Ecology and elimination of cockroaches and allergens in the home

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Cockroach infestations have been indicated as a major contributor to asthma throughout the world. Several studies have shown that large numbers of asthmatic patients are sensitized to cockroach allergens. Eliminating this pest from homes, schools, and public buildings involves a long-term commitment to a rational extermination process. This article covers the characteristics of the major cockroach species that invade homes, assesses the role of environmental exposure to cockroaches in asthma, and provides an intervention program for their extermination. (J Allergy Clin Immunol 2001;107:S422-9.)

Key words: *Cockroach, cockroach allergen, environmental exposure, asthma, intervention, integrated pest management*

Among the 3500 known species of cockroaches, only 5 commonly inhabit homes and have the potential to contribute to indoor allergens. These include the American *(Periplaneta americana)*, German *(Blattella germanica)*, Oriental *(Blatta orientalis)*, smokey brown *(Periplaneta fuliginosa)*, and brown-banded *(Supella longipalpis)* varieties.[1]

ANATOMIC AND LIFE-CYCLE CHARACTERISTICS

All the cockroach species that inhabit homes are quite similar in appearance (Fig 1), but there are enough distinguishing anatomic and life-cycle characteristics among them to permit ready identification. The German cockroach is about 16 mm in length and brown in color, with 2 dark longitudinal streaks on the protonotum. The female is slightly darker brown, with a broader rounded posterior. The American cockroach is larger, 38 mm in length, with fully developed reddish brown wings; it flies short distances. The Oriental cockroach is 25 mm in length and is dark brown to black, hence the common name black beetle. The male has rudimentary wings, but neither the male nor female can fly. The smokey brown cockroach is approximately 2 cm in length, with wings that are larger than the abdomen. The brown-banded cockroach is smaller, rarely larger than 1 cm, and is easily distinguished from the German cockroach by the lighter bands that cross at the base of the abdomen.

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Abbreviations used
ED: Emergency department
GST: Glutathione-S-transferase

ECOLOGY

Although cockroaches are found throughout the world, the American, brown-banded, and Oriental cockroaches tend to predominate in tropical and subtropical regions.[1]

German cockroaches gather or aggregate in dark, warm (21°C), humid crevices around water and food sources, such as heaters, laundries, bathrooms, appliances, and plumbing fixtures. They prefer narrow cracks (5 mm) that touch the abdomen and carapace, and rarely leave this harborage, except to feed and drink at night. They feed on almost anything with nutritive value, including grease, soap, glue, and toothpaste. Although they require freestanding water, they can live for days without food and water. Adults and nymphs cluster together. They move widely and rapidly within structures but uncommonly move across open spaces between structures, and they rarely fly. When these insects are seen during the day, it is an indication that large hungry populations are present.

Brown-banded cockroaches prefer to live in the higher temperatures generated by appliance motors, clocks, timers, television sets, and shower stalls. These roaches are quite active, and both males and females fly. Both adults and nymphs are found at high elevations within homes, such as on ceiling fixtures and the upper areas of walls. They do not require as much moisture as German cockroaches and can exist without freestanding water sources. They prefer feeding on starchy materials but will eat anything. In northern climates they are generally found in the warmest parts of buildings.

The Oriental cockroach (water bug, black beetle, or shad roach) is slower than the other species, and neither males nor females fly. They tend to aggregate in damp areas, such as basements, plumbing, and sewers. They are seldom found on walls or in the upper floors of buildings. They demonstrate marked seasonality; peak numbers of adults are found outdoors in late spring and early summer, and indoor populations increase during droughts and in cold weather. They feed on decaying organic matter wherever they colonize. Outdoors they are commonly found in refuse piles and landfills and beneath leaves and mulch. They are more dependent on water than other species and will die within 2 weeks without water. However, they can live for a month without food.

