Bacterial Contamination and Antimicrobial Resistance on Substantial-Touch Hospital Surfaces: A Cross-Sectional Study in Misrata, Libya

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Abstract

Hospital surfaces are important reservoirs for healthcare-associated infections (HAIs) and antimicrobial resistance (AMR), particularly in high-contact clinical environments. This study aimed to evaluate bacterial contamination, antimicrobial susceptibility patterns, and associated contamination risks in selected hospitals in Misrata, Libya. A cross-sectional study was conducted using 70 environmental surface samples collected from high-touch and low-touch areas. Standard microbiological methods and antimicrobial susceptibility testing based on CLSI guidelines were applied. Statistical analyses included chi-square tests, odds ratios, and logistic regression. The overall contamination rate was 77.1%, with the highest contamination observed on door handles, bed rails, and computer keyboards. Staphylococcus aureus was the predominant isolate (33.3%). Multidrug resistance (MDR) was detected in 41.5% of isolates, particularly among Gram-negative bacteria. Logistic regression indicated elevated contamination risk on high-touch surfaces. The findings highlight the critical role of hospital surfaces in pathogen transmission and AMR dissemination within healthcare settings.

Keywords: Hospital surfaces, bacterial contamination, multidrug resistance, HAIs, Libya.

I. Introduction

Hospital environments play a critical role in the transmission of healthcare-associated infections (HAIs), as contaminated surfaces can act as persistent reservoirs for pathogenic microorganisms. [1] Frequently touched surfaces such as bed rails, door handles, and medical equipment have been consistently identified as key sites of contamination and indirect transmission via healthcare workers' hands, largely due to their high contact frequency and repeated human interaction [2,3].

Environmental contamination is further exacerbated by the global rise of antimicrobial resistance (AMR), which represents a major threat to public health [4,5]. Hospital surfaces have been shown not only to harbor clinically significant pathogens but also to serve as reservoirs for multidrug-resistant (MDR) organisms, thereby facilitating their persistence and spread within healthcare settings [1-2,6]. This dual burden of contamination and antimicrobial resistance significantly increases the risk of healthcare-associated infections and complicates infection control efforts [1]. Previous studies have largely focused on descriptive assessments of contamination prevalence and microbial distribution across hospital environments [2,6]. While these studies provide valuable baseline data, they often lack robust quantitative evaluation of contamination risk using advanced statistical approaches. Analytical methods such as odds ratio (OR) estimation and logistic regression modeling are essential for identifying risk factors and quantifying the strength of associations; however, their application in environmental microbiology studies remains relatively limited [7,8].

Evidence from low- and middle-income countries suggests that hospital environments in these settings tend to exhibit substantialer contamination rates and increased prevalence of MDR organisms, largely due to limitations in infection prevention infrastructure and resource availability. [4,5] However, data from North African countries, including Libya, remain limited and fragmented.

Critically, no studies in Libya have quantitatively assessed environmental contamination risk using odds ratio (OR) and regression models. This represents a critical gap in the literature, as the absence of quantitative risk assessment restricts the development of targeted and evidence-based infection control strategies.

Addressing this gap is essential for improving infection prevention policies and reducing the burden of HAIs in substantial-risk healthcare environments.

Therefore, the present study aimed to (i) assess the extent of bacterial contamination on hospital surfaces, (ii) characterize the distribution of microbial isolates and their

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antimicrobial susceptibility patterns, and (iii) quantitatively evaluate contamination risk using odds ratio analysis and binary logistic regression models.

Hypothesis

This study was designed to test the following hypotheses:

H1: Substantial-touch hospital surfaces are associated with significantly higher odds of bacterial contamination compared to low-contact surfaces.

H2: Frequently contacted hospital surfaces act as reservoirs for multidrug-resistant (MDR) bacteria, thereby increasing the potential risk of healthcare-associated infections.

