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Comparative Study on High-Efficiency Particulate Air (HEPA) Filters for Enhancing Hospital Indoor Air Quality and its Role in Prevention of Infections During Post-Operative Care

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Abstract **Original Research Article**

Introduction: Recently, infectious diseases caused by airborne bacteria and viruses have been of primary global concern for social and economic reasons. HEPA is an acronym for high-efficiency particulate absorption filters. The preventable proportion of healthcare-associated infections (HAIs) may decrease over time as standards of care improve. Most hospitals do not effectively track, report, or prevent non-ventilator-associated hospital-acquired pneumonia (NVHAP), despite it being one of the most prevalent and morbid healthcare-associated illnesses. We assessed the use of portable HEPA filters in open settings, i.e., in general wards, to improve hospital indoor air quality in given hospital-acquired pulmonary infections. ***Aims and Objectives:*** To measure the efficacy of HEPA filters used in an open setting in preventing/reducing HAIs& improving indoor hospital air quality by the incidence of hospital-acquired respiratory/pulmonary infections and air culture studies. ***Materials and Methods:*** Portable HEPA filters were placed in the test group ward, i.e., for patients with various diagnoses. The rate of respiratory infections was compared with the control group ward, i.e., the ward without the filter. Periodical air cultures were done in respective wards during this study period. ***Results:*** A prospective comparative study was conducted during July 2020 till October 2022 in the surgical wards of BLDE DU Shri B. M. Patil Medical College, Vijayapura. There were 250 patients in the study, with 125 each in the test and control groups. All patients included in the study were evaluated in terms of history, physical findings, and chest x-ray findings. Periodical air cultures were taken in both wards, and reports were noted. Periodical data values of the HEPA filter arranged in the test group were noted. There were no significant differences in the incidence of respiratory infections between the groups, i.e., pneumonia changes in chest radiographs (CXRs). 27 patients among test groups developed pneumonia changes vs 24 patients among control group. (p=0.723). Air culture studies have shown similar microbes in both groups, with no significant differences. Sequential culture among test ward showed Klebsiella Pneumonia (43%), E Coli (40%), Citrobacter freundii (10%), Pseudomonas aeruginosa (7%). The Control ward cultures showed following organisms E coli(43%), Klebsiella Pneumonia(23%), Citrobacter freundii (20%), Pseudomonas aeruginosa (10%). ***Conclusion:*** Despite installing HEPA filters in the post-surgical ward, it didn't pronounce statistically significant protective effect against pulmonary infections demonstrable in the open setting over improvement in indoor hospital air quality.

Keywords: Air filters, air pollution, HEPA filter, infection, pneumonia, indoor air quality, airculture studies.

INTRODUCTION

Each day 10,000 litres of air enter the lungs to extract the 420 litres of oxygen required forlife and proper functioning. Our air quality affects how well our lungs and other organsfunction. Access to clean air is a fundamental requirement for human health and well-being. But air pollution still poses a major threat to everyone's health.[1]

The World Health Organization (WHO) reports that air pollution caused seven million deaths in 2012, demonstrating that it is currently the top environmental health hazard in the world.[2]

People spend 90% of their lives indoors, breathing indoor air. As a result, both indoor and outdoor air pollution expose people to risk. Air should be pre-cleansed or cleaned on-site to avoid this detrimental effect. Due to oxidative harm caused by particulate matter (PM) in air pollution, the airways become remodeled, inflamed, and more susceptible to sensitization. On the other hand, the strength of the evidence differs even though various pollutants have been linked to air contamination.[3]

Indoor air pollution is a complicated mixture of pollutants produced indoors and contaminants that move into the indoor environment.[4]

The term "aerodynamic equivalent diameter" (AED)characterizes pollutants, essentially particulate matter. The settling velocity of particles with the same AED is frequently the same. Particulate matter is divided into AED fractions, such as PM10, PM2.5, and PM0.1, according to how the particles are formed and where they land in human airways.[5]

The nose and upper airway filter out most particles larger than 10micrometers6.Particles with a diameter between 2.5 and 10 micrometers (PM2.5-10) are categorized as "coarse," fine, "and "ultrafine", respectively. These particles can penetrate the respiratory system and reach the alveoli, causing inflammation and infection.[4]

Infectious organisms, such as fungi, bacteria, and viruses, can be dispersed into the air due to coughing or sneezing. Due to their small size, droplet nuclei—tiny moisture droplets with a diameter of 1 to 5 micrometers containing infectious microorganisms—remain suspended for several hours and are disseminated over vast distances by air currents. They are tiny enough to get through the respiratory tract's defenses when breathed and settle in the lung, where they will spread infection.[6]

A mat of fibers organized in a random pattern makes up HEPA filters. The fibers typically have sizes between 0.5 and 2.0 micrometers and are made of polypropylene or fiberglass. These filters often consist of tangled bundles of tiny fibers. Air travels along a tiny, intricate channel created by these fibers. The fiber bundles act like a household sieve when the larger particles try to pass through this channel, physically preventing the particles from passing through.

