

A procedure for evaluation of the indoor environment

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(Received 8 October 1999; accepted in final form 9 February 2000)

Key words: aerobiology, environmental assessment, fungus, indoor environment

Abstract

Exposure to substances found in the indoor environment is known to trigger respiratory illnesses such as asthma. Despite this knowledge, information on how to identify and remove these exposures is scarce. To address this issue, we describe a program of environmental assessment developed at Children's Mercy Hospital in Kansas City, Missouri. We evaluated buildings using a standardized assessment protocol. This protocol included a combination of background information, visual inspection, volumetric air sampling, bulk sampling of suspicious areas, antigen measurement of housedust, and general measurements of the indoor climate. We inspected a total of 63 buildings including 49 single unit structures, 4 apartments, 4 town homes, 3 schools, 2 office buildings, and 1 mobile home. Most of these locations were identified because of respiratory ailments reported by the occupants. A screening questionnaire revealed factors that are known to be associated with fungal contamination such as leaks or flooding in 78% of the buildings. Visual inspection confirmed these sources of contamination in the majority of structures. Volumetric air sampling identified a high proportion of buildings with airborne *Aspergillus/Penicillium* species. *Stachybotrys* was found in nearly 30% of these structures both in air and on surface samples, and surprisingly, *Stachybotrys* spores were found only in air in nearly 20%. Climactic factors were only weakly associated with fungal contamination.

The homes of patients with respiratory diseases often have significant fungal contamination that can be identified with a questionnaire. Using this standardized approach, factors associated with respiratory illnesses, usually fungal contamination, frequently can be identified. Whether removal of the offending exposure will lead to improve health remains to be determined.

Abbreviations: HVAC – heating, ventilation and air conditioning; IAQ – Indoor Air Quality

Introduction

The incidence and prevalence of asthma has been increasing worldwide for the last several decades. This increase has occurred despite an overall improvement in outdoor air quality in many countries (Call et al., 1994; Platts-Mills, 1990; Platts-Mills et al., 1991). This has lead to a suspicion that indoor environments either through changes or increased exposure may contribute to this asthma epidemic (Platts-Mills, 1994). Americans for example spend a large amount of time in the indoor environment (Services, 1990). The home has been shown to be a major reservoir for indoor allergens (Gelber et al., 1993).

The standard method for evaluation of people with suspected environmentally triggered illness starts with identification of symptoms that are associated with exposures in their environment. This is typically done with simple questioning (Corey, 1994). Confirmation of allergic sensitivities can be confirmed with either skin tests or in-vitro tests of allergen specific IgE. Once relevant exposures are identified, their removal should result in diminished symptoms, though this has been difficult to consistently demonstrate in clinical studies.

The greatest deficiency in this model is a lack of information regarding which indoor exposures are causally related to illness. Consistent protocols for

their identification are not available in the medical literature. Without such standardization, it is impossible to compare results from one investigator to another in a meaningful and interpretable manner. In order to address this issue, we have developed a standardized approach for indoor environmental assessment and have used it to inspect 64 homes occupied by asthmatic patients. The results of these evaluations are described below.

Materials and methods

Subjects for indoor environmental testing were identified either from a population of asthmatic children seen in a pediatric allergy clinic, referrals by private allergists, or private, commercial, and/or government building managers who suspected that people were experiencing environmental illness. Our pediatric institutional review board exempted this study because it is the houses and not the humans who are the subject of investigation. The environmental assessment protocol consisted of six components: a questionnaire, visual inspection for evidence of contamination, volumetric air sampling, sampling of surfaces suspected of being contaminated, antigen measurement in samples of house dust, and evaluation of overall air quality.

Questionnaire

The questionnaire was designed to obtain background information. A wide variety of questions were selected to obtain a description of the age and type of building, unusual history or environmental characteristics and age and type of Heating, Ventilation, and Air Conditioning (HVAC) system. The questions also asked about individual symptoms of persons living in the home as well as their habits, occupations and hobbies. Questions about environmental triggers known to the occupants as well as a general medical history were also included. The questionnaire also contained elements that could be used by the home inspector to locate sources of contamination. These include inquiries related to visible mold, the location of musty smells, prior water damage (leaks, floods, rain), abnormal staining, condensation on walls or windows, standing water, location of crawl space or basement, wet carpet, indoor plants, humidifier use, air conditioner use, an indoor hot tub and the placement and use of exhaust fans. We included a number

of redundant questions so that a factor analysis could determine which are most predictive of environmental contamination.

