Evaluation of a new mobile system for protecting immune-suppressed patients against airborne contamination

Jean-Louis Poirot, MD, Jean-Pierre Gangneux, MD, Alain Fischer, MD, PhD, Mireille Malbernard, RN, Svetlana Challier, MD, Nicolas Laudinet, BSc, and Vance Bergeron, PhD

Rennes, Paris, and Lyon, France

Background: Invasive aspergillosis is one of the most lethal airborne dangers for immune-suppressed subjects. Providing patient protection from such airborne threats requires costly and high-maintenance facilities. We herein evaluate a new self-contained mobile unit as an alternative for creating a patient protective environment.

Methods: Airborne contamination levels were monitored for different simulated scenarios and under actual clinical conditions. Functional tests were used to challenge the unit under adverse conditions, and a preliminary clinical study with patients and staff present was performed at 2 different French hospitals.

Results: Functional tests demonstrated that the unit can rapidly decontaminate air in the protected zone created by the unit and in the surrounding room. In addition, the protected zone is not sensitive to large disturbances that occur in the room. The clinical study included 4 patients with 150 accumulated days of testing. The protected zone created by the unit systematically provided an environment with undetectable airborne fungal levels (ie, $<1$ CFU/m$^3$) regardless of the levels in the room or corridor ($P < .01$).

Conclusions: These tests show that the unit can be used to create a mobile protective environment for immune-suppressed patients in a standard hospital setting. (Am J Infect Control 2007;35:460-6.)

Invasive aspergillosis, notably *Aspergillus fumigatus*, is one of the most lethal airborne dangers for immune-suppressed subjects. Although the reported attributable mortality from invasive pulmonary aspergillosis differs depending on the patient population studied, the Centers for Disease Control and Prevention (CDC) reports rates as high as 95% in recipients of allogeneic bone marrow transplants and patients who have aplastic anemia, compared with rates of 13%-80% in leukemic patients. The most important nosocomial infection caused by *Aspergillus* sp is pneumonia, and the primary route of acquiring *Aspergillus* sp infection is via inhalation of the fungal spores. In severely immune-suppressed patients, primary *Aspergillus* sp pneumonia results from invasion of local lung tissue; subsequently, the fungus can disseminate via the bloodstream to involve other deep organs.

*Aspergillus* sp are ubiquitous environmental saprophytes whose concentration in the hospital setting varies depending upon several factors, including the season, building condition, ventilation system, general hygiene, and cleaning protocols implemented. A clear relationship between elevated environmental fungal contamination levels and the incidence of invasive aspergillosis in hematology patients has been established. Moreover, an increased risk of *Aspergillus* sp infection has been associated with building construction or renovation in or around the hospital. The small fungal spores (2-5 μm) are easily disseminated in the air by dust and airborne debris in these situations. The recommended guidelines to prevent the transmission and outbreak of such an airborne risk call for maintaining an environment as free as possible of the invasive spores—so-called "protective environments." Although the exact configuration and specifications of the protected environments differ between hospitals, such patient care areas are built to minimize fungal spore counts in the air by maintaining (a) filtration of incoming air by using central or point-of-use high-efficiency particulate air (HEPA) filters; (b) directed room airflow; (c) positive room-air pressure relative to the corridor; (d) well-sealed rooms; (e) high rates of room-air changes (range, 15-400 per hour) (note, however, that air-change rates at higher levels affect patient comfort); or (f) complete isolation of the patient in a protective bubble. The oldest and most...
studied protected environment is a room with laminar airflow. Such an environment consists of a bank of HEPA filters along an entire wall or ceiling of a room; air is pushed by blowers through these filters and into the room at a uniform velocity, forcing the air to move in a laminar (or at least unidirectional) pattern. The air usually exits at the opposite end of the room. A HEPA-filtered laminar airflow system can be effective in decreasing the risk for nosocomial aspergillosis in high-risk patients, however, such a system is costly to install and maintain. In many situations, retrofitting such a system into an existing facility’s heating, ventilating, and air-conditioning network is not possible. Furthermore, if rigorous maintenance protocols are not followed, these systems can actually pose serious contamination risks; microbial growth and release from the system can become an airborne contamination source, and the development of high pressure drops across the mechanical HEPA filter systems can lead to filter rupture and bypass.

We herein evaluate an alternative strategy for creating a protective environment using a mobile unit that recycles and distributes treated air through a plenum over an isolated zone. Instead of simply filtering the air, this unit uses a novel technology that was originally developed for space exploration and is currently used in the International Space Station, which destroys airborne micro-organisms. Thus the zone under the air distribution plenum is designed to be a highly protective environment against airborne microbial contamination.

