

Antimicrobial resistance of clinical isolates of bacteria in 2023

The antimicrobial susceptibility of major bacteria isolated from various clinical specimens sent to the Seoul Clinical Laboratories (SCL) in January-December 2023 were analyzed by hospital type. Request for bacteria cultures were received from general hospitals (GH) with more than 100 beds, small and medium-sized hospitals (SMH) with fewer than 100 beds, and long-term care hospitals (LTCH). Bacterial identification was performed using MALDI TOF MS Biotyper (Bruker Daltonics GmbH, Bremen, Germany). Antimicrobial susceptibility was tested using a VITEK 2 (bioMérieux, Marcy-l'Etoile, France) instrument according to the criteria of the Clinical and Laboratory Standards Institute (CLSI). From June 2023, some test agents have changed due to changes in the VITEK 2 susceptibility test card. Additional test agents are indicated in green, and data on deleted agents were excluded. All susceptibility data for infection control and duplicated data from the same patient were excluded.

Table 1. Antimicrobial susceptibility (%) of frequently isolated *Enterobacterales* at different types of hospitals in Korea in 2023

Antimicrobial agents	<i>Escherichia coli</i>			<i>Klebsiella pneumoniae</i>			<i>K. (Enterobacter) aerogenes</i>			<i>Klebsiella oxytoca</i>		
	SMH	GH	LTCH	SMH	GH	LTCH	SMH	GH	LTCH	SMH	GH	LTCH
	(26215)	(9000)	(2066)	(3434)	(1801)	(775)	(877)	(201)	(22)	(296)	(144)	(18)
	S R	S R	S R	S R	S R	S R	S R	S R	S R	S R	S R	S R
Ampicillin	32 67	28 71	9 91	0 100	0 100	0 100	0 100	0 100	0 100	0 100	0 99	0 100
Amox-clavulanate	76 12	72 12	44 26	59 23	60 24	26 45	0 100	0 100	0 100	92 5	92 5	94 6
Pip-tazobactam	92 6	90 8	68 27	60 32	58 36	25 63	88 10	85 13	29 71	89 5	91 5	100 0
Cefazolin	63 36	56 43	22 78	52 47	53 47	18 82	0 100	0 100	0 100	57 39	60 34	22 78
Cefotaxime	71 29	64 36	25 75	54 46	53 46	20 80	86 13	79 21	36 64	94 6	96 4	83 11
Ceftazidime	80 13	76 16	38 51	56 41	58 39	23 73	87 12	79 21	41 59	96 4	97 3	94 6
Cefepime	83 12	78 16	41 46	63 33	61 35	33 60	98 1	98 2	77 23	99 1	100 0	100 0
Ertapenem	99 <1	99 0	93 6	87 11	85 14	75 23	99 0	99 0	71 21	99 0	100 0	100 0
Imipenem	99 <1	99 0	94 5	88 10	86 12	75 21	95 0	92 1	77 18	99 1	99 0	100 0
Meropenem	100 0	100 0	95 5	89 10	87 13	77 22	100 0	100 0	82 18	99 <1	100 0	100 0
Ciprofloxacin	38 50	34 55	9 85	48 49	48 49	14 83	96 3	95 5	73 18	90 8	87 10	67 22
Amikacin	98 1	97 2	87 10	96 4	94 5	91 8	100 0	100 0	91 9	100 0	100 0	100 0
Gentamicin	76 24	74 26	57 42	77 21	76 23	59 41	99 1	99 1	95 5	99 1	98 2	100 0
Tobramycin	73 18	70 21	41 49	64 28	64 30	33 55	99 1	98 2	82 14	98 2	97 2	100 0
Cotrimoxazole	65 35	64 36	52 48	66 34	67 33	41 59	98 2	98 3	82 18	95 5	96 4	94 6
Nitrofurantoin	97 1	96 1	92 4	16 36	13 41	10 57	17 11	13 10	20 40	86 0	82 0	100 0

