Aerosol Distribution During Open Suctioning and Long-Term Surveillance of Air Quality in a Respiratory Care Center Within a Medical Center

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BACKGROUND: The investigation of hospital air quality has been conducted in wards, ICUs, operating theaters, and public areas. Few studies have assessed air quality in respiratory care centers (RCCs), especially in mechanically ventilated patients with open suctioning. METHODS: The RCC air quality indices (temperature, relative humidity, levels of CO_2, total volatile organic compounds, particulate matter [PM], bacteria, and fungi) were monitored over 1 y. The air around the patient's head was sampled during open suctioning to examine the probability of bioaerosol exposure affecting health-care workers. RESULTS: This investigation found that the levels of indoor air pollutants (CO_2, PM, bacteria, and fungi) were below the indoor air quality standard set by the Taiwan Environmental Protection Agency. Meanwhile, the levels of total volatile organic compounds sometimes exceeded the indoor air quality standard, particularly in August. The identified bacterial genera included *Micrococcus* species, *Corynebacterium* species, and *Staphylococcus* species, and the predominant fungal genera included yeast, *Aspergillus* species, *Scopulariopsis* species, and *Trichoderma* species. Additionally, airborne $PM_{2.5}$, PM_1, and bacteria were clearly raised during open suctioning in mechanically ventilated patients. This phenomenon demonstrated that open suctioning may increase the bacterial exposure risk of health-care workers. CONCLUSIONS: RCC air quality deserves long-term monitoring and evaluation. Health-care workers must implement self-protection strategies during open suctioning to ensure their occupational health and safety in health-care settings. *Key words: respiratory care center; indoor air quality; bioaerosol; open suctioning; mechanically ventilated patient; health-care workers.* [Respir Care 2015;60(1):1–•. © 2015 Daedalus Enterprises]

Introduction

The main sources of indoor bioaerosols in the studied hospital are patients, families, and health-care workers. Contamination risks may be increased by a central air conditioning system or by contact between health-care workers and patients. Critically ill patients in the ICU are frequently immunocompromised, and undergo numerous invasive procedures. Such patients thus suffer an increased

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risk of upper airway infections.[1-4] Consequently, hospital air quality is enormously important.

Hospital air quality indices include temperature and humidity,[5] levels of CO_2, total volatile organic compounds (TVOCs),[5] particulate matter (PM),[6,7] bacteria,[6,8,9] fungi,[8,10,11] viruses,[12] and toxic metals.[7] Both temperature and relative humidity were the recommended indices to reflect the efficiency of ventilation systems in hospitals.[13] The most important index for evaluating indoor air quality was CO_2 concentration, since it was correlated with both number of persons in a space and the PM concentrations,[14,15] and was significantly related to airborne bacterial count.[16] A previous study showed an association between PM concentrations and nearby human activity, exchange frequency, and filtration system effectiveness.[17] Additionally, the TVOCs could release to the air from building structural materials, glues and rubbers in the air conditioning system, or chemical solvents.

The research on hospital air quality has primarily been conducted in wards and ICUs,[10,18,19] operating theaters and postoperative recovery rooms,[20-22] and public areas.[7,23-28] Slezakova et al[7] found high averaged 24-h particulate matter (PM_{10} and $PM_{2.5}$) in a Portuguese hospital. Moreover, a previous study found that 90% of CO_2 samples in the ICU of a medical center in northern Taiwan exceeded 1,000 ppm, and 20% of PM_2 samples failed to meet the air quality standard set by the United States Environmental Protection Agency (EPA). Seasonal changes were observed in airborne bacterial and fungal concentrations in the ICU.[19] Gram-positive bacteria (such as *Bacillus* species, *Micrococcus* species, and *Staphylococcus* species) were commonly found in the monitored operating rooms.[22] The postoperative recovery room had considerably higher CO_2 and bacterial concentrations than the operating theaters.[21] Perdelli et al[18] found that the use of an air conditioning system with a high efficiency particulate air filter markedly reduced airborne bacterial and fungal concentrations.

