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The dietary inflammatory index and current wheeze among children and adults in the United States

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Abstract

Background—A pro-inflammatory diet may increase allergic airway inflammation by affecting innate and adaptive immune responses.

Objectives—In this study, we examine the relation between the diet's inflammatory potential, measured by the Dietary Inflammatory Index (DII[®]), and current asthma, current wheeze, and lung function in U.S. children and adults.

Methods—We analyzed data from 8,175 children (ages 6–17 years) and 22,294 adults (ages 18–79 years) who participated in the 2007–2012 National Health and Nutrition Examination Survey. The DII was calculated by nutrient intake based on 24-hour dietary recalls, and normalized as per 1,000 calories of food consumed to account for total energy intake. Multivariable regression models were used for the analysis of the DII and: current asthma, current wheeze, and lung function measures.

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Conflicts of Interest: N Shivappa and MD Wirth are employees of CHI. JR Hébert owns controlling interest in Connecting Health Innovations LLC (CHI), a company planning to license the right to his invention of the dietary inflammatory index (DII) from the University of South Carolina in order to develop computer and smart phone applications for patient counseling and dietary intervention in clinical settings. JC Celedón received materials from Merck (inhaled steroids) and Pharmavite (vitamin D and placebo tablets), to provide medications at no cost to participants in two NIH-funded studies, unrelated to the current work. The other authors declare they have no relevant conflicts of interest.

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Results—Higher DII (a pro-inflammatory diet) was associated with current wheeze among adults (e.g., odds ratio (OR) for quartile 4 vs. 1, OR=1.41, 95% CI=1.17–1.70 ($P_{\text{trend}} < 0.01$) and among children with high exhaled nitric oxide (FeNO, a marker of eosinophilic airway inflammation; OR=2.38, 95% CI=1.13–5.02; $P_{\text{trend}} = 0.05$). The DII also was associated with decreased FEV₁ and FVC in adults without asthma or wheezing. The DII was not associated with lung function in children or current asthma in either age group.

Conclusions—Our findings suggest that a pro-inflammatory diet, assessed by the DII, increases the risk of current wheeze in adults and children with allergic (atopic) wheeze. These results further support testing dietary interventions as part of the management of asthma.

Keywords

Dietary Inflammatory Index; Asthma; Wheezing; Lung function; NHANES

INTRODUCTION

Asthma is a chronic inflammatory airway disease that affects ~330 million people worldwide.¹ Temporal changes in environment and lifestyle, including diet, may partly explain the “asthma epidemic” in industrialized countries.^{2, 3} Whereas a Mediterranean diet [characterized by high intake of fruits, vegetables, and omega-3 polyunsaturated fatty acids (PUFA)] has been associated with lower risk of asthma and wheeze,⁴ a Westernized diet (characterized by low intake of fiber but high intake of saturated fats) has been associated with increased risk of asthma and wheeze.⁵

Dietary components can modulate immunity by regulating T-helper (Th)2 (pro-allergic) immune responses that lead to airway inflammation.⁶ Dietary lipids can contribute to allergic diseases (such as atopic asthma) by enhancing inflammation,⁷ while vitamin C and vitamin E have shown anti-inflammatory effects and potentially beneficial effects on asthma symptoms.⁸ We previously reported that frequent consumption of vegetables and grains, coupled with less frequent consumption of dairy products and sweets, was associated with lower risk of asthma⁹ but better lung function (higher FEV₁ and FVC)¹⁰ in Puerto Rican children, a finding that may be mediated by interleukin (IL)-17F-dependent inflammatory pathways.^{9, 10}

Recent studies of diet and chronic diseases have focused on dietary patterns, as the combined and interacting effects of dietary components may have greater effects on disease pathogenesis than individual nutrients. The Dietary Inflammatory Index (DII®) is a score that categorizes an individual’s diet on a continuum from the most anti-inflammatory to the most pro-inflammatory. The DII was developed and validated to account for the whole diet of an individual, and not individual nutrients or food items.^{11, 12} A higher DII score, which reflects a pro-inflammatory diet, was recently associated with asthma and lower FEV₁ in a small case-control study of adults.¹³

We hypothesized that a pro-inflammatory diet is associated with increased asthma or wheeze, and worsened lung function. To test this hypothesis, we examined the relation between DII score and current asthma, current wheeze, and lung function in a large

representative sample of U.S. children and adults. Because the pro-inflammatory effects of diet may vary by allergic status, we also examined whether the estimated effects of the DII on asthma or lung function are modified by the level of fractional exhaled nitric oxide (FeNO, a marker of eosinophilic airway inflammation).

