Cost-effectiveness of a home-based environmental intervention for inner-city children with asthma

Meyer Kattan, MD, CM,[a] Sally C. Stearns, PhD,[b] Ellen F. Crain, MD, PhD,[c] James W. Stout, MD, MPH,[d] Peter J. Gergen, MD,[e] Richard Evans III, MD, MPH,[f] Cynthia M. Visness, MA, MPH,[g] Rebecca S. Gruchalla, MD, PhD,[h] Wayne J. Morgan, MD, CM,[i] George T. O'Connor, MD, MS,[j] J. Patrick Mastin, PhD,[k] and Herman E. Mitchell, PhD[g]

New York and Bronx, NY, Chapel Hill and Research Triangle Park, NC, Seattle, Wash, Bethesda, Md, Chicago, Ill, Dallas, Tex, Tucson, Ariz, and Boston, Mass

Background: Exposure to indoor allergens contributes to increased asthma morbidity. The Inner-City Asthma Study, a randomized trial involving home environmental allergen and irritant remediation among children aged 6 through 11 years with moderate-to-severe asthma, successfully reduced asthma symptoms. A cost-effectiveness analysis can help stakeholders to evaluate the potential costs and benefits of adopting such a program.

Objective: We sought to assess the cost-effectiveness of the environmental intervention of the Inner-City Asthma Study.

Methods: Incremental cost-effectiveness ratios for a 2-year study period were calculated. Health outcome was measured as symptom-free days. Resource use measures included ambulatory visits, hospitalizations, and pharmaceutical use. CIs were obtained by using bootstrapping.

Results: The intervention, which cost $1469 per family, led to statistically significant reductions in symptom days, unscheduled clinic visits, and use of β-agonist inhalers. Over the year of the intervention and a year of follow-up, the intervention cost was $27.57 per additional symptom-free day (95% CI, $7.46-$67.42). Subgroup analysis showed that targeting the intervention to selected high-risk subgroups did not reduce the incremental cost-effectiveness ratio.

Conclusions: A targeted home-based environmental intervention improved health and reduced service use in inner-city children with moderate-to-severe asthma. The intervention is cost-effective when the aim is to reduce asthma symptom days and the associated costs. (J Allergy Clin Immunol 2005;116:1058-63.)

Key words: *Asthma, inner city, cost-effectiveness, asthma intervention, allergen mitigation*

Children living in inner-city locations have a disproportionate burden of asthma morbidity.[1] Environmental factors, including high levels of exposure to indoor allergens and irritants, contribute to this increased morbidity.[2] For example, exposure combined with allergic sensitization to cockroach antigen in this population has been shown to be associated with more symptoms, emergency department visits, and hospital use.[3]

National guidelines for asthma recommend mitigation of environmental exposures to allergens and irritants as an integral part of asthma management. The Inner-City Asthma Study (ICAS) developed a home-based intervention that used an environmental counselor (EC) to help families reduce exposures. The counselor implemented environmental modules that were specific to the child's sensitization profile and exposures. In a randomized controlled clinical trial, this intervention was successful in decreasing allergen levels in the home and in reducing asthma symptoms.[4] This report provides an economic analysis of the ICAS environmental intervention. The findings can be useful for prioritizing decisions regarding asthma care in this underserved population.

From [a]the Department of Pediatrics, Mount Sinai School of Medicine, New York; [b]the Department of Health Policy and Administration, University of North Carolina at Chapel Hill; [c]the Department of Pediatrics (Emergency Medicine), Albert Einstein College of Medicine/Jacobi Medical Center, Bronx; [d]the Department of Pediatrics, University of Washington School of Medicine, Seattle; [e]the Asthma, Allergy, Inflammation Branch, Division of Allergy, Immunology, Transplantation, National Institute of Allergy and Infectious Disease, National Institutes of Health, Bethesda; [f]the Departments of Pediatrics and Medicine, Northwestern University Medical School, Chicago; [g]Rho, Inc, Chapel Hill; [h]the Departments of Medicine and Pediatrics, University of Texas Southwestern Medical Center at Dallas; [i]Respiratory Sciences Center, University of Arizona College of Medicine, Tucson; [j]Boston University School of Medicine; and [k]the National Institute of Environmental Health Sciences, Research Triangle Park.