In the Taiwanese health-care system, patients receiving mechanical ventilation exceeding 21 d in the ICU must transfer to a respiratory care center (RCC) for weaning off assisted ventilation and further care. These patients are frequently diagnosed with upper airway infection owing to compromised immunity. In clinical practice, mechanically ventilated patients must be suctioned repeatedly using an endotracheal tube to remove secretions, maintain optimal oxygenation, reduce breathing effort, and prevent atelectasis and infection. Technically, suctioning systems can be divided into two types: open and closed. A previous study indicated higher bacterial concentration in the surrounding air and higher ventilator-associated pneumonia rate in patients following open suctioning compared with closed suctioning.[29] Thus, the air quality of the RCCs warrants evaluation.

QUICK LOOK

Current knowledge

Hospital air quality indices include temperature and humidity levels, as well as the presence of particulate matter (PM), bacteria, fungi, and toxic metals. Air quality is often evaluated using carbon dioxide concentration, as this correlates with the number of people in a space and the PM concentrations.

What this paper contributes to our knowledge

Respiratory care center air quality is affected by use of open circuit suctioning. Bacteria and PM concentrations were highest in the summer and above indoor air quality standards. Health-care workers should wear appropriate personal protection during open suctioning.

To date, few studies have assessed air quality of RCCs, especially in mechanically ventilated patients with open suctioning. This study investigated the air quality of an RCC in a medical center over a 1-y period, and also assessed the possibility of health-care worker exposure to bioaerosols during open suctioning.

Methods

Study Location

This study was performed in a 24-bed RCC in Chang Gung Memorial Hospital in northern Taiwan, and the study protocol was approved by the institutional review board of Chang Gung Hospital. Indoor air quality was sampled weekly for 1 y. Air quality indices included temperature, relative humidity, concentrations of CO_2, TVOCs, PM, bacteria, and fungi. The PM was classified into PM_{10} (aerodynamic diameter $\leq 10\ \mu m$), $PM_{2.5}$ (aerodynamic diameter $\leq 2.5\ \mu m$), and PM_1 (aerodynamic diameter $\leq 1\ \mu m$). To assess the influence of the open suctioning procedure, the PMs and bacterial concentrations were measured before, during, and after the procedures ($n = 30$).

The air change rate of the RCC in the hospital was 12/h. Environmental surfaces of the RCC were disinfected with a solution containing 0.05% sodium hypochlorite for daily routine cleaning. Once environmental surfaces were contaminated with blood, body fluids, or secretions, a 0.5% sodium hypochlorite solution was used for disinfection.

Indoor Air Sampling

To better assess the risks associated with long-term exposure of health-care workers in the RCC, air quality in-
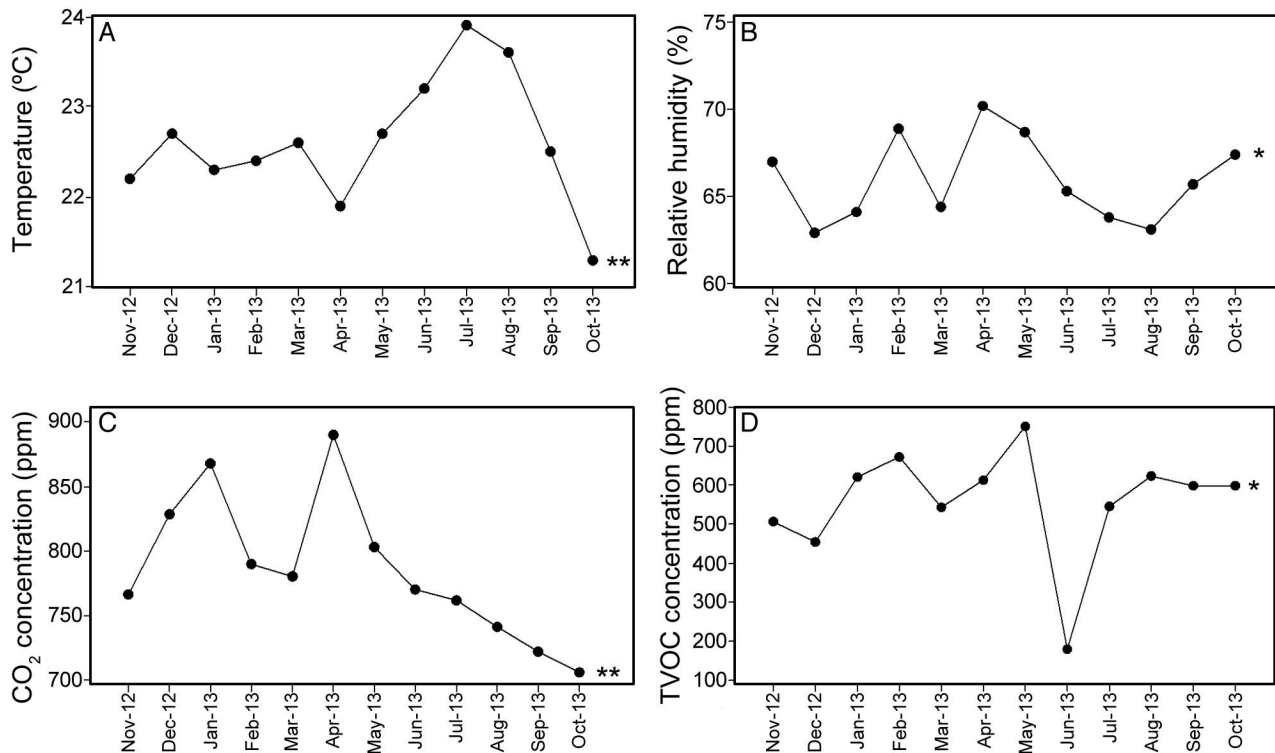
Fig. 1. Seasonal variation of temperature, relative humidity, and gaseous pollutant levels in the respiratory care center. * $P < .05$, **$P < .01$. TVOC = total volatile organic compound.

