Optimisation of Environmental Cleaning Strategies for Prevention and Control of *Candida auris* in a Tertiary-Care Intensive Care Unit: A Prospective Interventional Study

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Abstract
Background: *Candida auris* is an emerging multidrug-resistant yeast capable of prolonged survival on healthcare surfaces, contributing to outbreaks in intensive care units (ICUs). Environmental decontamination is central to its control, but the comparative effectiveness of commonly used disinfectants remains uncertain in routine clinical settings.
Aim: To evaluate the effectiveness of different environmental disinfectants against C. auris contamination and to identify high-risk surfaces within an ICU.
Methods: A prospective before-and-after interventional study was conducted in a 15-bed ICU at Apollo Excelcare Hospitals, Guwahati, India over two consecutive 12-month periods (2024–2025). During the pre-intervention phase, environmental contamination was assessed under existing cleaning practices. The intervention phase involved implementation of stabilised hydrogen peroxide wipes. Environmental sampling was performed on high-touch surfaces. The performance of hydrogen peroxide wipes was compared with sodium hypochlorite (1,000 ppm and 5,000 ppm) and quaternary ammonium compounds (QACs). Clinical surveillance for C. auris infection and colonisation was maintained throughout.
Results: At baseline, C. auris was recovered from 70% of patient care environments, most frequently from bed rails, ventilator controls and infusion pumps. Sodium hypochlorite at 5,000 ppm and stabilised hydrogen peroxide wipes achieved the highest environmental clearance (>95–100%), whereas QACs demonstrated poor activity, with persistence in >60% of samples. Following introduction of hydrogen peroxide wipes, environmental contamination decreased from 70% to 5%. No new cases of C. auris infection or colonisation were detected during the 12-month post-intervention period.
Conclusion: Stabilised hydrogen peroxide wipes were highly effective for routine ICU decontamination and were associated with sustained interruption of C. auris transmission. Their use offers a practical alternative to high-concentration chlorine-based disinfectants for daily cleaning in critical care settings.
Keywords: *Candida auris*; environmental cleaning; hydrogen peroxide; intensive care unit; infection prevention
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INTRODUCTION

Hospital-acquired infections (HAIs) caused by *Candida auris* have emerged as a significant global public health threat due to the organism's extensive multidrug resistance, its ability to cause severe invasive disease, and its exceptional persistence within healthcare environments. [1] First identified in 2009, *C. auris* can survive for extended periods on both dry and moist surfaces, facilitating rapid transmission across healthcare facilities. [2]

Several clinical factors increase the risk of *C. auris* acquisition, including:

- Severe underlying immunosuppression (e.g., bone marrow transplantation or corticosteroid therapy).
- Chronic comorbidities such as malignancy, chronic kidney disease, or diabetes mellitus.
- Prolonged stays in Intensive Care Units (ICUs) requiring mechanical ventilation.
- The presence of invasive devices, such as central venous or urinary catheters.
- Extended exposure to broad-spectrum antibiotics or antifungal agents. [2]

C. auris has been isolated from a wide array of clinical specimens, including blood, urine, bile, cerebrospinal fluid (CSF), and respiratory secretions. [3] Furthermore, detection in axillary and groin swabs often indicates a persistent carrier state. This colonization serves as a silent reservoir for transmission, as the pathogen's resilience allows it to survive routine environmental cleaning and sustain prolonged outbreaks in clinical settings. [4] Environmental contamination is a primary driver of *C. auris* transmission. High-touch surfaces—including bed rails, ventilator knobs, syringe pumps, and monitoring devices—frequently harbor the organism. [5] The ability of *C. auris* to withstand standard cleaning protocols underscores the urgent need for disinfection strategies that are not only potent and microbicidal but also safe for frequent application and compatible with sensitive medical equipment. In this context, the present study evaluates the efficacy of various disinfectants—specifically stabilized hydrogen peroxide wipes, sodium hypochlorite, and quaternary ammonium compounds (QACs)—in reducing environmental contamination and interrupting the nosocomial transmission of *C. auris* within a multispecialty tertiary-care ICU in Guwahati, Assam.