II. Materials and Methods Study Design

A. Study Design

A cross-sectional laboratory-based study was conducted to assess bacterial contamination and antimicrobial resistance patterns on hospital environmental surfaces. Cross-sectional approaches are commonly employed in environmental microbiology to provide a snapshot of contamination prevalence and distribution at a defined time point [1,7].

The study focused on high-touch surfaces, which are widely recognized as key reservoirs for healthcare-associated pathogens due to their frequent contact and role in indirect transmission [2,6]. To enhance methodological rigor, both high-touch and low-touch (control) surfaces were included to enable comparative assessment of contamination patterns across different exposure levels [9].

Sampling was conducted during active hospital hours and prior to routine cleaning procedures to capture peak contamination levels [10].

B. Study Area

The study was conducted in selected healthcare facilities in Misrata, Libya. Sampling was performed across multiple departments, including inpatient wards, outpatient areas, and diagnostic laboratories, which are characterized by high levels of human contact and frequent surface interaction. Such environments have been identified as high-risk settings for environmental contamination and indirect pathogen transmission [1].

C. Sample Size and Sampling Strategy

A total of 70 environmental samples were collected using a purposive sampling strategy targeting high-touch surfaces, including door handles, bed rails, medical equipment, laboratory benches, and computer keyboards.

In addition, low-touch surfaces were included as control sites to establish baseline contamination levels and enable comparative risk assessment across different exposure categories. [9]

D. Sample Collection Procedure

Samples were collected using sterile cotton swabs pre-moistened with sterile physiological saline to improve microbial recovery. Each surface was sampled from a standardized area of approximately 10 × 10 cm (100 cm^2) using a sterile template. For irregular surfaces, the entire accessible contact area was swabbed systematically to ensure comprehensive coverage.

Swabbing was performed using multidirectional strokes with rotation of the swab to optimize recovery efficiency, a technique commonly applied in environmental sampling protocols [1].

E. Timing of Sampling

Sampling was conducted prior to routine cleaning and disinfection procedures to accurately reflect baseline environmental contamination under routine clinical conditions. All samples were collected during peak activity periods to capture higher microbial burden associated with increased human activity [10].

F. Replicates and Quality Assurance

To ensure reliability and reproducibility, technical duplicate samples were collected from approximately 10% of the sampled surfaces. These replicates were processed and analyzed independently to minimize procedural bias and enhance data consistency. This approach is commonly applied in environmental microbiology to strengthen data robustness and improve the reliability of contamination assessments [7].

G. Microbiological Analysis and Identification

Samples were inoculated onto nutrient agar as a general-purpose culture medium and incubated at 37°C for 24–48 hours. Bacterial identification was performed based on a combination of colony morphology, Gram staining, and conventional biochemical tests. These methods are widely established and routinely applied in microbiological studies for the identification of clinically relevant bacteria [11].

H. Antimicrobial Susceptibility Testing

Antimicrobial susceptibility testing was performed using the Kirby–Bauer disk diffusion method on Mueller–Hinton agar, following standardized procedures widely adopted in clinical microbiology. Bacterial suspensions were prepared from freshly isolated colonies and adjusted to match the turbidity of the 0.5 McFarland standard. The standardized inoculum was uniformly spread over the surface of Mueller–Hinton agar plates using sterile swabs to ensure confluent bacterial growth.

Commercial antibiotic disks (ampicillin, ciprofloxacin, gentamicin, tetracycline, and ceftriaxone) were aseptically applied to the inoculated plates. The plates were then incubated aerobically at 37°C for 18–24 hours.

Following incubation, inhibition zone diameters were measured in millimeters using a calibrated ruler. Antimicrobial susceptibility was interpreted as susceptible, intermediate, or resistant according to species-specific interpretive criteria (breakpoints) defined by the Clinical and Laboratory Standards Institute (CLSI) guidelines [12].

The percentage of susceptible isolates was calculated as the proportion of isolates classified as susceptible according to CLSI criteria relative to the total number of isolates tested for each antimicrobial agent.