However, smaller particles cannot keep up and crash into the fibers when they move through the air with it as it twists and rotates. The tiny particles constantly move around the air molecules as if these molecules are assaulting them because they have very little inertia. Theyeventually crash against the fibers due to their movement.[7]

Fiber diameter, face velocity, and filter thickness are important variables that impact how well it performs. Unlike sieves or membrane filters, which allow particles smaller than apertures or pores to pass through, HEPA filters target a range of particle sizes. These particles are captured/stuck to a fiber through a combination of the three techniques outlined below.[8]

1. Diffusion: In a HEPA filter, diffusion is used to catch particles smaller than 0.3μm. The tiniest particles, notably those with diameters under 0.1μm, collide with gas molecules, leading to the development of this process. The tiny particles are blasted or bounced around and strike the fibers of the filter medium. This behavior resembles Brownian motion and increases the likelihood that a particle will be stopped by impaction or interception; this mechanism becomes dominant with lower airflow.
2. Interception: Particles travelling along a flow line in the air stream approach a fiber within one radius and stick to it. Mid-sized particles are captured by this method.
3. Impaction: Larger particles must directly embed in a fiber instead of avoiding them by following the curves of the air stream. This impact worsens as airflow velocity and fiber spacing decrease. The photocatalytic oxidation (PCO) technique is becoming increasingly well-liked for the disinfection of airborne microorganisms. A photon from the light excites a catalyst, causing an electron in the valence band to hop to the conduction band and leave a hole behind when a photocatalyst, primarily TiO2, is exposed to UV light. While the electron in the conduction band combines with oxygen to form a superoxide radical anion, that hole can also react with the surrounding water to produce a hydroxyl radical (-OH) (-O2). These radicals can damage the cell membranes of microorganisms, releasing K+, RNA, proteins, and other vital elements that finally lead to cell death.[9]

Filters have developed over the years to meet the ever-increasing requirements for air quality in various high-tech industries, including aerospace, the pharmaceutical industry, hospitals, health care, nuclear fuels, and integrated circuit fabrication. There is a resurgence of interest in the usage of air filters in the COVID-19 era for several reasons, including the decrease of aerosol contamination, the reduction of particulate matter, and the reduction of HAIs. Although the advantages in high-density service areas like ICUs, ORs, etc., are well known, their contribution to reducing air contamination in common wards is not well understood. Even though few studies have demonstrated advantages, the numerous elements and proper scientific confirmation are crucial. To reduce particulate matter, organisms circulating in the air, and HAIs, this study aims to evaluate the contribution of air filters in open environments.

While filtration is essential to preserving the standard of hospital air, filters can occasionally serve as a haven for living organisms and thus promote their growth. As a result, the gadget itself could end up being contaminated. The primary drawbacks of HEPA filters include their high maintenance costs and electrical requirements due to their high-pressure drop, which increases fan energy consumption.[10]

This thesis focuses mainly on-air purification by portable air filters with HEPA in an open setting.

AIM OF THE STUDY:

• To observe the efficiency of HEPA filter portable air purifiers in enhancing the hospital indoor air quality in reducing the hospital-acquired pulmonary infections.

OBJECTIVES OF THE STUDY:

• To measure the efficacy of HEPA filters in preventing/reducing hospital-acquired infection & improving indoor hospital air quality in terms of
  - o Incidence of Respiratory infection (pneumonia)
  - o Quality of indoor air in open setting-air culture study.