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Reprint requests: Meyer Kattan, MD, Department of Pediatrics, Mount Sinai School of Medicine, Box 1202B, One Gustave L. Levy Place, New York, NY 10029. E-mail: meyer.kattan@mssm.edu.

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Abbreviations used
EC: Environmental counselor
HEPA: High-efficiency particulate air (filter)
ICAS: Inner-City Asthma Study
ICER: Incremental cost-effectiveness ratio
NCICAS: National Cooperative Inner-City Asthma Study
SFD: Symptom-free day

METHODS

Full details of the ICAS environmental intervention and outcome have been published previously.[4,5] The study was undertaken at 7 urban locations across the United States (Boston, Mass; Bronx, NY; Chicago, Ill; Dallas, Tex; New York, NY; Seattle, Wash; and Tucson, Ariz). Children aged 5 to 11 years who were diagnosed with asthma by a physician and had at least 1 positive skin test response to an indoor allergen were enrolled. Additional inclusion criteria were that the child had to have at least 1 hospitalization or 2 unscheduled asthma visits in the 6 months before enrollment (to ensure that subjects with severe asthma were enrolled) and should reside at one address for at least 5 nights per week (to ensure consistent exposure to the same household environment). Only 1 child per family could participate to avoid contamination in the event that siblings were randomized into separate groups. After informed consent and baseline information were obtained from the caretaker and child, 937 children were enrolled in the study, with 469 randomized to the intervention group by means of block randomization within site. The intervention took place during the first year of the study, and follow-up continued for a second year. Children in the intervention and control groups were equally likely to be missing data in the second year of service use. Therefore the 2-year cost-effectiveness analysis is conducted with data for the 800 (85%) children with complete 2-year service use data.

High school graduates from the community were trained as ECs by using centralized training sessions. The ECs were trained to implement 6 environmental modules that focused on remediation of exposure to dust mites, passive smoking, cockroaches, pets, rodents, and mold. The specific modules delivered were tailored to the environmental risk and allergen skin test sensitivity of each child. The environmental modules included both education and demonstration of remediation techniques. The ECs made a median of 5 home visits over the 12-month period. All subjects in the intervention were given dust mite remediation strategies and were provided with impermeable mattress and pillow covers. Families of children exposed to environmental tobacco smoke were given high-efficiency particulate air (HEPA) filters and education regarding reduction of exposure.

The cost of the intervention was estimated at $1469 per family (all costs are in 2001 US dollars). Cost estimates for the intervention components were as follows: $50 for the skin test to determine eligibility, $422 for equipment (impermeable mattress and pillow covers, HEPA vacuum cleaner, HEPA air cleaner [for houses with smokers, pets, or mold problems], vent filters [for homes with forced air heat], and miscellaneous cleaning equipment), $784 for salary (primarily the salary of the ECs; a very small amount was added for physician oversight), $100 for the average travel costs to implement the intervention, and $113 for pest management services (as needed). Intervention costs were adjusted slightly upward to account for the fact that approximately 6% of children screened were determined not to be eligible on the basis of their skin test response, resulting in an estimated intervention cost of $1472 per enrolled family.

Standardized telephone interviews were done every 2 months to collect data on asthma symptoms and medication use in the previous 2 weeks. Service use over the prior 2 months was recorded at baseline and in the follow-up telephone surveys every 2 months. Measures of resource use included scheduled clinic visits, unscheduled clinic visits, emergency department visits, hospital admissions and length of stay, and pharmaceutical use. Payments and source of payments were not recorded. Estimated costs for these services were developed by identifying likely average service costs from various sources, as indicated in Table I. The estimated costs were comparable to costs used by Sullivan et al[6] in their analysis of the National Cooperative Inner-City Asthma Study (NCICAS).

