ORIGINAL ARTICLE

# Role of Antimicrobial Air Purifier in Reducing the Microbial Load in the Critical Care Unit in Oncology Center: An Intervention Study

Vijeta B Batra[1], Jyotirmay Kirtania[2], Shashank Tiwari[3], Priyanshu Kumar[4], Amit Kumar[5], Subarna Chakraborty[6]

*Received on:* 01 October 2024; *Accepted on:* 02 January 2025; *Published on:* 31 March 2025

## Abstract

**Introduction:** High quality and effective ventilation system operation plays a major role in maintaining indoor air quality in critical care unit (CCU). Aim of this study was to detect the role of antimicrobial-air-purifier in reducing the colony counts of microbes in air and high surface.

**Methods:** This prospective study was conducted in CCU over a period of 18 months from November 2022 to May 2024 after approval from Hospital Ethics Committee. Microbial load was tested in CCU in the presence of and absence of purifier and air/high touch surface sampling was done by using settle-plate method on consecutive days in two phases (with/without purifier). Microorganism culture and identification was done using VITEK-2, and colony counting was performed using Omeliansky formula.

**Results:** The comparison of microbial load in the CCUs between two phases revealed significant difference in the air and surface on days 1, 7, 14, 30, and 60 ($p < 0.0001$). Among gram-positive cocci (GPC), the most common isolate identified was coagulase-negative *Staphylococcus* species [35 (92.10%)], followed by *Micrococcus luteus* [5 (13.15%)] and *Staphylococcus aureus* [1 (2.63%)]. All GPC were resistant to methicillin and erythromycin while 1 (5%) strain was resistant to vancomycin, teicoplanin, and linezolid. Among gram-negative bacilli (GNB), the most common isolate was *Acinetobacter* species [8/23 (34.78%)], followed by *P.* species [5 (21.74%)]. About 19–23 (85–100%) GNB strains were resistant to third-generation cephalosporins and beta-lactam and beta-lactamase inhibitors. About 9–15 (42.3–67.64%) were resistant to tigecycline and carbapenems. Decreased bloodstream infections/catheter-associated urinary tract infections (CAUTI) rate of 3.49–2.92/3.97–1.95/1,000 patient-days was observed in CCU, while the device utilization ratio was same.

**Conclusion:** Antimicrobial air purifier showed an effective role in decreasing the central line-associated blood stream infections and CAUTI rates in CCU.

**Keywords:** Antimicrobial air purifier, Critical care unit, Hospital-acquired infections, Patient safety.

*Indian Journal of Critical Care Medicine* (2025): 10.5005/jp-journals-10071-24910

## Highlights

High quality and effective ventilation system operation plays a major role in maintaining indoor air quality in ICU. Microbial load in air and surface decreased more rapidly during the first week of air purifier installation approximately by 50% both in air and surfaces in ICU.

## Introduction

Effective ventilation systems in critical care units (CCU) play a crucial role in prevention of hospital-acquired infections (HAI).[1] There are various factors in CCU, such as types of host diseases, observed microorganisms, indoor air pollutants, handwashing, and environmental cleanliness, which determines the prevalence rate and impact of the healthcare-associated infections. We know that cancer patients in oncology critical care are highly immunosuppressed patients and most susceptible to such infections.[2] The most common challenges are being faced when CCU patients are infected with multidrug-resistant (MDR) bugs, as these bugs are resistant to various group of antimicrobials, which results in prolonged patient's hospital stay, increased treatment costs, and eventually higher morbidity and mortality to the patients.[3] Hospital infection control and preventive measures are used to minimize the spread of microorganisms, such as environment cleanliness. The movement of staff, patients, and attendants cause more generation of aerosols and increase air particulate counts that may include contaminated microorganisms.[3] Air handler units installed in CCU like heating, ventilation, and air conditioning

[1,4,5]Department of Microbiology, HBCH & MPMMCC (Tata Memorial Centre) Varanasi, Homi Bhabha National Institute (HBNI), Mumbai, Maharashtra, India

[2,3]Department of Anesthesiology, Critical Care & Pain, HBCH & MPMMCC (Tata Memorial Centre) Varanasi, Homi Bhabha National Institute (HBNI), India

[6]Department of Nursing, HBCH & MPMMCC (Tata Memorial Centre) Varanasi, Homi Bhabha National Institute (HBNI), Mumbai, Maharashtra, India

**Corresponding Author:** Vijeta B Batra, Department of Microbiology, HBCH & MPMMCC (Tata Memorial Centre) Varanasi, Homi Bhabha National Institute (HBNI), Mumbai, Maharashtra, India, Phone: +91 9902623877, e-mail: vijetabajpaikgmu@gmail.com

**How to cite this article:** Batra VB, Kirtania J, Tiwari S, Kumar P, Kumar A, Chakraborty S. Role of Antimicrobial Air Purifier in Reducing the Microbial Load in the Critical Care Unit in Oncology Center: An Intervention Study. Indian J Crit Care Med 2025;29(4):327–332.

