JIDC | THE JOURNAL OF INFECTION IN DEVELOPING COUNTRIES

Original Article

A nine-year surveillance of healthcare-associated infections in a pediatric Intensive Care Unit: epidemiology, pathogens, and antimicrobial resistance trends

Eren Çağan[1], Şeyma Nur Karataş[2], Begüm Bodur[2], Abdullah Taşdelen[2], Nevin Kiliç[3]

[1] *Pediatric Infectious Diseases, Bursa Yüksek İhtisas Training and Research Hospital, Bursa, Turkey*
[2] *Department of Pediatrics, Bursa Yüksek İhtisas Training and Research Hospital, Bursa, Turkey*
[3] *Department of Pediatric Intensive Care Unit, Bursa Yüksek İhtisas Training and Research Hospital Bursa, Turkey*

Abstract

Introduction: Healthcare-associated infections (HAIs) remain a major cause of morbidity and mortality in pediatric intensive care units (PICUs), particularly in the context of increasing antimicrobial resistance. This study aimed to evaluate the incidence of HAIs, causative microorganisms, antimicrobial resistance patterns, and temporal trends over a nine-year period in the PICU of a tertiary care hospital.

Methodology: HAI data obtained through active surveillance between January 1, 2016, and December 31, 2024, were retrospectively analyzed. Patients who developed HAIs during their PICU stay were included. Diagnoses were established according to the National Healthcare-Associated Infections Surveillance Network (UHESA) criteria adapted from CDC definitions. Microorganisms were identified using the automated VITEK® 2 system (bioMérieux), and antimicrobial susceptibility testing was interpreted according to EUCAST criteria. Data were evaluated by calendar year and in three-year intervals.

Results: No statistically significant change in HAI incidence was observed over the nine-year period ($p = 0.56$). Gram-negative bacteria were the most frequently isolated pathogens, particularly *Klebsiella pneumoniae* and *Pseudomonas aeruginosa*. Among Gram-positive organisms, *Staphylococcus aureus* and coagulase-negative staphylococci predominated, while *Candida* species were the most common fungal isolates. The mortality rate among patients with HAIs was 44.7%, markedly higher than the overall PICU mortality rate (1.72%). Resistance rates increased notably, especially for carbapenems and colistin, whereas resistance to linezolid and vancomycin remained limited.

Conclusions: HAIs continue to represent a major clinical challenge in PICUs. Increasing resistance among Gram-negative pathogens highlights the urgent need for strengthened infection control strategies, continuous surveillance, and effective antimicrobial stewardship programs.

Key words: pediatric intensive care unit; healthcare-associated infections; antimicrobial resistance; Gram-negative bacteria; bloodstream infections; infection control.

J Infect Dev Ctries 2026; 20(8):1171-1178. doi:10.3855/jidc.22442

(Received 01 October 2025 – Accepted 11 March 2026)

Introduction

Healthcare-associated infections (HAIs) continue to pose a serious health problem, particularly in intensive care units (ICUs), where they are associated with high morbidity and mortality [1,2]. Pediatric intensive care units (PICUs) care for critically ill children who often require prolonged invasive interventions and may be immunocompromised; therefore, PICUs constitute clinical environments with a high propensity for HAI development [3]. In the literature, HAI incidence in PICUs ranges from 5% to 25%, with substantial differences across countries and centers depending on healthcare system levels, implemented infection control measures, and patient profiles [4,5]. In this study, active surveillance data collected in the Bursa Yüksek İhtisas Training and Research Hospital PICU between January 1, 2016, and December 31, 2024, were retrospectively analyzed to assess HAI incidence, distribution of causative microorganisms, and changes in antimicrobial resistance patterns over time.

Recent reports from the World Health Organization (WHO) and the Centers for Disease Control and Prevention (CDC), particularly their global evaluations for 2023–2024, emphasize that HAIs in ICUs remain among the most critical patient safety challenges [4,6]. These reports indicate that rising antibiotic resistance in Gram-negative pathogens poses substantial treatment challenges and that resistance patterns vary considerably across countries. In this context, our study aims to present long-term data specific to PICUs in our country, in line with the global findings mentioned.

Methodology

Study Design and Setting

Bursa Yuksek Ihtisas Training and Research Hospital is a 1520-bed tertiary referral center. The PICU has a 17-bed capacity. Infection prevention and control activities are conducted by a multidisciplinary Infection Control Committee, including an infection control physician and dedicated infection control

nurses, with daily active surveillance performed in accordance with national regulations.

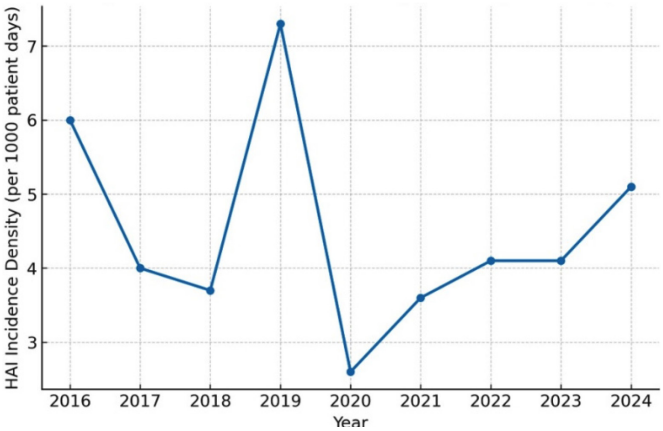
Study Period and Population

The PICU admits patients aged 1 month to 18 years, excluding neonatal intensive care patients. All patients monitored in the PICU between January 1, 2016, and December 31, 2024, were included. Infections that developed within the first 48 hours after ICU admission were excluded because they were not considered HAIs.