dices were sampled over a long period. The temperature, relative humidity, and CO_2 concentration in the RCC were measured using a digital psychrometer (TSI, Shoreview, Minnesota) at set intervals over an 8-h period. Indoor TVOC concentrations were sampled using a ppbRAE monitor (model PGM-7600, RAE Systems, San Jose, California) over a consecutive 8-h period. The sampling head was attached to a water filter to prevent interference by moisture. The PM measurements were performed with a portable monitor (model 1.108 particle size analyzer, Rimm Aerosol Technik, Ainring, Germany) at 6-s intervals over a consecutive 8-h period. The measured particulate sizes ranged from 0.3 to 20 μm, and we divided PM into three sizes: PM_{10}, $PM_{2.5}$, and PM_1.

Both bacterial and fungal concentrations were assessed using an Andersen one-stage viable impactor (N6; Thermo Fisher Scientific, Atlanta, Georgia), with 20 mL of tryptic soy agar (Difco/Becton Dickinson, Franklin Lakes, New Jersey) for bacterial sampling and malt extract agar for fungal sampling, with an air pump at 28.3 L/min for 3 min. The sampler comprises 400 orifices used to collect bacteria and fungi larger than 0.65 μm. All measurement instruments were positioned at 1.2–1.5 m above the floor, approximating the height of the human breathing zone. The plate samples were incubated at 30°C for 1–2 d for bacteria, and at 25°C for 3–4 d for fungi. Concentrations were reported as colony-forming units (CFU)/m^3, and were

calculated using the positive-hole conversion table[30] and the sampled air volume. The species of bacteria and fungi in the air were then identified. Identified bacterial genera included *Bacillus*, *Micrococcus*, *Staphylococcus*, *Acinetobacter*, *Moraxella*, *Pseudomonas*, and others. Additionally, fungal genera such as *Aspergillus*, *Cladosporium*, *Penicillium*, *Scopulariopsis*, *Verticillium*, and yeast were also identified.

Air Sampling During Open Suctioning

Bacterial and PM concentrations during open suctioning were measured at the following times: (1) 3-min sampling before the procedure to determine background air quality in the RCC, (2) 1.5-min sampling during the procedure, and (3) 3-min sampling 5 min after the procedure. Particulate concentrations were sampled using the continuous method, and bacterial contributions were sampled at the first and third samplings.

Statistical Analysis

Statistical analyses were performed using SPSS 21.0 (SPSS, Chicago, Illinois). Figures were constructed using GraphPad Prism 6.0 software (GraphPad Software, San

Diego, California), and the significance level was set to 0.05. Seasonal variations in indices indicating particular concentrations in indoor air in the RCC and concentration variations in PM/bacteria concentrations during open suctioning were assessed using non-parametric repeated-measures analysis of variance for skewed distributed data. The correlation strength was assessed using the Spearman test for non-normally distributed data to determine the relationship between the airborne PM and bacteria concentrations during open suctioning.