METHODS

Study Design and Setting

We conducted a prospective, before-and-after interventional study in a 15-bedded Intensive Care Unit (ICU) at Apollo Excelcare Hospitals, a multispecialty tertiary-care center in Guwahati, Assam, India. The study spanned two consecutive 12-month periods:

- Pre-intervention Phase (January–December 2024): Baseline data and environmental samples were collected under existing cleaning protocols. During this period, 20 patients with culture-confirmed *Candida auris* infections were monitored. (Fig 1)
- Post-intervention Phase (January–December 2025): Data were collected following the implementation of a standardized disinfection protocol using stabilized hydrogen peroxide wipes to evaluate their impact on contamination and infection rates.

Surveillance and Clinical Identification

In compliance with CDC and institutional policies, surveillance was performed for all patients with *C. auris*-positive cultures from any clinical source (e.g., blood, urine, sputum, or wound swabs). [6] Specimens were processed as follows:

- Culture: Samples were inoculated onto Blood agar and sub-cultured on Sabouraud's Dextrose Agar (SDA) at 40°C–42°C for 48 hours to differentiate *C. auris* from other *Candida* species. CHROMagar™ was utilized for further differentiation, where *C. auris* typically appears as pale purple or pink colonies.
- Identification: Initial identification was performed using the BD Phoenix™ M50 automated system, with molecular confirmation via Real-Time PCR (RT-PCR). [7]

Environmental Sampling

Environmental surveillance was conducted twice weekly throughout both the pre-intervention (January–December 2024) and post-intervention (January–December 2025) study periods. Sampling was performed before routine daily cleaning to determine baseline environmental contamination. High-touch surfaces sampled included bed rails, bedside tables, ventilator control panels, syringe pumps, infusion pumps, monitor keypads, and blood pressure cuffs.

One sterile swab was collected from each of the seven predefined high-touch surfaces in every patient care environment during each sampling session. During the pre-intervention phase, 20 patient care environments associated with culture-confirmed *Candida auris* cases were evaluated, yielding 140 environmental samples. The same sampling protocol was followed during the post-intervention period. Sterile rayon swabs moistened with sterile normal saline were used to sample approximately a 10 × 10 cm surface area using horizontal and vertical strokes. Swabs were transported immediately to the microbiology laboratory and processed within 2 hours.

Samples were inoculated onto Sabouraud Dextrose Agar (SDA) supplemented with chloramphenicol and incubated at 40–42°C for 48 hours. Suspected colonies were subcultured onto CHROMagar Candida, and species identification was confirmed using the BD Phoenix™ M50 automated identification system with confirmation by real-time PCR (RT-PCR) where required. Environmental contamination was considered positive when *Candida auris* was recovered from any sampled surface.

Interventions

The study compared the efficacy of three distinct environmental disinfection strategies:

1. Sodium Hypochlorite: Evaluated at concentrations of 1,000 ppm and 5,000 ppm.
2. Stabilized Hydrogen Peroxide: Applied via ready-to-use wipes.
3. Quaternary Ammonium Compounds (QACs): Standard liquid disinfectants.

All confirmed *C. auris* cases were managed under strict contact precautions. To reduce skin and mucosal reservoirs, patients received daily 4% chlorhexidine gluconate (CHG) body baths and CHG-based oral care.

Outcomes and Statistical Analysis

The primary outcome was the reduction in environmental contamination with *Candida auris*, defined as the absence of recoverable *C. auris* from post-cleaning environmental swabs. Secondary outcomes included comparison of disinfectant efficacy and the incidence of new *C. auris* infection or colonization during the post-intervention period.

Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Categorical variables were summarized as frequencies and percentages, whereas continuous variables were expressed as mean ± standard deviation (SD) or median (interquartile range), where appropriate. Comparisons between the pre-intervention and post-intervention phases were planned using the Chi-square test or Fisher's exact test, as appropriate. A two-sided p-value <0.05 was considered statistically significant.