NEED FOR STUDY

Maintaining excellent indoor air quality is an important non-pharmacological technique forreducing HAIs and cross-contamination. The quantity of breathing infectious microorganisms in indoor air has some bearing on the airborne transmission of infectious diseases.[11]

HAIs are nosocomial (originating or occurring in a healthcare facility) acquired infections that can happen up to 30 days after surgery, up to 3 days after discharge from the hospital, up to 48 hours after hospital admission, or in a healthcare facility when someone is admitted fora reason unrelated to the infection.[12]

Most hospitals do not effectively track, report, or prevent non-ventilator-associated hospital acquired pneumonia (NVHAP), despite it being one of the most prevalent and morbid healthcare-associated illnesses. Through the air, an infection can spread from one person to another epidemically.[13]

Few studies have calculated how many illnesses would be prevented or lives saved if hospitals used the most effective infection prevention and control methods (IPC). The study predicted the efficacy of the Nosocomial Infection Control (SENIC) initiative of the Centers for Disease Control and Prevention more than 30 years ago. White, Culver, and Haley, the authors concluded that with efficient surveillance and control strategies, 30 to 35 percent of the majority of healthcare-associated infections (HAIs) might be avoided19. Since then, a great deal of research has looked at strategies to lower the most prevalent HAIs, including central line-associated bloodstream infections (CLABSIs), catheter-associated urinary tractinfections (CAUTIs), ventilator-associated pneumonia (VAP), and surgical site infections (SSI).[14]

There is still a lot of opportunity for development. Implementing evidence-based methods can still result in a 30 to 50 percent reduction in HAI, which suggests that current recommendations have not been followed to their full potential. Importantly, the effectiveness of infection control efforts cannot be determined just by a nation's economic standing.[12]

In 0.5 to 2.0% of patients, pneumonia complicates hospitalization and is linked to high morbidity and mortality. Mechanical breathing for more than 48 hours, ICU residency, length of ICU or hospital stay, the severity of underlying illness, and comorbidities are risk factors for hospital-acquired pneumonia (HAP). The most frequent causes of HAP are Pseudomonas aeruginosa, Staphylococcus aureus, and Enterobacter. The majority of HAP cases involve polymicrobial flora. Hospital-acquired pneumonia (HAP) affects 0.5 to 2.0% of hospitalized patients and makes up 15% of all nosocomial infections. HAP has a mortality rate of more than 30%; however, attributable mortality is lower. In various studies, the etiologic factors causing HAP have been clarified. Gram-negative bacteria, including Pseudomonas aeruginosa, Enterobacter, Acinetobacter, and enteric Gram-negative rods, cause 55 to 85% of HAP cases; Grampositivecocci, including Staphylococcus aureus, cause 20% to 30%; and 40 to 60% of cases are multi-microbial. The intensity and severity of the disease, the length of hospitalization, and prior antibiotic exposure are important variables influencing the probability of infections.[14]

One in every 100 hospitalized patients develops non-ventilator-associated hospital-acquired pneumonia (NVHAP), which increases antibiotic use, lengthens hospital stays by up todays, necessitates ICU admission in up to 46% of non-ICU cases, and is associated with readmission within 30 days in up to 20% of survivors. Despite the high morbidity, mortality, and expense associated with this condition, hospitals lack norms or standards to monitor or prevent NVHAP consequences.[13]

Over the past 20 years, healthcare institutions and policymakers have committed significant resources to reduce additional healthcare-associated illnesses. Many device-associated infections, particularly ventilator-associated pneumonia, have dramatically decreased due to these steps, while NVHAP rates have remained chronically high. The development of microbiome diagnostic techniques has made it easier for us to understand that the lung is nota sterile organ but a complex ecosystem of bacteria interacting with their host and one another. One of the top causes of death in children and the elderly worldwide is pneumonia. Pneumonia is an infection brought on by a virus, bacteria, or other germs; it causes lung inflammation and, if not treated promptly, can be fatal.[14]

Furthermore, pneumonia is risky, especially in underdeveloped countries where millions of people lack access to healthcare and live in poverty. The World Health Organization (WHO)estimates that air pollution-related pneumonia and other infections result in more than four million fatalities annually.[15]

Escherichia coli (20.1%), Staphylococcus aureus (17.8%), Pseudomonas species. (11.5%), Enterobacteriaceae (10.6%), Candida spp. (11.5%), Enterococci (6.5%), Acinetobacter species. (5.7%), and coagulase-negative staphylococci (5.3%) were the pathogens that caused. HAI most frequently worldwide in 2011, according to WHO.[16]