Results

Air sampling was performed between November 2012 and October 2013. The 8-h averaged room temperature of the RCC was 22.6°C, with a peak of 23.9°C in July and a low of 21.3°C in October (Fig. 1). Meanwhile, the mean relative humidity was 66%, with a peak of 70.2% in April and a low of 62.9% in December. Additionally, the averaged CO_2 concentration was 785.5 ppm, with a high of 889.9 ppm in April and a low of 705.8 ppm in October. The mean TVOC level was 558.6 ppb, with a peak of 750.73 ppb in May and a low of 179.30 ppb in June. The 24-h averaged PMs concentrations were 2.6 $\mu g/m^3$ for the PM_{10}, 1.4 $\mu g/m^3$ for $PM_{2.5}$, and 1.1 $\mu g/m^3$ for PM_1. The PM levels (PM_{10}, $PM_{2.5}$, and PM_1) exhibited a peak in December and a low in May (Fig. 2). The indices showed a different monthly trend to the TVOCs at some times, yet always met Taiwan EPA standards. The average disqualification TVOC rate was 23.7%, with a peak of 71.9% in August and a low of 0% in June.

The annual average bacterial concentration in RCC was 131.9 CFU/m^3. Meanwhile, the average morning concentration was 137.0 CFU/m^3, with a high of 238.63 CFU/m^3 in August and a low of 84.15 CFU/m^3 in January. The average afternoon concentration was 126.9 CFU/m^3, with a high of 237.21 CFU/m^3 in November and a low of 38.89 CFU/m^3 in March. The concentrations changed significantly throughout the year, whether in the morning ($P = .02$), afternoon ($P < .01$), or whole day ($P < .01$) (Fig. 3). The bacterial concentrations were compliant with the Taiwan EPA standards. The fungal concentration in RCC averaged 36.7 CFU/m^3 over the whole year. Meanwhile, the highest and lowest airborne fungal concentrations in the morning and afternoon in the RCC occurred in May (94.72 CFU/m^3) and October (16.57 CFU/m^3), and in July (122.37 CFU/m^3) and February (7.92 CFU/m^3), respectively. This study thus found significant monthly variation in airborne fungal concentrations throughout the year.

The predominant bacterial genera in the air of the RCC included *Micrococcus* species, (80%), *Staphylococcus* species (28%), and coagulase-negative *Staphylococcus* (20%) (Table 1). The highest morning bacterial concentrations were *Micrococcus* species (53.61 CFU/m^3) and *Coryne-*
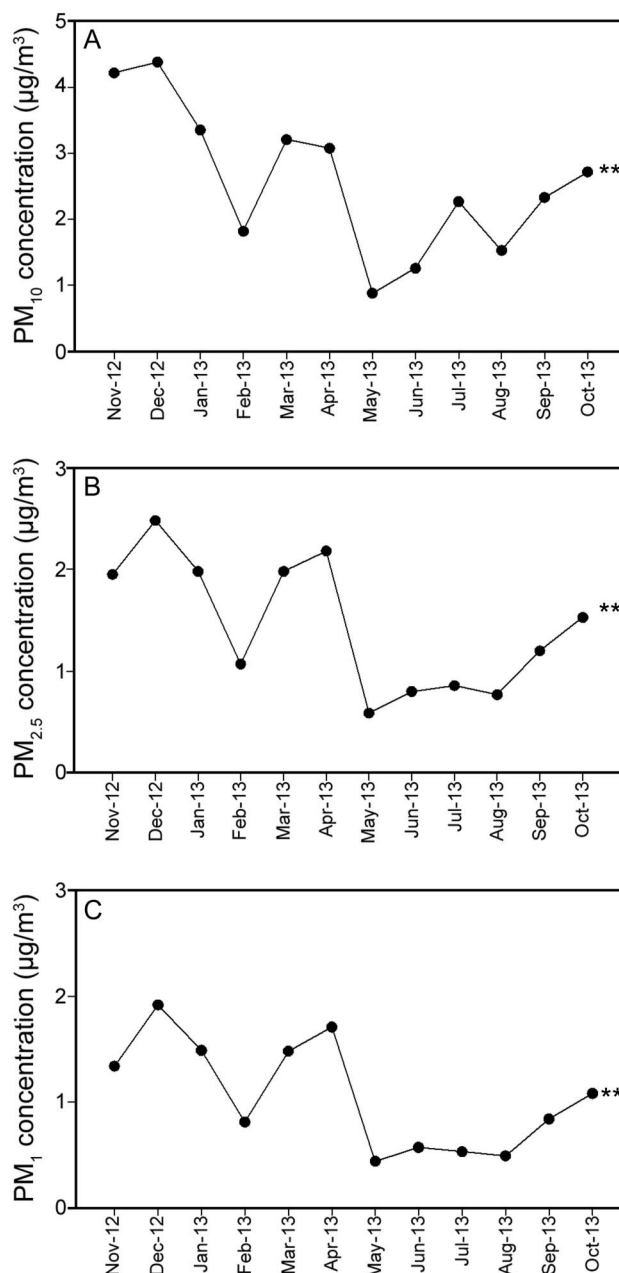
Fig. 2. Seasonal variation of PM_{10}, $PM_{2.5}$, and PM_1 levels in the respiratory care center. **$P < .01$.

