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TANAFFOS

Effect of Ventilation on Occupational Exposure to Airborne Biological Contaminants in an Isolation Room

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Background: Airborne pathogens play an important role in a hospital air quality. Respiratory infections are the most common occupational disease among the health care staff. The aim of this study was to determine the effect of ventilation system parameters and patient bed arrangements on concentration of airborne pathogens in indoor air of an isolation room.

Materials and Methods: A single-bed room was considered in which a patient diagnosed with tuberculosis had been admitted. Five different ventilation types, each at four different capacities were installed in the room while two different locations for the patient's bed were assessed. A direct-impact sampling method (blood agar plate) was used in order to determine the intensity of the bio-aerosols in indoor air of the isolation room.

Results: The results showed that when the air was supplied through a circular vent located on the northern wall and the vented air was exhausted via a linear vent located on the southern wall, the average concentration of the bio-aerosols in the air, (with 12 air changes per hour) was reduced to 25 colonies per cubic meter (cfu/m^3) (in the range of 25-88 cfu/m^3 and a 95 percent confidence interval). In accordance with the analysis applied upon the two different locations of the bed, no significant difference was observed ($P>0.05$).

Conclusion: Installation of ventilation systems as determined by the study is recommended for tuberculosis isolation rooms.

Key words: Occupational Exposure, Biological, Ventilation, Airborne

INTRODUCTION

Airborne infectious pathogens play an important role in the quality of the hospital indoor air. Respiratory infections are the most common occupational diseases (1). Tuberculosis is an example of the diseases that can be transmitted via airborne particles (2, 3). The tuberculosis bacterium is one of the most dangerous infectious particles that may exist within the indoor air of healthcare centers. Compared with other airborne pathogens, it is a higher risk for the healthcare staff. In accordance with previous studies, the most important causes for tuberculosis among healthcare staff include late diagnosis, lack of proper ventilation, re-circulating the infected air, deficient isolation rooms and lack of personal respiratory protective devices (4). Circulating fresh air may decrease the risk of diseases for personnel.

The average prevalence of tuberculosis in health care workers in low, moderate, and high-incidence-rate countries has been 68, 91, and 1,180 cases per 100,000, respectively (5). In a single hospital, the transmission of the infection was between 1 and 10 percent annually (6). A research conducted in Italy demonstrated that after one year, about 148 nurses and 43 practitioners out of 2182 healthcare personnel studied, showed differences in their tuberculosis skin tests (7). The results of other studies conducted in the Netherlands showed that among 101 people monitored for a period of five years, 67 people were diagnosed with tuberculosis (8). A study of 1,289 healthcare staffs in Canada revealed that 238 were tuberculosis carriers (9). Accurate statistics on the prevalence of tuberculosis among healthcare workers are not yet available in Iran (10).

The current available engineering methods including filtering of air using ventilation systems and the exterior air filtration, sterilization by radiating UV, and isolation by controlling air pressure play important roles in reduction of airborne pathogens. Ventilation is probably the most effective choice among all engineering methods in order to reduce and resolve airborne pathogens (2-4, 10- 13). High-efficiency particulate air filters (HEPA) designed for particles, as well as ultraviolet germicidal irradiation (UVGI) lamps are also considered to be effective supplements to the ventilation systems in high-risk areas (4, 10, 12).

Six air changes per hour are recommended by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) for controlling odors and acceptable indoor air quality (13). The number of air changes per hour was calculated by dividing the volume of supplied air (m^3/h) by the room volume (m^3). However, this level of ventilation may not be sufficient for reducing infectious droplets in isolation rooms. Previous studies reported a necessity of 3 to 12 air changes per hour (10, 11).

Twelve air changes per hour are recommended by ASHRAE for new buildings (13). Given that the increasing ventilation capacity may lead to an increase in maintenance costs, the lack of proper ventilation may increase the risk of disease in healthcare staffs. It is therefore necessary to consider the effect of ventilation systems on factors that are known to be involved in disease transmission such as the number of bacteria present in air. In addition to the ventilation capacity, type of ventilation, position of air supply and exhaust vents may have an important impact on reduction of the concentration of airborne bacteria (10).