**Source of support:** Nil

**Conflict of interest:** None

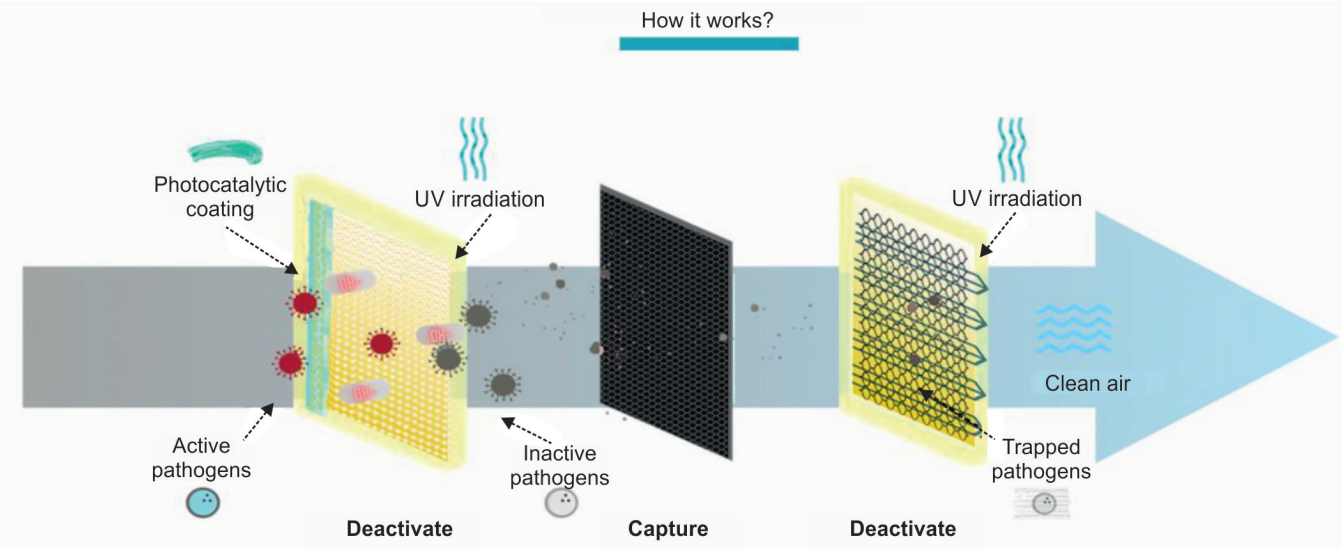


**Fig. 1:** Design and principle of air purifier

units (HVAC) are used for improving the air quality, pressure, and cooling. Also, high-efficiency particulate air (HEPA) filters act by removing 99.97% of dust, pollen, and other particulate matters.[4] High-efficiency particulate air-based air purifiers can protect from air pollution, but they allow microbial growth on its filters, and hence, can become a source of airborne disease transmission due to the possibility of resuspension.[4] Air purifiers may be effective alternative and complement to HVAC systems in CCUs, especially in resource-limited hospitals. They can be effectively reducing the microbes, particles, and other contaminants in the air and on high touch surface.

## Objectives

### Primary Objective

Identification and prevalence of microorganisms detected in the CCU environment before and after the placement of air purifier.

### Secondary Objective

Changes in HAI rate after the intervention period.

## Study Design

This prospective intervention study was done over a period of 18 months, from November 2022 to May 2024, after getting Institutional Ethics Committee approval.

Our CCU infrastructure and design are according to the guidelines recommended for Indian CCU, which says that ambient temperature of CCU must be 16–25°C, relative humidity of 30–60%, filtration of suspended particulate matter up to 99% efficiency till 5 µm, and neutral air pressure, maintained by central HVAC system. There is a considerable variation in the guideline recommendations across the world in respect of air quality of CCUs.[4]

Our CCU is located on the fourth floor, with an approximate floor area of 240 square meters, with 13 beds. There is a central HVAC system with diffusers for air inlet, and return air vents distributed over the ceiling of the CCU. The building management system senses and electronically maintains the ambient temperature of 18–22°C, humidity of 30–60%, and about five air changes (outside air/total) per hour, with neutral air pressure gradient between CCU and the buffer zone. There is no HEPA filter fitted on the diffusers (air inlet) into the CCU. The buffer zone between CCU and the main corridor is about 9 square meters, with two wide doors fitted with automatic door closers.