**METHODS**

**Air purification system**

Figure 1 depicts a schematic of the mobile air-decontamination unit used in this study. This device is manufactured by the company AirInSpace, and has the tradename Immunair. The Immunair is a self-contained system that can be folded and wheeled to any location within the hospital (Fig 1a)—a rapid, versatile, and inexpensive means of creating a protective environment on demand. Once in position, the system is unfolded and the overhead plenum is deployed 1.94 meters above the floor (Fig 1b). Transparent polyvinyl chloride curtains are then snapped into place and suspended down from the plenum to approximately 6 cm from the floor, creating an isolated zone of approximately 4.5 m² under the plenum. Room air is then drawn through the principle column of the unit and subsequently decontaminated by cold-plasma reactors that destroy airborne micro-organisms and capture residues via electrostatic forces inside charged porous dielectric media.

The intrinsic efficiency of the reactors used in the Immunair unit has been extensively tested in so-called “single-pass” testing at the Harvard School of Public Health, Harvard University, United States, and the Health Protection Agency, Centre for Emergency Preparedness and Response Porton Down, United Kingdom, prior to this study. Together, these tests demonstrate single-pass airborne reduction efficiencies greater than 99% at air speeds up to 1.5 m/s for a wide range of micro-organisms, including *Aspergillus niger*, *Staphylococcus aureus*, *Bacillus atrophaeus*, *Serratia marcescens*, *Vaccinia* virus, and MS2 coliphage.

Once decontaminated, air exiting the reactors in the Immunair is directed into the overhead plenum and evenly distributed at a velocity of 0.05–0.12 m/s (corresponding to the unit operating at air throughputs of 450–1050 m³/hr) over the entire protected zone confined within the transparent curtains. This zone is large enough for a hospital bed, nursing staff, and peripheral equipment needed for patient treatment. Rapid access into and out of the protected zone along its perimeter is provided by several overlapping slits in the curtains. A slight positive pressure is created within the protected zone, which causes air to flow back into the room with a velocity greater than 0.6 m/s through the gap between the floor and the bottom of the curtains. This air is subsequently recycled through the system. In our tests, the device used operates at approximately 540 m³/hr and 640 m³/hr for the night and day settings, respectively. This provides an air exchange rate within the protected zone from 65 to 80 changes per hour.

**Experimental testing**

Two series of tests were conducted in this study: (1) functional tests, without patients and staff present, in the Immuno-Haematology Paediatric Service at Necker Children’s Hospital in Paris, France; and (2) preliminary clinical tests with patients present in the same service at Necker Children’s Hospital and in the hematology wing of the Paediatric Service at Rennes University Hospital, Rennes, France. The functional tests were performed to verify the Immunair performance in a hospital setting before using the system with patients. These tests were designed to monitor the fungal and total mesophilic flora (TMF) airborne levels within the protective area under the plenum of the Immunair unit and in the surrounding room environment. Tests were conducted with the Immunair operating under night and day settings and during biocleaning periods to simulate the different conditions anticipated for the clinical study. We also note that during the functional tests the hospital sector was undergoing renovation and tests were conducted without special precautions. The objective of the clinical tests was to monitor and compare with patients present, airborne fungal levels under the protective environment of the
Immunair, with levels in the surrounding room and the adjacent corridor. These tests were performed in hematology wards under normal working conditions and included a total of 4 patients with 150 accumulated days of testing. Patients were placed under the protective environment of the Immunair day and night.

**Air sampling methods**

At Necker Children’s Hospital, air sampling was performed by an independent accredited external firm, MSIS, Gif-sur-Yvette, France, using the normative procedures and guidelines referenced in Table 1. The patient rooms used in these tests were approximately 42 m³, with a hermetically sealed window and a door that leads directly to the corridor. In the functional tests, 3 sample locations were used in the room: 1 within the protected zone, and 2 in the surrounding room. Air samples were taken with Merck MAS 100 biocollectors from a height of 1 m above the floor and operating at 100 L/min for 5 minutes. Petri dishes containing Sabouraud culture media were used for fungal analysis, while standard plate-count agar dishes were used for the TMF evaluations. Fungal cultures were incubated at 27°C and read after 3, 5, and 7 days to determine the colony-forming units and to discriminate for *Aspergillus* isolates.

The clinical study at Rennes University Hospital was conducted by the hospital’s Parasitology-Mycology and Hygiene laboratories using equivalent protocols to those implemented at Necker. However, in this case a BioMérieux Air Ideal biocollector was used with culture dishes containing malt extract agar to analyze 1000-L air samples (10-minute samples at 100 L/min). The resulting cultures were incubated at 32°C and read after 2 days and again at 5 days for quantification and identification of fungal species. For both clinical studies, air samples were taken within the protected zone of the Immunair, in the surrounding room, and in the adjacent corridor.