Linear exhaust vents can be used for uniform evacuation of air contaminants and circular supply vents can deliver concentrated fresh air to rooms. For maximum effectiveness, circular supply vents should be installed near the sources of pollution (14). The patient's bed was considered as the main source of airborne pathogens in the isolation room. Changing patient bed position changes the location of pathogens' source and can affect the range of dispersion of contaminants in the isolation room (10). This study aimed to determine the effect of ventilation parameters and patient bed arrangements on the concentration of airborne pathogens in indoor air of an isolation room.

MATERIALS AND METHODS

Ventilation type-bed location scenarios

This experimental study was conducted in order to study the effect of bed arrangements and types of ventilation on concentration of airborne pathogens in an isolation room. A single bed hospital isolation room without a ventilation system was considered in which a patient diagnosed with tuberculosis had been admitted. In order to allow airflow into the room, five ventilation systems with variable airflow rates were applied. The ventilation capacities were 0, 2, 6 and 12 air changes per hour. For this purpose, a 1.1 Kw blower fan with 460 cubic feet/min capacity (Brook Crompton, Huddersfield, England) was used, which could provide the highest required volume of 12 air changes per hour plus 20% airflow, for the proposed isolation room with a volume of 1944 ft^3. A centrifugal fan (VIVO Asynchronous Electric

Motor, Italy) with a power of 0.55 Kw was used as an exhaust fan. Two types of exhaust hoods including slot exhaust hood as a linear exhaust (hood length: 1.5m and slot width: 2 cm) and simple exhaust hood (20×20 cm opening) were used. Thermal anemometer (TA2, Airflow Co., Taunton, UK) was applied to measure the airflow in this investigation. Following this, the corrections of the air density for non-standard conditions were considered. The outside fresh air was supplied to the room while 80% of its volume was removed from the room.

Thereafter, five different ventilation types were applied at four different ventilation capacities including 0, 2, 6 and 12 air changes per hour. Table 1 presents the different ventilation scenarios applied in the study.

Table 1. Different types of ventilation systems

Type	Supply air	Exhaust air
1	Circular diffuser at the northern wall	Linear exhaust from the southern wall
2	Circular diffuser at the northern wall	Circular exhaust from the southern wall
3	Circular diffuser at the ceiling	Circular exhaust from the southern wall
4	Circular diffuser at the ceiling	Linear exhaust from the southern wall
5	Circular diffuser at the northern wall	Circular exhaust from the ceiling

With each ventilation type applied to the room, two series of experiments were carried out considering two bed locations. Figure 1 shows the patient bed arrangements at different locations in the isolation room. At location 1, the patient's bed was located at a corner of the room, next to the wall and close to the exhaust hood. At location 2 however, the bed was located in the middle of the room. Applications of 20 ventilation type-bed location scenarios were studied. Throughout each experiment, environmental samples were taken from the bio-aerosols in the room. The 120 samples were taken considering five different ventilation types, two different locations for the patient's bed and four ventilation capacities. Each sampling was repeated three times.

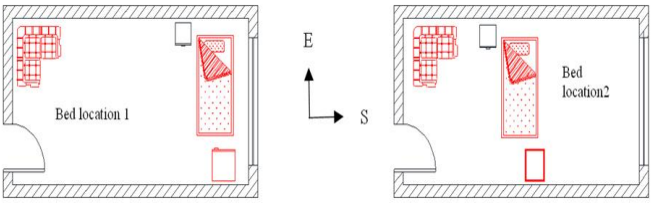

Figure 1. Two different locations of the patient's bed within an isolation room as studied

Collection of bio-aerosol samples according to the ventilation scenarios was performed at 20 days. Doors and windows of the patient room were kept closed in order to prevent entry of air from other routes. Samples representing the exterior air were taken from the supply air diffuser.

Methods used to determine the intensity of bio-aerosols

A direct-impact sampling method was used to determine the intensity of the bio-aerosols in the ambient air of the isolation room. Main equipment used for the experiment included a Casella airborne bacteria sampler, plate, blood agar plate (for bacterial culture) and other laboratory equipment. All equipment was calibrated before the experiment. Blood agar plates were produced in a laboratory and were transferred and placed into the room under sterile conditions. Thereafter, the agar plate was placed, a bacteria sampler of 30 L/minute discharge (hydrology), was used and the sample was taken for four minutes. After 48 hours of incubation at 38 degrees Celsius, the number of colonies was counted. The bio-aerosols were calculated as cfu/m^3 considering temperature and pressure (15, 16).