Antimicrobial agents	<i>Enterobacter cloacae</i>			<i>Citrobacter freundii</i>			<i>Citrobacter koseri</i>			<i>Serratia marcescens</i>		
	SMH	GH	LTCH	SMH	GH	LTCH	SMH	GH	LTCH	SMH	GH	LTCH
	(634)	(308)	(70)	(556)	(219)	(47)	(355)	(89)	(110)	(392)	(149)	(80)
	S R	S R	S R	S R	S R	S R	S R	S R	S R	S R	S R	S R
Ampicillin	1 98	1 99	1 99	6 94	3 97	2 96	0 100	0 100	0 100	0 99	1 99	0 96
Amox-clavulanate	1 99	1 99	0 100	7 92	3 96	6 94	83 11	86 11	17 64	1 99	0 99	0 98
Pip-tazobactam	76 18	81 16	55 39	81 14	70 22	76 20	84 15	83 13	18 65	94 4	97 1	69 29
Cefazolin	1 99	1 99	0 100	1 99	0 100	2 98	81 19	83 17	13 87	0 100	0 100	0 100
Cefotaxime	72 28	72 28	27 70	79 21	69 31	64 36	81 19	80 20	15 85	87 11	91 9	54 44
Ceftazidime	73 26	73 26	37 60	81 18	69 29	68 32	82 18	88 13	19 78	94 5	97 3	85 11
Cefepime	85 10	86 11	60 27	97 2	96 3	87 13	83 16	92 6	27 66	95 4	97 2	85 6
Ertapenem	93 1	93 2	82 11	97 2	98 1	88 13	93 5	98 0	65 31	97 2	100 0	95 5
Imipenem	98 1	95 3	91 9	98 1	99 0	89 6	95 4	99 0	69 25	96 3	97 0	89 8
Meropenem	99 1	97 3	91 9	99 1	100 0	94 6	95 5	99 0	70 25	97 3	100 0	93 8
Ciprofloxacin	72 22	76 20	26 66	58 36	62 29	49 40	80 17	84 11	17 76	79 19	84 14	21 75
Amikacin	99 1	97 2	94 6	98 2	99 1	96 4	97 2	95 5	73 27	98 2	100 0	93 5
Gentamicin	90 10	92 7	70 29	89 10	91 8	91 9	86 14	90 9	28 72	96 4	99 1	88 13
Tobramycin	88 11	90 7	56 37	85 8	86 9	81 17	84 12	91 8	28 52	77 5	78 3	69 18
Cotrimoxazole	87 13	91 9	51 49	82 18	84 16	81 19	97 3	94 6	77 23	98 2	100 0	96 4
Nitrofurantoin	46 9	42 1	38 8	94 0	94 1	95 0	86 1	76 2	43 31	0 99	0 100	0 100