METHODS

Subject recruitment and study procedures

The National Health and Nutrition Examination Survey (NHANES) is a cross-sectional nationwide survey designed to assess the health and nutritional status of the noninstitutionalized U.S. population. Study participants were selected by using stratified multistage probability sampling. By design, persons 60 years and older and ethnic minorities (African Americans and Hispanics) were oversampled to increase the statistical power for data analysis, and to represent the U.S. population across all ages. Both children (age 6–17 years) and adults (age 18–79 years) who participated in the 2007–2008, 2009–2010, and 2011–2012 NHANES cycles were included in this analysis. The NHANES interview includes questions on demographic, socioeconomic, dietary, and health-related factors. The examination component consists of medical and physiological measurements, as well as laboratory tests administered by highly trained medical personnel. NHANES was approved by the Institutional Review Board of the National Center for Health Statistics of the U.S. Centers for Disease Control and Prevention (CDC). Informed consent was obtained from all participants. A proxy provided information for survey participants who were less than 16 years of age and for subjects who could not answer the questions by themselves.

Survey participants aged 6 years to 79 years were eligible for spirometry, except for those who were on supplemental oxygen or had painful ear infections, current chest pain or a physical problem with forceful expiration, surgery (of the eye, chest or the abdomen) in the prior 3 months, heart disease, history of an aneurysm or a detached retina, hemoptysis, or history of a collapsed lung or tuberculosis exposure. Eligible participants performed spirometry following American Thoracic Society (ATS) recommendations.¹⁴ The best forced expiratory volume in 1 second (FEV₁) and forced vital capacity (FVC) were selected for analysis. Participants whose baseline FEV₁/FVC ratio was below the lower limit of normal (LLN)^{15, 16} and/or whose baseline FEV₁ was below 70% of the predicted value for their demographic characteristics underwent a repeat spirometry, 15 minutes after inhalation of albuterol. Participants were excluded from bronchodilator administration if they had recently used a short-acting inhaled β 2-agonist or had a previous adverse reaction to albuterol; had a history of congenital heart disease, hypertension, major arrhythmia or an implanted defibrillator; or were pregnant or breastfeeding. Percent (%) predicted FEV₁, FVC and FEV₁/FVC in children and adults were calculated using Global Lung Initiative equations that account for age, sex, race/ethnicity, and height.¹⁷ FeNO was measured using the Aerocrine NIOX MINO, a portable, hand-held NO analyzer (Aerocrine AB, Solna, Sweden). The NHANES protocol required two valid FeNO measurements that were reproducible. High FeNO was defined as 20 ppb in children and 25 ppb in adults.¹⁸ Further details of the methods, protocols, and definitions used in NHANES can be found at <http://www.cdc.gov/nchs/nhanes.htm>.

The dietary inflammatory index (DII®)

The development and validation of the DII has previously been reported.^{11, 12} Peer-reviewed literature published between 1950 to 2010 was evaluated, and 1943 articles linked to 45 individual nutrients, foods or flavonoid intake parameters were identified. Points were assigned to each of these parameters according to whether they: 1) increased (+1), decreased (−1) or had no (0) effect on the four established pro-inflammatory biomarkers: IL-1β, IL-6, tumor necrosis factor-α (TNF-α) and C-reactive protein (CRP); or 2) decreased (+1), increased (−1) or had no (0) effect on the 2 established anti-inflammatory biomarkers: IL-4 and IL-10. Based on the study designs and total number of research articles, the score for each of the food parameters was weighted. An overall inflammatory effect score was then calculated for each parameter, based on the ratio of the total weighted number of articles to the weighted pro- and anti-inflammatory articles for that parameter, followed by subtracting the anti- from the pro-inflammatory fraction. Parameters with a number of weighted articles greater than the median of 236 were assigned the full value of that score. Parameters with a total article weight less than 236 were adjusted by dividing it by 236, and then multiplying this fraction by the previously defined inflammatory effect score.

