Mold Exposure and Health Effects Following Hurricanes Katrina and Rita

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Abstract

The extensive flooding in the aftermath of Hurricanes Katrina and Rita created conditions ideal for indoor mold growth, raising concerns about the possible adverse health effects associated with indoor mold exposure. Studies evaluating the levels of indoor and outdoor molds in the months following the hurricanes found high levels of mold growth. Homes with greater flood damage, especially those with >3 feet of indoor flooding, demonstrated higher levels of mold growth compared with homes with little or no flooding. Water intrusion due to roof damage was also associated with mold growth. However, no increase in the occurrence of adverse health outcomes has been observed in published reports to date. This article considers reasons why studies of mold exposure after the hurricane do not show a greater health impact.

BACKGROUND

LDHH: Louisiana Department of Health and Hospitals

The central U.S. Gulf Coast region received a one-two punch when Hurricanes Katrina and Rita ripped through the coast on August 29, 2005, and September 24, 2005, respectively (15, 32, 33). Hurricane Katrina's high winds (140 miles/h) and low pressure (920 mb) pushed a reported 28-foot tidal wave along the Mississippi coast (24, 33). The eye of the storm passed 20 nautical miles east of downtown New Orleans; but even on the weaker western side of the storm, a 15–19-foot storm surge occurred in the lower Louisiana parishes, devastating these areas and destroying most buildings and structures in the storm's path.

The City of New Orleans escaped the immediate impact of the storm surge from Hurricane Katrina; however, the high waters in Lake Pontchartrain and the Industrial Canal breached floodwalls at multiple sites in the city's extensive drainage canal system, filling the "bowl" with up to 15 feet of water (15, 33). Older areas of the city, built on higher ground near the Mississippi River, did not flood, but high winds damaged roofs, resulting in water intrusion. Hurricane Rita (one month later) delivered large amounts of rainfall that further inundated homes and derailed clean-up efforts (15, 32). Approximately 80% of the city was flooded for more than 2 weeks, and it ultimately took the city's pumping system 43 days to remove the flood waters from lower-lying areas (15, 33).

The extensive flooding created conditions ideal for mold growth. Residents returning to their flood-damaged homes confronted not only the loss of their possessions but also copious mold growth and odors. More than 100,000 homes in the flooded areas were estimated to have experienced significant mold growth (45). The Louisiana Department of Health and Hospitals (LDHH) recommended that residents discard all porous household goods and remove drywall that had been in flood waters (34, 35, 37).

Residents and workers clearing out household items and gutting homes entered buildings that contained excessive molds and mildews. Indoor mold growth received widespread attention because of concern for its possible health effects (12). The purpose of this article is to discuss the potential implications of the aftermath of Hurricane Katrina to mold-induced adverse human health effects and to review the evidence relating mold exposure to adverse health outcomes.

MOLD AND THE ENVIRONMENT

Fungi are a diverse group of eukaryotic organisms that share unique features, which distinguish them from animals and plants (30). Unlike animals, fungi have rigid cell walls composed of chitin and glucan, which protect the cells from harsh conditions. Unlike plants, fungi are heterotrophs; they must absorb nutrients from their surroundings. They produce an assortment of enzymes capable of digesting some of the toughest materials in the environment (e.g., chitin, keratin, cellulose, and lignin). This feature makes fungi ideal nutrient recyclers, allowing them to break down dead organic matter; but it also allows them to grow on nutrients in the indoor environment, such as drywall board, ceiling tiles, carpeting, and building materials made from organic matter. Fungi are ubiquitous in the environment. They are found in soil, water, air, and decaying vegetation, and they grow wherever there is adequate nutrients and moisture (30). The damp, warm conditions in water-soaked structures following Katrina encouraged an explosion of fungal growth by molds naturally present in the environment (**Figure 1**).