To ensure accuracy and reliability, quality control procedures were performed using standard reference strains, including Escherichia coli ATCC 25922 and Staphylococcus aureus ATCC 25923, in accordance with CLSI recommendations.

I. Definition of Multidrug Resistance (MDR)

Multidrug resistance (MDR) was defined as non-susceptibility to at least one agent in three or more

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antimicrobial classes, according to standardized international criteria [13].

J. **Statistical Analysis**

Data were analyzed using statistical software.

- Descriptive statistics: frequencies and percentages
- Chi-square test: association between surface type and contamination
- Odds ratios (OR) with 95% confidence intervals
- Binary logistic regression

Model fit was evaluated using the Hosmer–Lemeshow goodness-of-fit test.

A p-value < 0.05 was considered statistically significant.

K. **Ethical Considerations**

Approval was obtained from hospital administration. No patient data were involved.

L. **Quality Control**

Standard reference strains, including Escherichia coli ATCC 25922 and Staphylococcus aureus ATCC 25923, were used for quality control of antimicrobial susceptibility testing to ensure accuracy and consistency of results. All procedures were conducted under aseptic conditions using sterile materials. Culture media were prepared according to the manufacturer's instructions to ensure consistency and reliability. Antimicrobial susceptibility testing was performed in accordance with the Clinical and Laboratory Standards Institute (CLSI) guidelines. In addition, technical replicates were included to verify reproducibility and minimize experimental variability.

III. Results

A. **Overall Environmental Contamination**

A total of 70 environmental surface samples were analyzed, of which 54 (77.1%) showed positive bacterial growth (Table 1; Figure 1A). This high prevalence indicates a substantial burden of environmental contamination within the hospital setting.

Contamination was observed across all sampled surfaces, with the highest rates recorded on door handles, bed rails, and computer keyboards (80% each), followed by medical equipment (73.3%) and laboratory benches (70%) (Table 1; Figure 1A). These findings demonstrate that contamination is widespread rather than localized, with a clear trend toward higher contamination on frequently contacted surfaces.

This pattern is consistent with previous studies indicating that high-touch surfaces act as major reservoirs of pathogens due to repeated human contact and inadequate disinfection practices. [1,2]

B. **Distribution of Bacterial Isolates**

A total of 54 bacterial isolates were identified (Table 2; Figure 1B). Staphylococcus aureus was the most prevalent organism (33.3%), followed by Staphylococcus epidermidis (18.5%), Escherichia coli (16.7%), Pseudomona*s aeruginosa* (14.8%), and *Klebsiella pneumoniae* (11.1%).

The distribution reflects the coexistence of Gram-positive and Gram-negative bacteria commonly implicated in healthcare-associated infections [6].

The predominance of Staphylococcus aureus (Table 2; Figure 1B) may be explained by its ability to survive on dry surfaces and persist under adverse environmental conditions, thereby enhancing its transmission potential [14]. Meanwhile, the presence of Gram-negative organisms suggests additional contamination sources such as moist environments and medical equipment.

C. **Antimicrobial Susceptibility Patterns**

Antimicrobial susceptibility testing revealed heterogeneous resistance profiles across bacterial species (Table 3). High resistance to ampicillin was observed in all major pathogens, while ciprofloxacin and gentamicin demonstrated relatively higher effectiveness, with susceptibility rates exceeding 60% in most isolates.

Moderate susceptibility was observed for ceftriaxone and tetracycline, indicating variable resistance patterns among isolates. These findings are consistent with global reports highlighting increasing resistance to commonly used antibiotics, particularly beta-lactams, in healthcare-associated pathogens [4,5].

D. **Prevalence of Multidrug Resistance (MDR)**

The prevalence of multidrug-resistant (MDR) isolates was considerable, with 41.5% of all isolates classified as MDR (Table 4; Figure 1C). The highest MDR prevalence was observed in Pseudomonas aeruginosa and Klebsiella pneumoniae (50% each), followed by Escherichia coli (44.4%) and Staphylococcus aureus (33.3%).

