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Indicators of airborne fungal concentrations in urban homes: Understanding the conditions that affect indoor fungal exposures

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HIGHLIGHTS

- We measured indoor airborne fungal types and levels in urban Syracuse, NY homes.
- We developed models predicting fungal exposure from home characteristics.
- High fungal levels were related to visible mold, musty odors and cockroaches.
- High fungal levels were also related to outdoor concentrations.
- Snow cover increased indoor/outdoor fungal ratios.

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ABSTRACT

Indoor fungal exposure can compromise respiratory health. Low-income urban areas are of concern because of high asthma and allergy rates and housing disrepair. Understanding the conditions that affect indoor fungal exposures is important for assessing health risks and for developing mitigation strategies. We examined the types and concentrations of airborne fungi inside and outside of homes in low-income areas of Syracuse, NY as well as the effect of snow cover on fungal levels. At 103 homes, air samples for viable fungi were collected, occupants were interviewed and homes were inspected for visible mold, musty odors, water problems and other factors. Multivariable logistic regression was used to relate high fungal levels to home conditions. Predominant indoor fungi included *Cladosporium*, *Penicillium*, *Aspergillus*, *Alternaria* and hyaline unknowns. Basidiomycetes and an uncommon genus *Acrodontium* were also found frequently due to analysis methods developed for this project. With snow cover, outdoor total fungal levels were depressed and indoor concentrations were three times higher than outdoor on average with a maximum of 29 times higher. Visible mold was related to elevated levels of *Penicillium* (OR 4.11 95% CI 1.37–14.0) and bacteria (OR 3.79 95% CI 1.41–11.2). Musty, moldy odors were associated with elevated concentrations of total fungi (OR 3.48 95% CI 1.13–11.6) and basidiomycetes. Cockroaches, an indicator of moisture, were associated with elevated levels of *Penicillium* (OR 3.66 95% CI 1.16–13.1) and *Aspergillus* (OR 4.36 95% CI 1.60–13.4). Increasing relative humidity was associated with higher concentrations of *Penicillium*, yeasts and basidiomycetes. Visible mold, musty odors, indoor humidity and cockroaches are modifiable factors that were important determinants of indoor fungal exposures. Indoor air investigators should interpret indoor:outdoor fungal ratios cautiously when snow cover is present.

1. Introduction

The increased prevalence of childhood asthma and allergies has focused attention on the exposure of young children to dampness and mold in homes. Low-income, urban areas are of particular concern because childhood asthma and allergy rates are higher there and respiratory problems may be more severe (Aligne et al., 2000; Gold and Wright, 2005). In addition, low-income housing is often of poor quality

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and deteriorated, presenting conditions that are conducive to pest infestations and fungal growth (Breysse et al., 2005; Rauh et al., 2002). Mold and dampness are common problems in the United States affecting an estimated 10–50% of all homes (Mudarri and Fisk, 2007; U.S. Census Bureau, 2011). Reviews of the worldwide literature have concluded that exposure to damp and moldy indoor environments is associated with health problems such as wheeze, cough, upper respiratory symptoms and asthma (Bornehag et al., 2001; Institute of Medicine, 2004; Mendell et al., 2011). Although dampness and mold are common and known to be related to adverse respiratory health effects, far less is known about the specific agents responsible for causing these problems (World Health Organization Europe, 2009). Quantitative measurements of fungi and other microbiological factors would seem to be of obvious importance for identifying causative agents; however, results have been inconsistent. Measured concentrations of specific fungal taxa (Gent et al., 2012; Pongracic et al., 2010; Reponen et al., 2012; Salo et al., 2006; Stark et al., 2005), fungal indicators and other microbiological factors (Celedon et al., 2007; Dales et al., 2006; Gillespie et al., 2006) have been linked to an increased risk of respiratory symptoms or other health effects. At the same time, inverse associations have been reported, suggesting a protective role for some of these factors (Behbod et al., 2015; Douwes et al., 2006; Karvonen et al., 2012; Sordillo et al., 2010). Given this uncertainty, further work is warranted.

