# Socioeconomic and Environmental Risk Factors for Pediatric Asthma in an American Indian Community

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## Abstract

**Background:** American Indian (AI)/Alaska Native children have increased asthma prevalence, morbidity, and mortality compared to non-Hispanic white children. Our study sought to examine environmental and socioeconomic factors of asthma among children in an AI community.

**Methods:** This case-control study included children with physician-diagnosed asthma and age-matched controls, ages 6 through 17 years, in an AI community. Diagnosis and clinical characteristics were obtained from medical record review. Home visits included interviews regarding sociodemographic and household environmental exposures, physical exams, spirometry, and asthma control questionnaires (cases only).

**Results:** Among the 108 asthma cases and 215 controls, 64% had an annual household income of <$25,000. Children with asthma had significantly higher odds of living in a multi-unit dwelling (odds ratio [OR], 2.3; 95% confidence interval [CI], 1.2−4.4) or in residences with rodent or insect infestation (OR, 2.1; 95% CI, 1.1−3.8) and were less likely to live in homes with more than 8 occupants (OR, 0.5; 95% CI, 0.3−0.9). Also, there was a trend for lower caregiver education level, unmarried caregiver marital status, and annual household income level of <$25,000 in univariate analysis. However, after adjustment for socioeconomic status and household environmental factors, these estimates were not significant. Nearly half of cases had poorly controlled asthma and reported persistent cough, wheeze, and dyspnea, yet only 24% reported using a controller medication.

**Conclusions:** In this low-income AI community, we identified several social and environmental determinants of asthma, which were mediated by socioeconomic status and other household environmental factors, suggesting a complex interplay between socioeconomic status and environmental exposures. Furthermore, many children with asthma reported poor asthma control.

**Keywords:** asthma; disparities; American Indian; Native; pediatrics

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## What's New

Risk factors for asthma and severity of asthma in American Indian children are poorly understood. This study identifies socioeconomic and environmental risk factors of asthma and poorly controlled asthma in a rural American Indian community in the US Midwest.

Asthma is a common chronic disease affecting >25 million adults and children in the United States.[1] In the 2016 National Health Interview Survey, the prevalence of asthma in American Indian (AI) or Alaska Native (AN) children under the age of 18 years was 16%, compared to 7% in non-Hispanic white children (reference). In a recent study measuring the prevalence of asthma in US children from 2001 to 2010, AI and AN children consistently had a higher asthma prevalence than non-Hispanic white children (9.4% vs 7.7%, respectively).[1] Further, the morbidity associated with asthma, including hospitalizations and poor clinical outcomes, is greater among indigenous children compared with their non-indigenous counterparts in Australia, Canada, New Zealand, and the United States.[1,2]

Individual, socioeconomic, and environmental factors may be associated with the greater burden of asthma in AI/AN communities (Fig. 1).[1] For example, AI/AN people have lower household incomes and higher poverty rates than the general US population.[3] The current study examines socioeconomic and household environmental risk factors for pediatric asthma among children with asthma and age-matched controls in a rural AI community in north-central South Dakota with a high level of poverty (>25% of families are below the federal poverty level). We also compare medical histories and respiratory symptoms between these 2 groups. Our exploratory aim sought to describe socioeconomic and household risk factors associated with poor asthma control based on Asthma Control Test (ACT) scores (QualityMetric Inc.; Lincoln, RI). We hypothesized that social determinants of health, including income level, crowding, and exposures in the home, are associated with the risk of pediatric asthma in this AI community.

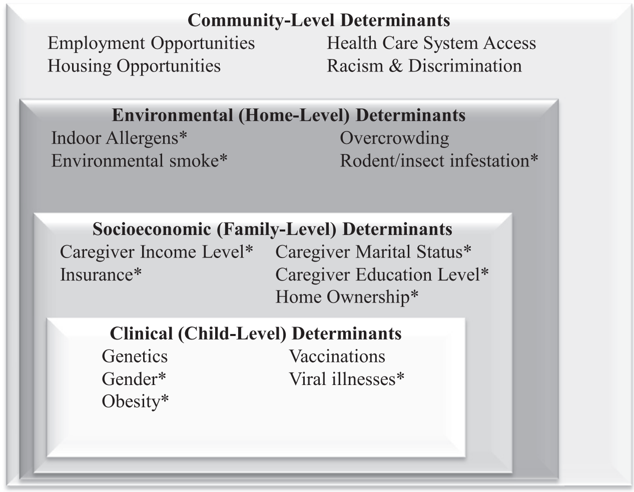


**Figure 1.** *Conceptual map illustrating the determinants of pediatric asthma previously described.*[1–4,9–14,17–20] **Factors evaluated in this American Indian pediatric population.*

