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A New Model for Environmental Assessment and Exposure Reduction

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Abstract

Environmental assessment and exposure reduction are a set of diagnostic and treatment techniques that work in tandem with the traditional medical approach by reducing a patient's exposure to adverse environmental conditions as part of medical care. Assessment involves identifying the specific exposures to which a patient is sensitive and locating the corresponding contaminants in the patient's environment. This provides a more complete diagnostic evaluation of a patient's problem than could be obtained merely by examining the patient alone. Exposure reduction involves reducing the identified triggers to levels that are below thresholds that are associated with increased risk of sensitization and disease morbidity.

Assessment of an environment for contaminants focuses on a chain of factors that include contaminant sources such as cockroaches, rodents, dust mites and fungi that excrete contaminants into an environment, facilitative factors such as moisture, food, water and shelter that help sources to thrive, and reservoirs where contaminants can accumulate prior to subsequent transport to occupants. By using this model to guide environmental assessments and their corresponding interventions, the root cause of health problems can be addressed, leading to improved quality of life for patients and reduced need for chronic medications.

Keywords

Environmental control; Abatement; Mitigation; Model; Environmental assessment; Exposure; Reduction; Contaminants; Interventions; Reservoirs; Pathways

Introduction

Environmental assessment and exposure reduction have been a mantra of the allergy profession almost since its inception. The idea is straightforward: a patient with a medical problem that is likely to be triggered by adverse environmental exposures is evaluated by an allergist who helps the patient to identify those exposures. Given that information, the patient is instructed to avoid future exposure using a variety of environmental interventions generically termed "avoidance". As a result of this advice, the illness abates, the patient can reduce his or her intake of medications, and all is well.

While this approach sounds rational, in practice it is not easily achieved (1). The problem is that many patients are sensitive to multiple environmental triggers, many of which have not been fully characterized and for which there are no readily available tests. In addition, since

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many exposures are ubiquitous, interventions to completely avoid them are not practical and therefore do not work. Finally, many patients are not willing to perform the recommended environmental interventions unless the situation is so extreme that they are forced to do so (2).

Certainly, it is not possible to avoid outdoor allergens unless the patient is willing to stay indoors throughout seasons when they are airborne. Indoor allergens, on the other hand, do have the potential of being controlled and therefore have been the focus of substantial research. Recently, in acknowledgement of the need for standardized approaches to environmental assessment with intervention, the Joint Taskforce on Practice Parameters has started to develop a series of practice guidelines for the management of environmental exposures (3).

This review will describe our current understanding of how adverse indoor environmental exposures are formed, where they are located, and how they travel from reservoirs to building occupants. Interventions including integrated pest management (IPM) are also briefly reviewed with an emphasis on how they integrate into a new model for exposure reduction.

The model

Health problems occur as a result of environmental exposures to substances referred to as contaminants (3). A contaminant is defined generically as any physical, chemical, biological, or radioactive substance that can have an adverse effect on air, water or soil, or on any interior or exterior surface, and that has the potential to cause harm to a building's occupants. Contaminants can consist of allergens, irritants or other types of substances, including biologically active ones. A mechanism for the production of allergen contaminants usually consists of biologic organisms such as fungi, rodents, dust mites, furry animals and insects. Non-allergen contaminant sources include chemical reactions, combustion by-products, particulates, and microbial organisms that produce substances such as endotoxin and volatile organic compounds.

Production of contaminants by biologic organisms can be facilitated when certain environmental conditions are present. Examples of such conditions include moisture, food, warmth and shelter, which are prerequisites for survival of most biologic organisms. Non-allergen contaminants do not require such conditions but are produced through both normal daily maintenance activity and when home conditions are altered by a significant event (construction, renovation, disaster restoration). This can include use of household products, introduction of new building materials, or more common activities such as burning candles, certain hobbies, and occupational substances.

Once contaminants are produced, they tend to remain in the environment, forming reservoirs until they either decay or dissipate. Common reservoirs for allergens include carpets, bedding, upholstered furniture, settled dust, wall cavities, inside cabinets, air ducts, and crawlspaces (4). While contaminants are present in reservoirs, they have a potential to travel along pathways to the living space of occupants where they can cause adverse health effects. Contaminants can travel via air and water, and on fomites (inanimate objects) or vectors (living animals).

Figure 1 shows this model of environmental exposure, starting with facilitative factors which assist organisms that serve as sources of allergens. Allergens are either transported to occupants along pathways or deposited in reservoirs from which they subsequently travel to the occupants. By understanding how these factors fit together, it is possible to measure the

contributions of each and to design a feasible intervention plan that is likely to reduce occupant exposure.