Antimicrobial agents	<i>Morganella morganii</i>			<i>Proteus mirabilis</i>			<i>Providencia rettigeri</i>			<i>Providencia stuartii</i>		
	SMH (483)	GH (137)	LTCH (118)	SMH (1830)	GH (582)	LTCH (925)	SMH (156)	GH (66)	LTCH (126)	SMH (133)	GH (25)	LTCH (120)
	S R	S R	S R	S R	S R	S R	S R	S R	S R	S R	S R	S R
Ampicillin	1 99	0 100	0 100	37 63	35 65	3 97	0 100	2 97	1 98	0 100	0 100	0 100
Amox-clavulanate	1 99	0 100	0 100	59 14	59 15	37 26	0 100	0 100	0 99	0 100	0 100	0 100
Pip-tazobactam	96 4	97 3	86 14	95 4	97 3	90 7	66 34	90 10	70 29	95 5	100 0	94 6
Cefazolin	1 99	0 100	0 100	50 49	48 51	8 92	1 99	0 100	1 98	0 100	0 100	0 100
Cefotaxime	67 25	67 24	25 63	57 43	55 45	12 87	42 51	48 50	18 78	42 56	68 28	30 65
Ceftazidime	84 11	81 13	52 40	85 13	87 12	58 39	55 44	55 44	33 65	95 3	100 0	84 14
Cefepime	95 2	97 1	79 11	70 11	70 12	42 19	55 28	70 12	43 38	86 3	84 12	75 9
Ertapenem	98 0	99 0	98 2	100 0	100 0	98 1	79 18	96 2	88 8	100 0	100 0	97 3
Imipenem	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Meropenem	100 0	100 0	97 2	100 0	100 0	99 0	84 16	97 2	98 1	100 0	100 0	98 2
Ciprofloxacin	64 34	68 32	26 71	44 56	40 60	4 96	40 58	39 59	28 67	9 89	12 84	3 98
Amikacin	98 1	96 4	81 17	80 19	82 17	46 53	58 41	52 48	28 71	69 31	80 16	75 24
Gentamicin	83 16	88 13	50 46	51 47	51 47	13 84	53 41	74 26	19 77	1 98	0 100	0 100
Tobramycin	84 8	89 7	62 27	55 36	57 32	18 71	52 42	58 20	24 73	1 98	0 96	0 100
Cotrimoxazole	72 28	75 25	50 50	53 47	51 49	28 72	59 41	76 24	52 48	43 57	72 28	38 63
Nitrofurantoin	0 99	0 97	0 100	0 99	0 100	0 100	0 100	7 93	9 91	0 98	0 100	0 100

Abbreviation: SMH, small and medium-sized hospital; GH, general hospital; LTCH, long-term care hospital; (), No. tested; S, susceptible; R, resistant; Amox, amoxicillin; Pip, piperacillin; -, Not tested. Intrinsic resistances are blue shaded and additional antimicrobial agents tested are green shaded.

In 2023, *Escherichia coli* was the most commonly isolated bacteria, followed by *Pseudomonas aeruginosa*, coagulase-negative *Staphylococcus*, and *Klebsiella pneumoniae*. Among the Gram-negative rods, *K. pneumoniae*, *Acinetobacter baumannii*, and *Proteus mirabilis* were commonly isolated in addition to *E. coli*, *P. aeruginosa*. The antimicrobial susceptibilities of *Enterobacterales* are shown in Table 1; glucose-nonfermented Gram-negative rods are shown in Table 2; and staphylococci and enterococci are shown in Table 3. The cefotaxime resistance rates of *E. coli* were 29%, 36%, and 75% in SMH, GH, and LTCH, respectively, similar to the first generation cephalosporin resistance rates, and the carbapenem resistance rate was less than 6% (Table 1). The fluoroquinolone resistance rate was about 50% in SMH and GH, but more than 80% in LTCH. The rate of cotrimoxazole resistance was 48% in LTCH, which was slightly higher than those of SMH and GH. The carbapenem resistance rates were high at 21-23% for *K. pneumoniae*, at 18-21% for *K. (Enterobacter) aerogenes*, and at 25-31% for *Citrobacter koseri* in LTCH. Carbapenem-resistant *K. pneumoniae* was also high in SMH and GH, 10-11% and 12-14%, respectively. The cefotaxime resistance rates of *Enterobacter cloacae*, *K. (E.) aerogenes*, and *Morganella morganii* isolated from LTCH increased by 10-18% compared to 2022.