RESULTS

Patient Demographics and Clinical Profile

During the pre-intervention phase (January–December 2024), 20 patients with culture-confirmed *Candida auris* infection were identified in the ICU. The cohort exhibited a significant male predominance (n=16, 80%), with only 4 females (20%) (Fig 2). The most frequently affected age group was 40–49 years (n=8, 40%), followed by 18–29 years (n=6, 30%). Other age groups, including 30–39, 60–69, and ≥70 years, each accounted for 10% of the cases (n=2 per group). (Fig 3)

Microbiological Characteristics and Colonization

C. auris was primarily isolated from blood cultures (n=13, 65%), indicating a high prevalence of bloodstream infections. (Fig 4). Additional isolates were recovered from urine (n=5, 25%) and central venous catheter tips (n=2, 10%). Invasive device utilization was high, with 60% of patients (n=12) having peripheral intravenous lines at the time of infection.(Fig 5). Baseline colonization screening revealed that 60% (n=12/20) of the infected patients were also positive for *C. auris* in axillary and groin swabs. (Fig 6)

Baseline Environmental Contamination

Prior to the intervention, environmental surveillance demonstrated widespread contamination, with *C. auris* recovered from 70% (n=14/20) of the immediate patient care environments. The most frequently contaminated high-touch surfaces included:

- Bed rails and bedside tables
- Ventilator control knobs
- Syringe and infusion pumps
- Monitor keypads and blood pressure cuffs

Comparative Efficacy of Disinfectants

The evaluation of different disinfection strategies revealed significant variations in antimicrobial performance:

- Sodium Hypochlorite (5,000 ppm): Achieved 100% elimination of recoverable *C. auris* from all sampled surfaces.
- Stabilized Hydrogen Peroxide Wipes: Demonstrated superior efficacy with >95% environmental clearance. Minimal residual growth was restricted to a few metallic high-touch surfaces.
- Sodium Hypochlorite (1,000 ppm): Showed suboptimal performance, with a 40% persistence rate of the pathogen.
- Quaternary Ammonium Compounds (QACs): Exhibited poor efficacy, failing to eliminate the organism in over 60% of environmental samples. (Table 1), (Fig 7)

Impact of Intervention on Incidence and Contamination

Following implementation of stabilized hydrogen peroxide wipes, integrated with strict contact precautions and daily chlorhexidine gluconate (CHG) decolonization, environmental contamination decreased from 70% (14/20) during the pre-intervention phase to 5% (1/20) during the post-intervention phase, indicating a marked reduction in environmental contamination after introduction of the intervention. Only a single low-colony-count isolate was recovered from a ventilator control panel after the intervention. No new cases of *Candida auris* infection or colonization were identified during the entire 12-month post-intervention follow-up period compared with the pre-intervention phase, suggesting that the multimodal infection prevention strategy was associated with interruption of *Candida auris* transmission within the ICU.

Figure 1: Monthly distribution of *Candida auris* cases during the pre-intervention period (2024)

Line-diagram showing the number of *Candida auris* cases detected per month in the intensive care unit from January to December 2024.

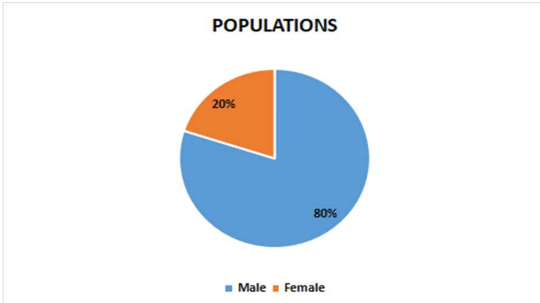

Figure 2: Sex distribution of patients with *Candida auris* infection

Pie- chart illustrating the proportion of male and female patients diagnosed with *Candida auris* infection during the pre-intervention period.

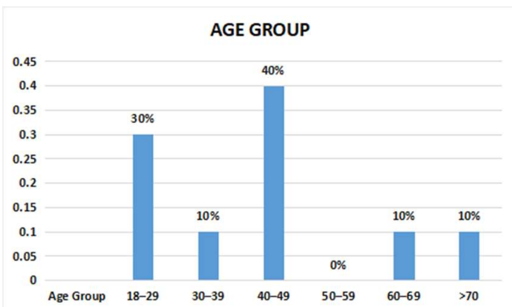

Figure 3: Age distribution of patients with *Candida auris* infection

Bar chart showing age categories (years) and corresponding number of *Candida auris* cases.

