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Indoor allergens

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The term "allergy" defines an immune response that is detrimental or harmful to the host. The human immune system is composed of interacting effector and regulatory systems, and allergy may result from the actions of any of these systems. Coombs and Gell¹ first divided the various mechanisms of allergy into four categories: (1) IgE mediated, (2) the result of specific antibody

binding to cell receptors, (3) the effect of circulating and tissue deposits of immune complexes, and (4) T-cell mediated by cytotoxic mechanisms. Some investigators have subsequently modified this scheme by subdividing these four categories of allergy.^{2 3}

The focus of this discussion is IgE-mediated allergy caused by exposure to indoor allergens. An antigen is a substance that can stimulate a detectable immune response, and an allergen is an antigen that evokes IgE antibody. An antigen or allergen usually has a molecular weight greater than 10,000 daltons (10 kd), a size sufficient to stimulate the immune system. Occasionally substances with a mass of 1000 to 10,000 daltons will be immunogenic. Substances with less than a 1000-dalton molecular weight, which include all airborne chemicals, may become immunogenic if these substances combine with proteins or other chemical entities in the environment or within the body. This most commonly occurs with highly reactive chemicals.

IgE-mediated allergy is common, with more than 40% of the population having IgE antibodies specific for environmental allergens, 20% having clinical allergic disease, and 10% having severe allergic disease.⁴ The prevalence of sensitivity varies with age. Twenty-two percent of children younger than 5 years of age have skin test sensitivity to inhalants, which increases to 44% between the ages of 5 and 13 years.⁵ The peak prevalence of allergic sensitivity to inhalant allergens occurs between the ages of 20 and 45 years.^{6 7}

IgE-mediated immune responses are regulated by T-lymphocytes. The nature of the antigen, the route and frequency of exposure, the amount of antigen, and the genetic background of the exposed person determine if exposure will result in the production of IgE antibody. Atopy is a genetically determined abnormal state of hypersensitivity characterized by an increase in the production of IgE antibody and a greater prevalence of rhinitis, asthma, and eczema when compared with a normal population. Atopic persons are predisposed to developing allergic symptoms after exposure to indoor allergens, usually with symptoms of rhinitis, conjunctivitis, and/or asthma. The immune response to indoor allergens also depends on the time a person spends within the environment and the level of a particular allergen in that environment. The levels of allergens are not usually uniform within a building. For example, dust mite allergen is often found at higher concentrations in the bedroom than in the kitchen, and cockroach allergen is more prevalent in the dining area of a home. Indoor allergens are generally perennial, but environmental exposure varies with seasonal changes. Relative humidity, use of central heating or air conditioning systems, and outside ventilation via windows or door are examples of seasonal changes that influence indoor allergen levels.

The indoor environment contains many allergens that can become airborne. These derive from organic and inorganic sources and are airborne as particles, vapors, or gases. Most indoor allergens are protein, but low-molecular weight chemicals, particularly in industrial settings, have also stimulated IgE immune responses. Indoor allergens can be derived from the outside, from the structure or furnishings of a building, or from the occupants, humans, animals, plants, and fungi. The major indoor allergenic proteins that have been characterized are house dust mite allergens, cat antigens, dog dander antigens, mouse antigens, cockroach antigens, and certain fungal allergens (■Table I).⁸

TABLE I. Defined indoor allergens

Allergen	Molecular weight (kd)	Nature of allergen
Cat		
<i>Fel d I</i>	17-18 or 35-39	Sebaceous and salivary gland secretions
Albumin	65-69	Serum albumin
Cockroach		
<i>Bla gl</i>	20-25 or 35	Unknown
<i>Bla g II</i>	≈36	Unknown
Dog		
<i>Can f I</i>	22-25	Epithelial and salivary protein
Albumin	65-69	Serum albumin
Housed dust mites		
Group I	24	Cysteine proteinase
Group II	14	?Lysozyme
Group III	29	?Trypsin or chymotrypsin
Rodent		
<i>Rat n IA</i>	20-21	Prealbumin
<i>Rat n IB</i>	16-17	Euglobulin
<i>Mus m I</i>	17-21	Urinary prealbumin
<i>Mus m II</i> (antigen 3)	16-21	Epithelial protein

House Dust Mite

TOP

House dust is a mixture of fibers from carpets, furniture, and clothing mixed with grit, sand particles, human skin scales, food debris, and products of various micro- and macroorganisms. These organisms include insects, other arthropods such as dust mites, domestic animals, bacteria, algae, and fungi.

