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ORIGINAL RESEARCH

The Analysis of Drug-Resistant Bacteria from Different Regions of Anhui in 2021

Yanyan Liu[1–3,*], Wei Wang[1,*], Mingjuan Guo[4,*], Zhicheng Xu[1], Yi Yang[1–3], Liang Yu[1–3], Yasheng Li[1–3], Lifen Hu[1–3], Ying Ye[1–3], Jiabin Li[1–4]

[1]Department of Infectious Diseases, The First Affiliated Hospital of Anhui Medical University, Hefei, People's Republic of China; [2]Anhui Center for Surveillance of Bacterial Resistance, Health Commission of Anhui Province, Hefei, People's Republic of China; [3]Institute of Bacterial Resistance, Anhui Medical University, Hefei, Anhui, People's Republic of China; [4]Department of Infectious Diseases, The Chaohu Affiliated Hospital of Anhui Medical University, Hefei, People's Republic of China

*These authors contributed equally to this work

Correspondence: Jiabin Li; Ying Ye, Department of Infectious Diseases, The First Affiliated Hospital of Anhui Medical University, Jixi Road no. 218, Hefei, 230022, People's Republic of China, Tel +86-551-2922713, Fax +86-551-2922281, Email lijiabin@ahmu.edu.cn; yeying2@163.com

Purpose: To analyze the differences in clinical distribution and antimicrobial resistance of pathogens among northern Anhui, central Anhui, and southern Anhui in 2021, and to provide a basis for the rational use of drugs for clinicians in different regions.

Methods: Nonrepetitive pathogens isolated from clinical samples of inpatients and outpatients from 59 member units with qualified data in 2021 were obtained from the Anhui Province Antimicrobial Resistance Surveillance System, which was divided into northern Anhui, central Anhui, and southern Anhui by region. Identification and antimicrobial susceptibility analyses were carried out using the Vitek 2 Compact and standard disc diffusion method. The results were determined according to the American Clinical Laboratory Standards Institute in 2021 with data analyzed using WHONET 5.6 and SPSS 17.0.

Results: A total of 133,268 pathogenic bacteria were isolated from clinical samples. *Staphylococcus aureus* (*S. aureus*) was the most common gram-positive bacterium and *Escherichia coli* (*E. coli*) was the most common gram-negative bacterium. Sputum was the main source of clinical specimens. The detection rates of methicillin-resistant *S.aureus*, methicillin-resistant coagulase-negative *Staphylococcus*, carbapenem-resistant *E. coli*, carbapenem-resistant *Klebsiella pneumonia*e (*K. pneumonia*e), carbapenem-resistant *Acinetobacter baumannii*, third-generation cephalosporin-resistant *E. coli*, and third-generation cephalosporin-resistant *K. pneumonia*e were higher in northern Anhui than in southern Anhui ($P<0.0001$). *E. coli, K. pneumonia*e, and *Pseudomonas aeruginosa* were sensitive to amikacin. Strains resistant to vancomycin, linezolid, and teicoplanin were not isolated until 2021.

Conclusion: There were significant differences in bacterial resistance in different regions of Anhui Province. Antibiotic resistance in northern Anhui was the most serious in 2021. Antimicrobial agents must be used according to the resistance of the bacteria in the local region.

Keywords: pathogens, antibacterial agents, drug resistance, different regions

Introduction

Bacterial drug resistance has become a major public health concern worldwide. Many infectious agents have acquired resistance to most, and in some cases, all of these Drugs.[1] Under the influence of different time and regional factors, there are obvious differences in the distribution of pathogens and the drug resistance spectrum, especially in the distribution of special drug-resistant bacteria,[2] including methicillin-resistant *Staphylococcus aureus* (MRSA), methicillin-resistant coagulase-negative *Staphylococcus* (MRCNS), vancomycin-resistant *Enterococcus faecalis* (VREA), vancomycin-resistant *Enterococcus faecium* (VREM), third-generation cephalosporin-resistant *Escherichia coli* (CTX/CRO-R ECO), third-generation cephalosporin-resistant *Klebsiella pneumoniae* (CTX/CRO-R KPN), carbapenem-resistant *Escherichia coli* (CR-ECO), carbapenem-resistant *Klebsiella pneumoniae* (CR-KPN), carbapenem-resistant *Pseudomonas aeruginosa* (CR-PAE), and *carbapenem-resistant Acinetobacter baumannii* (CR-ABA). However, there were few reports on distribution of special drug-resistant bacteria in

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different areas of Anhui Province. The aim of this study was to analyze the data on bacterial drug resistance in northern Anhui, central Anhui, and southern Anhui in 2021, to understand the distribution and drug resistance differences of clinically isolated pathogens and special drug-resistant bacteria in the three areas, to provide an effective reference for administrative departments in different areas, and to make relevant policies and for clinicians to make reasonable diagnoses and treatments.

Materials and Methods

Data Sources

All data were obtained from 59 member units of the Anhui Province Bacterial Resistance Surveillance Network (HuiNet) in 2021. According to the geographical location of the hospitals, they were divided into northern Anhui (Fuyang, Bozhou, Bengbu, Suzhou, Huaibei), central Anhui (Hefei, Chuzhou, Lu'an, Huainan), and southern Anhui (Anqing, Wuhu, Tongling, Huangshan, Chizhou, Xuancheng, Ma 'anshan). After the review, the number of hospitals in northern Anhui, central Anhui, and southern Anhui were 18, 24, and 17, respectively.

Bacterial Identification and Drug Susceptibility Test

Bacteria were identified using manual or automated testing instruments. The duplicate strains were excluded according to the principle of retaining the first strain of the same bacteria in the same patient. Antimicrobial susceptibility tests were performed using the disc diffusion, automated instrument, and broth dilution methods. Antimicrobial varieties were determined according to the monitoring technology scheme of the China Antimicrobial Resistance Surveillance System (CARSS, http://www.carss.cn/). The susceptibility test results were interpreted according to the American Clinical Laboratory Standards Institute (CLSI) in 2021.[3] The detection rates of 10 special drug-resistant bacteria in different areas were analyzed, including MRSA, MRCNS, VREA, VREM, CTX/CRO-R ECO, CTX/CRO-R KPN, CR-ECO, CR-KPN, CR-PAE, and CR-ABA.

Statistical Analysis

Data were analyzed using WHONET 5.6 software and SPSS version 17.0. Qualitative data were described by frequency. Univariate analysis was performed using the chi-square test or Fisher's exact test when appropriate. P-values were based on two-tailed test results, and P-values <0.05 were considered statistically significant.

Ethics

This study is conducted on already available data from HuiNet. Ethical approval was approved by the Ethics Committee of the First Affiliated Hospital of Anhui Medical University (Number: Quick-PJ 2022-12-26). The ethics committee approved the waiver of informed consent. The research data accessed were de-identified and anonymously analyzed. The study was conducted according to the Declaration of Helsinki.

Results

Number of Bacteria

The total number of bacteria analyzed in 2021 was 133,268. In total, 39,315 strains were analyzed from northern Anhui, among which the proportion of gram-positive bacteria was 26.2%, and that of gram-negative bacteria was 73.8%. A total of 54,783 strains were analyzed in central Anhui, among which the proportion of gram-positive bacteria was 27.2% and that of gram-negative bacteria was 72.8%. Of the 39,170 strains analyzed from southern Anhui, the proportion of gram-positive bacteria was 24.4% and that of gram-negative bacteria was 75.6%.

