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A multicenter study on antimicrobial resistance in bloodstream pathogens isolated in Korea: a survey study

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Abstract

Background: Bacterial antimicrobial resistance (AMR) is a major contributor to the mortality and disease burden associated with bloodstream infections worldwide. The authors investigated the AMR rates of bacterial isolates obtained from blood cultures in 2023 to provide essential baseline data for AMR management and compared these findings with Korea Global Antimicrobial Resistance Surveillance System (Kor-GLASS) (2023) data limited to the first isolate group in our data.

Methods: Through a multicenter survey, we collected AMR data for bacteria causing bloodstream infections in 2023. Sixteen university-affiliated hospitals participated in the survey; nine provided the first isolate data, and seven reported duplicate isolate data. The survey targeted five gram-positive organisms (*Staphylococcus aureus*, *Staphylococcus epidermidis, Streptococcus pneumoniae, Enterococcus faecalis, Enterococcus faecium*) and four gram-negative organisms (*Escherichia coli, Klebsiella pneumoniae, Acinetobacter baumannii, Pseudomonas aeruginosa*).

Results: Resistance to oxacillin was significantly higher for *S. epidermidis* (76.9%–83.2%) than *S. aureus* (39.1%–47.4%), while *S. pneumoniae* showed 38.9%–51.7% resistance to penicillin. Vancomycin resistance was significantly higher in *E. faecium* (33.6%–37.8%) than *E. faecalis* (0.3%). *E. coli, K. pneumoniae* and *P. aeruginosa* displayed resistance of 1.1%–1.7%, 10.2%–24.9%, and 20.2%–27.3%, respectively, to carbapenems. *A. baumannii* exhibited carbapenem resistance of 66.3%–87.4%.

Conclusion: Resistance rates among the nine pathogens in this survey were similar to those reported by Kor-GLASS, although *K. pneumoniae* showed a higher carbapenem resistance rate. Continuous monitoring and antimicrobial stewardship are necessary to reduce the AMR of major pathogens causing bloodstream infections.

Keywords: Antibiotic resistance, Microbial sensitivity tests, Bloodstream infection, Multicenter study, South Korea

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Introduction

Background

Antibiotic-resistant bacteria pose a global health threat and cause substantial mortality, particularly in low-income countries. A global assessment of antimicrobial resistance (AMR) initiated in 2014 projected up to 10 million AMR-attributable deaths annually by 2050 [1]. Recent estimates indicate that in 2021, 4.7 million deaths will be associated with bacterial AMR worldwide, with 1.1 million directly attributable to resistant pathogens [2]. Resistance patterns vary according to region and socioeconomic status [3-5], with Asia experiencing the highest mortality from bacterial bloodstream infections [3]. Cumulative AMR-related deaths from 2025 to 2050 are expected to be highest in Asia, reaching 11.8 million [2]. The World Health Organization (WHO) established the Global Antimicrobial Resistance and Use Surveillance System (GLASS) [5], which informs the bacterial priority pathogen list [6]. Many countries have implemented national surveillance systems [7] with South Korea participating via the Korea Global Antimicrobial Resistance Surveillance System (Kor-GLASS), which has published annual reports since 2017 and, currently in its third phase (2023–2025), collected AMR data on 15 major bacterial species from 11 general hospitals nationwide [8].

Objectives

This study investigated the prevalence of antibiotic-resistant bacteria causing bloodstream infections in university-affiliated hospitals in 2023 and compared these resistance rates with Kor-GLASS (2023) data and global studies to provide essential baseline data for AMR management.

Methods

Study design

This is a multicenter survey study.

Setting and participants

Survey data were collected via excel sheet from clinical microbiologists at 16 university-affiliated hospitals in South Korea: Asan Medical Center, Gyeongsang National University Changwon Hospital, Chonnam National University Hospital, Chungnam National University Hospital, Dong-A University Hospital, Kangdong Sacred Heart Hospital, Gyeongsang National University Changwon Hospital, Inje University Haeundae Paik Hospital, Keimyung University Dongsan Hospital, Konkuk University Medical Center, Kyung Hee University Hospital, Kyungpook National University Hospital, Pusan National University Hospital, Samsung Medical Center, Seoul St. Mary’s Hospital, and Soonchunhyang University Seoul Hospital.

