Impact of patient visiting activities on indoor climate in a medical intensive care unit: A 1-year longitudinal study

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Background: Bioaerosols from numerous sources have been implicated in respiratory diseases. This study evaluated the characteristics and weekly variations in indoor air in a medical intensive care unit (ICU) in northern Taiwan for 1 year. It also investigated the impact of patient visiting activities on the indoor climate in the medical ICU.

Methods: A 4-bed room with patients in the medical ICU was selected for long-term air monitoring. Air temperature, relative humidity, CO_2, particulate matter, bacteria, and fungi were measured.

Results: Approximately 90% of the CO_2 samples exceeded 1000 ppm, and 20% of the fine particle samples exceeded 35 $\mu g/m^3$. The levels of bacteria and fungi varied during the survey period. The measured values for all indoor air characteristics except bacterial concentrations were higher after patient visitation than before patient visitation. A significant association was found between the coarse particle concentration and the number of patient visitors.

Conclusion: Patient visiting activity impacts the indoor air quality of the ICU environment, especially in terms of coarse particle concentrations. Periodic monitoring of ventilation system efficiency is needed to ensure optimal indoor air quality.

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Bioaerosols, such as viruses, bacteria, and fungal spores, from a wide range of sources have been implicated in respiratory diseases.[1] Hospitalized patients are at significantly increased risk for bioaerosol exposure. A previous study found an incidence of nosocomial infection of 3% to 15%.[2] Surveillance data for intensive care units (ICUs) of medical centers and regional hospitals from the Taiwan Center for Disease Control and Prevention (CDC) showed that 17% to 25% of nosocomial infections are respiratory tract infections.[3] In Taiwan, the predominant microbial species for nosocomial respiratory tract infections in ICUs include *Pseudomonas aeruginosa*, *Acinetobacter baumannii*, *Klebsiella pneumoniae*, *Staphylococcus aureus*, and *Stenotrophomonas maltophilia*.[3] The most common pathogen in nosocomial infection is *S aureus* (17%~21%).[4]

The main sources of indoor bioaerosols in health care settings include patients, patient family members, and health care personnel. Severely ill patients in ICUs frequently require invasive devices, which may increase the risk of airway infections. The incidence of these infections is especially high in the ICU.[5] The probability of cross-infection among patients is increased with the use of a heating, ventilation, and air-conditioning (HVAC) system or from contacts between patients and health care personnel. The inadequacy of building air-conditioning systems, a low ventilation rate, the use of certain building materials, and overcrowding, especially of personnel, may result in indoor air pollution.[6] The quality of the indoor air is of great importance for ICU patients.

The evaluation of hospital indoor air characteristics includes particle concentration,[7] bacterial concentration,[7-9] fungal concentration,[8] viral concentration,[10] nitric oxide,[11] air temperature and humidity,[12] and volatile organic compounds.[12] High particle levels have been associated with the local human activity, air change rate, and filtration efficiency.[13] A linear relationship exists between particle concentration and CO_2 concentration/number of persons.[14] Numerous standards and guidelines have been established to protect humans from excessive exposure to air pollutants and ensure optimal indoor air quality.[15,16] To date,

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standards for hospital indoor air have not been established in most countries, including Taiwan.

To the best of our knowledge, no data are available for evaluating the influence of patient visitation activities on the indoor air characteristics in ICU environments. In the present study, we investigated hospital indoor air characteristics, including suspended particulate matter, bacteria, and fungi concentrations, in a medical ICU, and evaluated the effect of patient visitation on these characteristics.

METHODS

Sampling location

A 4-bed patient room in the medical ICU at Chang Gung Memorial Hospital in northern Taiwan was selected as the air monitoring site. There are no major local sources of industrial air pollution in the neighborhood of this hospital. During the 1-year sampling period, the indoor air was conditioned and no heating mode was used in the medical ICU.

Sampling frequency

The indoor air of the medical ICU was sampled on a fixed day each week for 1 year. The duration of each sampling was 90 minutes, including 30 minutes before patient visitation, 30 minutes during patient visitation, and 30 minutes after patient visitation. In this study, the air monitoring period after patient visitation was defined as extending from the start of the patient visiting activity to 30 minutes after the conclusion of the patient visiting activity.