Surveillance and Definitions

HAI data were collected by the hospital's Infection Control Team using active surveillance. Definitions followed the National Healthcare-Associated Infections Surveillance Network (UHESA) guideline, which is adapted from the CDC/NHSN criteria and updated annually [7,8]. Device-associated infections were classified as ventilator-associated pneumonia (VAP), central line-associated bloodstream infection (CLABSI), and catheter-associated urinary tract infection (CAUTI). Incidence density was calculated as the number of healthcare-associated infection episodes divided by the total number of patient-days, expressed per 1000 patient-days (Incidence density = (Number of HAI episodes / Total patient-days) × 1000).

Figure 1. Annual incidence density of healthcare-associated infections (HAIs) in the Pediatric Intensive Care Unit between 2016 and 2024 (per 1000 patient days).



The blue line represents the annual HAI incidence density. Data points indicate yearly values, the horizontal axis shows calendar years, and the vertical axis indicates the number of infections per 1000 patient days.

Data Collection

Demographic characteristics, length of stay, durations of invasive device use, HAI types, causative microorganisms, and antimicrobial susceptibility results were obtained retrospectively from the UHESA database and the hospital microbiology laboratory information system.

Microbiological Methods

Clinical specimens were processed according to standard microbiological procedures, and organism identification and antimicrobial susceptibility testing were performed using automated systems in accordance with laboratory routine. Isolate susceptibilities were interpreted using the most up-to-date clinical breakpoints issued by the Clinical and Laboratory Standards Institute (CLSI) 2025 (and previous versions, 2015–2024) and/or the European Committee on Antimicrobial Susceptibility Testing (EUCAST) 2025 (and previous versions, 2015–2024) [9,10]. For colistin, only broth microdilution (BMD) was accepted as the reference method; the potential for false susceptibility or resistance with non-BMD methods was considered.

Statistical Analysis

Analyses were performed using SPSS version 23.0 (IBM Corp., Armonk, NY, USA). Categorical variables were analyzed using the chi-square test or Fisher's exact test where appropriate. For comparisons involving more than two groups of numerical variables, one-way ANOVA or the Kruskal–Wallis test was applied according to distribution. For pairwise comparisons of numerical variables, Student's t-test or the Mann–Whitney U test was used as appropriate. In time-series analyses, years were grouped into three-year periods (2016–2018, 2019–2021, 2022–2024). Infection incidence was expressed as the number of infection episodes per 1000 patient-days. A $p < 0.05$ was considered statistically significant.

Results

During the nine-year study period, a total of 5,974 patients were admitted to the PICU, among whom 224 were identified with HAIs. The HAI incidence density (per 1000 patient-days) was highest in 2024 at 6.6 and lowest in 2020 at 2.0 (Table 1, Figures 1–2).

Table 1. Annual distribution of healthcare-associated infection metrics.

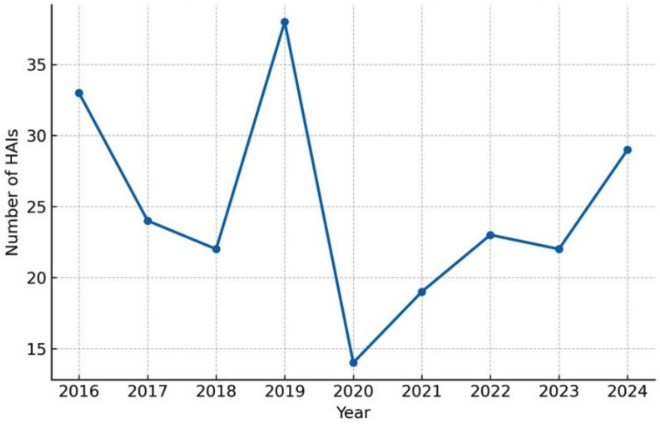
	2016	2017	2018	2019	2020	2021	2022	2023	2024	Total
Number of HAIs n (%)	33 (14.7)	24 (10.7)	22 (9.8)	38 (17)	14 (6.3)	19 (8.5)	23 (10.3)	22 (9.8)	29 (12.9)	224 (100)
Number of patients	653	726	827	642	698	758	626	611	433	5974
Total patient days	5412	5969	5820	5203	5299	5268	5592	5306	5592	49461
Rate of HAIs	5	3.3	2.6	5.9	2	2.5	3.6	3.6	6.6	3.7
Incidence Density	6	4	3.7	7.3	2.6	3.6	4.1	4.1	5.1	4.5

Table 2. Distribution of types of healthcare infections over the years.