Variables

Outcome variables were antimicrobial resistance rats of the tested bloods.

Data sources/measurement

Resistance rates were based on the antimicrobial susceptibility test (AST) results recorded in each hospital's electronic medical recording system from January 1 to December 31, 2023. The target organisms were five gram-positive species (*Staphylococcus aureus, Staphylococcus epidermidis, Streptococcus pneumoniae, Enterococcus faecalis, and Enterococcus faecium*) and four gram-negative species (*Escherichia coli, Klebsiella pneumoniae, Acinetobacter baumannii, and Pseudomonas aeruginosa*). The antibiotics tested for each organism and hospital are listed in Supplementary Table 1.

For each antibiotic, the resistance rates of gram-positive and gram-negative bacteria were calculated as (number of resistant isolates/number of tested isolates) × 100 (%). Data were analyzed separately for hospitals providing the first isolate results (first isolate group: organisms isolated for the first time) and duplicate results (duplicate group: organisms isolated on two or more occasions, with unknown time intervals between isolates).

Table 1. Baseline characteristics of the 16 university-affiliated hospitals participating in the survey

Categories		No.	(%)
No. of beds	≥1,000	6	(37.5)
	700–999	9	(56.3)
	500–699	1	(6.3)
Location	Seoul	7	(43.8)
	Other cities[a)]	9	(56.3)
Isolate count	First isolate	9	(56.3)
	Duplicate	7	(43.8)
Total		16	(100.0)

[a)]Busan (3 hospitals), Daegu (2), Daejeon (1), Gwangju (1), Changwon (1), and Jinju (1).

Bias

The number of isolates refers to those that underwent AST rather than the total number identified at each hospital. Selection and measurement biases may be present in duplicate isolates, and sampling bias may occur when AST for specific antibiotics is performed in a limited number of hospitals (Supplementary Table 1).

Study size

Sample size estimation was not done since data were collected from the respondents' hospital data of antimicrobial susceptibility tests.

Statistical methods

Results were summarized using descriptive statistics.

Results

Sixteen university-affiliated hospitals participated in the survey (Table 1), of which 37.5% had 1,000 or more beds, 43.8% ranged between 700 and 999 beds, 6.3% contained 500 to 699 beds; 43.8% were located in Seoul, and 56.3% were in other cities. Between January 1 and December 31, 2023, 56.3% (268,074 isolates) were categorized into the first isolate group (excluding duplicate results), while 43.8% (174,575 isolates) belonged to the duplicate group (including duplicates). Antibiotic susceptibility testing results were recruited (Table 2). Gram-negative bacteria were 2–3 times more common than gram-positive bacteria (2.7-fold in the first isolate group and 2.0-fold in the duplicate group). Overall, *E. coli* (first isolate, 43.1%; duplicate, 36.9%) and *K. pneumoniae* (first isolate, 21.1%; duplicate, 23.1%) were the most common, whereas *A. baumannii* (first isolate, 2.3%; duplicate, 4.4%) and *S. pneumoniae* (first isolate, 0.4%; duplicate, 0.2%) were the least frequent.

Table 2. Species distribution of bacterial isolates tested for antimicrobial susceptibility in 16 university-affiliated hospitals in 2023

Organisms	No. of isolates		% of isolates	
	First isolate	Duplicate	First isolate	Duplicate
Gram-positive bacteria	72,972	58,830	27.2	33.7
Staphylococcus aureus	23,692	22,892	8.8	13.1
Staphylococcus epidermidis	19,339	21,974	7.2	12.6
Enterococcus faecalis	14,694	4,405	5.5	2.5
Enterococcus faecium	14,188	9,264	5.3	5.3
Streptococcus pneumoniae	1,059	295	0.4	0.2
Gram-negative bacteria	195,102	115,745	72.8	66.3
Escherichia coli	115,557	64,388	43.1	36.9
Klebsiella pneumoniae	56,471	40,398	21.1	23.1
Pseudomonas aeruginosa	16,895	3,301	6.3	1.9
Acinetobacter baumannii	6,179	7,658	2.3	4.4
Total	268,074	174,575	100.0	100.0

Resistance rates for gram-positive and gram-negative bacteria comparing the first isolate and duplicate groups and the investigated antibiotics are summarized in Tables 3 and 4, respectively. The total resistance rates, without distinguishing between the first and duplicate groups, are presented in Supplementary Table 2.