Indoor climate survey

Field environmental measurements for air temperature, relative humidity, CO_2, suspended particulate matter, and bioaerosols (bacteria and fungi) were obtained inside the surveyed medical ICU. Air temperature, relative humidity and CO_2 were measured using a digital psychrometer (TSI Inc, Shoreview, MN). The suspended particulate matter concentrations were measured using a Grimm model 1.108 portable dust monitor (Grimm Aerosol Technik, Ainring, Germany). Both bacterial and fungal concentrations were measured using an Andersen N6 one-stage viable impactor (Andersen Samplers, Atlanta, GA) with 20 mL of tryptic soy agar for bacteria sampling and malt extract agar for fungi sampling, with air pumped at 28.3 L/minute for 3 minutes. These sampling instruments were placed 1.2 to 1.5 m above the floor to simulate the human breathing zone. The air samplers were placed about 1 m from the patient beds and located at a central point in the room. The plate samples were incubated at 30°C for 1 to 2 days for bacteria and at 25°C for 3 to 4 days for fungi. The bacterial and fungal counts were expressed in terms of colony-forming units in air (cfu/m^3), calculated using the positive holes conversion table[17] and the sampled air volume. Bacteria genuses identified included *Staphylococcus*, *Bacillus*, *Micrococcus*, *Acinetobacter*, *Flavobacterium*, *Pseudomonas*, and others.

Statistical analysis

All data were analyzed using SPSS version 13.0 (SPSS Inc, Chicago, IL). The suspended particulate matter was classified as PM_{10} (aerodynamic diameter < 10 μm), either coarse particles ($PM_{2\text{-}10}$, 2 μm $<$ aerodynamic diameter < 10 μm) or fine particles (PM_2, aerodynamic diameter < 2 μm). Spearman's correlation analysis was used to evaluate the relationships among the indoor environmental characteristics. The environmental characteristics before the patient visiting activity and after the patient visiting activity were compared using the Wilcoxon matched-pair signed-rank test. Simple logistic regression was used to analyze the importance of the number of patient visitors to indoor climate changes.

RESULTS

During the environmental sampling period, air temperature ranged from 21.2°C to 25.8°C, relative humidity ranged from 58% to 74%, and CO_2 concentration ranged from 828 ppm to 1570 ppm (Fig 1). Approximately 92% of the CO_2 samples exceeded 1000 ppm. The average CO_2 concentration was lower between May and October. PM_{10} concentration ranged from 4.2 to 43.7 μg/m^3, with the lowest values measured in the summer months (May to August). Coarse particle concentration was $<$ 45.0 μg/m^3 in all months, and fine particle concentration was $<$ 75.0 μg/m^3 in all months except November, when it was 415.6 μg/m^3. Twenty percent of the fine particle samples exceeded the 35- μg/m^3 standard for 24-hour $PM_{2.5}$ concentration set by the US Environmental Protection Agency (EPA) national ambient air quality standards,[18] and 36% of the fine particle samples exceeded the 25-μg/m^3 standard for 24-hour $PM_{2.5}$ concentration set by the World Health Organization air quality guidelines.[19] The measured bacteria and fungi concentrations varied among the surveyed weeks. The peak concentrations of indoor bacteria and fungi were found in June (7236 cfu/m^3 for bacteria and 7807 cfu/m^3 for fungi), October (3869 cfu/m^3 for bacteria and 5954 cfu/m^3 for fungi), and December (2964 cfu/m^3 for bacteria and 11,654 cfu/m^3 for fungi). Approximately 27% of the bacterial samples and 17% of the fungal concentrations exceeded 1000 cfu/m^3.

A positive association was found between CO_2 concentration and PM_{10} concentration (Spearman's rho coefficient [r_s] = 0.28; $P < .05$) (data not shown). The coarse particle concentration was related to the

Table 1. Isolation rates of microorganisms* in the medical ICU

Microorganisms	Spring (%)	Summer (%)	Autumn (%)	Winter (%)
Gram-positive bacteria				
Bacillus cereus	0	29	25	8
Micrococcus luteus	6	12	4	2
Staphylococcus aureus	10	0	0	2
Staphylococcus capitis	13	6	0	8
Staphylococcus epidermidis	17	6	13	23
Staphylococcus haemolyticus	8	0	8	14
Staphylococcus hominis	5	6	0	8
Others	13	23	8	23
Gram-negative bacteria				
Acinetobacter baumannii	4	12	42	2
Flavobacterium meningosepticm	4	0	0	2
Pseudomonas aeruginosa	10	0	0	2
Others	10	6	0	6

*The number of specific microorganism isolated/the total number of microorganisms isolated.

levels of PM_{10} ($r_s = 0.82$; $P < .01$) and fine particles ($r_s = 0.42$; $P < .01$). In addition, a significant association was found between the bacterial and fungal concentrations ($r_s = 0.74$; $P < .01$).