## METHODS

### STUDY DESIGN AND POPULATION

This is a case-control study derived from the Factors Influencing Pediatric Asthma study, which evaluated environmental and genetic influences on pediatric asthma in an AI community in north-central South Dakota.[4] The community has a population of 8500 (2500 between the ages of 5 and 18 years) in an area of 4266 square miles, resulting in a population density of 2 to 3 people per square mile. One county in the community has the second lowest per capita income of US counties, and 61% of children younger than 18 years live below the federal poverty level.

### ASCERTAINMENT OF CASES AND CONTROLS

Asthma cases and controls were ascertained between January 2013 and March 2015, as previously described.[4] Briefly, potential asthma cases were identified from Indian Health Service (IHS) electronic medical records using search queries including asthma-specific *International Classification of Diseases, 9th Revision* (ICD-9) codes 493.00 to 493.92, 786.07 (wheezing), and V17.5 (family history of asthma). Cases were AI children ages 6 through 17 years receiving care through the IHS and who had 1) been given a diagnosis of asthma on at least 2 occasions by more than 1 provider during the past 2 years, and 2) received refills of asthma treatment medications on at least 2 occasions during the past 2 years.

Exclusion criteria for both cases and controls included birthweight less than 2500 grams; history of neonatal mechanical ventilation; hospitalization at birth greater than 15 days; congenital heart defect requiring surgery; cystic fibrosis; congenital lung, diaphragm, chest wall, or airway anomaly; or congenital muscular disorder. Children were excluded if they had a diagnosis of pneumonia, pertussis, or tuberculosis within the past year.

Controls were identified by query of the IHS electronic database in the same community. Each control was age-matched to a case (ie, birthdate within 6 months of the previously identified asthma case). Controls did not have a diagnosis of asthma by a provider during the past 2 years, had no prescriptions of asthma medications in the past 2 years, had no forced expiratory volume in the first second ($FEV_1$) less than 80% of the predicted value if prior spirometry was performed, and otherwise met the same exclusion criteria as asthma cases.

### MEDICAL RECORD REVIEW

Information pertaining to the diagnosis and management of asthma was abstracted from medical records. These results included birth date, comorbid conditions, and prior spirometry measurements. Additionally, emergency department (ED) visits and hospitalizations were obtained from IHS records. To ensure chart review accuracy, the first 5 charts extracted by a researcher and every 10th subsequent chart abstraction were reviewed by a second, experienced reviewer.

### HOME INTERVIEW AND EXAMINATION

A one-time home visit for asthma cases and controls was performed by 3 research coordinators between January 2013 and March 2015. A structured interview collected information on demographics, educational attainment, current parental occupation, current location of residence, lifestyle factors, environmental exposures in the home, past medical history, and current medication use. Among cases, ACT scores were used to assess asthma control, with ACT scores $\geq$20 indicating well-controlled asthma.[5]

### SPIROMETRY

Spirometry was performed among cases and controls by a research nurse during the one-time home visit using a spirometer (QRS Diagnostic; Totowa, NJ). Over-reading of pulmonary function tests was based on Spirometry 360 to verify quality and reproducibility according to the American Thoracic Society criteria.[6,7] Interpretation of pulmonary function tests was performed by a pediatric pulmonologist (B.K.) according to American Thoracic Society criteria. Global Lung Initiative reference equations were used to calculate percent of predicted values.[8] Race was categorized as Caucasian, as the Global Lung Initiative does not contain American Indian-specific reference values.