Gram-positive bacteria

S. aureus exhibited high resistance to penicillin (85.1%–86.0%), oxacillin (39.1%–47.4%), and cefoxitin (60.0%). Cefoxitin was not assessed in any hospital in the first isolate group, whereas it was detected in only one hospital in the duplicate group, indicating a potential bias. Resistance to macrolides ranged from 13.5% to 33.0% and to minocycline from 1.2% to 3.4%. Resistance to vancomycin (0.0%), daptomycin (0.0%), and linezolid (0.0%–0.3%) was rare, and resistance to trimethoprim-sulfamethoxazole ranged from 0.7% to 2.0%. *S. epidermidis* showed very high resistance to penicillin (93.0%–94.2%) and oxacillin (76.9%–83.2%). Resistance rates for macrolides and trimethoprim-sulfamethoxazole were 34.0%–67.6% and 37.9%–45.2%, respectively. Rare resistance was observed for vancomycin (0.0%), daptomycin (0.0%), and linezolid (0.0%–

0.2%). *S. pneumoniae* demonstrated resistance to penicillin (38.9%–51.7%), third-generation cephalosporins (14.8%–33.3%), and meropenem (62.5%). Resistance to macrolide and tetracycline exceeded 71.2% and 75.6%, respectively, whereas that of trimethoprim-sulfamethoxazole ranged from 28.6% to 41.0%. Vancomycin resistance was not observed. *E. faecium* showed resistance rate exceeding 89.6% to penicillin and ampicillin and 33.6%–37.8% to vancomycin. Daptomycin resistance was 2.9% in the first isolate group (744 isolates) and 100% in the duplicate group (16 isolates, one hospital), whereas linezolid resistance was 0.1%–0.9%. *E. faecalis* exhibited penicillin resistance of 6.5% (first isolate) and 23.7% (duplicate) and vancomycin and daptomycin resistance of 0.3% and 0.0%–0.4%, respectively. High-level gentamicin and streptomycin resistance was observed 37.7%–48.2% and 11.6%–15.8%, respectively (Table 3).

Table 3. Prevalence of antimicrobial resistance of five gram-positive bacteria

Antibiotics \ Organisms		SAU		SEP		SPN		EFM		EFA	
		First	Dup	First	Dup	First	Dup	First	Dup	First	Dup
Penicillins	Penicillin	85.1	86.0	93.0	94.2	38.9	51.7	89.9	91.3	6.5	23.7
	Ampicillin							89.6	91.3	0.3	1.9
	Oxacillin	39.1	47.4	76.9	83.2						
Cephalosporins	Cefoxitin (2nd GC)	NA[a]	60.0[b]								
	Cefotaxime (3rd GC)					33.3	22.2				
	Ceftriaxone (3rd GC)					16.7	14.8				
	Ceftaroline (5th GC)	11.1[b]	4.7[b]								
Carbapenems	Meropenem					62.5	NA[a]				
Glycopeptides	Vancomycin	0.0	0.0	0.0	0.0	0.0	0.0	33.6	37.8	0.3	0.3
Lipopeptides	Daptomycin	0.0	0.0[b]	0.0	0.0			29.3	100.0[b]	0.4	0.0[b]
Macrolides	Azithromycin	30.9	33.0[b]	59.5	34.0						
	Erythromycin	30.1	30.3	58.5	67.6	87.8	88.6				
	Clindamycin	13.5	28.3	34.8	49.2	71.2	84.8				
Tetracyclines	Tetracycline	12.1	12.8	19.5	19.7	75.6	85.0				
	Minocycline	1.2	3.4[b]	0.0	1.1						
Aminoglycosides	Gentamicin (High-level)							28.0	36.4	37.7	48.2
	Streptomycin (High-level)									11.6	15.8
Fluoroquinolones	Levofloxacin					9.1	2.9				
	Moxifloxacin					14.3	3.8				
Folate pathway inhibitors	Trimethoprim-sulfamethoxazole	0.7	2.0	37.9	45.2	41.0	28.6				
Oxazolidinones	Linezolid	0.0	0.3	0.0	0.2			0.1	0.9	0.3	1.3
Rifamycins	Rifampin	1.2	6.1	11.7	14.8						
Total No. of isolates		23,692	22,892	19,339	21,974	1,059	295	14,188	9,264	14,694	4,405

The numbers shown in the colored cells indicate the antimicrobial resistance rates. Color-coded as follows: red (76.0–100%), orange (51.0–75.9%), yellow (26.0–50.9%), sky blue (1.0–25.9%), and blue (0.0–0.9%).