Composition Ratio of Strains

Staphylococcus aureus (*S. aureus*) was the most common gram-positive bacterium in 2021, with 33.2% in northern Anhui, 33.4% in central Anhui, and 32.5% in southern Anhui. There was no significant difference about the detection rate of *S. aureus* among the three regions (χ^2=2.281, P=0.32) (Table 1). *Staphylococcus epidermidis* (*S. epidermidis*) was the second most common gram-positive bacterium, with 15.6% in northern Anhui, 12.8% in central Anhui, and 13.4% in

Table 1 The Composition of Pathogenic Bacteria in Different Areas of Anhui Province in 2021

Bacteria	Northern Anhui		Center Anhui		Southern Anhui		χ^2	*P*
	Isolates	%	Isolates	%	Isolates	%		
Gram-positive bacteria	10,307		14,875		9554			
Staphylococcus aureus	3424	33.2	4962	33.4	3101	32.5	2.281	0.32
Staphylococcus epidermidis	1605[a]	15.6	1906	12.8	1276[c]	13.4	40.998	<0.0001
Staphylococcus hominis	912[a]	8.8	1105[b]	7.4	606[c]	6.3	45.144	<0.0001
Enterococcus faecium	910[a]	8.8	1444[b]	9.7	1011[c]	10.6	17.427	<0.0001
Enterococcus faecalis	798[a]	7.7	1683	11.3	1038[c]	10.9	93.118	<0.0001
Gram-negative bacteria	29,008		39,908		29,616			
Escherichia coli	8848	30.5	12,126	30.4	9096	30.7	0.869	0.648
Klebsiella pneumoniae	6158[a]	21.2	7998[b]	20	6620[c]	22.4	55.103	<0.0001
Pseudomonas aeruginosa	4115	14.2	5685[b]	14.2	3992[c]	13.5	9.498	0.009
Acinetobacter baumannii	2460[a]	8.5	3831[b]	9.6	2611	8.8	28.06	<0.0001
Enterobacter cloacae	937[a]	3.2	1622	4.1	1293[c]	4.4	54.607	<0.0001

Notes: [a]The statistical difference between northern Anhui and central Anhui; [b]The statistical difference between central Anhui and southern Anhui; [c]The statistical difference between southern Anhui and northern Anhui.

southern Anhui. There was a significant difference about the detection rate of *S. epidermidis* among the three regions (χ^2=40.998, *P*<0.0001) (Table 1). *Staphylococcus hominis* (*S. hominis*) was the third most common gram-positive bacterium, with 8.8% in northern Anhui, 7.4% in central Anhui, and 6.3% in southern Anhui. There was a significant difference about the detection rate of *S. hominis* among the three regions (χ^2=45.144, *P*<0.0001) (Table 1). *Enterococcus faecium* (*E. faecium*) was the fourth most common gram-positive bacterium, with 8.8% in northern Anhui, 9.7% in central Anhui, and 10.6% in southern Anhui. There was a significant difference about the detection rate of *E. faecium* among the three regions (χ^2=17.427, *P*<0.0001) (Table 1). *Enterococcus faecalis* (*E. faecalis*) was the fifth most common gram-positive bacterium, with 7.7% in northern Anhui, 11.3% in central Anhui, and 10.9% in southern Anhui, with a significant difference about the detection rate of *E. faecalis* among the three regions (χ^2=93.118, *P*<0.0001) (Table 1).

Escherichia coli (*E. coli*) was the most common gram-negative bacterium in 2021, with 30.5% in northern Anhui, 30.4% in central Anhui, and 30.7% in southern Anhui. There was no significant difference about the detection rate of *E. coli* among the three regions (χ^2=0.869, *P*=0.648) (Table 1). *Klebsiella pneumoniae* (*K. pneumoniae*) was the second most common gram-negative bacterium, with 21.2% in northern Anhui, 20% in central Anhui, and 22.4% in southern Anhui. There was a significant difference about the detection rate of *K. pneumoniae* among the three regions (χ^2=55.103, *P*<0.0001) (Table 1). *Pseudomonas aeruginosa* (*P. aeruginosa*) was the third most common gram-negative bacterium, with 14.2% in northern Anhui, 14.2% in central Anhui, and 13.5% in southern Anhui. There was a significant difference about the detection rate of *P. aeruginosa* among the three regions (χ^2=9.498, *P*=0.009) (Table 1). *Acinetobacter baumannii* (*A. baumannii*) was the fourth most common gram-negative bacterium, with 8.5% in northern Anhui, 9.6% in central Anhui, and 8.8% in southern Anhui. There was a significant difference about the detection rate of *A. baumannii* among the three regions (χ^2=28.06, *P*<0.0001) (Table 1). *Enterobacter cloacae* (*E. cloacae*) was the fifth most common gram-negative bacterium, with 3.2% in northern Anhui, 4.1% in central Anhui, and 4.4% in southern Anhui. There was a significant difference about the detection rate of *E. cloacae* among the three regions (χ^2=54.607, *P*<0.0001) (Table 1).

Source of Bacterial Specimens

Sputum was the most common specimen source of bacteria in 2021, with 40.9% in northern Anhui, 37.1% in central Anhui, and 38.1% in southern Anhui. Urine was the second most common specimen source of bacteria, with 15.9% in northern Anhui, 21.5% in central Anhui, and 26.5% in southern Anhui. Blood was the third most common specimen source of bacteria, with 12.5% in northern Anhui, 11.8% in central Anhui, and 9.6% in southern Anhui. Pus was the fourth most common specimen source of bacteria, with 10.6% in northern Anhui, 7.2% in central Anhui, and 6.4% in southern Anhui. Ascites was the fifth most common gram-negative bacterium, with 2% in northern Anhui, 1.5% in

central Anhui, and 2.4% in southern Anhui. The proportion of sputum, blood and pus specimen in northern Anhui were higher than those in central and southern Anhui (χ^2=142.671, P<0.0001; χ^2=181.478, P<0.0001; χ^2=534.805, P<0.0001, respectively) (Table 2). The proportion of urine and ascites specimen in southern Anhui were higher than those in northern Anhui and central Anhui (χ^2=1300.016, P<0.0001; χ^2=98.44, P<0.0001, respectively) (Table 2).

Drug Susceptibility of Gram-Positive Bacteria

The resistance rates of penicillin (PEN), sulfamethoxazole (SMX), clindamycin (CLI), and erythromycin (ERY) among *S. aureus* in northern Anhui were 96%, 14.4%, 34.1%, and 64.2%, respectively, which were higher than those in central Anhui and southern Anhui (χ^2=43.84, P<0.0001; χ^2=162.44, P<0.0001; χ^2=166.10, P<0.0001; χ^2=235.47, P<0.0001, respectively) (Table 3). The resistance rate of gentamicin (GEN) among *S. aureus* in southern Anhui was 4.9%, which was lower than that in northern Anhui and central Anhui (χ^2=2588.077, P<0.0001) (Table 3). The resistance rates of PEN, SMX, CLI, and ERY among coagulase-negative *Staphylococcus* in northern Anhui were 92.8%, 45%, 34.6%, and 80.7%, respectively, which were higher than those in central Anhui and southern Anhui (χ^2=17.318, P<0.0001; χ^2=170.30, P<0.0001; χ^2=39.882, P<0.0001; χ^2=45.395, P<0.0001, respectively) (Table 3). The resistance rate of GEN among coagulase-negative *Staphylococcus* in southern Anhui was 18.5%, which was higher than that in northern Anhui and central Anhui (χ^2=19.554, P<0.0001) (Table 3).

The resistance rates of gentamicin-high (GEH) and levofloxacin (LVX) among *E. faecalis* in northern Anhui were 41.8% and 38.2%, respectively, which were higher than those in central Anhui and southern Anhui (χ^2=25.131, P<0.0001; χ^2=21.019, P<0.0001, respectively) (Table 4). The resistance rate of streptomycin-high (STH) among *E. faecalis* in central Anhui was 19.7%, which was lower than that in northern Anhui and southern Anhui (χ^2=11.884, P=0.003) (Table 4). The resistance rate of linezolid (LNZ) among *E. faecalis* in central Anhui was 2.5%, which was higher than that in northern Anhui and southern Anhui (χ^2=21.019, P<0.0001) (Table 4). The resistance rates of ampicillin (AMP) and STH among *E. faecium* in northern Anhui were 90.8% and 32.9%, respectively, which were higher than those in central Anhui and southern Anhui (χ^2=11.348, P=0.003; χ^2=19.158, P<0.0001, respectively) (Table 4). The resistance rate of rifampicin (RIF) among *E. faecium* in southern Anhui was 85.4%, which was higher than that in northern Anhui and central Anhui (χ^2=72.93, P<0.0001) (Table 4). The resistance rate of *E. faecium* to LVX in southern Anhui was 80.4%, which was lower than that in northern Anhui and central Anhui (χ^2=9.199, P=0.01) (Table 4).