bacterium species (35.84 CFU/m^3), while, for the afternoon, they were *Micrococcus* species (114.48 CFU/m^3) and *Staphylococcus* species (35.86 CFU/m^3). The predominant fungal genera in the air of the RCC included *Aspergillus* species (60%), *Penicillium* species (40%), and *Cladosporium* species (16.67%) (Table 2). The highest fungal concentrations in the morning were of yeast (47.77 CFU/m^3) and *Aspergillus* species (29.98 CFU/m^3), while, in the afternoon, they were of *Scopulariopsis* species (36.06 CFU/m^3) and *Trichoderma* species (24.10 CFU/m^3).
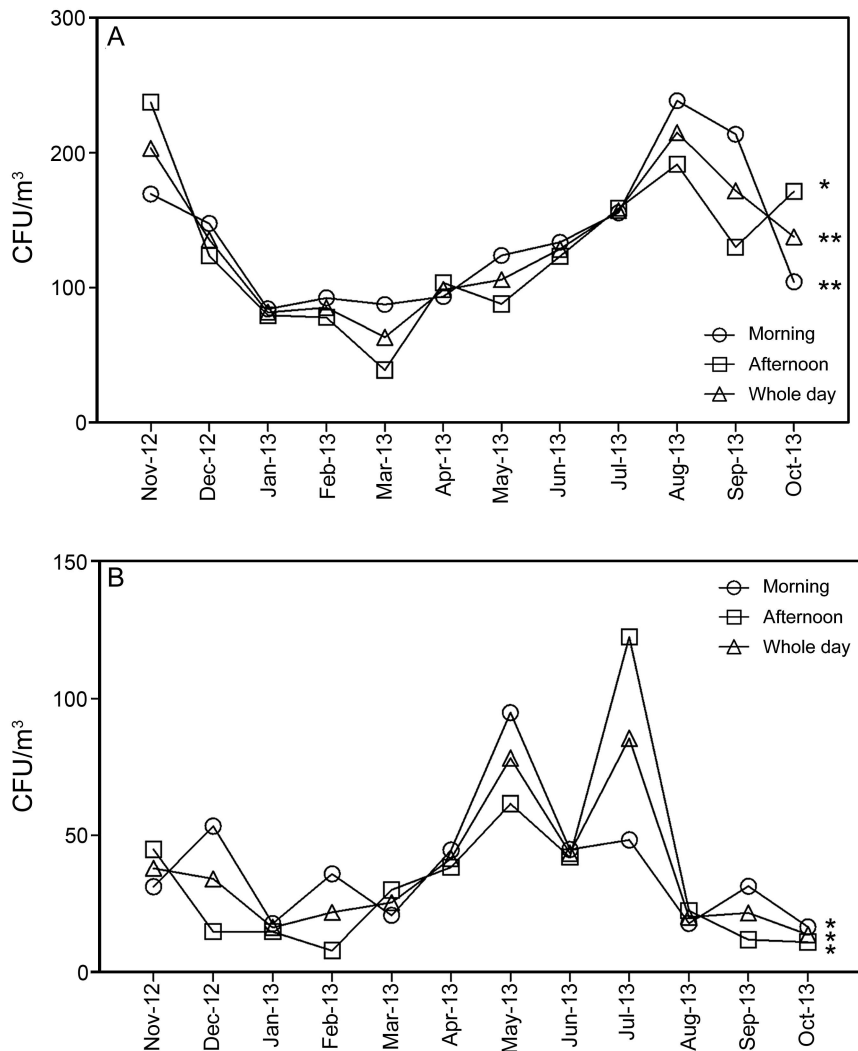
Fig. 3. Seasonal variation of A: bacterial and B: fungal concentrations in the respiratory care center. *$P < .05$, **$P < .01$.

