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Short Report

Are positive-pressure ventilation lobby rooms effective for protective and source isolation?

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SUMMARY

High-efficiency particulate air supplied to a positive-pressure ventilation lobby (PPVL) in isolation rooms offers the dual advantage of protective and source isolation. This study demonstrates the in-use validity of PPVL rooms for protective isolation of patients. Of the 48 PPVL air samples investigated, *Aspergillus fumigatus* was detected from only one (2%) sample. Local and remote monitoring of the PPVL rooms is essential for the safety of patients and healthcare workers. Remote and point-of-use engineering controls are essential for ongoing ventilation monitoring, but this should be complemented by visual inspection of the isolation suite. Periodic microbiological monitoring should also be considered with other control measures.

Introduction

Positive-pressure ventilation lobby (PPVL) rooms were introduced with the arrival of UK Health Building Notes (HBN) 04–01, Supplement 1 (2005), and were hypothesized to provide a protective environment for patients. The PPVL room was shown *in vitro* to be effective in providing the desired protection, but the literature supporting its clinical validity is sparse [1]. The HBN 04-01 Supplement 1 (2013) recommends a neutral-pressure ventilation (NPV) room with a PPVL for the prevention of transmission of infection by airborne pathogens [2]. Many newer healthcare facilities have provided PPVL-NPV rooms, and some are fitted with high-efficiency particulate air (HEPA) filters, but there are few data on their in-use effectiveness.

The at-risk patient groups for invasive aspergillosis (IA) have recently been expanded to include chronic lung disease,

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patients in critical care, and liver cirrhosis. [3] Additionally, emerging multi-triazole resistance in *Aspergillus fumigatus* limits therapeutic and prophylactic options [3]. The Irish National Guidelines recommend the use of HEPA-filtered positive-pressure facilities for patients' at increased risk of IA [4].

The aim of the study was to evaluate the in-use efficacy of the HEPA-supplied PPVL-NPV rooms for protection of patients at risk of IA, using three parameters, i.e. visualizing the direction of air flow, pressure differentials, and the microbiological monitoring for the presence of moulds, including *Aspergillus* spp.

Methods

Setting

Beaumont Hospital is an 800-bed tertiary acute adult national referral healthcare facility in Dublin, Ireland, incorporating national services in neurosurgery and kidney transplantation with a substantial cohort of haematology, oncology, and cystic fibrosis patients. The hospital has several PPVL-NPV rooms fitted with HEPA supply (hereafter referred to as 'NPV rooms') for protective isolation of immunocompromised patients to prevent IA. For bed access to any room, an appropriately sized door is required. Our NPV rooms are fitted with double-leaf sealed doors, from the corridor to the room, for bed access only and are access-controlled. Subsequent to their installation and commissioning, no demolition, construction, or renovation works have been performed to 'the envelope' in these purpose-built PPVL-NPV rooms, other than routine preventive maintenance [2].

Positive-pressure ventilation lobby room

The physical layout and airflow direction of a PPVL room is shown in Figure 1. The ante-room is supplied with HEPA-filtered air with ≥12 air changes per hour (ACH). The patient room and en-suite facility should have ≥10 ACH. While in operation, the en-suite facility should be at negative pressure with respect to the patient room. The airflow direction should be from the ante-room to the patient room to the en-suite facility. The doors leading into and out of the ante-room and patient room must be closed to facilitate the correct airflow. Engineering controls include a pressure differential display (magnahelic pressure gauge) and alarm lights. Air pressure displays of ≥10 Pa in a PPVL are a measure of adequate air supply. Visual display alarms are used for local monitoring and the safe functioning of these rooms. Pressure differential data are continuously recorded by estates and facilities.

