamase, the lack of membrane porin proteins, and the active efflux of antibacterial drugs. Extended-spectrum β-lactamase (ESBL)-producing *K. pneumoniae* has a high degree of drug resistance, which can simultaneously present with multiple resistance mechanisms, often resulting in multidrug resistance.[4]

Carbapenem antibiotics are commonly used in the clinic for the ESBL-producing *K. pneumoniae*. However, their overuse has led to significant increases in *K. pneumoniae* resistance rates in recent years. For example, the China Antimicrobial Resistance Surveillance Network (CHINET) showed that the resistance rate of *K. pneumoniae* to carbapenems was over 20% in 2018.[3] Carbapenem-resistant *K. pneumoniae* (CRKP) causes nosocomial infections with high morbidity, high mortality, and requiring extensive hospital stays; this has become a global problem with a high socioeconomic burden.[5] To understand the prevalence of *K. pneumoniae* infection in Hangzhou, China, and to provide a basis for clinical treatment and nosocomial infection control, this retrospective study investigated and analyzed the prevalence and resistance trends of *K. pneumoniae* in Hangzhou Xixi Hospital Affiliated to Zhejiang Chinese Medical University from 2006 to 2020, which specializes in treating liver disease and AIDS.

Materials and methods

Specimen sources

A total of 3054 routine clinical specimens, including sputum, urine, and blood, were taken from patients infected with *K. pneumoniae* who had been admitted to different wards of Hangzhou Xixi Hospital Affiliated to Zhejiang Chinese Medical University, a tertiary infectious diseases hospital, from 2006 to 2020. Informed consent was not required because the samples were obtained for a previous study. Patients were divided into two groups: the older group ($\geq$65 years old, n = 1196), and the younger group (<65 years old, n = 1858). Strains of *K. pneumoniae* were isolated from the samples using standard microbiology laboratory

procedures, and identified using the VITEK 2 compact system (bioMérieux, Craponne, France). Duplicate strains, defined as the same bacterial species from the same specimen source from the same patient, were excluded from analysis. This study was approved by the local medical ethics committee of Hangzhou Xixi Hospital.

Antimicrobial susceptibility testing

Antimicrobial susceptibility testing with the VITEK 2 compact system was performed using the VITEK 2 AST-GN13 card (bioMérieux). Based on the suggested groupings of antimicrobial agents that should be considered for testing and reporting on non-fastidious organisms by the Clinical and Laboratory Standards Institute (CLSI)[6], we selected group A antibiotics for analysis. This included antimicrobial agents considered appropriate for inclusion in a routine, primary testing panel, as well as for the routine reporting of results for the specific organism group. Ultimately, we assessed resistance to seven antibiotics: imipenem, cefazolin, gentamicin, tobramycin, ciprofloxacin, piperacillin–tazobactam, and ceftazidime. *E. coli* ATCC 25922 was used as a quality control.

Statistical analyses

Statistical analysis was performed with WHONET5.6[7] and IBM SPSS Statistics for Windows, Version 25.0 (IBM Corp., Armonk, NY, USA). Categorical variables were described as counts and percentages, and compared using the chi-square test (χ^2). P-values <0.05 were considered statistically significant.

Results

Distribution of K. pneumoniae

A total of 71,743 *K. pneumoniae* isolates were collected from clinical specimens between 2006–2020. Annual isolate numbers ranged from 55 to 1316. The largest number of isolates was detected in 2017 (n = 1316), and the detection rate peaked in 2020, accounting for up to 32.30% of the total isolates (Figure 1).

Characteristics of K. pneumoniae

Between 2008 and 2020, detection rates of *K. pneumoniae* were 9.72%, 12.52%, and 16.45% in the AIDS ward, hepatology ward, and intensive care unit (ICU),