Drug Susceptibility of Gram-Negative Bacteria

The resistance rates of amikacin (AMK), GEN, amoxicillin/clavulanic acid (AMC), ampicillin/sulbactam (SAM), piperacillin/tazobactam (TZP), cefuroxime (CXM), ceftriaxone (CRO), ceftazidime (CAZ), cefepime (FEP), cefoxitin (FOX), aztreonam (ATM), ciprofloxacin (CIP), LVX, and SMX among *E. coli* in northern Anhui were 5%, 44%, 17.5%,

Table 2 Constituent of Major Specimen Sourses of Bacteria in Different Areas of Anhui Province in 2021

Bacteria	Northern Anhui		Center Anhui		Southern Anhui		χ^2	P
	Isolates	%	Isolates	%	Isolates	%		
Sputum	16,079[a]	40.9	20,329[b]	37.1	14,930[c]	38.1	142.671	<0.0001
Urine	6262[a]	15.9	11,783[b]	21.5	10,365[c]	26.5	1300.016	<0.0001
Blood	4915[a]	12.5	6462[b]	11.8	3761[c]	9.6	181.478	<0.0001
Pus	4153[a]	10.6	3928[b]	7.2	2521[c]	6.4	534.805	<0.0001
Ascites	771[a]	2.0	830[b]	1.5	944[c]	2.4	98.440	<0.0001
Bile	699[a]	1.8	1093[b]	2.0	581[c]	1.5	34.219	<0.0001
Cerebrospinal fluid	307[a]	0.8	197[b]	0.4	88[c]	0.2	152.320	<0.0001
Pleural effusion	252[a]	0.6	254	0.5	188[c]	0.5	15.676	<0.0001
Bronchoalveolar fluid	224[a]	0.6	447[b]	0.8	75[c]	0.2	160.108	<0.0001
Faeces	126[a]	0.3	228[b]	0.4	61[c]	0.2	50.083	<0.0001

Notes: [a]The statistical difference between northern Anhui and central Anhui; [b]The statistical difference between central Anhui and southern Anhui; [c]The statistical difference between southern Anhui and northern Anhui.

Table 3 Resistance Rate of *Staphylococcus aureus* and *Coagulase-Negative Staphylococcus* in Different Regions of Anhui Province

Antibacterial Agents	*Staphylococcus aureus*						χ^2	*P*	*Coagulase-negative Staphylococcus*						χ^2	*P*
	Northern Anhui		Center Anhui		Southern Anhui				Northern Anhui		Center Anhui		Southern Anhui			
	Isolates	%	Isolates	%	Isolates	%			Isolates	%	Isolates	%	Isolates	%		
PEN	3287[a]	96	4369	93	2656[c]	92.2	43.84	<0.0001	3427[a]	92.8	4427[b]	91.5	2729[c]	89.8	17.318	<0.0001
GEN	3394	7.1	4953[b]	7.7	3082[c]	4.9	2588.077	<0.0001	3684[a]	14.6	4837[b]	16.8	3333[c]	18.5	19.554	<0.0001
RIF	3411[a]	1.2	4953[b]	2	3083[c]	1.4	743.321	<0.0001	3675	7.2	4826	6.8	3328	7.4	1.172	0.556
LVX	3282[a]	12.6	4622	14.6	2940	13.6	6.469	0.039	3468	46	4570[b]	44.3	3147	46.9	5.421	0.067
SMX	3406[a]	14.4	3889	7.2	2842[c]	6	162.441	<0.0001	3680[a]	45	3785[b]	35.6	3009[c]	29.8	170.308	<0.0001
CLI	3261[a]	34.1	4814[b]	24.7	3070[c]	20.3	166.109	<0.0001	3431[a]	34.6	4724[b]	28.1	3305[c]	30.3	39.882	<0.0001
ERY	3154[a]	64.2	4665[b]	52	3098[c]	45.2	235.471	<0.0001	3453[a]	80.7	4447[b]	76.6	3342[c]	73.9	45.395	<0.0001
LNZ	3287	0	4895	0	3077	0	NA		3433	0	4719	0.4	3277	0	NA	
VAN	3389	0	4912	0	2804	0	NA		3652	0	4815	0	3077	0	NA	
TEC	671	0	711	0	380	0	NA		352	0	354	0	469	0	NA	

Notes: [a]The statistical difference between northern Anhui and central Anhui; [b]The statistical difference between central Anhui and southern Anhui; [c]The statistical difference between southern Anhui and northern Anhui.
Abbreviations: PEN, penicillin; GEN, gentamicin; RIF, rifampicin; LVX, levofloxacin; SMX, sulfamethoxazole; CLI, clindamycin; ERY, erythromycin; LNZ, linezolid; VAN, vancomycin; TEC, teicoplanin.

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Table 4 Resistance Rate of *Enterococcus faecalis* and *Enterococcus faecium* in Different Regions of Anhui Province

Antibacterial Agents	*Enterococcus faecalis*						χ^2	*P*	*Enterococcus faecium*						χ^2	*P*
	Northern Anhui		Center Anhui		Southern Anhui				Northern Anhui		Center Anhui		Southern Anhui			
	Isolates	%	Isolates	%	Isolates	%			Isolates	%	Isolates	%	Isolates	%		
AMP	776	3.7	1487	3	910	4.2	2.321	0.313	882[a]	90.8	1302	86.9	859[c]	85.9	11.348	0.003
GEH	615[a]	41.8	1300[b]	30.2	529[c]	35.3	25.131	<0.0001	709[a]	54.7	1138[b]	42.4	603	49.8	27.636	<0.0001
STH	413[a]	26.9	970[b]	19.7	372	26.3	11.884	0.003	557[a]	32.9	882[b]	27.2	327[c]	19.3	19.158	<0.0001
RIF	202	54.8	178	58.4	315	55.6	0.538	0.764	258	53.8	136[b]	55.1	287[c]	85.4	72.93	<0.0001
CIP	556[a]	37.8	1363	32.7	564	34.6	4.496	0.106	714	86.3	1218[b]	87.3	483	82.6	6.314	0.043
LVX	777[a]	38.2	1563[b]	29	962[c]	33.7	21.019	<0.0001	873	85.6	1333[b]	83.6	989[c]	80.4	9.199	0.01
LNZ	583[a]	0.9	1489[b]	2.5	961	1.2	8.618	0.013	843	0.2	1380	0.4	980	0.4	0.646	0.724
VAN	794	0.4	1650	0.2	1007	0.2	0.857	0.651	890	0.9	1439	0.6	992	0.3	2.811	0.245
TEC	79	1.3	239	1.3	246	0.8	0.268	0.875	111	3.6	225	1.3	270	0.7	4.463	0.107

Notes: [a]The statistical difference between northern Anhui and central Anhui; [b]The statistical difference between central Anhui and southern Anhui; [c]The statistical difference between southern Anhui and northern Anhui.
Abbreviations: AMP, ampicillin; GEH, gentamicin-high; STH, streptomycin-high; RIF, rifampicin; CIP, ciprofloxacin; LVX, levofloxacin; LNZ, linezolid; VAN, vancomycin; TEC, teicoplanin.

57.7%, 5.9%, 62.7%, 60.8%, 29.5%, 30%, 14.1%, 43%, 62.3%, 56.6%, and 61.3%, respectively, which were higher than those in central Anhui and southern Anhui (χ^2=160.182, P<0.0001; χ^2=198.679, P<0.0001; χ^2=72.482, P<0.0001; χ^2=211.422, P<0.0001; χ^2=74.321, P<0.0001; χ^2=258.757, P<0.0001; χ^2=376.829, P<0.0001; χ^2=100.618, P<0.0001; χ^2=90.259, P<0.0001; χ^2=82.623, P<0.0001; χ^2=82.465, P<0.0001; χ^2=161.376, P<0.0001; χ^2=206.918, P<0.0001; χ^2=437.602, P<0.0001, respectively) (Table 5). The resistance rates of cefoperazone/sulbactam (CSL), cefotaxime (CTX), and imipenem (IPM) among *E. coli* in southern Anhui were 4.4%, 45.6% and 1.2%, respectively, which were lower than those in northern Anhui and central Anhui (χ^2=22.198, P<0.0001; χ^2=51.674, P<0.0001; χ^2=32.652, P<0.0001, respectively) (Table 5).

The resistance rates of AMK, GEN, CRO, FOX, LVX, and SMX among *K. pneumoniae* in northern Anhui were 13.7%, 29%, 36.9%, 23.2%, 28% and 29.2%, which were higher than those in central Anhui and southern Anhui (χ^2=235.193, P<0.0001; χ^2=47.919, P<0.0001; χ^2=67.987, P<0.0001; χ^2=9.338, P=0.009; χ^2=164.768, P<0.0001; χ^2=36.657, P<0.0001, respectively) (Table 5). The resistance rates of SAM, TZP, CAZ, FEP, ATM, IPM, and ciprofloxacin (CIP) among *K. pneumoniae* in southern Anhui were 31.6%, 14.2%, 22.1%, 21.3%, 24.7%, 9.1%, and 17.4%, which were lower than those in northern and central Anhui (χ^2=85.492, P<0.0001; χ^2=126.189, P<0.0001; χ^2=103.946, P<0.0001; χ^2=70.227, P<0.0001; χ^2=74.419, P<0.0001; χ^2=197.123, P<0.0001; χ^2=192.112, P<0.0001, respectively) (Table 5). The tigecycline (TGC) resistance rate among *K. pneumoniae* in southern Anhui was 4.4%, which was higher than that in northern Anhui and central Anhui (χ^2=56.811, P<0.0001) (Table 5).