Health Effects of Environmental Exposures

The effect that contaminant exposure has on health depends on the amount and duration of the exposure, the intrinsic biologic effect of the exposure, and the sensitivity to it of occupants. The amount of exposure that is associated with sensitization (development of specific IgE), sensitivity (development of symptoms after exposure to the allergen), and morbidity (long-term adverse health effects from ongoing exposure) has been studied extensively. Suggested exposure thresholds for selected allergens that are associated with development of symptoms in sensitized people are shown in Table 1.

For each of these allergens, there are data demonstrating that patients with exposure below each threshold experience fewer symptoms and less morbidity than those who are exposed to levels above the threshold. Even so, it should not be assumed that exposure to an allergen level below one of these thresholds is safe and above these thresholds is inevitably harmful. The shape of the dose response curve for most allergens is not known. It is just as likely that a sigmoidal curve is a more accurate representation of the health effects of a given exposure, suggesting that reduction of exposure to levels significantly below the suggested threshold may be necessary to achieve health benefits.

It is important to note that the relationship between exposure and health effects is not necessarily causal. The studies supporting this relationship are usually population studies that are either cross-sectional or observational, providing correlations between exposure and symptoms. The reason for this is that it would not be feasible to perform a randomized study in which selected subjects are exposed to increased allergen levels from birth while controls are not. Interventional studies in which exposure reduction leads to reduced symptoms supports the use of exposure reduction, but it does not prove that living in an intrinsically more allergenic environment causes the health effects.

Interventions

The goal of environmental interventions is to reduce occupant exposure to contaminants to concentrations that are below the threshold that causes adverse health effects. Interventions designed to prevent development of specific IgE antibodies using exposure reduction are referred to as primary prevention (5,6). What is interesting is that exposure to increased amounts of furry animal allergens in the first few months of life seems to provide a protective effect by reducing the risk of sensitization (7). This same effect is not found for cockroach (8) or mold, and the data are unclear for rodents.

Once a patient develops specific IgE antibodies, exposure reduction is necessary to prevent future development of a disease such as asthma. This is referred to as secondary prevention (9). Tertiary prevention, otherwise known as treatment, is necessary once a sensitized individual has developed asthma to prevent morbidity that would be caused by the exposure (10).

While a variety of individual interventions have been evaluated, none have proven to be effective for avoiding any of the allergens listed in Table 1 by itself. It appears to be necessary to combine interventions for this type of reduction to be achieved. For allergen sources such as cockroaches and rodents, strategies such as integrated pest management (IPM) are essential (11). Other exposures such as dust mites and fungi require similar strategies without the behavior components, since such organisms do not learn to thwart interventions the way that rats and cockroaches do. Furry animals have their own set of

challenges since homeowners often prefer to keep a pet in the house regardless of their allergy status.

This model of exposure reduction provides a framework for designing interventions. To reduce exposure, it is necessary to provide interventions that address each component of the model including facilitative factors, sources, reservoirs, and pathways. If any of these are left unmanaged, it is likely that the exposure reduction will be unsuccessful. For example, a combination of education, use of insecticides, professional cleaning, and habitat alteration appears to be necessary for cockroach control because it addresses facilitative factors, causative organisms, and reservoirs in combination. Application of insecticides alone can reduce the number of cockroaches in a house, but this does not necessarily lead to improved health (12).

Facilitative Factors

Facilitative factors for cockroaches and rodents include a means of ingress, appropriate temperature, food, water, and shelter. For that reason, IPM, which focuses on these pests, first emphasizes identification of facilitative factors. Once identified, interventions include sealing of openings that permit pests to enter a building, removal of food and water from areas where the pests can get to them, and elimination of clutter and other places where pests can find shelter. Elimination of facilitative factors reduces the carrying capacity of the environment for the pests (11). As a result, rodents and cockroaches either have to migrate somewhere else or die due to lack of resources needed to survive. Fungi and dust mites also require moisture and food to survive; however, they can thrive on sources that are not necessarily apparent. Moisture resulting from external sources (intrusion) or internal sources (condensation, leakage) may be sufficient to support growth of these microscopic sources. Food in the form of cellulose for fungi and skin cells for dust mites may be difficult to remove and result from a recurring water problem, which is why an emphasis is placed on moisture control (13).

Interventions that eliminate facilitative factors, therefore, include use of dehumidifiers to reduce humidity below 50%, elimination of sources of moisture, sealing of food and water containers, and elimination of clutter. In general, patients are moderately willing to reduce humidity; however, their willingness to perform other interventions less clear. The more difficult the intervention, the less likely it is to be done (2).

Sources

Sources of allergens consist of the organisms that produce them. Furry animals produce dog and cat allergens merely by their presence in the environment. To date, there are no proven non-allergenic dogs or cats despite advertisements to the contrary. Since most animal allergens are released in their sebaceous secretions, washing the animals regularly has been shown to reduce dissemination into the environment (14, 15). Denaturation with tannic acid or bleach can also reduce cat allergen exposure (16). In general, most patients are not willing to eliminate a pet though they are willing to wash pets regularly and to keep them out of bedrooms (2).