The biologic family of dust mites, *Pyroglyphidae*, includes 47 species in 17 genera. Eleven species of five genera have been found in carpet and mattress dust from human dwellings. The most frequently detected mites are *Dermatophagoides pteronyssinus*, *D. farina*, *Blomia tropicalis*, and *Euroglyphus maynei*. Mites are eight legged and sightless. They are approximately 0.3 mm in length and thus visible only by microscopic analysis of dust. Mites may be grown in the laboratory using various food sources. Their major food source in buildings is skin scales, fungi, and organic debris. Dust mites absorb water through a hygroscopic substance extruded from their leg joints and are entirely dependent on ambient humidity for moisture. Thus dust mites grow poorly if at all in dry or high-altitude climates. Dust mites have a narrow optimal temperature growth range from 18.3° C (65° F) to 26.7° C (80° F).

Dust mite allergen exposure is primarily the result of inhalation of fecal particles containing partially digested food and digestive enzymes. These particles are coated with a membrane that is not waterproof through which the antigens will elute when exposed to moisture, such as found on a mucosal surface. Mite fecal particles are similar in size to pollen grains (10 to 35 μm in diameter).

The first dust mite allergen purified and characterized is designated *D. pteronyssinus* allergen I (*Der p* I).⁹ This antigen and cross-reacting antigens are classified as group I mite antigens. *Der p* I is a cysteine proteinase that is derived from the alimentary canal of the mite. This 24 kd glycoprotein is heat labile and resembles papain structurally and enzymatically. A similar cross-reacting antigen has been isolated from *D. farina* (*Der f* I) and *Euroglyphus maynei* (*Eur m* I). Most mite-allergic persons have IgE specific for group I antigens, which makes this the most important family of dust mite allergens.

A second group of allergens, group II mite allergens, has been purified from *D. pteronyssinus* and *D. farina*. Group II antigens from these two species of dust mites have greater than 90% homology and are strongly cross-reactive. The antigens are 14 kd in size and may be a form of lysozyme, although this has not been firmly established. Group II antigens are more resistant than group I antigens to changes in temperature and pH.

Less information is available on the 29 kd antigen *Der f* III. Its chemical nature has not been precisely characterized. The significance of group III antigens with respect to allergic disease is probably less than that of group I and II antigens.

Two micrograms of group I allergen, or about 100 dust mites/gm of sieved dust, have been associated with the development of allergic sensitivity, and subjects with symptoms generally have more than 500 mites/gm of domestic dust.¹⁰ Subjects with asthma living in Florida who were treated in the emergency room for an asthma exacerbation had a significantly greater sensitivity and exposure to dust mites than a comparable group of subjects with asthma not requiring emergency room treatment.¹¹ It appears that there are levels of exposure or thresholds, below which the risk of sensitization and the development of asthma symptoms are reduced. Exposure to dust mites in buildings other than houses is probably less significant but is a potential problem in any building occupied by people, particularly if the temperature and humidity are controlled. Generally conditions comfortable for humans will permit the growth of dust mites.

Insects

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Anaphylactic reactions to insects result from stings and bites. Limited reports also indicate that insects may be a source of inhalant allergens. The insects described to cause inhalant allergy include cockroaches, moths, crickets, midges, locusts, beetles, and various flies. The primary indoor insect inhalant allergen that has been studied is the cockroach allergen. Three species of cockroaches are found inside buildings: *Blattella germanica*, the German cockroach; *Periplaneta americana*, the American cockroach; and *Blattella orientalis*, the Oriental cockroach. *B. germanica* is the most prevalent, particularly in large, crowded cities in the southern United States and in tropical countries throughout the world.