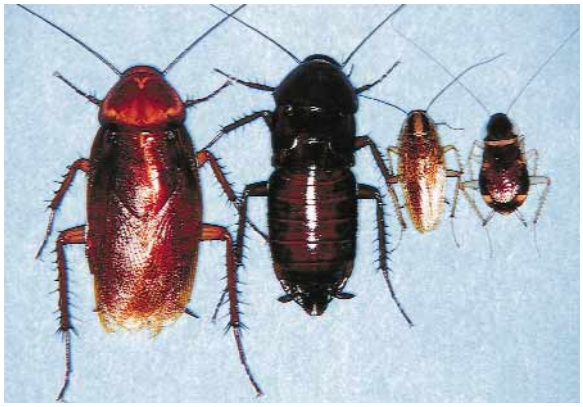


FIG 1. Common cockroaches found in homes. From Joseph Kalisch, Entomology Department, University of Nebraska (ianr-www.unl.edu/ianr/pat).

The American cockroach (water bug, flying water bug, or palmetto bug) aggregates in dark humid places, such as boiler rooms, heated steam tunnels, sewer manholes, floor drains, water heaters, clothes hampers, and bathtubs. In basements they are usually found in ceiling corners. They may migrate between freestanding buildings, traveling in the open or through steam tunnels; they can fly short distances in warmer areas. They may also live outdoors in the warmer climates in leaves, woodpiles, or pools; they are mostly outdoors in spring and early summer. Adults can live for a month without food or water. They eat any organic food but are especially attracted to sweets, beer, and other alcohol products. They may coexist with German cockroaches.

The smokey brown cockroach is another species that migrates in and out of buildings with weather. In homes it is found in attics, typically at the roof line. It generally eats decaying vegetation, but when it enters a building, it can feed on anything that other roach species eat.

The several species implicated in human disease have similar life cycles (Table I). Eggs are contained in egg cases, holding between 10 and 50 eggs each. These cases are usually deposited on objects in the environment. The exception is the German cockroach; its egg cases are attached to the female abdomen until a day or two before hatching. Nymphs are anatomically similar to adults and pass through 6 to 12 molts to reach maturity. Mature insects live from 3 to 15 months. Females lay numerous egg cases each year, with the highest number laid during optimal living conditions.

ALLERGENS

Cockroach allergens are derived from several sources, such as saliva, fecal material, secretions, cast skins, debris, and dead bodies. Significant amounts of allergen can be recovered from cockroach washings and from the secretory debris called *frass* that accumulates in jars where cockroaches are kept in the laboratory. Several allergens from both *B germanica* and *P americana*, the most common domiciliary cockroach species, have been purified, sequenced, cloned, and produced as recombinant proteins (Table II).[2-15]

Most cockroach allergens appear to be species specific. The only cross-reactive allergens that have so far been sequenced from both *B germanica* and *P americana* are the group 1 allergens Bla g 1 and Per a 1.[8,9,16] Natural Bla g 1 and Per a 1 have been previously identified by using immunochemical techniques and were shown to elicit IgE responses in 30% to 50% of patients allergic to cockroaches.[10,11] Bla g 1 has an unusual structure consisting of a series of up to 7 tandem repeats, each approximately 100 amino acid residues in length,[8] and includes an allergen originally reported as Bla g bd90K.[12] cDNAs encoding Bla g 1 show 70% to 72% sequence identity to Per a 1.[9] The cross-reactive group 1 cockroach allergens show 30% homology to a mosquito *(Anopheles gambiae)* protein precursor, ANG12, which is secreted only in the female insect after a blood meal. This finding may suggest that these proteins have a digestive function.[8,14]

Bla g 2 is a 36-kd allergen that shows homology to aspartic proteases, including pepsin, cathepsins, and chymosin.[4] High concentrations of Bla g 2 have been found in cockroach digestive organs, particularly in the esophagus, proventriculus, and gut. Bla g 2 can also be recovered in high levels from cockroach washings. Levels of Bla g 2 and Bla g 1 can be measured in house dust and airborne samples and have been widely used to assess the role of environmental exposure to cockroaches in asthma.[17] The prevalence of IgE to Bla g 2 among patients allergic to cockroaches ranges from 60% to 80%.