Many epidemiology studies have measured exposure to dampness and mold using indirect methods such as questioning occupants or by an inspector's observation of home conditions e.g. (Antova et al., 2008; Fisk et al., 2007; Gunnbjornsdottir et al., 2006; Simoni et al., 2005; Zock et al., 2002). Because fungal growth requires moisture, conditions such as leaking water, damp stains, excessive condensation, and high indoor humidity have potential to support fungal growth and contribute to airborne fungal exposures. Similarly, observations like visible mold and musty smells suggest a clear potential for airborne fungal exposures. The presence of carpeting may act as a potential source for indoor microbial exposure, where soil and plant debris tracked in from outdoors could accumulate and allow microbial growth and spore release from carpets (Bischof et al., 2002; Dharmage et al., 1999). Alternatively, carpets may act as potential sinks that trap and curb fungal growth and dispersal. Cats or dogs in the home can potentially transport fungi from outdoor soil and plant debris (Chew et al., 2003). Cat litter boxes have also been hypothesized as sources of moisture capable of supporting fungal growth (O'Connor et al., 2004). The observation of cockroaches may suggest that water and moisture sources are present and sufficient to support infestation (Portnoy et al., 2013). Home crowding and lack of ventilation can contribute to condensation problems. Poor upkeep, rodent infestation, and lack of sanitation each may suggest some potential for fungal growth and exposure in the home.

However, conditions that potentially contribute to exposure are not the same as actual exposure. The observation of water damaged materials or musty odor is not necessarily indicative of the presence of unusually high levels of fungal spores. Water damaged materials that have dried may not be supporting the current microbial growth. Musty odors are due to volatile organic compounds which can originate from sources other than fungi such as carpeting and furnishings (Kim et al., 2007) as well as from animals, both pets and pests. Measuring the types and concentrations of airborne fungi provides a means of assessing exposure more directly than through visual observation alone. As the relationships between fungal exposures and health effects continue to emerge, it is important to understand the home characteristics and conditions that give rise to these exposures, Understanding the conditions that predict indoor airborne fungi is important for developing effective interventions for controlling fungal exposure. Because the distribution of fungal types and levels varies by geographic location and climate, multi-year and seasonal information for a specific area provides valuable baseline and comparative data for public health and indoor air quality investigators in that region.

Direct measurements of fungi have several limitations that must be taken into account. Because fungi are naturally present in outdoor and indoor air in virtually all environments, there are no guidelines for typical or safe exposure levels. Outdoor airborne fungal spores readily infiltrate indoor spaces through windows, doors, ventilation systems and other openings in the building envelope so that interpretation of indoor air sampling results requires some consideration of the corresponding outdoor fungi (Dillon et al., 1996). Seasonal differences may also be important, with greater microbiological activity and higher fungal levels expected during warm weather. In cold climates, fungal concentrations can be affected by the presence of snow cover which may depress spore release by blanketing soil and plant matter (Li and Kendrick, 1995; Macher, 1999; Reponen et al., 1992). The choice of air sampling method influences exposure estimates because there is no single method that can comprehensively characterize airborne fungi. Non-viable, spore trapping methods facilitate recovery of spores, however many spores cannot be identified by direct microscopy. Culture-based methods facilitate the identification of spores but underestimate total spore levels because only spores that are viable and that grow on the chosen culture medium are counted (Dillon et al., 1999). The expertise of laboratory personnel also affects identification of spores. Air samples may not be representative of exposure because of the short sampling periods required to avoid over-loading sampling media. Finally, a lack of standardized methods for sample collection, analysis and reporting hinders comparisons between studies. Nonetheless, when these concerns are addressed in an epidemiology study, air sampling for fungi can contribute to greater understanding of the specific agents and exposures in indoor environments and their relationship to residential conditions.

In a previous study, we determined that exposure to high levels of indoor *Penicillium* was significantly associated with wheezing episodes among infants living in low-income urban homes in Syracuse, NY (Rosenbaum et al., 2010). In this study, we report further on the types and concentrations of fungi in the indoor and outdoor air. We examined the relationship between measured levels of indoor airborne fungi and home conditions and developed models predicting fungal exposure from these home conditions while considering important sources of variability. Frequent snowfall in this region allowed us to assess the effect of snow cover on indoor and outdoor fungal concentrations. We report on indoor to outdoor fungal ratios with snowfall because indoor air practitioners frequently use such ratios to assess building mold problems. This subject is not well documented in the literature and has not focused on temperate climates with episodic snowfall.

2. Methods

2.1. Project and cohort description

This project was part of a larger birth cohort study designed to examine the relationship between indoor environmental pollutants and infant wheezing in a low-income, urban setting. The AUDIT study (Assessment of Urban Dwellings for Indoor Toxics) was approved by the institutional review board of the State University of New York Upstate Medical University and all participants provided written informed consent. Full details of the methods and issues involved in implementing the study have been published previously (Crawford et al., 2006). In summary, 103 pregnant women with asthma from the low-income, obstetric population of Syracuse were recruited into the study. Eligibility criteria included residence in the city of Syracuse or adjacent metropolitan location, proficiency in English or Spanish, and anticipated residence in the home for one year from the start of the study. All 103 homes were visited approximately three months after the infant's birth in order to obtain environmental samples, conduct inspections and interview occupants. Forty-three occupants were willing to have a second home visit. Second visits were intended to assess