THE ABILITY OF HOSPITAL VENTILATION SYSTEMS TO FILTER *ASPERGILLUS* AND OTHER FUNGI FOLLOWING A BUILDING IMPLOSION

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ABSTRACT

OBJECTIVES: To assess the ability of hospital air handling systems to filter *Aspergillus*, other fungi, and particles following the implosion of an adjacent building; to measure the quantity and persistence of airborne fungi and particles at varying distances during a building implosion; and to determine whether manipulating air systems based on the movement of the dust cloud would be an effective strategy for managing the impact of the implosion.

DESIGN: Air sampling study.

SETTING: A 976-bed teaching hospital in Baltimore, Maryland.

METHODS: Single-stage impactors and particle counters were placed at outdoor sites 100, 200, and 400 m from the implosion and in five locations in the hospital: two oncology floors, the human immunodeficiency virus unit, the cardiac surgical intensive care unit, and the ophthalmology unit. Air handling systems would operate normally unless the cloud approached the hospital.

RESULTS: Wind carried the bulk of the cloud away from the hospital. *Aspergillus* counts rose more than tenfold at outdoor locations up to 200 m from the implosion, but did not increase at 400 m. Total fungal counts rose more than sixfold at 100 and 200 m and twofold at 400 m. Similar to *Aspergillus*, particle counts rose several-fold following the implosion at 100 and 200 m, but did not rise at 400 m. No increases in any fungi or particles were measured at indoor locations.

CONCLUSION: Reacting to the movement of the cloud was effective, because normal operation of the hospital air handling systems was able to accommodate the modest increase in *Aspergillus*, other fungi, and particles generated by the implosion. *Aspergillus* measurements were paralleled by particle counts (*Infect Control Hosp Epidemiol* 2002;23:520-524).

Aspergillus species are spore-forming fungi that cause serious, invasive disease in immunosuppressed hosts. Attributable mortality of these infections has been as high as 95% in some series.[1-3] *Aspergillus* spores, which range in size from 2 to 6 µm,[4] can be found in most organic material and, once released, can travel great distances as airborne particles. Construction work is known to liberate large quantities of *Aspergillus* spores[5,6] and the association between construction work and nosocomial outbreaks of aspergillosis has been well described.[7-9] It is not known what modifications, if any, should be made to hospital air handling systems to minimize entry of *Aspergillus* spores when construction or demolition work is being done near hospital buildings.

During the summer of 2000, the City of Baltimore scheduled the implosion of a 22-story building located approximately 100 m from the Johns Hopkins University Hospital (JHH), a 976-bed, multi-building, teaching hospital in Baltimore, Maryland. Because building implosions generate significant quantities of airborne particulate matter,[10] the event posed potential problems for the hospital air handling systems. As is often the case in academic medical centers, many of the JHH buildings are mixed-use, housing both patient care and laboratory space. The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) guidelines state that any building housing laboratory space using chemical and compressed gases requires non-recirculating air supply systems. Therefore, when the options for protecting the indoor hospital environment from airborne dust generated by the implosion were examined, temporarily recirculating the air could not be considered. Shutting off the air handling sys-

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tems completely was also not an attractive option because this would have resulted in the loss of air required for patient comfort and positive pressurization of patient rooms. Because all patient rooms (except for negative pressure rooms) at JHH are designed to be positive pressure with respect to the rest of the building, the loss of positive pressure would have generated either neutral or negative pressure in patient rooms with respect to the hallways, ceilings, and window seals, increasing the possibility that airborne contaminants and dust could be drawn into the patient rooms. Given these difficulties, we thought it would be optimal to continue to run the systems under normal operating conditions if this was at all possible.

The building was scheduled for implosion on August 19. Because the winds in autumn generally blow from the northwest and the implosion site was to the south of the hospital, we believed it was likely that most of the dust would be blown away from the hospital. Therefore, we developed a strategy whereby we would monitor the dust cloud from the implosion and alter air systems only if it approached hospital buildings. Because this approach has not been previously described, we undertook this study to monitor its effectiveness. We elected to monitor the impact of the implosion using both air cultures and particle counters. Because air sampling for *Aspergillus* can be difficult and expensive, we wanted to see whether particle counts could serve as a surrogate for direct *Aspergillus* measurements.