Bla g 4 was the first *B germanica* allergen to be cloned and belongs to a super family of ligand-binding proteins (also known as calycins or lipocalins).[5] This family includes other important allergens, such as mouse and rat urinary proteins[18,19]; dog, cow, and horse epithelial allergens[20-23]; and β-lactoglobulin from cow's milk.[5,23] The lipocalins are extracellular proteins that bind hydrophobic molecules with high affinity and selectivity. The rodent urinary allergens are pheromone-binding proteins. It is tempting to speculate that Bla g 4 may have a similar function in the cockroach.[19] Although the overall sequence homology is only approximately 20%, members of the calycin family share similar 3-dimensional structure. Models of the tertiary structure of Bla g 4 were obtained on the basis of the homology to butterfly bilin-binding protein and predicted a similar structure to other members of the calycin family. Recombinant Bla g 4 expressed both in bacteria and yeast has excellent allergenic activity.[5,7] Serologic studies suggest that the prevalence of IgE to recombinant Bla g 4 is 60%. Bla g 5 is a member of the glutathione-S-transferase (GST) family of enzymes,[6] showing 40% to 50% homology to other insect GSTs and 28% homology to house dust mite GST allergen (Der p 8). GSTs are enzymes involved in the detoxification of endogenous and xenobiotic toxic compounds, and their production in insects is associated with resistance to insecticides. Therefore it is possible that GST allergen production could be upregulated by the use of insecticides.

TABLE I. Life cycle of cockroaches

	Incubation (d)	Nymph (d)	Lifespan (d)	Egg cases	Cases per yr	Eggs per case
German	28	60	100-200	13-16 mm; female carries	5-6	18-50
American	30-60	180-400	100-500	8-10 mm; cracks, crevices	12-24	14-16
Brown-banded	50-75	160	113-136	8-10 mm; behind appliances	14	13-18
Oriental			318-533	5-8 mm; surfaces	16	1-8
Smokey brown	30-60	100-500	191-586	12-16 mm; black, attached to objects	24	17

TABLE II. Immunochemical properties of cockroach allergens

Species	Allergen	Prevalence of IgE antibody (%)	Molecular weight	Function
Blatella germanica	Bla g 1	30%-50%	20-25 kd	Unknown
	Bla g 1 (Bd90K)*	77%	90 kd	Unknown
	Bla g 2	60%	36 kd	Aspartic protease
	Bla g 4	40%-60%	18 kd	Lipocalin (calycin)
	Bla g 5	70%	23 kd	GST
	Bla g 6	50%	18 kd	Troponin C
Periplaneta americana	Per a 1†	~50%	20-25 kd	Unknown
	Per a 3	>80%	72 kd	Arylphorin-hemocyanin
	Per a 7	50%	33 kd	Tropomyosin

*The Bla g 1 allergen shows 94% homology to the nucleotide sequence previously termed Bla g Bd90K,[11] now designated as Bla g 1.0102, according to the World Health Organization/International Union of Immunological Societies nomenclature. The Bla g 1 clones presently identified comprise the isoforms Bla g 1.0101 and Bla g 1.0102 and the isoallergen Bla g 1.02 (75% sequence identity).[7] Group 1 cockroach allergens (Bla g 1 and Per a 1) consist of a number of tandem amino acid repeats of approximately 100 amino acid residues.[7,8,14]

†Per a 1 clones comprise 4 isoforms, Per a 1.0101, Per a 1 0102, Per a 1.0103, and Per a 1.0104, and one isoallergen, designated as Per a 1.02 (78.2% sequence identity).[8,14]

Bla g 5–specific IgE antibodies are found in 70% of the patients allergic to cockroaches. The cDNA for Bla g 6 encodes a protein of an estimated molecular weight of 21 kd, which shows homology to troponin-C.[2]

Two Per a 1 isoallergens (amino acid sequence identity ≥67%) have been cloned, and the Per a 1.01 sequence comprises 4 variant isoforms (amino acid sequence identity ≥93%). Recombinant Per a 1 has been expressed in yeast *(Pichia pastoris)* and bacterial systems.[9,15,24] Allergens from *P americana* reactive with sera from patients living in Taiwan have been reported,[13-15,24,25] including Per a 3, an insect storage protein related to arylphorin (20.1%-36.4%).[15] Skin tests with natural Per a 3 elicited positive reactions in 83% of the patients; however, only 47% of the patients showed reactivity to recombinant Per a 3 produced in bacteria.[24]

Per a 7, a major cockroach allergen that reacts with approximately 50% of sera from patients allergic to cockroaches, has been recently identified. It shows high a degree of sequence identity to tropomyosins from invertebrates, particularly from mites (80% identity), shrimp (82% identity), and snails.[3,26] Tropomyosins had been previously identified as important allergens in mites (*Dermatophagoides pteronyssinus* Der p 10 and *Dermatophagoides farinae* Der f 10) and shrimp.[27-32] It is possible that tropomyosin may be the basis for cross-reactivity among mites, cockroaches, and shrimp and that the high degree of sequence identity has clinical significance.[32] Recombinant cockroach proteins could potentially be used to standardize extracts, used in cocktails as skin test reagents, or used in a modified form for immunotherapy.