Incremental cost-effectiveness ratios (ICERs) for the 2-year intervention and follow-up period were calculated for the group that received the environment intervention under ICAS. Health outcome was measured as symptom-free days (SFDs) per child per year, and total annual costs were defined as the intervention cost (for the intervention group only) plus the estimated mean health service use cost (resource use for the intervention and control group children multiplied by cost per unit). The ICER is defined as the difference in average total costs for the intervention group minus the control group divided by the average difference in health outcome:

$$ICER=\frac{Cost_{\,Intervention\ group}-Cost_{\,Control\ group}}{SFD_{\,Intervention\ group}-SFD_{\,Control\ group}}=\frac{Incremental\ \text{cost}}{Incremental\ effect}.$$

The ICER gives the cost per additional unit of health outcome gained from the intervention relative to the standard (control) approach. An intervention is deemed to be cost-effective if the intervention leads to an improvement in outcome, even if it costs more than usual care (ie, the ICER is positive) but the incremental cost per additional unit of outcome is not more than the amount that society is willing to pay. An intervention is deemed to be cost-saving if outcome improves and total costs are reduced. A 3% discount rate was used to discount costs and benefits during the second year.

In theory randomization provides an unbiased estimate of the program effect on costs and benefits (both components of the ICER) by using means for each group, as described above. Dropout rates and characteristics of the dropouts were similar in both arms of the study. Bootstrapping was used to address uncertainty in the estimate of the ICER.[7] Bootstrapping uses repeated sampling from the analysis data set to determine the sampling distribution of the ICER. A specified number of samples (eg, 1000) of the same sample size as the original data set are drawn with replacement. The distribution of these 1000 observations provides an estimate of the sampling distribution of the ICER. The sampling distribution enables determination of a 95% CI for the ICER in cases in which all of the bootstrap estimates are positive (ie, in which both the incremental cost and incremental effect are positive). In addition, assessment of the incremental cost and incremental effect enables determination of the likelihood that the intervention is cost-saving or that the intervention results in reduced health outcome at higher cost. Both of these situations are reflected by a negative cost-effectiveness ratio. Because negative ICER values might represent either a situation in which the intervention is cost-saving or one in which the intervention is a bad investment with higher costs and worse health outcomes than those of the control group, the CI was coded as ''not applicable'' if more than 2.5% of the ICER values were negative.

RESULTS

A full assessment of the effect of the intervention on the child's asthma symptoms and pulmonary function and on the caretaker (eg, losing sleep or changing plans) has been published.[4] Measures of average annual health service use over the 2-year study period are provided in Table II. The

TABLE I. Cost estimates for health care use

Measure	Cost estimate	Source
Scheduled medical visit	$35.89	2001 Medicaid Reimbursement Survey, American Academy of Pediatrics, US Average for CPT 99213 www.aap.org/research/medreim01state.htm
Unscheduled clinic visit	$49.34	2001 Medicaid Reimbursement Survey, American Academy of Pediatrics, US Average for CPT 99214 www.aap.org/research/medreim01state.htm
Emergency department visit	$390	Extrapolated from Sullivan et al, 2002.[6] Sensitivity analyses using alternative values of $118 and $240 (documented Medicaid rates in New York and Chicago) showed only minor changes in the cost-effectiveness ratio.
Inpatient hospital day	$1131	Hospital Cost and Utilization Project, Kids Inpatient Database http://hcup.ahrq.gov/HCUPnet.asp, average cost for children ages 5-9 with inpatient asthma stay (CCS code 128), 2000
Anti-inflammatory medications		Drugs for Asthma, *The Medical Letter*, Vol. 42, March 6, 2000
Inhaled steroid inhalers	$46.00	[Steroid and cromolyn costs are based on 30 days' treatment with the lowest recommended adult dosage, according to wholesale price (AWP) listings in *Drug Topics Red Book*, February 2000
Cromolyn inhalers	$70.16	*Update and First DataBank Price Alert*, February 15, 2000]
β-Agonist inhalers	$20.49	

