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Research Article

The Risk of Exposure to Infectious Bacterial Bioaerosols in Different Hospital Wards: A Case Study

Ameneh Bahreini[1], Hamid Reza Ghaffari[2], Mahdi Behjati Ardakani[3], Shahram Zare[4], Kavoos Dinarloo[2*]

[1]Social Determinants in Health Promotion Research Center Hormozgan Health Institute Hormozgan University of Medical Sciences Bandar Abbas Iran

[2]Tobacco and Health Research Center Hormozgan University of Medical Sciences Bandar Abbas Iran

[3]Department Of Occupational Health Engineering Faculty of Health Hormozgan Medical Sciences Bandar Abbas Iran

[4]Professer of Epidemiologic Department Hormozgan University of Medical Sciences Bandar Abbas Iran

***Correspondence to**
Kavoos Dinarloo,
Email: kdindarloo@yahoo.com

Abstract

Background: Biological aerosol particles smaller than 10 microns in diameter are among the health concerns in hospitals since they remain in the air for a long time and are infectious and easily transported. We aimed to investigate the concentration of *Escherichia coli* and *Staphylococcus aureus* bioaerosols and evaluate their risk in the indoor environment of different wards of Khatam al-Anbia hospital, Jask, Iran, in 2020.

Methods: This descriptive-analytical study was performed by collecting and analyzing 50 samples from seven different hospital wards. The active sampling of bioaerosols was performed according to the standard method of the National Organization for Occupational Health and Safety and by a pump with a flow rate of 28.3 L/min for 10 minutes. Blood agar and eosin methylene blue were used to detect bacteria. Then, the Monte Carlo simulation technique was used to assess the microbial risk.

Results: The concentration of *S. aureus* in different wards of the hospital was 4.81 to 18.11 CFU/m^3. The lowest and highest concentrations of *S. aureus* were in the operating room and general emergency wards, respectively, while the highest and lowest concentrations of *E. coli* were in the inpatient wards (0 CFU/m^3) and infectious emergency ward (21.22 CFU/m^3), respectively. The highest and lowest daily risk of *S. aureus* was observed in the neonatal and general emergency wards (8.03×10^{-4} and 3.02×10^{-4}), respectively. Moreover, the lowest and highest daily risk of *E. coli* was found in the neonatal and male inpatient wards (zero and 7.21×10^{-3}), respectively.

Conclusion: In some hospital wards, the concentration and infection risk of *E. coli* and *S. aureus* were found to be higher than the acceptable value. Since high concentrations of airborne bacteria can play an important role in producing nosocomial infections in patients and staff, it is necessary for hospital officials to take corrective measures in equipment control, use proper ventilation systems in the wards, and closely monitor the disinfection process.

Keywords: Bioaerosol, Nosocomial infection, Risk assessment, *Escherichia coli*, *Staphylococcus aureus*

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Background

Nosocomial infections are recognized worldwide as an important health problem threatening the health of patients, staff, and those referring to hospitals (1). Increasing the length of hospital stay, reducing the quality of life of patients, patient death, imposing costs, improper use of antibiotics, and subsequent development of antibiotic resistance are the most important problems caused by nosocomial infections (1,2). Nosocomial infections occur 48-72 hours after admission and may occur up to six weeks after discharge (1-4). The World Health Organization (WHO) estimates that 5%-25% of admitted patients develop nosocomial infections (5). The rate of nosocomial infections is 4%-11% in developed countries and about 30% in developing countries. In Iran, the prevalence of nosocomial infections is estimated to be 10%-15% (6). The cause of these infections is mostly bacteria that are resistant to disinfectants and antibiotics and are present in most hospital wards because of the lack of adequate monitoring and control of bacterial concentrations (7).