Air flow test

The air flow was assessed by visualizing the direction of smoke into and out of the PPV lobby, patient room, and en-suite facility by using a smoke test (Smoke pen, Björnax, Nora, Sweden), on three non-consecutive time-points. The expected direction of the airflow is from the PPVL to the patient room through the pressure stabilizer, and through the diffuser grill to the extract in the en-suite facility. The smoke pen was directed to the door seals as well as to the door–floor–wall fittings, to observe any smoke penetration/leakage.

Pressure differential test

The doors leading into the ante-room from the corridor were held open for 30 s; the pressure reading should fall to '0' Pa. Thereafter, the door leading to the ante-room was closed; a reading of ≥10 Pa was deemed adequate. These tests were repeated weekly for eight weeks.

Microbiological monitoring

Environmental air sampling was done by active air sampling, ~1 m above the floor, where 1 m^3 of air per sample was collected to determine the fungal spore burden, most specifically *A. fumigatus* [4]. Air samples were collected from the NPV rooms at three locations: the ante-room (lobby), patient room,

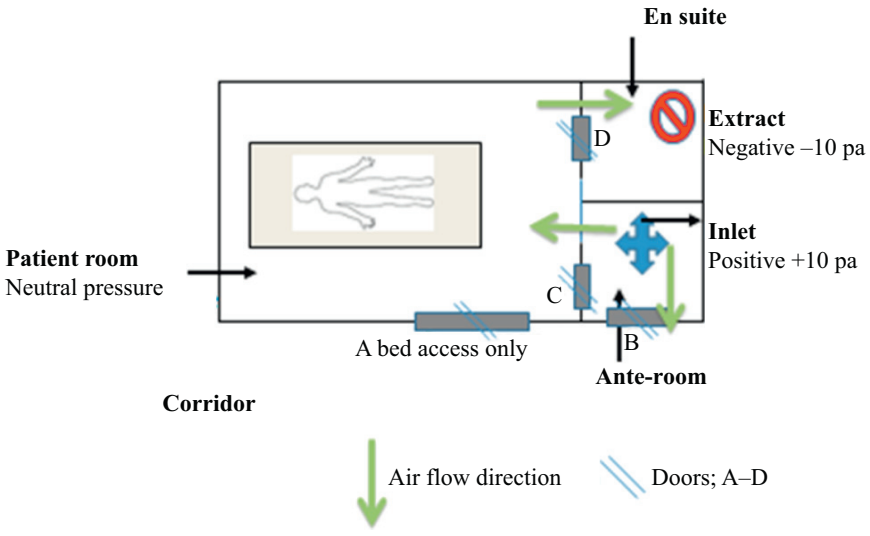

Figure 1. Layout and airflow direction of a positive-pressure ventilation lobby and neutral pressure isolation room.

Table I
Air-sampling locations and sites where *Aspergillus fumigatus* was identified (colony-forming units)

Week	Ward A								External	
	NPV-5			NPV-6			HEPA: General		NV	
	PPVL	PR	EX	PPVL	PR	EX	B8	B12	NV-4	NV-1
1	–	–	–	–	–	–	–	–	5	–
2	–	–	–	–	–	–	1	–	–	–
3	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–	3	–
5	–	–	3	–	–	–	–	1	20	3
6	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–	1	1
8	–	–	–	–	–	–	–		6	–

NPV, neutral-pressure ventilation infection isolation room; HEPA, high-efficiency particulate air ventilation; PPVL, positive-pressure ventilated lobby/ante-room; PR, patient room; EX, extract *en suite*; NV, natural ventilation.

and the en-suite facility. Two air samples were collected from atmospheric air outside the built-in areas which served as the environmental control.

Sabouraud Dextrose Agar (SDA) plates (Fannin Ltd, Dublin, Ireland) were used for air sampling using a Surface Air Sampler (SAS) PBI, Milan Italy, one day per week for eight consecutive weeks. Plates were incubated at 37°C for 48 h and suspect colonies for aspergillus were identified as described [5]. Ten air samples were collected each week for eight consecutive weeks; three each from two NPV rooms, two from the positive-pressure HEPA-ventilated 24-bed ward while occupied by patients, and two external atmospheric air samples).