METHODS

Hospital Air Handling Systems

The air handling units at JHH have gasketed filters installed in airtight frames. All filters are constructed of nonwoven, 100% synthetic media (Environmental Filter Corp., Smithfield, NC) except for high-efficiency particulate air (HEPA) filters, which are constructed of microfibered glass paper. Air intake systems in the ophthalmology building and the human immunodeficiency virus (HIV) unit are fitted with a prefilter that is 30% efficient, followed by a 65% efficient filter, which is, in turn, followed by a terminal non-HEPA filter that is 95% efficient at filtering particles of 1 μm or more. However, the efficiency of the terminal filter is raised to 99% because it is in a gasketed, airtight frame. A similar system is installed in the building that houses the cardiac surgical intensive care unit, but before reaching the unit, the air also passes through a 99.97% efficient HEPA filtration bank. The hospital has two oncology buildings, one built in 1982 and the other completed in 2000 but not in operation at the time of the implosion. In the older oncology center, air passes through two non-HEPA filters that are each 99% efficient at removing particles of greater than 1 μm because they are in gasketed frames. The air supplied to each patient room is mixed with air from a recirculating air system that has a 99.97% efficient HEPA filter.

The air handling systems ran under normal conditions throughout the implosion, except the system in the newer oncology building, which was shut down because the building was unoccupied. The only modification was the addition of a 30% efficiency filter to the older oncology building to prevent excessive dust loading of the air filters.

Several measures were also taken to prepare the hospital and ensure optimal operation of the air handling systems. First, all windows in the older oncology building were inspected in the days prior to the implosion to ensure that the gaskets were tightly sealed. Second, on the day of the implosion, maintenance staff conducted a walk-through in the hospital to make sure no doors or windows were propped open. Finally, around the time of the implosion, pedestrian traffic near the hospital was limited by security to keep door openings to a minimum.

Clinical Monitoring for Aspergillus *Infections*

JHH has conducted active surveillance for *Aspergillus* infections among high-risk populations for several years and keeps information on infection rates. Mycology reports, chest radiographs, and computed tomography scans of all oncology patients are reviewed weekly by an infection control practitioner for evidence of fungal pneumonia. Any patient who has a nodular or cavitary lesion on lung imaging and is treated with amphotericin B is considered a case of "probable" invasive fungal disease (*Aspergillus* infection). A patient with these lesions on imaging and a sputum or lung tissue culture that grows *Aspergillus* is defined as a case of "definite" *Aspergillus* infection. Autopsy reports are reviewed to find additional cases. A case is defined as nosocomial if the infection occurs more than 14 days after admission.

Air Sampling Strategy

Aerotech 6 air samplers (Aerotech Laboratories, Phoenix, AZ) were placed in three outdoor and five indoor locations (Fig. 1). Outdoor locations included the fourth floor patio of the newer oncology building, a ground floor patio of the older oncology building, and the tenth floor patio of the Children's Medical and Surgical Center, approximately 100, 200, and 400 m north of the implosion site, respectively. Indoor locations were chosen to focus on areas housing high-risk populations (oncology, critical care [intensive care unit], and HIV infected) and for proximity to the implosion (ophthalmology building).

Single-stage Anderson impactors meet National Institute for Occupational Safety and Health Methods 0800 and 0801 specifications for sampling indoor and outdoor air for viable microorganisms, and have been validated for detecting *Aspergillus*.[11] Air is drawn through the sampler and airborne particles are directed toward the surface of the agar collection medium. The impactor was operated at an airflow of 28.3 L/min, which was verified before and after sampling using a BIOS DryCal flow calibrator (BIOS International Corp., Pompton Plains, NJ). At each outdoor location, two 15-minute samples were collected 45 minutes and 30 minutes prior to the implosion. Starting at the moment of the implosion, samples were collected every 5 minutes for 30 minutes, then every 15 minutes for an additional 60 minutes. At indoor locations, one 30-minute background sample was taken and, following the implosion,