Our assessment of the DII included all of its 45 parameters. Dietary intake data were adjusted against a reference global daily mean and standard deviation intake for each parameter to obtain a Z-score and centered percentiles. The global intake data was based on consumption data from 11 countries in different parts of the world. In NHANES, 27 of the 45 DII food parameters were available, including carbohydrates, proteins, fats, alcohol, fiber, cholesterol, saturated fats, monounsaturated fats, PUFAs, omega-3 and omega-6 PUFAs, niacin, vitamins (A, B1, B2, B6, B12, C, D, and E), iron, magnesium, zinc, selenium, folic acid, beta carotene, and caffeine. The centered percentile for each intake parameter was multiplied by its respective parameter-specific inflammatory effect score, and then each of these 27 scores were summed to obtain an overall DII score for each participant. Higher (i.e. more positive) scores indicate a more pro-inflammatory diet, and more negative scores indicate a more anti-inflammatory diet. To control for the effect of total energy intake, the DII was calculated per 1,000 calories of food consumed (using a calorie-adjusted version of the global database for comparison). About 25% of the study participants reported intake of dietary supplements, and thus a separate DII score accounting for 24-hour dietary supplement was calculated. Sequence of steps in creating the dietary inflammatory index (DII) for the NHANES 2007–2012 study is shown in Supplemental Figure 1.

Statistical analysis

Current asthma was defined by a positive answer to both following questions: “Has a doctor or other health professional ever told you that you have asthma?”, and “Do you still have asthma?”. Participants who answered “no” to both questions were selected as control subjects. Current wheeze was defined by a positive answer to “In the past 12 months, have you had wheezing or whistling in your chest?”. Bronchodilator response (BDR) was defined as: $[(\text{post-bronchodilator FEV}_1 - \text{pre-bronchodilator FEV}_1) / \text{pre-bronchodilator FEV}_1] \times 100$.

Primary sampling units and strata for the complex NHANES survey design were taken into account for data analysis. Sampling weights, stratification, and clusters provided in the NHANES dataset were incorporated into the analysis to obtain proper estimates and their standard errors. All statistical analyses were conducted using the SAS[®] SURVEY procedure and SAS[®] 9.3 software (SAS Institute Inc., Cary, NC). Wald chi-square tests and t-tests were used for bivariate analyses of binary and continuous variables, respectively. Logistic and linear regression was used for the multivariable analysis of the DII, current wheeze, current asthma, and lung function. BMI was calculated as weight in kilograms divided by height (in meters) squared. BMI z scores in children were calculated based on the 2000 CDC growth charts.¹⁹ All multivariate logistic regression models were adjusted for age, gender, race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, or other), annual household income, BMI (adult) or BMI z-score (children), family history of asthma, and smoking status (measured by serum levels of cotinine). In addition, models for BDR were adjusting for pre-bronchodilator FEV₁. Interaction terms were tested to explore potential modification of the estimated effect of the DII on current wheeze or current asthma by the covariates included in the multivariate models.

RESULTS

A total of 8,175 children aged 6 to 17 years and 22,294 adults aged 18 to 79 years had information on asthma status, and underwent a 24-hour dietary recall interview and spirometry testing, were thus included in the current analysis from NHANES 2007–2008 to 2011–2012. The main characteristics of study participants are shown in Table 1. The overall prevalence of current asthma among children and adults was 11.3% and 7.9%, respectively. Compared to children and adults without current wheeze, children and adults with current wheeze were more likely to be non-Hispanic Black, and to have: a lower annual household income, family history of asthma, higher BMI, lower FEV₁ and FEV₁/FVC, and higher BDR and FeNO. Compared to adults without wheeze, adults with current wheeze were more likely to be female, to lack private health insurance, to be current smokers, and to have higher serum cotinine levels. The DII was significantly higher in adults with current wheeze than in those without current wheeze. Supplemental Table E1 shows the characteristics of study participants by current asthma, which yielded results similar to those for the comparison of subjects with and without current wheeze

