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Association of Obesity with IgE and Allergy Symptoms in Children and Adolescents: Results from NHANES 2005–2006

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Abstract

Background—The prevalence of both obesity and allergic disease has increased among children over the last several decades. Previous literature on the relationship between obesity and allergic disease has been inconsistent. It is not known whether systemic inflammation could be a factor in this relationship.

Objective—To examine the association of obesity with total and allergen-specific IgE levels and with allergy symptoms in U.S. children and adolescents, and to assess the role of C-reactive protein.

Methods—NHANES data from 2005–2006 included measurement of total and allergen-specific IgE and allergy questions. Overweight was defined as ≥ 85th to < 95th percentile of BMI-for-age, and obesity was defined as ≥ 95% percentile. Linear and logistic regression models were used to examine the association of weight categories with total IgE, atopy, allergen-specific IgE, and allergy symptoms among youth aged 2–19.

Results—Geometric mean total IgE levels were higher among obese (geometric mean ratio: 1.31; 95% CI: 1.10–1.57) and overweight children (ratio: 1.25; 95% CI: 1.02–1.54) than among normal weight children. The odds ratio for atopy (any positive specific IgE) was elevated in the obese children compared to those of normal weight; this association was driven largely by allergic sensitization to foods (OR for atopy: 1.26; 95% CI: 1.03–1.55; OR for food sensitization: 1.59; 95% CI: 1.28–1.98). C-reactive protein levels were associated with total IgE, atopy, and food sensitization.

Conclusions—Obesity may be a contributor to the increased prevalence of allergic disease in children, particularly food allergy. Systemic inflammation may play a role in the development of allergic disease.

Clinical Implications—Efforts to reduce or prevent childhood obesity may have the added benefit of reducing allergic disease, especially to foods.

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Keywords

Atopy; Allergen-Specific IgE; Total IgE; BMI; Obesity; Overweight; Allergic Disease; Inflammation

Introduction

The adiposity of the U.S. population has been growing steadily. This is true both for adults and children, and it is also the case throughout the developed countries of the world. This increase has been most apparent since about 1980. Before that time, only about 5% of U.S. children age 6–11 were considered overweight; by 2004 that rate had climbed to nearly 19%.[1]

Allergic disease has also been on the rise in recent decades. In the U.S. from the period 1976–1980 to 1988–1994, the prevalence of skin test reactivity to 6 common allergens increased from 22% to 42%.[2] Increases in atopy have also been observed in Europe.[3–5]

Some researchers have shown obesity to be related to allergy symptoms or to higher serum IgE levels (a marker for atopy),[6–8] while others have not.[9–11] Differences in the ages of the study populations, the specific outcomes examined, and the methods used for categorizing obesity may account for the disparate findings. Analyses of National Health and Nutrition Examination Survey (NHANES) III data, collected in 1988–1994, showed neither the prevalence of atopy (defined by any positive skin test) nor serum eosinophil counts (another marker for allergy) to be significantly related to increasing quartiles of body mass index (BMI) among children age 6–17 in adjusted models.[12] No IgE data were available in NHANES III.

Recent research suggests that systemic inflammation, as measured by C-reactive protein (CRP) levels, may be important in the relationship between obesity and asthma.[13] C-reactive protein is a marker for systemic inflammation and is often very high in overweight individuals. Differences in CRP levels by atopic status have not been previously examined. If CRP is associated with atopy as well, that would suggest a common pathway for the effect of overweight on allergic disease and asthma.

An Allergy/Asthma Component was added to the 2005–2006 NHANES, which included total and allergen-specific serum IgE measurements. This is the largest nationally-representative dataset of serum IgE levels that has ever been collected on the U.S. population. This analysis explores the complex relationships between obesity, serum IgE, and allergy symptoms, and examines how CRP plays a role in these relationships, using data from the NHANES 2005–2006.

Methods

Study Population

The NHANES is a nationally representative survey conducted periodically to assess the health and nutritional status of adults and children in the United States. The primary purpose of NHANES is to determine the prevalence of major diseases and risk factors for those diseases.[14] Details of the plan and operation of NHANES may be found online at http://www.cdc.gov/nchs/nhanes.htm. Written informed consent was obtained for all subjects.