Cockroaches continue to produce allergens, irritants such as chitin, and other inflammatory substances as long as they are present. Though reduction of the carrying capacity of the environment for cockroaches will eventually lead to decreased numbers, it may also be necessary to exterminate them to achieve a rapid reduction where an infestation exists. Glue boards can be used to monitor the extent of an infestation and its duration. If all captured cockroaches are from a single generation, the infestation is short-term. Representation from a variety of stages on a glue board suggests a longer-term problem. Extermination can be

done using a variety of insecticides, though it is important that as part of an IPM plan they are applied through targeted deployment using baits and gels according to the manufacturer's instructions to avoid adverse health effects on the building occupants. Ideally, a licensed, professional pest control contractor should apply insecticides (17).

Rodents produce significant allergens in their urine which they distribute as they move about. While elimination of rodents begins by eliminating facilitative factors, they can also be removed using snap traps, live traps, and glue boards. Predators such as cats can also reduce rodent populations, though there is a risk that the occupant could become sensitized to the cat (18). Rodenticides usually consisting of anticoagulants can also be used, though, as with insecticides, it is essential that these be applied properly using bait stations to avoid unintentional harm to other nontargeted animals (19).

Dust mites produce allergens in their fecal pellets. They generally live in bedding, carpets, and upholstered furniture and dine on skin cells, fungi, and each other. While acaricides such as benzoic acid have been used to eliminate dust mites, it is usually more feasible to eliminate the facilitative factors including moisture to reduce dust mite populations. The mites themselves are difficult to eliminate though they can be killed with washing in hot water and/or drying in high heat (20).

Fungi produce numerous allergens, irritants, and proinflammatory substances including volatile organic compounds. Molds can be removed from surfaces using detergent and water and killed using a dilute bleach solution as well as a variety of fungicides, but these need to be applied regularly to prevent regrowth (21). As long as the facilitative factors are present, fungi will grow. For that reason, an emphasis is placed on removal of moisture which is the main facilitative factor. If the substrate on which a fungus is growing is desiccated, the organism will not grow (13).

Reservoirs

Once elimination of facilitative factors and removal of the sources of allergen production has been accomplished, it is also necessary to remove reservoirs of allergens. Such reservoirs can remain for long periods of time before the allergens either decay into nonallergenic fragments or are removed. As long as the reservoirs are present, exposure of occupants will continue. The specific type of reservoir that needs mitigation depends on the source and type of allergen. Furry animals, dust mites, and fungi often leave allergens in carpeting and upholstered furniture. Cockroaches and rodents leave allergens in walls, along baseboards and in contaminated clutter.

Carpeting and upholstered furniture can be cleaned with a HEPA or high efficiency vacuum or with a central vac. Vacuums with low-efficiency bags tend to redistribute allergens and can make the reservoir worse. Mattresses can be covered with allergen-impermeable covers that separate allergens and dust mites from where the occupant sleeps. Fungus-contaminated wallboard and other materials may be cleaned with soap and water or with a dilute bleach solution if the degree of contamination is small. More extensively affected areas need to be removed and replaced.

The use of HEPA cleaners either in the HVAC or stand-alone units has been reviewed (22). The authors in this extensive review concluded that portable room air cleaners with HEPA filters appear to reduce occupant exposure. This is particularly true if the filter clears the breathing zone during sleep. In addition, the use of high-efficiency disposable filters is useful with forced-air HVAC systems along with regular maintenance (23).

Pathways

While ideally sources and reservoirs should be abated, it is also important to prevent residual allergens from traveling from remaining locations to occupants. Transport of contaminants can occur in air if the particles are small enough to become airborne and to remain airborne long enough to travel from sources and reservoirs to occupants. Pathways can occur when air ducts are leaky or when air circulates from contaminated areas to clean ones. Volatile compounds require ventilation for their removal. For these reasons, differential building pressures and differential pressure between rooms becomes an important consideration in both assessing exposure and in recommending effective interventions.

Implications

A number of studies have examined the efficacy of cockroach and rodent removal with subsequent reduction in allergen exposure, as a way to improve asthma symptoms. Researchers from the Inner City Asthma Study (ICAS) were the first to demonstrate that environmental interventions reduced asthma symptoms. They demonstrated that one year of interventions, which included professional cleaning, bait traps, insecticides, and HEPA filters, was sufficient to reduce cockroach allergen levels, and that these improvements were significantly correlated with decreased wheeze, decreased nighttime asthma symptoms, and fewer missed school days. In addition, clinical improvement persisted for at least one year after the environmental intervention had ceased (24). In a similar study, Eggleston et al. used environmental interventions to reduce cockroach allergen and, subsequently, daytime asthma symptoms (25).