Infectious agents with endogenous or exogenous origins are responsible for the pathogenesis of hospital-acquired infections (HAIs). Endogenous sources are areas of the patient's body typically colonized by the local microbial flora, such as the skin, nose, mouth, gastrointestinal system, etc. These bacteria have the potential to spread infection when given the right circumstances. Exogenous sources are not internal to the patient, but from staff members, guests, equipment used in healthcare, or the surrounding environment. Due to the use of antibiotics and colonization by new environmental bacteria in hospitalized patients, the natural flora alters. The use of antibiotics exerts selective pressure on the normal flora, killing off susceptible bacteria while allowing antibiotic-resistant ones to live, grow, and predominate. Hospitalized patient attendees will also come into contact with the hospital environment, picking up local bacteria that are frequently antibiotic-resistant because they can survive in a setting where antibiotics are frequently administered. Additionally, antibiotics can kill out the typical, susceptible flora at these locations, leaving them vulnerable to colonization by resistant flora from the environment.[17]

Finally, the use of invasive devices that are made of synthetic materials allows bacteria that have evolved to survive on those materials to proliferate and take over, while bacteria that have evolved to survive on human tissue are disadvantaged and go extinct (for example, the plastic of an endotracheal tube or central venous catheter). These variables help to explain why bacteria linked to hospital-acquired infections are frequently antibiotic-resistant and belong to distinct species from those frequently found in community-acquired infections. Because of the sterilized air, healthy humans' immunity may be reduced.[18]

Chest radiography is an efficient, convenient, affordable, and widely used diagnostic method to find disorders affecting the chest. The global standard for diagnosing pneumonia is the chest X-ray (CXR).[19]

Pulmonary opacities, areas of increased attenuation visualized within the lung fields on chest imaging, are commonly used as criteria to support a diagnosis of pneumonia. Despite Corbeling used as the primary radiographic test to evaluate for pneumonia, the test characteristics of CXR for detecting pneumonia are not well understood. Computed tomography (CT) is amore precise technique for imaging the chest, but has not supplanted CXR as the primary imaging test for pneumonia due to increased time, cost, and radiation exposure associated with CT.[20]

Therefore, this study aims to evaluate how well HEPA filters reduce pulmonary/respiratoria's in an open setting.

METHODOLOGY

A detailed history was taken and patients were examined. Required investigations like complete blood picture, blood urea, serum creatine, blood sugar, urine analysis was done and noted. Initial CXR was done at the time of admission which was used as baseline for comparison with the next CXR done after a week. Pulmonary opacities, areas of increased attenuation, cavitations/ infiltrations, consolidations within lung fields, were noted as CXR changes.

HEPA FILTER

The air filter used in this study is Eureka Forbes 4S with a HEPA filter. It is a portable air filter. This HEPA filter has effective filtration efficiency for PM 2.5-99.97% with 6 stages of filtration as follows according to product specifications,

1. Pre-filter
2. Swiss HEPA filter (H-13 grade)
3. Activated Carbon filter
4. NANOPURETM with 3600 UV C Germicidal technology
5. Photocatalyst TiO2 technology6. Patented Dorton technology (Ionizer)

Figure 1: Portable HEPA filter

Product specifications:
Product:
Aero guard 4S Air Purifier
Brand:
Eureka Forbes
Coverage Area:
46 m.Sq
Air Flow Control:
297 m3/h
Power Consumption:
17-85 W
Rated Voltage:
200 -240V AC/ 50/ 60 Hz
Dimensions:
53x45x23 cm
Weight:
9.20 Kgs

AIRBORNE MICRO FLORA SAMPLING PROTOCOL:

An air sampler is used for air sampling. Air was aspirated at a fixed rate of 180 l/min through sterilized perforated metal plate cover onto the surface of a 50mm contact plate containing a selected agar, i.e., blood and nutrient agar plate. Aspirated plates from the air sampler were incubated at 25oc for 7days or until visible growth appeared, after which results were noted.

Figure 2: Air sampler

STUDY AREA:

The indoor air quality survey was carried out in a surgical ward with an average of 200 m3with a 4-window area of 20m2. Accommodation of an average of 20 people with a variable range of 5 people (involving nursing staff and patients' attendees) is maintained. Written informed consent was obtained from all patients, along with a detailed explanation of the procedure, as well as risks and complications involved, as well the benefits and drawbacks of the same, and the patient was given the choice of participation. The primary outcome was changes noted in CXRs taken after a week.

STUDY DESIGN

- A prospective comparative study
- Study period: July 2020 –October 2022

With the Anticipated Proportion of hospital-acquired infections (clinically documented infections) between the study and control 23.3 % and 9.4%, a study conducted by Hemozoin et.al. A quasi-experimental study is taken as a reference.[21]

- The study required a sample size of 125 per group. (i.e., a total sample size of 250assuming equal group sizes), to achieve a power of 95% for detecting a difference in proportions between two groups at a two-sided p-value of 0.05.