### STATISTICAL ANALYSIS

The Factors Influencing Pediatric Asthma study sought to enroll 120 cases and 240 controls based on power to examine demographics and other risk factors of asthma using prevalence and odds ratios. Descriptive analysis included median and range for continuous variables and percentages for categorical variables. The Pearson chi-square test was used to compare categorical variables between asthma cases and controls. Univariate analysis using Mantel-Haenszel odds ratios (ORs) were generated to evaluate the association between socioeconomic status (SES) and household environmental factors (collapsed into binary categories) and asthma. Multivariate analysis was performed to further evaluate household exposures associated with asthma after adjusting for SES and other household environmental factors. Models included caregiver marital status (other/married), caregiver educational level (less than high school education/high school education or higher), income level (annual income of <$25,000 or ≥$25,000), government insurance program (yes/no), home ownership (yes/no), multi-unit housing (yes/no), increased home occupancy (defined as ≥8 individuals in the home), rodent or insect infestation, pets, and tobacco smoke exposure. As an exploratory aim to assess risk factors associated with poor asthma control, children with asthma were stratified based on ACT scores (score ≥20, well-controlled; score <20, poorly controlled). The univariate and multivariate analyses were performed to compare children with well-controlled asthma and those with poorly controlled asthma. Wilcoxon rank-sum tests were used to compare spirometric measurements between groups. The proportion of missing data was <5% for all variables. Statistical significance was set at $P < .05$. Stata 14.2 statistical software (StataCorp; College Station, Tex) was utilized to conduct all analyses.

### APPROVAL

This study was approved by the Sanford Research (Sioux Falls, SD) institutional review board, the Great Plains Indian Health Service (Aberdeen, SD) institutional review board, and the local tribal government. All participants' parents or guardians gave informed consent in writing, and children provided assent.

## RESULTS

### PATIENT DEMOGRAPHICS AND CLINICAL CHARACTERISTICS

Between 2012 and 2014, 108 asthma cases and 215 age-matched controls enrolled in the study (Fig. 2). One control was excluded due to misidentification of the participant. The median age of asthma cases was 11 years (range, 6−17 years) and for controls was 12 years (range, 6−17 years). Males comprised 51.9% and 51.2% of asthma cases and controls, respectively (Table 1).

Nearly 64% of all children had a household annual income less than $25,000. Compared to controls, children with asthma had significantly lower annual household income levels (Pearson chi-square test $P = .04$) (Table 1). Although not statistically significant, there was a trend in univariate analyses for increased risk of asthma among children residing in homes with an annual household income less than $25,000 (odds ratio [OR], 1.6; 95% confidence interval [CI], 0.9−2.6), a non-married caregiver (OR, 1.9; 95% CI, 0.9−2.9), or a caregiver with less than high school educational level (OR, 1.9; 95% CI, 0.9−3.8) (Table 2). However, after adjusting for other SES and household environmental factors, there was no difference in risk of asthma and any of the SES variables (Table 2).