A significant difference was found in the isolation rate for bacterial species among the 4 seasons of the year (Table 1). The predominant species isolated included gram-positive bacteria, such as *Bacillus cereus*, *Micrococcus luteus*, *S aureus*, *S capitis*, *S epidermidis*, *S haemolyticus*, *S hominis*, and gram-negative bacteria, such as *A baumannii*, *Flavobacterium meningosepticum*, and *P aeruginosa*. Higher isolation rates were found for *S epidermidis* (17%), *S capitis* (13%), *S aureus* (10%), and *P aeruginosa* (10%) in the spring. *A baumannii* (12% to 42%) and *B cereus* (25% to 29%) were the predominant species in summer and autumn. *S epidermis* (23%) and *S haemolyticus* (14%) were most predominant in the winter.

To evaluate the influence of patient visitation, indoor air characteristics measured before and after patient visitation were compared (Fig 2). Relative humidity ($P = .000$), CO_2 concentration ($P = .000$), PM_{10} concentration ($P = .001$), coarse particle concentration ($P = .000$), fine particle concentration ($P = .000$), and fungi concentration ($P = .012$) were significantly higher after patient visitation than before patient visitation. Evaluation of air quality in relation to the number of patient visitors demonstrated that variations in most of the environmental characteristics were not strongly associated with the number of patient visitors. An increased number of patient visitors was found to be positively related to elevated coarse particle concentrations ($r_s = 0.31$; $P < .05$), however (data not shown).

Simple logistic models were used to estimate the associations between the number of patient visitors and indoor climate variables in the ICU environment. Important independent factors, such as relative humidity and concentrations of CO_2, PM_{10}, coarse particles, fine particles, bacteria, and fungi, were considered. These models demonstrate a strong association between the number of patient visitors and coarse particle concentration. Table 2 shows that for every increment of 1, 3, and 5 patient visitors, the coarse particle concentration increased by 1.28 (odds ratio [OR]) (95% confidence interval [CI] = 1.08 to 1.52; $P = .004$), 1.91 (95% CI = 1.19 to 3.07; $P = .008$), and 2.81 (95% CI = 1.35 to 5.87; $P = .006$), respectively. This indicates a trend toward increasing coarse particle concentration with an increasing number of patient visitors.

DISCUSSION

This study is the first investigation in Taiwan to monitor the indoor climate in a medical ICU in an effort to characterize the differences in indoor characteristics before and after patient visitation in the ICU.

Table 2. Odds ratios (ORs) and 95% confidence intervals (CIs) for associations between patient visitors and indoor climate variables.

Dependent variables (baseline)		Patient visitors (per 1-person increment)			Patient visitors (per 3-person increment)			Patient visitors (per 5-person increment)		
		OR	95% CI of OR	*P* value	OR	95% CI of OR	*P* value	OR	95% CI of OR	*P* value
RH	(< 66%[†])	0.95	0.84~1.08	.434	0.85	0.59~1.24	.404	0.81	0.46~1.44	.476
CO_2	(< 1000 ppm)	1.16	0.88~1.54	.292	1.82	0.75~4.45	.188	1.77	0.54~5.84	.349
PM_{10}	(< 20.7 μg/m^3 [†])	1.13	0.99~1.30	.077	1.41	0.95~2.11	.092	1.78	0.96~3.32	.069
$PM_{2\text{-}10}$	(< 14.2 μg/m^3 [†])	1.28	1.08~1.52	.004	1.91	1.19~3.07	.008	2.81	1.35~5.87	.006
PM_2	(< 21.1 μg/m^3 [†])	0.97	0.87~1.12	.825	0.88	0.61~1.28	.515	0.88	0.50~1.55	.668
Bacteria	(< 1000 CFU/m^3)	0.90	0.77~1.06	.206	0.70	0.43~1.14	.156	0.69	0.34~1.37	.288
Fungi	(< 1000 CFU/m^3)	0.95	0.80~1.12	.525	0.83	0.50~1.39	.476	0.80	0.37~1.73	.577

[†] Median value.

