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ORIGINAL ARTICLE

Monitoring of airborne bacteria and aerosols in different wards of hospitals – Particle counting usefulness in investigation of airborne bacteria

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Abstract

Introduction and objective. The presence of airborne bacteria in hospital environments is of great concern because of their potential role as a source of hospital-acquired infections (HAI). The aim of this study was the determination and comparison of the concentration of airborne bacteria in different wards of four educational hospitals, and evaluation of whether particle counting could be predictive of airborne bacterial concentration in different wards of a hospital.
Materials and method. The study was performed in an operating theatre (OT), intensive care unit (ICU), surgery ward (SW) and internal medicine (IM) ward of four educational hospitals in Isfahan, Iran. A total of 80 samples were analyzed for the presence of airborne bacteria and particle levels.
Results. The average level of bacteria ranged from 75–1194 CFU/m^3. Mean particle levels were higher than class 100,000 cleanrooms in all wards. A significant correlation was observed between the numbers of 1–5 µm particles and levels of airborne bacteria in operating theatres and ICUs. The results showed that factors which may influence the airborne bacterial level in hospital environments should be properly managed to minimize the risk of HAIs especially in operating theaters.
Conclusions. Microbial air contamination of hospital settings should be performed by the monitoring of airborne bacteria, but particle counting could be considered as a good operative method for the continuous monitoring of air quality in operating theaters and ICUs where higher risks of infection are suspected.

Key words

airborne bacteria, hospital infection, particle counting

INTRODUCTION

The incidence of hospital-acquired infections (HAI) by pathogenic or potentially pathogenic bacteria is a serious problem worldwide. There is increasing evidence that some infectious agents are airborne and hospital air could be considered as a potential transmission route of nosocomial infections [1]. The principal pathogenic bacteria, such as *Streptococcus pyogenes*, *Neisseria meningitidis*, *Corynebacterium diphtheriae* and *Mycobacterium tuberculosis*, are known to be transmitted mainly by airborne droplets from infected people, and they may cause nosocomial infections [1, 2]. It is estimated that airborne bacteria cause about 10–20% of endemic nosocomial infections [3]. Hospital indoor air may contain a wide range of pathogenic and non-pathogenic microorganisms which could originate from patients, the staff, visitors, ventilation and air conditioning systems, and outdoors [4]. Although some airborne bacteria in the hospital environment may be harmless to healthy people, they can impact on a vulnerable group of hospitalized patients and cause serious threats to health [5]. Immunocompromised patients could be at a significantly increased risk of airborne bacteria exposure [1]. Due to an increase in immunocompromised patients [6], hospitals are now more often facing the problem of HAIs, and airborne bacteria may be a major factor in increasing morbidity and mortality in the patients.

Infection prevention in hospital environments, therefore, is an important issue in terms of both patient outcomes and cost of treatment [7]. Bioaerosol monitoring in indoor hospital environments could be used as an important approach in the prevention of airborne HAIs. In other words, monitoring of airborne microorganisms in hospital settings can provide information about bioaerosol sources, concentration and dispersion, and also could be used as a quality control measure [8]. There are some investigations on bioaerosol concentrations and characterizations in different wards of hospitals, especially operating theatres and intensive care units (ICU). There is, however, few data about the air quality in hospitals in developing and transition countries where factors such as hospital design, deficiency or improper control of high efficiency filtration systems and overcrowding can impact on the presence and concentration of airborne microorganisms. In addition, routine air biomonitoring of hospitals is time-consuming, labour intensive and is valid only for the moment and location of collection [9]. It has been suggested that particle counting could be used as a faster and simpler alternative. However, its value in the prediction of airborne bacteria in various parts of hospital environments has rarely been investigated [7, 9, 10].

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OBJECTIVES

The study was designed to determine and compare concentrations of airborne bacteria in different wards of four educational hospitals, and to evaluate whether particle counting could be predictive of airborne bacterial concentration in different wards of a hospital.

MATERIALS AND METHOD

Sampling locations. The study was performed in four educational hospitals in Isfahan, Iran, during 2014. Air samples were collected at four sites in each hospital, including the operating theatre (OT), intensive care unit (ICU), surgery (SW) and internal medicine (IM) ward. Each area in the hospital was visited five times. Therefore, a total of 80 samples were analyzed for airborne bacteria and particle levels. Air sampling and particle counting were performed at a height of 1.5 m above ground level to simulate the breathing zone.

Airborne bacteria. Airborne bacteria were drawn into all glass impingers (AGI), which contained 20 ml of phosphate buffer, using portable pumps at a flow rate of 12.5 L/min. Sampling time was adjusted in the range of 180–240 min to obtain sufficient colony numbers.

All samples were transferred to the laboratory in an insulated box with cooling packs, and were processed immediately after arrival at the laboratory.