Table 1.   Isolation Rate and Concentration Distribution of Airborne Bacteria in the Respiratory Care Center of a Hospital

Bacteria	Isolation rate (%)*	Concentration (CFU/m³)†		
		All	Morning	Afternoon
Bacillus species	12.00	23.75 (11.78–23.98)	23.75 (11.78–23.98)	0 (0)
Coagulase-negative *Staphylococcus*	20.00	17.69 (0–85.83)	29.90 (23.60–36.20)	11.78 (0–85.83)
Corynebacterium species	8.00	23.81 (11.78–35.84)	35.84 (35.84–35.84)	11.78 (11.78–11.78)
Flavimonas oryzihabitans	4.00	11.78 (11.78–11.78)	0 (0)	11.78 (11.78–11.78)
Gardnerella vaginalis	4.00	24.18 (24.18–24.18)	0 (0)	24.18 (24.18–24.18)
Micrococcus species	80.00	78.51 (23.56–279.15)	53.61 (23.56–266.20)	114.48 (23.81–279.15)
Moraxella atlantae	4.00	11.78 (11.78–11.78)	11.78 (11.78–11.78)	0 (0)
Staphylococcus species	28.00	11.78 (11.78–47.49)	11.78 (11.78–47.49)	35.86 (35.78–35.94)
Stenotrophomonas (Xan) maltophilia	4.00	11.78 (11.78–11.78)	11.78 (11.78–11.78)	0 (0)
Others	52.00	24.18 (11.78–71.68)	35.55 (11.79–71.68)	24.18 (11.78–59.90)

* The isolation rate of bacteria was defined as the number of specific microorganisms isolated divided by the total number of microorganisms isolated.
† Data are presented as median, with 25th to 75th percentiles in parentheses.
CFU = colony-forming units

Table 2. Isolation Rate and Concentration Distribution of Airborne Fungi in the Respiratory Care Center of a Hospital

Fungi	Isolation Rate (%)*	Concentration (CFU/m³)†		
		All	Morning	Afternoon
Acremonium species	3.33	12.09 (12.09–12.09)	0 (0)	12.09 (12.09–12.09)
Aspergillus species	60.00	12.04 (11.87–59.63)	29.98 (11.87–59.63)	11.99 (11.87–24.18)
Cladosporium species	16.67	11.97 (11.80–35.65)	11.88 (11.80–11.97)	11.98 (11.93–35.65)
Fusarium species	3.33	11.98 (11.98–11.98)	0 (0)	11.98 (11.98–11.98)
Paecelomyces species	3.33	11.87 (11.87–11.87)	0 (0)	11.87 (11.87–11.87)
Penicillium species	40.00	12.00 (11.86–171.09)	11.93 (11.86–158.56)	12.02 (11.88–171.09)
Scopulariopsis species	10.00	35.97 (12.01–36.15)	12.01 (12.01–12.01)	36.06 (35.97–36.15)
Trichoderma species	3.33	24.10 (24.10–24.10)	0 (0)	24.10 (24.10–24.10)
Verticillium species	6.67	17.92 (11.99–23.85)	17.92 (11.99–23.85)	0 (0)
Yeast	13.33	18.03 (11.87–71.56)	47.77 (23.98–71.56)	11.98 (11.87–12.09)
Others	50.00	12.01 (11.86–35.97)	12.00 (11.86–35.97)	12.09 (11.88–24.18)