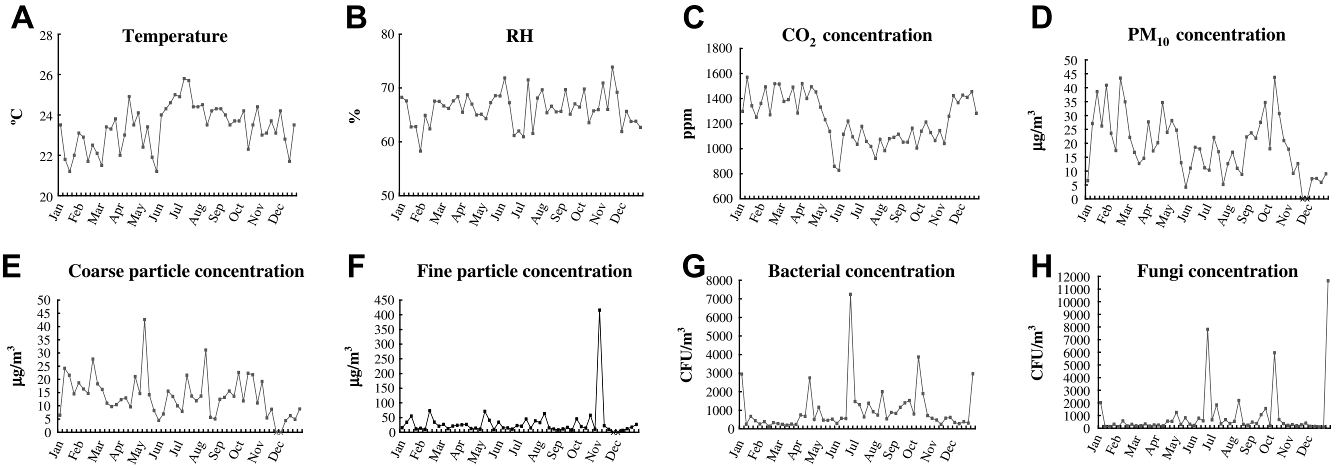

Fig 1. Weekly variations of indoor climate variables in the medical ICU. × in D, E, and F represents missing data, including the 4th week of November and the 1st week of December.

Concerning long-term indoor characteristics in the medical ICU, most of the CO_2 samples (92%) exceeded the suggested indoor limit of 1000 ppm,[20] indicating the need to inspect the ventilation and air-conditioning system and air change rate in the ICU environment. In addition, the CO_2 concentrations declined in the medical ICU from June to October. This decrease may be related to increased ventilation in the hotter months.

The coarse particle concentrations that we found (4.4 to 42.6 $\mu g/m^3$) are much lower than the concentrations of 5- to 10-μm particles measured in an ICU environment in a previous study (57 to 68 $\mu g/m^3$).[7] We found a positive linear relationship between CO_2 concentration and PM_{10} concentration, in agreement with the results of another previous study.[14] Previous epidemiologic studies have found an association