Symptom scores were calculated from the questionnaire based on reported frequency of health complaints such as cough, sneeze, asthma, rash, irritated eyes, stomach problems, central nervous system problems or fatigue. These symptom scores were measured using a 4-point scale ('never' = 0 to 'all the time' = 4). A composite score was generated by summing the individual scores. We compared that score to objective findings identified during the course of the inspection.

Volumetric air samples

Volumetric air samples can be collected either with a cascade impactor such as an Anderson sampler that detects viable spores, or with a suction trap that causes particles to impact onto an adhesive-coated glass microscope slide. We chose to use a Sampler MK3 (Allergenco, San Antonio, Texas, USA) because it is quicker than culture methods, less expensive, and the problem of overrepresentation of some spores due to overgrowth is avoided. We set the device to collect 10 minutes samples with a flow of 15 liters per minute and generally tested the patient's bedroom, the television room, the basement or crawl space and anywhere that known water damage was present. An outdoor sample was also obtained to determine the indoor to outdoor spore ratio in order to identify infiltration as opposed to indoor sources of contamination. Once the samples were obtained, slides were fixed and stained with Calberlas stain in glycerin jelly (Cage et al., 1996). The slides were read at 100X for general spore content and then counted and identified at 1000X using techniques described previously (Haines et al., 1999).

Surface samples

Areas with suspected contamination were sampled using transparent tape. The sticky side of a piece of tape was gently pressed onto any suspicious area and was subsequently mounted onto microscope slides sticky side down using Calberlas stain in glycerin jelly. These surface samples were graded using a semiquantitative scale for each type of spore identified (no = 0, rare = 1, few = 2, many = 3, loaded = 4). Epithelial cells and bacteria quantities were also estimated and recorded.

Measurement of house dust allergens

Dust samples were obtained using either a Dirt Devil portable cleaner with high-efficiency bags, or with freshly obtained dust using the subject's own vacuum cleaner and a new bag. These samples were next sifted through a 50 mesh brass screen (Thomas Scientific, Swedesboro, New Jersey, USA) to remove gross debris, weighed, and then extracted with distilled water using previously reported methods. (Portnoy et al., 1998) Allergen concentrations were measured using immunoassays based on rabbit polyclonal sera directed towards *Alternaria*, *Cladosporium*, *Penicillium*, *Aspergillus*, dog, cat, dust mite and cockroach (Barnes et al., 1999). Monoclonal antibody-based assays were also done for two dust mite allergens Der f1 and Der p1 (Indoor Biotechnologies, Charlottesville, VA, USA), and two *Alternaria* allergens Alt a1 and GP70 (Portnoy, 1998; Portnoy, 1993).

Indoor Air Quality (IAQ) evaluation

Indoor air quality was assessed by measuring carbon dioxide, temperature and relative humidity using a Q-Trak hand held meter (TSI Inc. St. Paul MN, USA). Carbon monoxide was measured with an AIM Gas Detector meter (Aim Safety Co., Ottawa, Canada).

Results

We performed environmental inspections on 63 buildings and obtained completed questionnaires on 49 of them. The structures represent residences and commercial buildings from all parts of the metropolitan area and the occupants are from a range of socioeconomic backgrounds. The distribution of locations included: 38% suburban, 22% inner city, 19% neighboring town, 13% commercial, and 8% rural. Single unit residences accounted for 49 of the buildings, multiunit residences for 8, and the others included 3 schools, 2 office buildings, and 1 mobile home. Most of the buildings had central air conditioning and central gas heat.

Building-related questions dealing with past moisture problems were the most useful and relevant to identifying problem areas. The questionnaire identified moisture problems in all but 22% of the buildings. These problems included a history of major leaks in 60%, wet basement in 38%, wet carpet in 24% and the presence of a crawl space in 23%. Crawl spaces were found to be a source of mold exposure as several

homes had crawl spaces attached and open to the basement foundation under part of the home. This seemed to allow microbial contaminants easier access to the interior of the home.