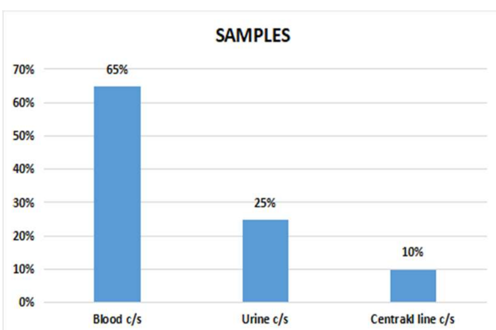

Figure 4: Clinical sources of *Candida auris* isolates

Bar chart depicting distribution of *Candida auris* isolates by specimen type (blood, urine, catheter tip).

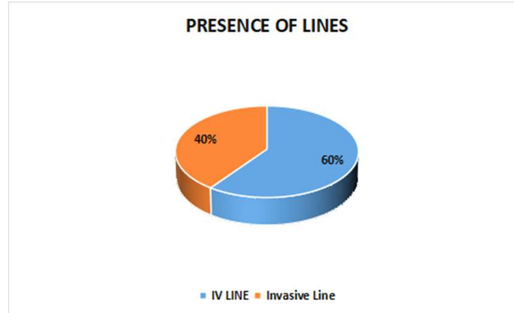

Figure 5: Invasive device utilisation among patients with *Candida auris*

Pie-chart showing proportion of patients with peripheral intravenous lines, central venous catheters and other invasive devices at the time of infection.

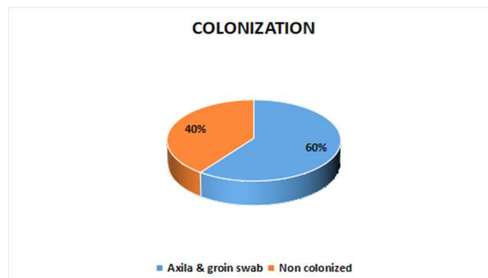

Figure 6: Colonisation status of patients with *Candida auris*

Pie-chart illustrating proportion of patients with positive axillary and/or groin colonisation compared with non-colonised patients.

Comparison with Other *Candida auris* Disinfection Studies

The findings of the present study are consistent with, and in several aspects extend, existing evidence on the effectiveness of environmental disinfection strategies against *Candida auris* in healthcare settings.

Sodium Hypochlorite

Multiple laboratory and clinical studies have demonstrated that high-concentration sodium hypochlorite (≥5,000 ppm) is highly effective against *C. auris*. Cadnum et al. (2017) and Rutala et al. (2019) showed that bleach-based and sporicidal disinfectants consistently achieved ≥5–6 $\log_{10}$ reductions of *C. auris* on hard surfaces, whereas lower concentrations showed variable efficacy. [8] In alignment with these observations, our study demonstrated complete elimination of recoverable *C. auris* from environmental surfaces using 5,000 ppm sodium hypochlorite, while 1,000 ppm resulted in approximately 40% persistence, supporting evidence that suboptimal concentrations may be insufficient, particularly in high-burden ICU environments. However, recent studies have highlighted the ability of *C. auris* to form dry-surface biofilms, which can confer tolerance to sodium hypochlorite, especially at lower concentrations and shorter contact times. This may explain the residual contamination observed in our study with 1,000 ppm hypochlorite and underscores the importance of appropriate concentration and contact time. [9]

Hydrogen Peroxide–Based Disinfection

The present study demonstrated that stabilized hydrogen peroxide wipes achieved greater than 95% environmental clearance, reducing contamination from 70% before intervention to 5% after intervention, representing a substantial improvement in environmental clearance. Similar findings have been reported in recent multicenter investigations. Ghaharian et al. reported a reduction in environmental contamination from approximately 70% to 16–20% following implementation of continuous dry hydrogen peroxide technology in burn and intensive care units.[11] Recent systematic reviews published between 2023 and 2025 have likewise concluded that hydrogen peroxide-based disinfectants provide consistently high fungicidal activity against *Candida auris* while remaining compatible with sensitive medical equipment.[14] Compared with these studies, our findings demonstrated an even greater reduction in environmental contamination, which may be attributed to the combined implementation of standardized cleaning protocols, chlorhexidine decolonization, strict contact precautions, and continuous microbiological surveillance.