Fungi are classified according to the nature and appearance (or absence) of microscopic sexual reproductive structures (30). Single-celled yeast reproduce asexually by budding. Multicellular molds, consisting of filamentous structures (called hyphae) that form an often visible mass (called a mycelium), reproduce sexually. Some dimorphic fungi exist as molds in the environment and yeast in the human body (30, 44). In studies that evaluate the presence of molds in the environment, the term mold often refers to visible fungal growth, without reference to specific organisms. Virtually all fungi owe their evolutionary survival to the release of spores or spore-like structures into the environment, where they remain for years until conditions spur germination and growth. Spores can be aerosolized and carried great distances by the wind or can be transported by animals and humans (30).

Evaluation of Molds in the Environment

Molds in the environment are evaluated by several sampling methods that involve collecting and analyzing their spores. Methods include the measurement of culturable (viable) fungi, total fungal spore counts, or fungal structural components (19, 26). Airborne culturable fungi are collected by impaction onto nutrient agar, impingement into a suitable liquid medium, or filtration onto a filter for subsequent plating on culture media (6). Settled dust, surface wipes, and bulk materials may also be plated to identify culturable fungi. Details outlining the operation, advantages, and disadvantages for some of the most widely used methods have been reviewed and presented in the literature (6, 19).

Total fungal spore counts are determined microscopically after collecting spores with slit impaction samplers (3, 20). Total spore counts provide information about culturable and nonculturable fungi. Because some fungi are difficult to grow on culture media, total spore counts may be a more sensitive indicator of the fungal diversity in an environment. They may also be better indicators of potential adverse health effects related to mold exposures because nonviable spores can trigger allergic reactions or carry other allergens that result in illness (49). However, because spores of different molds often look alike on microscopy, it may not be possible to differentiate molds into specific species using spore collection alone.

Surrogate markers can also be used to measure mold in the environment (14, 19, 28), including fungal metabolites (e.g., ergosterol, fungal volatile organic compounds, and mycotoxins) or cell-wall constituents (e.g., $(1 \rightarrow 3, 1 \rightarrow 6)$-β-D-glucan). Analytical methods available for measuring these substances include gas chromatography, gas chromatography-mass spectrometry, high-performance liquid chromatography, and enzyme immunoassays. Polymerase chain reaction (PCR) molecular techniques also assist with the identification of specific fungi (19).

CDC: Centers for Diseases Control and Prevention

The predominant fungi recovered from a particular environment depend on the analyses used to detect them (6, 14, 17). There is no consensus on methodology for monitoring spore concentrations in the environment. The use of different methodologies, equipment, and sampling times makes it difficult to compare results across studies. Furthermore, different fungal species release their spores at different times during the day or year, and some species are more prolific than others (30). Short sampling periods may miss important episodes of spore release, resulting in sampling error and reduced accuracy in estimating 24-h spore concentrations (49).

Mold Studies in New Orleans After Katrina and Rita

After Hurricane Katrina, the heat and wet debris provided a natural breeding ground for mold. The high mold concentrations prompted the CDC to conduct an investigation during October 22–27, 2005, in coordination with the LDHH (12, 42, 45). The CDC investigation included visually assessing water damage and mold growth in 112 homes in a four-parish area (12). The extent of water and wind damage (mild, moderate, and high) was classified by block. Investigators administered to each household a questionnaire on demographics, home occupancy, and participation in remediation activities. Indoor and outdoor air samples were collected from a subset of homes and tested for culturable fungi, total spore counts, and $(1 \rightarrow 3, 1 \rightarrow 6)$-β-D-glucan. Visible mold growth was observed in 44% of homes; 19% had heavy mold growth, correlating with extent of water and wind damage. Extrapolating from this sample, based on 2000 U.S. Census data, the CDC and LDHH estimated that

282,000 homes in the greater New Orleans area experienced flooding; 308,000 homes had roof damage; and 194,000 homes had visible mold growth, with 70,000 homes having heavy mold growth (45).