The resistance rates to AMK, GEN, tobramycin (TOB), and CIP in *P. aeruginosa* in northern Anhui were 5.8%, 15.1%, 8.4%, and 17.7%, respectively, which were higher than those in central Anhui and southern Anhui (χ^2=28.1, P<0.0001; χ^2=45.449, P<0.0001; χ^2=23.24, P<0.0001; χ^2=29.719, P<0.0001, respectively) (Table 6). The resistance rate of IPM among *P. aeruginosa* in northern Anhui was 16.6%, which was lower than that in central Anhui and southern Anhui (χ^2=31.036, P<0.0001) (Table 6). The resistance rates of TZP, CAZ, and FEP among *P. aeruginosa* in southern Anhui were 17.6%, 21.4%, and 15.8%, respectively, which were higher than those in northern Anhui and central Anhui (χ^2=76.953, P<0.0001; χ^2=39.476, P<0.0001; χ^2=57.223, P<0.0001, respectively) (Table 6). The resistance rates to cefoperazone/sulbactam (CSL) and meropenem (MEM) among *P. aeruginosa* in central Anhui were 17.5% and 19.6%, respectively, which were higher than those in northern Anhui and central Anhui (χ^2=21.71, P<0.0001; χ^2=65.615, P<0.0001, respectively) (Table 6).

The resistance rates of AMK, GEN, TOB, TZP, CSL, CAZ, FEP, IPM, MEM, CIP and LVX among *A. baumannii* in northern Anhui were 46.1%, 69.9%, 67.3%, 73.2%, 56.2%, 70.3%, 63.2%, 69.8%, 73.4%, 76.7%, and 58.8%, respectively, which were higher than those in central Anhui and southern Anhui (χ^2=11.442, P=0.003; χ^2=86.556, P<0.0001; χ^2=217.177, P<0.0001; χ^2=104.601, P<0.0001; χ^2=56.309, P<0.0001; χ^2=181.713, P<0.0001; χ^2=122.779, P<0.0001; χ^2=263.425, P<0.0001; χ^2=31.008, P<0.0001; χ^2=207.692, P<0.0001; χ^2=106.187, P<0.0001, respectively) (Table 6). The TGC resistance rate among *A. baumannii* in northern Anhui was 2%, which was higher than that in central Anhui and southern Anhui (χ^2=25.558, P<0.0001) (Table 6).

Differential Analysis of Special Drug-Resistant Bacteria

The detection rates of MRSA in northern Anhui, central Anhui, and southern Anhui were 51.4%, 39.2%, and 24.8%, respectively. There was a significant difference in the detection rate of MRSA among the three regions (χ^2=460.281, P<0.0001) (Figure 1A and C). The detection rates of MRCNS in northern Anhui, central Anhui, and southern Anhui were 75.8%, 75.8%, and 72.3%, respectively. The detection rate of MRCNS in southern Anhui was lower than that in northern Anhui and central Anhui (χ^2=15.206, P<0.0001) (Figure 1B and D). The detection rates of VREA in northern Anhui, central Anhui, and southern Anhui were 0.4%, 0.2%, and 0.2%, respectively. The detection rates of VREM in northern Anhui, central Anhui, and southern Anhui were 0.9%, 0.6%, and 0.3%, respectively. There were no significant differences in the detection rates of VREA and VREM among the three regions (Figure 2).

The detection rates of CTX/CRO-R ECO in northern Anhui, central Anhui, and southern Anhui were 60.5%, 55.0%, and 46.1%, respectively. There was a significant difference in the detection rate of CTX/CRO-R ECO among the three regions (χ^2=376.829, P<0.0001) (Figure 3A and C). The detection rates of CTX/CRO-R KPN in northern Anhui, central Anhui, and southern Anhui were 37.0%, 34.2%, and 29.9%, respectively. There was a significant difference in the

Table 5 Resistance Rate of *Escherichia coli* and *Klebsiella pneumoniae* in Different Regions of Anhui Province

Antibacterial Agents	*Escherichia coli*						χ^2	*P*	*Klebsiella pneumoniae*						χ^2	*P*
	Northern Anhui		Center Anhui		Southern Anhui				Northern Anhui		Center Anhui		Southern Anhui			
	Isolates	%	Isolates	%	Isolates	%			Isolates	%	Isolates	%	Isolates	%		
AMK	8001[a]	5	11,616[b]	2.6	9094[c]	1.8	160.182	<0.0001	5424[a]	13.7	7651[b]	11.1	6617[c]	5.6	235.193	<0.0001
GEN	3461[a]	44	8203[b]	32.9	6249[c]	30.2	198.679	<0.0001	2242[a]	29	4927[b]	26.3	3158[c]	19.6	47.919	<0.0001
AMC	2409[a]	17.5	4118	10.9	3197[c]	10.9	72.482	<0.0001	2691[a]	28.6	3068[b]	21.8	2544	26.4	36.944	<0.0001
SAM	2832[a]	57.7	7565[b]	45.1	5068[c]	40.9	211.422	<0.0001	1807	43.6	4736[b]	41	2659[c]	31.6	85.492	<0.0001
TZP	8694[a]	5.9	11,753[b]	4.7	9061[c]	3.2	74.321	<0.0001	5961	20.8	7804[b]	20.7	6613[c]	14.2	126.189	<0.0001
CSL	3491	6.4	5752[b]	7.1	2614[c]	4.4	22.198	<0.0001	2764	20.4	4345[b]	21.4	1837	18.6	6.181	0.045
CXM	2108[a]	62.7	5594[b]	56.9	4763[c]	44.3	258.757	<0.0001	2313[a]	41.8	4211	38.3	3377	39.3	7.726	0.021
CRO	8239[a]	60.8	10,914[b]	55	8727[c]	46.1	376.829	<0.0001	5663[a]	36.9	7050[b]	34.1	6450[c]	29.9	67.987	<0.0001
CTX	353[a]	51.8	1217[b]	60.2	1182[c]	45.6	51.674	<0.0001	282[a]	40.1	615[b]	52.8	869	42.7	19.406	<0.0001
CAZ	8748[a]	29.5	12,105[b]	25.3	8942[c]	23	100.618	<0.0001	6094	29.2	7981[b]	28.5	6578[c]	22.1	103.946	<0.0001
FEP	8673[a]	30	11,385	24.6	7247[c]	24.5	90.259	<0.0001	6093	27.1	7540[b]	27	5705[c]	21.3	70.227	<0.0001
FOX	3541[a]	14.1	4399[b]	12.2	4954[c]	8.1	82.623	<0.0001	3331[a]	23.2	3420[b]	19.9	3486[c]	22.1	9.338	0.009
ATM	3462[a]	43	8212[b]	36.9	6146[c]	33.7	82.465	<0.0001	2234	32.3	4952[b]	33.5	3139[c]	24.7	74.419	<0.0001
IPM	8774	2.3	11,918[b]	2	9093[c]	1.2	32.652	<0.0001	6109	15.6	7990[b]	16.8	6617[c]	9.1	197.123	<0.0001
MEM	886	1.2	2790[b]	2.2	2831	1.1	11.511	0.003	607	14.3	1667	16.9	1687	14.5	4.415	0.11
CIP	3480[a]	62.3	8198[b]	52.5	4407[c]	48.2	161.376	<0.0001	2247	32.7	5785[b]	31.3	2481[c]	17.4	192.112	<0.0001
CIP	8763[a]	56.6	10,602[b]	50.8	8602[c]	45.7	206.918	<0.0001	6111[a]	28	7970[b]	24.8	6272[c]	18.4	164.768	<0.0001
SMX	8793[a]	61.3	10,041[b]	49.2	8403[c]	46.5	437.602	<0.0001	6085[a]	29.2	5775	24.5	6166[c]	25.7	36.657	<0.0001
TGC	3707	0.1	4871	0.1	4827	0.1	0.006	0.997	2467[a]	1.3	3425[b]	2.2	3225[c]	4.4	56.811	<0.0001

Notes: [a]The statistical difference between northern Anhui and central Anhui; [b]The statistical difference between central Anhui and southern Anhui; [c]The statistical difference between southern Anhui and northern Anhui.
Abbreviations: AMK, amikacin; GEN, gentamicin; AMC, amoxicillin/clavulanic acid; SAM, ampicillin/sulbactam; TZP, piperacillin/tazobactam; CSL, cefoperazone/sulbactam; CXM, cefuroxime; CRO, ceftriaxone; CTX, cefotaxime; CAZ, ceftazidime; FEP, cefepime; FOX, cefoxitin; ATM, aztreonam; IPM, imipenem; MEM, meropenem; CIP, ciprofloxacin; LVX, levofloxacin; SMX, sulfamethoxazole; TGC, tigecycline.