As per the Hospital Infection Control Policy, before entering the CCU premises, all healthcare staff first wear the personal protective equipment. In phase I, air purifier was placed in CCU, and this phase is called as intervention period. After 6 months, the device was turned off and was removed. Phase II of the study lasted for another 6 months. No other air purification systems or filtration system was used in the CCU in this period.

### Equipment Principle

Antimicrobial air purifier equipment uses Indian Institute of Technology (IIT) Bombay patent-filed technology, which works on the basic principle of D-C-D (deactivate-capture-deactivate) mechanism. Compared with conventional ultraviolet (UV)-based air purifiers, it can provide up to 8,000 times better disinfection efficiency. In this technology, airborne pathogens and viruses get deactivated via inflight deactivation. AIRTH purifiers are built to optimize filtration and disinfection technologies. This unique innovation protects against airborne disease transmission and air allergens. Designed for efficiency, AIRTH purifiers are ideal for use in 500-square-foot rooms.

### Equipment Design

The equipment (AIRTH model name: vSure) has the capacity to deactivate and filter the bacteria. It is a floor free-standing, portable system with recirculating air with dimensions of 300 × 300 × 650 mm and weight of 14.2 kg. It has a clean air delivery rate of 320 $m^3$/hour; energy consumption of 70 W; and a noise level ranging from 10 to 12 decibel. Figure 1 describes the principle of the air purifier.

AIRTH aimed to scientifically validate the performance of their air purifier by testing its ability to reduce microorganisms in environment.

### HEPA Filtration

The HEPA filter removes at least 99% of airborne particulate matter, such as bacteria and allergens as small as 0.3 µm in size.

AIRTH's air purifier stands as a revolutionary product in the field of air purification, demonstrating outstanding performance and energy efficiency, backed by scientific evidence from IIT Kanpur.

## Method of Study

### Sample Collection from High Touch Surface and Air

Air-exposed culture plates were used in phase I and phase II of the study for the purpose of air surveillance. It was done when there is minimum interference of the CCU staff like cleaning and patient procedures. The air-exposed culture plates were placed at five different designated points inside the CCU. In total, half liter of air were collected using the air-sampler at a steady rate of 100 liter/minute.

Results were provided in the form of colony-forming units (CFU). From high touch surface, such as the bed cardiac trolley, headboards, ventilator monitors, bed table, and nursing station in the CCUs, transport microbiology swabs were collected. Omeliansky formula was used to calculate the aerobic bacteria count, and the results were shown as CFU/10 $cm^3$.[5] The process of sample collection was done before and after the device was turned on (day 0), as well as on days 7, 14, 30, and 60 of one phase in similar manner. Details of sample collection are illustrated through timeline workflow in Figures 2 to 4.

Also, in both phases, healthcare-associated infections were calculated by infection control nurses as per Centers for Disease Control and Prevention (CDC) criteria.[6] Data was collected for monitoring infections in the study period, and the patients' culture results were evaluated.

### Microbiology Laboratory Analysis

The exposed blood agar plates were incubated at 37°C in microbiology laboratory to identify the most frequently identified organisms in the air. The growth of microorganisms in the blood agar was identified by conventional/automated microbiological methods (Vitek 2Automated identification system, Biomerieux, Germany). The antibiotic susceptibility was done by both Vitek and Kirby Bauer disc diffusion method. The processing of swabs collected from high touch surfaces were done in 5% sheep blood agar.

### Data Analysis

Statistical Package for the Social Sciences (SPSS version 22) (IBM Corp., Armonk, NY, USA) was used for evaluation of descriptive data using nonparametric tests. A *p*-value <0.05 was considered as statistically significant for all analyses.

## Results

The total distribution and prevalence of microorganisms isolated from the CCUs during the sampling days in both phases is mentioned in Table 1. The prevalence of gram-positive cocci (GPC) in 40 (58.82%) samples was more in comparison with

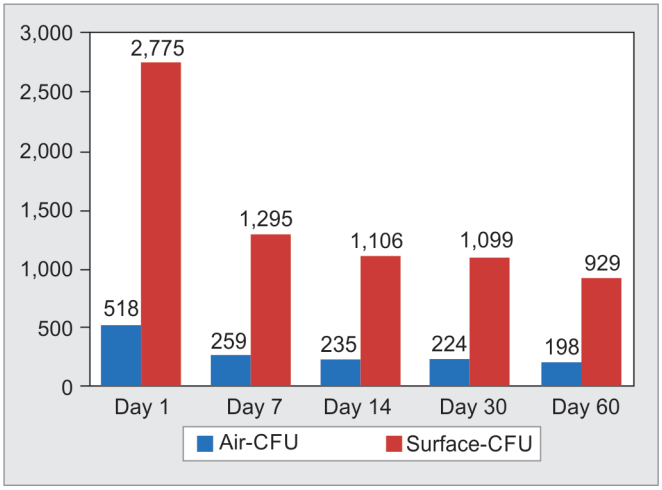


**Fig. 2:** Distribution of colony counts of microorganisms according to sampling days in air and surface in phase I with purifier