Subsequent studies evaluated the presence of a variety of fungi in the indoor and outdoor air environment (**Table 1**). For the most part, molds isolated were typical of molds found in indoor and outdoor air samples throughout the United States. Although some methods used for sampling did not allow for species identification, *Aspergillus*, *Penicillium*, and *Cladosporium* were most prevalent across the studies. Homes with greater flood damage, especially >3 feet of indoor flooding, demonstrated higher levels of mold growth (45) compared with homes with little or no flooding. Water intrusion due to roof damage was also associated with mold growth. Some of the molds identified are indicators of extensive and long-term water damage, such as *Chaetomium* and *Stachybotrys* (26). Many of the molds identified are allergenic, including *Alternaria*, *Aspergillus*, *Cladosporium*, *Curvularia*, and *Penicillium* (26). In general, the types of molds isolated after the storm were different from those previously reported for nonwater-damaged buildings in the Southeastern United States (27).

Overall, the levels of spores, culturable fungi, and β-D-glucans were quite high. In most cases, the level of mold indicators from air samples taken inside flood-damaged homes was higher than in samples taken from outdoor air (12, 17, 42, 45, 47, 49). Aerosolized spores from the outside environment may be carried indoors. In those instances, the indoor spore levels are lower than the spore levels measured outdoors, and the indoor/outdoor spore ratio is less than one. A high indoor/outdoor spore ratio is suggestive of a significant indoor source of mold growth. In studies conducted in the months following the hurricanes, the mean indoor/outdoor spore ratios ranged from 4.11 (47) to 8.3 (49). Indoor spore counts ranged from 6142 to 735,123 spores/m^3, whereas outdoor spore counts ranged from >6500 to 102,000 spores/m^3. Culturable mold ranged from 22,000 to 515,000 colony forming units (CFU)/m^3 (17). Exposure to mold levels similar to those measured following Hurricanes Katrina and Rita have been found by others to be associated with adverse health effects in certain populations (21).

Mold levels varied considerably across studies. Most of the studies were conducted in the months immediately following the hurricanes, and homes were at different stages of remediation; some had not been cleaned up and still contained damaged furnishings and other belongings, whereas others had been completely gutted and remediated. Remediation can decrease indoor mold levels (2, 17). Homes in the most severely affected areas were not sampled because access to these areas was restricted at the time of the investigations. These reports, therefore, likely underestimate the extent of mold growth (49) in the months following Hurricanes Katrina and Rita.

Interpretation of these post-Katrina studies, or any study evaluating the health effects of indoor mold exposure, is difficult because of the wide variability of human responses to mold and other naturally occurring substances. This limitation is one reason why health-based standards for mold exposure are still lacking (6, 17). The American Conference of Governmental Industrial Hygienists (ACGIH) recommendations have been used as guidelines, but their authors never intended these recommendations to be interpreted as criteria for judging indoor air quality or for determining health effects associated with mold exposures (6). Because data are limited in the published literature describing mold levels in New Orleans prior to the Hurricanes Katrina and Rita, it is difficult to determine if these hurricanes changed the mold species profile in the area.

ADVERSE HEALTH OUTCOMES ASSOCIATED WITH MOLD EXPOSURE

The health consequences associated with exposure to high levels of indoor mold and mold fragments are unclear. Illnesses associated with

Table 1 Previously published investigations of indoor and outdoor mold following Hurricanes Katrina and Rita