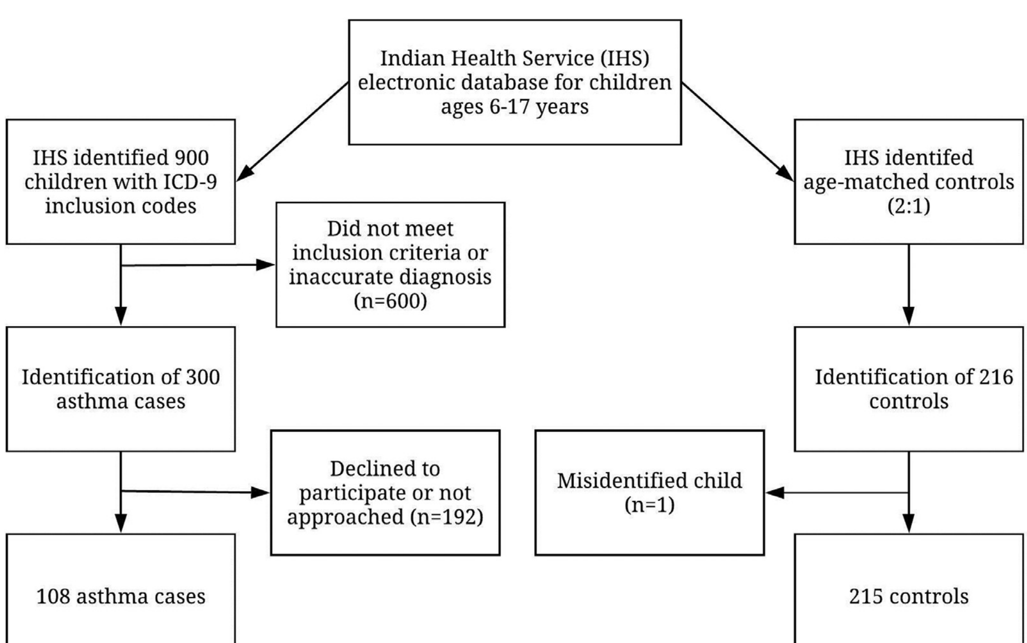


**Figure 2.** *Flow diagram of ascertainment of asthma cases and controls.*

**Table 1.** Demographic, Socioeconomic, and Household Environmental Characteristics of Asthma Cases and Controls

| Characteristics | Asthma Cases (N = 108) | Controls (N = 215) |
|---|---|---|
| Age (y), median (range) | 11 (6–17) | 12 (6–17) |
| Male gender, n (%) | 56 (52) | 110 (51) |
| Socioeconomic Characteristics, n (%) | | |
| Caregiver marital status | | |
| Never married | 36 (34) | 51 (24) |
| Married | 31 (29) | 83 (39) |
| Previously married | 26 (25) | 50 (24) |
| Significant other/partner/roommate | 13 (12) | 28 (13) |
| Caregiver educational level | | |
| Less than high school education | 20 (19) | 23 (11) |
| Completed high school | 56 (53) | 130 (62) |
| Undergraduate/graduate/professional | 30 (28) | 57 (27) |
| Annual household income† | | |
| Less than $25,000 | 76 (72) | 130 (64) |
| $25,000–$50,000 | 24 (23) | 46 (22) |
| Greater than $50,000 | 5 (5) | 29 (14) |
| Government insurance program | 86 (80) | 163 (76) |
| Private health insurance | 10 (10) | 25 (12) |
| Home ownership | 33 (31) | 73 (35) |
| Household Environmental Characteristics, n (%) | | |
| Multi-unit housing† | 26 (25) | 26 (13) |
| Occupants in home | | |
| ≤4 occupants | 46 (43) | 48 (23) |
| 5–8 occupants | 44 (41) | 108 (52) |
| >8 occupants | 17 (16) | 51 (25) |
| Rodent or insect infestation† | 29 (27) | 32 (15) |
| Water damage in home | 24 (23) | 48 (23) |
| Wood-burning stove | 5 (5) | 6 (3) |
| Pets in home | 74 (69) | 154 (74) |
| Tobacco smoke exposure‡ | 76 (72) | 136 (66) |
| Home environment worsening child health | 63 (60) | 35 (17) |

*Numbers may not add up to totals because of missing data; percentages represent proportion of non-missing data for a given variable. Data are missing for <5% of observations.

†*P* value < .05 for comparison of cases and controls using Pearson chi-square test.

‡Tobacco smoke exposure in the home, outside the home, and/or in a car.

**Table 2.** Univariate and Multivariate Analysis of Socioeconomic and Household Environmental Risk Factors for Asthma

| | Univariate Analysis* | | Multivariate Analysis† | |
|---|---|---|---|---|
| Characteristics | OR (95% CI) | *P* Value | OR (95% CI) | *P* Value |
| **Socioeconomic Characteristics** | | | | |
| Caregiver marital status | 1.6 (0.9–2.9) | 0.06 | 1.4 (0.8–2.4) | 0.30 |
| Caregiver educational level | 1.9 (0.9–3.8) | 0.05 | 1.2 (0.5–2.8) | 0.65 |
| Annual household income | 1.6 (0.9–2.6) | 0.08 | 1.3 (0.6–2.7) | 0.46 |
| Government insurance program | 1.2 (0.7–2.3) | 0.44 | 1.2 (0.5–2.5) | 0.78 |
| Private health insurance | 1.3 (0.6–3.2) | 0.50 | 1.3 (0.5–3.1) | 0.57 |
| Home ownership | 1.2 (0.7–2.0) | 0.48 | 0.9 (0.5–1.8) | 0.82 |
| **Household Environmental Characteristics** | | | | |
| Multi-unit housing | 2.3 (1.2–4.4) | <0.01 | 1.4 (0.7–3.0) | 0.33 |
| Increased home occupancy | 0.5 (0.3–0.9) | 0.03 | 0.6 (0.3–1.2) | 0.16 |
| Rodent or insect infestation | 2.1 (1.1–3.8) | <0.01 | 1.6 (0.8–3.2) | 0.15 |
| Water damage in home | 1.0 (0.5–1.8) | 0.97 | 1.0 (0.5–1.9) | 0.99 |
| Wood-burning stove | 1.7 (0.4–6.8) | 0.39 | 2.0 (0.5–7.1) | 0.30 |
| Pets in home | 0.8 (0.5–1.4) | 0.47 | 1.0 (0.5–1.9) | 0.93 |
| Tobacco smoke exposure‡ | 0.8 (0.4–1.3) | 0.28 | 0.9 (0.5–1.6) | 0.76 |