Table 2. Antimicrobial susceptibility (%) of frequently isolated glucose nonfermenting gram-negative bacilli at different types of hospitals in Korea in 2023

Antimicrobial agents	<i>Acinetobacter baumannii</i>			<i>Acinetobacter spp.</i>			<i>Pseudomonas aeruginosa</i>			<i>Stenotrophomonas maltophilia</i>		
	SMH (1251)	GH (960)	LTCH (1616)	SMH (1114)	GH (585)	LTCH (604)	SMH (4106)	GH (2165)	LTCH (3306)	SMH (723)	GH (537)	LTCH (545)
	S R	S R	S R	S R	S R	S R	S R	S R	S R	S R	S R	S R
Amp-sulbactam	25 53	19 63	9 65	75 14	74 14	63 26	- -	- -	- -	- -	- -	- -
Pip-tazobactam	19 81	15 85	4 96	53 42	49 46	27 68	50 42	55 35	34 56	- -	- -	- -
Ceftazidime	20 79	16 84	6 94	60 27	55 24	50 39	62 31	64 29	53 38	- -	- -	- -
Cefepime	- -	- -	- -	- -	- -	- -	61 27	65 25	52 32	- -	- -	- -
Imipenem	20 80	15 85	5 95	69 30	61 37	51 46	54 45	58 40	39 59	- -	- -	- -
Meropenem	18 81	15 85	4 95	66 33	58 40	48 47	54 40	60 34	41 52	- -	- -	- -
Amikacin	57 41	53 45	45 51	84 12	89 9	70 20	- -	- -	- -	- -	- -	- -
Gentamicin	28 68	26 71	15 79	68 27	63 29	53 36	- -	- -	- -	- -	- -	- -
Tobramycin	32 68	25 75	19 81	66 32	61 38	60 40	71 28	74 26	55 45	- -	- -	- -
Ciprofloxacin	16 83	13 86	3 97	50 45	48 49	24 74	46 51	51 45	27 71	- -	- -	- -
Levofloxacin	22 74	17 82	4 90	57 30	53 36	31 45	- -	- -	- -	75 18	80 15	72 20
Cotrimoxazole	29 71	24 76	15 85	72 28	78 22	59 41	- -	- -	- -	87 13	89 11	83 17
Tetracycline	21 30	29 18	14 31	67 25	68 32	27 47	- -	- -	- -	- -	- -	- -
Minocycline	- -	- -	- -	- -	- -	- -	- -	- -	- -	93 3	96 1	95 3

Abbreviation: Amp, ampicillin; Pip, piperacillin.

The resistance rates of *A. baumannii* were 53-65% for ampicillin-sulbactam, 80-95% for carbapenem, 74-97% for fluoroquinolone and 41-51% for amikacin. By contrast, the resistance rates of non-*baumannii* *Acinetobacter* isolates were 14-26% for ampicillin sulbactam, 30-47% for carbapenem, and 9-20% for amikacin, and the rates increased by 6-7%, 10-15%, and 5-6%, respectively, compared to 2022 (Table 2). The resistance rates of *P. aeruginosa* were 29-38% for ceftazidime, 35-56% for piperacillin-tazobactam, 34-59% for carbapenem, and 45-71% for ciproflouxacin, which were similar to the resistance rates of isolates in 2022. Both *Acinetobacter* and *P. aeruginosa* had high resistance rates among isolates from LTCH. *Stenotrophomonas maltophilia* resistance rates were 15-20% for levofloxacin, 11-17% for cotrimoxazole, and 1-3% for minocycline.

Table 3. Antimicrobial susceptibility (%) of *Staphylococcus* and *Enterococcus* at different types of hospitals in Korea in 2023