Reference	Type of samples collected	Mold sampling method	Study specifics	Mold types isolated
17	Air (indoor, outdoor)	Culturable fungi, total spore counts, PCR[a,b] Sample collection period: 20 min; 2.5 liters/min (culturable fungi), 15 liters/min (spores, outdoor samples)	Period: November 2005 to January 2006 Demonstration project looking at safe remediation techniques and mold levels during cleanup 3 single-family homes tested at 3 points in time (before, during, and after renovations) Indoor sites: living room, other Outdoor sites: 3 and 10 m from front door	Most common fungi by all three methods: *Aspergillus*, *Penicillium* Others: *Paecilomyces*, *Cladosporium*, *Trichoderma*, *Stachybotrys*, *Curvularia*, Basidiomycota, *Alternaria*, *Chaetomium*, zygomycetes, yeast
39	Air (indoor, outdoor)	Culturable fungi	Period: Feb/March 2006, April/May 2006 Indoor samples: collected overnight from sleeping area Outdoor samples: sidewalk, at least one per zip code; 30 min collection time	Most common cultured fungi: *Cladosporium*, *Penicillium* Others: *Trichoderma*, *Paecilomyces*, *Alternaria*, *Zygomycota*
12, 42, 45	Air (indoor, outdoor)	Culturable fungi, total spore counts, (1–3, 1–6)-β-D-glucan[b] Sample collection period: 36–144 min; 3 liters/min	Period: October 22–27, 2005 Sampling neighborhoods categorized by damage level (mild, moderate, heavy) Subset of 112 surveyed residences, varying degree of flooding (high, medium, low) 20 indoor sites: moldiest room or sleeping area (if occupied) 11 outdoor sites: front yard	Most common cultured fungi: *Penicillium* and *Aspergillus* Others: *Eurotium*, *Cladosporium*, *Paecilomyces*, zygomycetes (e.g., *Syncephalastrum* spp.)
47	Air (indoor, outdoor) Surface mold	Total spore counts (air), culturable fungi (surface) Sample collection period: 10–17 min; 10–15 liters/min	Period: October 13–14, 2005 Sites categorized into 4 regions on the basis of wind and water damage 13 matched indoor and outdoor sites	Most common indoor and outdoor: *Aspergillus/Penicillium* Others: *Cladosporium*, *Curvularia*
49	Air (indoor, outdoor)	Total spore counts[b] Continuous sampling (6-h or 24-h period); 10 liter/min Results extrapolated to 24-h estimates	Period: October 2005, November 2005 23 stationary outdoor sites (flooded, not flooded, distant) 8 indoor sites (varying degree of flooding and remediation)	Most common indoor and outdoor: *Cladosporium* and *Aspergillus/Penicillium* Others: *Alternaria*, Ascomycetes, *Aureobasidium*, Basidiomycetes, *Chaetomium*, *Curvularia*, *Ganoderma*, smuts, *Stachybotrys*, *Ustilago*, *Wallemia*, yeast

[a]Abbreviation: PCR, polymerase chain reaction.
[b]Also measured indoor and outdoor airborne endotoxin (a component of some bacterial cell membranes).

IOM: Institute of Medicine

fungal exposure depend on the route and magnitude of exposure and the immune status of the person exposed (14, 44). Inhalation is the most important route of exposure for most fungi, particularly in the indoor environment, making the respiratory system a prime target.

Illnesses associated with mold exposure can be divided into two general categories: infectious illnesses and noninfectious illnesses. True invasive fungal infections (fungal pneumonia and acute fungal sinusitis) are uncommon, particularly in healthy individuals. Of the 50,000–250,000 species of fungi described, fewer than 500 are associated with human disease and ~100 are associated with disease in immunocompetent individuals (44). Most fungi are opportunists, causing illness in certain vulnerable populations.

A 2004 Institute of Medicine (IOM) report (28) investigated the impact of damp indoor environments on health, including health effects associated with indoor mold growth. The report found sufficient evidence of an association between the presence of mold in damp indoor environments and upper respiratory tract symptoms, cough, and wheezing (28). These symptoms were not specific for any particular disease. The report also found that healthy children exposed to mold in damp indoor environments have more lower respiratory tract illnesses. There was no evidence to support an association between infections of the upper or lower respiratory tract and indoor mold exposure in otherwise healthy adults; however, there was sufficient evidence of an association between exposure to *Aspergillus* spp. in indoor environments and pulmonary aspergillosis and aspergillomas in severely immunocompromised individuals.

The noninfectious effects of mold can be broken down into immune and nonimmune responses to fungal spores, fragments, mycotoxins, or other substances (28, 38). Allergic sensitization to fungi with detectable IgE antibodies by radioallergosorbent test (RAST) or skin prick testing is a significant risk factor for acute asthma exacerbation. Approximately 6%–10% of the general population is sensitized to fungal allergens; this number increases to 19% in atopic individuals, i.e., those with allergies (28). The IOM report found sufficient evidence of an association between the exposure to mold in a damp indoor environment and exacerbations of asthma in sensitized asthmatics; however, there was insufficient evidence of an association between the development of asthma in people not previously diagnosed and the presence of mold in a damp indoor environment.

