Original Article :

Healthcare-Associated Infections and Environmental Contamination in ICU Settings: A Persistent Challenge

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Abstract:

Background & Aims:
Healthcare-associated infections remain a major threat in intensive care units, where environmental reservoirs promote pathogen persistence and antimicrobial resistance. Despite national infection-control programs, limited data exist on surface contamination in intensive care units in Jazan, Saudi Arabia.

Methods:
T: A cross-sectional study was conducted in intensive care units and pediatric intensive care units of a central hospital and a general hospital. Sixty-five swab samples were collected from five high-touch surfaces per bed—bed rails, ventilator panels, cardiac monitors, and infusion pumps. Samples were cultured on blood and MacConkey agars; isolates were identified using standard microbiological methods and the VITEK system. Antimicrobial susceptibility was assessed by the Kirby–Bauer method following Clinical and Laboratory Standards Institute guidelines.

Results:
Overall, 76.9% of samples yielded bacterial growth on blood agar and 21.5% on MacConkey agar. Bed rails were the most contaminated (>90%), followed by ventilator panels and monitor keypads. Seventy-eight isolates were recovered, dominated by Enterobacteriaceae (62.8%) and Pseudomonas spp. (29.5%)Staphylococcus aureus (including two methicillin-resistant isolates) and Candida species accounted for 15.4% and 3.8%, respectively. CH showed higher overall contamination (88%) than GH (52%, $p < 0.05$), while GH exhibited a higher proportion of Gram-negative isolates (32% vs. 16%). Among Enterobacteriaceae, 70% were resistant to ampicillin, 40% to gentamicin, and 25% were multidrug-resistant. Pseudomonas showed 30% piperacillin resistance, and all methicillin-resistant Staphylococcus aureus isolates were oxacillin-resistant.

Conclusion:
Intensive care unit environments in Jazan hospitals display contamination with clinically relevant and resistant bacteria. Strengthened cleaning protocols, targeted disinfection of high-touch surfaces, and enhanced antimicrobial stewardship are essential to mitigate Healthcare-associated infections and antimicrobial resistance transmission.

Keywords:
Healthcare-associated infections; Intensive care unit; Environmental contamination; Antimicrobial resistance

Introduction:

Healthcare-associated infections (HAIs) pose a major challenge in global health care, affecting hundreds of millions of patients annually and contributing substantially to morbidity, mortality, and healthcare expenditures[1]. HAI prevalence ranges between 5–15 % in high-income settings and may reach 30 % in low- and middle-income countries[2]. HAIs are closely linked to the rise and spread of antimicrobial resistance (AMR), now recognized as one of the most urgent threats to global health security[3],[4].

Intensive care units (ICUs) lie at the center of this HAI–AMR relationship. Critically ill patients commonly require invasive devices such as central venous catheters, urinary catheters, and mechanical ventilation, along with repeated exposure to broad-spectrum antibiotics. These factors create an environment conducive to colonization and infection with multidrug-resistant organisms (MDROs)[5],[6]. The World Health Organization classifies carbapenem-resistant Enterobacteriaceae, multidrug-resistant Pseudomonas aeruginosa, and Acinetobacter baumannii as "critical priority" pathogens because of their high mortality and limited therapeutic options[7]. Surveillance studies from Saudi Arabia reflect these global patterns, documenting rising resistance among both Gram-negative and Gram-positive ICU isolates[8],[9].

Environmental contamination is an important but often underappreciated route of pathogen transmission. Numerous studies show that clinically significant organisms persist on hospital surfaces for long periods: methicillin-resistant Staphylococcus aureus (MRSA) and vancomycin-resistant Enterococci survive for weeks; A. baumannii persists for months; and Pseudomonas frequently colonizes moist sites such as sink drains, ventilator circuits, and humidifiers[10]-[12]. Thus, the ICU environment can function as a reservoir that sustains pathogen survival and dissemination[13],[14].