Formula used
• n= (zα+zβ)2 2 p*q
MD2
Where Z = Z statistic at a level of significance MD = Anticipated difference between two proportions = Common Proportion = 100-p

Statistical Analysis

- The data obtained was entered into a Microsoft Excel sheet, and statistical analysis was performed using a statistical package for the social sciences (Version 20).
- Results were presented as Mean ± SD, counts and percentages, and diagrams. The normally distributed continuous variables between two groups were compared using an independent t-test; the Mann-Whitney U test was used for those not normally distributed. Categorical variables between the two groups were compared using the Chi-square test/Fisher`s Exact test.

INCLUSION CRITERIA:

• Inpatients with more than 5 days of hospital stay
• Patients with normal respiratory function
• Age more than 18 years

EXCLUSION CRITERIA:

• Inpatients with less than 48 hours of hospital stay
• Patients with a history of lower respiratory tract infections needed treatment within one year or present.
• Patients with immunocompromised status

RESULTS

In total, 250 patients enrolled in the study who were admitted in male surgical ward.

TEST GROUP: This group included 125 patients admitted to male surgery ward1 with HEPA portable filter.

CONTROL GROUP: This group included 125 patients admitted to male surgery ward2 with no air filter.

Under predetermined objectives, all patients included in the study were evaluated in terms of history, physical findings, and chest x-ray findings. Periodical air cultures were taken in both wards, and reports were noted. Periodical data values of the HEPA filter arranged in the test group were noted. The observations made during the study were as follows.

Table 1: Age wise distribution of cases in the research population

Age	Test Group		Control Group	
	No. of patients	Percentage	No of patients	Percentage
<20	5	4%	1	0.8%
20-29	7	5.6%	10	8%
30-39	23	18.4%	23	18.4%
40-49	25	20%	11	8.8%
50-59	21	16.8%	30	24%
60-69	31	24.8%	31	24.8%
70-79	9	7.2%	11	8.8%
80-90	4	3.2%	8	6.4%
Total	125	100%	125	100%