Besides allergic rhinitis or asthma, other IgE-mediated conditions due to fungal exposure include allergic bronchopulmonary aspergillosis and allergic fungal sinusitis (28, 38). The IOM report found sufficient evidence for an association between mold exposure and hypersensitivity pneumonitis, a cell-mediated immune response to the inhalation of fungal particles deep into the airways in a small proportion of susceptible persons (28).

The most common nonimmune health effect caused by mold exposure is irritation. Exposure to high levels of $(1 \rightarrow 3)$-β-D-glucan, a cell-wall component not specific to fungi, has been associated with health effects including cough; airway hyperreactivity; influenza-like symptoms; ear, nose, and throat irritation; and decreased lung function (21). Nasal lavage fluid from workers exposed to mold has demonstrated increased levels of inflammatory markers in parallel with complaints of eye irritation and cough (25). Other nonimmune effects include inhalation fever, toxin-mediated disease, and the still-debated idiopathic pulmonary hemorrhage, all of which are uncommon (7, 38).

Mold and Respiratory Health in New Orleans Prior to Katrina

Dr. John Salvaggio, the late director of the Tulane Section of Allergy and Immunology, described New Orleans Asthma in relation to epidemics of patients with acute asthma presenting to local emergency rooms because of mold spore exposure (46). A study of children presenting to the Charity Hospital Pediatric Emergency Room (43) revealed significant sensitization to basidiomycetes in addition to fungi imperfecti, an old term to describe fungi for which a sexual reproductive phase has not been identified (30).

Additionally, available skin test records from the Tulane–Charity Hospital Pediatric Allergy Clinic from the 12 years prior to the flood revealed a high rate of sensitization to fungi in local children with asthma, even in the youngest children: 63% of 3–5-year-olds, 59% of 6–11-year-olds, and 66% of 12–16-year-olds (31).

Clinical Illness Seen Following Katrina and Rita

In the first several weeks following Hurricanes Katrina and Rita, a number of infectious diseases, dermatological conditions, and mental health problems were identified in evacuees and rescue workers (8, 9, 10, 13, 16). In the month immediately after Katrina, there was a small increase in the number of acute respiratory infections according to a survey of local health care facilities, but this statistic was driven by a single facility that identified multiple cases among members of a National Guard battalion (9). The close living quarters of the troops, rather than environmental exposures, was felt to be the cause of the increase in illnesses.

No increase in invasive fungal infections has been identified as a consequence of flooding due to Hurricane Katrina. A case series by Rao et al. showed an increase in the isolation of *Syncephalastrum* spp. in clinical specimens of New Orleans residents in one area hospital following the hurricanes (40). All eight of the clinical specimens were believed to be colonization and not true infection because all patients improved with treatment for other illnesses and without appropriate treatment for *Syncephalastrum*. In another study, looking at the incidence of invasive mold infections among 199 immunocompromised patients seeking care at hematology/oncology and solid-organ transplant clinics between February 22, 2006, and May 11, 2006, investigators found no increase in the incidence of invasive mold infections seen among even the most severely immunocompromised patients (41). The authors noted that profoundly immunocompromised patients were more likely to avoid activities associated with mold exposures, but they also found that less than 40% of patients reporting mold exposures wore N95 masks during periods of mold contact. Despite the low use of personal protection equipment during mold exposure, an increased incidence of invasive infections was not seen in this high-risk group (41).

A study released in April 2006 by the Department of Health and Hospitals, Office of Public Health, concluded that dust and sediment from Hurricane Katrina did not cause an increase in severe respiratory problems for people living in the Greater New Orleans area (36).

More than 50,000 emergency room visits in the area from October 2005 to March 2006 were tracked along with visits to clinics and medical triage sites. The study examined patients seeking treatment for medical conditions such as cough, sinus drip, sneezing, wheezing, chest congestion, or sore throat. They reported no significant increase in respiratory illnesses in the New Orleans area in comparison to other parts of the state or the country. However, as seen in the 2004 IOM report (28) discussed above, those with a prior history of asthma or allergies were more likely to experience symptoms because of exposure to dust and mold.