	2016	2017	2018	2019	2020	2021	2022	2023	2024	Total
BSI	23 (69.7)	20 (83.3)	18 (81.8)	30 (78.9)	11 (78.6)	13 (68.4)	15 (65.2)	15 (68.2)	17 (58.6)	162 (72.3)
LCBSI-1	7 (21.2)	12 (50)	6 (27.3)	12 (31.6)	3 (21.4)	9 (47.4)	5 (21.7)	8 (36.4)	9 (31)	71 (31.7)
LCBSI-2	0 (0)	0 (0)	0 (0)	0 (0)	1 (7.1)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.4)
CLABSI	16 (48.5)	8 (33.3)	12 (54.5)	18 (47.4)	7 (50)	4 (21.4)	10 (43.5)	7 (31.8)	8 (27.6)	90 (40.2)
Pneumonia	6 (18.2)	2 (8.3)	3 (13.6)	5 (13.2)	2 (14.3)	6 (31.6)	4 (17.4)	4 (18.2)	9 (31)	41 (18.3)
VAP	16 (18.2)	2 (8.3)	2 (9.1)	4 (10.5)	2 (14.3)	6 (31.6)	4 (18.2)	4 (18.2)	7 (24.1)	37 (16.5)
PNU2	0 (0)	0 (0)	1 (4.5)	1 (2.6)	0 (0)	0 (0)	0 (0)	0 (0)	2 (6.9)	4 (1.8)
UTI	1 (3)	1 (4.2)	1 (4.5)	3 (7.9)	1 (7.1)	0 (0)	3 (13)	1 (4.5)	2 (6.9)	13 (5.8)
CAUTI	0 (0)	0 (0)	1 (4.5)	3 (7.9)	1 (7.1)	0 (0)	2 (8.7)	1 (4.5)	2 (6.9)	10 (4.5)
Non-CAUTI	0 (0)	1 (4.2)	0 (0)	0 (0)	0 (0)	0 (0)	1 (4.3)	0 (0)	0 (0)	2 (0.9)
ABUTI	1 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.4)
Meningitis or ventriculitis	1 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (4.3)	2 (9.1)	1 (3.4)	5 (2.2)
SSTI	2 (6.1)	1 (4.2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3 (1.3)
Total	33 (100)	24 (100)	22 (100)	38 (100)	14 (100)	19 (100)	23 (100)	22 (100)	29 (100)	224 (100)

Comparison of annual HAI incidence rates over the nine-year period showed no statistically significant difference (chi-square test for trend, $p = 0.56$). The median age of patients who developed HAIs was 1.27 years (IQR: 0.34–5.9), and 124 (55.4%) were male. While the overall PICU mortality during the study period was 1.72%, the mortality among patients who developed HAIs was significantly higher at 44.7%. At least one chronic comorbidity was present in 46.9% of patients. The most common comorbidities were chronic neurological diseases (32.2%), chronic heart diseases (8.9%), and congenital anomalies (7.1%), while the remaining 8.0% comprised chronic diseases of the renal, endocrine, hepatic, and other systems. Percentages of specific comorbidities exceed the overall prevalence because some patients had multiple chronic conditions.

Figure 2. Annual number of healthcare-associated infections (HAIs) in the Pediatric Intensive Care Unit between 2016 and 2024.



The bars represent the total annual number of HAIs. The horizontal axis shows calendar years, and the vertical axis indicates the absolute number of infections recorded each year.

Table 3. Distribution of microorganisms causing healthcare-associated infections over the years.

	2016	2017	2018	2019	2020	2021	2022	2023	2024	Total
Gram negative	21 (63.6)	16 (66.7)	14 (63.6)	28 (73.7)	7 (50)	13 (68.4)	14 (60.9)	15 (68.2)	23 (79.3)	151 (67.4)
Klebsiella pneumoniae	6 (18.2)	5 (20.8)	8 (36.4)	10 (26.3)	5 (35.7)	5 (26.3)	2 (8.7)	7 (31.8)	7 (24.1)	55 (24.6)
Klebsiella oxytoca	0 (0)	1 (4.2)	1 (4.5)	1 (2.6)	0 (0)	0 (0)	1 (4.3)	0 (0)	1 (3.4)	5 (2.2)
Pseudomonas aeruginosa	8 (24.2)	2 (8.3)	2 (9.1)	8 (21.1)	1 (7.1)	3 (15.8)	5 (21.7)	4 (18.2)	6 (20.7)	39 (17.4)
Acinetobacter baumannii	5 (15.2)	5 (20.8)	2 (9.1)	3 (7.9)	0 (0)	3 (15.8)	6 (26.1)	2 (9.1)	6 (20.7)	32 (14.3)
Escherichia coli	1 (3)	0 (0)	0 (0)	5 (13.2)	1 (7.1)	0 (0)	0 (0)	0 (0)	0 (0)	7 (3.1)
Stenotrophomonas maltophilia	0 (0)	1 (4.2)	1 (4.5)	0 (0)	0 (0)	1 (5.3)	0 (0)	0 (0)	1 (3.4)	4 (1.8)
Serratia marcescens	0 (0)	1 (4.2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (4.5)	0 (0)	2 (0.9)
Enterobacter spp.	0 (0)	1 (4.2)	0 (0)	1 (2.6)	0 (0)	1 (5.3)	0 (0)	0 (0)	1 (3.4)	4 (1.8)
Proteus mirabilis	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (3.4)	1 (0.4)
Citrobacter spp.	1 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.4)
Sphingomonas paucimobilis	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (4.5)	0 (0)	1 (0.4)
Gram positive	5 (15.2)	4 (16.7)	3 (13.6)	5 (13.2)	3 (21.4)	3 (15.8)	0 (0)	0 (0)	1 (3.4)	24 (10.7)
Staphylococcus aureus	3 (9.1)	4 (16.7)	0 (0)	4 (10.5)	2 (14.3)	2 (10.5)	0 (0)	0 (0)	1 (3.4)	16 (7.1)
Coagulase-negative staphylococci	0 (0)	0 (0)	2 (9.1)	1 (2.6)	1 (7.1)	1 (5.3)	0 (0)	0 (0)	0 (0)	5 (2.2)
Enterococcus faecium	2 (6.1)	0 (0)	1 (4.5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3 (1.3)
Candida species	7 (21.2)	4 (16.7)	5 (22.7)	5 (13.2)	4 (28.6)	3 (15.8)	9 (39.1)	7 (31.8)	5 (17.2)	49 (21.9)
Candida albicans	3 (9.1)	1 (4.2)	1 (4.5)	0 (0)	1 (7.1)	0 (0)	5 (21.7)	1 (4.5)	1 (3.4)	13 (5.8)
Candida parapsilosis	3 (9.1)	2 (8.3)	3 (13.6)	4 (10.5)	3 (21.4)	1 (5.3)	1 (4.3)	3 (13.6)	3 (10.3)	23 (10.3)
Candida tropicalis	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1(5.3)	2 (8.7)	0 (0)	1 (3.4)	4 (1.8)
Candida lusitaniae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (4.3)	1 (4.2)	0 (0)	2 (0.9)
Candida glabrata	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (4.5)	0 (0)	1 (0.4)
Candida spp. (unidentified)	1 (3)	1 (4.2)	1 (4.3)	1 (2.6)	0 (0)	1 (5.3)	0 (0)	1 (4.5)	0 (0)	6 (2.7)
Total	33 (14.7)	24 (10.7)	22 (9.8)	38 (17)	14 (6.3)	19 (8.5)	23 (10.3)	22 (9.8)	29 (12.9)	224 (100)