Table 6 Resistance Rate of *Pseudomonas aeruginosa* and *Acinetobacter baumannii* in Different Regions of Anhui Province

Antibacterial Agents	*Pseudomonas aeruginosa*						χ^2	*P*	*Acinetobacter baumannii*						χ^2	*P*
	Northern Anhui		Center Anhui		Southern Anhui				Northern Anhui		Center Anhui		Southern Anhui			
	Isolates	R%	Isolates	R%	Isolates	R%			Isolates	R%	Isolates	R%	Isolates	R%		
AMK	3630[a]	5.8	5255	4.1	3974[c]	3.4	28.1	<0.0001	343[a]	46.1	2047	37	1928[c]	36.7	11.442	0.003
GEN	1588[a]	15.1	2753	9	2134[c]	9.3	45.449	<0.0001	1048[a]	69.9	1759[b]	52.1	1072[c]	58	86.556	<0.0001
TOB	2698[a]	8.4	4807	7	3315[c]	6	23.24	0.001	1696[a]	67.3	3036[b]	50.7	1989[c]	43.5	217.177	<0.0001
TZP	3603[a]	10.5	4756[b]	14.6	3835[c]	17.6	76.953	<0.0001	1894[a]	73.2	2473	60	1185[c]	58.1	104.601	<0.0001
CSL	1925[a]	13.2	3264[b]	17.5	1137	13.4	21.71	<0.0001	1222[a]	56.2	2701[b]	45.6	757[c]	40.4	56.309	<0.0001
CAZ	3998	16.5	5568[b]	17.1	3958[c]	21.4	39.476	<0.0001	2444[a]	70.3	3827[b]	57.3	2606[c]	52.3	181.713	<0.0001
FEP	4041	10.5	5587[b]	11.7	3971[c]	15.8	57.223	<0.0001	2446[a]	63.2	3819[b]	52.8	2561[c]	48	122.779	<0.0001
IMP	3987[a]	16.6	5367	21	3925[c]	20.4	31.036	<0.0001	2452[a]	69.8	3629[b]	59.9	2198[c]	46.4	263.425	<0.0001
MEM	2043[a]	12	3921[b]	19.6	2159[c]	14.3	65.615	<0.0001	811[a]	73.4	2400[b]	64.2	1473[c]	62.1	31.008	<0.0001
CIP	3479[a]	17.7	5455	13.5	3116[c]	14.8	29.719	<0.0001	1660[a]	76.7	3354	57.3	1456[c]	55.7	207.692	<0.0001
LVX	3942[a]	17.6	5252[b]	15.7	3190	18.1	9.894	0.007	2451[a]	58.8	3706[b]	47.8	2502[c]	41	106.187	<0.0001
POL	70	1.4	709	1.8	325	0.3	4.997	0.082	51	2.0	664	1.1	250	0.8	0.168	0.791
MNO	–	–	–	–	–	–	–	–	1040[a]	11.8	2227	15.4	1025	13.6	7.801	0.02
TGC	–	–	–	–	–	–	–	–	1080[a]	2	2392	5.3	1076[c]	6.4	25.558	<0.0001

Notes: [a]The statistical difference between northern Anhui and central Anhui; [b]The statistical difference between central Anhui and southern Anhui; [c]The difference between southern Anhui and northern Anhui. "–": No sensitivity test of the drug.

Abbreviations: AMK, amikacin; GEN, gentamicin; TOB, tobramycin; TZP, piperacillin/tazobactam; CSL, cefoperazone/sulbactam; CAZ, ceftazidime; FEP, cefepime; IPM, imipenem; MEM, meropenem; CIP, ciprofloxacin; LVX, levofloxacin; POL, Polymixin B; MNO, Minocycline; TGC, tigecycline.

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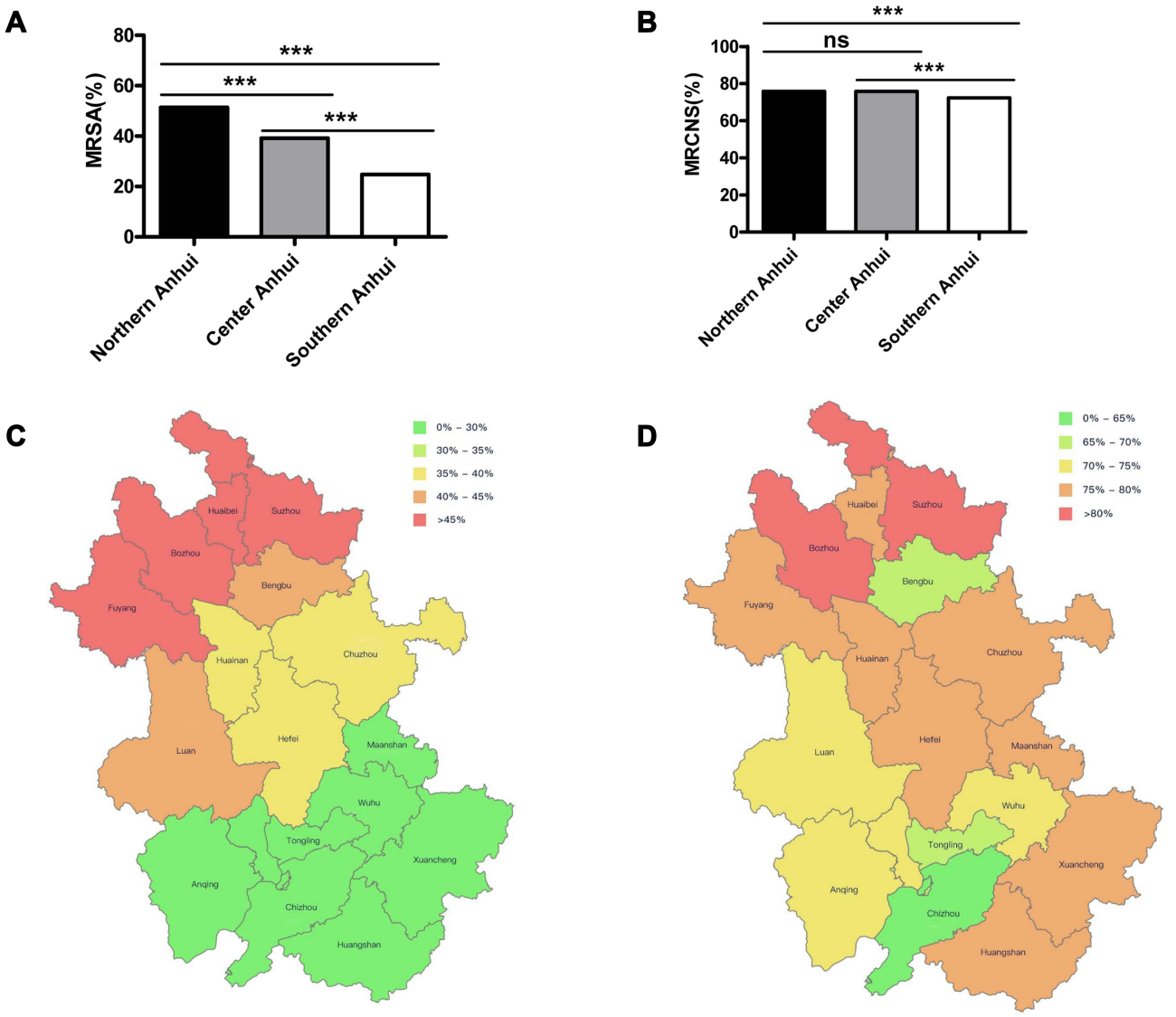

Figure 1 The detection rates of methicillin-resistant *staphylococci* in different regions of Anhui. (**A**) Differences of detection rates of MRSA in northern, central and southern Anhui. (**B**) Differences of detection rates of MRCNS in northern, central and southern Anhui. (**C**) Prevalence of MRSA among different cities in Anhui (HuiNet data). (**D**) Prevalence of MRCNS among different cities in Anhui (HuiNet data). ***$P<0.0001$.

