Ventilation management for patient care protection during construction in a bone marrow transplant unit

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ABSTRACT

Protecting immune suppressed patients from construction generated airborne opportunistic infectious agents is essential during their hospitalization. During modernization of the hospital's 32-bed bone marrow transplant unit (BMTU), an empty intensive care unit was retrofitted to BMT ventilation criteria. Filtration, pressurization and room air exchange criteria were required at <50 p/cm^3, pressure for rooms at 0.5 Pa and for the BMTU suite at 2.5 Pa. Room air exchanges were set at >12/h. A condensate particle counter and a digital pressure gauge were used to assess these criteria. A high volume slit impactor (700 l/min) was used to evaluate airborne fungal samples before and during occupancy to assure fungal spore control. The results show that the pre-retrofit particle counts in patient rooms had an average of 900 p/cm^3 with a range of 700–1200 p/cm^3; the post-retrofit particle levels had an average of 27 p/cm^3 and a range from 1 to 285 p/cm^3 before occupancy and an average of 74 p/cm^3 with a range of 1–3770 p/cm^3 after occupancy. The BMTU was pressurized to about 2.5 Pa after ventilation adjustment. Nosocomial fungal infections caused by airborne fungi did not increase during the time that patients occupied the retrofitted unit. This case study demonstrates using ventilation performance criteria for establishing special ventilation requirements.

INDEX TERMS

Hospital; Ventilation specifications; Infectious diseases; Construction

INTRODUCTION

Construction impact on immune compromised patient care wards such as a bone marrow transplant is well documented (CDC Environmental Infection Control Guidelines, 2003). When modernization of a bone marrow transplant unit (BMTU) is warranted, the challenge for renovation safety for patients is difficult with susceptible hosts in close proximity to reconstruction methods. The challenge of healthcare facilities with these units during modernization is paramount because the best prescription is to provide an equivalent ventilation for patient safety from airborne environmental opportunistic fungi.

We specified ventilation criteria (air exchanges, filtration and pressure) to help establish a short-term patient care area for the immune compromised bone marrow transplant patient (Table 1).

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Table 1 Ventilation criteria

Criteria	Ventilation specification goal for the retrofit BMTU	Ventilation of intensive care unit before renovation
Air changes	>12 air changes/h	6 air changes/h
Pressure (ΔP)	>2.5 Pa (unit); >0.5 Pa (room)	< 0.0 Pa
Filtration efficiency	99.97%	90.00%
Airflow direction	Out of the room	Neutral or into the room

METHODS

A condensation particle counter (P-Trak, TSI, Inc. St. Paul, MN) was used to determine objective information on the respective areas in the facility. The particle counter is used to provide a relative analysis of areas in the patient care areas. This device measures condensation particles ranging from 0.01 to 1.0 µm diameter. The particles per cubic centimetre samples demonstrate the relative differences according to filter efficiency.

A pressure gauge (Digital Pressure Gauge (DPG) Energy Conservatory, Minneapolis, MN) was used to provide pressure differentials across the doors for the BMT rooms. The DPG measure the pressure differential in Pascal's using a piezo-resistive sensor sensitive to less than 0.1 Pa.

An air balance hood (Alnor,TSI, Inc., St. Paul, MN) was used to set the airflow for each room supply and exhaust/return air volumes to achieve the criteria for the respective fan service areas(ICUs and BMTU).

Sample sites measurements were taken from five sample locations; outside reference, old BMT, retrofitted BMT, medical office building and ICU.

Sampling time consisted of 10-s average readings with the CPC in each location. The cultures for airborne fungi were collected with volumetric slit sampler for 2 min samples at a rate of 700 lpm.

Microbiology samples were collected on inhibitory mould agar (BBL) and incubated for 96 h at 35°C before analysis. Standard fungal identification keys for filamentous fungi were used.

Epidemiology for nosocomial disease was differentiated from community acquired fungal infections. This was determined by definition from radiological analysis and length of time in the hospital before suspect symptoms were detected.

The design criteria recommended by the American Institute of Architects Guidelines for Construction of Hospitals and Healthcare Facilities 2001 were used to set the ventilation parameters. These criteria were made more specific for the unique requirements associated with retrofitting patient care areas for special ventilation. These ventilation criteria required modification to achieve environmental measurement goals and airborne particulate levels, which have not been previously stated.

Major limitations for the retrofit of the rBMT were associated with priorities with other patient care units on the same air handling system. Original design of the ICU intended for only 6 air changes/h (AIA Guidelines, 2001). There was a minimal seal on rooms because sliding doors and perforated metal pan ceiling were also limitations because of excess leakage of air. The doors were sealed to minimize leakage around the frame of the sliding portion of the door. The air volumes for the air handling systems were adjusted to refine airflow to

appropriate levels in all clinical areas of the AHS zone. The excess air from the zone was diverted with the use of a small booster fan to provide the added air into the rBMT zone. This adjustment was sufficient to provide the necessary volumes to achieve the rBMT suite pressure along with the BMT room pressures. Note that the room pressures would have ideally been 2.5 Pa but the compromise was necessary to achieve the renovation goal.

Table 2 Airborne particle count (p/cm^3) in rBMT rooms

Sampling period	Average	Minimum	Maximum	Median	Standard deviation
Pre-retrofit	900	700	1200	900	
After-retrofit cleaning	3628	11	31 700	667	6036
After-retrofit before occupancy	503	1	12 400	12	2427
After-retrofit during occupancy	64	1	3700	10	318

Table 2 shows the CPC counts which were to achieve the goal of <50 p/cm^3. However, these data indicate a higher count of 64 because of the inclusion of an outlier data point that represented an emergency procedure with eight healthcare workers providing emergency service to a patient. This maximum level of 3700 p/cm^3 was reduced to <10 p/cm^3 within 3 h after the emergency was finished indicating ventilation efficacy for removing particles.