Table 4. Distribution of causative microorganisms by types of healthcare-associated infections.

Subtypes of HAIs n (%)	BSI	Pneu	SSTI	UTI	CNS	All HAIs
Gram-negative, HAIs n (%)	93 (57.4) (41.5)	38 (92.6) (16.9)	3 (100) (1.3)	13 (100) (5.8)	4 (80) (1.8)	151 (100) (67.4)
Klebsiella pneumoniae	40 (24.7) (17.8)	9 (22) (4)	0 (0)	5 (38.5) (2.2)	1 (20) (0.4)	55 (100) (24.5)
Acinetobacter baumannii	20 (12.3) (8.9)	14 (34.1) (6.2)	1 (33.3) (0.4)	3 (23.1) (1.3)	1 (20) (0.4)	39 (100) (17.4)
Escherichia coli	14 (8.6) (6.2)	14 (34.1) (6.2)	1 (33.3) (0.4)	1 (7.7) (0.4)	2 (40) (0.9)	32 (100) (14.2)
Pseudomonas aeruginosa	4 (2.5) (1.8)	0 (0) (0)	0 (0) (0)	1 (7.7) (0.4)	0 (0) (0)	5 (100) (2.2)
Klebsiella oxytoca	4 (2.5) (1.8)	0 (0) (0)	0 (0) (0)	3 (23.1) (1.3)	0 (0) (0)	7 (100) (3.1)
Others*	11 (6.8) (4.9)	1 (2.4) (0.4)	1 (33.3) (0.4)	0 (0) (0)	0 (0) (0)	13 (100) (5.8)
Gram positive, HAIs n (%)	21 (13) (9.3)	3 (12.5) (1.3)	0 (0) (0)	0 (0) (0)	0 (0) (0)	24 (100) (10.7)
Staphylococcus aureus	13 (8) (5.8)	3 (7.3) (1.3)	0 (0) (0)	0 (0) (0)	0 (0) (0)	16 (100) (7.1)
CoNS*	5 (3.1) (2.2)	0 (0) (0)	0 (0) (0)	0 (0) (0)	0 (0) (0)	5 (100) (2.2)
Enterococcus faecium	3 (1.9) (1.3)	0 (0) (0)	0 (0) (0)	0 (0) (0)	0 (0) (0)	3 (100) (1.3)
Candida species, HAIs n (%)	48 (29.6) (21.4)	0 (0) (0)	0 (0) (0)	0 (0) (0)	1 (20) (0.4)	49 (100) (21.8)
Candida parapsilosis	23 (14.2)	0 (0) (0)	0 (0) (0)	0 (0) (0)	0 (0) (0)	23 (100) (10.2)
Candida albicans	13 (8) (10.2)	0 (0) (0)	0 (0) (0)	0 (0) (0)	0 (0) (0)	13 (100) (5.8)
Others[&]	13 (8) (10.2)	0 (0) (0)	0 (0) (0)	0 (0) (0)	1 (20) (0.4)	13 (100) (5.8)
All pathogens, HAIs n (%)	162 (100) (72.3)	41 (100) (18.3)	3 (100) (1.3)	13 (100) (5.8)	5 (100) (2.2)	224 (100) (100)

By infection type, bloodstream infections predominated, accounting for 72.3% of all HAIs, followed by pneumonias (18.3%) and urinary tract infections (5.8%) (Table 2).

In terms of causative agents, Gram-negative bacteria were predominant, accounting for 67.4%; the main pathogens were *Klebsiella pneumoniae* (24.6%), *Pseudomonas aeruginosa* (17.4%), and *Acinetobacter baumannii* (14.3%). Gram-positive bacteria accounted for 10.7% and Candida species for 21.9% of isolates (Tables 3–4).

Period-based susceptibility analyses among Gram-negative organisms demonstrated low susceptibility to carbapenems (meropenem) and high resistance rates to piperacillin–tazobactam and fourth-generation cephalosporins. Overall, colistin resistance was 7.1%, although advanced confirmatory testing could not be performed (Tables 5–8). Resistance rates were generally similar across the study periods; however, cefepime resistance among *Klebsiella pneumoniae*

Table 5. The antibiotic resistance status of Gram-negative bacteria over the years.