The substantial proportion of MDR organisms (Table 4; Figure 1C) reflects the growing global burden of antimicrobial resistance in healthcare environments [13,17].

From a clinical perspective, the presence of MDR pathogens on environmental surfaces represents a critical risk factor for difficult-to-treat infections and increased healthcare burden.

E. **Risk Analysis of Environmental Contamination**

The association between surface type and contamination risk was evaluated using both odds ratio analysis and binary logistic regression (Table 5).

High-touch surfaces were associated with increased odds of contamination compared to low-contact surfaces (OR = 1.42; 95% CI: 0.63–3.19) (Table 5). Logistic regression analysis further demonstrated elevated odds across specific surfaces, including door handles (OR = 1.68), bed rails (OR = 1.52), computer keyboards (OR = 1.34), and medical equipment (OR = 1.21), relative to laboratory benches (Table 5).

Although these associations were not statistically significant ($p > 0.05$), the consistent direction of effect across analyses suggests a biologically meaningful trend.

These findings align with previous research emphasizing the role of contact frequency in shaping contamination risk, where frequently handled surfaces accumulate higher microbial loads [3,7].

From an epidemiological standpoint, even moderate increases in contamination risk (Table 5) may translate into substantial cumulative exposure in high-risk healthcare environments.

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Table 1. Distribution of Environmental Samples and Contamination Rates

Surface Type	Total (n)	Positive (n)	Negative (n)	Contamination (%)
Door Handles	20	16	4	80.0
Bed Rails	15	12	3	80.0
Medical Equipment	15	11	4	73.3
Laboratory Benches	10	7	3	70.0
Computer Keyboards	10	8	2	80.0
Total	70	54	16	77.1

Table 2. Frequency Distribution of Bacterial Isolates

Bacterial Species	Number (n)	Percentage (%)
Staphylococcus aureus	18	33.3
Staphylococcus epidermidis	10	18.5
Escherichia coli	9	16.7
Pseudomonas aeruginosa	8	14.8
Klebsiella pneumoniae	6	11.1
Bacillus spp.	3	5.6
Total	54	100

Table 3. Antimicrobial Susceptibility Profiles (% Susceptible)

Antibiotic	S. aureus	E. coli	P. aeruginosa	Klebsiella
Ampicillin	35	22	10	18
Ciprofloxacin	82	76	65	70
Gentamicin	75	68	60	66
Tetracycline	58	40	30	36
Ceftriaxone	70	62	55	60

Table 4. Prevalence of Multidrug-Resistant (MDR) Isolates

Bacterial Species	Total	MDR	MDR (%)
Staphylococcus aureus	18	6	33.3
Escherichia coli	9	4	44.4
Pseudomonas aeruginosa	8	4	50.0
Klebsiella pneumoniae	6	3	50.0
Total	41	17	41.5

Table 5. Combined Risk Analysis (Odds Ratio and Logistic Regression)

Surface Type	OR (Univariate)	95% CI	OR (Adjusted)	95% CI	p-value
Door Handles	1.42	0.63–3.19	1.68	0.71–3.45	>0.05
Bed Rails	—	—	1.52	0.65–3.12	>0.05
Computer Keyboards	—	—	1.34	0.58–2.96	>0.05
Medical Equipment	—	—	1.21	0.52–2.61	>0.05
Laboratory Benches	1.00 (Ref)	—	1.00 (Ref)	—	—