Contact with contaminated surfaces and patient secretions is the most important method of transmitting nosocomial infections. Moreover, airborne bioaerosols are mentioned as one of the main causes of infections in different parts of the hospital (6,8). Studies show that 10%-20% of nosocomial infections are transmitted through the air in the form of bioaerosols (9). The greatest health concern is related to biological aerosol particles with a diameter of fewer than 10 micrometers, especially

between 0.1-0.5 μm, that remain in the air for a long time, are easily transported, and cause disease because of their small size (9,10). It is estimated that bioaerosols, especially bacterial and fungal bioaerosols of biological origin, are responsible for about 5%-34% of air pollution in various environments such as hospitals, dental centers, shopping malls, subway stations, public libraries, and other workplaces (6,10). Bioaerosols enter the hospitals through various routes such as air conditioners, visitors, and patients. The density of bioaerosols varies from department to department and from hospital to hospital in a specific city or geographical area. Numerous physical and environmental factors can affect the number and type of bioaerosols in hospital settings (6,9,10). Inhalation is the main route for exposure to bioaerosols, respiratory infections, and their symptoms, and decreased lung function is the most important health complication of bioaerosol exposure (6).

Quantitative microbial risk assessment is a useful tool for estimating the health risks of human exposure to pathogens in various environmental settings (11). Probabilistic risk assessment is performed by Monte Carlo simulations in which sequential and random sampling is performed based on the cumulative distribution function of each input variable. The simulation results are expressed as the probability of infection, disease, or death (12).

Considering the importance of biological air quality in hospitals and given few studies conducted in the field of microbial risk assessment of hospitals (7), we aimed to evaluate the risk of exposure to *Escherichia coli* and *Staphylococcus aureus in* different parts of Khatam Al-Anbia hospital, Jask, Iran.

Materials and Methods

Sampling

This descriptive-analytical study was performed in Khatam Al-Anbia hospital in Jask affiliated to the Hormozgan University of Medical Sciences in 2020. This hospital covers a population of 58 884 individuals with 18 000 square meters of area and 64 beds. This study examined different wards of the hospital for the existence of *E. coli* and *S. aureus* bacterial aerosols and then calculated the risk of exposure to them. Sampling was performed in the general emergency, infectious emergency, dialysis, operating room, intensive care, inpatient, and internal wards, as well as the corridor, nursing station, and outside the hospital. In total, 50 samples were taken for identification using Anderson single-stage bioaerosol sampling pump (SKC, USA). For this purpose, a Biostage was installed on the inlet pipe of the pump, and a plate containing the culture medium was placed in the Biostage. The flow rate of the sampling pump was calibrated (Digital calibrators, Defender) before sampling. The Biostage was placed at the height of 150 cm above the ground and a distance of more than one meter from the walls and windows (13). Then, the air was pumped with a certain flow rate (28.3 L/min) and passed through the culture medium for 10 minutes (13).

Identification of Bacteria

This study used blood agar and eosin methylene blue culture (Merck Conda, Spain) medium for bacterial colony growth. To this end, 40 g of blood agar powder was dissolved in 1000 mL of distilled water and sterilized at 121°C and 15 Pa pressure for 45 minutes. Then, under completely sterile conditions, 50 mL of defibrinated blood was added, and the culture medium was kept upside down in the refrigerator until use. After sampling, the plates containing the culture medium were incubated at 37°C for 48 hours (13). The formed colonies were counted using the CW-HPC400 (B) colony counting machine (Laser Counter Device China Way), and the bacterial concentration was calculated in CFU/m^3 according to the flow rate and sampling time. For differential diagnosis of bacteria, hot staining methods and biochemical detection methods were used, including catalase, oxidase, coagulase, urease, citrate test, antibiotic resistance of novobiocin, and bacitracin (7).

Quantitative Microbial Risk Assessment

The quantitative microbial risk assessment consisted of two steps:

Exposure Assessment

This step measures the amount, frequency, and duration of exposure to the target organism and describes the number and characteristics of the exposed population (14). Daily exposure (d) to bacteria can be calculated by the following equation (15):

$$d = (EC \times BR \times T) \times AG$$

where *EC* is the exposure concentration (CFU/m3), *BR* is the adult respiration rate (lognormal distribution: mean= 0.58 and SD= 0.22 m^3/hour), *T* is the exposure time (8 hours), and *AG* is the aerosol swallowing rate (uniform distribution: min=10 and max=50%). The route of exposure to bioaerosols containing gastrointestinal pathogens is assumed to be a combination of inhalation and ingestion because inhaled pathogens can be accumulated in the upper respiratory tract and then ingested. A uniform distribution of 10%-50% was considered for *AG* due to the uncertainty and variability associated with this type of exposure (15).