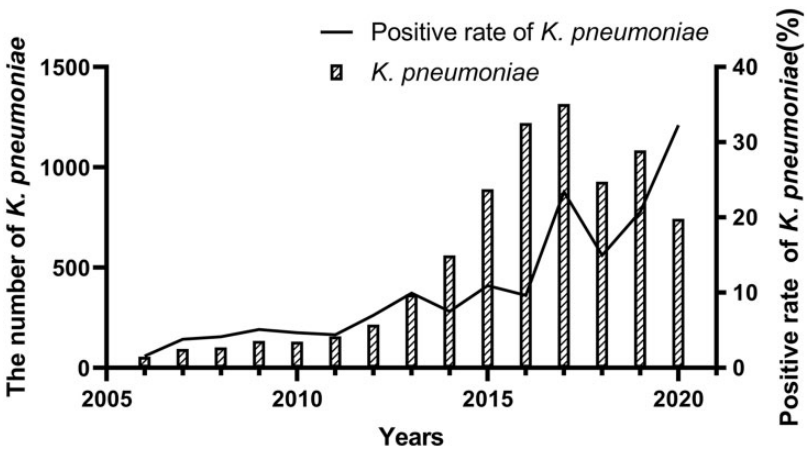

Figure 1. The number and positive rate of *K. pneumoniae* infections from 2006 to 2020.

respectively, and 61.31% in other wards. There was no detailed division of wards in 2006 to 2007, so this analysis was excluded. Figure 2 shows that the numbers of *K. pneumoniae* detected in the ICU and AIDS ward increased over time, especially in the ICU between 2015 and 2017, while numbers in the hepatology ward remained relatively stable.

K. pneumoniae strains were mostly isolated from sputum (53.77%) and urine (14.70%). Strains were also isolated from blood (8.42%), pus (7.89%), ascites (2.69%), bile (2.10%), and other specimens (10.45%). The proportion of *K. pneumoniae* isolated from sputum was consistently highest. The number of *K. pneumoniae* isolated from urine, but not blood, increased over time. *K. pneumoniae* isolated from bile and ascites occupied a relatively small percentage of the total bacterial population (Figure 3).

Antibiotic resistance of K. pneumoniae

K. pneumoniae resistance rates to six of the antibiotics increased in varying degrees from 2006 to 2020, while that to piperacillin–tazobactam was relatively stable (Figure 4). Increases in resistance rates were significant for imipenem (which increased from 2.33% to 12.83% from 2006–2020; $P < 0.05$), and ciprofloxacin (which increased from 18.60% to 44.61% from 2006–2020; $P < 0.05$). Resistance rates were not significantly different for the other five antibiotics (Table 1).

Considering resistance trends of *K. pneumoniae* isolated from blood, sputum, and urine samples, we detected the highest resistance rate to cefazolin, regardless of the specimen analyzed (Figure 5). *K. pneumoniae* resistance rates to different antibiotics were then compared between different sample types. Only cefazolin and ciprofloxacin resistance rates showed significant differences between blood and sputum specimens ($P < 0.05$; Figure 6). Significant differences in the resistance rates of all seven antibiotics were identified between blood and urine specimens and between sputum and urine specimens ($P < 0.05$; Figure 6).

Isolated CRKP were then compared with respect to specimen type, patient age, and hospital ward. The detection rate of CRKP in older patients (15.55%) was significantly higher than in younger patients

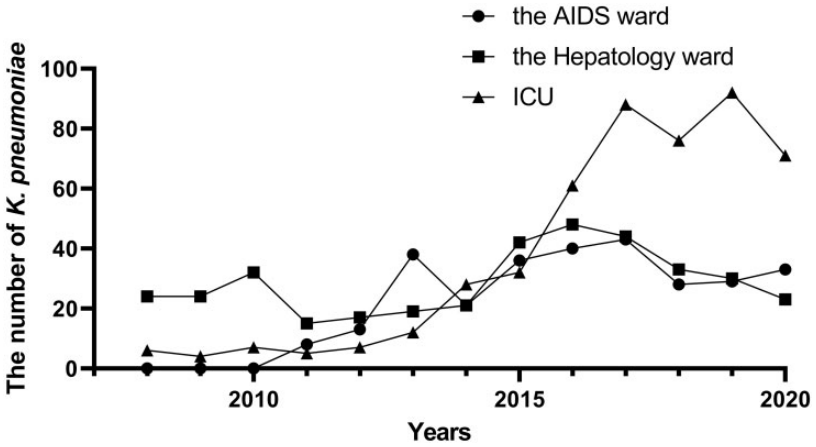

Figure 2. The number of *K. pneumoniae* infections in different hospital wards. Because there was no detailed division of wards in 2006–2007, this analysis was not included.