OR indicates odds ratio; CI, confidence interval.

*Univariate analysis using Mantel-Haenszel ORs.

†Multivariate model included caregiver marital status (other/married), caregiver educational level (less than high school education/high school education or higher), income level (annual income <$25,000/≥$25,000), government insurance program (yes/no), home ownership (yes/no), multi-unit housing (yes/no), increased home occupancy (defined as ≥8 individuals in the home), rodent/insect infestation, pets, and tobacco smoke exposure.

‡Tobacco smoke exposure in the home, outside the home, and/or in a car.

Over 60% of caregivers of children with asthma believed that their home environment was worsening their child's health, compared to 17% of caregivers of controls ($P < .001$). Children with asthma had significantly higher odds of living in a multi-unit dwelling (apartment, fourplex, or duplex) versus a single-occupancy residence (single-family home, trailer) (OR, 2.3; 95% CI, 1.2−4.4), were more likely to live in residences with parent-reported rodent or insect infestation (OR, 2.1; 95% CI, 1.1−3.8), and were less likely to live in homes with more than 8 occupants (OR, 0.5; 95% CI, 0.3−0.9) (Table 2). After adjusting for SES and the other environmental exposures, there were no significant associations between household environmental characteristics and risk of asthma (Table 2).

Children with asthma had significantly higher odds of atopy (history of hay fever and/or seasonal allergies), food allergies, and history of respiratory syncytial virus (RSV) infection than controls (Table 3). There was no difference in the proportion of children who were overweight or obese. Children with asthma had higher odds of lifetime respiratory ED visits reported in IHS electronic medical records (OR, 2.6; 95% CI, 1.42−4.56) and parental report of respiratory hospitalization (OR, 4.4; 95% CI, 2.32−8.43); however, there was no difference between asthma cases and controls in the odds of lifetime respiratory hospitalization as recorded by the IHS. Many asthma cases and controls reported persistent respiratory symptoms, although the prevalence was significantly higher among asthma cases: cough, 48% versus 14% (OR, 5.6; 95% CI, 3.2−10.1); wheeze, 53% versus 5% (OR, 19.0; 95% CI, 9.1−41.4); and dyspnea, 49% versus 6% (OR, 14.1; 95% CI, 6.9−30.2).

### SPIROMETRY

Spirometry was performed for 108 asthma cases and 215 controls. After over-reading, $FEV_1$ measurements were acceptable among 89 cases and 143 controls. Median $FEV_1$ percent predicted was in the normal range and did not differ between cases and controls: 106% (interquartile range [IQR], 93−113) for cases versus 102% (IQR, 94−114) for controls ($P = .52$). Due to premature termination of exhalation, forced vital capacity (FVC) measurements were not acceptable, so the $FEV_1$/FVC ratio could not be analyzed.

### ASTHMA CASES

Among children with asthma, 57 (53%) were well controlled (ACT score ≥20), and 51 (47%) were poorly controlled (ACT score <20) (Supplementary Table 1). Children with poorly controlled asthma were more likely to have annual household income levels less than $25,000 (OR, 3.2; 95% CI, 1.2−8.7) and to be enrolled in a government insurance program (OR, 5.4; 95% CI, 1.6−23.5) (Supplementary Table 2) compared to children with well-controlled asthma. After adjusting for SES and household exposures, there were no differences between asthma cases and controls for any of the socioeconomic or environmental variables (Supplementary Table 2). Median $FEV_1$ percent predicted did not differ between children with well-controlled versus poorly controlled asthma: 107% (IQR, 94−116) for children with well-controlled asthma versus 105% (IQR, 92−110) for children with poorly controlled asthma ($P = .41$).