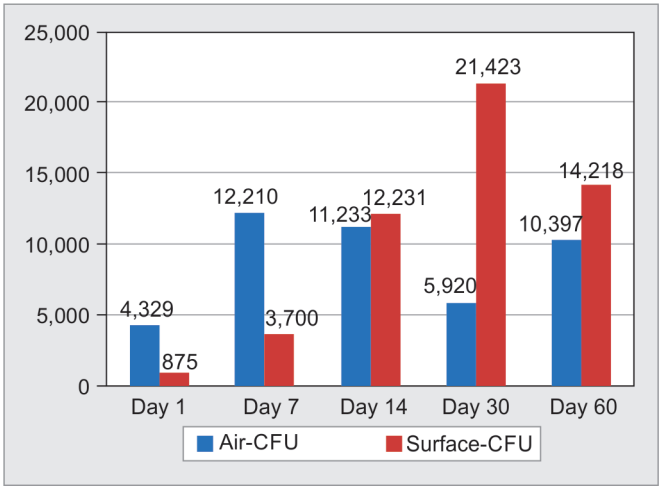


**Fig. 3:** Distribution of colony counts of microorganisms according to sampling days in air and surface in phase II without purifier

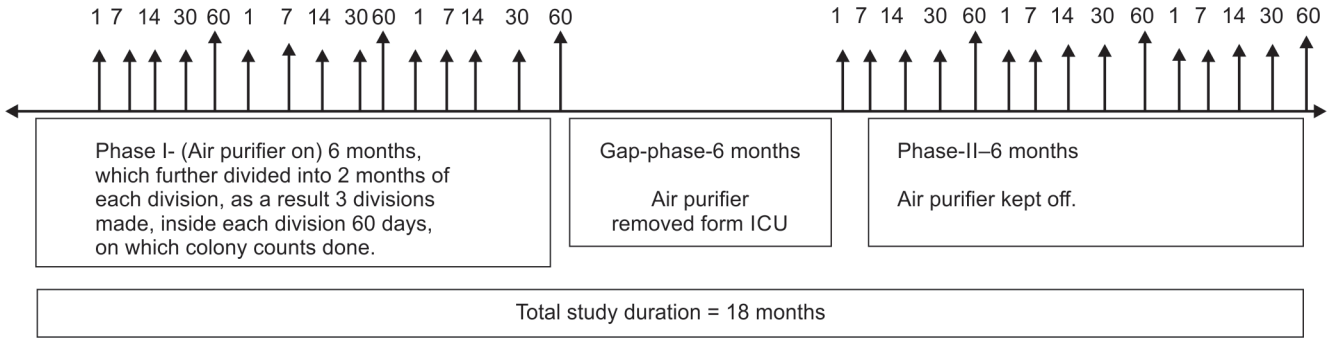


**Fig. 4:** Timeline of study duration with subsequent distribution of time into phases

**Table 1:** Distribution of microorganisms in phase I and phase II

| | *Phase I (with purifier)* | | *Phase II (without purifier)* | |
|---|---|---|---|---|
| *Organism* | *Air and surface* | *HAI in CCU* | *Air and surface* | *HAI in CCU* |
| GNB | *Acinetobacter* (14.28%)<br>*Klebsiella* spp. (14.28%)<br>*Pseudomonas* spp. (42.85%)<br>*E. coli* (14.28%)<br>*Sphingomonas paucimobilis* (14.28%) | *E. coli* (25%)<br>*Klebsiella pneumoniae* (75%) | *Acinetobacter* spp. (29.16%)<br>*Klebsiella* spp. (8.33%)<br>*Pseudomonas* spp. (8.33%)<br>*Sphingomonas paucimobilis* (4.16%)<br>*Serratia* (8.33%)<br>*E. coli* (8.33%)<br>*Moraxella* spp. (4.16%) | *E. coli* (12.5%)<br>*Klebsiella* spp. (37.5%)<br>*Pseudomonas* spp. (25%) |
| GPC | CONS (92.85%)<br>*(S. haemolyticus, S. hominis, S. warneri, Micrococcus luteus)*<br>*Streptococcus* spp. (7.14%) | Nil | CONS (96.15%)<br>*(S. haemolyticus, S. hominis, S. warneri, M. luteus, S. epidermidis, S. arlettae)*<br>*S. aureus (3.84%)* | *Enterococcus faecium* (12.5%) |
| Fungi | *Candida* spp. | *Candida* spp. (25%) | *Aspergillus* spp. | *C. albicans, C. tropicalis* (37.5%) |