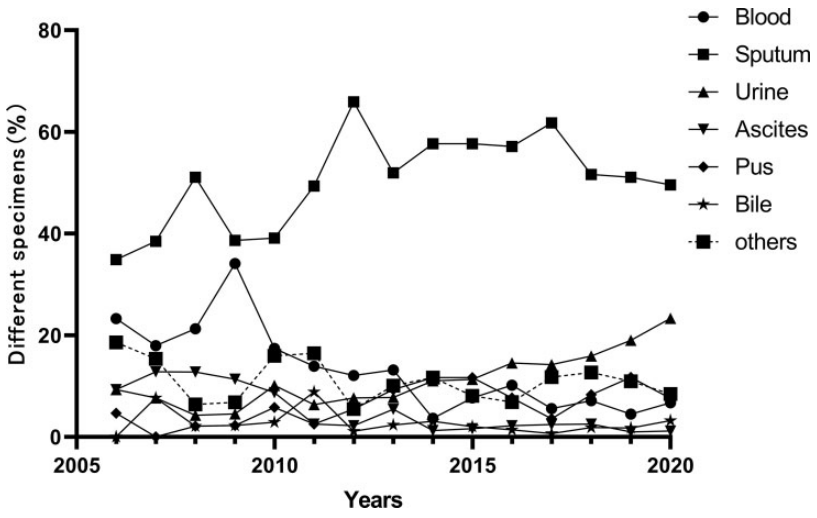

Figure 3. Percentage of different specimens with positive *K. pneumoniae* isolates from 2006 to 2020.

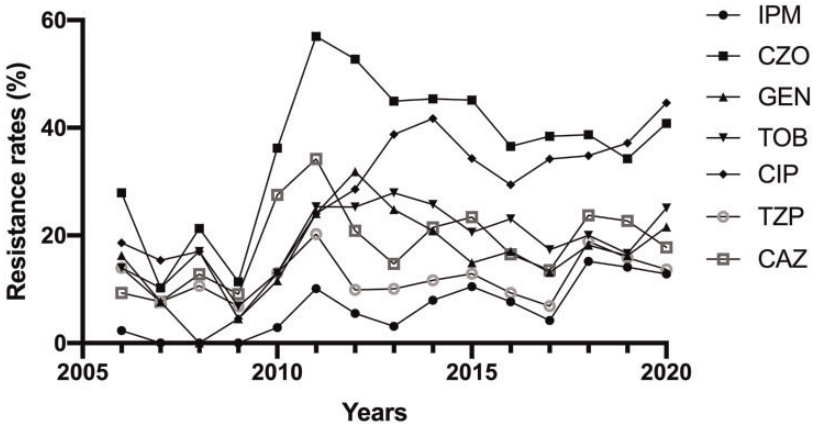

Figure 4. Resistance rates of *K. pneumoniae* to different antibiotics from 2006 to 2020
IPM, imipenem; CZO, cefazolin; GEN, gentamicin; TOB, tobramycin; CIP, ciprofloxacin; TZP, piperacillin–tazobactam; CAZ, ceftazidime.

(5.49%) ($P < 0.05$). Detection rates of CRKP among blood (8.17%), sputum (9.56%), and urine (13.36%) specimens were also significant ($P < 0.05$). Similarly, data analyzed from 2011 to 2020 showed that CRKP detection rates differed significantly among the hepatology ward (1.37%), ICU (21.19%), and AIDS ward (5.88%) (Table 2).

Discussion

As an important conditional pathogen of hospitals, *K. pneumoniae* can cause multiple systemic infections such as pneumonia, urinary tract infections, and bloodstream infections.[1] *K. pneumoniae* is the second most common pathogen of nosocomial infections in China.[3] This study analyzed

Table 1. Comparison of K. pneumoniae drug resistance.

Antibiotic	Resistance rate in 2006 (%)	Resistance rate in 2020 (%)
IPM	2.33 (1/43)	12.83 (44/343)*
CZO	27.91 (12/43)	40.82 (140/343)
GEN	16.28 (7/43)	21.57 (74/343)
TOB	13.95 (6/43)	20.07 (86/343)
CIP	18.60 (8/43)	44.61 (153/343)*
TZP	13.95 (6/43)	13.70 (47/343)
CAZ	9.30 (4/43)	17.78 (61/343)

*$P < 0.05$. IPM, imipenem; CZO, cefazolin; GEN, gentamicin; TOB, tobramycin; CIP, ciprofloxacin; TZP, piperacillin–tazobactam; CAZ, ceftazidime.