**RESULTS**

Results from the functional tests are presented in Figs 2 and 3. In both cases, the airborne contamination levels, quantified as the number of colony-forming units per cubic meter (CFU/m³), are plotted as a function of the testing timeline. The time periods are not represented on a linear scale so that we can project the entire test period clearly on 1 graph. Furthermore, the negative values on the timeline seen in Fig 2 indicate the period prior to activating the decontamination unit.

The first series of functional tests were performed to test the capacity of the Immunair unit to decontaminate 1 within the protected zone, and 2 in the surrounding room. Air samples were taken with Merck MAS 100 biocollectors from a height of 1 m above the floor and operating at 100 L/min for 5 minutes. Petri dishes containing Sabouraud culture media were used for fungal analysis, while standard plate-count agar dishes were used for the TMF evaluations. Fungal cultures were incubated at 27°C and read after 3, 5, and 7 days to determine the colony-forming units and to discriminate for *Aspergillus* isolates.

The clinical study at Rennes University Hospital was conducted by the hospital’s Parasitology-Mycology and Hygiene laboratories using equivalent protocols to those implemented at Necker. However, in this case a BioMérieux Air Ideal biocollector was used with culture dishes containing malt extract agar to analyze 1000-L air samples (10-minute samples at 100 L/min). The resulting cultures were incubated at 32°C and read after 2 days and again at 5 days for quantification and identification of fungal species. For both clinical studies, air samples were taken within the protected zone of the Immunair, in the surrounding room, and in the adjacent corridor.

**Table 1.** List of normative procedures and guidelines used to perform the airborne biological sampling in functional and clinical tests

<table>
<thead>
<tr>
<th>Internation Standard</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 14698-1</td>
<td>Cleanrooms and Associated Controlled Environments Biocontamination Control—Part 1. General Principles and Methods</td>
</tr>
<tr>
<td>UNICLIMA Guide</td>
<td>French Air Handling, Air Conditioning and Refrigeration Equipment Manufacturers Association Guide for Environmental Controls in High Risk Zones</td>
</tr>
</tbody>
</table>
air starting from very high airborne contamination levels. Thus, without cleaning the test room, and prior to activating the unit, a vigorous dry dusting was performed in the room. This procedure generated airborne fungal levels in excess of 400 CFU/m³ and TMF levels greater than 300 CFU/m³ (eg, the culture dishes were saturated). These ambient levels were established 13.5 hours before starting the unit, during which time natural sedimentation resulted in a slight decay, as witnessed in Fig 2. The zero in the figure’s timeline corresponds to the moment when the device was switched on and operated at 640 m³/hr. Subsequently, we find that within 20 minutes, airborne fungal and TMF contamination concentrations within the protected zone drop to undetectable levels (ie, <1 CFU/m³). Concomitantly, room fungal and TMF levels were reduced to below 45 CFU/m³. These levels were continuously maintained for over 5 hours, after which time the unit was switched to the night air-throughput setting of 540 m³/hr. Upon completing 22 hours of continuous operation, a bio-cleaning of the surrounding room was performed. Immediately following this cleaning a slight increase in the room TMF levels is observed, however, no significant airborne contamination is detected in the protected zone, and the low levels were maintained for the duration of the test, which lasted for 27 hours.

To further evaluate the level of protection provided under extreme conditions, a second series of functional tests was conducted to establish the continuous performance of the unit during significant disturbances in the surrounding room. The progression of this test can be followed in Fig 3. Here the baseline airborne contamination level in the room was 57 and 27 CFU/m³ for fungal flora and TMF, respectively, with corresponding values of 24 and 14 CFU/m³ in the protected zone. After switching on the Immunair unit, operating at 640 m³/hr, within 15 minutes airborne contamination in the protected zone was brought below 1 CFU/m³ and room levels were reduced to less than 5 CFU/m³. Once these low values were reached, the unit was set to the lower 540 m³/hr operating conditions. After 120 minutes of steady-state performance, a rigorous bio-cleaning of the surrounding room was performed, at which time the unit was placed in the high throughput operating mode of 640 m³/hr to compensate for the anticipated disturbance. We see from Fig 3 that the bio-cleaning appears to produce peak levels of airborne fungal flora that reach 50 CFU/m³ in the surrounding room. This contamination is subsequently abated as the room air is recycled through the Immunair air treatment system. Significantly, during the entire room cleaning perturbation, undetectable levels of airborne contamination are sustained within the protected zone.