Statistical analysis

The data were imported to SPSS ver. 17.0 software package (SPSS Inc., Chicago, IL, USA) and the statistics were analyzed. In this research, the data were analyzed using a four-way analysis of variance to study a three-level factorial design. Upon observation of any significant

influence or interaction, the post hoc Dunnett's test was applied. A significance level was set at P = 0.05.

RESULTS

In order to determine the total bio-aerosol counts, environmental samples were also taken from the air entering the room. For this purpose, the samples were taken from the air supplying diffuser to the isolation room. To prevent any additional pollution, the samples were taken whilst the patient was not present in the room. The results showed that the average bio-aerosols in outside air were 11±7.6 cfu/m^3.

The results are illustrated in four different parts. The effect of ventilation type and capacity on bio-aerosol counts of the studied isolation room when the bed was located in its 1st position is depicted in Figure 2. The results revealed that when the ventilation was applied, with the patient's bed located at location 1, ventilation type 3 with 12 air changes per hour had the best performance reducing the bio-aerosols to 33.3 ±16.7 cfu/m^3. Ventilation type 5 with 2 air changes per hour had the least influence on bio-aerosol concentration diluting it to 194.4±45.8 cfu/m^3.

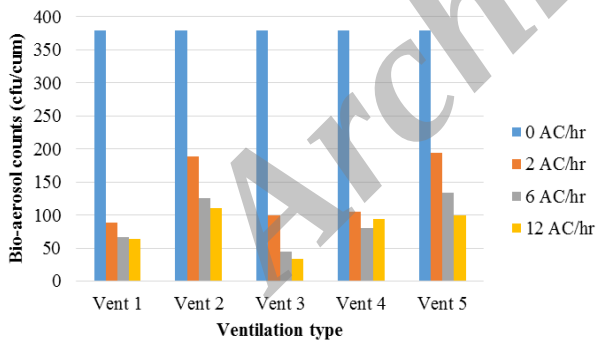

Figure 2. The effects of ventilation type and capacity on bio-aerosol concentration of studied isolation room with patient's bed at location 1

In the second part, the effects of ventilation type and capacity on bio-aerosol concentration in the air are illustrated in Figure 3. With ventilations applied and the patient's bed at location 2, the ventilation type 1 with 12 air changes per hour had the highest effect on bio-aerosol concentration in the air reducing it to 25.0 ±8.3 cfu/m^3. At these conditions, the ventilation type 2 with 2 air changes per hour had the least effect reducing the bio-aerosols to 186.0 ±25.5 cfu/m^3.

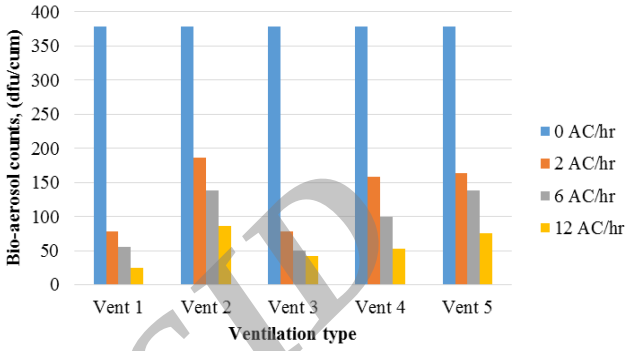

Figure 3. The effect of ventilation type and capacity on bio-aerosol concentration in the isolation room with patient's bed at location 2.

The comparisons between the roles of different ventilation capacities on the average bio-aerosol counts at different ventilation type-bed location scenarios are shown in Figure 4. The least number of bio-aerosols (25.0 ± 8.3 cfu/m^3) recorded, belonged to the 1st type of ventilation with 12 air changes per hour along with the 2nd location of the patient's bed. The highest number of bio-aerosols (379.0±5.7 cfu/m^3) was observed with no ventilation applied to the room. The highest number of bio-aerosols (194.4 ±45.8 cfu/m^3) recorded with ventilation applied to the room belonged to the 5th type of ventilation with 2 air changes per hour with the bed in the 1st location.

