



CME Review

Environmental control measures for the management of atopy

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ARTICLE INFO

Article history:

Received for publication September 28, 2015.

Received in revised form December 22, 2015.

Accepted for publication December 29, 2015.

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Participants will be able to demonstrate increased knowledge of the clinical treatment of allergy/asthma/immunology and how new information can be applied to their own practices.

Learning Objectives

At the conclusion of this activity, participants should be able to:

- Define major in-home allergens associated with allergic sensitization
- Describe methods of allergen abatement in the home environment specific to each allergen

Release Date: February 1, 2017

Expiration Date: January 31, 2019

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Disclosures: Authors have nothing to disclose.

Funding Sources: National Institutes of Health grants T32HD075720 (to M.A.D.) and K24AI106822 (to W.P.).

<http://dx.doi.org/10.1016/j.anai.2015.12.029>

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Disclosure of Relevant Financial Relationships:

M. Dilley and W. Phipatanakul have nothing to disclose. M.H. Grayson has received research grants from Children's Research Institute/Medical College of Wisconsin, Merck, National Institutes of Health (NIH), and Polyphor. G.D. Marshall has received research grants from Amgen, AstraZeneca, HRSA and National Institutes of Health (NIH). J.J. Oppenheimer has been a consultant/advisor for AstraZeneca, GlaxoSmithKline, Meda, Mylan, and Sunovion; has received research grants from AstraZeneca, Boehringer Ingelheim, GlaxoSmithKline and Novartis. A.K. Ellis has received research grants from Circassia, Sun Pharma Advanced Research, Merck, Novartis, Pfizer, and GlaxoSmithKline; has also been a consultant/advisor for Circassia, Merck, Novartis, and GlaxoSmithKline; and has been a speaker for Merck, Novartis, Takeda and AstraZeneca. J.A. Bernstein, G. Krishnaswamy have nothing to disclose. Reviewers and Education/Editorial staff have no relevant financial relationships to disclose. No unapproved/investigative use of a product/device is discussed.

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Introduction

With the increasing prevalence of allergic airway disease in recent years, efforts have focused on the importance of environmental control measures to decrease morbidity and improve quality of life in the allergic population. Once allergy and asthma have been established, allergen abatement is an important aspect of managing the atopic population. We review current evidence of the role of environmental control and abatement measures for common allergens including furry animals, rodents, cockroach, dust mite, and mold.

The reader should be aware that comprehensive practice parameters for management of allergy to furry animals,¹ rodents,² cockroaches,³ and dust mites⁴ have been published from 2012 to 2014. In accordance with these parameters, important terms used throughout this review are *reservoir* and *facilitating factor*. For this purpose review, a *reservoir* is a confined area where allergen can concentrate, and a *facilitating factor* is a factor that promotes allergen production.^{1–4} This review does not discuss the role of primary prevention in the development of atopy and wheeze. This review focuses on evidence-based methods of allergen abatement strategies aimed at decreasing morbidity in sensitive individuals.

Furry Animals

Sensitization to furry animals has increased in recent years, especially to household pets. Environmental control measures aim to decrease dander in the environment. Pet removal is an effective way to decrease exposure to allergen. In a study of pet owners with asthma sensitized to furry animals, one group opted to remove their pet from the home and the other group opted to keep their pet. Those in the pet removal group had decreased airway hyper-responsiveness and decreased use of asthma controller medication after 1 year.⁵ Although pet removal from the home is an effective way to decrease exposure, most pet owners will not remove pets because of emotional attachment. Even after pet removal, residual allergen can persist. Further, dog and cat allergens are found in homes without pets.⁶

Cat

Fel d 1 is the major cat allergen; it is found primarily on skin and fur and is produced in sebaceous, anal, and salivary glands. Highly concentrated areas of cat allergen include upholstery, bedding, and carpet.¹ After removal of cats from the home,⁶ the decrease of Fel d 1 levels can be slow over time. Therefore, although removal of cat from the environment is important, other methods of allergen elimination are necessary.

Cat immersion washing has been shown to significantly decrease Fel d 1 levels but only for a short time.⁷ Washing must be repeated regularly to maintain effectiveness. Further, there is no proved clinical benefit from washing of cats alone. Cat and dog allergens are present on walls, and efficient removal of allergen from walls has been demonstrated through direct washing of walls or through the use of dust cloths.^{1,6} Use of high-efficiency particulate arrestance (HEPA) filters in addition to removal of cat from living room and bedroom areas can decrease the level of airborne Fel d 1 allergen, but the clinical benefits of this intervention vary.⁸ Because cat allergen is found on settled dust, aggressive interventions including carpet removal also can decrease the level of cat allergen.⁹ Therefore, techniques for decreasing dust, discussed later, can contribute to less cat allergen exposure.