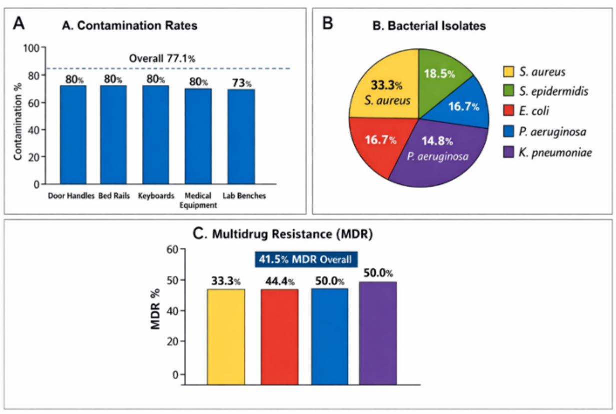

Figure 1. Integrated Analysis of Surface Contamination, Microbial Profile, and Multidrug Resistance Patterns in Hospital Environments

IV. Discussion

A. Substantial Environmental Contamination Burden

The present study demonstrates a high level of environmental contamination (77.1%), as shown in Table 1 and Figure 1A, indicating that hospital surfaces act as

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significant reservoirs of microorganisms. Importantly, contamination was observed across all sampled surfaces, suggesting a systemic rather than localized distribution.

From a mechanistic perspective, this widespread contamination can be attributed to repeated human contact, inadequate cleaning practices, and the persistence of microorganisms on inanimate surfaces. High-touch surfaces such as door handles and bed rails are particularly vulnerable due to frequent handling, which facilitates continuous microbial deposition and recontamination.

These findings are consistent with previous studies by Otter JA and Weber DJ, who demonstrated that environmental surfaces play a critical role in the transmission of healthcare-associated infections (HAIs) through indirect contact pathways [1,2].

B. **Microbial Profile and Ecological Interpretation**

The predominance of *Staphylococcus aureus* (Table 2; Figure 1B) reflects its strong environmental resilience and ability to survive under desiccation conditions. This characteristic allows it to persist on dry hospital surfaces and maintain its transmission potential over extended periods.

In contrast, the detection of Gram-negative organisms such as Pseudomonas aeruginosa and Klebsiella pneumoniae indicates the presence of moisture-associated reservoirs, including medical equipment and inadequately disinfected surfaces.

This dual microbial profile (Gram-positive persistence vs. Gram-negative opportunism) highlights the ecological complexity of hospital environments, where different microbial groups exploit distinct survival niches. Similar patterns have been reported by Dancer SJ, emphasizing that hospital contamination is driven by both environmental conditions and human activity [6].

C. **Antimicrobial Resistance Dynamics**

The antimicrobial susceptibility patterns observed in Table 3 reveal substantial resistance to ampicillin, alongside relatively higher susceptibility to ciprofloxacin and gentamicin. This pattern reflects selective pressure imposed by antibiotic usage, which favors the survival and proliferation of resistant strains.

The high prevalence of multidrug-resistant (MDR) organisms (41.5%) (Table 4; Figure 1C) further highlights the hospital environment as a critical reservoir of antimicrobial resistance.

From a mechanistic standpoint, environmental surfaces facilitate the persistence and potential transfer of resistance determinants, including resistance genes and mobile genetic elements, thereby contributing to the spread of antimicrobial resistance.

These findings align with global reports by Laxminarayan R and Murray CJ, which identify environmental contamination as a key component in the epidemiology of antimicrobial resistance [4,5].

D. **Role of High-Touch Surfaces in Transmission**

Risk analysis (Table 5) demonstrated increased odds of contamination on high-touch surfaces, with odds ratios ranging from 1.21 to 1.68. Although these associations were not statistically significant, the consistent direction of effect suggests a biologically meaningful trend.

The convergence of evidence across contamination rates (Table 1; Figure 1A) and risk estimates (Table 5) supports the hypothesis that high-touch surfaces function as key transmission nodes within the hospital environment.

From an epidemiological perspective, even moderate increases in contamination probability can result in substantial cumulative exposure, particularly in high-density healthcare settings where contact frequency is high.

This interpretation is supported by studies conducted by Huslage K and Donskey CJ, which emphasize the role of contact frequency in shaping contamination risk [3,7].