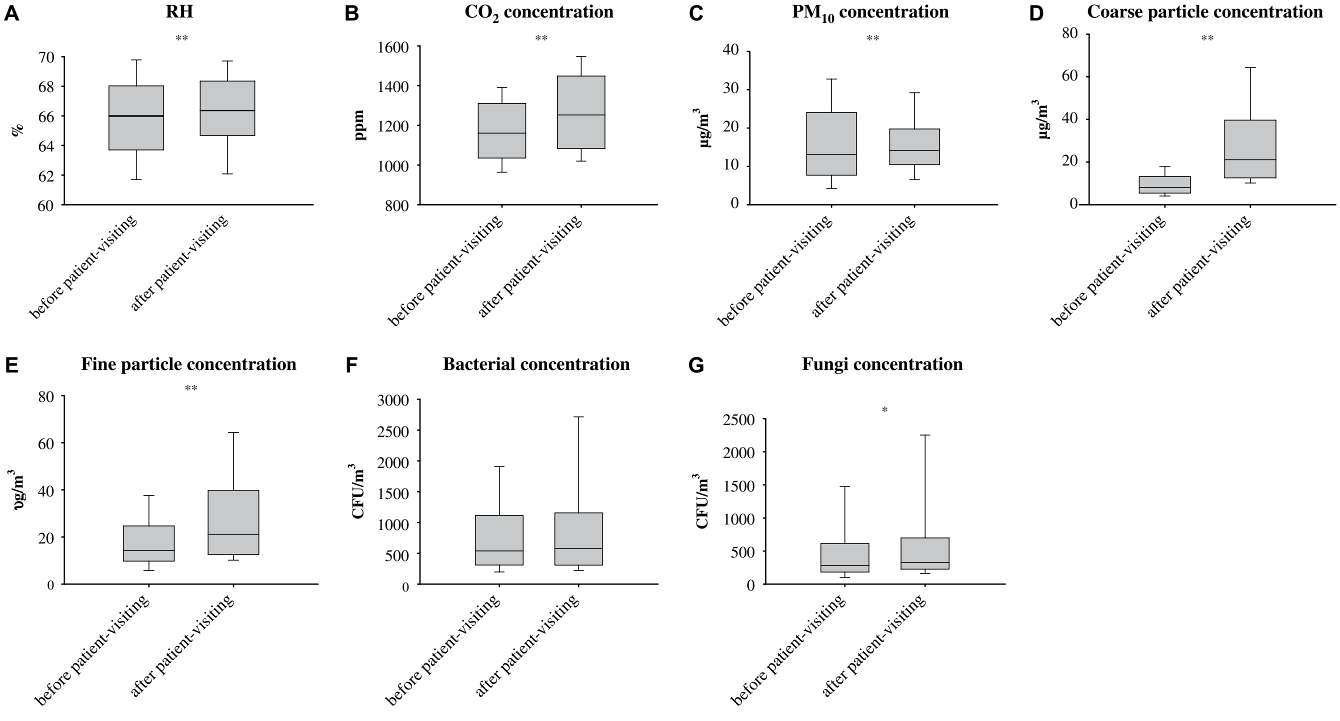

Fig 2. Influences of patient-visiting activity to indoor climate variables in the medical ICU. *Wilcoxon match-pair signed-rank test, $P < .05$; ** $P < .01$.

between airborne particulate pollution and respiratory and cardiovascular morbidity and mortality.[21-25] In our investigation, we found that 20% and 36% of the weekly average PM_2 levels in the ICU environment exceeded the 24-hour $PM_{2.5}$ standards of the US EPA[18] and WHO,[19] respectively. This demonstrates the need to monitor airborne particle concentrations to help ensure the health of patients and health care workers in the hospital environment.

Of our samples, 27% had bacterial concentrations and 17% had fungal concentrations exceeding the recommended level for indoor environments of 1000 cfu/m^3.[26] The peak concentrations of both bacteria and fungi were found in June, October, and December. These results can be attributed to seasonal variations in the growth of bioaerosols. Periodic monitoring of bioaerosol concentrations in the ICU environment is recommended. Airborne bacteria can reach a wound or medical devices through direct sedimentation from the air. Between 5% and 10% of patients admitted to the hospital contract infections.[27] We detected the important microbial species for nosocomial infections in the respiratory tract, including *S aureus*, *A baumannii*, and *P aeruginosa*. The relationship between airborne microbes and nosocomial respiratory tract infections merits further attention.

In addition to outdoor air pollutant concentrations, indoor air quality is affected mainly by internal sources, including HVAC systems, building materials, cleaning products, the number of personnel, and the types of human activities.[28,29] The CO_2 concentration and the number of persons in a room are important factors affecting indoor air quality. Our data showed that the measured values for relative humidity and CO_2, PM_{10}, coarse particle, fine particle, and fungal concentration were higher after patient visitation than before patient visitation, but the bacterial concentration before and after patient visitation did not differ significantly. Airborne bacteria originate mainly from human contact. The possible reason for the lack of difference in bacterial concentrations before and after patient visitation might be that all patient visitors were requested to wear masks and gowns while inside the medical ICU. We found a significant association between the increased coarse particle concentration in the medical ICU and the number of patient visitors in the room, in agreement with the results of a previous study.[14] We noted a trend toward a marked elevated coarse particle concentration OR related to the number of patient visitors. An increased number of patient visitors is related to an increase in coarse particle concentration in the ICU due to human activity. This finding demonstrates that the number of patient visitors has a significant affect on the indoor air quality in the ICU environment. Increasing the ventilation after patient visitation in ICUs will help improve the indoor air quality. Air distribution system flow-balancing in the ICU environment should be carried out once a year to decrease nosocomial transmission.[30] We did not measure the flow of supply air and exhaust air of the HVAC system in the ICU; we will consider monitoring the air change rate and the performance of the HVAC system in an ICU environment in a future study.

To characterize the association between patient visitation and indoor air quality in the ICU environment, we evaluated the weekly variations in indoor air quality in a medical ICU over a 1-year period in Taiwan, a subtropical region. We evaluated the distribution of bioaerosols (bacteria and fungi) and suspended particulate matter (PM_{10}, $PM_{2\text{-}10}$, and PM_2). We found that patient visitation impacts the indoor climate in the ICU environment. Although bacterial concentrations were not significantly different after patient visitation than before patient visitation, our findings still indicate that limiting the number of patient visitors in the ICU environment can improve indoor air quality, especially if the HVAC system cannot be adjusted to increase ventilation after patient visitation. Further studies are needed to characterize the bioaerosol exposure, especially bacteria, in the ICU environment in relation to nosocomial airway infections.

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