Abbreviations: MRSA, methicillin-resistant *Staphylococcus aureus*; MRCNS, methicillin-resistant coagulase-negative *Staphylococcus*; HuiNet, the Anhui Province Bacterial Resistance Surveillance Network.

detection rate of CTX/CRO-R KPN among the three regions (χ^2=69.495, P<0.0001) (Figure 3B and D). The detection rates of CR-ECO in northern Anhui, central Anhui, and southern Anhui were 2.5%, 2.4%, and 1.5%, respectively. The detection rate of CR-ECO in southern Anhui was lower than that in northern Anhui and central Anhui (χ^2=25.495, P<0.0001) (Figure 4A and C). The detection rates of CR-KPN in northern Anhui, central Anhui, and southern Anhui were 16.5%, 17.4%, and 9.7%, respectively. The detection rate of CR-KPN in southern Anhui was also lower than that in northern Anhui and central Anhui (χ^2=197.123, P<0.0001) (Figure 4B and D). The detection rates of CR-PAE in northern Anhui, central Anhui, and southern Anhui were 16.6%, 21.0%, and 20.4%, respectively. The detection rate of CR-PAE in northern Anhui was lower than that in central Anhui and southern Anhui (χ^2=31.036, P<0.0001) (Figure 5A and C). The detection rates of CR-ABA in northern Anhui, central Anhui, and southern Anhui were 69.9%, 64.2%, and 60.8%, respectively. The detection rate of CR-ABA in northern Anhui was higher than that in central Anhui and southern Anhui (χ^2=263.425, P<0.0001) (Figure 5B and D).

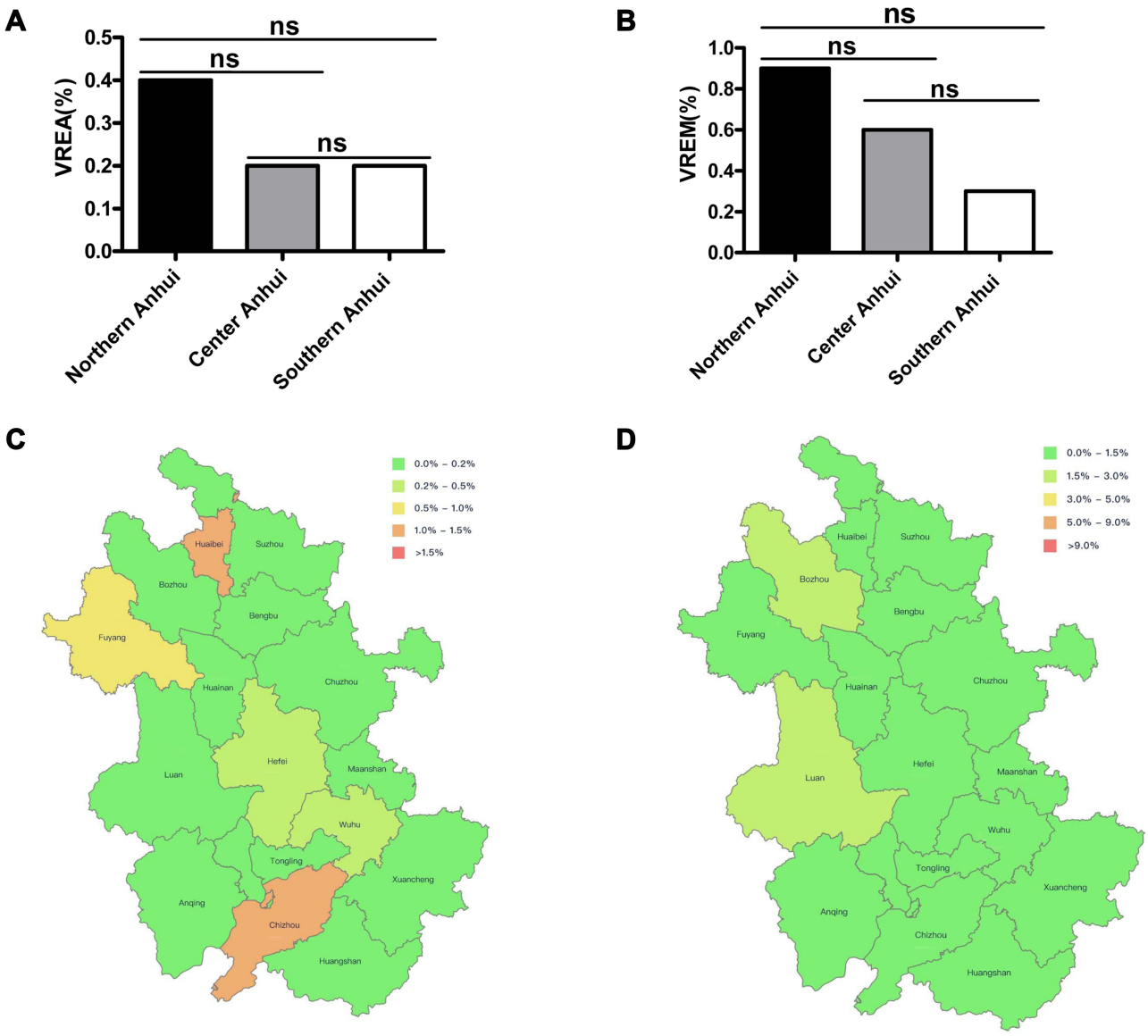

Figure 2 The detection rates of vancomycin-resistant *enterococcus* in different regions of Anhui. (**A**) Differences of detection rates of VREA in northern, central and southern Anhui. (**B**) Differences of detection rates of VREM in northern, central and southern Anhui. (**C**) Prevalence of VREA among different cities in Anhui (HuiNet data). (**D**) Prevalence of VREM among different cities in Anhui (HuiNet data).

Abbreviations: VREA, vancomycin-resistant *Enterococcus faecalis*; VREM, vancomycin-resistant *Enterococcus faecium*; HuiNet, the Anhui Province Bacterial Resistance Surveillance Network.

Discussion

Our data showed that 133,268 strains of bacteria were isolated from clinical specimens in 2021. The detection rates of gram-negative bacteria in northern Anhui, central Anhui, and southern Anhui were higher than those of gram-positive bacteria, which is consistent with other reports from China.[4] *S. aureus* was the most common gram-positive bacterium in northern Anhui, central Anhui, and southern Anhui, and *E. coli* was the most common gram-negative bacterium. There were no significant differences in the detection rates of *S. aureus* and *E. coli* among the three regions. The detection rates of *S. epidermidis* and *S. hominis* in northern Anhui were higher than those in central Anhui and southern Anhui, while the detection rates of *E. faecium, E. faecalis*, and *E. cloacae* in northern Anhui were lower than those in central Anhui and southern Anhui. Our data also showed that the sputum, blood, pus, and cerebrospinal fluid specimens in northern Anhui were higher than those in central Anhui and southern Anhui, while the urine and ascites samples in southern Anhui were