Results

Air flow

In the lobby, smoke flow was observed diffusing into the patient room through the pressure stabilizers. From the patient room, the flow of smoke moved into the en-suite facility through the integrated grills while the door was closed. In the en-suite facility, smoke flow was towards the ceiling-mounted extractor. No smoke penetration was observed through the bed-access-only door seals or via the flush door–floor–wall fixtures.

Pressure differential

The pressure gauge differential reading was ≥10 Pa in both positive-pressure lobby rooms when the doors were closed, and fell to '0' Pa upon opening the lobby door, but returned to ≥10 Pa when the doors were closed. The observed pressure differential readings during the eight weeks in both PPVL rooms were consistently ≥10 Pa.

Microbiological monitoring

Eighty air samples were collected over eight weeks. No moulds, including *A. fumigatus*, were isolated in the PPV lobby or in the patient rooms. Three colony-forming units (cfu) of *A. fumigatus* were isolated on one occasion from the en-suite facility of one of the NPV rooms. From the two open ward locations, mould was isolated on two separate sampling points, 1 cfu each, and identified as *A. fumigatus*. Of the eight sampling points, *A. fumigatus* was isolated on five occasions from atmospheric air, i.e. the environmental control. The air-sampling results are summarized in Table I.

Discussion

Controlled ventilation is used in healthcare facilities for the protection of patients, healthcare workers and other users. It often does not deliver the recommended ventilation, it may fail to maintain negative pressure, and it may even be under positive pressure [5]. Other problems with mechanical ventilation include the loss of negative-pressure differentials in airborne isolation rooms due to the opening of the doors and clogged filters. The undesirable airflow in and out of the negative-pressure isolation room, i.e. permeability, shows how leaky it is, as any leak presents a route of airborne transmission. In the absence of works carried out in the isolation facility that affect the envelope of the isolation suite, or any physical defects in a PPVL-NPV room, an air leak may occur from broken door seals or faulty doors [2].

Historically, isolation rooms that are switchable from positive to negative air pressure were used, but investigators found that these units were not delivering air according to the set parameters. An evaluation of 115 negative-pressure ventilation isolation rooms in the USA found that 52 (40%) of these rooms had positive airflow to the corridor with the doors closed [5]. In the absence of well-sustained negative pressure, contamination of adjacent rooms is likely, therefore posing a significant clinical risk to patients and to others such as staff [6].

Investigators in Hong Kong assessed rooms used for severe acute respiratory syndrome isolation rooms for negative pressure, airflow path, air-change rate, and local ventilation effectiveness. They found that, of the 38 rooms tested, 97% met the recommended negative-pressure difference of 2.5 Pa between the corridor and the ante-room, and 89% met the same requirement between the ante-room and the patient room. Although no leakage to the corridor was found, 60% of the en-suite facilities were operating under positive pressure. More than 90% of the corridor–ante-room or ante-room–patient room doors had a bi-directional flow when the door was open [7]. This casts doubt on the efficacy of negative-pressure ventilated rooms for source isolation.

The latest UK guidelines no longer recommend isolation rooms that are switchable from positive to negative air pressure, because of the risk of an incorrect setting [2]. The HEPA-fitted PPVL rooms therefore offer the dual advantage of 'protective' clean air supply to prevent IA, and airborne isolation with negative-pressure ventilation. The design of the PPVL room stipulates unidirectional airflow from the lobby to the patient room and this air is extracted in the en-suite facility. The design of the NPV suite limits the risk of inadvertent exposure to airborne pathogens, in the event of a failure in the air supply or extractor, which are inter-locked. However, this is dependent on robust engineering and regular safety checks.