[a]None of the hospitals performed the test; [b]Only one hospital contributed data.

Abbreviations: SAU, *Staphylococcus aureus*; SEP, *Staphylococcus epidermidis*; SPN, *Streptococcus pneumoniae*; EFM, *Enterococcus faecium*; EFA, *Enterococcus faecalis*; First, first isolate group; Dup, duplicate group; GC, generation cephalosporins; NA, not available.

Gram-negative bacteria

E. coli demonstrated high resistance to ampicillins (70.2%–71.1%) and moderate to most of beta-lactams (13.0%–45.6%), except for piperacillin-tazobactam (5.2%–6.3%), cefoxitin (8.5%–10.8%), and ceftazidime-avibactam (0.9%). Carbapenem resistance remained low (1.1%–1.7%). Fluoroquinolone resistance ranged from 46.9% to 53.1%, with levofloxacin reaching 100% in the duplicate group (1,042 isolates, two hospitals) compared with 46.9% in the first isolate group (6,925 isolates). Trimethoprim-sulfamethoxazole resistance was 37.0%–37.6%. *K. pneumoniae* exhibited very high resistance to ampicillin (96.9%–99.8%) and 18.8%–49.6% to other beta-lactams. Carbapenem resistance ranged from 10.2% to 24.9%. Fluoroquinolone resistance was 34.1%–44.6%, with 100% resistance to levofloxacin in the duplicate group (727 isolates, two hospitals) and 34.1% in the first isolate group (3,294 isolates). Trimethoprim-sulfamethoxazole resistance was 35.2%–40.0%. *A. baumannii* displayed resistance exceeding 49.1% to most antibiotics, except minocycline (1.2%–9.9%). Carbapenem resistance was particularly high (66.3%–87.4%). *P. aeruginosa* showed 14.3%–30.2% resistance to most of beta-lactams and carbapenem resistance was 20.2%–27.3%. Tobramycin and fluoroquinolones resistance was 8.1%–11.2% and 28.3%–30.2%, respectively (Table 4).

Table 4. Prevalence of antimicrobial resistance of four gram-negative bacteria

Antibiotics \ Organisms		ECO		KPN		ABM		PAE	
		First	Dup	First	Dup	First	Dup	First	Dup
Penicillins	Penicillin								
	Ampicillin	70.2	71.1	96.9	99.8				
Penicillin/beta-lactamase inhibitor combinations	Amoxicillin-clavulanate	13.0	28.3	18.8	27.1				
	Ampicillin-sulbactam	27.5	22.1	44.1	45.3[b]	55.9	73.7		
	Piperacillin-tazobactam	5.2	6.3	27.1	34.9	63.9	87.5	21.2	30.2
Cephalosporins	Cefazolin (1st GC)	45.6	44.4	32.3	44.4				
	Cefuroxime (2nd GC)	38.7	44.0	48.8	49.6				
	Cefoxitin (2nd GC)	8.5	10.8	24.0	25.5				
	Cefotaxime (3rd GC)	32.8	44.1	38.4	45.6				
	Ceftriaxone (3rd GC)	26.4	30.4[b]	45.5	46.8[b]	67.3	88.7		
	Ceftazidime (3rd GC)					76.7	85.1	20.4	27.6
	Cefepime (4th GC)	37.4	42.8	37.6	39.6	65.3	76.0	15.2	19.9
	Ceftazidime-avibactam	0.9	NA[a]	4.6	NA[a]			14.3	NA[a]
	Ceftolozane-tazobactam							80.0[b]	20.0[b]
Carbapenems	Imipenem	1.3	1.2	16.1	19.3	67.9	87.2	23.9	27.3
	Meropenem	1.4	1.3	17.1	24.9	66.3	87.4	20.2	25.0
	Ertapenem	1.1	1.7	10.2	20.5				
Tetracyclines	Tetracycline	41.5	45.0[b]	36.4	51.7[b]				
	Minocycline					1.2	9.9		
Aminoglycosides	Gentamicin	25.0	23.6	14.4	23.9	58.9	76.9		
	Tobramycin	25.5	6.0	27.2	19.7	57.2	89.8	11.2	8.1
	Amikacin	1.1	0.4	1.0	2.1	53.9	49.1		
Fluoroquinolones	Ciprofloxacin	49.4	53.1	40.9	44.6			29.0	28.3
	Levofloxacin	46.9	100.0	34.1	100.0	64.0	85.2	28.6	30.2
Folate pathway inhibitors	Trimethoprim-sulfamethoxazole	37.6	37.0	40.0	35.2	61.1	83.3		
Total No. of isolates		115,557	64,388	56,471	40,398	6,179	7,658	16,895	3,301