Results from the multivariable analysis of the DII, current asthma, and current wheeze are shown in Table 2. After adjusting for age, gender, race/ethnicity, annual household income, BMI, family history of asthma, and serum cotinine, a one-point increment in the DII was significantly associated with 9% increased odds of current wheeze. In a multivariable analysis of quartiles of DII, adults in the third and fourth quartile of the DII had significantly higher odds of current asthma than those in the first quartile [e.g., quartile 4 vs. 1, the OR=1.41, 95% CI=1.17–1.70]. The DII was not significantly associated with current asthma in children or adults, or with current wheeze in children. Similar results were found using the DII that accounted for 24-hour intake of dietary supplements. Because the interaction terms between the DII and gender, race/ethnicity, annual household income, BMI and current smoking were significant on current wheeze among adults (data not shown), multivariate analyses stratified by these variables were conducted and shown in Table 3. The

association between the higher DII and current wheeze was more pronounced among those who were male, current smokers, non-Hispanic white, and overweight or obese, as well as in those who had an annual household income $\geq$ \$20,000.

To examine whether the estimated effect of the DII on current asthma or current wheeze is modified by allergic (eosinophilic) airway inflammation, an interaction term between the DII and level of FeNO was tested. Significant interactions between the DII and FeNO level on current wheeze were found in both children ($p=0.04$) and adults ($p=0.01$). We thus repeated the multivariable analysis in children and adults after stratification by level of FeNO (Figure 1 and Supplementary Table E2). In this analysis, children with the DII in the second to fourth quartiles and who had a high FeNO had two- to three-fold significantly increased odds of current wheeze. In contrast, there was no significant association between the DII and current wheeze among children with low FeNO. Among adult participants, those in the fourth quartile of the DII had significantly higher odds of current wheeze than those in the first quartile of the DII, both in the low/normal FeNO group and in the high FeNO group. The DII was not significantly associated with current asthma in children or adults, regardless of their FeNO level (data not shown).

Table 4 shows the multivariable analysis of the DII and lung function measures among study participants. In adults without current asthma or current wheeze, each unit increment in the DII was significantly associated with 0.22%–0.35% decrements in % predicted FEV1 ($\beta=-0.22$, 95% CI= -0.44 , -0.01) and % predicted FVC ($\beta=-0.35$, 95% CI= -0.55 , -0.15). In adults with current wheeze, there was no significant association between the DII and FEV1 or FVC. The DII was significantly associated with higher BDR among children ($\beta=2.17$, 95% CI=1.91, 2.43) with current wheeze and adults without current asthma or wheeze ($\beta=0.23$, 95% CI=0.05, 0.41). The DII was not associated with FEV1, FVC, or FEV1/FVC in children.

DISCUSSION

To our knowledge, this is the first report of an association between a high DII score and wheeze or lung function in a large sample of children and adults. Among adults, a higher DII (indicating a pro-inflammatory diet) was significantly associated with current wheeze, as well as with decreased FEV₁ and FVC in subjects without active wheezing. Among children, a higher DII was significantly associated with current wheeze, but only among those with a high FeNO (≥ 20 ppb).

Quality of dietary intake has been associated with socioeconomic disparities²⁰. The association between the DII and current wheeze was found to be more pronounced among males, non-Hispanic whites and blacks, those who had a higher household income, and those who were overweight or obese. Identifying how these variables contribute to food patterns and the DII score may help improve respiratory health in underserved populations. Our negative findings for current asthma in children and adults may be due to under-diagnosis or misclassification of this disease. Current wheeze, which is not dependent on a physician's diagnosis, is highly correlated with asthma in children ages 6 years and older, but may be due to asthma or chronic obstructive pulmonary disease (COPD) in adults.

However, misclassification of COPD as asthma is unlikely to fully explain our results, as we accounted for cigarette smoking in our multivariable analysis. Moreover, we obtained similar results in an analysis restricted to non-smoking adults (see Supplementary Table E3).