Cockroach allergens are derived principally from fecal material and saliva. The allergens of *B.*

germanica have been best characterized with two allergens identified, *Bla g I* with a molecular weight of 20 to 25 kd, and *Bla g II* with a molecular weight of ~36 kd. An allergen from *P. americana* has been identified as having a molecular weight similar to that of *Bla g I*. There is cross-reactivity of various degrees among the cockroach allergens. The functions of the allergenic proteins of the cockroach are unknown.

Numerous reports have provided evidence that urban subjects with asthma have sensitivity to cockroach antigens.^{12 15} Sensitivity to cockroach antigens is less common in suburban than in urban settings. Sensitivity to cockroach antigens was related to environmental exposure in one study.¹⁶ Bronchoconstriction with inhalation of cockroach antigens in sensitive subjects has been described.^{14 17} Emergency room visits for asthma have been associated with cockroach sensitivity in an urban environment.¹⁸ Significant levels or thresholds of cockroach allergen exposure have not been determined. Any detectable level of cockroach allergen, using currently available assays, is considered of potential significance. Exposure has been described in homes and apartment buildings, but nondomestic exposure could be important.

CAT

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Approximately 100 million domestic animals live in or in close proximity of homes in the United States.¹⁹ The most common animals kept as pets are cats and dogs, with one third to one half of houses in the United States having a mammalian pet. The sensitivity to cat dander among subjects with asthma ranges from 9% to 41%. Approximately 2 million persons with cat allergies in the United States have a cat in their home. An epidemiologic survey of 16,204 persons ranging in age from 6 to 74 years demonstrated that 2.3% have sensitivity to cat antigens. Extrapolating this data to the general population indicates that 6 to 10 million persons in the United States are allergic to cats.

The major cat allergen, *Fel d I*, is an acidic glycoprotein or group of proteins with a molecular weight of 35 to 39 kd as measured by size exclusion high-pressure liquid chromatography and 17 to 18 kd as measured by gel electrophoresis.²⁰ A portion of the molecule is glycosylated, and removal of the carbohydrate abolishes more than 50% of its IgE-binding activity as measured by RAST. The antigen occurs in all breeds but in varying amounts. Male cats have higher levels than do female cats. The antigen is found in or on cat pelt, saliva, basal squamous epithelial cells, and sebaceous gland excretions. It is detected in voided urine but not in urine collected by catheterization. The concentration of *Fel d I* is 10 times greater at the root of a hair than at the tip.²¹ The antigen is stored on the skin and fur and is distributed by licking and grooming of the animal. Approximately 3 to 7 µg of *Fel d I* is produced daily by the average cat, but this amount is highly variable. The level of 8000 ng of *Fel d I* per gram of dust demarcates a low and significant level of indoor exposure.

Minor cat allergens include proteins from the serum, such as albumin, and from the skin. Some of these minor allergens cross-react with dog.

The size range of airborne particles containing cat allergen is diverse and ranges from less than 2.5

²² μm in diameter to 10 μm . A significant portion of the total indoor cat allergen load is found on particles less than 2.5 μm in diameter, particles that may escape the nasopharyngeal filtration mechanisms. Classroom environments, as well as other nondomestic locales without cats, may contain cat proteins due to passive transportation of the adherent allergens on the clothing of individuals with a cat in their home. Thus cat allergen exposure in nondomestic situations is a potential concern.

Dog

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Dogs are common indoor pets. One survey of nonselected persons showed that 2.3% of 16,204 subjects had skin test sensitivity (immediate wheal-and-flare response) to dog allergen extract.⁶ This was equivalent to the prevalence of cat sensitivity, although other studies have shown a greater prevalence of significant cat allergy in the population. The lack of a well-characterized and standardized extract has hampered efforts to investigate the prevalence and significance of dog sensitivity.