Table 3 Pressure (Pa) in rBMT rooms

Sampling period	Average	Minimum	Maximum	Medium	Standard deviation
Pre-retrofit	–0.4	–0.6	0.0	–0.4	
After-retrofit cleaning	0.2	–1.5	2.3	0.2	0.6
After-retrofit before occupancy	0.3	–1.5	2.4	0.3	0.6
After-retrofit during occupancy	0.0	0.4	2.2	1.0	0.6

Table 3 shows the BMT unit pressures for patient rooms. The perimeter doors were maintained at 2.4 Pa on two of the three egress doors. The third door was not evaluated because it was sealed with ‘break away’ tape for fire emergency egress.

The average room air exchanges in the 13 rBMT rooms was 20 with a range from 14 to 23 air changes/h.

Airborne fungal levels were collected in the rBMT unit and outside before and during the renovation project. The average 37°C culture results show 14 cfu/m^3 before versus 4.2 cfu/m^3 after renovation. Outside levels were 325 cfu/m^3 before versus 120 cfu/m^3 after renovation. This represents a similar decrease in the indoor outdoor ratio.

The patient epidemiological data for nosocomial infections did not change from the same period of time that the patients were in the rBMT compared to the previous 4 years of data in the paediatric population; 1999—1 case *A. fumigatus*, 2000—1 case *A. terreus*, 2001—1case *A. fumigatus* and 1 case 2002. These patients were considered nosocomial acquisitions of the opportunistic fungi.

DISCUSSION

Criteria for managing indoor air quality in patient care facility is uncertain. We provided guidance ventilation parameters, which specified the air quality content for particles in air. The difficulty with specifying fungal particles includes time delay for culture results and response factors. Responding to the presence of airborne fungi is problematic because of transient nature of their presence in indoor air (Streifel *et al.*, 1990). The data suggests that the exposure is not associated with the ventilation but may be due to behavioural factors such as patient's family or healthcare worker carriage of fungal spores (Dart and Obendorf, 2000). The ability to provide HEPA filtration in these critical settings is paramount with limiting factors such as fan power to drive air through the filters. These limitations can be extremely cost prohibitive to the safety of patients in a diagnostic related group reimbursement contracts in hospitals in the USA.

With healthcare advances and the 24 h/7 day occupancy of hospitals the difficulty of upgrading the facility while occupied is challenging. Aspergillosis is often associated with hospital construction (HICPAC CDC, 2003). Because of this concern, the need to move patients away from that activity is paramount. However, if the temporary move subjects the patient to environmental opportunistic fungi due to less than recommended ventilation, the exposure and potential infection becomes a concern for patient safety.

With careful engineering with a focus on temporary management of a less than ideal location the exposure can be minimized with ventilation parameters of room air exchanges, pressure and filtration can be provided to satisfy protective environments for immune compromised patients. The advent of low-pressure drop filters with HEPA filtration certainly provides opportunity to provide sanitized air with sufficient volume to allow for safe care of patients. The advantage of point of use filtration certainly removes the 'dirty' duct concern. Too often the final filters, if efficiency is increased, will actually reduce the air volume. This reduction in air exchanges will also potentially reduce the offset of supply versus exhaust/return air, which could reverse air flow causing air to flow into the room. Our situation allowed us to pressurize a depressurized smoke compartment zone in our ICU area to achieve a perimeter pressure in the suite at 2.4 Pa, which is very close to the recommended pressurization in the AIA Guidelines.

We could not pressurize the rooms to the 2.5 Pa level due to perforated plate ceilings and sliding doors. The doors were sealed to minimize leakage and the air balance was adjusted to achieve an average of 32 m^3 air supply for an average of 20 air exchanges/h. The air exchanges before the adjustment was about 6 air changes/h. The air volumes were achieved by the rebalance and the use of a booster fan (2.6×10^6 J/h). A problem existed when the booster fan was installed. The decibel level initially was 50 dbA and with the fan on the level in the room where the fan was installed increased to 64 dbA. The room became unbearable because of the noise for critical patient care. That room was converted into an employee break/report room.

In addition, with the use of self-contained filtration units at the entrance supply ducts, the conversion of the intensive care ward ventilation supplement to a BMTU was complete.

All maintenance was conducted before the move of patients to minimize disturbing the patient care environment during the time the patients were in the retrofitted unit.

Ongoing surveillance was conducted with the pressure gauge and CPC. The pressures on the rooms and patient care suite stayed constant and the particle counts varied with activity but the normal conditions in the patient room demonstrated most often <10 p/cm^3. The real-time analysis of the environment parameters allows for 'now' certainty rather than 'later' assurance of fungal spore presence. The issue is controversial and really must consider what to do 'if' pathogens are found? The BMT unit cannot be abandoned patient care because of the presence of pathogens especially if there is no disease. However, measures must be

focused on the presence of these organism due to some independent variable, which is probably not associated to the ventilation system.

CONCLUSIONS

Establishing a safe environment of care for preventing exposure to environmental airborne fungal spores remains a difficult task unless certain ventilation parameters and behaviour modification are provided. The establishment of criteria for ongoing monitoring is important to assure that environmental parameters associated with mechanical systems are functioning properly. New technology allows for final filtration at HEPA quality with low-pressure drop possible for retrofit to BMT ventilation criteria. Behaviour factors such as in-room activity, pass to the outside, consistency of masking, all are beyond the control of the mechanical systems.

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