		2016-2018	2019-2021	2022-2024	Total		*p*
Amikacin	S	32 (65.3)	28 (62.2)	33 (66)	93 (66)	141	0.71
	R	17 (34.1)	17 (37.8)	14 (34)	48 (34)		
Colistin	S	33 (97.1)	37 (92.5)	35 (89.7)	105 (92.9)	113	0.47
	R	1 (2.9)	3 (7.5)	4 (10.3)	8 (7.1)		
Meropenem	S	20 (47.6)	22 (52.4)	19 (42.2)	61 (47.3)	129	0.63
	R	22 (52.4)	20 (47.6)	26 (57.8)	68 (52.7)		
Piperacillin-Tazobactam	S	10 (27.8)	11 (28.2)	9 (25)	30 (27)	111	0.94
	R	26 (72.2)	28 (71.8)	27 (75)	81 (73)		
Cefepime	S	9 (29)	5 (12.8)	3 (8.8)	17 (16.3)	104	0.06
	R	22 (71)	34 (87.2)	31 (91.2)	87 (83.7)		
Ceftazidime	S	7 (19.4)	7 (17.5)	4 (11.1)	18 (16.1)	112	0.6
	R	29 (80.6)	33 (82.5)	32 (88.9)	94 (83.9)		
Ciprofloxacin	S	18 (40.9)	12 (27.3)	14 (31.8)	44 (33.3)	132	0.38
	R	26 (59.1)	32 (72.7)	30 (68.2)	88 (66.7)		

Table 6. The antibiotic resistance status of *Klebsiella pneumoniae* over the years.

		2016-2018	2019-2021	2022-2024	Total		*p*
Amikacin	S	10 (66.7)	12 (66.7)	13 (68.4)	35 (67.3)	52	0.99
	R	5 (33.3)	6 (33.3)	6 (31.6)	17 (32.7)		
Colistin	S	12 (92.3)	17 (89.5)	14 (82.4)	43 (87.8)	49	0.68
	R	1 (7.7)	2 (10.5)	3 (17.6)	6 (12.2)		
Meropenem	S	11 (73.3)	14 (73.7)	11 (57.9)	36 (67.9)	53	0.50
	R	4 (26.7)	5 (26.3)	8 (42.1)	17 (32.1)		
Piperacillin-Tazobactam	S	4 (31.3)	5 (26.3)	4 (21.1)	14 (25.9)	54	0.79
	R	11 (68.8)	14 (73.7)	15 (78.9)	40 (74.1)		
Cefepime	S	3 (23.1)	0 (0)	0 (0)	3 (6)	50	0.01
	R	10 (76.9)	18 (100)	19 (100)	47 (94)		
Ceftazidime	S	3 (20)	0 (0)	2 (10.5)	5 (9.4)	53	0.13
	R	12 (80)	19 (100)	17 (89.5)	48 (90.6)		
Ciprofloxacin	S	10 (66.7)	6 (31.6)	6 (31.6)	22 (41.5)	53	0.06
	R	5 (33.3)	13 (68.4)	13 (68.4)	31 (58.5)		

Table 7. The antibiotic resistance status of *Acinetobacter baumannii* over the years.

		2016-2018	2019-2021	2022-2024	Total		*p*
Amikacin	S	10 (66.7)	12 (66.7)	13 (68.4)	35 (67.3)	52	0.99
	R	5 (33.3)	6 (33.3)	6 (31.6)	17 (32.7)		
Colistin	S	12 (92.3)	17 (89.5)	14 (82.4)	43 (87.8)	49	0.68
	R	1 (7.7)	2 (10.5)	3 (17.6)	6 (12.2)		
Meropenem	S	11 (73.3)	14 (73.7)	11 (57.9)	36 (67.9)	53	0.50
	R	4 (26.7)	5 (26.3)	8 (42.1)	17 (32.1)		
Piperacillin-Tazobactam	S	5 (31.3)	5 (26.3)	4 (21.1)	14 (25.9)	54	0.79
	R	11 (68.8)	14 (73.7)	15 (78.9)	40 (74.1)		
Cefepime	S	3 (23.1)	0 (0)	0 (0)	3 (6)	50	0.01
	R	10 (76.9)	18 (100)	19 (100)	47 (94)		
Ceftazidime	S	3 (20)	0 (0)	2 (10.5)	5 (9.4)	53	0.13
	R	12 (80)	19 (100)	17 (89.5)	48 (90.6)		
Ciprofloxacin	S	10 (66.7)	6 (31.6)	6 (31.6)	22 (41.5)	53	0.06
	R	5 (33.3)	13 (68.4)	13 (68.4)	31 (58.5)		

Table 8. The antibiotic resistance status of *Pseudomonas aeruginosa* over the years.

		2016-2018	2019-2021	2022-2024	Total		*p*
Amikacin	S	11 (78.6)	7 (58.3)	9 (81.8)	27 (73)	37	0.37
	R	3 (21.4)	5 (41.7)	2 (18.2)	10 (27)		
Colistin	S	9 (100)	11 (100)	8 (88.9)	28 (96.6)	29	0.31
	R	0 (0)	0 (0)	1 (11.1)	1 (3.4)		
Meropenem	S	3 (37.5)	4 (36.4)	4 (36.4)	11 (36.7)	30	0.99
	R	5 (62.5)	7 (63.6)	7 (63.6)	19 (63.3)		
Piperacillin-Tazobactam	S	1 (7.1)	4 (36.4)	1 (9.1)	6 (16.7)	36	0.10
	R	13 (92.9)	7 (63.6)	10 (90.9)	30 (83.3)		
Cefepime	S	3 (23.1)	4 (33.3)	2 (22.2)	9 (26.5)	34	0.79
	R	10 (76.9)	8 (66.7)	7 (77.8)	25 (73.5)		
Ceftazidime	S	2 (14.3)	5 (41.7)	1 (9.1)	8 (21.6)	37	0.11
	R	12 (85.7)	7 (58.3)	10 (90.9)	29 (78.4)		
Ciprofloxacin	S	5 (41.7)	4 (33.3)	6 (50)	15 (41.7)	36	0.71
	R	7 (58.3)	8 (66.7)	6 (50)	21 (58.3)		

isolates increased from 76.9% in 2016–2018 to 100% in subsequent periods, a statistically significant increase ($p = 0.01$), while no other significant temporal changes were observed. Annual resistance trends for key pathogens are illustrated in Figure 3.