Air permeability tests should be done as part of commissioning, at regular intervals, following physical alterations to

the room structure or if breaches to the supply and air-handling units occur, as specified in HBN (2013), Appendix 2. The UK Building Services Research and Information Association (BSRIA) standards on air permeability testing (BTS 3/2018) recommend testing at intervals not exceeding 14-month intervals. If further work is carried out in the isolation facility that affects the envelope of the isolation suite, the test must be repeated [8]. In the absence of alterations in the regular air flow, smoke tests to observe the direction of air flow could be employed as these provide reassurance of a functioning ventilation system when the intentional air flow direction is observed. Local monitoring of the pressure differential readings should be incorporated into daily visual checks to confirm the adequate functioning of the ventilation system.

We recorded pressure differential readings of the PPV lobby with the doors (B, C) closed and opened which provided visible evidence on the functioning of the HEPA-ventilated lobby. Automated remote continuous-pressure differential monitoring should be incorporated into healthcare building management systems for safety and governance. However, the poor reliability of continuous monitoring devices has been reported elsewhere, emphasizing the benefits of frequent visible smoke tests [9]. We observed the appropriate direction of smoke flow from the PPV lobby to the patient room to the en-suite facility extract, while all the doors were closed. No leakage of smoke was observed through the door-lips or seals.

The effective functioning of a PPV lobby room is dependent on the doors leading into and out of the rooms (A—D), being closed at all times. This requires a coordinated effort from clinical, engineering, hygiene services staff, patients, and visiting public. Staff must be educated on the correct functioning of these rooms in addition to noting and acting on warning alarm lights. Local monitoring and troubleshooting must be part of staff training. Patients in such rooms and their visitors must be provided with appropriate information, including the necessity of keeping the doors closed. In our experience, where patients were not given appropriate information the lobby/ante-room doors were sometimes sealed with tape, pressure dampers were blocked, doors were wedged open, and window seals broken. Sealed bed-access-only doors must be access controlled to prevent accidental and inadvertent use of these doors and thus prevent the ingress of contaminated air.

Irish guidelines recommend environmental air sampling before construction and at intervals [4]. As clean-air-supplied PPVL rooms are also intended for protective isolation, microbiological monitoring of HEPA-ventilated rooms by air sampling is prudent [3,4]. Determining baseline fungal spore burden before building works will facilitate future comparison. In the HEPA-supplied PPVL rooms, the recovery of *A. fumigatus* is unexpected, and, if present, it must be investigated. A two-year study to assess whether the PPVL room provides a similar environment to positive-pressure rooms found that mould concentrations were similar in the positive- and neutral-pressure room [1].

In our study, *A. fumigatus* was cultured once from the NPV en-suite facility. The NPV room was occupied by a patient during sampling. No environmental deficits could be detected other than dust on the extract fan grills. A comparable study has reported similar contamination from en-suite facilities in controlled ventilation rooms [10]. In the absence of a numeric threshold for *Aspergillus* counts to indicate when action needs to be taken, a threshold of <1 cfu/m^3 HEPA-filtered rooms with $>99.95\%$ efficiency is suggested [3]. The absence of fungal growth from PPVLs and NPV patient room air samples confirms the capacity for protective isolation.

Following the isolation of aspergillus in environmental air samples in another HEPA ventilation room (not the two NPV rooms studied), we noted dampness on the ceiling and walls arising from water leaks as the most likely cause. Therefore, regular environmental checks of ceilings and walls for dampness and water leaks are essential. Our findings contribute to growing evidence on the efficacy of PPVL-NPV isolation rooms for protecting at-risk patients from airborne pathogens as well as source isolation of patients with airborne-transmissible infections.

Limitations to our study include assessing only two HEPA-supplied PPVL-NPV isolation rooms and only over a period of eight weeks, in one centre yielding a small sample size. Larger studies involving multiple NPV rooms for longer duration should be performed to validate clinically the safety and efficacy of these expensive specialized rooms.

Conflict of interest statement
None declared.

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None.

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