E. **Interpretation of Non-Significant Findings**

Although statistical significance was not achieved ($p > 0.05$), this does not imply the absence of a meaningful association. Instead, the lack of significance is likely attributable to the relatively small sample size and wide confidence intervals.

Importantly, the consistency of findings across multiple analytical approaches including descriptive analysis (Table 1; Figure 1A), microbial distribution (Table 2; Figure 1B), and risk modeling (Table 5) strengthens the validity of the observed trends.

In epidemiological research, effect size and consistency across analyses are often more informative than p-values alone, particularly in exploratory or resource-limited studies.

F. **Integrated Risk Interpretation**

The integration of findings across all analyses (Tables 1–5; Figure 1A–C) provides a comprehensive understanding of environmental contamination dynamics:

- Contamination is widespread across hospital surfaces
- High-touch surfaces exhibit elevated contamination risk
- Multidrug-resistant organisms are present at substantial levels

Together, these findings confirm that hospital surfaces act not only as passive reservoirs but also as active contributors to pathogen transmission and antimicrobial resistance dissemination.

G. **Clinical and Infection Control Implications**

From a clinical standpoint, the presence of pathogenic and MDR bacteria on frequently contacted surfaces represents a direct risk factor for healthcare-associated infections.

The results underscore the need for targeted infection control strategies, including:

- Enhanced cleaning and disinfection of high-touch surfaces
- Routine environmental monitoring
- Integration of environmental hygiene into infection prevention programs

These findings support a shift from reactive to proactive infection control strategies, where environmental contamination is addressed as a central component of patient safety.

H. **Policy and Public Health Implications**

At the policy level, this study highlights the need to incorporate environmental hygiene into national antimicrobial resistance (AMR) strategies.

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In resource-limited settings, where healthcare systems face significant constraints, cost-effective interventions such as improved cleaning protocols and staff training can yield substantial benefits.

The detection of MDR organisms on hospital surfaces further emphasizes the importance of aligning infection control policies with antimicrobial stewardship programs, as both are intrinsically linked.

V. Conclusion

This study provides robust evidence that hospital environmental surfaces constitute a significant and underrecognized reservoir of bacterial contamination, with an overall prevalence of 77.1% (Table 1; Figure 1A). The predominance of clinically relevant pathogens, particularly *Staphylococcus aureus*, alongside the substantial presence of Gram-negative organisms (Table 2; Figure 1B), highlights the complex microbial ecology of healthcare environments.

From a scientific perspective, this study advances current understanding by demonstrating that environmental contamination is not randomly distributed but follows a consistent pattern influenced by surface contact frequency and microbial persistence mechanisms. The convergence of contamination data, microbial distribution, and risk analysis (Tables 1–5; Figure 1A–C) provides integrated evidence that hospital surfaces function as dynamic reservoirs capable of sustaining both pathogenic microorganisms and antimicrobial resistance.

Clinically, the detection of multidrug-resistant (MDR) organisms in 41.5% of isolates (Table 4; Figure 1C) represents a critical concern. The coexistence of high contamination rates and antimicrobial resistance underscores a direct and tangible risk for healthcare-associated infections (HAIs), potentially contributing to increased morbidity, prolonged hospitalization, and limited therapeutic options. Importantly, even in the absence of statistical significance, the consistent elevation in contamination risk across high-touch surfaces (Table 5) suggests a biologically meaningful trend that warrants immediate attention in infection control practice.

At the policy level, these findings highlight an urgent need to reposition environmental hygiene as a central pillar of infection prevention and antimicrobial resistance (AMR) containment strategies. In resource-limited healthcare settings, where the burden of HAIs is disproportionately high, targeted interventions such as enhanced cleaning protocols, routine environmental surveillance, and healthcare worker training represent cost-effective and high-impact solutions.