TABLE II. ICAS environmental intervention effects on average annual health care use over the 2-year follow-up

Measure (average annual use)	Intervention group, n = 408 (mean ± SE)	Control group, n = 392 (mean ± SE)	Difference	*P* value
Scheduled medical visits	1.44 ± 0.09	1.51 ± 0.11	−0.07	.62
Unscheduled clinic visits	1.06 ± 0.07	1.29 ± 0.08	−0.24*	.03
Emergency department visits	0.77 ± 0.07	0.87 ± 0.06	−0.10	.30
Inpatient hospital days	0.62 ± 0.08	0.73 ± 0.11	−0.11	.39
Anti-inflammatory medications				
No. of inhaled steroid inhalers	4.84 ± 0.21	5.35 ± 0.22	−0.51	.30
No. of cromolyn inhalers	2.64 ± 0.17	2.60 ± 0.17	0.04	.86
No. of β-agonist inhalers	5.95 ± 0.16	6.81 ± 0.17	−0.86*	<.001

P values are for *t* tests of differences in means.
*Difference is statistically significant at a *P* value of less than .05.

intervention reduced the number of unscheduled clinic visits by 0.24 per year (a 19% reduction relative to the control group) and reduced the number of β-agonist inhalers used per year by 0.86 (a 13% reduction). Scheduled medical visits, emergency department visits, hospital days, and inhaled steroid or cromolyn inhaler use did not decrease significantly, although all measures except for cromolyn inhaler use decreased slightly.

Table III provides the estimated direct medical (health service use) costs and SFDs over the 2-year period. The discounted costs for the intervention group were $1042 greater than for the control group, and therefore the service use reductions were sufficient to offset approximately one third of the intervention costs. The intervention led to an estimated increase of 37.8 SFDs per person over the study period. The cost per additional SFD was $27.57, with a 95% CI from $7.46 to $67.42.

Fig 1 provides an acceptability curve, which shows the cumulative distribution of the estimated ICER distribution from the bootstrapping procedure. The acceptability curve indicates the likelihood that the intervention is cost-effective (ie, the likelihood that the intervention's value is worthwhile to the payer) for each dollar value that one might be willing to pay (ie, the threshold ICER or cost per additional SFD measured along the horizontal axis). The bootstrapped sampling distribution showed only a very small likelihood (0.5%) that the intervention was cost-saving over the 2-year follow-up period. If one is willing to pay $28 for an additional SFD, then the likelihood that the intervention is cost-effective (ie, worthwhile to the payer) is approximately 50%. If one is willing to pay $52 for an additional SFD, then the likelihood that the intervention is cost-effective is approximately 90%, and if one is willing to pay $100 or more per additional SFD, then the intervention is definitely cost-effective.

The ICAS intervention used 2 program staff members for each home visit. The cost of the intervention would decrease by roughly one third (to $1026) if the EC made

TABLE III. Two-year total costs, outcomes, and ICERs (full Sample, n = 800; 3% discount rate)

	Total direct medical costs per child (2 y)	SFDs (2 y)
ICAS intervention group (n = 408)	$4704	566.6
Control group (n = 392)	$3662	528.8
ICER	$27.57 per SFD gained (95% CI, $7.46-$67.42)	

The ICER gives the cost per additional SFD gained per child over the 2-year period.