gram-negative bacilli (GNB) in 24 (36.92%) and fungal organisms in 4 (6.15%) in air and surface samples in both phases. Overall, the most common isolates identified were coagulase-negative *Staphylococcus* species (CONS) in 39 (97.5%), *S. hemolyticus* in 14 (40%), *S. hominis* in 7 (15.26%), *S. warneri* in 4 (10.52%), *S. cohnii* in 2 (5.26%), *S. epidermidis* in 3 (7.89%), *S. arlettae* in 1 (2.63%), *S. aureus* in 1 (2.63%), *Micrococcus luteus* in 5 (13.15%), and *Streptococcus* species in 1 (2.63%) in CCU surveillance. All GPC, such as CONS and *S. aureus*, were resistant to methicillin and erythromycin. Of those, 15 (93.2%) GPC were resistant to cefradine, 16 (94.7%) GPC were resistant to clindamycin, 8–11 (25.8–32.4%) GPC were resistant to fluoroquinolones, 10 (29.16%) GPC were resistant to rifampin, 3 (27.3%) GPC were resistant to tetracycline, 1 (5%) GPC was resistant to vancomycin and teicoplanin, and 1 (4%) was resistant to linezolid.

Among the isolated GNBs, most common organism was *Acinetobacter* species 8/23 (34.78%) followed by *P.* species 5 (21.74%), *Serratia* species 1 (4.34%), *Klebsiella oxytoca* 2 (8.69%), and *Escherichia coli* 3 (13.04%). The prevalence of antimicrobial resistance in GNB strains from both phases of the study were found to be 23 (100%) resistant to cefotaxime and ceftriaxone, while 20 (89%) GNB strains were found to be resistant to piperacillin/tazobactam, 19 (85%) to cotrimoxazole, 18 (83.33%) to fosfomycin, 17 (72.2%) to piperacillin and ticarcillin (15–16) 67.6–71.46%, 15 (67.64%) to meropenem, 10 (45.45%) to ceftazidime/avibactam, 8 (33.33%), 9 (42.3%), tigecycline, cefoperazone/sulbactam, gentamicin, 7 (32.35%) to ciprofloxacin, 7 (32.35%) to amikacin, 6 (31.2%) to imipenem, 5 (26.6%) to cefepime, 5 (25.8%) to levofloxacin, and 2 (9.9%) to aztreonam.

Significant difference was present in comparison of the number of colonies in the CCU air on days 1, 7, 14, 30, and 60 days ($p < 0.0001$, $< 0.0001$, $< 0.0001$, 0.03856, and $< 0.0001$, respectively) in phase I and phase II. Significant difference was found in CCU in colony concentrations high touch surface on days 1, 7, 14, 30, and 60 days ($p < 0.0001$, $< 0.0001$, $< 0.0001$, $< 0.0001$, and $< 0.0001$, respectively) in both phases. The colony counts in the high touch surface in the CCU on day 60 was significantly higher compared with phase I ($p < 0.001$). Colony counts and their distribution are mentioned in Table 2 and Figures 1 and 2. The high touch surfaces microbial count was significantly higher in phase II on day 1 and day 7 ($p < 0.001$ and $< 0.001$, respectively).

As per central line-associated blood stream infections (CLABSI) and catheter-associated urinary tract infections (CAUTI) surveillance in CCU, we found that the predominant organisms isolated were *Klebsiella pneumoniae* 11 (22.92%), *Enterococcus faecium* 7 (14.58%), *P. aeruginosa* 6 (12.50%), and *Acinetobacter baumannii* 5 (10.42%), which were resistant to carbapenems, tigecycline, and beta-lactam and beta-lactamase inhibitors combinations, and were the main cause of HAI. When the HAI rates were compared in between two phases of the study, we found that there is a decrease in bloodstream infections (BSI) rate in CCU over a period of 1 year from 3.49 to 2.92, and also there is a decrease in urinary tract infection (UTI) incidence rate and CAUTI rate from 3.97 to 1.95 and 4.11 to 0.97, respectively, while the device utilization ratio (DUR) in both phases were approximately same (BSI 0.5–0.45 and UTI 1.00–0.97) (Tables 3 and 4).

**Table 2:** Distribution of colony counts of microorganisms in phase I and phase II

| *CFU* | *Phase I (with air purifier)* | *Phase II (without air purifier)* | *Chi-square test* |
|---|---|---|---|
| Air | 1,434 | 44,089 | **<0.0001** |
| Surface | 7,204 | 52,447 | **<0.0001** |
| Chi-square test | **<0.001** | **<0.001** | |

Chi-square test $p$-value < 0.05 is statistically significant

Figures 2 and 3 show the distribution of the rate of HAI in the intervention and phase II, and the incidence density rate of HAI by study time in both phases of the study.