The major dog allergens are *Can f I* and albumin. *Can f I* is detected on the coat and in dog saliva, with very little in the urine and feces.^{23, 24} The allergen is 25 kd in size and is responsible for approximately 25% of the in vitro binding of IgE to dog proteins. The protein source of *Can f I* is unknown. The amount of *Can f I* produced by different breeds varies, but no breed has been found not to produce some of the allergen. The variability of allergenic potential among differing breeds has been shown by skin testing with extracts from various breeds.²⁵

Levels of *Can f I* sufficient to result in the development of symptoms or sensitivity have not been established. Two thirds of indoor air samples from homes with dogs contained measurable dog allergen. *Can f I* levels range from 10,000 $\mu\text{g/gm}$ of dust in homes with dogs to less than 0.3 μg in homes without dogs. However, up to 23 $\mu\text{g/gm}$ of dust was detected in selected homes without a dog, indicating that *Can f I* is persistent or readily passively transported. Dog allergen exposure is a potential problem in buildings other than homes, if some of the occupants have a dog in their home.

Rodents and Rabbits

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Rodent and rabbit allergy is a major problem among workers exposed to laboratory animals; 11% to 15% of such individuals have measurable sensitivity.²⁶ Most laboratory workers are sensitive to more than one species, most commonly rat, mouse, and rabbit. Hamsters, gerbils, and guinea pigs are of increasing importance as sources of exposure to allergenic proteins because of the increased popularity of these animals as pets. Subjects with a history of atopy develop sensitivity and symptoms more rapidly and of greater severity after exposure to rodents and rabbits.²⁷

The allergens of rats and mice have been characterized to a limited degree, but very little information is available on other rodent allergens. The two major allergens, *Rat n IA* and *Rat n IB*, are prealbumin and euglobulin, respectively. Both proteins are detected primarily in the urine and immunologically cross-react. *Rat n IB* is found in high concentrations in sexually mature male

animals but minimally in females or juvenile animals. The rat allergens readily become airborne when the animals' living quarters are disturbed, with the levels varying with differing degrees of disturbance—highest with feeding or cleaning of cages and 10-fold lower during surgery and

sacrifice.²⁸ Two major mouse allergens have been partially characterized. *Mus m* I has 80% homology with *Rat n* IA and is murine urinary prealbumin. The second allergen, *Mus m* II or antigen 3, is found principally in hair follicles and squamous epithelial cells. The urinary proteins of mice vary among different inbred strains, which partially explains the variable tolerance of allergic subjects to different strains.

Mouse allergenic proteins have been detected in air filters, wall wipe samples, and air samples from animal housing rooms. Mouse antigens have been identified in air samples from urban domestic dwellings, but it is not known whether the levels of these allergens are sufficient to result in

disease.²⁹

Rabbit allergens have not been well characterized, but their major sources seem to be saliva and fur. Likewise, guinea pig allergens have not been studied sufficiently to identify specific antigens, but the primary source of allergens is the urine. IgE has been demonstrated to bind to hamster dander extract and gerbil serum and pelt extract. Exposure to these latter rodents will probably cause symptoms in allergic subjects.

Birds

TOP

Exposure to avian proteins not uncommonly results in diseases in occupations such as egg-processing and bird breeding. Ten percent or more of workers in egg-processing plants develop allergic asthma.²⁹ Other indoor environments in which the potential exposure to avian proteins exist include areas in which feather pillows, comforters, quilts, or down-filled clothing is used. The chemical identity of avian allergens has not been determined, although the antigen responsible for pigeon breeder's disease is pigeon serum γ -globulin. Feather extracts may be contaminated with dust mite antigen, which results in an overestimate of feather sensitivity.

Fungi

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Fungi are eukaryotic organisms that reproduce asexually and sexually and produce spores in one or both of these reproductive life cycles. Fungi grow at variable pH levels, including acidic conditions, and compete with bacteria for organic nutrients. Digestion of their food sources occurs externally after the excretion of enzymes into the environment. Bacterial competition is controlled by excreting toxins, which inhibit bacterial growth. The combination of excreted materials is designated mycotoxins. Fungi are ubiquitous with species found in the soil (e.g., *Basidiomycetes*, which produce visible fruiting bodies), in living plant tissues, in stored organic material (e.g., *Aspergillus* and *Penicillium* species), and in indoor damp environments such as basements, window sills, shower stall surfaces, carpeting, air conditioning systems, and humidifiers. *Aspergillus*, *Curvularia*, *Cladosporium*, and other species of fungi may grow saprophytically on mucous membranes of human sinuses and bronchi, resulting in a severe, hypersensitivity reaction. This colonization occurs in atopic individuals and is associated with marked elevation of total serum IgE as well as an

increase in specific IgE against the causative organism. The requirement for the growth of the organism in these situations suggests that the excretion of various products by the growing fungi is important in the development of the immune response and allergy to the fungus.