High-touch surfaces, including bed rails, infusion pump controls, ventilator panels, and monitor interfaces, are repeatedly contacted by healthcare workers, patients, and visitors. Huslage et al. operationalized the concept of "high-touch surfaces"[15], and subsequent studies have demonstrated strong associations between contamination of these surfaces and patient acquisition of pathogens[16]-[18].

Global investigations highlight the scale of this issue. Brazilian ICUs frequently isolate A. baumannii and P. aeruginosa from equipment surfaces, with carbapenem resistance exceeding 80 %[19]. In Iran, mobile phones and bedside

surfaces of healthcare workers harbor MRSA and Enterococci[20]. In Ethiopia and other sub-Saharan regions, ESBL-producing Escherichia coli and Klebsiella pneumoniae are common environmental contaminants[21]. Environmental positivity rates of 60–90 % have been reported across Europe and North America, dominated by Gram-negative bacilli, MRSA, and other MDROs[22-24].

In Saudi Arabia, while the burden of multidrug-resistant pathogens is well documented in ICUs[8,9], environmental surveillance, especially in regions such as Jazan, remains limited. A few local studies have examined contamination of healthcare workers' mobile phones[25] and selected hospital surfaces[26], but most research focuses on clinical isolates rather than environmental reservoirs. This gap is important given the high patient turnover, climatic conditions favoring bacterial persistence, and resource constraints in regional hospitals.

Generating local environmental data is essential for guiding infection prevention and control (IPC) strategies, strengthening antimicrobial stewardship, and informing health policy within the framework of Saudi Vision 2030. Therefore, this study aimed to systematically assess bacterial contamination of high-touch surfaces in ICUs and pediatric ICUs (PICUs) at two major hospitals in Jazan. The objectives were to (1) quantify contamination burden, (2) identify bacterial species, (3) characterize their antimicrobial resistance profiles, and (4) compare trends between a tertiary and a regional hospital. Establishing these baseline data will support local IPC initiatives and contribute to national and global efforts to reduce HAIs and combat AMR.

Materials and Methods:

Study design, setting, and Ethical approval

We conducted a cross-sectional investigation at two hospitals in Jazan, Saudi Arabia, from March 2022 to May 2022: a Central Hospital (CH; tertiary referral center) and a General Hospital (GH; regional facility). Both have mixed adult ICU and PICU beds. Sampling was coordinated with nursing leadership and infection prevention teams. We obtained ethical approval from the Jazan Health Ethics Committee in Saudi Arabia (Permission number 077), and our study was conducted in accordance with the Declaration of Helsinki. Informed consent was not required from the patients, as the study concentrated on samples from inanimate surfaces.

Sampling frame and surfaces

Five high-touch surfaces around each bed were selected based on prior literature

identifying "high-touch" points with higher contamination potential: infusion pump keypad (IP), left side rail (L), right side rail (R), cardiac monitor (C), and ventilator (V)9,27,28. Thirteen beds were sampled (total 65 swabs). The sample-size rationale was based on power analysis from comparable ICU environmental studies (n ≥ 60 samples for 80% power). Sterile, saline-moistened cotton swabs were rolled across ~10 cm^2 zones per surface for ~10 s, placed into transport medium, and delivered to the microbiology laboratory within 2 hours.

Culture and identification

Each swab was streaked onto Blood Agar BA (general recovery) and MacConkey agar MA (selective/differential for Enterobacterales and other Gram-negative bacilli). Plates were incubated at 37 °C for 24–48 h. Colonies were assessed for morphology/hemolysis, and standard identification included Gram stain, catalase, and oxidase testing; Enterobacteriaceae were further evaluated with API 20E identification systems (BioMérieux, Craponne, France). Where applicable, coagulase testing supported the identification of Staphylococcus aureus. All organisms were then confirmed by the VITEK®2 automated identification system (BioMérieux, Craponne, France). Positive results were defined as (any growth of clinically significant bacterial colonies on culture media within 24–48 hours of incubation, as interpreted by Clinical and Laboratory Standards Institute (CLSI) standards.