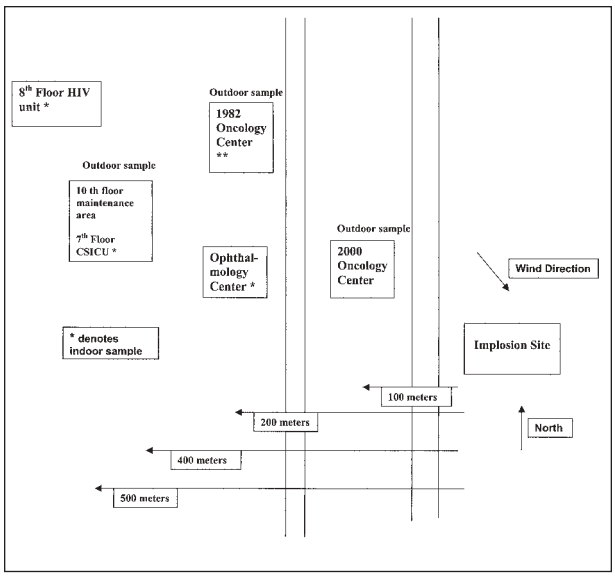

FIGURE 1. Map of the implosion site and sampling locations.

samples were collected every 30 minutes for 90 minutes. Between each sample, the impactors were cleaned with alcohol wipes.

Each impactor was paired with an MIE DataRAM (MIE, Inc., Beford, MA), a real-time monitor that measures particle concentrations from 0.001 to 400 mg/m^3 for particles between 0.1 and 10 µm in diameter. For this study, the DataRAM reported concentration data every 10 seconds.

Microbiologic Methods

Standard, 115-mm plates with Sabouraud's agar and 100 µg/mL of gentamicin were incubated at 25°C for 7 days. Fungal colonies were counted and all fungi were identified at least to genus level if conidia were produced. All *Aspergillus* was identified to species level.

Climatic Conditions

At 10:00 am on August 19, 2000 (the scheduled implosion time and date), the temperature in Baltimore, Maryland, was 21.6°C with a relative humidity of 65%. The wind was blowing from the northwest at 1.8 m/s with gusts up to 11 m/s, which placed the hospital upwind of the implosion site.

RESULTS

Microbiologic and Particle Monitoring

Aspergillus counts rose several-fold at outdoor locations up to 200 m from the implosion (Fig. 2). *A. niger* and *flavus* were the only *Aspergillus* species recovered, with *A. niger* accounting for 78% of all *Aspergillus* isolates. *Aspergillus* colonies could not be counted on the 5-minute post-implosion sample from the 200-m location or on the 5- and 10-minute samples from the 100-m location because these plates were overgrown with fungi. However, *Aspergillus* counts rose approximately tenfold at these locations on the first post-implosion plate that could be analyzed. *Aspergillus* counts remained above baseline for 30 minutes following the implosion at 100 m and for 20 minutes at 200 m. There was no increase in *Aspergillus* counts at the outdoor location 400 m away.

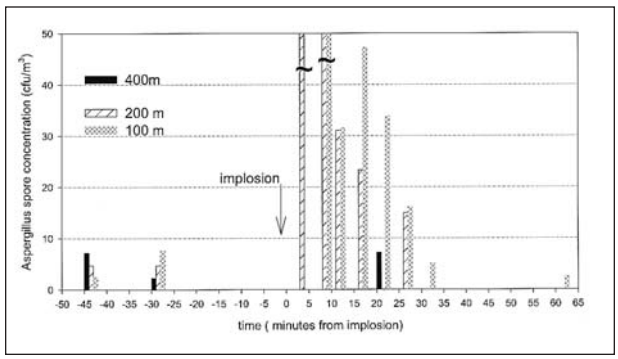

FIGURE 2. *Aspergillus niger* and *A. flavus* colony concentrations at each outdoor location before and after the implosion. During the first 10 minutes after the implosion at 100 m and the first 5 minutes at 200 m, *Aspergillus* concentrations could not be quantified due to plate overgrowth. Bars for those time periods represent total fungal overgrowth.