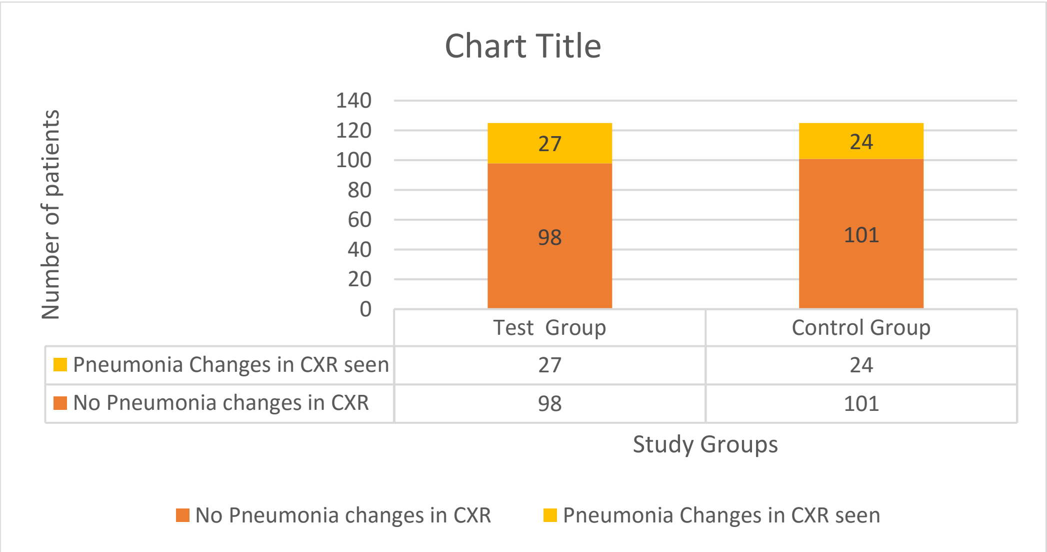

Chart 1: Pneumonia changes across groups in the study

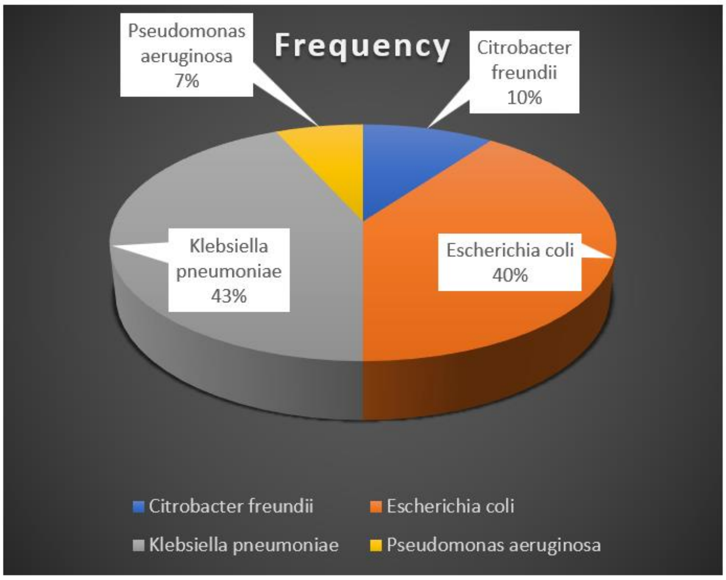

Chart 2: Organisms developed upon air culture in test ward

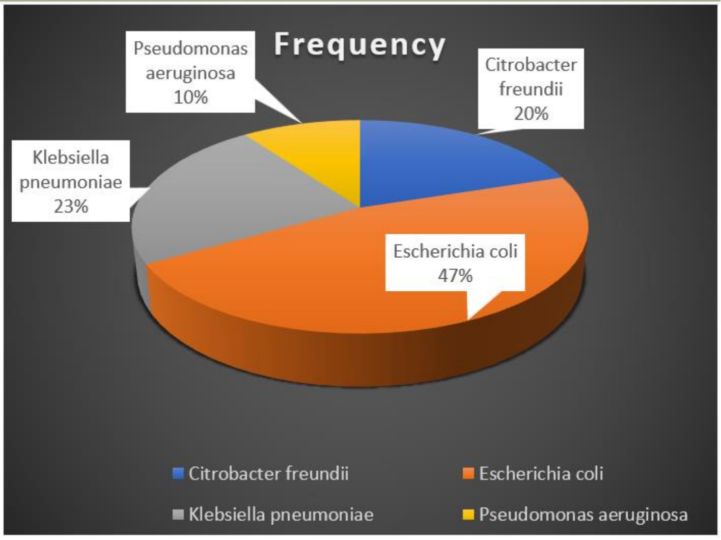

Chart 3: Organisms developed upon air culture in control ward

DISCUSSION

Pneumonia is a known complication causing morbidity and mortality in hospitalized patients. In the past, majority studies done mainly concentrated on areas like operation theatres, ICUs etc., to assess the efficacy of air filters. In our study, we looked into the filter's effect in an open setting, i.e., general wards. To our knowledge, this is the first prospective study that compares the outcome of HEPA filter in open setting enhancing hospital indoor air quality by assessing HAI (pneumonia using CXR)

In a study done by Wolfgang Rosenberger on Effect of charcoal equipped HEPA filters on cabin air quality in aircraft, he concluded that HEPA filters improve air quality by reducing the concentration of air pollutants in order of 30%.[22]

A Randomized trial of asthmatic children receiving a HEPA filter intervention combined with integrated pest management concluded that there were significant improvements to indoor air quality, with a 45% reduction in indoor PM2.5 in HEPA-treated classrooms as compared to untreated classrooms.[23]

A randomized crossover study of HEPA filtration, without a washout period, in 23 homes of low-income Puerto Ricans in Boston and Chelsea, MA, concluded that a portable HEPA filter intervention resulted in significant improvement of indoor air quality, by showing filtration rate of 50 to 85% when compared to no filtration homes, but there was no observed benefit in terms of reduced inflammation in alveoli.[24]

In a multicenter study of Hospital Acquired Pneumonia (HAP) in non- ICU patients by Nieves, Nenos study group, showed S. pneumoniae, L. pneumophila, Aspergillus pseudomonas aeruginosa and Enterobacteriaceae sp were most frequent etiologies and pneumonia attributed to 13.9% cause-specific mortality concluding non-ICU HAP is an important cause of hospital mortality and morbidity.[25]

In a HEPA filter intervention study among healthy elderly couples in Denmark, Bräuner et al found an improvement of 8.1% In Reactive Hyperemia Index (RHI) with filtration, which reduced PM2.5 from 12.6 to 4.7 mg/m3.[26]