* The isolation rate of bacteria was defined as the number of specific microorganisms isolated divided by the total number of microorganisms isolated.
† Data are presented as median, with 25th to 75th percentiles in parentheses.
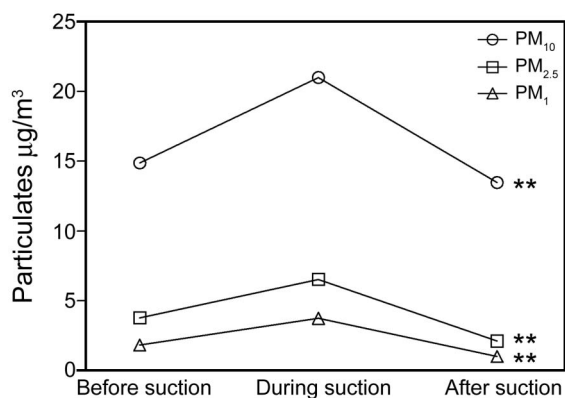CFU = colony-forming units

Fig. 4. Concentration variation of particulate matter (PM) during open suctioning procedure. **$P < .01$ during suctioning vs after suctioning.
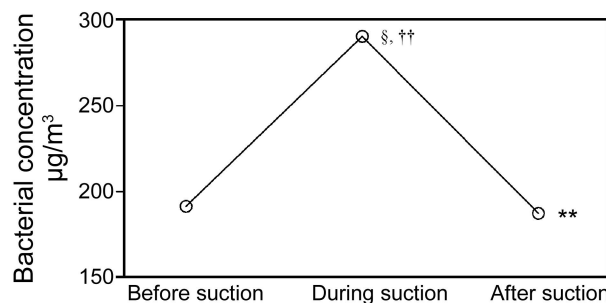

Fig. 5. Concentration variation of bacteria during open suctioning procedure. **$P < .01$ during suction vs after suction; ††$P < .05$ during suction vs after suction; §$P < .05$ before suctioning vs during suctioning.

Furthermore, the geometric mean concentrations of PM were 14.88 μg/m³ for PM_{10}, 3.78 μg/m³ for $PM_{2.5}$, and 1.84 μg/m³ for PM_1 before open suctioning, versus 21.01 μg/m³, 6.54 μg/m³, and 3.75 μg/m³ during the procedure, and 13.48 μg/m³, 2.12 μg/m³, and 1.01 μg/m³ afterwards. The changes in PMs before, during, and after suctioning were significant ($P < .01$) (Fig. 4). The geometric mean concentrations of PM_{10} and $PM_{2.5}$ were significantly higher before suctioning than afterwards ($P < .1$). The geometric mean PM concentrations during suctioning exceeded the averaged backgrounds in RCC (PM_{10} for 2.6 μg/m³, $PM_{2.5}$ for 1.4 μg/m³, and PM_1 for 1.1 μg/m³).

To assess the influence of the open suctioning procedure, the air bacterial concentration (290.45 CFU/m³) during the procedure significantly exceeded that before (191.52 CFU/m³, $P = .017$) and after (187.46 CFU/m³, $P = .019$)

the procedure (Fig. 5). Airborne bacterial concentration exhibited significant change ($P < .01$). Moreover, this study identified strong associations between airborne PM_{10} and $PM_{2.5}$ levels ($r_s = 0.824$, $P < .01$), and between PM_{10} and PM_1 ($r_s = 0.671$, $P < .01$) during the start of suctioning around the heads of patients (Table 3). Additionally, bacterial concentration was strongly associated with PM_{10} ($r_s = 0.380$, $P < .01$), $PM_{2.5}$ ($r_s = 0.314$, $P < .01$), and PM_1 ($r_s = 0.228$, $P = .031$).