There was also a substantial increase in total fungal counts of fungi other than *Aspergillus* after the implosion at all three outdoor locations. Baseline, 15-minute fungal counts for the three locations averaged 144 ± 9 colony-forming units (CFU)/m^3. Fungal counts from the overgrown plates at the 100- and 200-m locations exceeded 900 CFU/m^3 based on growth from the first plate that could be analyzed (Figs. 3 and 4, lower panels). Increases were more modest at the outdoor location 400 m from the implosion site, with peak total fungal counts only double those at baseline. Counts in all locations remained above baseline 90 minutes after the implosion. *Penicillium* and *Cladosporium* species were the most frequently recovered fungi and accounted for more than 95% of all isolates.

Total fungal counts in all indoor locations were low, ranging from 0 to 8 CFU/m^3 of air, and only one colony of *Aspergillus* was recovered in one location. There was no increase following the implosion.

Similar to *Aspergillus* measurements, particle concentrations increased at the two closest outdoor locations immediately after the implosion (Figs. 3 and 4, upper panels). Particle mass increased from 0.001 µg/m^3 to 54 mg/m^3 at the 100-m location and 0.605 mg/m^3 at the 200-m location, and returned to baseline within 20 minutes of the implosion. Also similar to *Aspergillus*, particle mass did not increase above baseline at the 400-m location.

Clinical Monitoring

Ongoing surveillance revealed no change in the rates of definite or probable *Aspergillus* infections among oncology patients in the 3 months following the implosion. There was also no increase in the number of positive *Aspergillus* cultures reported by the hospital mycology laboratory in the 3 months following the implosion.

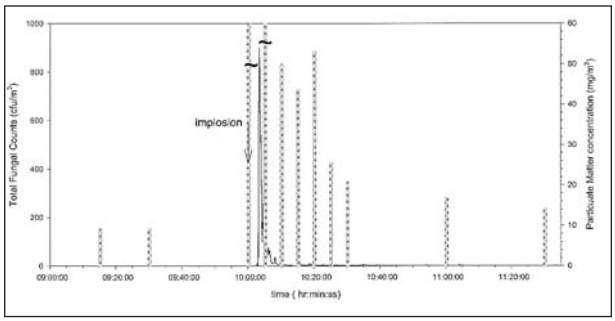

FIGURE 3. Particle concentrations and total fungal concentrations (bars) at the 100-m location. Bars for the 5- and 10-minute samples represent fungal overgrowth of the plates. Time of the implosion was 10:03 am. Collection of data on particle mass concentration began 60 minutes before and continued for 120 minutes after the implosion. Collection of data on fungal count began 45 minutes before and continued for 90 minutes after the implosion.

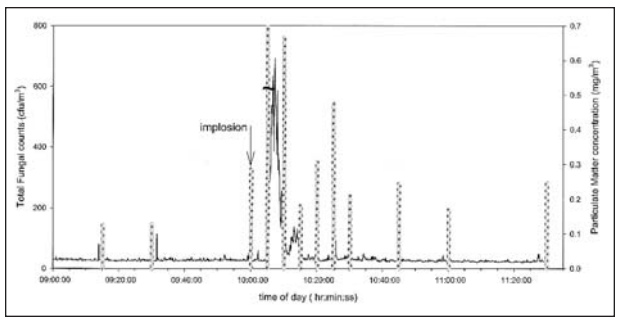

FIGURE 4. Particle concentrations and total fungal concentrations (bars) at the 200-m location. The bar for the 5-minute sample represents fungal overgrowth of the plate. Time of the implosion was 10:03 am. Collection of data on particle mass concentration began 60 minutes before and continued for 120 minutes after the implosion. Collection of data on fungal count began 45 minutes before and continued for 90 minutes after the implosion.