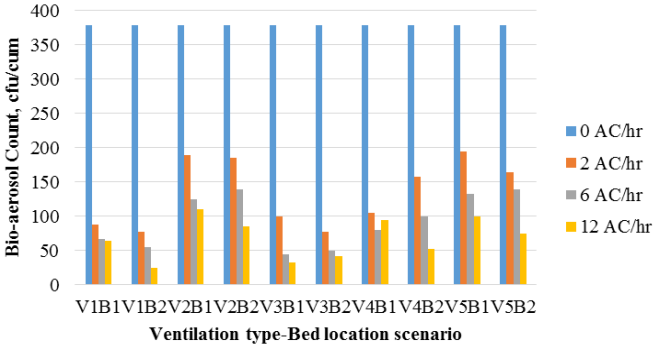

Figure 4. The average bio-aerosol counts at different ventilation-type bed location scenarios

Figures 5 and 6 illustrate the patient's bed position and the effect of bed location at the highest ventilation capacity of 12 air changes per hour. According to these figures, when the bed is located at the middle of the room less bio-aerosol counts are expected in an isolation room with 12 air changes per hour.

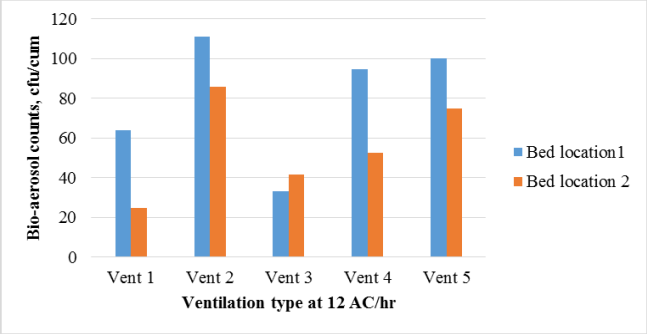

Figure 5. The difference between different bed locations at 12 air changes per hour

Figure 6 shows the contrast between bed locations with different ventilation types at the lowest ventilation rate. The results show that in all ventilation types except ventilation system with a circular diffuser located at the middle of the ceiling and a linear exhaust hood at the southern wall (if the bed is located at the middle of the room) less bio-aerosol counts are expected to be present in indoor air.

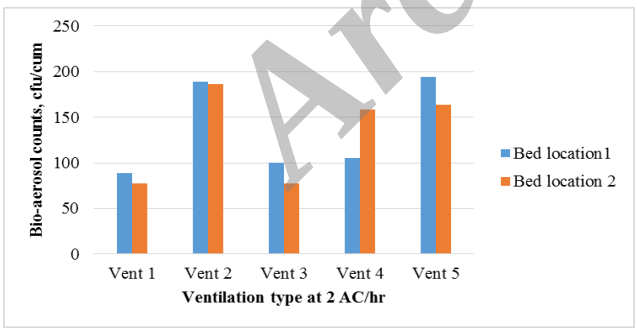

Figure 6. The difference between different bed locations at two air changes per hour

DISCUSSION

This study was set out to investigate the effect of ventilation type and capacity as well as the bed location on airborne bio-aerosol concentration in an isolation room in which a patient diagnosed with tuberculosis had been admitted. The research indicated that medical staff had exposure to bio-aerosols in the hospital environment (17). The results of this study showed that the total number of bio-aerosols taken from the outdoor air at two different days was 11±7.6 cfu/m^3. The American Conference of Governmental Industrial Hygienists (ACGIH) has not determined any standard for the amount of available colonies in outdoor air at miscellaneous locations (14). The best standard, regarding indoor air, is to compare the amount of bio-aerosols with the outdoor air, as well as the difference of pollution between indoor and outdoor air, and attempt to apply corrections and adjustments (10, 15, 16, 18).

The results showed that when the air is supplied through a circular diffuser located on the northern wall and the vented air is removed via a linear vent located on the southern wall, the average concentration of the bio-aerosols in the air, (in ventilation capacities of 12 AC/h), was reduced to 25 cfu/m^3 (in the range of 25-88 cfu/m^3 and 95 percent confidence interval).

With regard to the fact that some resources recommend the amount of bio-aerosols to be no more than 75 cfu/m^3 (18) and the comparison of this value with the total number of bio-aerosols taken from the outdoor air, it can be argued that the type 1 ventilation method used in this study, which falls within this limit, is the best type of ventilation. The findings of this study prove that it is the best ventilation type for a room to be aired via a circular diffuser on a wall and ventilated via a linear exhaust hood located on the opposite wall, which is similar to the type of ventilation recommended for isolation rooms by the Centers for Disease Control and Prevention (CDC United States) (4). Type 3 also had a relatively good performance but this type was not recommended. In the air entering the room via a circular diffuser on the ceiling, bio-aerosols may be released into the breathing zone of healthcare staffs or other visitors.