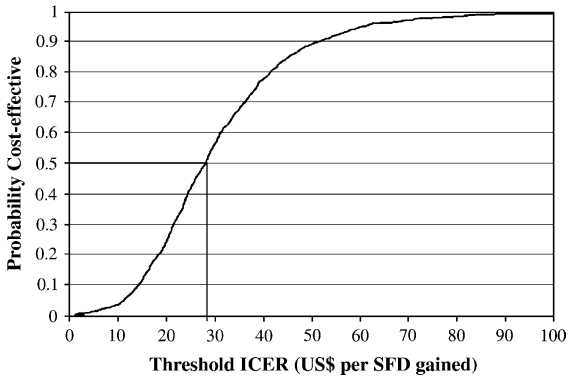

FIG 1. Acceptability curve.

unaccompanied visits. Assuming that the effectiveness of the intervention would likely remain the same, the cost per additional SFD of this modified intervention is $15.76, with a slightly higher (5%) chance that the modified intervention would be cost-saving (eg, result in more SFDs and reduced net cost). The acceptability curve for this simulation shows that if one is willing to pay $32 for an additional SFD, then the likelihood that the intervention is cost-effective is approximately 90%, and if one is willing to pay $61 or more per additional SFD, then the intervention is definitely cost-effective. Furthermore, the salaries paid to the staff members for this demonstration were research staff salaries that might be higher than the salaries used in an ongoing program. Rerunning the model with one quarter of the original labor costs (ie, assuming only 1 person making the visit at one half the salary), the ICER decreased to $10.61, with a 12.7% chance of cost-savings, a 90% chance of cost-effectiveness if one is willing to pay $27 per additional SFD, and virtual certainty of cost-effectiveness if one is willing to pay $55 per additional SFD.

A common way to decrease the cost per additional unit of outcome from health-related interventions is to target the intervention to higher-risk individuals. Subgroup analyses were conducted for study participants according to whether they (1) had a hospitalization in the 2 months before the baseline interview, (2) had 2 or more unscheduled clinic visits or emergency department visits in the 2 months before baseline, or (3) reported 10 or more days with symptoms during the 2 weeks before the baseline interview. None of the subgroups with these high-risk characteristics had ICERs that were substantially lower than the ICER for the overall sample.

The ICER estimate for the children with a hospitalization within 2 months of the baseline interview was high and had an extremely large CI, possibly because of the fact that hospitalization is a relatively rare event that was not significantly affected by the intervention. The results for the other 2 subgroups are shown in Table IV, which provides the ICER, the 95% CI (if applicable), and a characterization of the distribution of the bootstrap ICER estimates with respect to values of the numerator (incremental cost) and denominator (incremental effect). The subgroup analysis for children with 2 or more unscheduled visits before baseline had a 13.2% chance of being cost-saving (decreased costs and improved health outcomes), but the ICER was not lower than the overall ICER of $27.57. (The ICERs for both subgroups for children with or without 2 or more prior unscheduled visits are both greater than the ICER for the overall sample because the ICER is a nonlinear statistic.) Frequency of reported symptoms also did not appear to be a good indication of high-risk status that could result in a lower cost per additional SFD. Children with fewer than 10 symptom days during the 2 weeks before baseline had a lower ICER and a greater chance of the intervention being cost-saving than children with 10 or more symptom days.

DISCUSSION

The ICAS home-based environmental intervention resulted in clinically significant improvement in health status and reductions in resource use among inner-city children with moderate-to-severe asthma. Over the 2 years of cost assessment, which included a year of intervention and a second year of follow-up only, the intervention cost was $27.57 per SFD gained. This study was carried out at 7 sites across the United States, making the findings generalizable to other inner-city populations in which the burden of asthma is particularly high.

The majority of patients received more than 1 intervention module. Furthermore, no direct measures of exposure to environmental tobacco were made. Therefore the effectiveness and costs of individual components of the intervention cannot be separated.