## Discussion

The study evaluated the total microbial load, bacterial pathogens present in air surveillance and high touch surface of CCU, and their antimicrobial resistance patterns. We also analyzed the efficacy of air purifiers in decreasing the HAI over a span of 6 months. It is a well-known fact that CCU environments are the rich reservoir of many MDR GPC and GNB; this is because CCU patients are critically ill and stay for a long time, especially the cancer patients who are highly susceptible for acquiring the HAI and airborne infections.[7]

Approximately, 5–10% of patients in developed countries are affected by HAI. In fact, the risk of HAI is 20 times higher in developing countries, including India. It has been found in various studies that inadvertent use of antibiotics leads to the emergence of resistant microorganisms.[8,9] Inefficient environmental cleaning leads to significant transmission of pathogenic bacteria among

**Table 3:** CLABSI rate in phase I and phase II

| *Time period* | *CLABSI* | *Non-CLABSI* | *Secondary BSI* | *Total BSI rate* | *CLABSI rate* | *DUR* |
|---|---|---|---|---|---|---|
| Phase I | 3 | 0 | 0 | 2.92 | 3.46 | 0.50 |
| Phase II | 4 | 1 | 4 | 3.49 | 5.78 | 0.45 |

**Table 4:** CAUTI rate in phase I and phase II

| *Time period* | *#CAUTI* | *#Non-CAUTI* | *UTI incidence rate* | *CAUTI rate* | *DUR* |
|---|---|---|---|---|---|
| Phase I | 1 | 1 | 1.95 | 0.97 | 1.00 |
| Phase II | 10 | 0 | 3.97 | 4.11 | 0.97 |

CAUTI rate, catheter-associated urinary tract infections; DUR, device utilization ratio

patients, staff, and the inanimate environment, such as high touch surface.[10,11] Patients' unstable clinical status predisposes them to infection, and environment may have more important role in carrying those infections, especially in CCUs and operation theater (OT).[12–15] The good and effective air quality in hospitals has become a critical part to prevent air pollutants in hospital environment.[16,17] The prevalence of HAI in CCU is quite high in India, which ranges from 9.6 to 17.7%.[9,18,19]

Cancer patients are prone to higher rates of BSI than the nononcological hospital population, which is due to multiple factors responsible for the transmission of HAI, such as microbial counts in air, host immunity status, particle size, indoor air quality (IAQ), CCU design, patient numbers, and their CCU turnover.[10,20,21]

Antimicrobial air purifier (AIRTH) was developed with a state-of-the-art preventive measure against infection spread and air pollution. It provides active and real-time protection against airborne disease spread for hospitals. In the present situation, it is an effective way to prevent the spread of bacteria, virus, and fungi. There are various studies which have been done using portable air purifier in CCU, which are based on HEPA filter-based air purifiers.[11]

High-efficiency particulate air-based air purifiers can protect from air pollution, but they allow microbial growth on its filters, and hence, can become a source of airborne disease transmission due to the possibility of resuspension.[16,22]

The air purifier used in this study is based on the principle of deactivation of the pathogens present in the air to provide real-time protection against spread of infectious diseases and air pollution. It uses a technology that works on D-C-D mechanism. Compared with conventional UV-based air purifiers, it can provide up to 8,000 times better disinfection efficiency. In this technology, airborne pathogens and viruses get deactivated via inflight deactivation. These purifiers are designed in a way to provide maximized intensity, thus optimizing the filtration and disinfection technology.

The important aspect of hospital infection control management is to keep the CCU environment clean.[22,23] Infection control nurse audited the compliance with cleaning and disinfection protocol prepared by Hospital Infection Control Committee on basis. The placement of the four air purifiers were done according to the capacity of CCU (mm), and positioning was done in a manner to avoid any interference in staff routine activities. There is already an effective HVAC system in CCU which controls the transmission of bacteria and other allergens in air, our central HVAC system. Air handling units like HVAC units maintain good IAQ through adequate ventilation with filtration and provide thermal comfort. However, the volume of traffic and human activities inside the CCU vary widely throughout the day, evening, and night shifts. This results in widely varying biological and nonbiological aerosol loads in the CCU air. We hypothesized that portable air purifiers are needed in addition to the HVAC system for purification of circulating air in the CCU to cope up with this fluctuating aerosol loads.