On the other hand, the National Inner City Asthma Study demonstrated a decrease in cockroach allergen that persisted for 6 months after interventions, but levels had returned to baseline by 12 months (26). As noted previously, Sever et al. found significant reduction in cockroach allergen 12 months after interventions performed by professional entomologists, but no reduction at 12 months after intervention by a commercial pest removal company (17). This demonstrates that continuous efforts (professionally or family directed) to eliminate these allergens may be necessary for sustained cockroach allergen reduction. Similar long-term studies are needed on the reduction of rodent allergen.

The efficacy of IPM for rodents had some success in the ICAS where *Mus m 1* levels were reduced by a small but significant 27 % (27). A subset of children whose homes had at least a 50 % reduction in *Mus m 1* had fewer missed school days, reduced sleep disruption, and reduced caretaker burden, suggesting that an intervention that can achieve at least a 50 % reduction in allergen levels may improve asthma (28).

For furry animals, a multiple intervention study demonstrated that 11 months of biweekly cat washing, use of mattress and pillow encasings, weekly washing of encasings at 60°C, excluding the cat from the bedroom, and application of tannic acid led to reductions of *Fel d 1* concentration in house dust by 91.4 % in an active intervention group but not in a control group (29). While a combination of environmental interventions does seem to be effective in the reducing the cat allergen load in homes, they also appear to lead to reduced symptoms. Such intervention combinations, involving both mechanical methods for allergen reduction and educational efforts of asthmatic children and their parents, appear to be necessary to reduce exposure to asthma triggers and improved health outcomes for asthmatic children (30).

Conclusions

The traditional medical approach involves diagnosing what is wrong with the patient and fixing it, usually with medications. Since respiratory and many other illnesses are, at least in part, exacerbated by adverse environmental exposures, it seems only reasonable that diagnosis and treatment aimed at a patient's environment should be part of routine care.

Environmental assessment and exposure reduction has the potential to reduce exposure to adverse environmental conditions. If such exposures can be decreased to levels that are below thresholds associated with increased risk of sensitization and disease morbidity, patients may experience improved health while taking less medication. By focusing on facilitative factors, contaminant sources, and reservoirs, environmental assessment and its corresponding set of interventions can be incorporated into routine medical care. The challenge will be to make this transition in an era of tightening healthcare resources.

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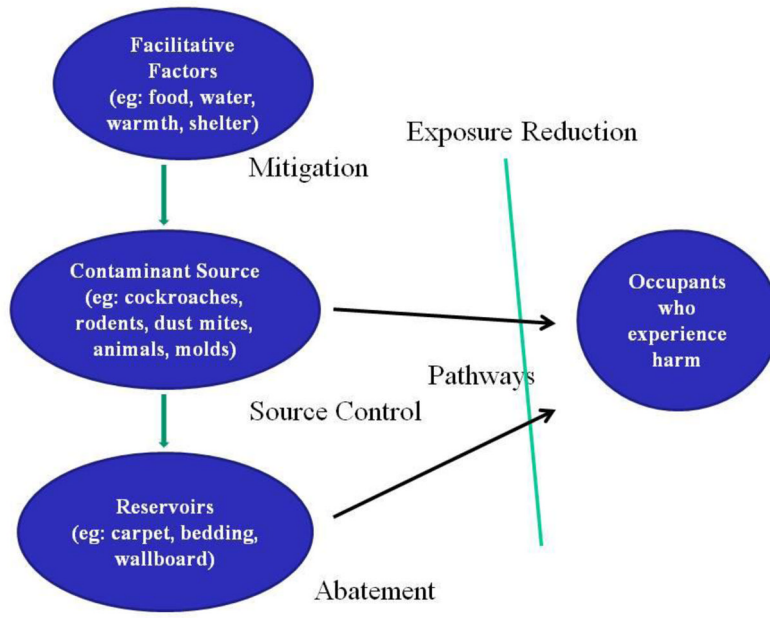


Figure 1.
A model for contaminant production leading to occupant exposure.

Table 1

Allergen exposure thresholds reported in studies of health effects. (Data from Salo et al. [31].)

Dust Mmite (Der p 1)	2 m μ cg/gram
Dust Mmite (der f 1)	2 mc μ g/gram
Cat (fFel d 1)	8 mc μ g/gram
Dog (Can f 1)	10 mc μ g/gram
German Ccockroach (Bla g 1)	2 Uunits/gram
German Ccockroaoch (Bla g 2)	0.04 mc μ g/gram
Mouse (Mus m 1)	1.6 mc μ g/gram