The effect of dietary patterns on lung function is less clear. Consistent with our prior report that dietary patterns did not affect lung function among Puerto Rican children with asthma,¹⁰ we found that the DII did not significantly affect FEV₁ and FVC among adults with current wheeze. Because subjects with asthma or active wheezing typically have lower lung function and greater airway inflammation, dietary intake might affect lung function differently among those with wheezing symptom and disease free individuals. Because a repeated spirometry was only tested among those individuals who demonstrated airway obstruction, the BDR results should be interpreted with caution.

Among the food parameters included in the DII, saturated fat, *trans* fat, and cholesterol are the main pro-inflammatory contributors, while n-3 and n-6 fatty acids have anti-inflammatory properties.¹¹ A Westernized diet, including consumption of food rich in energy and fat, has been linked to airway inflammation,²¹ respiratory symptoms²² and reduced lung function.²³ Mice fed a high-fat diet develop obesity and airway hyperreactivity (AHR) through upregulation of the pro-inflammatory cytokine IL-17A.²⁴ N-3 fatty acids have shown stronger and more consistent anti-inflammatory effects on asthma than n-6 fatty acids; however, the ratio of n-3 to n-6 fatty acids is thought to be important.²⁵ A murine model reported that whereas a high-fiber diet leads to increased circulating levels of short chain fatty acids (SCFAs, which reduce allergic airway inflammation), a low-fiber diet leads to decreased levels of SCFAs (and increased severity of allergic airway inflammation).²⁶ Dietary intake of high fat and low fiber has been associated with lower FEV₁ and worsened airway inflammation among adults with asthma.²⁷ Consistent with pro-inflammatory effects of a Westernized diet on the airways, we show that a higher DII is significantly associated with higher BDR among individuals with obstruction of the lung in NHANES

Among the DII food parameters, nutrients mainly derived from fruits and vegetables (such as fiber, β -carotene, riboflavin, flavones, and vitamins A, C, D, and E) exhibit anti-inflammatory effects. Fruits and vegetables may have protective effects against allergic diseases such as asthma through downregulation of Th2 immune responses, airway inflammation, and oxidative stress⁸. A pooled study recently reported that dietary intake of fruits and vegetables was associated with 14%–46% decreased risk of wheeze and asthma in both children and adults.²⁸ Higher intake of fruit and vegetables has been positively associated with FEV₁ and FVC but inversely associated with IL-8 levels in nasal lavage in asthmatic children.²⁹ In a study of adults in NHANES, participants in the highest quartile of fiber intake had 80 ml to 130 ml higher FEV₁ and FVC than those in the lowest quartile.³⁰ A higher Alternative Healthy Eating Index (AHEI) score (greater compliance to dietary guidelines) was associated with a slower FEV₁ decline in American men. Moreover, consuming one additional serving of vegetables or fruit per day could attenuate lung function decline among smoking men.³¹

FeNO is a sensitive marker of eosinophilic airway inflammation, with low FeNO levels (<20 ppb in children or <25 ppb in adults) denoting low likelihood of eosinophilic airway

inflammation or corticosteroid responsiveness.¹⁸ Our finding of an association between the DII and current wheeze in children with high FeNO suggests that children with predominantly allergic (atopic) asthma are more susceptible to the pro-inflammatory effects of their diet. Moreover, this association does not show a dose-response trend, suggesting a potential threshold effect. Among adults, higher DII was associated with wheeze in those with or without eosinophilic airway inflammation, while the effect size of the DII on wheeze was higher among those with eosinophilic airway inflammation.

Consistent with its ability to assess the pro-inflammatory effects of diet, the DII is associated with serum CRP, IL-6, and homocysteine levels.^{12, 32} Moreover, a high DII score has been linked to inflammatory conditions such cardiovascular disease,³³ colorectal cancer³⁴ and glucose intolerance.³⁵ Consistent with some of our findings, Wood et al reported that a higher DII is associated with asthma, decreased FEV₁, and increased IL-6 in a small case-control study of non-smoking Australian adults.¹³

Randomization of overweight or obese adults to a plant-based diet resulted in improved DII scores,³⁶ but whole-diet interventions on asthma or lung function are scarce. Current studies of dietary interventions or weight loss and asthma control have mostly focused on “obese asthma”,³⁷ but our findings for wheeze or lung function were independent of obesity. Prospective studies are needed to evaluate whether change of dietary intake towards anti-inflammatory patterns improve wheezing and lung function in both children and adults.