Medical problems reported by building occupants included upper and/or lower respiratory complaints in 95%, eye symptoms in 75%, skin problems in 63%, and gastrointestinal problems in 56%. A substantial number of the occupants (63%) also had central nervous system complaints including a high frequency of fatigue in 58%. The questions with the greatest correlation with high spore counts included the presence of a musty smell ($r = 0.467$) and a history of a major leak in the structure ($r = 0.404$).

Visual inspection uncovered evidence of fungal contamination in the majority of houses. The most common observations included stains around light fixtures, fungal growth on walls along the exterior perimeter of the buildings, particularly near windows where flashing had been installed improperly, and evidence of previous flooding or leaks. Musty smells were commonly noted, though the occupants of the residences rarely were aware of them. Other observations included the presence of boxes that had become wet, piles of laundry that had been sitting for lengthy period of time, and general debris that indicated a lack of proper house cleaning. In several cases, carpeting was noted to have become discolored by massive infiltration of fungal mycelia.

Air samples were collected in rooms where the initial inspection suggested the presence of contamination. The most common spores identified were *Penicillium/Aspergillus* species followed by *Cladosporium* (Table 1). Interestingly, counts tended to be quite elevated when *Penicillium/Aspergillus* spores were identified as was also true for *Stachybotrys*, which was found in 25% of the homes tested. We don't know whether this is due to the presence of *Stachybotrys* or whether the presence of this fungus is a marker for a grossly contaminated building. The highest spore counts were found in laundry rooms followed by bathrooms and basements – both finished and unfinished (Table 2). Bedrooms tended to have intermediate counts while kitchens and TV/family rooms had the lowest counts.

When identified, *Stachybotrys* was found on dry-wall material in 52% of samples, wood, carpet, and cardboard boxes in 15%, and wood paneling in 5%. In buildings that were contaminated with *Stachybotrys*, spores were found in air and on surfaces in 53%, airborne in 16%, and on surfaces only in 31%.

Table 1. Percent of rooms in which fungal genera are found and mean spore counts in those rooms

Spore	Percent of rooms tested	Mean spore count (spores/cubic Meter)
Pcn/Asp	97%	5,384
<i>Cladosporium</i>	86%	694
Ascospores	57%	511
<i>Alternaria</i>	46%	318
<i>Periconia</i>	38%	186
<i>Stachybotrys</i>	27%	1,322
Mycelia	22%	326
Basidiospore	14%	510
<i>Chaetonium</i>	11%	147
Smut	5%	462
<i>Torula</i>	3%	168
<i>Sordoria</i>	3%	84
Rust	3%	84

Table 2. Mean spore counts for different types of rooms

Room use	Mean spore count (spores per cubic meter)
Laundry	11,424
Bathroom	8,540
Basement – Unfinished	6,694
Basement – Finished	5,544
Bedroom, Sibling	5,208
Bedroom, Master	5,003
Closet	4,452
Bedroom, Patient	4,284
Attic	2,856
Living Room	2,814
Kitchen	2,672
Family/TV Room	2,167

We next examined total symptom scores and spore counts comparing homes with counts less than 4,500 spores per cubic meter with those having counts greater than 4,500. In addition, homes with *Stachybotrys* were considered separately (Table 3). Homes with elevated counts were associated with slightly higher but insignificant symptom scores than the homes without such counts. Additionally, homes with *Stachybotrys* were found to be associated with even higher symptom scores than those that did not have *Stachybotrys*.

Antigen levels in house dust are shown in Table 4. The most prevalent antigen, cat, was found in 92% of

Table 3. Mean symptom score for homes with low or high spore counts and with *Stachybotrys*

Type of home	Mean symptom score	Spore count (spores per cubic meter)
Homes without mold	37.1	4,251
Homes with mold	38.7	84,143
Homes with <i>Stachybotrys</i>	48.2	116,168

Table 4. Number of dust samples with detectable amounts of 10 different antigens. GP70 and Alt a1 are allergens found in *Alternaria*, Der f1 and Der p1 are allergens found in dust mite. These four allergens are measured with monoclonal antibody-based assays. The others are measured with rabbit polyclonal-based assays

Antigen	Present	Percent	Total samples
<i>Aspergillus</i>	9	37%	24
<i>Penicillium</i>	6	26%	23
<i>Cladosporium</i>	20	87%	23
Cockroach	9	41%	22
Cat	22	92%	24
Dog	12	54%	22
GP70	15	68%	22
Alt a1	16	73%	22
Der f1	18	82%	22
Der p1	10	45%	22

homes followed by *Cladosporium*, which was found in 87% of homes. *Alternaria* allergens were detectable in about 70% of houses while Der f1 was found in 82%. Interestingly, Der p1 was only found 45% of the time. Kansas City homes have cockroach antigen only about 41% of the time.