The Children's Respiratory Health Study was performed in 2006 to examine the effects of indoor mold exposure on children's lung function, as measured by simple spirometry (39). Children ages 7–14 years were recruited from a private school in an area of the city that did not flood. Parents completed a respiratory health symptom questionnaire, including information about household allergens and the child's asthma and allergy status. Indoor air samples were collected overnight from the area where the child slept. An outdoor air sample was collected from the sidewalk in front of a representative sample of homes in each zip code. Spirometry results and air samples were collected within one week of each other. Initial testing was performed in February/March and follow-up testing was performed in April/May.

HEAL: Head-off Environmental Asthma in Louisiana

Only 10% of the study population had previous physician-diagnosed asthma or bronchitis and 20% had a history of allergy. The majority of the children were living at their pre-Katrina residences, and about half of the homes had been repaired before the study began. The majority of homes had minor or no water damage, and only 17% of the children were living in a house that had flooded.

Lower respiratory tract symptoms were higher in the initial testing compared with follow-up, but investigators observed no changes in the frequency of upper respiratory tract symptoms or the spirometry results between the two testing periods. Children also missed more days of school because of symptoms and had more physician visits during the initial evaluation period, but neither of these observations was statistically significant (39).

As one portion of the Head-off Environmental Asthma in Louisiana (HEAL) study (still ongoing), skin prick testing was carried out between March 2007 and March 2008 on children ages 4–12 years old with moderate to severe asthma living in the Greater New Orleans area impacted by the flood (22). Of the 182 enrolled, 87% were allergic to at least one indoor allergen. In that atopic subgroup, sensitivity to *Alternaria* was present in 53%, *Penicillium* 48%, *Cladosporium* 29%, and *Aspergillus fumigatus* 24%; 75% tested positive to at least one of those 4 primary molds (23). These results contrast the results of the Inner-City Asthma Study during which skin testing of 937 atopic children with moderate to severe asthma enrolled in 7 cities revealed reactivity to at least one of the primary molds to be 50% (18). Data from the Tulane–Charity Pediatric Clinic revealed that 64% of the atopic children with asthma reacted to at least one of these 4 molds prior to Katrina (48).

Why Are Studies to Date Not Showing a Greater Health Impact Following Katrina and Rita?

Why have studies, to date, not observed a greater health impact in the aftermath of Hurricanes Katrina and Rita? The measurements of mold and spores confirm the opportunity for high exposure for people who returned to the city, particularly those participating in remediation activities. The public was highly concerned that mold and other environmental agents would result in disease; yet, public health surveillance and published reports from clinical studies do not show the anticipated impact on health. Several factors may contribute to this lack of observed health effects:

1. Types of adverse health effects. Mold is associated with few serious adverse effects in healthy people. The results of the post-Katrina investigations are consistent with the findings of the 2004 IOM report discussed above (28). Furthermore, people with mild allergic symptoms may not have sought medical care. Of those who did seek care by a physician, their symptoms and diagnoses were not reportable and, therefore, may have been missed by surveillance systems.
2. Alternate housing. Many residents were forced to seek alternate housing because of extensive damage to their original homes and lack of running water and electricity, thereby avoiding home-related mold exposure (11).
3. Self-selection. Healthier people were more likely to clean up and gut houses, given the harsh conditions and physical demands.
4. Time-limited exposures. Although persons engaged in house cleaning and remediation activities during the day, many returned to other housing at the end of the day. In the CDC cross-sectional survey of 112 households conducted in October 2005 to assess the extent of mold exposures (12), participants reported being indoors doing heavy cleaning an average of 13 hours (range 0–84 h) and doing light cleaning 15 hours (range 0–90 h) since the hurricanes. Approximately 60% of participants reported inhabiting their homes overnight for an average of 25 nights; 40% did not inhabit their homes overnight.