Quaternary Ammonium Compounds (QACs)

Consistent with published evidence, QAC-based disinfectants demonstrated poor activity against *Candida auris*, with persistence observed in more than 60% of environmental samples.[12] Laboratory studies involving isolates from multiple geographic regions have consistently reported significantly lower fungicidal activity of QACs compared with chlorine- and hydrogen peroxide-based disinfectants.[13] These findings are supported by current CDC and EPA recommendations, which advise against the use of QAC-only products for *Candida auris* environmental decontamination during outbreaks.

Impact on *Candida auris* Incidence

While many published studies focus on environmental clearance, fewer demonstrate a direct reduction in clinical incidence. Our study contributes novel data by showing that implementation of effective environmental disinfection—particularly hydrogen peroxide–based cleaning—was associated with a complete absence of new *C. auris* cases over a 12-month post-intervention period. This sustained incidence reduction aligns with conclusions from recent systematic reviews (2020–2025), which emphasize that environmental disinfection combined with patient decolonization and strict contact precautions is essential for successful long-term control of *C. auris* outbreaks. [18] Beyond disinfectants and technologies, effective infection prevention also depends on adherence to standardized cleaning protocols, staff education, and continuous surveillance. Kordalewska and Perlin reviewed current infection control measures for *Candida auris* and emphasized that successful containment requires strict environmental cleaning, contact precautions, surveillance, and consistent implementation of institutional infection prevention practices. [2]

Table 1. Effectiveness of disinfectants against *Candida auris*

Disinfectant	Concentration / Format	Environmental clearance	Operational notes
Sodium hypochlorite	5,000 ppm	Complete elimination	High efficacy but corrosive; handling and dilution challenges
Sodium hypochlorite	1,000 ppm	Approx. 60% clearance (40% persistence)	Suboptimal for C. auris
Hydrogen peroxide (stabilized)	Ready-to-use wipes	>95% clearance	Non-corrosive; equipment-safe; high staff compliance
Quaternary ammonium compounds	Various	<40% clearance (>60% persistence)	Not recommended for C. auris in ICU

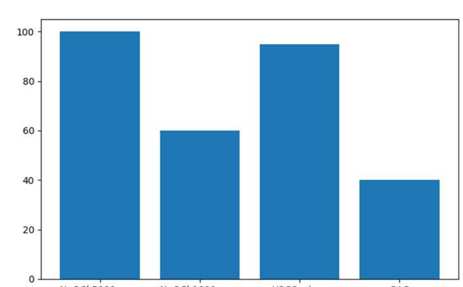

Figure 7. Comparative effectiveness of disinfectants against environmental *Candida auris*

Bar chart comparing percentage environmental clearance achieved with sodium hypochlorite (1,000 ppm and 5,000 ppm), stabilised hydrogen peroxide wipes and quaternary ammonium compounds.

DISCUSSION

This prospective interventional study demonstrated that implementation of stabilized hydrogen peroxide wipes as part of a multimodal infection prevention strategy resulted in a marked reduction in environmental *Candida auris* contamination from 70% to 5%, accompanied by the absence of new cases of infection or colonization during the 12-month follow-up period. These findings support growing evidence that environmental decontamination is a critical component of *Candida auris* outbreak prevention. Recent multicenter studies and systematic reviews have consistently shown that sporicidal disinfectants, particularly hydrogen peroxide- and chlorine-based formulations, achieve substantially greater environmental clearance than quaternary ammonium compound (QAC)-based products and contribute to interruption of healthcare-associated transmission. [16] Our results support a multimodal approach: the combination of hydrogen peroxide-based environmental disinfection, 4% chlorhexidine gluconate (CHG) patient decolonization, and strict contact precautions substantially reduced environmental contamination. These findings are consistent with previous studies demonstrating the persistence of *Candida auris* on healthcare surfaces and highlighting the importance of comprehensive infection prevention strategies to interrupt transmission. [16]