The numbers shown in the colored cells indicate the antimicrobial resistance rates. Color-coded as follows: red (76.0–100%), orange (51.0–75.9%), yellow (26.0–50.9%), sky blue (1.0–25.9%), and blue (0.0–0.9%).

[a]None of the hospitals performed the test; [b]Only one hospital contributed data.

Abbreviations: ECO, *Escherichia coli*; KPN, *Klebsiella pneumoniae*; ABM, *Acinetobacter baumannii*; PAE, *Pseudomonas aeruginosa*; First, first isolate group; Dup, duplicate group; GC, generation cephalosporins; NA, not available.

Discussion

Interpretation/comparison with previous studies

This study analyzed the resistance rates of major pathogens isolated from bloodstream infections in Korea in 2023 using AST data from 16 university-affiliated hospitals and compared the findings with the 2023 Kor-GLASS annual report [8]. As Kor-GLASS excluded duplicate results, comparisons were made only with the first isolate group (nine hospitals). Our dataset includes a higher number of isolates, whereas Kor-GLASS covers a broader geographic range. For *S. aureus, S. pneumoniae, E. faecalis*, and *E. faecium*, Kor-GLASS collected only 832, 27, 287, and 543 isolates, respectively, compared to 23,692, 1,059, 14,694, and 14,188 isolates, respectively, in our dataset. For *E. coli, K. pneumoniae, A. baumannii,* and *P. aeruginosa*, Kor-GLASS collected 2,844, 1,244, 269, and 269 isolates, respectively, compared to 115,557, 56,471, 6,179, and 16,895 isolates, respectively in our study. Kor-GLASS included 11 general hospitals from each of the 10 regions, providing a more balanced regional distribution than that in our study, comprising five hospitals in Seoul, one in Gyeongbuk, two in Gyeongnam, and one in Busan.

For *S. aureus*, the methicillin-resistant *S. aureus* (MRSA) rate in Kor-GLASS was 45.2%, similar to previous years, whereas our data showed a rate of 39.1%, which is 6.1% lower than that of Kor-GLASS. The multidrug-resistant (MDR) *S. aureus* rate was 47.6% in Kor-GLASS and 84.6% (22/26) in long-term care hospitals, with SCC*mec* type IV, the most prevalent genotype (30.5%) [8,9], characterized by high transmissibility and rapid growth and is now increasingly observed among MRSA strains worldwide [10-12].

For *S. pneumoniae*, the small number of isolates analyzed in Kor-GLASS (27 isolates) limits the generalizability; the resistance rates for penicillin, cefotaxime, ceftriaxone, and meropenem were 11.1%, 7.4%, 7.4%, and 51.9%, respectively, all of which were significantly lower than those observed in our study (38.9%, 33.3%, 16.7%, and 62.5%, respectively). Resistance to erythromycin was also high in both Kor-GLASS (81.5%) and our study (87.8%). Jung et al. [13] reported 7.7% penicillin and cefotaxime and 92.3% erythromycin resistance among *S. pneumoniae* isolates from invasive infections in a children's hospital (2014–2018) in South Korea, showing especially high erythromycin resistance. As data on macrolide resistance in *S. pneumoniae* from bloodstream infections in our country are limited, Kor-GLASS is needed to monitor resistance rates separately by age, particularly for pediatric patients.