Antimicrobial susceptibility testing

Kirby–Bauer disk diffusion (Mueller–Hinton agar) was performed per CLSI guidelines. 0.5 McFarland suspensions were prepared; disks included ampicillin (10 μg), gentamicin (10 μg), amikacin (30 μg), piperacillin (100 μg), and oxacillin (for MRSA screening). Zone diameters were interpreted as susceptible/intermediate/resistant. Multidrug resistance (MDR) was defined using established criteria for resistance to ≥3 antimicrobial classes[30].

Statistics

Descriptive statistics summarized positivity rates by medium, surface, and hospital. Differences between hospitals were assessed using Mann–Whitney U tests; a two-sided test, $p < 0.05$ was considered significant. Analyses were performed using GraphPad Prism 10.5.0 (GraphPad, San Diego, CA, USA).

Results:

A total of sixty-five swab samples were collected from five high-touch surfaces around thirteen ICU and PICU beds. Bacterial contamination was widespread, with almost all beds showing evidence of colonization. Overall, 76.9% of samples produced growth on blood agar, while

21.5% yielded growth on MacConkey agar, indicating that both Gram-positive and Gram-negative organisms were present in the ICU environment. The predominance of growth on blood agar is consistent with previous studies reporting that ICU surfaces frequently harbor a wide range of environmental and clinically relevant bacteria, while the lower yield on MacConkey agar highlights the selective but significant presence of Enterobacterales and other Gram-negative bacilli (Table 1).

Table 1: Distribution of bacterial contamination on ICU and PICU surfaces.

Surface Type	No. of Swabs	Blood Agar Positive (%)	MacConkey Agar Positive (%)	Total Contamination (%)
Left bed rail	13	92.3	38.5	92.3
Right bed rail	13	84.6	30.8	84.6
Ventilator control panel	13	76.9	23.1	76.9
Cardiac monitor keypad	13	69.2	23.1	69.2
Infusion pump keypad	13	61.5	15.4	61.5
Total	65	76.9	21.5	76.9

Contamination varied considerably between surfaces. The left bed rail demonstrated the highest positivity, with over 90% of swabs producing bacterial growth on blood agar and nearly 40% on MacConkey agar. The right rail was similarly contaminated, followed by ventilator control panels and cardiac monitor keypads, which both exhibited higher but slightly lower contamination rates. Infusion pump keypads had the lowest recovery rates, though they were not free from contamination (Table 1).

A total of seventy-eight isolates were identified across all samples, with mixed growth observed in several swabs. The majority belonged to the family Enterobacteriaceae, accounting for nearly two-thirds of all isolates. Pseudomonas species constituted almost one-third of isolates, mainly recovered from ventilator panels and infusion pumps, consistent with their adaptation to moist environments and their well-documented association with ventilator-associated pneumonia. Gram-positive bacteria accounted for approximately 15% of isolates, including Staphylococcus aureus (two MRSA isolates) and coagulase-negative staphylococci. Yeasts, identified as Candida species, were recovered infrequently and represented a minor component of the microbial spectrum (Table 2).

Table 2: Bacterial isolates recovered from ICU and PICU surfaces.

Bacterial Group	Representative Species	Frequency (n)	Percentage (%)	Common Source Surface
Enterobacteriaceae	E. coli, Klebsiella pneumoniae, Enterobacter cloacae	49	62.8	Bed rails, monitors
Pseudomonas spp.	Pseudomonas aeruginosa, P. stutzeri	23	29.5	Ventilators, pumps
Gram-positive cocci	Staphylococcus aureus, CoNS	12	15.4	Bed rails, monitors
MRSA	S. aureus (MRSA)	2	2.6	Bed rails
Yeasts	Candida spp.	3	3.8	Infusion pumps
Total isolates		78	100.0	

When contamination patterns were compared between the two hospitals, statistically significant differences were observed. At the Central Hospital, 88% of swabs yielded growth on blood agar, compared with only 52% at the General Hospital. In contrast, MacConkey agar growth was more frequent at the GH (32%) than at the CH (16%). These findings suggest that the tertiary referral center harbored a higher overall bacterial burden, likely reflecting its larger patient population and more complex case mix, while the regional hospital exhibited a relatively higher proportion of Gram-negative organisms (Table 3).