The prevalence of fungal allergy as defined by epicutaneous testing varies from 1% to 10% in subjects with respiratory symptoms to 27% in atopic populations.^{30 31} A study of subjects with asthma in a humid climate demonstrated a prevalence of fungal sensitivity as high as 70%.³² The most commonly recognized outdoor allergenic molds include *Alternaria*, *Cladosporium*, *Aspergillus*, *Penicillium*, *Candida*, *Botrytis*, and *Helminthosporium*. The most prevalent indoor molds responsible for allergy are *Aspergillus* species, *Cladosporium*, and *Penicillium*.³³

Outdoor factors that increase indoor mold spore levels include the use of shaded buildings, storing organic debris near the building, and nearby natural or unkempt property.³⁴ Indoor factors that lower mold spore levels include central electrostatic filtration, lower ambient humidity, and consistent compliance with “dust avoidance measures.”³⁵ The principal concerns of potential mold exposure in nondomestic buildings are contamination of equipment containing moisture, such as humidifiers and air conditioning equipment, dampness in carpeting and stored paper and other organic materials, and soil used for indoor plants.

Fungal allergens are found primarily in the spores but also occur in other structures, such as mycelia. Fungal allergens may be derived from the structural components of the organism or from the material excreted into the environment. The mycotoxins and other excreted materials may be allergens or act as modifiers to amplify or accentuate the allergic response. All the identified fungal allergens to date are water-soluble glycoproteins, some of which are enzymes. Evidence suggests that high-molecular weight carbohydrates may be allergens.³⁶ Unfortunately, only a few fungal allergens have been sufficiently characterized to determine their precise chemical nature.^{36 40}

Currently available fungal extracts are complex mixtures of soluble materials from mycelia, spores, and cellular metabolites and cytoplasm. These extracts are usually produced from fungi grown in laboratories, usually in liquid media. The life form of fungi may vary during the culture process, adding to the complexity of the extract and reducing the batch-to-batch consistency. Mushroom and other macrofungi extracts are often prepared from collections of field samples. Batch-to-batch variability may exceed the variability among strains, species, or even genera.^{41 42} The location of fungal growth, nutritional source, and even season of the year may influence the contents of an allergenic extract.⁴³ All these factors have confounded efforts to standardize and characterize fungal allergens.

Plants and Plant Products

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The pollen produced by wind-pollinated plants is a common cause of seasonal allergic disease in atopic subjects. Pollen production is seasonal and varies in quantity, depending on geographic location and climatic conditions. Outdoor pollen can enter indoor environments by way of ventilation systems, open windows, or transport by objects such as clothing. Indoor pollen concentration may

be significant during the peak outdoor pollen season, with up to 5 to 6 million pollen grains per gram of dust.^{[44](#) [47](#)} Although the pollen burdens in the indoor environment do not rival the levels found outdoors, the fact that most people spend most of their time indoors makes the contribution of indoor pollen exposure potentially significant.

Indoor plants are grown for their foliage and are adapted to the reduced light of inside environments. These plants do not produce pollen and are not highly allergenic. However, some indoor plant parts are potential allergens, including airborne leaf parts from *Ficus benjamina* (weeping fig) and the nectar secretions of *Abutilon striatum* (flowering maple), an ornamental plant frequently kept indoors.^{[48](#) [49](#)}

Plant materials are another potential source of indoor allergens. Psyllium, a fiber derived from a grass species, has been reported to result in allergic symptoms from inhalation of dust in both manufacturing and hospital settings. This fiber is used for bowel control by many individuals and is a potential indoor allergen in other environments. Latex is another plant product that may be an important indoor allergen in certain health care environments, particularly hospitals. Other plant-derived allergens, such as cotton dust, coffee dust, soy bean dust, and flour dust, are found primarily in manufacturing environments.