The present study has considerable strengths, including a large sample representative of the US population, performance of standardized procedures by uniformly trained personnel, and the ability to account for several potential confounders. We must also acknowledge several limitations. First, we cannot determine a temporal relationship between the DII and wheeze or lung function in a cross-sectional study. However, most children or adults with wheeze or worsened lung function are unlikely to differentially adopt a pro-inflammatory dietary pattern. Second, dietary intake was based on one 24-hr dietary recall, which does not account for day-to-day or seasonal variability in diet patterns. However, a longitudinal study recently found that the DII stays relatively constant over a period of years.³⁸ Third, few nutrients (i.e. flavones, anthocyanidins) were not included in the DII calculation due to the lack of information from NHANES. Fourth, the study did not account for other potential confounders, including allergic sensitization, use of asthma medications, and exposure to air pollution.

In summary, our study suggests detrimental effects of a pro-inflammatory diet on wheeze in adults and in atopic children (who have allergic airway inflammation). These results further support studying whole-diet interventions to improve asthma and respiratory health in the United States.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

BDR	bronchodilator response ($[(\text{post-bronchodilator FEV}_1 - \text{pre-bronchodilator FEV}_1)/\text{pre-bronchodilator FEV}_1] \times 100$)
BMI	body mass index ($\text{weight [kg]}/\text{height[m]}^2$)
DII	dietary inflammatory index
FeNO	fractional exhaled nitric oxide
FEV₁	forced expiratory volume in 1 second
FVC	forced vital capacity
NHANES	National Health and Nutrition Examination Survey
PUFA	polyunsaturated fatty acids
SCFAs	short chain fatty acids

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Highlights

What is already known about this topic?

Dietary patterns are associated with asthma and lung function, likely through pro-inflammatory pathways.

What does this article add to our knowledge?

An overall pro-inflammatory diet, assessed by the dietary inflammatory index (DII), increases the risk of current wheeze in adults and in children with high fractional exhaled nitric oxide (FeNO). Moreover, the DII is associated with decreased FEV₁ and FVC in adults without wheezing.

How does this study impact current management guidelines?

A diet with higher pro-inflammatory components and lower anti-inflammatory components may have detrimental effects on asthma symptoms in adults and atopic children in the US. Our findings further support studies of whole-diet interventions to reduce asthma burden.

Figure. The dietary inflammatory index (DII) and current wheeze by fractional exhaled nitric oxide (FeNO) level, NHANES 2007–2012

All models were adjusted for age, gender, race/ethnicity, household income, BMI z-score (children) or BMI (adults), and family history of asthma. [†]P<0.05