Although the health service use reductions were not sufficient to offset the intervention cost within a 2-year period, several considerations make the estimated cost per additional SFD a conservative one. First, families had, on average, nearly 2 other children in the household in addition to the child participating in the study. Although some of these other family members, both children and adults, also had asthma and might have benefited from the intervention, we only have data for a single child in each home. Therefore our analysis at the child level rather than the household level might understate the benefits and overstate the cost per effect, although a more detailed assessment of this issue is beyond the scope of the available data.

TABLE IV. Two-year ICERs: Severity subgroups

			Distribution of bootstrap estimates			
			I:	II:	III:	IV:
			Incremental effect > 0	Incremental effect < 0	Incremental effect < 0	Incremental effect > 0
			Incremental cost > 0	Incremental cost > 0	Incremental cost < 0	Incremental cost < 0
Severity subgroup	**ICER**	**95% CI**	**Cost-effective**	**Bad investment**	**Flip cost-effective**	**Cost-saving**
≥2 Unscheduled visits before baseline (n = 192)	$27.94	NA	81.1%	5.6%	0.1%	13.2%
<2 Unscheduled visits before baseline (n = 606)	$29.58	$8.84, $80.97	98.8%	0.1%		0.1%
≥10+ Symptom days during 2 weeks before baseline (n = 219)	$33.66	$7.11, $168.59	99.1%	0.4%		0.5%
<10 Symptom days during 2 weeks before baseline (n = 577)	$25.58	NA	95.1%			4.9%

The ICER indicates the cost per additional SFD gained per child. The CI is coded as not applicable if more than 2.5% of the ICER values were negative because negative ICER values might represent either a situation in which the intervention is cost-saving or one in which the intervention is a bad investment (ie, has higher costs and worse health outcomes than the control group).
NA, Not applicable.

Second, the more detailed data presented by Morgan et al[4] show that the reductions in asthma symptoms and unscheduled visits were maintained during the second follow-up year after the intervention ended. Therefore a longer follow-up period might reveal continued health improvements and reduced resource use for the intervention group relative to the control group without any additional investment.

Third, the major cost of the intervention was related to the salaries for 2 ECs per home visit. The ICER using 1 EC per visit to each home is substantially lower. We chose to use 2 counselors in the study for security reasons. However, public health home interventions in major urban areas, such as directly observed therapy for tuberculosis and postnatal home visitations, are routinely performed by 1 person.

Fourth, although the intervention had a significant effect on school days lost and days on which the caretaker had to change plans because of the child's asthma, we had no way to estimate the economic effect of these outcomes. As shown recently, indirect costs from asthma morbidity are substantial, and adding the savings from these important societal measures could lead to an even lower overall cost or possible cost-savings for this intervention.[8-11]

The control group had a substantial reduction in symptom days over the 2 years. Although this improvement might represent a regression to the mean, we suspect that the bimonthly telephone contacts to assess morbidity and medication and health service use caused control families to focus more attention on their child's asthma, leading to this reduction. This ''attentional'' effect results in an underestimate of the cost-effectiveness of the environmental intervention.

The ICAS environmental intervention is more costly per SFD gained in comparison with the NCICAS asthma counselor intervention.[6] The NCICAS used a hospital- or clinic-based social worker, who addressed psychosocial and environmental barriers to successful asthma management by caretakers of children 5 through 11 years of age. The NCICAS asthma counselor intervention resulted in a $9.20 cost per additional SFD. Although more expensive, the ICAS home-based environmental intervention resulted in more than 40% additional SFDs. The added value of this increased reduction in symptoms must be considered when weighing the cost per SFD. In addition, when we analyzed costs using personnel and salaries that are more likely to be used in community settings, the differences in cost between the EC and the asthma counselor were small.