The indicator microorganisms isolated more frequently during both phases of the study were *Staphylococcus* species, *Acinetobacter baumannii*, and *P. aeruginosa* from air and surface. Strains with similar antibiogram (MDR) patterns were also isolated from patients' blood samples and urine samples depicting the HAI and confirming the importance of air and surface surveillance. Most of the HAI in patients were due to *Klebsiella pneumoniae* 11 (22.92%) and *Enterococcus faecium* 7 (14.58%), which are endogenous microbes and might get into contact of air and high touch surface through contaminated hands. High colony concentration in the CCU in phase II was associated with an increase in HAI rates (CLABSI and CAUTI), which confirms the hypothesis of our study. If we exclude the other confounders responsible for the burden of HAI as total number of patient's turnover, staff number, and visit, it might be possible to postulate that 20–50% HAI comes from air and surfaces. For proving this hypothesis, it is important to ensure that CCU is effectively designed, there is presence of minimal staff members in CCU, and ventilation systems operate. Previous study was done over a period of short span (2 months only).[1] Our study was done over a period of 12 months in which first phase (with purifier) was followed by a rest of 1 month and then next phase of 6 months sampling was done to observe the microbial load and increase in HAI rates, which also gave more statistically significant difference of the results.

### Limitations

Microbiological samples were collected when there was minimal activity (cleaning, changing sheets, patients visit, etc.).

Though routine air and surface surveillance is not recommended by CDC guidelines, here we conducted this as a part of study to check its compliance, and we found significant reduction in microbial load after installation of air purifier. Bacterial strains isolated in the CCU were not analyzed for the molecular testing that come under our limitations criteria; however, we have done comparison in the antimicrobial sensitivity testing and antibiogram pattern of GPC and GNB isolated in CCU and in the study. Based on our study results, future replicative studies may be conducted to assess if air purifiers installed inside the CCU can smoothen the diurnal fluctuations in the aerosol load in the CCU or not, and find its causal link to HAI.

## Conclusion

Microbial load in air and surface decreased more rapidly during the first week of air purifier installation approximately by 50% both in air and surfaces in CCU. The CLABSI rates and CAUTI rates decreased in presence of air purifier. These findings signify the importance of installation of antimicrobial air purifier in critical areas such as CCU and OTs. Using air purifier in addition to a hospital HVAC system may be one of the effective ways to reduce the MDR microbial load in air in CCUs, given that performance of HVAC systems may not match the diurnal fluctuations in the levels of biological and nonbiological aerosol loads in the CCU air.

## Acknowledgments

Air purifiers and air sampling devices were provided by AIRTH Pvt. Ltd. company for the study. Authors are thankful to Mr Ravi Kaushik and the company associates for the financial support of the study.

## Declaration

This study has been plagiarism checked by author which falls under acceptable range.

### Ethical Approval

This study has been approved by Institute of Ethics Committee, MPMMCC, Varanasi, and it is an interventional study in CCU with study no. 11000060.

## Orcid

*Vijeta B Batra* https://orcid.org/0000-0002-1884-1700
*Jyotirmay Kirtania* https://orcid.org/0000-0002-4426-6877
*Shashank Tiwari* https://orcid.org/0000-0002-9161-5144
*Priyanshu Kumar* https://orcid.org/0009-0008-7713-8768
*Amit Kumar* https://orcid.org/0000-0001-9056-5598
*Subarna Chakraborty* https://orcid.org/0009-0006-6146-8442