Among children with asthma, 52.8% reported bronchodilator use, 13.0% reported inhaled corticosteroid use, 19.4% were on a leukotriene receptor antagonist, and 17.6% were on an allergy medication (not mutually exclusive). Twenty-five of the 108 asthma cases (23.2%) reported non-compliance with asthma medications due to believing the medication was not needed, perceived side effects, or other concerns.

## DISCUSSION

In this rural AI community, clinical, SES, and environmental factors were associated with asthma, supporting existing literature on the social determinants of health (Fig. 1). In univariate analysis, childhood asthma was associated with household environmental characteristics associated with poverty, such as living in a multi-unit

**Table 3.** Clinical Characteristics of Asthma Cases and Controls

| | Asthma Cases (N = 108) | | Controls (N = 215) | | | | |
|---|---|---|---|---|---|---|---|
| Characteristics | N | % | N | % | OR | 95% CI | *P* Value* |
| Overweight/obese | 49 | 45 | 78 | 36 | 1.5 | 0.9−2.4 | .11 |
| Family history of asthma | 50 | 49 | 69 | 33 | 1.9 | 1.1−3.2 | .01 |
| Atopy | 56 | 55 | 49 | 23 | 4.0 | 2.4−6.9 | <.001 |
| Food allergy | 18 | 17 | 7 | 3 | 5.9 | 2.2−17.2 | <.001 |
| History of RSV infection | 37 | 35 | 33 | 16 | 2.9 | 1.6−5.2 | <.001 |
| Parental report of hospitalization† | 35 | 32 | 22 | 10 | 4.4 | 2.3−8.4 | <.001 |
| IHS ED visits‡ | 35 | 32 | 34 | 16 | 2.6 | 1.4−4.6 | <.001 |
| IHS hospitalizations‡ | 8 | 7 | 7 | 3 | 2.4 | 0.7−7.9 | .09 |
| Cough in past 4 wk | 51 | 48 | 30 | 14 | 5.6 | 3.2−10.1 | <.001 |
| Wheeze in past 4 wk | 56 | 53 | 12 | 6 | 19.0 | 9.1−41.4 | <.001 |
| Dyspnea in past 4 wk | 52 | 49 | 13 | 6 | 14.1 | 6.9−30.2 | <.001 |
| Behind in class due to illness | 14 | 14 | 5 | 2 | 6.5 | 2.1−23.6 | <.001 |

OR indicates odds ratio; CI, confidence interval; RSV, respiratory syncytial virus; PCP, primary care provider; ED, emergency department; and IHS, Indian Health Service.

*Mantel-Haenszel ORs.

†Parental or self-reported history of respiratory hospitalization.

‡Lifetime history of respiratory-related ED visits or hospitalizations according to IHS medical records.

dwelling and exposure to residential insect or rodent infestation. Although our goal was not to assess causal inference, our multivariable model did suggest that the effect of household exposures was mediated by SES, illustrating a complex interplay between SES and household environmental exposures.

One county in this AI community is among the 25 lowest per capita income counties in the United States. Even in this fairly homogeneously resource-limited community, we demonstrated an association between asthma and lower household income level. Similarly, Chang et al[9] demonstrated that Canadian Aboriginal children from families with lower annual income (<$30,000) had a higher prevalence of asthma compared to families with higher income. Lower income level and poor living conditions have been associated with increased prevalence and severity of asthma[1,10] and contribute to inadequate health care utilization and lack of asthma awareness and education.[11]

Poor living conditions, including residential insect or rodent infestation, were associated with childhood asthma, mediated through SES. Previous reports have shown that AIs have the highest rate of severe physical housing problems in the United States.[12] In a study of 33,201 households of 6- to 17-year-old children with asthma, Hughes et al[11] demonstrated that poor housing quality was associated with asthma diagnosis and ED visits, and home ownership was associated with lower odds of asthma-related ED visits. Although there was no difference between asthma cases and controls with regard to home ownership in our study population, asthma cases were more likely to live in multi-unit dwellings, or rental properties, and therefore less likely to control their residential exposures. According to existing literature, nearly 40% of asthma in minority children has been attributed to exposure to residential allergens. Minority children have been found to live in homes that have high allergen levels and low indoor air quality, and they live in environments with more air pollution.[13] Focusing on amelioration of housing defects may decrease the severity of asthma.