Of the 22 Gram-positive isolates in total, linezolid resistance was detected in two. One of these was a coagulase-negative staphylococcus (CoNS) resistant to both linezolid and vancomycin; the other was a linezolid-resistant, vancomycin-susceptible *Staphylococcus aureus*. Vancomycin resistance was observed in only one CoNS isolate (4.5%).

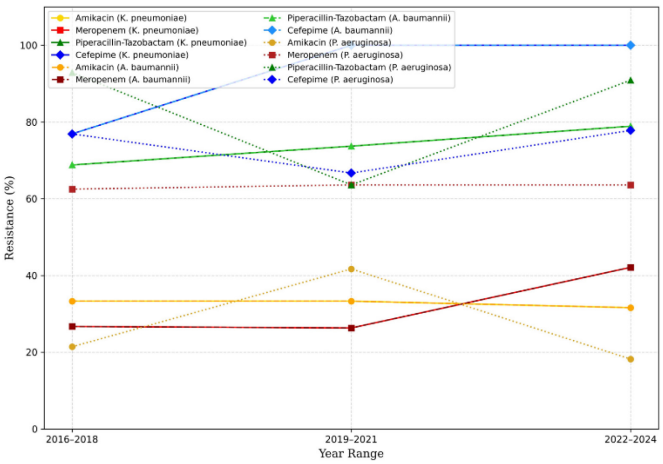
Among fungal isolates, no resistance to liposomal amphotericin B or caspofungin was detected. Across all fungal isolates, fluconazole resistance was 28.2% and voriconazole resistance 17.1%. Evaluation over three-year periods revealed no statistically significant differences in fluconazole ($p = 0.09$) or voriconazole ($p = 0.34$) resistance rates.

Discussion

Overall Assessment

This nine-year single-center surveillance demonstrates a persistent burden of HAIs in the PICU, with Gram-negative pathogens predominating. The lack of a significant change in HAI incidence density across years ($p = 0.56$; Table 1) suggests relative stability in case mix and invasive device use in the unit. The variation in annual HAI incidence density, with the lowest rate observed in 2020 (2.0 per 1000 patient-days) and the highest in 2024 (6.6 per 1000 patient-days), deserves further consideration. The decrease in 2020 may be related to reduced PICU admissions, shorter lengths of stay, or changes in case mix during

Figure 3. Trends in antibiotic resistance among Gram-negative bacteria isolated from healthcare-associated infections in the PICU between 2016–2018, 2019–2021, and 2022–2024.



the COVID-19 pandemic, as many centers reported altered patient flows and postponement of elective procedures. Conversely, the increase observed in 2024 may reflect a return to pre-pandemic admission patterns, higher patient acuity, increased device utilization, or the growing impact of antimicrobial resistance. However, because detailed data on device utilization ratios and staffing levels were not available, these findings should be interpreted with caution. Bloodstream infections were the most frequent HAI type, constituting 72.3% of all cases (Table 2). This proportion exceeds the 40–60% range reported in the literature and may be related to the frequency of central venous catheter use [1,3,5]. To address this issue, strict adherence to catheter care protocols and regular staff training are recommended as potential strategies to reduce BSI incidence. Incorporating these points provides a clearer interpretation of our findings and highlights practical implications for improving institutional infection control practices.

Distribution of Pathogens

The predominance of Gram-negative organisms, particularly *K. pneumoniae*, *P. aeruginosa*, and *A. baumannii*, in our PICU is likely related to the frequent use of invasive devices, prolonged hospital stays, and selective pressure from broad-spectrum antibiotic use. Gram-positive organisms and Candida species were less common, which may reflect differences in colonization patterns and host immune status. These findings are consistent with previous reports from UHESA and the ECDC 2021 ICU data, which highlight that local infection control practices, antimicrobial stewardship, and patient characteristics significantly influence pathogen distribution in pediatric intensive care units [1,5].

Carbapenem and Beta-Lactam Resistance

Antimicrobial resistance patterns among Gram-negative isolates were remarkable. In Klebsiella pneumoniae, meropenem susceptibility remained at 38.6%, with near-universal resistance to fourth-generation cephalosporins (cefepime and ceftazidime) (Table 5), suggesting the presence of ESBLs and carbapenemases. *Acinetobacter baumannii* isolates exhibited > 90% resistance to piperacillin–tazobactam and cephalosporins, with colistin as the only reliably susceptible agent at 87.8% (Table 6); however, because only BMD is considered reliable for colistin testing, this figure should be interpreted with caution [11–13]. In Pseudomonas aeruginosa, resistance to meropenem and cephalosporins ranged from 60% to 80%, and piperacillin–tazobactam susceptibility was only 16.7% (Table 7).

These resistance profiles may also be related to local antibiotic use policies in our PICU; restricted carbapenem use and limited colistin administration could have influenced selective pressures, shaping these resistance trends.

During the study period, standard infection control measures were implemented in the PICU, including routine hand hygiene monitoring, contact precautions for patients colonized or infected with multidrug-resistant organisms, device care bundles (e.g., central line and ventilator bundles), and regular surveillance by the infection control team. These measures may have contributed to the relative stability of infection and resistance trends observed over time and should be considered when interpreting our findings.

Overall, resistance trends among Gram-negative organisms are consistent with ECDC 2021 ICU data and represent a substantial therapeutic challenge [1,6,14].