Regular use of high-efficiency and standard vacuums can decrease the level of cat and dog allergens in settled dust and improve lung function, although health effects are variable.⁹ Mattress encasings can prevent passage of dust and cat allergen; encasings that are woven and have small pores might be more effective than nonwoven encasings.¹⁰ In sum, a combination of minimizing exposure to cat allergen (removing reservoirs, cat removal) combined with HEPA filters and frequent cleaning of the cat can decrease allergen exposure.

Dog

Can f 1 is the major dog allergen. Sebaceous glands secrete dog allergen, and Can f 1 is found in canine saliva, fur, and dander, and reservoirs for dog allergen include bedding, furniture, and carpeting.¹ Many patients allergic to dog report better tolerance of certain breeds over others, leading to various breeds being referred

to as *hypoallergenic*. In a study that examined dust samples taken from homes with various breeds of dogs, those in homes with hypoallergenic breeds had no difference in Can f 1 levels compared with other breeds.¹¹ Another study found that Can f 1 levels were actually higher in hair and coat samples in breeds that were touted as hypoallergenic.¹² Currently, evidence does not support breed-specific differences in allergenicity.

Abatement of dog allergen in many ways parallels that of cat allergen. Rooms inhabited by dogs have higher allergen levels, so keeping dogs outdoors or out of specific rooms can lower allergen levels. Repetitive vacuuming has been associated with lower Fel d 1 levels.⁹ Frequent vacuuming for decreasing allergen in settled dust, use of HEPA air filters, and other techniques to decrease dog allergen in settled dust are recommended to decrease exposure.⁹ In sum, allergy to furry animals is increasingly common, and the clinical benefits of combined intervention measures can be effective in lessening symptoms in sensitized individuals.

Pests

Rodents

The primary source of allergen from pests such as mice and rats is urine,¹³ and the major allergens in mice and rats are Mus m 1 and Rat n 1, respectively.² Mouse allergen is prevalent in inner-city and suburban home and schools,¹³ whereas rat allergen is less prevalent than mouse but still common in the inner-city setting.¹⁴ Individuals sensitized and exposed to rodents in turn can have higher asthma morbidity, highlighting the importance of abatement tactics in homes and schools.¹⁴

As with cats and dogs, decreasing exposure to rodent allergen involves removal of facilitating factors, reservoir elimination, and allergen abatement. Food and shelter are key facilitating factors for rodents, so eliminating any potential rodent food source and blocking route of entry are important. This can involve a thorough survey of one's environment.¹⁵ Eliminating rodents once present can be accomplished in several ways. Having a cat can deter or kill rodents, but this might not be a feasible option, especially in those sensitized to cat.² Rodents also can be eliminated through the use of traps.² A rodenticide such as warfarin also is an effective way of eliminating rodents, but care must be taken to prevent small children from ingesting the rodenticide or household pets from ingesting the rodenticide or the killed rodents.¹⁶

Abatement of an allergen reservoir (carpeting, bedding, etc) is another key component of minimizing exposure to rodent allergen. Integrated pest management (IPM) combines the decrease of facilitative factors and the removal of allergen reservoirs.¹⁷ Studies have demonstrated a successful decrease of mouse allergen levels with IPM including filling holes, cleaning, vacuuming, use of traps, and pesticides.¹⁸

Cockroach

The major allergens in cockroach are Bla g 1 and 2; Bla g 1 is found in cockroach fecal material, whereas Bla g 2 is an aspartic protease.³ Asthma morbidity in inner-city children is associated with cockroach allergy,¹⁹ making cockroach allergen abatement a focus of study in the inner-city asthma population. Further, cockroach exposure in inner-city children has been indicated as a risk factor in the development of asthma.²⁰