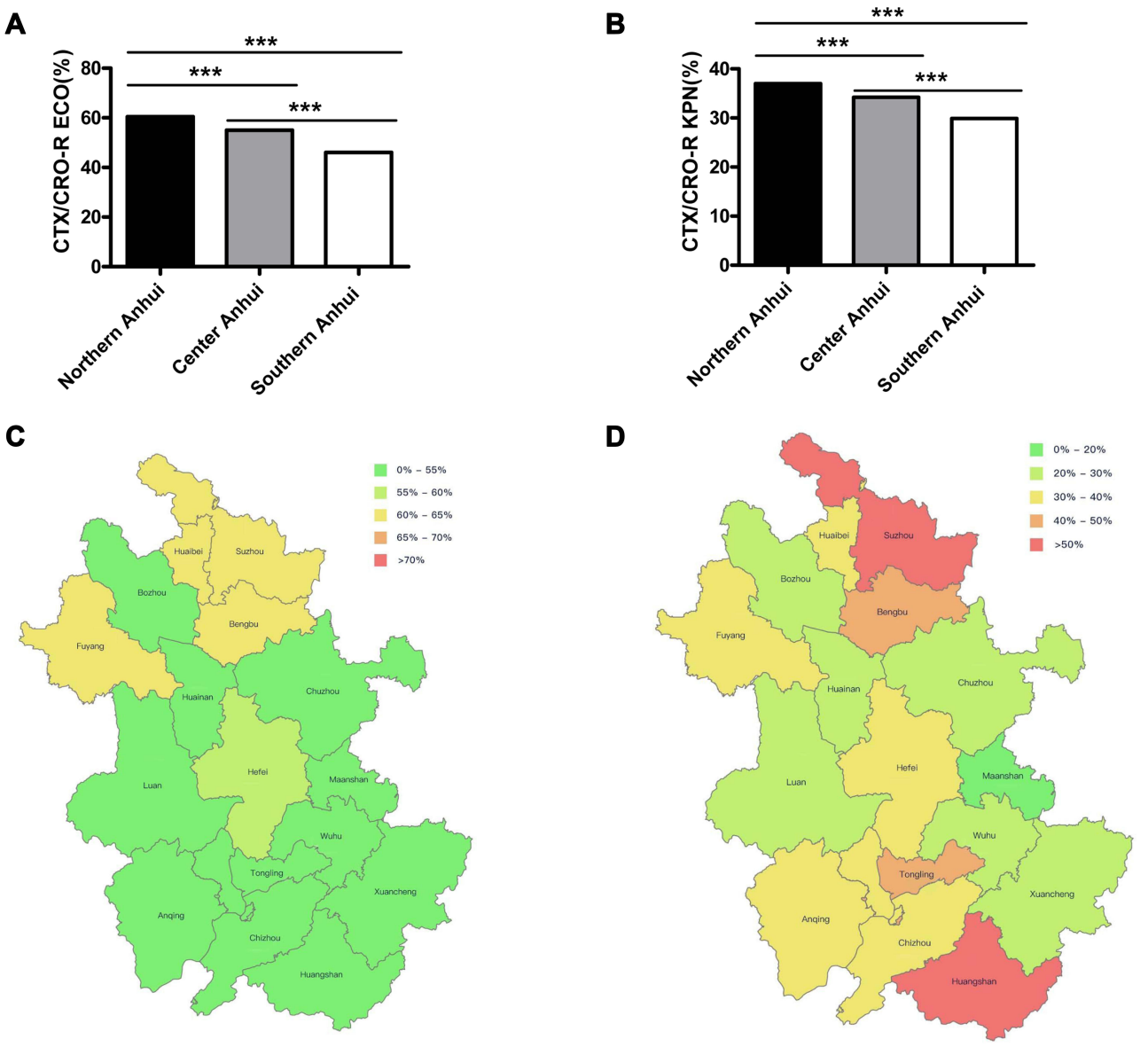

Figure 3 The detection rates of third-generation cephalosporin-resistant *Escherichia coli* and *Klebsiella pneumoniae* in different regions of Anhui. (**A**) Differences of detection rates of CTX/CRO-R ECO in northern, central and southern Anhui. (**B**) Differences of detection rates of CTX/CRO-R KPN in northern, central and southern Anhui. (**C**) Prevalence of CTX/CRO-R ECO among different cities in Anhui (HuiNet data). (**D**) Prevalence of CTX/CRO-R KPN among different cities in Anhui (HuiNet data). ***P<0.0001.

Abbreviations: CTX/CRO-R ECO, third-generation cephalosporin-resistant *Escherichia coli*; CTX/CRO-R KPN, third-generation cephalosporin-resistant *Klebsiella pneumoniae*; HuiNet, the Anhui Province Bacterial Resistance Surveillance Network.

higher than those in northern Anhui and central Anhui. The above results indicate that the distribution of bacteria and specimen sources differed among the different regions.

The present study showed that the resistance rates of *Staphylococci* to PEN, SMX, CLI, and ERY in northern Anhui were higher than those in central Anhui and southern Anhui, which may be related to the degree of antibiotic use in northern Anhui. Interestingly, the resistance rate of *S. aureus* to PEN in southern Anhui was lower than that in northern Anhui and central Anhui, whereas the resistance rate of coagulase-negative *Staphylococcus* to PEN in southern Anhui was higher than that in northern Anhui and central Anhui, indicating that the resistance rate of *Staphylococcus* to PEN in different regions was significantly different. The detection rate of MRSA in northern Anhui was higher than that in central Anhui, and the detection rate of MRSA in central Anhui was higher than that in southern Anhui. The obvious regional differences should be carefully considered. In addition, the detection rate of MRCNS in southern Anhui was

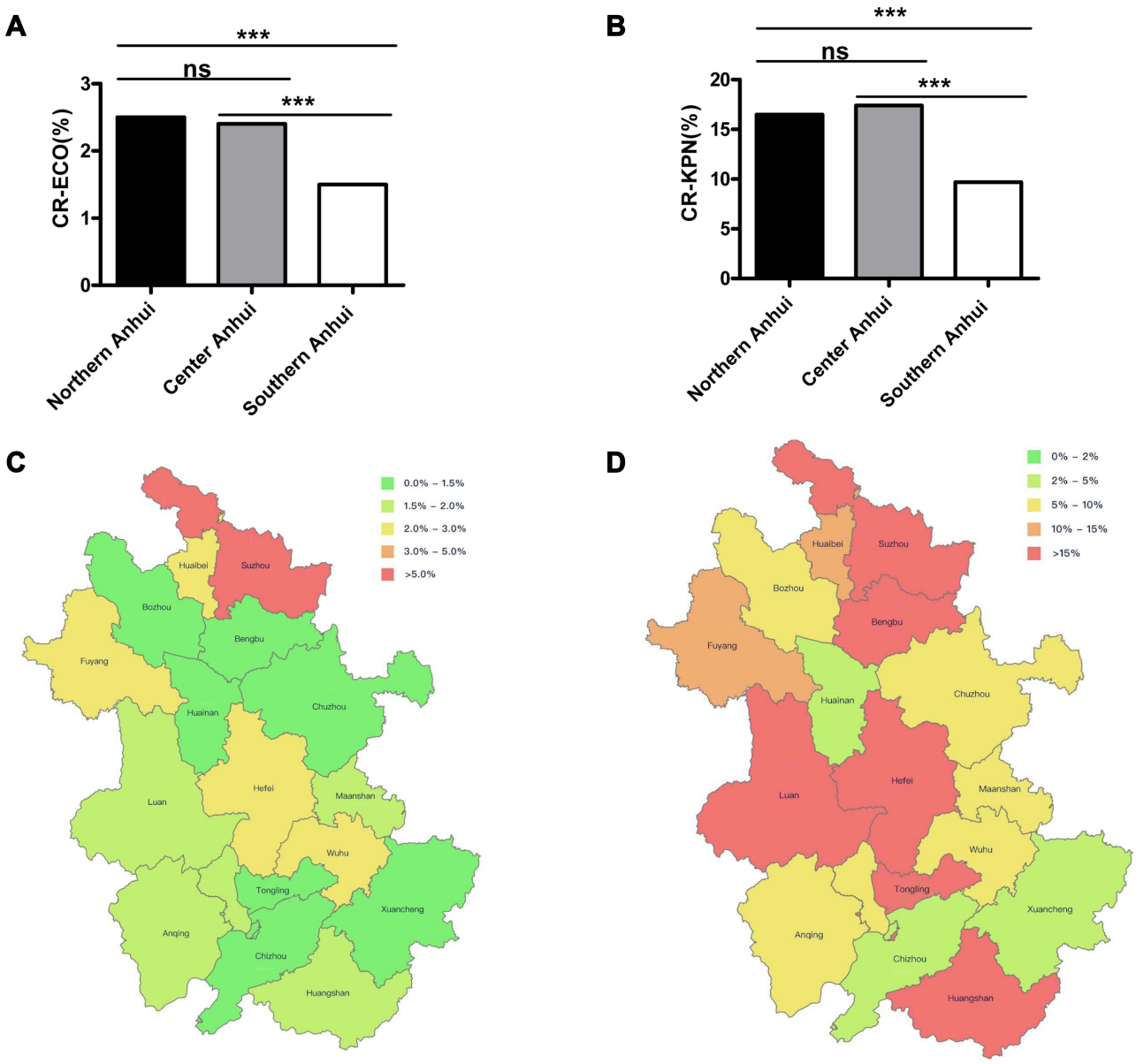

Figure 4 The detection rates of carbapenem-resistant *Escherichia coli* and *Klebsiella pneumoniae* in different regions of Anhui. (**A**) Differences of detection rates of CR-ECO in northern, central and southern Anhui. (**B**) Differences of detection rates of CR-KPN in northern, central and southern Anhui. (**C**) Prevalence of CR-ECO among different cities in Anhui (HuiNet data). (**D**) Prevalence of CR-KPN among different cities in Anhui (HuiNet data). ****P*<0.0001.

Abbreviations: CR-ECO, carbapenem-resistant *Escherichia coli*; CR-KPN, carbapenem-resistant *Klebsiella pneumoniae*; HuiNet, the Anhui Province Bacterial Resistance Surveillance Network.

lower than that in northern Anhui and central Anhui. The resistance rates of MRCNS to most antibacterial agents were high. However, the sensitivity rates of MRCNS to vancomycin (VAN), LNZ, and teicoplanin were 100%, indicating that the three antibacterial agents could still be used as the treatment of choice. The resistance rate of *Staphylococcus* to PEN in the three regions was greater than 90%, indicating that PEN was no longer suitable for *Staphylococcus* in Anhui Province. Shariati et al found moderate VAN-resistant *S. aureus* in Asia, and the detection rate was on the rise in recent years.[5] At present, VAN-resistant *S. aureus* has not been found in Anhui province. However, the presence of VAN-mediated and VAN-resistant *staphylococci* should be monitored with the widespread use of VAN.[6,7] Control and treatment guidelines should be formulated according to geographical areas to prevent the further spread of VAN-resistant *S. aureus*.