The effect of portable HEPA filter air cleaner use during pregnancy on fetal growth: The UGAAR randomized controlled trial by Prabjot Barna, Enkhjargal Gombojav et al, shows the use of HEPA filters was associated with a 40% reduction in PM2.5 concentrations causinggreater birth weight only among babies born at term.[27]

In a study done by Battsetseg uMzimkhulu, Enkhjargal Gombojav, et al over portable HEPA air filter indicated that reducing PM air pollution during pregnancy improve cognitive performance in childhood as Portable HEPA air filters will help to reduce the neurodevelopmental impacts of air pollution.[28]

Reduction in MRSA environmental contamination with a portable HEPA-filtration unit-study done by T.C. Boswell, P.C. Fox concluded that portable HEPA-filtration unit can significantly reduce MRSA environmental contamination within patient isolation rooms.[29]

By these studies, we can conclude that HAP is a notable cause for longer hospital stay causing morbidity and morbidity to patient. And HEPA filter is efficient in filtering PM and shown good outcomes over health improvement. We conducted the study, Use of portable HEPA air filter in general wards to enhance the indoor hospital air quality by reducing HAP.

CONCLUSION

The present study comparing intervention of HEPA filters in inpatient health and hospital indoor air quality concludes:

1. The HEPA filter in a portable air filter in an open setting, i.e., an uncontrolled environment, may not improve hospital indoor air quality as inpatients in wards with HEPA filters showed pulmonary infections the same as without filters.
2. In terms of particulate matter filtration, the filter shown poor result, i.e., showing continuous positive air cultures as in areas without the filter.
3. Due to limitations of the setting this study needs to be repeated in various settings to strengthen the observations. Further research is indicated to investigate and supplement strategies to use HEPA filter in open setting

SUMMARY

The present study compared the HEPA filter intervention to enhance the hospital's indoor air quality, namely in the view of pulmonary infections in inpatients and air culture studies. The present was done between July 2020 – October 2022. A total of 250 patients were included in the study, with 125 in the test group, i.e., with HEPA filter and 125 in the control group. The results were inferred, and it was found that portable HEPA filter intervention showed poor result in enhancing the hospital indoor air quality in an open setting.

BIBLIOGRAPHY

1. Vijayan VK, Paramesh H, Salvi SS, Dalal AA. Enhancing indoor air quality–The air filter advantage. Lung India: Official Organ of Indian Chest Society. 2015Sep;32(5):473.
2. Ambient (outdoor) Air Quality and Health, Fact Sheet No. 313. World Health Organization. Available from: http://www.who.int/mediacentre/factsheets/fs313/en/
3. Guarnieri M, Balmes JR. Outdoor air pollution and asthma. The Lancet. 2014 May3;383(9928):1581-92.
4. Diette GB, McCormack MC, Hansel NN, Breysse PN, Matsui EC. Environmental issues in managing asthma. Respiratory care. 2008 May 1;53(5):602-17.
5. Anderson JO, Dhoundiyal JG, Stelmach A. Clearing the air: a review of the effects of particulate matter air pollution on human health. Journal of medical toxicology. 2012 Jun;8(2):166-75.
6. Secretariat MA. Air cleaning technologies: an evidence-based analysis. Ontario health technology assessment series. 2005;5(17):1.
7. Christopherson DA, Yao WC, Lu M, Vijayakumar R, Sedaghat AR. High-efficiency particulate air filters in the era of COVID-19: function and efficacy. Otolaryngology–Head and Neck Surgery. 2020 Dec;163(6):1153-5.
8. First MW. HEPA filters. Journal of the American Biological Safety Association. 1998 Mar 1;3(1):33-42.
9. Chuaybamroong P, Chotibai R, Pothina S, Sibongile P, Larpkiattaworn S, WuCY. Efficacy of photocatalytic HEPA filter on microorganism removal. Indoor Air. 2010 Jun;20(3):246-54.
10. Messina G, Spataro G, Catarsi L, De Marco MF, Grasso A, Cevenini G. A mobile device reducing airborne particulate can improve air quality. AIMS Public Health. 2020;7(3):469.
11. Schreiber PW, Sax H, Wolfensberger A, Clack L, Kuster SP. The preventable proportion of healthcare-associated infections 2005–2016: systematic review andmeta-analysis. Infection Control & Hospital Epidemiology. 2018 Nov;39(11):1277- 95.
12. Munro SC, Baker D, Giuliano KK, Sullivan SC, Haber J, Jones BE, Crist MB, NelsonRE, Carey E, Lounsbury O, Lucatorto M. Nonventilated hospital-acquired pneumonia:a call to action: recommendations from the National Organization to Prevent Hospital-Acquired Pneumonia (NOHAP)