Table 1

Characteristics of participants by current wheeze, NHANES 2007–2012

Characteristics	Children 6–17 years		Adults 18–79 years	
	Current wheezing			
	No n=6,343	Yes n=744	No n=15,313	Yes n=2,204
Age (years)	11.7 ± 0.1	11.7 ± 0.3	44.0 ± 0.4	44.1 ± 0.7
Male gender	3166 (48.7)	437 (51.8)	7639 (49.5)	1007 (44.3) [‡]
Race/ethnicity				
Non-Hispanic White	1914 (59.1)	221 (53.3) [‡]	6579 (67.9)	1131 (72.1) [‡]
Non-Hispanic Black	1428 (12.9)	248 (21.2)	3081 (10.8)	528 (13.1)
Mexican American/other Hispanic	2438 (21.6)	208 (16.7)	4481 (14.9)	422 (8.9)
Other	563 (6.4)	67 (8.8)	1172 (6.4)	123 (5.9)
Private health insurance coverage	2155 (59.8)	240 (54.1)	6360 (65.2)	769 (54.9) [‡]
Annual household income < \$20,000	1304 (15.0)	175 (17.8)	2819 (13.2)	614 (21.2) [‡]
Family history of asthma	1686 (26.6)	413 (53.5) [‡]	2709 (17.6)	801 (36.9) [‡]
Current asthma	330 (4.7)	483 (59.1) [‡]	526 (3.4)	787 (36.4) [‡]
Body mass index (kg/m ²)	21.0 ± 0.1	21.5 ± 0.2	28.4 ± 0.1	30.7 ± 0.3 [‡]
BMI z-score	0.64 ± 0.03	0.76 ± 0.06	-	-
Current smoker	-	-	2845 (18.8)	858 (42.1) [‡]
Serum cotinine level (ng/ml)	5.5 ± 1.2	8.8 ± 3.2	50.0 ± 2.4	110.3 ± 6.9 [‡]
The dietary inflammatory index (DII) ²	0.91 ± 0.05	1.01 ± 0.10	0.22 ± 0.04	0.77 ± 0.06 [‡]
Fractional exhaled nitric oxide (FeNO), ppb	15.0 ± 0.4	24.3 ± 1.6 [‡]	16.0 ± 0.3	21.2 ± 0.9 [‡]
% predicted pre-bronchodilator FEV ₁	104.3 ± 0.4	100.6 ± 0.7 [‡]	98.6 ± 0.3	89.1 ± 0.7 [‡]
% predicted pre-bronchodilator FVC	105.9 ± 0.4	105.4 ± 0.9	101.8 ± 0.3	97.0 ± 0.5 [‡]
% predicted pre-bronchodilator FEV ₁ /FVC	98.0 ± 0.2	95.1 ± 0.5 [‡]	96.6 ± 0.2	91.3 ± 0.4 [‡]
Bronchodilator response (%)	9.3 ± 0.6	14.4 ± 1.5 [‡]	5.3 ± 0.2	8.9 ± 0.6 [‡]

Results are shown as mean ± standard error (SE) for continuous variables, and as N (%) for binary variables.

[‡]P<0.05 or[‡]P<0.01 for current wheezing vs no current wheezing (within each age group)¹Data are only available in NHANES 2007–2010 (N= 4,398 children and N=12,945 adults)²The DII was calculated per 1000 calories of daily food consumed

Table 2

The dietary inflammatory index (DII), current wheeze, and current asthma by age group, NHANES 2007–2012

	Children (n=8,175)	Adult (n=22,294)
Odds ratio (95% CI), P-value		
Current wheeze		
DII (continuous)	1.01 (0.92, 1.10)	1.09 (1.05, 1.13)[‡]
DII		
Quartile 1	1.0 (reference)	1.0 (reference)
Quartile 2	1.28 (0.85, 1.95)	0.98 (0.76, 1.27)
Quartile 3	1.16 (0.72, 1.89)	1.22 (1.01, 1.47)[†]
Quartile 4	1.00 (0.67, 1.50)	1.41 (1.17, 1.70)[‡]
	<i>p-trend</i> = 0.89	<i>p-trend</i> < 0.01
Current asthma		
DII (continuous)	1.03 (0.93, 1.13)	1.01 (0.94, 1.08)
DII		
Quartile 1	1.0 (reference)	1.0 (reference)
Quartile 2	1.06 (0.72, 1.55)	0.90 (0.64, 1.27)
Quartile 3	1.09 (0.67, 1.79)	0.97 (0.66, 1.42)
Quartile 4	1.14 (0.73, 1.79)	0.94 (0.66, 1.33)
	<i>p-trend</i> = 0.57	<i>p-trend</i> = 0.81

All models adjusting for, gender, race/ethnicity, annual household income, BMI z-score (children) or BMI (adults), family history of asthma, and serum level of cotinine.

[†]P<0.05;

[‡]P<0.01

Table 3

The dietary inflammatory index (DII) and current wheeze, stratified by relevant covariates in adults