Aliquots of each impinger collection medium were plated onto duplicate tryptic soy agar (TSA) and incubated at 30 °C for 2–3 days. Colonies growing on both media were enumerated and calculated as colony-forming units per cubic meter (CFU/m^3).

Particle counting. An optical particle counter (GRIMM 1.109 dust monitor, Germany) was used to measure the number-size distribution of aerosols. Particle numbers were classified in six size ranges (less than 0.5 µm), (0.5–0.9 µm), (1.0–2.9 µm), (3–4.9 µm), (5–9.9 µm) and ≥ 10 µm and the values of particles were calculated per 1 cubic meter. However, as the threshold values were reported per cubic foot (as '10,000', '100,000'), the values per 1 cubic foot are shown in parentheses.

Measurement of humidity and temperature. During sampling, temperature and relative humidity were also recorded by use of a portable weather station (Kimo) at each sampling site.

Statistical analysis. Statistical analysis was conducted with SPSS 20.0. Kolmogorov-Smirnov test for normality was performed for the use of parametric or non-parametric tests. The Kruskal-Wallis test was used to compare the concentration differences of airborne bacteria among the sampling sites. The relationships between particle numbers and airborne bacterial concentrations were examined using the non-parametric Spearman's rank correlation method. All probability (P) values smaller than 0.05 were considered statistically significant for all analyses.

RESULTS AND DISCUSSION

Hospital environments are complex settings where various factors, such as hospital design, ventilation system, temperature, relative humidity, population density and disinfection methods, can influence the concentration of airborne bacteria. Table 1 presents the average airborne bacterial levels in different wards of the investigated hospitals. Airborne bacteria were isolated from different parts of the hospitals at a level ranged from 30–3,250 CFU/m^3. Fluctuations occurred in airborne bacterial concentrations in hospitals and in different wards (Tab. 1). However, significant differences were not found among the four hospitals. Generally, the mean bacterial levels in the investigated hospitals were lower than mean levels recorded in five hospital wards in the United Arab Emirates [11], and a hospital ward in a tropical setting situated in West Chennai, India [12]. However, the mean bacterial levels determined in this study were comparable with levels reported in Silesian hospitals in Poland [1], and mean monthly concentrations of airborne bacteria in a ward hospital in Poland [13]. The highest of total mean level of both particle count and airborne bacteria were observed in surgical wards, (Tab. 1, 2). However, there was no significant difference in airborne bacteria among the four investigated areas, including the surgical ward, internal medicine, operation theatre and ICU. On the other hand, the lowest total level of airborne bacteria was found in ICUs, while particle counts in operating theatres were lower than ICUs (Tab. 1, 2). According to a study by Li and Hou, the bacterial concentrations in hospital ICU varied over a wide range (1–423 CFU/m^3) [8]. A possible explanation for the lowest total level of airborne bacteria in the ICU would be the special condition of the ward as a restricted area, and also the presence of high ventilation rate systems [2]. The bacterial levels determined in operating theatres ranged from 45–1,733 CFU/m^3, with a mean level of 396 CFU/m^3 (Tab. 1) which was higher than those previously reported in other studies [1, 8, 9, 10, 14].

Table 1. Average level of airborne bacteria (CFU/m^3) in different wards of hospitals

Hospital	Sampling Location				
	OT	ICU	SW	IM	Total
1	102	130	337	117	171
2	673	75	84	88	230
3	168	446	1194	944	688
4	642	239	532	948	590
Total	396	222	537	524	420

However, differences in airborne bacterial levels between studies may be due to sampling or culturing method and to environmental quality. Some countries have set airborne bacterial limits for operating theatres [15]. Microbial air contamination of operating theatres during surgical procedures could be a risk factor for surgical site infection through settling of airborne bacteria [10, 16]. The presented results show higher airborne bacterial concentrations than the limits. Various factors influence the airborne bacteria during surgical procedures. High concentration of airborne bacteria in the current study may be related to filtration systems efficiency, operating team numbers, and their activity

Table 2. Mean particle counts by size in different wards

Location	Particulate count/m³(/ft³)					
	<0.5 µm	0.5–0.9 µm	1–2.9 µm	3–4.9 µm	5–9.9 µm	≥10 µm
OT	32326341 (915385)	4211993 (119271)	833563 (23604)	163082 (4618)	40965 (1160)	4732 (134)
ICU	40013278 (1133056)	5041989 (142774)	922732 (26129)	175018 (4956)	41636 (1179)	7275 (206)
SW	43174771 (1222580)	6212099 (175908)	1464068 (41458)	305188 (8642)	90793 (2571)	15185 (430)
IM	32507116 (920504)	4922379 (139387)	957199 (27105)	273334 (7740)	94749 (2683)	11336 (321)