EPIDEMIOLOGY

The initial observations by Bernton and Brown[33] in New York showed that approximately 40% of their patients with asthma were sensitized to cockroach allergens. In Chicago, Kang et al[34] identified up to 60% of patients with cockroach allergy among those with asthma. A similar prevalence of cockroach sensitization has been found in several other US cities, including Boston; Detroit; Washington, DC; New Orleans; Atlanta; Louisville; Tampa; and Kansas City.[2] Emergency department (ED) asthma studies carried out in Charlottesville, Virginia, and Wilmington, Delaware, confirmed that sensitization to cockroaches was an important risk factor associated with asthma admissions to the ED for both adults and children. In each of the ED studies, the prevalence of IgE antibodies to cockroach, ranging from 18% to 33%, was comparable with the prevalence seen to mite, cat, or pollen allergens.[35-37]

Cockroaches are an important cause of asthma in many other regions of the world, including Taiwan, Japan, Thailand, and Singapore in the Pacific Rim; Costa Rica and Puerto Rico in Central America; India; South Africa; and, more recently, Europe.[2] In France 24.5% of patients with asthma, rhinitis, or both, have been deemed sensitive to cockroach allergen on the basis of skin test reactions to *B germanica*.[38] A study from Italy showed that 12.7% of children with allergies had positive skin test responses to cockroach extracts, including patients with asthma, rhinitis, urticaria, and atopic dermatitis.[39] A recent study from Brazil showed that 55% of children and young adults with asthma, rhinitis, or both had positive skin prick test responses to *B germanica* or *P americana*.[3]

DISTRIBUTION IN HOMES, SCHOOLS, AND PUBLIC BUILDINGS

ELISAs have been developed for assessing allergen exposure to cockroach allergens, including Bla g 1, Bla g 2, Per a 1, and Per a 3,[2] which provide a quantitative test for measuring allergen in house dust. The primary site of cockroach accumulation is the kitchen, where levels of cockroach allergens are highest. However, somewhat lower allergen levels can also be found in dust samples from sofas, bedding, and bedroom floors.[35,40] Levels as high as 14,000 U of Bla g 1 per gram of dust have been reported in homes in the United States and elsewhere. Approximately 20% to 48% of homes without visible cockroaches contain detectable cockroach allergen in dust samples.[35,41]

Cockroach allergen Bla g 1 was detectable in bedding and bedroom floor samples of 85.3% of homes of inner-city children with asthma, and levels of Bla g 1 of 8 U/g of dust or greater, which are considered high and proposed as a disease-induction threshold, were found in 50.2% of those bedrooms. On the other hand, only 12.6% and 9.7% of the bedrooms had high levels of cat and mite allergens, respectively, indicating that cockroach exposure is very important in this group of asthmatic children.[42] Heavy cockroach infestations in homes may create reservoirs of allergen in carpets and rugs, as well as in inaccessible spaces around appliances and furniture.

In the inner-city schools of Baltimore, 69% of the dust samples were shown to contain detectable levels of the cockroach allergen Bla g 1.[43] Levels were reported higher in food-related areas (median, 5.8 U/g; maximum, 591 U/g) compared with levels in the classroom (median, 2.4 U/g; maximum, 186 U/g). It is likely that current infestation was the problem on the basis of visual evidence of cockroach infestation in those schools. In British schools 65% of the classrooms sampled had levels of the cockroach allergen Bla g 2 of greater than 2 U/g of dust.[44] These results indicate that schools may be an important source of exposure to cockroach allergens. In day nurseries in Marseille, France, levels of Bla g 1 and Bla g 2 in mattresses, pillows, soft toys, and on floors were mostly undetectable or very low.[45] No cockroach allergen (Bla g 2) was detected in dust and air samples from hospitals in England.[46]