Antimicrobial agents	<i>Staphylococcus aureus</i>						Coagulase-neg. <i>Staphylococcus</i>						<i>Enterococcus faecalis</i>						<i>Enterococcus faecium</i>					
	SMH		GH		LTCH		SMH		GH		LTCH		SMH		GH		LTCH		SMH		GH		LTCH	
	(3553)		(1464)		(468)		(7033)		(2205)		(847)		(3484)		(1129)		(288)		(965)		(790)		(459)	
	S	R	S	R	S	R	S	R	S	R	S	R	S	R	S	R	S	R	S	R	S	R	S	R
Ampicillin	-	-	-	-	-	-	-	-	-	-	-	-	99	1	99	1	99	1	9	91	5	95	3	97
Penicillin G	14	86	11	89	2	98	11	89	9	91	1	98	94	6	85	15	77	23	8	92	4	96	3	97
Oxacillin	52	48	46	54	8	92	41	59	32	68	4	96	-	-	-	-	-	-	-	-	-	-	-	-
Clindamycin	71	29	65	35	46	54	70	28	66	33	46	52	-	-	-	-	-	-	-	-	-	-	-	-
Erythromycin	67	32	61	38	39	61	57	47	48	51	36	63	-	-	-	-	-	-	-	-	-	-	-	-
Tetracycline	85	15	84	16	88	12	83	17	82	18	83	17	14	86	15	85	7	93	78	22	87	13	88	12
Tigecycline	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Cotrimoxazole	97	3	97	4	94	6	90	10	88	12	84	16	-	-	-	-	-	-	-	-	-	-	-	-
Ciprofloxacin	68	31	66	33	14	85	66	31	59	37	14	82	79	20	63	36	16	83	4	95	1	98	1	99
Levofloxacin	70	30	67	33	18	82	64	35	61	39	14	85	-	-	-	-	-	-	-	-	-	-	-	-
Teicoplanin	100	0	100	0	100	0	96	2	95	2	95	3	99	1	99	1	98	2	74	25	70	30	62	37
Vancomycin	100	0	100	0	100	0	100	0	100	0	100	0	100	0	99	1	99	1	64	36	62	38	51	49
Gentamicin	72	23	74	21	42	47	65	17	64	19	35	39	-	-	-	-	-	-	-	-	-	-	-	-
Linezolid	100	0	100	0	100	0	100	0	99	1	100	0	100	0	100	0	100	0	99	<1	100	0	100	0
Rifampin	99	1	99	1	99	1	94	5	93	7	82	16	-	-	-	-	-	-	-	-	-	-	-	-
Nitrofurantoin	-	-	-	-	-	-	-	-	-	-	-	-	99	<1	99	<1	98	1	7	73	6	79	6	81

The oxacillin resistance rate of *Staphylococcus aureus* (MRSA) was 48% and 54% in SMH and GH, respectively, and 92% in LTCH. The resistance rates were 29-54% for clindamycin, 3-6% for cotrimoxazole, and 0% for vancomycin, teicoplanin, tigecycline, and linezolid (Table 3). The antimicrobial resistance of coagulase-negative *Staphylococcus* was similar to those of *S. aureus*, but the resistance rates to cotrimoxazole were 10-16%. The ampicillin resistance rate of *E. faecalis* was less than 1%, whereas that of *E. faecium* was 91-97%. Vancomycin and teicoplanin resistance rates were less than 2% for *E. faecalis*, but 25-49% for *E. faecium*. Nitrofurantoin resistance rate was less than 1% for *E. faecalis*, but was 73-81% for *E. faecium*. The resistance rates of Gram-positive cocci were similar to 2022, but the teicoplanin and vancomycin resistance rates of *E. faecium* isolated in LTCH increased by 17% and 7%, respectively.

Spectrum of activity of zosurabalpin

Microorganism	MIC (mg/L)	
	Zosurabalpin	Meropenem
<i>E. coli</i> ATCC 25922	>64	≤0.06
<i>K. pneumoniae</i> ATCC 700603	>64	≤0.06
<i>P. aeruginosa</i> ATCC 27853	>64	0.5
<i>S. aureus</i> ATCC 29213	>64	0.12
<i>C. albicans</i> ATCC 90028	>64	>64
<i>A. baumannii</i> ATCC 17978	≤0.06	0.5
<i>A. baumannii</i> ATCC 19606	0.25	1
<i>A. baumannii</i> (10 MDR isolates)	0.25 (0.12-1)	64 (1-64)