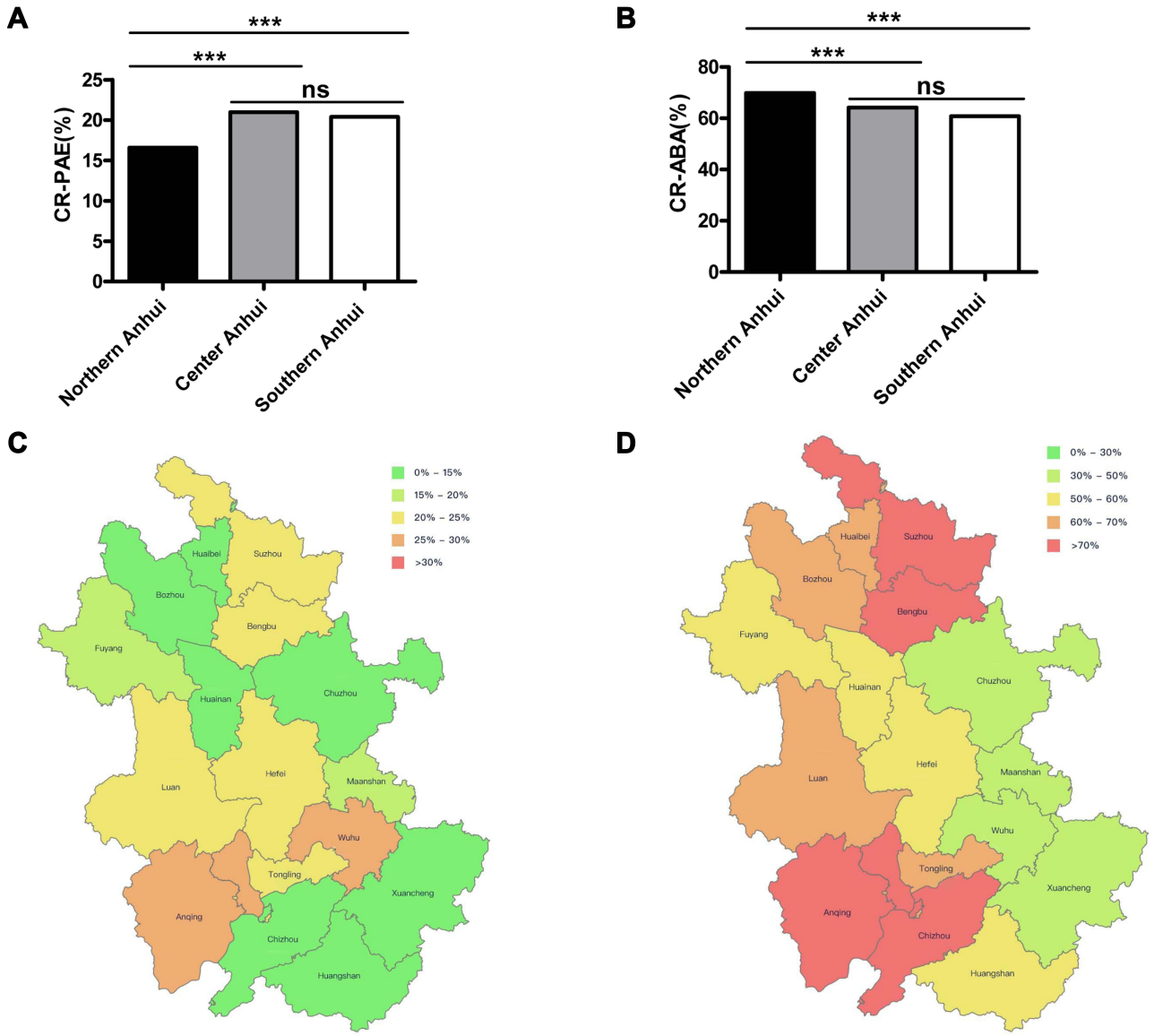

Figure 5 The detection rates of carbapenem-resistant *Pseudomonas aeruginosa* and *Acinetobacter baumannii* in different regions of Anhui. (**A**) Differences of detection rates of CR-PAE in northern, central and southern Anhui. (**B**) Differences of detection rates of CR-ABA in northern, central and southern Anhui. (**C**) Prevalence of CR-PAE among different cities in Anhui (HuiNet data). (**D**) Prevalence of CR-ABA among different cities in Anhui (HuiNet data). ***$P<0.0001$.

Abbreviations: CR-PAE, carbapenem-resistant *Pseudomonas aeruginosa*; CR-ABA, carbapenem-resistant *Acinetobacter baumannii*; HuiNet, the Anhui Province Bacterial Resistance Surveillance Network.

Our results showed that the resistance rates of *E. faecalis* to GEH and LVX in northern Anhui were higher than those in central Anhui and southern Anhui. Meanwhile, the resistance rates of *E. faecium* to AMP and STH in northern Anhui were higher than those in central Anhui and southern Anhui. The above results indicate that the resistance rates of *enterococci* to relevant antimicrobial agents were significantly different in the three regions, and antimicrobial agents should be carefully selected. The resistance rates of *E. faecium* to VAN in northern Anhui, central Anhui, and southern Anhui were 0.9%, 0.6%, and 0.3%, respectively. There were no significant differences in the detection rates among the three regions. Although the detection rate of VAN-resistant enterococci (VRE) was low, the problems such as high mortality, prolonged hospital stay and increased medical expenditure caused by VRE should not be ignored.[8] At present, the activities of LNZ, daptomycin (DAP) and TGC in vitro against *enterococcus* were high.[9,10] However, LNZ was easy to produce erythrocyte, hemoglobin, platelet reduction and other hematological adverse reactions.[11,12] DAP has more advantages in safety, efficacy and prognosis, therefore, the clinician may choose DAP to treat *Enterococcus*.[13]

This study showed that *E. coli* was the main gram-negative bacterium isolated in Anhui province, following *K. pneumoniae* and *P. aeruginosa*, which is consistent with previous studies.[14,15] The resistance rates of most antibiotics among *E. coli* and *A. baumannii* in northern Anhui were higher than those in central Anhui and southern Anhui, indicating that antibiotics should be carefully selected for the treatment of infections caused by *E. coli* and *A. baumanni*i in northern Anhui. At present, carbapenem-resistant Enterobacteriaceae (CRE) is a serious situation in China.[16] CRE is widely, or even fully, resistant to most clinical antibiotics, and its resistance is related to a variety of molecular mechanisms. Therefore, CRE has become a major challenge in clinical anti-infective therapy and an important reason for its high mortality.[16–18] This study showed that the detection rates of CR-ECO, CR-KPN, and CR-ABA in northern Anhui were higher than those in southern Anhui in 2021, suggesting that the use of carbapenems in clinical work in northern Anhui was higher and should be more standardized and rational for clinical anti-infection treatment in the future. Carbapenemase is the main resistance mechanism of carbapenems antibacterial agents in *Enterobacteriaceae*, including KPC, NDM, OXA-48, VIP, and IMP.[19] It was reported that *E. coli* mainly produced NDM metalloenzyme and *K. pneumoniae* produced KPC enzyme.[20] However, in recent years, class D OXA-48 enzymes have been prevalent in CR-KPN.[21] Ceftazidime/avibactam showed high antibacterial activity against KPC or OXA-48 carbapenemase strains, but poor activity against NDM metalloenzyme strains.[22] Therefore, it is recommended to carry out combined antibacterial agents for carbapenem-resistant strains in order to provide a more accurate regimen for clinicians. The high sensitivity of *E. coli, K. pneumoni*ae, and *P. aeruginosa* to amikacin in Anhui suggests that amikacin could be used as an antimicrobial agent of choice for these infections. However, amikacin has ototoxicity and nephrotoxicity,[23] which still need to be carefully considered in clinical treatment.

Conclusion

Gram-negative bacteria were the main pathogens in the different regions of Anhui Province in 2021. The resistance rates of bacteria to antibiotics were different in northern Anhui, central Anhui, and southern Anhui, with the resistance rate in northern Anhui being the highest. Therefore, it is very important to conduct long-term dynamic monitoring and understand the trends in drug susceptibility in real time. The differences of bacterial resistance in different regions suggest that attention should be given to the rational selection of antimicrobial agents in clinical anti-infection treatment according to the situation of local bacterial resistance to reduce the emergence of drug-resistant strains and delay the rate of bacterial resistance.

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Disclosure

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