Seasonal variation in cockroach infestation has been found in a study of 6 inner-city apartments in Blacksburg, Virginia, where samples were taken monthly for a period of 1 year. In the kitchen the number of cockroaches captured in sticky traps peaked in June, whereas the highest levels of Bla g 2 allergen did not peak until August. Allergen levels remained elevated several months after the drop in the number of detected cockroaches in the apartments.[47]

AIRBORNE ALLERGEN

Cockroach aeroallergen particles have properties similar to those of mite allergens: they are relatively large (>10 μm in diameter), are detectable mainly after disturbance, and fall to the ground and settle rapidly.[40,48] For cockroaches, 74% to 80% of aeroallergens are associated with particles larger than 10 mm, which is in contrast to animal allergens, which are carried on small airborne particles. Patients are usually not aware of being allergic to cockroaches and do not report symptoms of asthma on entering a house that is infested with them.

Recently, intranasal and air samplers and a sensitive immunostaining system were used to investigate the behavior of cockroach allergen–carrying particles in Australia.[48] Bla g 1–carrying particles could be detected during quiet domestic activity or even under no disturbance both in the air and in nasal filters in houses containing low levels (geometric mean, 1.5 U of Bla g 1/g of dust) of allergen. In agreement with previous studies, airborne particles containing cockroach allergens were associated with particles greater than 10 mm in diameter. These particles, described as flakes or fibers, may contain sufficient allergen to induce sensitization and chronic inflammation on inhalation.

RELATIONSHIP TO SENSITIZATION

Bernton and Brown[33] were the first to report positive skin test responses to cockroach allergen in 44% of 755 allergy clinic patients in New York. Subsequently, many authors recognized that patients with asthma living in cities were commonly sensitized to this insect.[2] Kang et al[34] established the causal relationship between cockroach allergy and asthma by showing early-phase, late-phase, and dual bronchoconstriction after inhalation of cockroach extract by sensitized asthmatic patients. These studies have clearly demonstrated that asthma caused by cockroaches is antigen specific and is similar to other types of atopic asthma.

Several studies[2,35,49] have demonstrated that most patients sensitized to cockroaches were exposed to high levels of cockroach allergens in their homes and that cockroach allergy is an important risk factor for emergency department (ED) visits for asthma and hospital admissions. A clear relationship has also been demonstrated between current exposure to Bla g 1 and current sensitization to cockroaches in asthmatic children living in the inner-city environment. Although the highest levels of cockroach allergens were detected in the kitchen, the best correlation was found between sensitization and allergen concentration in the children's bedroom.[50] These studies provided the basis to propose threshold levels of cockroach exposure above which susceptible individuals would be at an increased risk of having sensitization or asthma symptoms. These levels have been defined as 2 U/g and 8 U/g of allergen, respectively.

A recent prospective study[51] has demonstrated a significant association between exposure to cockroach allergens in the first 3 months of life and the development of repeated wheeze in the first year among children in metropolitan Boston. The presence of cockroach allergen in the family room and repeated wheezing continued to be significant after adjustments for socioeconomic factors,