The probable reason for the maximum performance of ventilation type 1 could be explained by airflow patterns in this type similar to airflow patterns in clean rooms where the staffs are recommended to be kept in the clean room between the supply diffuser and the pollution source (19).

The least efficient ventilation belongs to types 2 and 5 with an average number of bio-aerosols of 139 cfu/m^3 and 134 cfu/m^3, respectively. Statistically, no significant differences were observed between the two types. The reason for this could be the adverse mixing of air in both types; an obstacle (the patient's bed), placed between the supply inlet and the exhaust outlet, could have been the reason why the mixing of air was not very efficient at the southern parts of the room.

The outcome illustrated that the concentration of the bio-aerosols in a patient's room decreases significantly ($P<0.001$). Even throughout the application of the least ventilation and the worst aeration, there would be a significant difference ($P < 0.001$) in the amount of bio-aerosols detected within the air and reduced about 200 percent compared to the room when it is not ventilated. The results of type and concentration of bioaerosols in the operating room of five educational hospitals of Hamadan University of Medical Sciences and effectiveness of ventilation systems demonstrated that only one hospital had an active ventilation system with airflow supply rate of 140 ft^3/min and exhaust airflow rate of 326 ft^3/min, and ventilation capacity of 2.3 air changes per hour during the sampling time. There were no significant differences between the concentrations of bio-aerosols in the hospital operating room in a system-on condition as compared to switched-off condition (20). However, the findings of the current study did not support those of Ghorbani-Shahna et al (2006). This rather contradictory result may be due to using a negative pressure in the hospital operating room and employing improper ventilation capacity in their hospital (20).

For isolation rooms, the least amount of ventilation recommended by the American Institute of Architects (AIA), ASHRAE and Health Resources and Services Administration (HRSA) are six air changes per hour for old buildings and 12 air changes per hour for new buildings (10). In accordance with these organizations, six air changes per hour are for the ease of application and to reduce smell; therefore, the effectiveness of these circulation methods in reducing the concentration of infectious droplets in the room has not been proven. A total ventilation capacity of more than six air changes per hour would have most probably resulted in additional reduction in the concentration of airborne bio-aerosols in the room (10). In order to reduce the concentration of infectious droplets in the air of an isolation room designed for tuberculosis patients and other hospital rooms, there needs to be a ventilation system with a capacity of more than six air changes per hour. However, in accordance with the findings of this study, it could be understood that there would be no significant differences between the numbers of bio-aerosols in the air, in either six or 12 air changes per hour capacities.

Considering the cost of transforming the capacity from six to 12 air changes per hour, and the fact that it amounts to a very insignificant reduction of bio-aerosols in the room, this action may seem to be neither necessary nor logical. However, because of the danger of tuberculosis bacteria, the risk of choosing six air changes per hour cannot be taken. It is therefore recommended that the capacity of 12 air changes per hour for isolation rooms designed for tuberculosis patients be used. On the other hand, the smaller capacity of six air changes per hour could be used for other medical sites where the risk is not as critical.

The location of the bed was another aspect of this research. Positioning the bed against the ventilation system could be important. In accordance with the analysis applied upon the two different locations of the bed, no significant difference was observed. However, where the position of the bed was examined with the influence of the ventilation, a significant difference was observed ($P<0.001$). The best location of the bed, considered together with the ventilation type, is understood to belong to the 1st type of

ventilation and the 2nd location of the patient's bed, with an average of 25.0 ±8.3 cfu/m^3.

The contrast between different bed locations at 12 air changes per hour (e.g. recommended ventilation capacity) showed that in all studied ventilation types except type 3, the bed location 2 had a better result leading to less airborne bio-aerosols in the room air (Figure 5). The same comparison at two air changes per hour (the lowest ventilation capacity) also revealed that in all ventilation types except type 4, bed location 2 had a better results leading to less airborne bio-aerosols in room air (Figure 6).

In the sampling period, the researcher and other persons entering to the isolation room used appropriate personal protective equipment such as respiratory masks.

Ethical considerations

The proposal of this study was approved by the ethical committee of Shahid Beheshti University of Medical Sciences. Ethical principles for medical research involving human subjects were considered.

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Conflict of interest

The authors have no conflict of interests.

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