Various methods have been investigated to determine the most effective way to remove cockroach from an infested environment. Although cockroach allergen levels are decreased with extermination, cockroach extermination alone is not effective in lowering allergen levels below clinically relevant levels.²¹ The use of sodium hypochlorite has not been shown to aid in cockroach allergen elimination in homes,²¹ and the use of boric acid has been shown to

paradoxically increase Bla g 1 levels and thus is not currently recommended.²²

Cockroach allergen abatement has been achieved through IPM including combined use of insecticide, professional cleaning, and occupant education to decrease the allergen reservoir and facilitating factors.²³ Removal of a cockroach allergen reservoir can include removal of carpeting, bedding, or other areas harboring allergen.³ In a study by Sever et al, cockroach allergen levels were effectively decreased in 12 months when the intervention was performed by a professional entomologist but not when performed by a commercial pest removal company, indicating that the effectiveness of allergen elimination can depend on who performs the intervention.²⁴ Once an intervention has been performed, sticky traps can be used to monitor effectiveness of the intervention.³

Integrated pest management aimed at cockroach elimination also has demonstrated clinical benefit. In a study that used comprehensive pest management (professional cleaning, insecticides, and HEPA filters), results demonstrated decreased cockroach allergen and a decrease in asthma symptoms in study subjects.²⁵ In another study, decrease of cockroach allergen by IPM combined with occupant education was associated with decreased daytime asthma symptoms compared with the control group.²⁶ In summary, control of cockroach infestation aimed at decreasing allergen includes a combination of reservoir elimination, elimination of facilitative factors, and IPM.^{3,17} Combined tactics, if performed regularly, can lead to lower allergen levels and clinical improvement.

Dust Mites

The common household dust mites (HDMs) in the United States are *Dermatophagoides farinae* and *Dermatophagoides pteronyssinus*, and the major allergenic proteins are Der p 1 and Der f 1.⁴ Abatement of dust is multifaceted. Dust mites require adequate moisture and a feeding source for survival, so abatement tactics should focus on these factors. HDMs feed off dead skin cells and microorganisms, so minimizing the food source as a facilitating factor can decrease HDMs in the environment. HDMs thrive in humid environments, so maintaining humidity below 50% limits dust mite growth.⁴

Key reservoirs for dust mites include carpets and rugs, upholstered furniture, mattresses, bedding, and clothing. Because complete removal of these reservoirs often is not feasible, frequent washing and other minimizing techniques are needed. Use of chemical killing devices such as acaricides has been studied extensively. Although acaricides can effectively kill mites, other methods such as mattress encasings are more effective and have less risk of chemical side effects.²⁷

Encasings for pillows, mattresses, and box springs are effective for containing dust mite allergen.²⁸ Also, washing bedding and clothing in hot water and drying can effectively kill most HDM.²⁹ Although numerous studies have tested the effectiveness of different water temperatures, washing bedding at a temperature higher than 25°C (77°F) with detergent can remove most HDMs.²⁹

Regular vacuuming of carpets and mattresses with HEPA filtration can remove dust allergen but might not eliminate live mites.³⁰ Trials examining the clinical benefit of air filtration have had varied results. In a review of 10 trials, HEPA filtration was found to be associated with decreased symptom reporting.³¹ Use of HEPA air filters is likely not effective as a stand-alone intervention but can be especially helpful when placed in the room where an individual sleeps.³²

Efforts to decrease dust mite exposure have shown clinical benefit. One study associated intensive dust mite control with decreased asthma symptoms.³³ When home visit and dust avoidance measures (dust mite covers, hot water to wash bedding) were used in an at-risk inner-city asthma population, there was a

decrease in acute visits.³⁴ In sum, there is evidence to support the efficacy of interventions targeted at dust elimination, and these interventions should be combined and repeated often for the greatest impact.⁴

Mold

Approximately 5% to 20% of individuals with atopy are sensitized to mold.³⁵ Mold depends on moisture for growth, and individual molds thrive on different levels of moisture to support growth. Common indoor molds include *Fusarium*, *Penicillium*, and *Aspergillus* species; common outdoor molds include *Cladosporium*, *Alternaria*, and *Epicoccum* species. Many outdoor molds contaminate indoor areas by way of open windows, clothing, or pet fur.³⁶ A mold's propensity to thrive in certain environments depends on the moisture level needed for optimal growth. In particular, *Alternaria* and *Cladosporium* species grow outdoors in a damp or humid environment.³⁷ Other molds require higher moisture level including *Penicillium*, *Aspergillus*, *Stachybotrys*, and *Chaetomium* species, so these molds can be found indoors in the setting of sustained water intrusion.³⁷