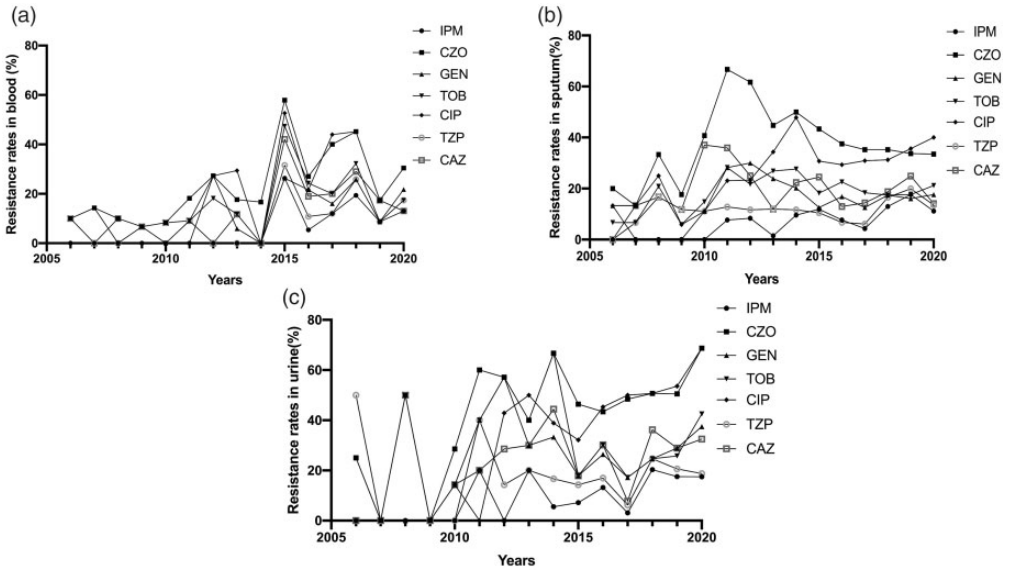

Figure 5. Resistance of *K. pneumoniae* to different antibiotics among specimens.
IPM, imipenem; CZO, cefazolin; GEN, gentamicin; TOB, tobramycin; CIP, ciprofloxacin; TZP, piperacillin–tazobactam; CAZ, ceftazidime.

data from Hangzhou Xixi Hospital Affiliated to Zhejiang Chinese Medical University, a tertiary that takes site-directed admissions of infectious disease cases in Zhejiang Province, China. Between 2006 and 2020, the isolation rate of *K. pneumoniae* has progressively grown from 1.57% to 32.30%, and now exceeds the national average. This suggests that *K. pneumoniae* is becoming increasingly widespread and dominating in this area.[2,8]

The treatment of AIDS and liver disease is a feature of our hospital, and ICU patients are prone to opportunistic infections because they are immunocompromised. Accordingly, we observed the highest detection rate of *K. pneumoniae* in the ICU; the rate increased rapidly between 2015 and 2017, and remained at a high level since then. A moderate increase was observed in the AIDS ward, while the rate was relatively stable in the hepatology

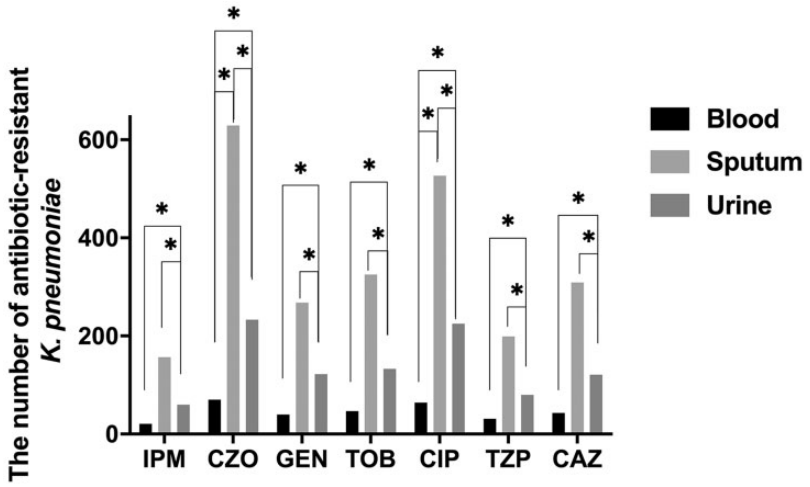

Figure 6. The number of antibiotic-resistant *K. pneumoniae* among different specimens. *$P < 0.05$. IPM, imipenem; CZO, cefazolin; GEN, gentamicin; TOB, tobramycin; CIP, ciprofloxacin; TZP, piperacillin–tazobactam; CAZ, ceftazidime.