In a study of Yup'ik children in southwestern Alaska, crowded housing conditions, low income levels, and frequent exposure to environmental tobacco and wood-burning stove emissions predisposed children to asthma.[3] Interestingly, households with ≥8 individuals had decreased odds of asthma; however, overcrowding data were unavailable so interpretation is limited. The use of indoor wood-burning stoves among AI/AN people has been linked to poor indoor air quality and higher rates of lower respiratory tract infections and is possibly related to increased asthma prevalence and hospitalization.[14] In our study, the prevalence of wood-burning stoves was low for both asthma cases (4.6%) and controls (2.8%) and therefore was unlikely to be a major contributor to asthma risk. We found high rates of tobacco exposure in both asthma cases and controls (72.4% and 66.3%, respectively), which may in part explain the high rate of respiratory symptoms in both groups. AIs have the highest reported rates of smoking of any racial/ethnic group in the United States.[15,16] Because tobacco is the leading and most preventable respiratory irritant, environmental tobacco smoke exposure should be the focus of further community education and intervention programs.

Our study reinforced the importance of known clinical risk factors for asthma, including RSV infection. AI/AN children are known to have higher morbidity and mortality from RSV.[17,18] The proportion of overweight/obese children was high in both asthma cases and controls (45% and 36%, respectively), reflecting the known high rates of obesity,[19] a risk factor for asthma,[9] in AI communities.

AI children are at a greater risk for poor control of their asthma. In our study, 47% were poorly controlled according to ACT scores and reported persistent cough, wheeze, and dyspnea; yet, only 24% of asthma cases reported using a controller medication (inhaled corticosteroid and/or montelukast). Furthermore, only 50% reported bronchodilator use, which is concerning for suboptimal treatment of symptoms. In a study among Navajo American Indians with asthma, many participants stopped taking their medications when their symptoms improved, and many discontinued medication for asthma.[20] This same study found that 80% of AI children had assumed responsibility for taking their own medication, leading to low compliance.[20] Although our study lacked medication compliance data, intervention programs focusing on asthma education, increasing controller medication prescribing practices and compliance, and emphasizing the importance of medication use supervision could improve asthma management according to National Asthma Education and Prevention Program guidelines.[21,22]

Interestingly, spirometry ($FEV_1$) was generally in the normal range and did not vary between children with asthma and controls. Unfortunately, we were not able to evaluate $FEV_1$/FVC as a potentially more sensitive measure of airway obstruction due to suboptimal spirometry technique.

This study has several limitations. First, the small sample size, particularly for our exploratory aim to assess risk factors associated with asthma control, limited our power to detect differences between the 2 groups. Selection bias may have occurred, as children and families who participated in the study may be different from those who chose not to participate; thus, generalizability of the findings may be limited. Another limitation is the potential for recall bias, as questionnaires were used to collect medical history. Furthermore, recall bias may be differential, as asthma cases or caregivers of asthma cases may report differently than those without an established asthma diagnosis. Misclassification may have occurred, as some controls may have had undiagnosed asthma, biasing the results toward the null. Because home visits occurred year-round, seasonal bias may have occurred, potentially skewing clinical characteristics; however, enrollment and home visits for cases and controls were performed simultaneously, so seasonal variability was likely to be similar in both groups. Finally, pulmonary function test results may have over- or underestimated lung function, as we used Caucasian reference values in the absence of normative values for AI children; however, this bias should have been the same in cases and controls.

## CONCLUSIONS

In this low-income AI community, we identified several socioeconomic and environmental determinants of asthma, which were mediated by SES and other household environmental factors, suggesting that improved social services could decrease the risk of asthma in this AI community. Nearly half of children with asthma reported poorly controlled asthma, and community interventions aimed at asthma education are essential to reduce the morbidity of childhood asthma in this community.

## ACKNOWLEDGMENTS

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## SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at https://doi.org/10.1016/j.acap.2019.05.006.

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