Resistance in Gram-Positive Organisms

Of the 22 Gram-positive isolates, linezolid resistance was detected in two (one was also vancomycin-resistant CoNS; the other was a linezolid-resistant but vancomycin-susceptible *S. aureus*). Vancomycin resistance was identified in only one CoNS isolate (4.5%) (Table 8). These figures are consistent with the literature; linezolid resistance remains uncommon [15,16], although heteroresistance in CoNS and its clinical implications should be considered [17].

Fungal Resistance

The absence of resistance to liposomal amphotericin B and caspofungin is clinically important. However, the fluconazole (28.2%) and voriconazole (17.1%) resistance rates (Table 4) may be associated with *Candida parapsilosis* clusters. As highlighted in the IDSA guidelines, these rates support echinocandin-based initial therapy [18–20].

COVID-19 Period

Although many centers reported increased HAI incidence during the pandemic (2020–2021) [4], comparison of all study years (2016–2024) revealed no statistically significant difference in HAI incidence across years (Table 1). Therefore, no COVID-19–specific increase was observed in our cohort. This finding may be related to unit capacity, patient load, and the continuity of infection control practices. However,

in the absence of data on device utilization and nurse-to-patient ratios, further interpretation remains limited.

Clinical Implications

These findings indicate that broad Gram-negative coverage may be necessary for empiric therapy, while carbapenem-sparing strategies may be implemented in stable patients based on local resistance data. For colistin therapy, confirmation with BMD is advised, and where possible, access to newer antibiotic options (e.g., sulbactam–durlobactam, ceftazidime–avibactam) should be explored [13,21]. From an infection control standpoint, routine auditing of evidence-based measures—such as central line bundles, ventilator care, and hand hygiene adherence—appears critical [4,21,22].

Limitations

This study has several limitations. Firstly, as a single-center retrospective study with a relatively limited number of cases, the generalizability of our findings to other settings may be restricted. Our study is single-center and focused on patients who developed HAIs, resulting in a relatively limited sample size. This may contribute to potential Type II errors, where true differences, particularly in certain antimicrobial resistance trends, might not have been detected as statistically significant. The study includes only data from the PICU at Bursa Yüksek İhtisas Training and Research Hospital; patient profiles, device use intensity, and infection control practices may vary across centers. Second, important parameters such as device utilization ratios, nurse-to-patient ratios, and unit occupancy could not be analyzed, which limits the interpretation of the high proportion of bloodstream infections. Third, due to the retrospective design of the study, comprehensive annual demographic data for all PICU admissions were not fully available, which limited our ability to assess potential changes in overall patient case-mix over time. Fourth, molecular mechanisms of resistance (e.g., carbapenemase genotypes) could not be investigated in resistant isolates; only phenotypic susceptibility testing was performed. Finally, species-level detailed stratification could not be performed in antifungal resistance analyses; differences in resistance among Candida species should be explored in future studies.

Conclusions

This nine-year single-center surveillance study shows that healthcare-associated infections continue to impose a substantial burden in pediatric intensive care units, with bloodstream infections and multidrug-resistant Gram-negative bacteria being predominant. The high prevalence of carbapenem resistance emphasizes the critical importance of antimicrobial stewardship and infection control measures.

Acknowledgements

The authors gratefully acknowledge the contributions of Infection Control Committee nurses, Fatma Tosun and Ayşegül Kahrıman, for their assistance in data collection.

Ethics Statement

The study was approved by the Ethics Committee of Bursa Yüksek İhtisas Training and Research Hospital (Protocol No: 2024-TBEK 2025/03-14).

Authors' contributions

EÇ conceived and designed the study. ŞNK, BB, AT, and NK collected and curated the data. EÇ, ŞNK, and NK performed data analysis and interpretation. EÇ and ŞNK drafted the manuscript. All authors critically revised the manuscript for important intellectual content, approved the final version, and agreed to be accountable for all aspects of the work.

Corresponding author

Associate Professor Dr. Eren ÇAĞAN
Department of Pediatric Infectious Diseases,
Bursa Yüksek İhtisas Training and Research Hospital,
Mimar Sinan Mahallesi, Emniyet Caddesi,
Yıldırım/Bursa. Postcode: 16310
Tel: 0905067015360; 0902242955000
E-mail: erencagan@gmail.com

Conflict of interest

No conflict of interest is declared.

References

1. European Centre for Disease Prevention and Control (2024) Healthcare-associated infections acquired in intensive care units: Annual epidemiological report for 2021. Available: https://www.ecdc.europa.eu/en/publications-data/healthcare-associated-infections-intensive-care-units-annual-epidemiological-report-2021. Accessed: 2 September 2025.
2. World Health Organization (2022) Global report on infection prevention and control. Available: https://www.who.int/publications/i/item/9789240051164. Accessed: 01 June 2026.
3. Atıcı S, Kılıç S, Karadeniz Cerit K, Kıyan G, Soysal A (2025) Healthcare-associated infections in the first four years of a pediatric surgical intensive care unit. J Infect Dev Ctries 19: 576–581. doi: 10.3855/jidc.21092.
4. Centers for Disease Control and Prevention (CDC) (2023) National and State HAI Progress Report. Atlanta (GA): U.S. Department of Health & Human Services; 2024. Available: https://www.cdc.gov/healthcare-associated-infections/php/data/progress-report.html. Accessed: 2 September 2025.