Exposure to mold has been linked to asthma morbidity, and mold exposure is prevalent indoors and outdoors.³⁸ Outdoor molds thrive in humid climates, especially during summer months, and spore counts often decrease significantly during cold, winter months.³⁹ In one study, patients with asthma sensitized to *Alternaria* species reported increased symptoms in the late spring and summer months compared with the winter months.⁴⁰ Thus, clinical symptoms in those sensitized to molds could correlate with fungal spore counts. Immunotherapy with standardized fungal extracts for *Alternaria* and *Cladosporium* species has been shown to decrease symptom reporting in European studies, so immunotherapy can be considered in individuals sensitized to mold.³⁵

Indoor mold thrives in damp areas with high humidity, so eliminating the source of dampness should be a focus of efforts to decrease mold.⁴¹ Methods of decreasing moisture include maintaining humidity below 50%, sealing leaks, using fans in areas prone to dampness, and using air conditioning during humid, summer months.⁴¹ Cleaning and maintenance of contaminated air conditioning units also can be helpful in decreasing indoor mold, especially because heating, ventilation, and air conditioning systems can recirculate contaminated air.⁴²

The use and effectiveness of chemical cleaning products has been assessed in various studies. Use of soap and water alone can remove mold, but it has been shown to grow back after a few weeks.⁴³ Cleaning agents containing hypochlorite can effectively kill and denature mold protein⁴⁴ and can kill mold on contaminated building materials.⁴⁵ Tannic acid has been studied more extensively in the past. Although shown to be effective in lowering allergen level (especially cat and dust) over a short period, the decreased allergen level was not sustained.⁴⁶ In one study, various cleaners were compared based on the ability to remove *Stachybotrys* species from contaminated walls; the most effective cleaners included Borax, Lysol All-Purpose Cleaner (Orange Breeze), Orange Glo Multipurpose Degreaser, and Fantastik Orange Action.⁴⁷

Killing mold does not remove allergenic particles completely, so attention must be paid to removal of mold particles and spores. For mold remediation of nonporous areas such as walls or flooring, surface cleaning can be applied. However, mold particles might be more difficult to remove from carpeting and upholstered furniture.⁴¹ When such porous surfaces have been contaminated with mold, complete removal is advisable. Even papers and books can harbor mold and should be examined carefully for contamination. Dust is a key reservoir for mold in the indoor environment, and dust aerosolization can lead to increased mold exposure.⁴⁸ Therefore, dust abatement techniques also can decrease mold exposure.

Because carpet harbors dust, carpet removal or use of frequent vacuuming can decrease mold exposure.³⁰

Although numerous methods are available to test for the presence of mold, there are no standardized methods for gathering data or analyzing the results. Importantly, results of an environmental assessment for mold might not correlate with actual health outcomes.⁴⁹ Practitioners must be familiar with techniques for identifying and measuring mold in the environment and understand the usefulness and limitations of the various methods, which are highlighted below.

1. Petri dish mold counts are inexpensive but biased toward heavier spores and spore clumping. Spores that prevail in the Petri dish might not represent true air samples. They also might overestimate species tolerant to culture media.^{49,50}
2. Areas with visible mold or increased surface mold counts typically indicate water leakage and might not be representative of airborne mold counts.⁴⁹
3. Indoor air mold counts must be compared with concurrent outdoor counts from around the same area and should be considered significant only when higher than outdoor counts. An outdoor count taken from a shaded area with an aggregate of vegetation near an open window might indicate a mold source if compared with a representative sample from freely moving outdoor air. However, such a source should be obvious through observation alone, without needing to use time or resources on a mold count. Pruning of vegetation is recommended in such cases.^{49,50}
4. During winter freeze, mold sources are frozen over and less likely to yield fungal spores. In patients with suspected environmental allergies in cold and wet weather who show clinical improvement during the winter, mold allergy is likely.

Outcomes related to mold intervention efforts have shown promise. Extensive interventions including cleaning of damaged areas and other moisture sources also have been shown to decrease asthma-related morbidity.³⁸ In a population of subjects with asthma and in-home mold exposures, interventions combining education with in-home remediation efforts aimed at decreasing moisture led to decreased symptom reporting and fewer health care visits.³⁸

Home- and School-Based Interventions

In patients with at least 1 allergic sensitization, the importance of a multifaceted approach to allergen abatement is vital. The effectiveness of a comprehensive home-based intervention in improving allergy and asthma-related morbidity has been a focus of research in recent years (Table 1).^{25,38,51–56} Combining disease-based education in addition to interventions (weatherization, home interventions including carpet replacement and decreasing moisture and mold) can be beneficial in decreasing asthma morbidity.^{25,38}