Other Indoor Allergens

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Bacteria are able to grow in a wide range of conditions, both outdoors and indoors. A diversity of species can be found in soil and natural bodies of water. Gram-negative bacteria often predominate on the surfaces of plants and are able to survive for brief periods while airborne. The primary source of indoor bacterial aerosols are water-containing devices, such as humidifiers and cooling towers, and stored organic material. *Bacillus* species predominate in house dust. Thermophilic organisms grow in warm temperatures (45° to 60° C) and may be found in refrigerator drip pans, exhausts of clothes driers, humidifiers integrated into heating systems, evaporative cooler systems, and organic material that is stored in the warmth or is decomposing.

Bacteria and bacterial product aerosols are the etiologic agents of several diseases, including pneumonia and hypersensitivity pneumonitis. Bacteria are less frequently recognized as the etiologic agent for IgE-dependent allergic responses. Endotoxin, a product of certain bacteria, may serve as an adjuvant, increasing the symptoms after a specific allergen exposure or increasing the potential for the development of allergic sensitivity after exposure.^{[50](#)}

Protozoa are microscopic organisms that occupy aquatic or other very moist environments. Protozoa are too large to remain airborne and are therefore not a source of allergens if intact. However, fragments or excretions of these organisms may become airborne in water droplets and have been associated with humidifier fever and occupational asthma.^{[51](#)} The major source of exposure is water-filled devices.

Exposure to more than 100 low-molecular weight chemicals has been reported to result in allergic reactions in select populations.^{[52](#)} Low-molecular weight chemicals are of insufficient size to evoke an immune response. They must usually combine with proteins, after which the chemical substance

serves as a hapten and the protein, an immunologic carrier. Sensitivity to chemicals may result in allergic respiratory and dermatologic disease as well as systemic disease. Most exposures occur in industrial settings and not in domestic, office, or other nonmanufacturing buildings. Chemicals that have been identified to result in allergic symptoms include anhydrides in plastic manufacturing, isocyanates in facilities in which paint or polyurethane is used, metal salts related to processing or welding activities, antibiotics and other select pharmaceuticals in pharmaceutical manufacturing as well as hospitals and pharmacies, ethylenediamine from indoor use of certain coatings, and azo-dyes in buildings in which dyes are manufactured or used in bulk quantity. Isocyanate exposure could occur in nonmanufacturing settings from use of refinishing agents during remodeling and ethylenediamine from use of shellacs and lacquers.^{53 54} Formaldehyde has been suspected to result in allergic disease. Although positive bronchial challenge studies have been reported, other investigators have not confirmed these findings, even when IgE for formaldehyde has been detected.^{55 58} Other volatile organic chemicals, such as toluene, serve as indoor irritants without evidence of specific sensitivity.

Conclusions

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The indoor environment is of increasing importance with respect to allergen exposure as a result of the large percentage of time spent inside. Environmental factors that have increased indoor allergen exposure in the later half of the twentieth century include the prevalence of pets and other indoor animals, higher mean indoor temperatures, increased use of water-containing equipment such as humidifiers and air coolers, increased relative humidity resulting from high-occupancy buildings with tight insulation and reduced ventilation, fitted carpets, and cleaning procedures that use cool water washing. The role of construction material and decors emphasizing synthetic materials and plants is less well defined. Research objectives to enhance an understanding of indoor allergens include the development of standardized allergen extracts for diagnostic purposes, studies to determine the relative importance and distribution of indoor airborne fungal material, and improvement in indoor allergen exposure quantification.

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Gustavo Silveira Graudenz, Richardt G. Landgraf, Sonia Jancar, Arlindo Tribess, Simone G. Fonseca, Kellen Cristhina Faé, Jorge Kalil

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Evaluation of air and dust sampling schemes for Fel d 1, Der f 1, and Der p 1 allergens in homes in the Detroit area

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Edward L. Peterson, PhD^a, Dennis R. Ownby, MD^b, Lee Kallenbach, PhD^c, Christine C. Johnson, PhD^a

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Influence of airborne nitrogen dioxide or formaldehyde on parameters of skin function and cellular activation in patients with atopic eczema and control subjects

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