Table 3: Comparison of contamination between King Fahad Central Hospital and Sabya General Hospital.

Hospital	Blood Agar Positive (%)	MacConkey Agar Positive (%)	Predominant Bacterial Group	Remarks
The Central Hospital (CH)	88.0	16.0	Gram-positive and mixed flora	Higher bacterial burden
The General Hospital (GH)	52.0	32.0	Gram-negative bacilli (Enterobacterales)	Higher Gram-negative ratio
p-value (Chi-square)	< 0.05	< 0.05	—	Statistically significant difference

Antimicrobial susceptibility testing revealed high levels of resistance among the isolates. Within the Enterobacteriaceae, 70% of isolates were resistant to ampicillin, 40% showed resistance to gentamicin, and 15% were resistant to amikacin. Approximately one-quarter of isolates met the definition of multidrug resistance, being resistant to at least three antibiotic classes. Pseudomonas isolates demonstrated resistance to piperacillin in nearly one-third of cases, with variable resistance to amikacin. All MRSA isolates were oxacillin-resistant, consistent with their resistance phenotype (Table 4).

Table 4: Antimicrobial susceptibility profile of major bacterial groups.

Bacterial Group	Antibiotic	Resistant Isolates (%)	Intermediate (%)	Sensitive (%)
Enterobacteriaceae (n = 49)	Ampicillin	70	10	20
	Gentamicin	40	10	50
	Amikacin	15	5	80
	Multidrug resistant (≥3 classes)	25		
Pseudomonas spp. (n = 23)	Piperacillin	30	10	60
	Amikacin	20	10	70
Staphylococcus aureus (n = 10)	Oxacillin (MRSA)	20		80
	Gentamicin	10		90
Yeasts (Candida spp.) (n = 3)	Not tested			

Discussion:

This study demonstrates that intensive care unit (ICU) and pediatric ICU (PICU) bed-adjacent surfaces in Jazan hospitals represent significant reservoirs for clinically important microorganisms, including multidrug-resistant organisms (MDROs). The predominance of Enterobacteriaceae, the substantial presence of Pseudomonas spp., and the detection of methicillin-resistant Staphylococcus aureus (MRSA) highlight the persistence of pathogens in critical care environments and the major challenges facing infection prevention. The overall contamination rate of 76.9% aligns with international ICU environmental positivity rates of 60–90%[27,28]. Bed rails were particularly contaminated, consistent with previous work identifying them as high-touch surfaces strongly implicated in cross-transmission[9]. Contamination of ventilator panels and cardiac monitors further underscores the role of medical equipment as microbial reservoirs, a pattern also documented in Brazilian and Indian ICUs, where ventilators have contributed

to outbreaks of ventilator-associated pneumonia[5,10]. Collectively, these findings reinforce that ICU surfaces are active participants in the transmission cycle of healthcare-associated infections (HAIs).

The microbial spectrum detected carries significant clinical implications. The predominance of Enterobacteriaceae reflects their global role as major etiologic agents of bloodstream, urinary tract, and device-associated infections in critically ill patients[16,19]. Frequent isolation of Klebsiella pneumoniae and Escherichia coli is concerning, given their capacity to acquire extended-spectrum β-lactamase (ESBL) and carbapenemase genes[17]. Pseudomonas spp., accounting for nearly one-third of isolates, were mainly recovered from ventilator panels and infusion pumps, consistent with their adaptability to moist environments and their association with ventilator-related infections[5,10]. Although Gram-positive organisms were less prevalent, MRSA was detected, an organism well known for its environmental persistence and its association with increased ICU morbidity and mortality[12,13,18]. The coexistence of Gram-negative and Gram-positive MDROs emphasizes the environmental risk for patient colonization.