Table 2. CRKP analysis between 2006 and 2020.

Characteristic	Total *K. pneumoniae* cases, n (%)	CRKP cases, n (positivity %)	*P*-value
Patient age (years)			
≥65	1196 (39.16%)	186 (15.55%)	<0.05
<65	1858 (60.84%)	102 (5.49%)	
Specimen			
Blood	257 (8.42%)	21 (8.17%)	<0.05
Sputum	1642 (53.77%)	157 (9.56%)	
Urine	449 (14.70%)	60 (13.36%)	
Ward			
Hepatology ward	292 (10.38%)†	4 (1.37%)	<0.05
ICU	472 (16.79%)†	100 (21.19%)	
AIDS ward	289 (10.28%)†	17 (5.88%)	

†Data from 2011 to 2020.

ward. A possible explanation for this is that the ICU primarily admits patients with severe disease, including critically ill patients with infections and those with multiple diseases. Moreover, cross-infection can occur through a variety of channels, including treatment devices and equipment. Conversely, patients in the AIDS and hepatology wards have usually received some treatment and developed a level of immunity. Patients in the ICU may also be at a higher risk of developing ventilator-associated pneumonia (VAP) because invasive mechanical ventilation damages the respiratory tract's local mucosal barrier. Indeed, in Taiwan, Thailand, and Singapore, *K. pneumoniae* is one of the most prevalent bacteria causing hospital-acquired pneumonia and VAP.[9,10] We recommend that increased attention be

paid to the management of hospital departments to prevent and control the spread and cross-infection of *K. pneumoniae*.

With respect to *K. pneumoniae* detection among different specimens, we observed the highest rate in sputum samples, followed by samples of urine and blood, which is consistent with nationwide findings in China.[3] This suggests that *K. pneumoniae* is one of the main pathogenic bacteria of respiratory tract infections, which should be taken into account during diagnosis. Several studies have analyzed *K. pneumoniae* isolated from blood or urine specimens.[11–14] Zanichelli et al. showed that the isolation frequency of *K. pneumoniae* from urine samples in Switzerland between 2009 and 2016 was secondary only to that of *E. coli*, and the drug resistance trend was increasingly serious, which was consistent with the findings of Ding et al. in Chongqing, China. Most pathogens associated with urinary tract infections were previously shown to be Enterobacteriaceae, while 5% to 10% were *K. pneumoniae*.[15,16] Moreover, *K. pneumoniae* was reported to be the second most prevalent Gram-negative bacilli pathogen of bacteremia in hospitals and communities, after *E. coli*, and to have a high mortality rate.[17]

Increasing resistance rates of *K. pneumoniae* to imipenem, resulting in CRKP, pose a huge challenge to clinical treatment. In our study, CRKP detection rates were highest in the ICU, which is consistent with previous findings.[5] The main risk factors of CRKP infection were reported to be sputum suction[18] and admission to the ICU.[19,20] We observed significant differences in the resistance rates of *K. pneumoniae* to seven antibiotics among blood, urine, and sputum specimens, indicating that different antibiotic treatment schemes should be adopted for patients with different infection sites.

CHINET data from 2018 revealed increased resistance rates of *K. pneumoniae* to imipenem and meropenem,3 while the resistance rate of *K. pneumoniae* to carbapenem similarly increased from 2% to 12% in Singapore,[21] and showed steady increases in Vietnam, Thailand, Malaysia, the Philippines, and Italy.[22,23] As one of the most important treatments for ESBL-producing bacteria, carbapenem antibiotics are widely used to treat serious infections.[22,24] However, the overuse of antibiotics has increased the spread of CRKP, and even resulted in the emergence of extensively drug-resistant bacteria, which has caused challenges for clinical treatment.[11]

Carbapenemase production is the main cause of *K. pneumoniae* resistance to carbapenems. The first *K. pneumoniae* carbapenemase-1-producing *K. pneumoniae* strain was reported in the USA in 2001 by Yigit et al.[25] It caused CRKP nosocomial outbreaks in many countries and regions because of the easy transmission of genes encoding KPC-1 enzymes.[26–29] In China, the first KPC-2-producing *K. pneumoniae* was reported in Zhejiang Province in 2007;[30] KPC-2 strains are currently the most common isolates in the clinic.[5,31]

The present study has some limitations. Because of its long time span, the antibiotics used for susceptibility testing at the start of the study differed from those used more recently. Accordingly, we did not analyze the resistance of *K. pneumoniae* to all antibiotics, but only seven. Additionally, this was a single-center study of *K. pneumoniae* drug resistance trends, which does not necessarily reflect the entire region. Future work will analyze the underlying molecular biology of the CRKP resistance mechanism identified here.