Because children spend a large percentage of their time in schools, attention has been placed on allergen exposure in the school. Studies have found significant exposure to mouse and rat in schools but also exposure to cat, dog, cockroach, mold, and dust.^{13,14,19,20} Beyond identifying exposures in the school, current research is underway to determine the impact of environmental interventions in the school on asthma morbidity in affected individuals. Based on knowledge of exposures in schools and the impact on student health, the United States Environmental Protection Agency's Indoor Air Quality Tools for Schools Program was created with the aim of improving environmental conditions in schools.⁵⁷ This program provides schools with means to assess and improve the school environment for the benefit of children's health. A key focus of this program is to improve conditions for children with allergies and asthma.⁵⁷ Study of the effect of

Table 1
Home intervention studies

Study	Population	Design	Population size	Intervention	Effectiveness of intervention
Morgan et al ⁵² (2004)	Children with asthma (5–11 y; US)	Randomized control trial	937 total, intervention group 468, control group 469	Education and remediation for exposure allergens and smoke	At each 2-wk interval, the intervention group had fewer symptoms than the control group throughout the intervention year In the year after intervention, there were decreases in allergen levels in homes (dust, cockroach) Decreased allergen levels were significantly correlated with decreased asthma symptoms
Kercsmar et al ³⁸ (2006)	Children with asthma (2–17 y) living in homes with mold (US)	Randomized control trial	62 total, intervention group 29, control group 33	Household repairs and modifications Asthma education	At 6 mo, the intervention group showed lower mold scores; at 12 mo, the 2 groups had significant decreases Remediation group had a significant decrease in symptom days ($P = .003$, randomized; $P = .004$, intent to treat) after remodeling; control group showed no significant change Remediation group had a lower prevalence of exacerbations compared with control subjects with asthma ($P = .003$, as treated; $P = .11$, intent to treat)
Breyse et al ⁵¹ (2014)	Families with ≥ 1 child with asthma (3–17 y; US)	Quasi-experimental design	102 total, intervention group 34, control group 68	Weatherization plus health intervention and education vs education alone	Percentage of subjects in intervention group with not well-controlled or very poorly controlled asthma decreased more than the comparison group ($P = .04$) Intervention group caregiver quality-of-life improvements exceeded comparison group ($P = .002$) by 0.7 U Decrease in study home asthma triggers (evidence of mold, water damage, pests, smoking) was marginally greater than decrease in comparison group ($P = .089$) Percentage of allergen floor dust samples at or above detection limit decreased (except mouse) in intervention group; most decreases were not statistically significant
Turcott et al ⁵² (2014)	Children with asthma (1–15 y; US)	Intervention design	170 total, intervention group 116, households, 170, control 0	Targeted household interventions and asthma education	Study population had significant health improvements related to asthma from baseline to follow-up Cost of interventions (not including personnel) was \$36,240, estimated medical savings over 4 wk was \$71,162, estimated annual savings was \$821,304
Lanphear et al ⁵³ (2011)	Children with asthma (6–12 y) living in homes with smokers (US)	Double-blinded randomized control trial	215 total, intervention group 110, control group 115	HEPA filters	25% decrease in particles counts $>0.3 \mu\text{m}$ in intervention group vs 5% decrease in control group (statistically significant) No statistically significant decreases in particle counts $>0.5 \mu\text{m}$ or in airborne nicotine In intervention group, there were 42 fewer unscheduled asthma visits ($P = .043$) compared with control group after adjustment for baseline differences Improvements in lung function were not significant
Howden-Chapman et al ⁵⁴ (2008)	Children with asthma (6–12 y; New Zealand)	Randomized control trial	409 total, intervention group 200, control group 209	Installation of nonpolluting heater (heat pump, wood pellet burner, or flued gas)	Intervention group children had 1.80 fewer days off school (95% CI 0.11–3.13), 0.40 fewer visits to a physician for asthma (0.11–0.62), and 0.25 fewer visits to a pharmacist for asthma (0.09–0.32) than control group Children in intervention group had fewer reports of poor health (adjusted OR 0.48, 95% CI 0.31–0.74), less sleep disturbed by wheezing (0.55, 0.35–0.85), less dry cough at night (0.52, 0.32–0.83), and lower scores for lower respiratory tract symptoms (0.77, 0.73–0.81) than control group Lower NO ₂ levels were measured in intervention living rooms than in those of control group (geometric mean 8.5 vs 15.7 $\mu\text{g}/\text{m}^3$, $P < .001$); a similar effect was found in children's bedrooms (7.3 vs 10.9 $\mu\text{g}/\text{m}^3$, $P < .001$)
Colton et al ⁵⁵ (2014)	Families living in public housing (US)	Observational cohort	24 total, conventional 6 in year 1, 13 in year 2, green 18	Environmental sampling, home inspections, and health questionnaires in conventional vs green housing	There were 57%, 65%, and 93% lower concentrations of PM _{2.5} , NO ₂ , and nicotine (respectively) in green vs control homes ($P = .032$, $P < .001$, $P = .003$, respectively)