It was surprising that the subgroup analyses did not show a lower cost per additional SFD because risk targeting usually improves the economic return from a health-related intervention. Subgroup analysis for the NCICAS asthma counselor did find a greater degree of cost-saving for children with more severe asthma.[6] However, the NCICAS project had different eligibility criteria, allowing more children with mild asthma to be enrolled. Children enrolled in ICAS were required to meet criteria for moderate-to-severe asthma, and their asthma might have been severe enough to make it difficult to find an indicator of risk that discriminates well. Alternatively, it might be that frequency of reported symptoms simply is not a good measure of risk for asthma health service use.[12]

Most cost-effectiveness studies in asthma involve comparisons between inhaled corticosteroids and other drugs, and most have been done in adult populations. Paltiel et al[13] used a mathematic simulation in a recent meta-analysis to show that inhaled corticosteroid use in adults could increase SFDs at a cost of $7.50 per SFD. However, it is not clear whether this result would be achievable with children or in the inner city, with its

disproportionate barriers to adherence. Sullivan et al[14] reported on the cost-effectiveness of early intervention with budesonide among patients with mild asthma aged 5 to 66 years in a multinational, randomized controlled trial. The cost was $11.30 per SFD gained when only direct medical care expenses and not schooldays or workdays were considered. Although children were enrolled in this study, the mild nature of their asthma makes comparison with ICAS in terms of the costs per SFD gained difficult.

In the 2 years of the ICAS, we did not demonstrate a reduction in the use of controller medications. However, we relied on parent report of medication use, and we were unable to obtain detailed information on the amount of medications used over the study period.

Most pharmacotherapy interventions report modest costs per SFD gained. However, they address the treatment of symptoms and not the precipitating factors that promote inflammation in asthma and that might contribute to airway remodeling.[4] Tailored environmental interventions such as this might be more labor intensive and costly than other approaches. However, by reducing important triggers of asthma, they might have a more substantial long-term clinical effect. Moreover, they might be particularly beneficial for inner-city children with asthma, who are exposed to multiple allergens and irritants and have disproportionately high barriers to quality health care.

The ICAS project has shown that a tailored environmental intervention can reduce asthma symptoms. These interventions have costs associated with them, and this study has provided initial data on the cost-effectiveness of this home-based environmental intervention. Although we were only able to document the costs and effects of this intervention for 2 years, the long-term benefits of the intervention are likely to continue to return value in terms of reduced symptoms and asthma use. Future environmental intervention studies should include an economic analysis so that we can better understand their costs, as well as their clinical benefits.

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APPENDIX

The Inner-City Asthma Study was a collaboration of the following institutions and investigators (principal investigators are indicated by asterisks): Boston University School of Medicine, Boston, Mass—G. O'Connor,* S. Steinbach, A. Zapata, J. Cline, L. Schneider; Albert Einstein College of Medicine/Jacobi Medical Center, Bronx, NY—E. Crain,* L. Bauman, Y. Senturia, D. Rosenstreich; Children's Memorial Hospital, Chicago, Ill—R. Evans III*, J. Pongracic, A. Sawyer, K. Koridek; UT Southwestern Medical Center at Dallas, Dallas, Tex—R. S. Gruchalla,* V. Gan, Y. Coyle, N. F. Gorham; Mount Sinai School of Medicine, New York, NY—M. Kattan,* C. Lamm, M. Lippmann, E. Luder, M. Chassin, G. Xanthos; University of Washington School of Medicine and Public Health, Seattle, Wash—J. Stout,* G. Shapiro, L. Liu, J. Koenig, M. Lasley, S. Randels, H. Powell; The University of Arizona College of Medicine, Tucson, Ariz—W. Morgan,* P. Enright, J. Goodwin, T. Garcia; Data Coordinating Center, Rho, Inc, Chapel Hill, NC—H. Mitchell,* M. Walter, H. Lynn, S. Hart, W. Tolbert, E. Nuebler; Allergen Assay Laboratory, Harvard School of Public Health, Boston, Mass—H. Burge, M. Muilenberg, D. Gold; National Institute of Allergy and Infectious Diseases, Bethesda, Md—M. Plaut, E. Smartt; National Institute of Environmental Health Sciences, Research Triangle Park, NC—G. Malindzak.