Conclusion

We observed a significant increase in the *K. pneumoniae* detection rate at our hospital between 2006 and 2020, particularly in the ICU. We also detected significant

differences in *K. pneumoniae* resistance to seven antibiotics among different types of specimens. Although the detection rates of CRKP observed in this study were lower than those reported by CHINET, the rising trend is still of concern. We suggest that increased efforts should focus on the prevention and control of hospital infections, and the management of antimicrobial clinical applications to maximize bacterial resistance surveillance.

Acknowledgement

We are grateful to Shibo Liu for proofreading the article.

Ethical approval

This study was approved by the local medical ethics committee of Hangzhou Xixi Hospital.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the Science and Technology Project from the Health Commission of Zhejiang Province of the People's Republic of China [2015KYB321].

ORCID iDs

Zhezhe Lin https://orcid.org/0000-0001-9816-0835

Shourong Liu https://orcid.org/0000-0002-8813-2555

References

1. Martin RM and Bachman MA. Colonization, infection, and the accessory genome of Klebsiella pneumoniae. *Front Cell Infect Microbiol* 2018; 8: 4.
2. China Antimicrobial Resistance Surveillance System. Antimicrobial resistance of bacteria: surveillance report from China Antimicrobial Resistance Surveillance System in 2014–2019. *Chin J Infect Control* 2021; 20: 15–31. (in Chinese).
3. Hu F, Guo Y, Yang Y, et al. Resistance reported from China antimicrobial surveillance network (CHINET) in 2018. *Eur J Clin Microbiol Infect Dis* 2019; 38: 2275–2281.
4. Chong Y, Shimoda S and Shimono N. Current epidemiology, genetic evolution and clinical impact of extended-spectrum β-lactamase-producing Escherichia coli and Klebsiella pneumoniae. *Infect Genet Evol* 2018; 61: 185–188.
5. Hu Y, Liu C, Shen Z, et al. Prevalence, risk factors and molecular epidemiology of carbapenem-resistant Klebsiella pneumoniae in patients from Zhejiang, China, 2008–2018. *Emerg Microbes Infect* 2020; 9: 1771–1779.
6. Clinical and Laboratory Standards Institute. Performance Standards for Antimicrobial Susceptibility Testing; 29th ed. *CLSI supplement M100*. Wayne PA: Clinical and Laboratory Standards Institute, 2019.
7. WHONET 5.6 software. Available at: https://whonet.org/software.html (Accessed 15 February 2022).
8. Hu FP, Guo Y, Zhu DM, et al. Resistance trends among clinical isolates in China reported from CHINET surveillance of bacterial resistance, 2005-2014. *Clin Microbiol Infect* 2016; 22 Suppl 1: S9–14.
9. Chou CC, Shen CF, Chen SJ, et al. Recommendations and guidelines for the treatment of pneumonia in Taiwan. *J Microbiol Immunol Infect* 2019; 52: 172–199.
10. Chung DR, Song JH, Kim SH, et al. High prevalence of multidrug-resistant nonfermenters in hospital-acquired pneumonia in Asia. *Am J Respir Crit Care Med* 2011; 184: 1409–1417.
11. Zhang H, Zhang G, Yang Y, et al. Antimicrobial resistance comparison of Klebsiella pneumoniae pathogens isolated from intra-abdominal and urinary tract infections in different organs, hospital departments and regions of China between 2014 and 2017. *J Microbiol Immunol Infect* 2020; 54: 639–648.