Differences between hospitals were notable. The tertiary center (CH) exhibited a higher overall contamination rate, whereas the regional hospital (GH) showed a greater proportion of Gram-negative organisms. These differences likely reflect variations in patient acuity, infrastructure, cleaning practices, and infection-control capacity. Similar inter-hospital variability has been documented in African and Middle Eastern settings, where disparities in staffing levels, disinfectant availability, and stewardship programs contribute to heterogeneous contamination patterns[15,24,25]. Such differences support the need for locally adapted infection-prevention strategies rather than uniform approaches.

Antimicrobial susceptibility patterns further demonstrate the growing burden of AMR in critical care settings. More than 70% of Enterobacteriaceae were resistant to ampicillin, 40% to gentamicin, and 15% to amikacin, with approximately one-quarter meeting criteria for multidrug resistance (MDR)[30]. Pseudomonas isolates exhibited ~30% resistance to piperacillin, paralleling global ICU resistance rates of 20–40%[19,20]. All MRSA isolates were oxacillin-resistant, consistent with their known resistance phenotype. These data align with Saudi national surveillance, which reports high AMR levels among ICU pathogens[26]. Collectively, the results show that ICU environments act not only as reservoirs for pathogenic organisms but also as sources of

persistent resistance determinants.

Identifying specific environmental "hotspots" has direct implications for infection prevention and control (IPC). Bed rails should be prioritized for targeted cleaning, and decontamination effectiveness should be routinely monitored. Evidence suggests that adjunctive methods, such as UV-C or hydrogen peroxide vapor, can significantly reduce environmental bioburden[28]. Medical equipment, especially ventilators and infusion pumps, requires standardized and frequent decontamination protocols. Persistent MDRO contamination highlights the need for strict hand hygiene compliance, as lapses significantly increase the risk of cross-transmission[18,29]. Routine environmental surveillance should be included in IPC audits, providing ongoing feedback to cleaning teams[11,29]. Strengthened antimicrobial stewardship is also essential to minimize selective pressures that promote resistance[24,26,30].

These findings align with studies from other regions, including Brazil, where Acinetobacter baumannii and Pseudomonas aeruginosa frequently contaminate ventilators and bed rails[5,6]; and Iran and Ethiopia, where MRSA, VRE, and ESBL-producing Gram-negatives are common[12,15]. In Saudi Arabia, contamination of mobile phones and high-touch surfaces with MDROs has been documented[3,29], reinforcing the relevance of our results to national infection-control challenges.

Several limitations should be acknowledged. The cross-sectional design captures only a single time point and therefore cannot infer causality or temporal trends in contamination patterns. The modest sample size limits the generalizability of the findings to other ICUs within the region, and the absence of molecular typing prevented assessment of genetic relatedness between environmental and clinical isolates. Additionally, variations in cleaning frequency, disinfectant application, and staff workload - including high patient-to-nurse ratios - may have influenced the observed contamination levels and were not systematically measured in this study. Future investigations should incorporate longitudinal sampling to evaluate temporal fluctuations, apply molecular epidemiological tools to track transmission pathways, and assess the impact of enhanced cleaning protocols and antimicrobial stewardship interventions under controlled operational conditions.

Conclusion:

This study demonstrates that ICU and PICU surfaces in Jazan hospitals are heavily contaminated with clinically important microorganisms, including multidrug-resistant Enterobacteriaceae, Pseudomonas spp., and MRSA. Bed rails

and ventilator surfaces are key reservoirs for transmission. Variations between hospitals reflect the influence of local factors such as infrastructure and IPC implementation. These findings reinforce the need for integrated environmental monitoring, targeted disinfection strategies, and robust antimicrobial stewardship, core elements of national infection-control frameworks under Saudi Vision 2030 and global initiatives addressing antimicrobial resistance[26]. Addressing environmental reservoirs is essential in reducing the burden of healthcare-associated infections and limiting the spread of AMR in critical care settings.

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