For *E. faecium*, the resistance rates to ampicillin (89.0% in Kor-GLASS, 89.6% in our data) and vancomycin (34.6% and 33.6%) were high or moderate, respectively, whereas linezolid resistance was very low (0.0% and 0.1%, respectively). Daptomycin resistance differed markedly (0.7% vs. 29.3%), likely because of a bias of 90.9% (676/744) in the isolates originating from a single hospital. The prevalence of MDR *E. faecium* steadily increased, reaching 65.7% in Kor-GLASS. Although *vanB*-positive vancomycin-resistant enterococci (VRE) remains rare (0.5%) [8], its increasing prevalence in regions such as Europe and Australia, and its potential to spread resistance genes [14,15], particularly in anaerobic bacteria, underscores the need for ongoing surveillance. For *E. faecalis*, the ampicillin and vancomycin resistance rates were very low in both Kor-GLASS (0.7% each) and our data (0.3% each). Two vancomycin-resistant *E. faecalis* isolates from Kor-GLASS carried *vanA*. The high gentamicin and streptomycin resistance rates in Kor-

GLASS were 42.2% and 5.9 %, respectively, which are similar to our data (37.7% and 11.6%, respectively). High-level gentamicin resistance in *E. faecalis* is clinically significant owing to its association with combination therapy failure, and its rate has declined steadily in Kor-GLASS over the past 3 years. A meta-analysis [16] reported a high-level gentamicin resistance of 44.3%, which is consistent with data from South Korea. The proportion of MDR isolates in Kor-GLASS was 3.8% for *E. faecalis*, which was substantially lower than the 65.7% observed for *E. faecium*.

For *E. coli*, the resistance rates were 38.9% for cefotaxime and 12.0% for ceftazidime in Kor-GLASS, whereas our data showed rates of 32.8% and 26.4%, respectively. The predominance of CTX-M likely explains the higher cefotaxime resistance among 3rd generation cephalosporins [17]. Carbapenem resistance rates were very low in Kor-GLASS (imipenem, 0.2%; meropenem, 0.2%; and ertapenem, 0.7%) and slightly higher in our study (1.3%, 1.4%, and 1.1%, respectively). Kor-GLASS identified seven carbapenem-resistant (CR) *E. coli* isolates. KPC is now the most common type in South Korea [8,18], whereas NDM-1 and OXA-48 have been more frequently reported [19].

For *K. pneumoniae*, Kor-GLASS reported resistance rates of 42.6% for cefotaxime and 30.3% for ceftazidime, whereas our data showed rates of 45.6% and 46.8%, respectively. Carbapenem resistance was lower, probably due to the small number of isolates, but increased in Kor-GLASS (5.9%–7.2% among 1,244 isolates) and higher in our data (10.2%–17.1% among 4,199–6,950 isolates), while a single-center study in South Korea also reported a 10% prevalence in 2020 [20]. In South Korea, carbapenemase-producing *Enterobacterales* (CPE) account for 63.4% of carbapenem-resistant *Enterobacterals* infections [21], with *K. pneumoniae* accounting for 58.9% [22]. Recently, KPC-2, NDM-1, and OXA-48 have become the most common carbapenemase-producing (CP)-*K. pneumoniae* strains [18,22], and KPC is the most prevalent strain globally [23]. The use of ceftazidime-avibactam for KPC producers has led to resistant KPC variants and increased ceftazidime-avibactam-resistance [24] and NDM-producing *K. pneumoniae*, with resistance rates of 5.5% in Kor-GLASS and 4.6% in our data. However, continued surveillance is needed considering the rapid global spread of CPE [6].