TABLE III. Insecticides for cockroach control

	Preparations	Mechanism	Effectiveness	Toxicity	Preparations	Comment
Organophosphates	Diazinon chlorpyriphos (Dursban)	Cholinesterase inhibitor	Diazinon 40%-98% kill in 1 mo	LD_{50} 135 mg/kg, CNS, flu-like GI symptoms, short residual time	Liquid spray 1%-2% dust	
Carbamates	Carbaryl (Sevin), propoxur (Baygon)	Cholinesterase inhibitor		LD_{50} 500 mg/kg, CNS, flu-like GI symptoms	Granules, wetable powder emulsion	
Pyrethrins	Permethrin, deltamethrine, fenvalerate sumethrine	Inhibit ATP formation	Sumethrine 50%-85% kill in 2 wk	LD_{50} 4000 mg/kg, tremor, choreoathetosis	Microencapsulated Wetable powder	Also added for quick kill, flushing of insects
Chlorinated hydrocarbons	Chlordane, lindane	CNS inhibitor		LD_{50} 400 mg/kg		Long residual
Avermectins	Abamectin (Avert, Raid)	GI, neurotoxin, ovulation inhibitor	Abamectin 92% kill 1 mo	LD_{50} 5000 mg/kg	0.05% gel granules, bait stations	
Miscellaneous	Fipronil, hydromethylnon (Combat, Max-Force), sularamide	Fipronil blocks GABA-gated Cl channel is an ATP inhibitor	92% kill in 1 mo	LD_{50} 1500-5000 mg/kg	Gel, bait stations	
Growth regulators	Methoprene, hydroprene, fenoxycarb; biflubenzaron, alsystin	Molting hormone inhibitors; chitin synthase inhibitors	90% kill 4-5 mo	LD_{50} 10,000 mg/kg	0.125% liquid aerosol	
Inorganics	Boric acid	ATP inhibitor	25%-50% kill in 2 wk	LD_{50} 2500 mg/kg	1% spray, 30%-50% baits	

LD_{50}, Dose causing death in 50% of test animals; *CNS,* central nervous system; *GI,* gastrointestinal; *ATP,* adenosine triphosphate.

such as income and race. One study[52] has reported an increased risk of sensitization to cockroaches among asthmatic children born during the winter months in Chicago.

RELATIONSHIP TO MORBIDITY

Distinctive characteristics of asthmatic subjects with cockroach allergy compared with those of asthmatic subjects sensitive to other allergens, particularly ragweed, have been identified by analyzing patients living in Chicago.[53] Cockroach sensitivity affected more female subjects, except in the age group under 15 years. Patients allergic to cockroaches had year-round symptoms of asthma, with winter exacerbations requiring ED visits or hospitalization. In addition, they had a longer duration of asthma, were sensitive to fewer other allergens beside cockroach, and showed a higher proportion of steroid dependency, suggesting a more severe disease. Patients with cockroach allergy also had high levels of serum IgE antibodies compared with other asthmatic subjects and a higher prevalence of elevated total IgE compared with patients allergic to ragweed. Most patients with cockroach-induced asthma also had allergic rhinitis. Cockroach sensitization is specifically associated with the severity of inner-city asthma caused by exposure to high levels of cockroach allergen in the home.

More recently, the National Cooperative Inner City Asthma Study[42] has confirmed that the association of sensitization and exposure to cockroach allergens is a major risk factor for morbidity caused by asthma in children from large cities in the United States. Children with asthma who were sensitized to cockroaches and exposed to high levels of cockroach allergen in their bedrooms had more clinical symptoms, greater effects on daily activities, increased missed school days, more nights with lost sleep, and more frequent use of health care services than asthmatic children not sensitized to cockroach or not exposed.

SOCIOECONOMIC STATUS RELATIONSHIP

Cockroach allergy is strongly linked to socioeconomic factors, and it occurs wherever living conditions favor cockroach infestation.[2,17,54] In the early 1970s, the close association between cockroach sensitivity and low socioeconomic status of patients was already appreciated.[55-57] It has become apparent that this association is a result of increased exposure to cockroach allergens, particularly in the indoor environment, and it appears to be independent from age, sex, and race. In southeast San Diego cockroaches are a significant cause of IgE-mediated sensitization among Hispanic children with asthma.[58]

Most of these socioeconomically disadvantaged children were exposed to levels of the cockroach allergens Bla g 1 and Bla g 2 that were above those reported as threshold levels for increased sensitization, particularly in dust recovered from bedroom carpet samples.

Studies in Charlottesville, Virginia, and Wilmington, Delaware, both medium-sized cities, have emphasized that cockroach sensitization is not confined to inner-city populations but occurs wherever substandard housing or apartment buildings sustain cockroach infestation.[35-37] An association between higher frequency of cockroach sensitization in individuals living in houses valued at less than $60,000 compared with those living in houses valued at more than $100,000 has been reported.[2]

INTERVENTIONS TO ELIMINATE COCKROACHES AND ALLERGENS

Inspection is an important first step in cockroach extermination. Not only can the species be identified, but their likely hiding places and travel routes can also be identified. The inspection should be conducted with an understanding of the ecology of the insects and with the idea that insecticides will be most effective and least toxic to human residents if they are targeted to hiding areas. In addition to seeing living insects, evidence of cockroach habitation should be sought, including body parts, feces (black specks the size of sand grains), and stains from regurgitated digestive juices that appear as brown stains in the edges of cabinets or inside drawers. The inspection should also target food sources that harbor insects. These food sources include grease and other cooking debris in the kitchen, garbage cans kept inside, pet food, and open snack food containers. Water sources, which provide another living requirement and determine migratory patterns, should also be identified to provide targets for baiting and pesticide spraying.