Dose-Response Evaluation

Dose-response evaluation can be defined as the quantitative relationship between dose and response, which is generated after an exposure time and according to the level of exposure. The β Poisson model was used

to estimate the risk of *E. coli* infection. The mathematical equation of the β Poisson model is as follows (16):

$$P_{id} = 1 - [(1 + (d / N_{50}))(2^{1/\alpha} - 1)]^{-\alpha}$$

where P_{id} denotes the daily risk of infection, N_{50} is the average infectious dose, α refers to the infectious factor, and d is the exposure rate. The values of α and N_{50} for *E. coli* are 0.155 and 2.11 (10^6), respectively (16).

Furthermore, the following exponential model was used to estimate the risk of *S. aureus*.

$$P_{id} = 1 - \exp(k \times dose)$$

The calue of k for *S. aureus* is 7.64 (10^{-8}) (16).

Furthermore, the annual infection risk (P_{id}) was calculated using the following equation (17):

$$P_{ia} = 1 - (1 - P_{id})^{d}$$

where d is the number of days a person is exposed to a microbial contaminant, and the *P50* and *P90* were applied to compare the infection risk with acceptable limit.

Monte-Carlo Simulation

The constant value of the parameters in the models causes uncertainty in the calculated risk. To overcome this problem, the Monte-Carlo simulation with 10 000 replications was used. The Monte-Carlo simulation technique selects the parameter value within the specified range and then calculates the response. These iterations eliminate the uncertainty and variability of the parameters (18). Therefore, the obtained results are more reliable and valuable than the results calculated by the point estimation method. The simulation was performed using Oracle Crystal Ball software.

Results

In this study, the concentration of bioaerosols is based on CFU/m^3, and the daily and annual risks of *E. coli* and *S. aureus* are presented in Tables 1 to 5.

Discussion

According to Tables 1 and 2, bacterial concentration and the daily and annual risks of *E. coli* and *S. aureus* were not at the standard level of 10^{-4} in the infectious emergency, intensive care, general emergency, operating room, and men's admission wards (16). However, *E. coli* and *S. aureus* and their subsequent risks were at the standard

Table 1. *Escherichia coli* and *Staphylococcus aureus* concentrations in different hospital wards

Ward	Mean *E. coli* concentration (CFU/m^3)	Mean *S. aureus* concentration (CFU/m^3)
Infectious emergency	21.22	15.56
General emergence	7.35	18.11
Operating room	5.66	4.81
Intensive care	0	7.25
Men's admission	0	30.84
Obstetrics and gynecology	0	5.09
Neonatal	0	17.82

Table 2. Mean daily risk of *Staphylococcus aureus* in different wards of the hospital

Ward	Mean daily risk	SD	Percentile 10	Percentile 50	Percentile 90
Infectious emergency	3.02×10^{-4}	1.70×10^{-4}	1.17×10^{-4}	2.68×10^{-4}	5.27×10^{-4}
General emergence	3.02×10^{-4}	1.70×10^{-4}	1.18×10^{-4}	2.69×10^{-4}	5.23×10^{-4}
Operating room	3.22×10^{-4}	1.82×10^{-4}	1.26×10^{-4}	2.87×10^{-4}	5.66×10^{-4}
Intensive care	2.60×10^{-5}	1.48×10^{-5}	1.02×10^{-5}	2.29×10^{-5}	4.53×10^{-5}
Men's admission	6.90×10^{-4}	3.88×10^{-4}	2.72×10^{-4}	6.14×10^{-4}	1.20×10^{-3}
Obstetrics and gynecology	3.40×10^{-4}	1.89×10^{-4}	1.33×10^{-4}	3×10^{-4}	5.94×10^{-4}
Neonatal	8.03×10^{-4}	4.47×10^{-4}	3.17×10^{-4}	7.14×10^{-4}	1.40×10^{-3}

Note. SD: Standard deviation.

