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Major Article

Could we predict airborne *Aspergillus* contamination during construction work?

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Background: *Aspergillus fumigatus* is a major opportunistic pathogen causing nosocomial infection. Hospital outbreaks of invasive aspergillosis have been associated with demolition and building construction. This study was designed to examine the impact of meteorologic factors and different periods of work on outdoor fungal airborne concentrations.
Methods: The study was conducted at Necker Enfants Malades Hospital, a 650-bed teaching care hospital recently involved in a large construction program, including renovation, construction, and demolition. During the work phases, prospective external air samplings were performed 3 times a week, and meteorologic parameters were collected every day.
Results: Two hundred and one samples were collected. *Aspergillus* spp were found in 80.1% of samples, with a median concentration of 16 colony forming units (CFU)/m^3. A significant increase in the colony count of molds occurred after demolition. In the multivariate analysis, factors associated with overall fungi concentration were the type of work construction and temperature. Elevated *Aspergillus* spp concentrations (>20 CFU/m^3) were associated with higher temperature.
Conclusions: Our findings underline the importance of environmental surveillance. According to our results we suggest that demolition work should be performed during the winter and fall seasons.

Building work activities and specifically demolition[1] cause serious dust contamination. Several work-related aspergillosis outbreaks have been described in the literature.[2] During construction, indoor and outdoor fungal contamination seem to be correlated.[3] Despite conflicting data, there are some arguments to suggest that climatic conditions influence airborne fungal contamination.[4] For some authors, the fall season was associated with lower quantities of fungi,[5] whereas for others there is a correlation between the relative humidity and the external conidia in the air. Insufficient data are available concerning fungal airborne contamination according to type of building work and climatic conditions.

The aim of this study was to evaluate the impact of the different steps of building work on the outdoor fungal contamination in hospital areas, according to weather conditions.

MATERIALS AND METHODS

During a large construction program in our hospital, total airborne viable fungal counts were determined 3 times a week over

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a 2-year period using the Air Ideal 90 mm biocollector (bioMérieux, Marcy l'Etoile, France). Air samples were collected at approximately 1.5 m above the ground at 11 AM by aspiration with the Air Ideal biocollector according to the impaction principle recommended by the International Organization for Standardization Draft International Standard 14698-1. The Sabouraud chloramphenicol plates were incubated at 30°C. Fungi were identified at the genus level. Quantitative results were provided in terms of the number of colony forming units (CFU) per cubic meter of air.

Meteorologic data were prospectively collected every day. The mean daily temperature, humidity, maximum wind speed, and rainfall were obtained from the French National Institute of Meteorology. The seasons were arbitrarily defined as cloudy (November-April) and sunlight (May-October).

Work construction was characterized by area, type (we arbitrarily divided work construction in 2 different situations: demolition and building), and geographic zone.

Overall fungi concentrations were log-transformed for analyses to obtain a normal distribution, assessed by a Shapiro-Wilk test of normality ($P = .1856$). The positive rate for *Aspergillus* culture was defined as >20 CFU/m^3.[6] Quantitative data (log-concentration of overall fungi cultures, temperature, wind speed, and area of work construction) were summarized as medians. Bivariate (positive *Aspergillus* culture, seasonal period, rainfall, and type of work construction) and categorical data (zones of work construction) were summarized as numbers and percentages. Analytical analysis was performed with linear regression models for overall fungi concentration (log-transformed) and logistic regression models for positive *Aspergillus* culture (defined as >20 CFU/m^3) to identify associated covariates. Univariate analyses were presented with regression coefficients. All of the variables, except zone of work, because it was correlated to the variable entitled area, were included in an initial multivariate model and a stepwise backward procedure, based on the Akaike information criterion, allowing the identification of the most parsimonious model that best fitted the data. All tests were bilateral, and type I risk (α) was fixed at 0.05. All statistical analyses were computed with R software version 3.2.2 (R. Statistics software, Vienna, Switzerland).

RESULTS

During the surveillance period, a total of 201 outdoor air samples were collected: 94 (46.8%) during the demolition, and 107 (53.2%) during the building (Table 1). All of the air samples yielded positive fungal cultures, and the median concentration of overall viable fungi was 104 CFU/m^3 (interquartile range [IQR], 52-188). *Aspergillus* spp grew from 80.1% (n = 161) of the air samples. The median concentration of *Aspergillus* spp was 16 CFU/m^3 (IQR, 4-28), with 54 samples (26.9%) having a concentration >20 CFU/m^3.

The median temperature was 11.9°C (IQR, 8.5-15.5), and there was rainfall in 65% (n = 128) of the observations. The average wind speed was 9 km/h (IQR, 6-11). Variables significantly associated with overall fungi and *Aspergillus* concentrations are reported in Table 2. In summary, there was no evidence of association between elevated *Aspergillus* spp concentration and type of work construction. Factors associated with overall fungi concentrations were the season (lower fungi concentration for the samples collected in cloudy compared with sunlight periods), temperature (higher temperature is associated with higher overall fungi concentration), and work construction characteristics: zone of active work construction, area of site construction (greater the surface area, the higher the fungi concentration raised), and type of work construction (demolition was more associated with high fungi concentration than building work). Elevated *Aspergillus* spp concentration was associated with season and higher temperature. The multivariate model hold meteorologic characteristics, but only temperature stilled remained significantly associated with positive culture of *Aspergillus* spp.