Available insecticides are listed in Table III. Although the pesticides may be applied in almost any form, the preferred method is to use selected placement of gels or baits. This approach is termed *integrated pest management*, and it has become a widespread practice used in inhabited buildings to avoid risk from the pesticides.

In kitchens, for example, it is possible to apply the 5- to 15-mm gel spots widely to cracks, crevices, and the junctures of cupboards or walls with floors and of counters with walls without making them accessible to children and pets. Neither the materials nor the application methods are more expensive than the older spray methods. Because the gels contain sugars and other attractants for roaches, the pesticides are carried back to harborage and provide a more effective population reduction that lasts longer than previously used methods.

Bait traps have been developed with narrow openings that limit access to the attractant and pesticide; these products are just as effective as the gel baits if used properly. One of the important conditions for successful use of enclosed or gel baits is to provide enough coverage for large populations. Be aware that hungry roaches may clean out the traps before the whole population is controlled. Most technicians will recommend a second treatment within a week or two to overcome this problem.

Typically, successful treatments will provide significant reduction within 2 weeks, will demonstrate maximal effect by about a month after application, and will keep populations under control for 3 to 6 months. The time frame can be extended by changing cleaning practices to remove grease and other food debris from the kitchen, by storing food in plastic containers or in a refrigerator, and by eliminating food debris from other areas of the home (the television room or bedroom).

Household cleaning is an essential adjunct to successful allergen removal. Before applying insecticide, a good general cleaning should remove additional food sources so that the insects are more likely to eat the gels or baits. After the application of insecticides, cleaning should be delayed for a week to avoid removal of the insecticides. After that time, begin with a thorough vacuuming, concentrating on places such as the tops, bottoms, and insides of kitchen cabinets and the spaces behind stoves, refrigerators, and other kitchen appliances that are likely to harbor dead cockroaches and frass. Hard surfaces in the kitchen and the rest of the house should be scrubbed thoroughly with detergent and water to remove allergen in sticky secretions. Adding liquid bleach to wash water can facilitate this cleaning. In the rest of the house, attention should be turned to furniture and cracks that have been identified as likely harborages by the initial inspection. Rugs should be vacuumed thoroughly, although this is unlikely to be completely successful and must be repeated several times a week for months to remove most of the contaminating dust. Allergen is likely to be left adherent to walls, floors, appliances, counter tops, and woodwork; these areas should be scrubbed with water and detergent. Bedding, curtains, and clothing are usually contaminated and should be washed as well.

CLINICAL TRIALS OF ALLERGEN REDUCTION METHODS

Field trials of allergen reduction methods have shown that extermination is much easier than allergen removal.[59,60] The best one can expect is to reduce settled dust allergen concentrations by 95% with repeated cleaning for 6 months after successful extermination.[61] In less-contaminated environments this may mean that allergen is completely eliminated from settled dust. However, in heavily contaminated areas, with Bla g 1 or Bla g 2 concentrations greater than 100 U/g of settled dust, treated rooms still contain allergen at levels that have been associated with disease. The only reported clinical trial of the health effects of allergen reduction is the National Cooperative Inner City Asthma Study.[60] In that trial cockroach allergen treatment was only one part of a global intervention. Disease activity was significantly improved, but median cockroach allergen concentration in treated homes was not reduced; therefore the improvement of disease activity could not be attributed to allergen reduc-

tion. Other trials are currently underway, but outcomes are not yet available.

CONCLUSIONS

Severe cockroach infestations are not easily eliminated within homes, schools, and buildings. However, when general cleaning practices, proven extermination techniques, and consistent maintenance methods are adhered to, infestations can be brought under control.

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