5. Ministry of Health of the Republic of Türkiye (2024) National healthcare-associated infections surveillance network (UHESA) pathogen distribution and antimicrobial resistance report. Available: https://hsgm.saglik.gov.tr/depo/birimler/bulasici-hastaliklar-ve-erken-uyari-db/Dokumanlar/Raporlar/ETKEN_DAGILIM_VE_DIRENC_2024.pdf. Accessed: 2 September 2026. [Article in Turkish].
6. World Health Organization (2024) WHO updates list of drug-resistant bacteria most threatening to human health (BPPL 2024). Geneva: World Health Organization; 2024. Available: https://www.who.int/news/item/17-05-2024-who-updates-list-of-drug-resistant-bacteria-most-threatening-to-human-health. Accessed: 2 September 2025.
7. Centers for Disease Control and Prevention (CDC) (2025) NHSN patient safety component manual. Atlanta (GA): U.S. Department of Health and Human Services. Available: https://www.cdc.gov/nhsn/pdfs/validation/2025/pcsmanual_2025.pdf. Accessed: 2 September 2025.
8. Republic of Türkiye Ministry of Health, General Directorate of Public Health, Department of Communicable Diseases and Early Warning (2025) National surveillance and diagnostic guide for healthcare-associated infections. Ankara: General Directorate of Public Health. [Article in Turkish].
9. Clinical and Laboratory Standards Institute (CLSI) (2025) Performance standards for antimicrobial susceptibility testing. CLSI supplement M100. Wayne (PA).
10. European Committee on Antimicrobial Susceptibility Testing (EUCAST) (2025) Breakpoint tables for interpretation of MICs and zone diameters. Available: https://www.eucast.org. Accessed: 2 September 2025.
11. EUCAST (2024) Colistin susceptibility testing – EUCAST statement. 2024. Available: https://www.eucast.org/eucast_news/news_singleview?tx_ttnews%5Btt_news%5D=569. Accessed: 2 September 2025.
12. Antony T, Senthilnathan Y, Madhavakumar R, Amudhan P, Venkataraman S, Rally S, Pitani RS, Arumugam I (2024) Comparative evaluation of colistin-susceptibility testing in carbapenem-resistant *Klebsiella pneumoniae* using VITEK, colistin broth disc elution, and colistin broth microdilution. Cureus 16: e65796. doi:10.7759/cureus.65796.
13. Clinical and Laboratory Standards Institute (CLSI) AST News Update – January 2024. Wayne (PA): CLSI. Available: https://clsi.org/media/ijnmzkr4/ast_newsletter24_web.pdf. Accessed: 2 September 2025.
14. Sati H, Carrara E, Savoldi A, Hansen P, Garlasco J, Campagnaro E, Boccia S, Castillo-Polo JA, Magrini E, Garcia-Vello P, Wool E, Gigante V, Duffy E, Cassini A, Huttner B, Pardo PR, Naghavi M, Mirzayev F, Zignol M, Cameron A, Tacconelli E (2025) The WHO bacterial priority pathogens list 2024: a prioritisation study to guide research, development, and public health strategies against antimicrobial resistance. Lancet Infect Dis 25: e177-e188. doi: 10.1016/S1473-3099(24)00727-8.
15. Baos E, Candel FJ, Merino P, Pena I, Picazo JJ (2013) Characterization and monitoring of linezolid-resistant clinical isolates of *Staphylococcus epidermidis* in an intensive care unit 4 years after an outbreak of infection by cfr-mediated linezolid-resistant *Staphylococcus aureus.* Diagn Microbiol Infect Dis 76: 325–9. doi: 10.1016/j.diagmicrobio.2013.03.014.
16. Mendes RE, Hogan PA, Jones RN, Sader HS, Flamm RK (2014) Surveillance for linezolid resistance via the Zyvox Annual Appraisal of Potency and Spectrum (ZAAPS) programme (2014): evolving resistance mechanisms with stable susceptibility rates. J Antimicrob Chemother 71: 1860–5. doi: 10.1093/jac/dkw047.
17. Dao TH, Alsallaq R, Parsons JB, Ferrolino J, Hayden RT, Rubnitz JE, Rafiqullah IM, Robinson DA, Margolis EB, Rosch JW, Wolf J (2020) Vancomycin heteroresistance and clinical outcomes in bloodstream infections caused by coagulase-negative staphylococci. Antimicrob Agents Chemother 64: e00944-20. doi: 10.1128/AAC.00944-20.
18. Perlin DS (2015) Echinocandin resistance in *Candida.* Clin Infect Dis 61: S612–7. doi: 10.1093/cid/civ791.
19. Pappas PG, Kauffman CA, Andes DR, Clancy CJ, Marr KA, Ostrosky-Zeichner L, Reboli AC, Schuster MG, Vazquez JA, Walsh TJ, Zaoutis TE, Sobel JD (2016) Clinical practice guideline for the management of candidiasis: 2016 update by the Infectious Diseases Society of America. Clin Infect Dis 62: e1–50. doi: 10.1093/cid/civ933.
20. McHugh J, Chesdachai S, Dunsirn M, Wengenack N, Vergidis P (2025) Increasing fluconazole resistance in *Candida parapsilosis*: a 10-year analysis of blood culture isolates at a US reference laboratory (2015–2024). J Infect Dis 232: 1198-1202. doi: 10.1093/infdis/jiaf249.
21. European Centre for Disease Prevention and Control (ECDC) (2025) Carbapenem-resistant Enterobacterales – third update. Stockholm: ECDC; 2025. Available: https://www.ecdc.europa.eu/sites/default/files/documents/risk-assessment-carbapenem-resistant-enterobacterales-third-update-february-2025_0.pdf. Accessed: 2 September 2025
22. Centers for Disease Control and Prevention (CDC) (2024) NHSN reports portal (Device-Associated Module resources). Atlanta (GA): U.S. Department of Health & Human Services; 2024. Available: https://www.cdc.gov/nhsn/datastat/index.html. Accessed: 2 September 2025.