12. Zanichelli V, Huttner A, Harbarth S, et al. Antimicrobial resistance trends in Escherichia coli, Klebsiella pneumoniae and Proteus mirabilis urinary isolates from Switzerland: retrospective analysis of data from a national surveillance network over an 8-year period (2009-2016). *Swiss Med Wkly* 2019; 149: w20110.
13. Ding Y, Wang H, Pu S, et al. Resistance trends of Klebsiella pneumoniae causing urinary tract infections in Chongqing, 2011-2019. *Infect Drug Resist* 2021; 14: 475–481.
14. Gavriliu LC, Benea OE and Benea S. Antimicrobial resistance temporal trend of Klebsiella pneumoniae isolated from blood. *J Med Life* 2016; 9: 419–423.
15. van Driel AA, Notermans DW, Meima A, et al. Antibiotic resistance of Escherichia coli isolated from uncomplicated UTI in general practice patients over a 10-year period. *Eur J Clin Microbiol Infect Dis* 2019; 38: 2151–2158.
16. Sokhn ES, Salami A, El Roz A, et al. Antimicrobial susceptibilities and laboratory profiles of Escherichia coli, Klebsiella pneumoniae, and Proteus mirabilis isolates as agents of urinary tract infection in Lebanon: paving the way for better diagnostics. *Med Sci (Basel)* 2020; 8: 32.
17. Li B, Zhao Y, Liu C, et al. Molecular pathogenesis of Klebsiella pneumoniae. *Future Microbiol* 2014; 9: 1071–1081.
18. Zheng B, Dai Y, Liu Y, et al. Molecular epidemiology and risk factors of carbapenem-resistant Klebsiella pneumoniae infections in eastern China. *Front Microbiol* 2017; 8: 1061.
19. Saidel-Odes L and Borer A. Limiting and controlling carbapenem-resistant Klebsiella pneumoniae. *Infect Drug Resist* 2013; 7: 9–14.
20. Wang Z, Qin RR, Huang L, et al. Risk factors for carbapenem-resistant Klebsiella pneumoniae infection and mortality of Klebsiella pneumoniae infection. *Chin Med J (Engl)* 2018; 131: 56–62.
21. Teo JQ, Cai Y, Lim TP, et al. Carbapenem resistance in Gram-negative bacteria: the not-so-little problem in the little red dot. *Microorganisms* 2016; 4: 13.
22. Hsu LY, Apisarnthanarak A, Khan E, et al. Carbapenem-resistant Acinetobacter baumannii and Enterobacteriaceae in south and southeast Asia. *Clin Microbiol Rev* 2017; 30: 1–22.
23. Hoxha A, Kärki T, Giambi C, et al. Attributable mortality of carbapenem-resistant Klebsiella pneumoniae infections in a prospective matched cohort study in Italy, 2012-2013. *J Hosp Infect* 2016; 92: 61–66.
24. Li J, Zou M, Dou Q, et al. Characterization of clinical extensively drug-resistant Pseudomonas aeruginosa in the Hunan province of China. *Ann Clin Microbiol Antimicrob* 2016; 15: 35.
25. Yigit H, Queenan AM, Anderson GJ, et al. Novel carbapenem-hydrolyzing beta-lactamase, KPC-1, from a carbapenem-resistant strain of Klebsiella pneumoniae. *Antimicrob Agents Chemother* 2001; 45: 1151–1161.
26. Aires-de-Sousa M, Ortiz de la Rosa JM, Gonçalves ML, et al. Epidemiology of carbapenemase-producing Klebsiella pneumoniae in a hospital, Portugal. *Emerg Infect Dis* 2019; 25: 1632–1638.
27. Gu D, Dong N, Zheng Z, et al. A fatal outbreak of ST11 carbapenem-resistant hypervirulent Klebsiella pneumoniae in a Chinese hospital: a molecular epidemiological study. *Lancet Infect Dis* 2018; 18: 37–46.
28. Lau MY, Teng FE, Chua KH, et al. Molecular characterization of carbapenem resistant Klebsiella pneumoniae in Malaysia hospital. *Pathogens* 2021; 10: 279.
29. Migliorini LB, de Sales RO, Koga PCM, et al. Prevalence of bla(KPC-2), bla(KPC-3) and bla(KPC-30)-carrying plasmids in Klebsiella pneumoniae isolated in a Brazilian hospital. *Pathogens* 2021; 10: 332.
30. Wei ZQ, Du XX, Yu YS, et al. Plasmid-mediated KPC-2 in a Klebsiella pneumoniae isolate from China. *Antimicrob Agents Chemother* 2007; 51: 763–765.
31. Qin X, Wu S, Hao M, et al. The colonization of carbapenem-resistant Klebsiella pneumoniae: epidemiology, resistance mechanisms, and risk factors in patients admitted to intensive care units in China. *J Infect Dis* 2020; 221: S206–s214.