Table 1
Description of reported data, Paris area (France), between 2009 and 2010

Variables	Samples (N = 201)	Demolition sample (n = 94)	Building samples (n = 107)
Work constructions characteristics			
Area (per 1,000 m^2)	2.95 (0.4-5.73)	2.95 (0.4-5.73)	2.95 (0.4-7.45)
Zone of work construction*			
A	18 (9)	18 (19.1)	0 (0)
C	21 (10.4)	9 (9.6)	12 (11.2)
B	110 (54.7)	52 (55.3)	58 (54.2)
D	52 (25.9)	15 (16.0)	37 (34.6)
Type of work construction during sampling			
Demolition	94 (46.8)		
Building	107 (53.2)		
Culture characteristics			
Overall fungi			
Samples with positive culture	201 (100)	94 (100)	107 (100)
CFU/m^3 per sample	104 (52-188)	144 (100-224)	68 (38-122)
Aspergillus spp			
Samples with positive culture of *Aspergillus**	161 (80.1)	80 (85.1)	81 (75.7)
Median CFU/m^3†	16 (4-28)	16 (4-28)	8 (4-20)
Samples with >20 CFU/m^3	54 (26.9)	30 (31.9)	24 (22.4)
Meteorologic characteristics			
Seasonal observation			
Cloudy season	95 (47.3)	35 (37.2)	60 (56.1)
Sunlight season	106 (52.7)	59 (62.8)	47 (43.9)
Temperature median (°C)	11.9 (8.5-15.5)	14 (9.9-16.5)	10.2 (7.3-13.9)
Wind speed median (km/h)	9 (6-11)	9 (6-13)	7 (6-11)
Rainfall	128 (65)	56 (59.6)	72 (67.3)

Values are n (%) or median (interquartile range).
CFU, colony forming units; *Zone A*, 400 m^2 site where the work construction was demolition; *Zone B*, area divided into 2 pieces (300 and 13,300 m^2) where both types of work construction were performed simultaneously and then building alone occurred during the last 8 months of observation; *Zone C*, area sized 400 m^2 where demolition occurred for 6 months and building for 13 months; *Zone D*, area sized 5,500-5,800 m^2 where demolition occured for 2.5 months and building for 10 months.
**Aspergillus* identified at ≥1 CFU/m^3.
†Positive culture of *Aspergillus* spp.

Table 2
Associations between covariates and logarithmic concentrations of total fungi and *Aspergillus* spp cultures (CFU >20 m^3), univariate and adjusted regression coefficients, Paris area (France) between 2009 and 2010

	Total fungi (n = 201)				Total *Aspergillus* (n = 201)			
	Univariate		Adjusted*		Univariate		Adjusted*	
Variables	β (σ)	*P* value	β (σ)	*P* value	β (σ)	*P* value	β (σ)	*P* value
Season								
Cloudy vs sunlight	–0.78 (0.13)	<.001	—	—	–0.68 (0.33)	.039		
Temperature	0.09 (0.01)	<.001	0.07 (0.01)	<.001	0.08 (0.03)	.019	0.08 (0.04)	.036
Wind speed	0.02 (0.02)	.215	0.03 (0.02)	.093	0.03 (0.04)	.339		
Rainfall	–0.02 (0.15)	.898	—	—	–0.51 (0.34)	.125	–0.58 (0.35)	.106
Area (per 1,000 m^2)	–0.046 (0.012)	.898	–0.019 (0.011)	.0866	0.01 (0.01)	.176		
Type of work construction								
Demolition vs building	0.81 (0.13)	<.001	0.53 (0.13)	<.001	0.48 (0.32)	.132		
Zone of work construction†								
B vs A	–0.5 (0.24)	<.001	—		0.27 (0.61)	.601		
C vs A	0.26 (0.3)		—		0.77 (0.72)			
D vs A	–0.74 (0.25)		—		0.05 (0.66)			

CFU, colony forming units; *Zone A*, 400 m^2 site where the work construction was demolition; *Zone B*, area divided into 2 pieces (300 and 13,300 m^2) where both types of work construction were performed simultaneously and then building alone occurred during the last 8 months of observation; *Zone C*, area sized 400 m^2 where demolition occurred for 6 months and building for 13 months; *Zone D*, area sized 5,500-5,800 m^2 where demolition occured for 2.5 months and building for 10 months.
*Coefficient of a linear regression for fungi and logistic regression for *Aspergillus* (β, and its SD σ). For a β significantly different from 0, the corresponding *P* value must be <.05, and β > 0 indicates a positive association.
†This variable was not included in the multivariate analysis.

DISCUSSION

Surprisingly, in our study, meteorologic conditions and specifically temperature were the only factors associated with outdoor *Aspergillus* spp positive cultures. These results contrast with other studies in which a dramatic increase in *Aspergillus* spp counts during building activities was observed.[7]

Several studies suggest an increase in *Aspergillus* concentrations during construction work,[2] and demolition appears at higher risk.[8] However, authors also suggest the highest fungal concentrations appear in the summer and fall because abundant dead plant materials, suitable temperature, and relative humidity lead to high fungal concentrations.

Non-*Aspergillus* fungi were the most frequent isolated mold during work construction[1]; however, we were surprised by the high *Aspergillus* airborne concentrations during our survey. Indeed, >75% of samples grew with at least 1 *Aspergillus* CFU/m^3, and in 27% of cases the *Aspergillus* concentration was >20 CFU/m^3. These results are significantly above the known levels associated with the higher risk of infection. Despite the absence of consensus concerning the conidial density and onset of invasive aspergillosis, some authors suggested a higher risk when the average fungal density inside the hospital was 0.9 CFU/m^3,[9] whereas others suggested a marked decrease of infections when the density fell from 2 to <0.2 CFU/m^3.[10]

Our study should be interpreted with caution because it is monocentric and has a small number of samples collected. Moreover, timing and location of samples and other factors, such as car traffic, could have influenced these results.

According to our results, we suggest that from an infection control point of view, demolition work should be performed during the winter and fall seasons. However, more data are needed to confirm these findings.

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