DISCUSSION

Our study demonstrated that *Aspergillus* and other fungi are dispersed into the air by a building implosion. This was also demonstrated by Streifel et al.[10] in a building implosion study that showed *Aspergillus* counts increasing 1,000-fold at a site 60 m from the implosion center. Although prevailing winds carried much of the dust away from the hospital, we did observe increases in total fungal, *Aspergillus*, and particle counts at outdoor monitoring sites up to 200 m away. We found no increase in either fungal or particle concentrations at any indoor locations, indicating that the air handling systems operated under normal working conditions were able to handle the increase in fungi and airborne particles generated by the implosion.

Our results suggest that the fungi were carried into the air along with the particle cloud generated by the implosion, but remained aloft after particle concentrations had returned to background levels. This may be in part due to differences in densities and, therefore, settle velocities between the fungi and the particles generated from the implosion.

Because environmental sampling for *Aspergillus* is highly dependent on climatic conditions, there are limits to how broadly our findings can be applied. However, we believe there are three important conclusions that can be drawn from our results. First, it appears that most *Aspergillus* spores liberated by the implosion tracked with the dust cloud, which made reacting to the cloud an effective strategy for managing the hospital response to the implosion. We were prepared to temporarily turn off air systems in the event that the cloud approached a particular building. However, because the bulk of the cloud moved away from the hospital, we were able to operate all systems normally and observed no increases in fungal or particle counts at any indoor monitoring location. The theory that most of the *Aspergillus* tracked with the dust cloud is perhaps also supported by the fact that we observed increases in *Aspergillus* that were 100-fold less than the increases measured by Streifel et al.[10]

Second, normal operation of the hospital air handling systems was able to accommodate an increase in fungal and particle counts. Despite substantial increases in total fungal, *Aspergillus*, and particle counts observed at the outdoor sites, none of these levels increased inside the buildings adjacent to these outdoor sites. Although one of these buildings was an oncology center with a HEPA filtered air system, the other building (the ophthalmology center) has a standard hospital air handing system. This result is particularly encouraging in that it suggests that even standard hospital air handling systems, with filtration exceeding minimum ASHRAE standards in gasketed, airtight frames, have a significant safety buffer in filtering *Aspergillus* spores and other fungi and particles. HEPA filtered air systems would likely provide an even greater buffer given the increased filtering efficiency.

Finally, our results indicate that monitoring for particles can give a useful qualitative assessment of likely fungal presence. Particles measured in this study were between 0.1 and 10 µm in aerodynamic or spherical diameter. Because *Aspergillus* conidia are 2.5 to 6 µm in diameter, they fall into the range of the measured particles and it can thus be hypothesized that they are part of the particle mass being measured by the monitors. Our results suggest that monitoring particle mass concentration may serve as a practical surrogate for fungal spores. *Aspergillus* counts did increase at both outdoor sites where there was an increase in particle counts and, further, no increase in *Aspergillus* was seen at the outdoor site where particle counts did not rise. Particle counters have the advantage of being easier and less expensive to operate than air culture devices. Further, they provide real-time data, unlike *Aspergillus* measurements, which require several days for growth and analysis. We suggest that particle counts may prove an effective way of monitoring the impact of events such as implosions on sensitive environments such as hospitals, and believe that this should be an area of future study.

There is now a growing awareness of the role environmental factors play in the safety of hospitalized patients. This is evidenced by the fact that the Centers for Disease

Control and Prevention is developing new guidelines for environmental monitoring and control and the fact that the Joint Commission on Accreditation of Healthcare Organizations has taken a regulatory interest in how the hospital environment affects patient safety. Building demolition and construction remain necessary activities both in and around hospitals and provide examples of external events that can significantly impact the hospital environment. Infection control practitioners and engineers must therefore work together to minimize the impact these projects will have on at-risk patient populations. Although this study was conducted in the setting of an implosion, we believe our results may be more broadly applicable. Our data indicate that monitoring of dust clouds along with careful preparation of hospitals may prove an effective way of managing large and small demolition projects near hospitals and that monitoring particle counts may be a useful alternative to *Aspergillus* air cultures.

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