Jacobs et al. ⁵⁶ (2015)	Public housing and low-income subsidized housing (US)	Mixed-methods study	325 apartments total, 803 individuals	Green vs control (dilapidated housing)	In green vs conventional housing, there were fewer reports of mold, pests, inadequate ventilation, and stuffiness Differences in formaldehyde and CO₂ were not statistically significant Participants in green homes had 47% fewer sick-building syndrome symptoms ($P < .01$) Housing conditions and self-reported physical and mental health improved significantly in green healthy housing study group compared with control group and dilapidated public housing group from which the residents moved Symptoms including hay fever, headaches, sinusitis, angina, and respiratory allergy Asthma severity measured by self-reported lost schooldays or workdays, disturbed sleep, and symptoms improved significantly Sadness, nervousness, restlessness, and child behavior improved significantly Medicaid data in this exploratory study were inconclusive and inconsistent with self-reported health outcomes and visual assessment data on housing quality

Abbreviations: CI, confidence interval; HEPA, High Efficiency Particulate Arrestance; OR, odds ratio; PM2.5, particulate matter 2.5.

comprehensive school-based intervention on asthma outcomes is underway in the School Inner City Asthma Intervention Study 2 (SICAS2), which will determine the health effects of a comprehensive intervention in Boston inner-city public schools (clinical trial NCT02291302).

Future Directions

Newer technology and research for air purification has important implications for patients with allergy and asthma. The temperature-controlled laminar airflow device is a new device that can be used at night to displace aeroallergens from the breathing zone of the individual with allergy.³² Use of this device is associated with improved quality of life and decreased airway inflammation.³² In another study, installation of nonpolluting, improved heating systems in the homes of children with asthma led to decreased asthma symptom reporting in the intervention vs control group, although there was no significant change in lung function in the study.⁵⁴

Beyond home-based interventions for exposure minimization, the concept of green housing has been studied as a method to improve health outcomes in the allergic population. Green housing uses low-impact materials with the goal of energy efficiency and improved health effects.⁵⁵ In one study of a low-income population, those in green vs conventional housing had lower concentration of particulate matter 2.5, NO₂, and nicotine and decreased mold and pest infestation.⁵⁵ After green housing was implemented in Chicago housing developments, self-reported asthma symptoms, quality of life, and other self-reported health measurements showed significant improvement.⁵⁶ These interventions highlight important avenues for needed ongoing research, which could improve symptom control and create a cleaner environment in sensitive individuals.

The microbiome has gained attention in recent years as an important factor in the development of allergies and asthma. Early life microbial gut dysbiosis has been indicated in the development of atopy in humans.⁵⁸ Variations in the environmental microbiome also have been implicated in the development of atopic disease. In a study of children raised in inner-city environments, exposure to specific allergens and bacteria early in life were negatively associated with the development of atopy and wheeze.⁵⁹ In another study, children living on farms were exposed to greater environmental microbial diversity, which was associated with lower prevalence of asthma.⁶⁰ Future work is needed to characterize further the association between the gut and environmental microbiomes in the development of atopy and how knowledge of the complex interactions between the developing immune system and the microbiome can be used to guide future preventive measures.

Conclusion

Ultimately, the goal of environmental intervention measures in the patient with atopy should be aimed at decreasing symptoms and improving quality of life. In the sensitized individual, a multifaceted approach to decreasing exposure and abatement of the allergen reservoir can improve overall symptom control and quality of life. Future efforts should focus on effective ways of implementing more sophisticated home and school interventions and a greater understanding of the impact of clean air interventions on allergy and asthma. Efforts should focus on advancing our understanding of the impact of the gut and environmental microbiomes on the development of atopy, because this might highlight new avenues for prevention and intervention.

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