## References

1. Arıkan I, Genç Ö, Uyar C, Tokur ME, Balcı C, Renders DP. Effectiveness of air purifiers in intensive care units: An intervention study. J Hosp Infect 2022;120:14–22. DOI: 10.1016/j.jhin.2021.10.011.
2. Blot S, Ruppé E, Harbarth S, Asehnoune K, Poulakou G, Luyt CE, et al. Healthcare-associated infections in adult intensive care unit patients: Changes in epidemiology, diagnosis, prevention and contributions of new technologies. Intensive Crit Care Nurs 2022;70:103227. DOI: 10.1016/j.iccn.2022.103227.
3. Brusselaers N, Vogelaers D, Blot S. The rising problem of antimicrobial resistance in the intensive care unit. Ann Intensive Care 2011;1:47. DOI: 10.1186/2110-5820-1-47.
4. Saran S, Gurjar M, Baronia A, Sivapurapu V, Ghosh PS, Raju GM, et al. Heating, ventilation and air conditioning (HVAC) in intensive care unit. Crit Care 2020;24(1):194. DOI: 10.1186/s13054-020-02907-5.
5. Vanlalruati R, Khiangte L, Hmar V, Vanlalchhanhimi LV, Chongthu JL, Hmar L, et al. Microbiological surveillance of operation theatres of a tertiary care hospital in Mizoram, north eastern part of India: 4 years retrospective analysis. IP Int J Med Microbiol Trop Dis 2022;8(1):19–23. DOI: 10.18231/j.ijmmtd.2022.005.
6. Horan TC, Andrus M, Dudeck MA. CDC/NHSN surveillance definition of health care-associated infection and criteria for specific types of infections in the acute care setting. Am J Infect Control 2008;36(5):309–332. DOI: 10.1016/j.ajic.2008.03.002.
7. Madebo C, Haile A, Eticha T, Solomon F. Hospital-based air-borne and surface-borne bacterial pathogens and their antimicrobial profiles in Wolaita Sodo, Southern Ethiopia. Int J Microbiol 2022;2022:5718341. DOI: 10.1155/2022/5718341.
8. Sikora A, Zahra F. Nosocomial infections. Treasure Island, FL: StatPearls Publishing; 2023.
9. Gunasekaran S, Mahadevaiah S. Healthcare-associated infection in intensive care units: Overall analysis of patient criticality by acute physiology and chronic health evaluation IV scoring and pathogenic characteristics. Indian J Crit Care Med 2020;24(4):252–257. DOI: 10.5005/jp-journals-10071-23384.
10. MacPhail A, Dendle C, Slavin M, McQuilten Z. Hospital-acquired bloodstream infections in patients with cancer: Current knowledge and future directions. J Hosp Infect 2024;148:39–50. DOI: 10.1016/j.jhin.2024.03.002.
11. Salmonsmith J, Ducci A, Balachandran R, Guo L, Torii R, Houlihan C, et al. Use of portable air purifiers to reduce aerosols in hospital settings and cut down the clinical backlog. Epidemiol Infect 2023;151:e21. DOI: 10.1017/S0950268823000092.
12. Kuczewski E, Henaff L, Regard A, Argaud L, Lukaszewicz AC, Rimmelé T, et al. Bacterial cross-transmission between inanimate surfaces and patients in intensive care units under real-world conditions: A repeated cross-sectional study. Int J Environ Res Public Health 2022;19(15):9401. DOI: 10.3390/ijerph19159401.
13. Huang PY, Shi ZY, Chen CH, Den W, Huang HM, Tsai JJ. Airborne and surface-bound microbial contamination in two intensive care units of a medical center in Central Taiwan. Aerosol Air Qual Res 2013;13:1060–1069. DOI: 10.4209/aaqr.2012.08.0217.
14. Bonadonna L, Briancesco R, Coccia AM, Meloni P, Rosa G, Moscato U. Microbial air quality in healthcare facilities. Int J Environ Res Public Health 2021;18(12):6226. DOI: 10.3390/ijerph18126226.
15. Watson R, Oldfield M, Bryant JA, Riordan L, Hill HJ, Watts JA, et al. Efficacy of antimicrobial and anti-viral coated air filters to prevent the spread of airborne pathogens. Sci Rep 2022;12(1):2803. DOI: 10.1038/s41598-022-06579-9.
16. Guo J, Xiong Y, Kang T, Xiang Z, Qin C. Bacterial community analysis of floor dust and HEPA filters in air purifiers used in office rooms in ILAS, Beijing. Sci Rep 2020;10(1):6417. DOI: 10.1038/s41598-020-63543-1.
17. Fujiyoshi S, Tanaka D, Maruyama F. Transmission of airborne bacteria across built environments and its measurement standards: A review. Front Microbiol 2017;8:2336. DOI: 10.3389/fmicb.2017.02336.
18. Mahmoudi A, Sany SBT, Salmasi MA, Bakhshi A, Bustan A, Heydari S, et al. Application of nanotechnology in air purifiers as a viable approach to protect against Corona virus. IET Nanobiotechnol 2023;17(4):289–301. DOI: 10.1049/nbt2.12132.
19. Pradhan NP, Bhat SM, Ghadage DP. Nosocomial infections in the medical CCU: A retrospective study highlighting their prevalence, microbiological profile and impact on CCU stay and mortality. J Assoc Physicians India 2014;62(10):18–21. PMID: 25906516.
20. Willis DN, Looper K, Malone RA, Ricken B, Slater A, Fuller A, et al. Eliminating central line associated bloodstream infections in pediatric oncology patients: A quality improvement effort. Pediatr Qual Saf 2023;8(3):e660. DOI: 10.1097/pq9.0000000000000660.
21. Blot K, Hammami N, Blot S, Vogelaers D, Lambert ML. Gram-negative central line-associated bloodstream infection incidence peak during the summer: A national seasonality cohort study. Sci Rep 2022;12:5202. DOI: 10.1038/s41598-022-08973-9.
22. Ribeiro B, Vázquez-López A, Vazquez-Pufleau M, Llamosí M, Sempere J, Yuste J, et al. Control of microbial agents by functionalization of commercial air filters with metal oxide particles. Mater Chem Phys 2024;313:128684. DOI: 10.1016/j.matchemphys.2023.128684.
23. Argyropoulos CD, Skoulou V, Efthimiou G, Michopoulos AK. Airborne transmission of biological agents within the indoor built environment: A multidisciplinary review. Air Qual Atmos Health 2023;16:477–533. DOI: 10.1007/s11869-022-01286-w.