The DII	Q1	Q2	Q3	Q4	<i>p-trend</i>
Gender					
Male	1.0	1.14 (0.83, 1.57)	1.39 (1.04, 1.86)[‡]	1.64 (1.23, 2.18)[‡]	<0.01
Female	1.0	0.87 (0.62, 1.23)	1.11 (0.87, 1.41)	1.24 (0.96, 1.61)	0.05
Race/Ethnicity					
Non-Hispanic White	1.0	1.05 (0.75, 1.45)	1.45 (1.14, 1.84)[‡]	1.58 (1.22, 2.05)[‡]	<0.01
Non-Hispanic Black	1.0	1.04 (0.61, 1.79)	0.99 (0.68, 1.45)	1.48 (1.08, 2.02)[‡]	<0.01
Mexican American/ other Hispanic	1.0	0.72 (0.42, 1.22)	0.80 (0.49, 1.32)	1.06 (0.68, 1.66)	0.71
Other	1.0	0.96 (0.45, 2.08)	0.80 (0.35, 1.85)	0.59 (0.23, 1.52)	0.29
Household income					
< \$20,000/year	1.0	0.63 (0.43, 0.93) [‡]	0.82 (0.55, 1.21)	1.03 (0.70, 1.52)	0.43
\$20,000/year	1.0	1.09 (0.79, 1.51)	1.35 (1.10, 1.66)[‡]	1.54 (1.23, 1.92)[‡]	<0.01
BMI (kg/m²)					
25 (kg/m ²)	1.0	0.71 (0.47, 1.10)	0.89 (0.56, 1.40)	1.15 (0.74, 1.49)	0.38
> 25	1.0	1.13 (0.84, 1.54)	1.46 (1.20, 1.78)[‡]	1.67 (1.29, 2.15)[‡]	<0.01
Current smoker					
No	1.0	0.99 (0.74, 1.35)	1.17 (0.92, 1.49)	1.28 (1.01, 1.62)[‡]	0.02
Yes	1.0	0.79 (0.46, 1.36)	1.23 (0.76, 2.00)	1.55 (1.07, 2.25)[‡]	<0.01

All models adjusting for age, gender, race/ethnicity, annual household income, BMI, family history of asthma, and serum level of cotinine except for the covariate used for stratification in each model.

[‡]P<0.05;

[‡]P<0.01

Table 4

The dietary inflammatory index (DII) and lung function measures, NHANES 2007–2012

Lung Function Measures	Children (n = 5,796)	Adults (n = 15,791)
All participants		
% predicted pre-bronchodilator FEV ₁	−0.25 (−0.67, 0.18)	−0.27 (−0.47, −0.08)[‡]
% predicted pre-bronchodilator FVC	−0.21 (−0.63, 0.21)	−0.36 (−0.55, −0.18)[‡]
% predicted pre-bronchodilator FEV ₁ /FVC	−0.05 (−0.28, 0.19)	0.07 (−0.03, 0.18)
Bronchodilator response (%) ^I	0.62 (−0.09, 1.32)	0.18 (−0.01, 0.38)
Participants without asthma or wheeze		
	n = 4,892	n = 13,303
% predicted pre-bronchodilator FEV ₁	−0.22 (−0.64, 0.20)	−0.22 (−0.44, −0.01)[‡]
% predicted pre-bronchodilator FVC	−0.20 (−0.61, 0.22)	−0.35 (−0.55, −0.15)[‡]
% predicted re-bronchodilator FEV ₁ /FVC	−0.04 (−0.29, 0.22)	0.12 (−0.01, 0.24)
Bronchodilator response (%) ^I	0.60 (0.00, 0.20)	0.23 (0.05, 0.41)[‡]
Participants with current wheeze		
	n = 629	n = 2,001
% predicted pre-bronchodilator FEV ₁	−0.33 (−1.65, 0.99)	0.07 (−0.60, 0.73)
% predicted pre-bronchodilator FVC	0.12 (−1.22, 1.45)	−0.12 (−0.70, 0.47)
% predicted re-bronchodilator FEV ₁ /FVC	−0.38 (−1.10, 0.35)	0.09 (−0.31, 0.50)
Bronchodilator response (%) ^I	2.17 (1.91, 2.43)[‡]	−0.20 (−0.43, 0.03)

Data presented as β (95% CI), P-value. All models adjusting for annual household income, BMI z-score (children) or BMI (adults), family history of asthma, serum level of cotinine and current asthma (in all participants).

^IIn addition adjusting for age, gender, race/ethnicity, and pre-bronchodilator FEV₁

[‡]P<0.05;

[‡]P<0.01