Overall air quality was tested by measuring carbon dioxide as a surrogate for ventilation, temperature, and relative humidity. Most homes had CO₂ levels that were below the 1000 ppm that is considered healthy. We did find extremely elevated CO₂ concentrations in classrooms in a school suggesting a deficiency in ventilation for the number of students that are present in the classroom. This may account for some of the symptoms of headache and fatigue that students were complaining of. Temperature did show a direct correlation with spore counts while humidity did not. Carbon monoxide was not found in any of these buildings.

Discussion

The association between human illness and environmental exposure has been a subject of intense investigation (Wood, 1986). Initially, these investigations focused on the outdoor environment in the form of pollen and mold counts. More recently, concern has shifted to exposure in indoor environments. The primary limitation has been a lack of standardized and consistent protocols for indoor inspection. As a result, many surveys use ad hoc methods that are inadequate for comparison with other studies. In this report, we have attempted to develop a standardized protocol that can be applied to buildings with suspected environmental problems.

We chose to inspect these buildings because either a physician or the occupants themselves suspected that their home environment was causing health problems. Most of the surveys were done on single-family homes in the inner city or surrounding suburbs of Kansas City, Missouri so that a range of socioeconomic and ethnic groups were represented.

Our main finding was that we were able to identify a potential source of indoor contamination in up to 80% of homes. The most common problem in homes turned out to be fungal contamination, either due to poor maintenance of older structures, or due to improper construction techniques. The former presents a substantial challenge when remediation is attempted while the latter frequently can be repaired.

Our identification of *Stachybotrys* in 25% of homes may be significant since other investigators have linked this fungus to respiratory problems (Johanning et al., 1999). In addition, *Stachybotrys* has been reported to be highly uncommon in building surveys, however, this may be an artifact of the sampling technique. Since *Stachybotrys* requires high water content, it tends to grow on water-damaged wallboard. This would explain why we were able to detect the fungus in so many of the structures.

Symptom scores indicated that inhabitants of homes contaminated with *Stachybotrys* generally had poorer health than the inhabitants of homes with no appreciable fungal presence, though this may be due to the generally increased fungal contamination of those buildings. Since the typical circumstances leading to *Stachybotrys* contamination involved a chronic water or dampness problem that was in contact with a cellulose based media, most fungi are able thrive in those same locations.

The specific allergen measurements in Table 4 confirm what allergists have reported many other times before. Cat allergen is the most universal of the currently measured allergenic proteins (Enberg et al., 1993). Ninety-one percent of the locations tested contained measurable amounts of this allergen. *Cladosporium* was the most frequently found fungal-derived antigen with 87% of tested homes containing measurable levels of this antigen. This is not surprising because *Cladosporium* is one of the most abundant fungi found in both indoor and outdoor air collections (Frost, 1988; Tarlo et al., 1988; Cosentino et al., 1990). Likewise, even though *Alternaria* is usually considered an outdoor fungus we were not surprised to find it in indoor environments in significant quantities, as it is a major sensitizing agent (Fadel et al., 1992).

The results of this type of inspection may be of immense value when the homeowner is trying to determine what to do to improve their environment. Its main limitations are that we still haven't proven a causal relationship between identified exposures and illness. Such proof would require a double-blinded, placebo remediation controlled study specifically designed to evaluate the health outcomes of such interventions. Hopefully, as improved methods for inspecting homes are developed, such studies will be forthcoming.

Conclusions

We conclude that homes of patients suffering from respiratory disease often have significant fungal contamination. This contamination can take many forms but it is usually associated with water damage. Additionally we conclude that the toxigenic fungus, *Stachybotrys*, is often associated with indoor environments where respiratory related environmental disease is found. It appears that fungal antigens are present in house dust as frequently as other commonly known indoor allergens such as cat and dust mite (Henderson and Beck, 1994; Enberg et al., 1993). Standardized inspection protocols such as this one will hopefully improve our understanding of the indoor environment, how it affects human health, and they may eventually lead to procedures for improving the quality of the air we breathe.

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