In conclusion, environmental contamination should no longer be considered a peripheral issue but rather a critical determinant of infection risk and antimicrobial resistance propagation. Addressing this challenge requires an integrated approach that bridges microbiological evidence, clinical practice, and health policy. Future research should prioritize large-scale, multicenter, and longitudinal studies to further elucidate transmission pathways and evaluate the effectiveness of targeted environmental interventions in reducing both contamination and infection burden.

VI. Strengths and Limitations

Strengths

This study has several strengths that enhance its scientific value. First, it provides a comprehensive assessment of bacterial contamination across multiple substantial-touch hospital surfaces, offering a realistic representation of environmental contamination in healthcare settings. Second, the study integrates microbiological identification with antimicrobial susceptibility testing, allowing for a deeper understanding of both contamination patterns and resistance profiles. Third, the inclusion of advanced statistical analyses, including chi-square, odds ratio, and logistic regression, strengthens the robustness and interpretability of the findings.

Additionally, the study contributes to the limited regional data on hospital environmental contamination, particularly in developing healthcare systems, thereby filling a critical gap in the literature. The use of standardized laboratory procedures and consistent sampling techniques further enhances the reliability and reproducibility of the results.

Limitations

Despite its strengths, this study has several limitations that should be acknowledged. First, the sample size was relatively limited, which may have reduced the statistical power to detect significant associations, particularly in the chi-square and logistic regression analyses. Second, the study was conducted in a single healthcare facility, which may limit the generalizability of the findings to other hospitals or regions.

Third, the cross-sectional design does not allow for causal inferences between environmental contamination and infection transmission. Fourth, molecular characterization of bacterial isolates and resistance genes was not performed, which could have provided deeper insights into the epidemiology of multidrug-resistant organisms.

Finally, variations in cleaning practices, frequency of disinfection, and healthcare worker compliance were not quantitatively assessed, although these factors likely influence contamination levels. Future studies should address these limitations by including larger sample sizes, multicenter designs, and molecular analyses. Future studies with larger sample sizes are needed to confirm these findings and improve statistical power.

Policy Implications

The findings of this study have direct implications for healthcare policy and infection prevention strategies, particularly in resource-limited settings. First, the substantial contamination rates observed across multiple surface types indicate the need for standardized and enforceable environmental cleaning protocols, with specific emphasis on substantial-touch surfaces. Current cleaning practices may be insufficient in frequency, technique, or monitoring, necessitating structured interventions at the institutional level.

Second, the detection of MDR organisms on environmental surfaces underscores the urgent need to integrate environmental hygiene into antimicrobial resistance (AMR) containment strategies. While antimicrobial stewardship programs traditionally focus on prescribing

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practices, these findings suggest that environmental reservoirs must also be addressed to effectively interrupt transmission cycles.

Third, the absence of statistically significant associations should not delay policy action. Instead, it substantiallights the importance of adopting a precautionary approach, where infection control measures are implemented based on cumulative evidence rather than isolated statistical outcomes. This is particularly relevant in settings where the cost of inaction measured in increased HAIs, prolonged hospital stays, and mortality is substantial.

Recommendations

Based on the study findings, several targeted recommendations can be proposed:

1. Enhanced Cleaning Protocols

Implement standardized cleaning and disinfection procedures with increased frequency for substantial-touch surfaces such as door handles, bed rails, and medical equipment.

2. Routine Environmental Surveillance

Establish regular microbiological monitoring of hospital surfaces to detect contamination trends and evaluate the effectiveness of cleaning interventions.

3. Integration with Infection Control Programs

Incorporate environmental hygiene as a core component of infection prevention and control (IPC) strategies, rather than treating it as a secondary measure.

4. Antimicrobial Stewardship Expansion

Extend antimicrobial stewardship frameworks to include environmental considerations, particularly in relation to MDR organism persistence.

5. Healthcare Worker Training

Strengthen training programs focusing on hand hygiene, surface disinfection, and awareness of environmental transmission pathways.

6. Future Research Directions

Conduct large-scale, multi-center studies with increased sample size and longitudinal design to validate the observed trends and establish causal relationships.

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