Table 3. Mean annual risk of *Staphylococcus aureus* in different wards of the hospital

Ward	Mean annual risk	SD	Percentile 10	Percentile 50	Percentile 90
Infectious emergency	9.47×10^{-2}	4.99×10^{-2}	3.83×10^{-2}	8.60×10^{-2}	1.62×10^{-1}
General emergence	9.47×10^{-2}	4.98×10^{-2}	3.88×10^{-2}	8.63×10^{-2}	1.61×10^{-1}
Operating room	1.01×10^{-1}	5.30×10^{-2}	4.12×10^{-2}	9.15×10^{-2}	1.73×10^{-1}
Intensive care	8.67×10^{-3}	4.88×10^{-3}	3.42×10^{-3}	7.66×10^{-1}	1.51×10^{-2}
Men's admission	2×10^{-1}	9.66×10^{-2}	8.72×10^{-2}	1.86×10^{-1}	3.32×10^{-1}
Obstetrics and gynecology	1.06×10^{-1}	5.48×10^{-2}	4.37×10^{-2}	9.57×10^{-2}	1.81×10^{-1}
Neonatal	2.28×10^{-1}	1.07×10^{-1}	1.01×10^{-1}	2.13×10^{-1}	3.75×10^{-1}

Note. SD: Standard deviation.

Table 4. Mean daily risk of *Escherichia coli* in different wards of the hospital

Ward	Mean daily risk	SD	Percentile 10	Percentile 50	Percentile 90
Infectious emergency	1.86×10^{-3}	1.05×10^{-3}	7.34	1.66×10^{-3}	3.25×10^{-3}
General emergence	3.65×10^{-3}	2.06×10^{-3}	1.43×10^{-3}	3.23×10^{-3}	6.37×10^{-3}
Operating room	1.59×10^{-3}	8.88×10^{-4}	6.28×10^{-4}	1.42×10^{-3}	2.79×10^{-3}
Intensive care	2.59×10^{-5}	1.48×10^{-5}	1.0×10^{-5}	2.30×10^{-5}	4.56×10^{-5}
Men's admission	7.21×10^{-3}	3.91×10^{-3}	2.92×10^{-3}	6.50×10^{-3}	1.23×10^{-2}
Obstetrics and gynecology	0	0	0	0	0
Neonatal	0	0	0	0	0

Note. SD: Standard deviation.

Table 5. Mean annual risk of *Escherichia coli* in different wards of the hospital

Ward	Mean annual risk	SD	Percentile 10	Percentile 50	Percentile 90
Infectious emergency	4.35×10^{-1}	1.68×10^{-1}	2.18×10^{-1}	4.26×10^{-1}	6.64×10^{-1}
General emergence	6.46×10^{-1}	1.85×10^{-1}	3.80×10^{-1}	6.62×10^{-1}	8.83×10^{-1}
Operating room	3.90×10^{-1}	1.57×10^{-1}	1.90×10^{-1}	3.79×10^{-1}	6.07×10^{-1}
Intensive care	8.63×10^{-3}	4.89×10^{-3}	3.35×10^{-3}	7.69×10^{-3}	1.51×10^{-4}
Men's admission	8.42×10^{-1}	1.43×10^{-1}	6.25×10^{-1}	$8./87 \times 10^{-1}$	9.84×10^{-1}
Obstetrics and gynecology	0	0	0	0	0
Neonatal	0	0	0	0	0

Note. SD: Standard deviation.

concentrations in environmental bioaerosols in the obstetrics, gynecology, and neonatal wards.

The indoor air of medical centers contains a mixture of fungal, bacterial, viral, and allergenic bioaerosols that originate from a variety of sources. These sources include outside air, staff and patients (when talking, coughing, and sneezing), ventilation systems, toilet flushing, and cleaning activities. Hospital staff, visitors, and patients who are exposed to bioaerosols during their stay in hospitals and those with weaker immune systems are at higher risk of possible infections (19). Using the Monte-Carlo relationship, Adhikari et al found that the mean daily risk of exposure to *S. aureus* and *E. coli* was 1.33×10^{-8}, 1.18×10^{-8}, 6.36×10^{-9}, and 2.73×10^{-8} for nurses, healthcare workers (e.g., physicians), visitors, and other patients in public rooms, respectively (20).