among nonventilated patients. Infection Control & Hospital Epidemiology. 2021 Aug;42(8):991-6.
13. Lynch III JP. Hospital-acquired pneumonia: risk factors, microbiology, and treatment. Chest. 2001 Feb 1;119(2):373S-84S.
14. Jaiswal AK, Tiwari P, Kumar S, Gupta D, Khanna A, Rodrigues JJ. Identifying pneumonia in chest X-rays: A deep learning approach. Measurement. 2019 Oct 1; 145:511-8.
15. F. Nightingale, Notes on Nursing: What It Is, and What It Is Not, D. Appleton and Company, New York, NY, USA, 1860.
16. Capolongo S. Architecture as a generator of health and well-being. Journal of public health research. 2014 Apr 24;3(1): jphr-2014.
17. Khan W, Zaki N, Ali L. Intelligent pneumonia identification from chest x-rays: A systematic literature review. IEEE Access. 2021 Mar 30; 9:51747-71.
18. Fehr R, Capolongo S. Healing environment and urban health. Epidemiol Prev. 2016Mar 1;40(3-4):151-2.
19. D'Alessandro D, Fara GM. Hospital environments and epidemiology of healthcareassociatedinfections. Indoor air quality in healthcare facilities 2017 (pp. 41-52).Springer, Cham.
20. D'Alessandro D, Tedesco P, Rebecchi A, Capolongo S. Water use and water saving in Italian hospitals. A preliminary investigation.
21. Özen M, Yılmaz G, Coşkun B, Topçuoğlu P, Öztürk B, Gündüz M, Atilla E, Arslan Ö, Özcan M, Demirer T, İlhan O. A quasi-experimental study analyzing the effectiveness of portable high-efficiency particulate absorption filters in preventing infections in hematology patients during construction. Turkish Journal of Hematology. 2016 Mar;33(1):41.
22. Rosenberger W. Effect of charcoal equipped HEPA filters on cabin air quality in aircraft. A case study including smell event related in-flight measurements. Building and Environment. 2018 Oct 1; 143:358-65.
23. Carmona N, Seto E, Gould T, Shirai JH, Hayward L, Cummings BJ, Larson T, Austine. Indoor Air Quality Intervention in Schools; Effectiveness of a Portable HEPA Filter Deployment in Five Schools Impacted by Roadway and Aircraft Pollution Sources. Med Rxiv. 2022 Jan 1.
24. Brugge D, Simon MC, Hudda N, Zellmer M, Corlin L, Cleland S, Lu EY, Rivera S, Byrne M, Chung M, Durant JL. Lessons from in-home air filtration intervention trials to reduce urban ultrafine particle number concentrations. Building and environment.2017 Dec 1; 126:266-75.
25. Sopena N, Sabri M, Nenos 2000 Study Group. Multicenter study of hospitalacquiredpneumonia in non-ICU patients. Chest. 2005 Jan 1;127(1):213-9.
26. uMzimkhulu B, Gombojav E, Bansari C, Bat Sukh S, Enkhtuya E, Boldbaatar Bellinger DC, Lanphear BP, McCandless LC, Tamana SK, Allen RW. Portable HEPA filter air cleaner use during pregnancy and children's cognitive performance at four years of age: the UGAAR randomized controlled trial. Environmental healthperspectives. 2022 Jun 22;130(6):067006.
27. Kajbafzadeh M, Brauer M, Karlen B, Carlsten C, van Eeden S, Allen RW. The impacts of traffic-related and woodsmoke particulate matter on measures of cardiovascular health: a HEPA filter intervention study. Occupational and environmental medicine. 2015 Jun 1;72(6):394-400.
28. Boswell TC, Fox PC. Reduction in MRSA environmental contamination with a portable HEPA-filtration unit. Journal of Hospital Infection. 2006 May 1;63(1):47-54.
29. Self WH, Courtney DM, McNaughton CD, Wunderink RG, Kline JA. High discordance of chest x-ray and computed tomography for detection of pulmonary opacities in ED patients: implications for diagnosing pneumonia. The American journal of emergency medicine. 2013 Feb 1;31(2):401-5.