5. Lack of access to health care. In a CDC survey of Jefferson and Orleans parish residents conducted 7 weeks after Katrina, 55.7% of households contained one or more members with a chronic medical condition, 23.3% reported problems in obtaining medical care, and 9.4% reported problems obtaining prescription medications (11). Seven months after the hurricanes, 7 area hospitals remained closed; bed capacity had dropped from 3.03 hospital beds per 1000 persons to 1.99 beds per 1000 persons after the storm (5). Because of limited resources within the New Orleans area, persons who experienced adverse health effects may have sought care outside the area, resulting in failure to be captured in the public health surveillance system. In addition to limited health care facilities, problems obtaining health care stemmed from loss of health insurance and financial concerns (11).
6. Katrina Cough. The Katrina Cough was widespread after the hurricanes and thought to be an irritant phenomenon resulting from a unique confluence of environmental influences: a dryer fall season, resulting in high levels of particulates in outdoor air; the regular allergy season, resulting in hay fever and asthma exacerbations, possibly aggravated by high mold spore counts; and the start of the regular flu season (4, 36, 50).

Limitations of Currently Available Literature

Published studies, to date, of the adverse health effects caused by mold exposure following Hurricanes Katrina and Rita suffer from three important limitations.

1. Short-term follow-up. Most studies of health effects in persons with previously diagnosed asthma only examine acute and subacute effects. Studies are needed to assess the overall impact of long-term mold exposures. Adhikari et al. (1) found that significant levels of culturable fungi, total fungal spores, and (1–3)-β-D-glucan could be aerosolized from flooring and bedding materials one year after flooding by Hurricane Katrina. Further studies are needed on the longer-term health effects of chronic mold exposure in persons with underlying asthma.
2. Limited data on the role of early sensitization. Further studies are needed to evaluate the role of early sensitization to mold in the development of asthma in susceptible persons. Although the 2004 IOM report found insufficient evidence to determine whether an association exists between exposure to mold and the development of asthma, it found evidence suggestive of an association between exposure to damp indoor spaces and the development of asthma. It was not clear which factor related to damp indoor environments (e.g., mold, bacteria, or other agent) was responsible for the association (28). Furthermore, studies on the role of gene-environment interactions are also needed to assess the risk of asthma development in susceptible persons.
3. Role of health disparities. Published studies of the health impact of mold exposure in the aftermath of Hurricanes Katrina and Rita do not account for the critical role of health disparities. The Kaiser Family Foundation conducted its first of three planned in-person surveys of more than 1500 post-Katrina residents of Orleans, Jefferson, Plaquemines, and St. Bernard Parishes in September and October 2006 (29). The purpose of this first survey was to document the baseline impact of Hurricane Katrina on the economic well-being, physical and mental health, and personal lives of area residents. According to the survey, 77% of the Greater New Orleans population reported facing challenges in health, health care, or employment. Half of the residents reported facing problems in obtaining medical care. Nineteen percent

of residents reported that their physical health had declined since the storm, and 16% reported a decline in mental health. Twenty-seven percent reported that their usual source of care was the emergency room. One-third of households with children under age 19 reported that there was a child in the household with a serious health need or potential problem obtaining access to health care. Problems with access to health care were even more pronounced in African Americans; 72% reported some sort of ongoing problem in health care access or coverage. Furthermore, 58% of African Americans, compared with 34% of white residents, were living in areas that received an average of at least 2 feet of flooding during the storm. Further studies are needed to address how the distal factors of health disparities impact the relationship between mold exposures and respiratory health, particularly in children and other vulnerable populations.

ONGOING AND FUTURE STUDIES

Longer-term studies are ongoing to evaluate further the impact of mold on the health of children and workers. These studies include (*a*) HEAL study, funded by the National Institutes of Health (NIH); (*b*) the Respiratory Effects in Workers from Post-Katrina-Related Airborne Exposures study, funded by the CDC, and (*c*) the Investigation of Biomarkers of Mold Exposure study, funded by the Tulane Enhancement Fund.