in operating theaters, and surgery operation. Pankhurst et al. indicated that the presence of people within the operating theatre had the greatest impact on both airborne bacteria and particle counts, resulting in an increase in both cases [17]. Nevertheless, the lowest mean particle numbers were measured in operating theatres (Tab. 2). Some studies have shown that the particle peaks are not associated with the peak of airborne bacteria, due to the presence of non-bacteria carrying particles [9, 16]. The mean particle counts (particle size ≥0.5µm) were above maximum level for class 100,000 cleanroom [15] (Tab. 2). Particle counting for operating theatres were somewhat higher than levels in class 100,000 of cleanroom. Among the 20 analyzed samples of operating theatres, only 11 (55%) particle samples were below the maximum level for class 100,000 cleanroom. Ortiz et al. reported that bacterial concentrations in operating theatres were lower than levels in class 100,000 cleanroom, but higher than class 100 [14]. According to the study by Li and Hou, most particle counts were higher than the designated 10,000/ft³ level in an operating theatre [8]. In other wards of the hospitals surveyed (internal medicine and surgical ward), the average particle concentration exceed the European ISO 14644 standard limits [15] for ISO 8 cleanroom.

In addition, the particle count of ICUs showed that 60% (12/20) of the samples had a particle level (≥0.5 µm) higher than 100,000/ft³ in class 100,000 cleanroom.

In order to identify the possible association between the different sized particles and airborne bacterial concentration in various sampling sites of the hospitals, a correlation analysis was performed (Tab. 3). Although there was no relationship among class level and airborne bacterial concentrations, significant correlations were observed between airborne bacterial concentrations and particle size of 1–5 µm in operating theaters and ICUs (Tab. 3). Stocks et al. found a correlation between the number of particles ≥10 µm with the number of CFUs in operating theatres [7]. Seal and Clarck also demonstrated a significant correlation between particles sized 5–7 µm and microbial contamination during surgical operations performed in an ultra-clean theatre [18]. This relationship between the numbers of particles 1–5 µm and airborne bacterial concentrations supports the notion that particle counting may act as a surrogate measure of airborne bacteria in operating theatres and ICUs. However, the applicability of particle counting in the monitoring of airborne bacteria is controversial. Scaltriti et al. and Landrin et al. observed no correlation between particle counts and microbial load in operating theaters [9, 10]. They recommended that there is no reason to replace microbiological sampling with particle counting for routine assessment of microbiological contamination. The results of the current study also revealed no correlation in internal medicine wards. In addition, there was a different correlation for surgical wards (correlation between particles 0.5–1 µm and airborne bacteria). Overall, it seems that particle counting as a rapid and real-time monitoring technique can be used in some aspects of HAIs control, particularly where higher rates of infection are suspected [17]. However, more studies are required to explore the usefulness of particle counting as a surrogate measure of airborne bacteria monitoring in hospital settings.

Table 3. Spearman's correlation coefficient between bacterial levels and different size of particles in different wards

Particle size	OT	ICU	IM	SW
< 0.5 µm	0.438	0.706*	0.035	0.490
0.5-1 µm	0.504	0.448	-0.259	0.671*
1-5 µm	0.655*	0.762**	-0.028	0.154
≥5 µm	0.27	0.371	0.007	0.266

* Correlation significant at the 0.05 level (2 tailed)

Temperature and relative humidity are important environmental factors that affect bioaerosols survival. The airborne bacterial concentration in hospital environments was significantly correlated to relative humidity, but not to temperature (Tab. 4). Similarly, Obbard and Fang reported a significant correlation between airborne bacteria and relative humidity, but not temperature in wards of a Singapore hospital [19]. However, some studies found no significant relationship between airborne bacteria and environmental parameters in hospital wards [13, 20].

Table 4. Correlation analysis results between meteorological conditions and airborne bacterial levels

	Bacteria	Temperature	Relative humidity
Bacteria	1		
Temperature	0.019	1	
Relative humidity	0.328*	0.182	1

* Correlation significant at the 0.05 level (2 tailed)

CONCLUSION

This study analyzed the levels of airborne bacteria and particle counts in various wards of four educational hospitals in Isfahan, Iran. Airborne bacteria were isolated from different wards of the hospitals at a level ranging from 30–3,250 CFU/m³. The results showed that airborne bacterial levels in operating theatres were higher than reasonable and acceptable limits. Evaluation of particle counts in operating theatres and ICUs showed that most of the particle levels were higher than the designated concentration in class 100,000 cleanrooms. Therefore, the factors which may influence the airborne bacterial level in hospital settings should be properly managed to minimize the risk of HAIs, especially in operating theatres. A correlation was also observed between particle counting (particles sized 1–5 µm) and airborne bacterial concentration in operating theatres and ICUs. This suggests that the combining of particle counting as a real-time monitoring method with routine evaluation of microbial air contamination in hospital settings could provide instantaneous information about rapid variations of air quality in some aspects of infection control.

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