Motivated by the high level of environmental protection demonstrated in the functional tests, 2 preliminary clinical studies with the Immunair were initiated. The data from these studies are presented in Fig 4. At Necker Children’s hospital, tests were performed with 3 different immune-suppressed pediatric patients kept within the protected zone of the Immunair unit day and night for 19, 61, and 55 days, respectively, thus accumulating 135 days of testing. During this
time, 129 airborne fungal samples were taken within the protected zone and in the surrounding room, with reference samples from the corridor in 70% of the cases. Sampling in the different locations was performed at the same moment to provide meaningful references. At the Rennes University Hospital, the study consisted of one immune-suppressed pediatric patient kept in the protected zone of the Immunair

---

**Fig 3.** Airborne contamination levels (CFU/m$^3$) versus test duration time (minutes). Time periods indicated directly on the figures by the letters “a,” “b,” “c,” “d,” and “e” identify periods where the Immunair unit was operating at different air throughputs; “a” corresponds to when the unit was off, “b” and “d” correspond to when it was operating at 640 m$^3$/hr, and “c” and “e” correspond to when it was operating at 540 m$^3$/hr.

**Fig 4.** Results from the combined clinical study showing airborne contamination levels (CFU/m$^3$) observed in the corridor, in the surrounding room, and within the protected zone of the Immunair unit. For each location the average value (filled square symbol) and a standard deviation bar (boldface line) for the accumulated data set are plotted directly in the figure. For precise comparison these values are also reported alongside the corresponding data set for each sample location.
unit over a 15-day period. During this time, 10 airborne fungal samples from each location (protected zone, surrounding room, and corridor) were taken along with 5 surface samples from different areas within the protected zone: the top of the bed, under the bed, the table top, the interior side of the curtains, and from the overhead air distribution plenum. No fungal counts were seen in any of the 50 surface samples taken (data not shown).

DISCUSSION

Outbreaks of invasive aspergillosis increase the importance of maintaining environments as free as possible of *Aspergillus* spores for patients who have severe granulocytopenia. Although the sources and routes can at times be unclear, air control measures remain crucial to reduce environmental dissemination of fungal conidias. To accomplish this, specialized services in many large hospitals—particularly bone marrow transplant services—have installed “protected environments” for the care of their high-risk, severely granulocytopenic patients. These environments implement HEPA filtration and laminar air flow systems to treat the air, which can be effective but are costly and difficult to maintain. More cost-effective air control measures could help hospitals increase their level of protective environments and decrease the risk of aspergillosis infection.

The tests conducted in this study provide evidence that creating a mobile protective environment in a full clinical situation with the Immunair unit is possible. We find that a significant difference in the airborne fungal levels between the adjacent corridor, the surrounding room, and the protected zone of the Immunair can be achieved. Indeed, the protected zone systematically provides an environment with airborne fungal levels lower than 1 CFU/m$^3$ regardless of the levels in the room or corridor. A Wilcoxon statistical comparison test demonstrates that:

- within the protected zone created by the Immunair, airborne fungal levels are maintained below 1CFU/m$^3$, $P < .01$,
- significantly lower airborne fungal levels are achieved in the protected zone compared with those of the surrounding test room, $P < .05$,
- airborne fungal levels in the surrounding room are lower than those of the corridor, $P < .05$.

The unit achieves this by combining efficient air decontamination, directed airflow, positive pressure, and high air change rates within the zone under the air distribution plenum, all recommended measures for achieving highly protective environments. Additionally, because the room air is recycled, airborne contamination is significantly lowered in the surrounding room. Consequently, a buffer zone between the unit and the adjacent corridor is created. Moreover, this type of internal room treatment can abate sources coming from within the room, such as that from clothing of visitors and medical staff, and also personal and medical materials.

The unique features of the Immunair unit are its mobility and use of cold-plasma reactors to destroy and not simply capture airborne micro-organisms. Thus, the unit can be used to quickly convert standard hospital rooms into areas that can host immune-suppressed patients without the need for major building renovation. Furthermore, destruction of the micro-organisms within the unit also eliminates the risk posed by mechanical HEPA filter systems concerning the growth and release of airborne micro-organisms. Although it was not formally studied here, the ergonomics of the unit (eg, noise, size, ease of use, etc) appeared to be relatively well accepted by the patients and the nursing staff.

Potential environmental sources of *Aspergillus* sp are not restricted to air; consequently, a comprehensive preventative plan against infection requires the implementation of proper protocols and surveillance measures in addition to air control strategies. Controlling and monitoring levels of both airborne and surface levels of *Aspergillus* sp will help to ensure that the preventative measures put into place remain effective, and furnish indispensable data needed to track, identify and remedy incidences of nosocomial fungal infections should they occur.

References


Availability of Journal back issues

As a service to our subscribers, copies of back issues of AJIC: American Journal of Infection Control for the preceding 5 years are maintained and are available for purchase from Mosby until inventory is depleted. Please write to Subscription Customer Service, 6277 Sea Harbor Dr, Orlando, FL 32887, or call 800-654-2452 or 407-345-4000 for information on availability and prices of particular issues.