HEAL is a prospective observational study whose goals are to assess the effects of mold on children's asthma following Hurricane Katrina and to test further the effectiveness of asthma case management and environmental risk control to reduce asthma symptoms. Through this unique study, clinical and environmental measurements will be collected and correlated to assess the effects of the allergens and molds found post-Katrina on children's asthma status. The study also includes an asthma counselor intervention, adapted from the National Cooperative Inner-City Asthma Study and the Inner City Asthma Study funded by the NIH (18). The conditions in post-Katrina New Orleans provide a setting to demonstrate a field-applicable approach to the control of asthma following natural disasters. The study recruits children ages 4 to 12 years who have moderate-to-severe asthma and live in the Hurricane Katrina–impacted area.

The Respiratory Effects in Workers from Post-Katrina-Related Airborne Exposures study is a five-year longitudinal study evaluating associations between exposure to post-Katrina flooding, cleanup, and restoration work and the risk of respiratory illness, symptoms, and excessive longitudinal decline in lung function in workers (R.J. Rando, personal communication). Study researchers postulate that post-Katrina flooding, cleanup, and restoration work will entail large and protracted airborne exposures to noxious particulates and bioaerosols that will have adverse effects on the respiratory system. These effects may be manifested as increased incidences of asthma, bronchitis, pneumonia, hypersensitivity pneumonia, and symptoms associated with those conditions, as well as abnormal annual declines in expiratory flow rates, exhaled volumes, or both.

The Investigation of Biomarkers of Mold Exposure study will provide data on biomarkers associated with mold exposures. Blood samples from persons exposed to fungal allergens have been collected to conduct immunologic marker assays. Changes over time in total IgE levels and species-specific IgE and IgG levels and their association with environmental mold exposures will be monitored.

CONCLUSIONS

The extensive flooding in the aftermath of Hurricanes Katrina and Rita created conditions ideal for indoor mold growth, raising concerns about the possible adverse health effects associated with indoor mold exposure. Residents and workers who returned to clean up flooded homes were exposed to extremely high levels of multiple types of molds, predominantly *Aspergillus* spp., *Penicillium* spp., and *Cladosporium* spp. Despite the opportunity for workers to be exposed to mold, public health surveillance systems and published reports did not show an increase in emergency room visits or hospitalizations due to mold exposures (9, 13). Several ongoing studies will provide further data to assess the impact of any longer-term effects from the post-Katrina mold exposures. This information will provide public health officials with information that will be beneficial for managing other flood-related events.

As indicated in the 2004 IOM report, *Damp Indoor Spaces and Health* (28), the most common health effect associated with mold exposure is allergy. Those with previously diagnosed asthma may suffer exacerbations, particularly if they also have allergies to molds. Although the IOM report did not find sufficient evidence to show an association between mold exposure and the development of asthma in undiagnosed persons, it found evidence suggestive of an association between exposure to damp indoor spaces and the development of asthma. The factors, or more likely the combination of factors, related to moist indoor environments that are responsible for the development of asthma still need to be elucidated. Furthermore, studies on the role of gene-environment interactions are also needed to assess the risk of asthma development in susceptible persons.

The influence of health disparities also needs to be addressed. Specifically, previous studies may not have accounted for the role health disparities play in exposure to mold and in the impact on vulnerable populations susceptible to the development of asthma.

SUMMARY POINTS

1. High indoor/outdoor mold ratios were observed in the months immediately following Hurricanes Katrina and Rita, indicating significant indoor sources of mold growth and therefore high potential for indoor mold exposure.
2. Published studies and reports, to date, seem to indicate that the health impact of mold exposures following Hurricanes Katrina and Rita was less than expected. Several factors may influence these findings.
3. Gaps exist in the current knowledge of the adverse health impacts of mold exposure, particularly in terms of the implications of early sensitization to molds and the development of asthma and of the effects of longer-term mold exposure on persons with diagnosed asthma.
4. Several studies are under way to address these gaps.

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Figure 1

Extensive mold growth after flooding during Hurricanes Katrina and Rita (courtesy of Dr. Samuel B. Lehrer).

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