Discussion

Most of the air quality indices measured in the RCC of a medical center in northern Taiwan met the indoor air quality standard of the Taiwan EPA, with the exception of TVOC levels. Possible reasons for TVOC levels sometimes failing to meet the standard may be related to alcohol evaporation from health-care worker hand hygiene prac-

Table 3. Associations Between PM Level and Bacterial Concentration During Opening Suctioning in Mechanically Ventilated Patients

Concentration	PM_{10}	$PM_{2.5}$	PM_1	Bacteria
PM_{10}	1.000			
$PM_{2.5}$	0.824*	1.000		
PM_1	0.671*	0.944*	1.000	
Bacteria	0.380*	0.314*	0.228†	1.000

* $P < .01$.
† $P < .05$.
PM = particulate matter

tices following contact with patients, and the hypochlorite solution used for floor cleaning.

The microorganism distribution analyses conducted in this study demonstrated high concentrations of *Micrococcus* species, *Corynebacterium* species, and *Staphylococcus* species in the air of the RCC. Yeast, *Aspergillus* species, *Scopulariopsis* species, and *Trichoderma* species were the most common fungal genuses in the RCC. The results of this study differ from those of a previous study conducted in an ICU.[19] However, the highest *Staphylococcus* species concentration occurred in the air of the RCC and the ICU. Both bacterial and fungal concentrations in the RCC peaked in the summer and fell in the winter, falling below 300 CFU/m^3. These concentrations were much lower than those obtained by a previous study on the air of the ICU.[19] It was recommended to maintain 15 air changes/h in the ventilation of ICUs with highly infective and particularly vulnerable patients.[31] Therefore, increasing air circulation and periodically maintaining the ventilation system are recommended to reduce the exposure of bioaerosol and TVOCs in hospitals.

Before performing open suctioning, the endotracheal tube must be disconnected from a ventilator circuit. A few phenomena are observable while the endotracheal tube of the patient is discontinued from a mechanical ventilator. First, the thoracic pressure of the patient becomes negative to the atmosphere, creating a risk of inhalation of airborne pathogens. Second, the mechanical ventilator provides a much higher flow to compensate for the low pressure in the ventilator circuit, and the condensates in the ventilator circuit may then be aerosolized from the forceful gas flow. This results in contamination of the air in the room. Finally, the opened ventilator circuit is frequently set on the chest of the patient, and the resuscitator for providing oxygen during suctioning is set on top of the bed sheet, an arrangement likely to cause contamination. Further contamination may then occur if proper hand hygiene is not carried out after contact with either the patient or hospital surfaces.

Significant changes occurred in PMs (PM_{10}, $PM_{2.5}$, PM_1) and bacterial levels during open suctioning on mechanically ventilated patients. The PM concentrations during open suctioning strongly exceeded those of the background air. This phenomenon demonstrated that the open suctioning procedure may increase the bioaerosol exposure risk for health-care workers in hospitals. Additionally, the analytical results also indicated that the concentrations of PM_{10} and $PM_{2.5}$ during open suctioning exceeded those after open suctioning. This phenomenon can be attributed to the aerosolization of condensates and pathogens in the airway during open suctioning. Additionally, the PM_{10} concentration ($16.46 \ \mu g/m^3$) measured near the patients was higher than the background concentration of the RCC ($2.6 \ CFU/m^3$) in this study. Besides the open suctioning procedure, health-care worker activities such as walking around, turning patients, or chest physical therapy may also have caused elevated PM levels. The concentration of PM_{10} during open suctioning was clearly associated with the concentrations of $PM_{2.5}$ and PM_1, and all 3 PM concentrations were significantly correlated with bacterial concentration. These outcomes resemble the results of previous studies.[19]

Additionally, the patients with tracheostomy tubes only require open suctioning. Thus, the risk of bioaerosol exposure of health-care workers during open suctioning in patients with tracheostomy tubes warrants further attention. Wearing suitable personal protective equipment is a good way to decrease the biological exposure of health-care personnel in hospitals. However, the relationship between hospital air quality, infection rate of hospitalized patients, and occupationally acquired diseases is still not clear. Thus, it deserves further investigation. The limitation of this study was that only one medical center was selected. We will consider reproducing the data regarding evaluation of indoor air quality if more medical centers become available for study.

To ensure the occupational health and safety of health-care workers, based on the results presented here, we suggest the following strategies: (1) periodically inspecting the ventilation system in the RCC, (2) increasing environmental disinfections in the summer, and (3) arranging continuing education on proper precautions and hand hygiene to minimize bioaerosol exposure risk in hospital health-care workers.

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