CR-*A. baumannii* remains a major global issue, with Kor-GLASS reporting very high resistance rates (85.3%–85.6%) compared to our data showing 66.3%–67.9% based on relatively few isolates (269 in Kor-GLASS, 588 in our data), while WHO/European Centre for Disease Prevention and Control (2020–2022) [4] reported prevalence exceeding 50% in 35 countries and 96.3% in the Asia-Pacific region [25]. OXA-23 is the predominant carbapenemase globally as well as in South Korea (99.3% in Kor-GLASS). In Kor-GLASS, resistance rates for ampicillin-sulbactam, minocycline, tigecycline, and colistin used for OXA-23-producing *A. baumannii* were 77.4%, 7.6%, 2.3%, and 1.1%, respectively, along with Asia-Pacific data (over 80%, 7.2%, 6.7%, and 1.7%, respectively) [25], whereas our data showed lower rates for ampicillin-sulbactam (55.9%) and minocycline (1.2%).

For *P. aeruginosa,* piperacillin-tazobactam resistance was 20.4%–24.9% in Kor-GLASS and 21.2% in our study. The carbapenem resistance rates for imipenem and meropenem were 30.5% and 27.1% in Kor-GLASS (269 isolates), 35.4% and 34.4% in Choi et al. [26] (212 isolates), and 23.9% and 20.2% in our data (2,147 isolates), respectively, likely due to differences in the number of isolates. In Kor-GLASS, CP-

P. aeruginosa was 45.1% of the CR isolates, mainly NDM-1 and GES genotypes; however, Choi et al. [26] found IMP-6 and NDM-1 most frequently, indicating genotype heterogeneity. Globally, VIM and IMP are the most common, with IMP prevalent in the Asia-Pacific region and NDM increasing in Europe and Asia [27].

Although new agents such as lefamulin, tedizolid, sulbactam-durlobactam, imipenem-relebactam, meropenem-vaborbactam, plazomicin, and cefiderocol have been developed to address the increasing antibiotic resistance, none were used in the hospitals surveyed. Meta-analyses have identified resistance to imipenem-relebactam (14.6% among gram-negative bacilli, higher in intensive care units [ICUs] and developing countries) [28] and cefiderocol (3.0% in *A. baumannii*, 1.4% in *P. aeruginosa*) [29], emphasizing the need for ongoing monitoring. Because resistance inevitably increases over time, antimicrobial stewardship programs (ASP) are crucial for prevention. Alawi et al. [30] achieved a 40% reduction in intravenous antibiotic use, leading to an 80.9% decrease in the incidence of MDR organisms in ICUs and a 62.0% decrease in long-term care facilities over 5 years. Sumathi et al. [31] reduced the duration of antibiotic use from 12 to 8 days and lowered the MRSA rates from 45% to 30% in India. In addition, ASPs have shown substantial economic impacts: Timbrook et al. [32] reported a 16.4% decrease in daily antibiotic use and savings of 1,892,895 USD in the US; Banan et al. [33] observed a 55.5% (5,669.2 USD) reduction in expenses for colistin, meropenem, and tigecycline in Palestine.

Limitations

A major limitation of this study was its focus on university-affiliated hospitals, excluding smaller hospitals and long-term care facilities where AMR may be more prevalent. From 2020 to 2022, the average antibiotic use in South Korean clinics and long-term care hospitals was 17.7% and 7.2% higher, respectively, than that in general hospitals [8], and 34.9% of long-term care physicians acknowledged unnecessary or inappropriate antibiotic prescriptions [34]. The predominance of institutions in Seoul and other metropolitan areas further limits regional generalizability. We included both the first isolate and duplicate data, which might have affected the resistance rate if AMR strains were isolated more frequently. The AMR data for the duplicate group showed similar or slightly higher resistance rates. Finally, although the AST methods and equipment were not standardized among the participating hospitals, they may have affected the AMR data.

Conclusion

This study analyzed AMR rates of the bloodstream isolates of major gram-positive and gram-negative bacteria in university-affiliated hospitals, showing trends largely consistent with Kor-GLASS (2023), except for higher CR-*K. pneumoniae*. Moreover, this study demonstrated that a retrospective multicenter analysis can provide valuable insights into the AMR rates of blood culture isolates. Broader surveillance across diverse hospital types and regions and monitoring of resistance to new antibiotics are needed for the effective management of major pathogens causing bloodstream infections.

Ethics statement

This study was approved by the Institutional Review Board of Gyeongsang National University Changwon Hospital (IRB No. 2024-09-011).

Conflicts of interest

No potential conflicts of interest relevant to this article were reported.

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Data availability

The datasets generated during the current study are available from the corresponding author upon request.

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