In the general emergency ward, the highest concentration of *S. aureus* was 18.11 CFU/m^3. The reason for this is the high rate of admission and the subsequent crowdedness of this ward. According to the WHO guidelines, the acceptable level of bacteria in the air of the general ward of the hospital is 100 CFU/m^3 (21). One study reported that the highest concentration of *S. aureus* was observed in the general ward (28.85%), which is consistent with our results (22).

In the operating room, the lowest concentration of *S. aureus* was 4.81 CFU/m^3. This is related to the sensitivity of this unit and constant monitoring of accurate disinfection of surfaces and equipment in the operating room. According to the Environmental Protection Agency, an amount of 30 to 500 CFU/m^3 is permitted for operating rooms (23). In a study in Sri Lanka, the concentration of *S. aureus* bacterium in the operating room was 0.84 CFU/m^3, which is in the standard range and consistent with our study (24).

In the neonatal ward, the concentration of *S. aureus* was 17.82 CFU/m^3, which is consistent with the recommended standard. This result was attributed to limited human traffic in the ward, the use of a proper ventilation system, and the low number of visitors. In another study, the highest concentration of bacteria was reported in the intensive care unit (ICU) because of poor environmental factors such as temperature, humidity, light, external factors related to all health workers (doctors, nurses, and other staff) and other patients and visitors, as well as controlling the conditioning equipment (heating, ventilation, and air conditioning) in the ICU, which is not consistent with our study (25).

Moreover, the highest daily risk of *S. aureus* was observed in the neonatal ward (8.03×10^{-4}) and the general emergency ward (3.02×10^{-4}). This is attributed to the presence of mothers, opening the windows, lack of proper disinfection, crowdedness, and the presence of critically ill patients in the wards. Mirzaei et al reported a bacterial risk of 1.03×10^2 in the general emergency departments (26). However, the concentration in the operating room was 6.33×10^2 CFU/m^3 (13). Hoseinzadeh et al reported moderate levels of bioaerosol concentration in hospital wards 1.6×10^2 CFU/m^3 (27). The results of a study in India showed that the bacterial bioaerosol concentration is in the range of 3.7×10^2 to 1.9×10^5 CFU/m^3 (28). Bielawska-Drózd et al reported that the concentration of bacterial bioaerosols in the health emergency department is 1.3×10^2 to 4.2×10^3 CFU/m^3 (29).

Conclusion

In this study, the concentration of *S. aureus* and *E. coli* bacteria in the air of different wards of a hospital in Jask was measured. In addition, the risk of infection due to contact with these bacteria through the air was determined. In some hospital wards, the concentration and infection risks of *E. coli* and *S. aureus* were found to be higher than the acceptable value. Since high concentrations of airborne bacteria can play an important role in creating nosocomial infections in patients and staff, it is necessary for hospital officials to take corrective measures to control equipment and use proper ventilation systems in the wards. Furthermore, it is essential to strictly monitor the disinfection process and control the movement of people, especially the patient's companions in different wards and wards with high susceptibility to nosocomial infections (e.g., operating rooms, ICUs, and pediatricians).

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Authors' Contribution

Conceptualization: Kavoos Dinarloo, Hamid Reza Ghaffari, Ameneh Bahreini.
Data Curation: Ameneh Bahreini.
Formal Analysis: Shahram Zare.
Funding Acquisition: Kavoos Dinarloo.
Investigation: Ameneh Bahreini, Mahdi Behjati Ardakani.
Methodology: Kavoos Dinarloo, Hamid Reza Ghaffari, Ameneh Bahreini.
Project Administration: Kavoos Dinarloo.
Resources: Ameneh Bahreini, Mahdi Behjati Ardakani.
Supervision: Kavoos Dinarloo.
Validation: Kavoos Dinarloo, Hamid Reza Ghaffari.
Visualization: Kavoos Dinarloo, Hamid Reza Ghaffari.
Writing – Original Draft: Ameneh Bahreini, Mahdi Behjati Ardakani.
Writing – Review & Editing: Kavoos Dinarloo, Hamid Reza Ghaffari.

Competing Interests

The authors declare that there is no conflict of interests.

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