Notably, while some studies report variable efficacy for hydrogen peroxide under heavy organic loads, our protocol mitigated this through standardized pre-cleaning and ensuring adequate wet contact time. In alignment with findings by Cadnum et al. (2017), our study confirms that Quaternary Ammonium Compounds (QACs) are largely ineffective against *C. auris*, showing over 60% persistence in environmental samples. [12] This reinforces CDC and EPA recommendations to prioritize disinfectants with proven fungicidal activity against this resilient pathogen. [13,18] Furthermore, our baseline data reflects the global trend of *C. auris* persistence on high-touch surfaces, which facilitates rapid recontamination and outbreak propagation. [16,18] While "no-touch" technologies (e.g., vaporized hydrogen peroxide) are effective, they often face logistical and financial barriers. Stabilized hydrogen peroxide wipes offer a practical, scalable alternative that integrates seamlessly into existing nursing workflows without inducing pathogen resistance. [14,15] (Table 2)

Table 2: Comparison of Present Study with Published Evidence

Disinfectant Strategy	Published Evidence	Present Study Findings
Sodium hypochlorite ≥5,000 ppm	Highly effective (≥5–6 log_{10} reduction)	100% environmental clearance
Sodium hypochlorite 1,000 ppm	Variable efficacy; biofilm tolerance	~40% persistence
Hydrogen peroxide (wipes/DHP)	>90–95% clearance; outbreak control	95% clearance; zero new cases in 12 months
Quaternary ammonium compounds	Poor efficacy; CDC-not recommended	>60% persistence

The present findings are broadly consistent with recent international literature, although direct comparisons should be interpreted cautiously because of differences in study design, sampling frequency, environmental surveillance protocols, and patient populations. Nevertheless, the marked reduction in environmental contamination observed in the present study (70% vs. 5%) compares favorably with previously published multicenter investigations and supports the incorporation of hydrogen peroxide-based environmental disinfection into routine infection prevention programs for *Candida auris*.

Limitations

This study has several limitations. First, it was conducted in a single tertiary-care intensive care unit, which may limit the generalizability of the findings to other healthcare settings. Second, the study included a relatively small sample size of **20 patients**, reducing the statistical power for subgroup analyses. Third, the intervention was implemented as part of a multimodal infection prevention strategy that included stabilized hydrogen peroxide wipes, strict contact precautions, chlorhexidine bathing, and enhanced environmental cleaning. Therefore, the independent effect of each intervention could not be determined. In addition, environmental surveillance relied on culture-based methods, which may underestimate low-level contamination. The study also did not assess long-term cost-effectiveness, staff compliance, or sustainability of the intervention. Despite these limitations, the prospective design, standardized environmental surveillance, and 12-month follow-up provide valuable real-world evidence supporting hydrogen peroxide-based environmental disinfection for controlling *Candida auris* in intensive care units.

CONCLUSION

Our findings corroborate global evidence that sodium hypochlorite (5,000 ppm) and stabilized hydrogen peroxide-based disinfectants are significantly superior to Quaternary Ammonium

Compounds (QACs) for the control of *Candida auris*. While high-concentration bleach remains effective, stabilized hydrogen peroxide wipes emerged as the operationally optimal choice due to their strong antimicrobial performance, non-corrosive properties, and high compatibility with sensitive ICU equipment. The implementation of a multimodal infection prevention strategy—integrating effective environmental decontamination with 4% CHG patient decolonization and strict contact precautions—resulted in a durable reduction of environmental contamination from 70% to 5%. Most importantly, this intervention led to a complete cessation of new *C. auris* cases over a 12-month period, demonstrating that sustained suppression is achievable in a real-world tertiary-care setting.

Recommendations for Clinical Practice:

- **Targeted Disinfection:** Prioritize stabilized hydrogen peroxide wipes for daily cleaning of high-touch surfaces and medical equipment.
- **Terminal Cleaning:** Reserve 5,000 ppm sodium hypochlorite for terminal cleaning in areas with heavy organic load or visible soiling.
- **Restrict QACs:** Limit the use of QAC-only products in units with a high risk of *C. auris* transmission, as they are insufficient for environmental clearance.
- **Multimodal Care:** Maintain daily 4% CHG bathing and oral care for colonized or infected patients alongside rigorous contact precautions.
- **Continuous Monitoring:** Conduct weekly patient screening (axilla/groin) and bi-weekly environmental audits to provide real-time feedback to frontline clinical teams.

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