The target population of NHANES is the civilian, non-institutionalized population of the U.S. The NHANES uses a stratified, multi-stage probability sampling design with oversampling of persons believed to be at increased health risk. The stages of sampling are 1) Primary Sampling Unit (PSU) which is usually a county or block of contiguous (low-population) counties; 2)

segments within PSUs (blocks or clusters of households); 3) households within segments; 4) one or more participants within households. Weights are supplied with the public use dataset so that estimates can be produced that reflect the U.S. population distribution and can be considered to be nationally representative. Eligible persons age 16 or older are interviewed directly, while interviews for those under age 16 are done with a proxy. All persons who complete the household interview are invited to participate in the Medical Examination component of NHANES. In the 2005–2006 NHANES, 4,321 children age 2–19 completed both the interview and the medical examination components, and 4,269 children had their height and weight measured.

Allergy Outcomes

Allergy was determined in two ways: questionnaire about symptoms and serum IgE levels. The questionnaire that was added to NHANES in the 2005–2006 cycle asks individuals to report previous diagnoses of hay fever, eczema, and allergies. For those reporting a diagnosis, further questions are asked regarding age at diagnosis and occurrence of symptoms over the past year. This analysis uses current symptoms – those occurring in the previous 12 months.

Participants aged 1 year and older were tested for total and allergen-specific serum IgE using the Pharmacia Diagnostics ImmunoCAP 1000 System (Kalamazoo, Michigan). A detailed description of the laboratory method can be found at NHANES 2005–2006 web page (http://www.cdc.gov/nchs/data/nhanes/nhanes_05_06/al_ige_d.pdf). Total IgE is available for 3,617 (84%) of the children age 2–19. Because smaller quantities of serum were available for young children, the number and type of allergen-specific IgE tests performed varied by age. Children age 1 to 5 were tested for total IgE and specific IgE to dust mite (*D. farinae* and *D. pteronyssinus*), cat, dog, cockroach, *Alternaria*, peanut, egg, and milk. Children and young adults age 6 and above also have specific IgE measurements for ragweed, ryegrass, bermuda, white oak, birch, shrimp, *Aspergillus*, thistle, mouse, and rat.

We definied atopy as a positive response ($\geq$ 0.35 kU/L) to at least one of the allergens tested. Analysis of atopy included only individuals with information for the full panel of allergens (9 allergens for those under age 6, and 19 for those age 6–19). Of the 4,321 children with a physical exam, 703 (16.3%) did not have enough blood for specific IgE testing, and 100 (2.3%) did not have a full panel. Except that younger children were more likely to be missing the blood sample, socio-demographic characteristics and prevalence of allergy (by questionnaire) did not differ between those with IgE measurements and those without.

Weight Measurements

All participants who attended the medical examination had their weight and height measured following a standard protocol. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Sex-specific BMI percentile-for-age was calculated using the Centers for Disease Control and Prevention 2000 reference standards.[15] Children between the 5th and 85th percentile of BMI-for-age were considered to be normal weight, those between the 85th and 95th percentile were considered overweight, and those at or above the 95th percentile were considered obese, as recommended by the American Medical Association.[16]

Other Measures

The age, sex, and race/ethnicity of the child, as reported in the personal interview, were examined as potential confounders and effect modifiers. As measures of socioeconomic status (SES), the highest education level obtained by the household reference person (typically the household head) and quartiles of the poverty income ratio (PIR) were also examined for their relationship to overweight and atopy. The PIR is the relationship of family income to the poverty threshold based on family size and composition.[17]

Other potential confounders considered were current household smoking (yes/no), maternal smoking during pregnancy (yes/no), birthweight (low birthweight vs. not), and several physical activity measures. All children were asked the average number of hours per day they spent either watching television or using a computer. For children age 2–11, the proxy respondent answered one question about how many times per week the child played or exercised enough to sweat or breathe hard. Children age 12–19 answered more detailed questions about the specific activities that qualified as moderate or vigorous activity and the number of times they did those activities in the past month. For this analysis, the number of times vigorous activities were reported were summed and recalculated as a weekly rather than a monthly total to make this information comparable to that for the younger children.

Statistical Analyses

Because underweight has been associated with increased risk for allergic disease,[18] we excluded 144 children who were less than the 5th percentile of BMI for their age and sex (3.4%). Of the 4,125 children and adolescents above this cut-off, 4,111 have data on allergy symptoms and 3,387 have data for atopy.

The association of overweight with geometric mean total IgE was estimated using the ratio of the geometric means in a linear regression model. Logistic regression was used to determine the prevalence odds ratio for weight category in relation to atopy, a positive test to any food allergen, a positive test to any inhalant allergen (the non-food allergens), a positive test to any perennial allergen (dust mite, cockroach, mold, cat, dog, rat, mouse), a positive test to any seasonal allergen (trees and grasses), and to the following allergic symptom outcomes: the occurrence of allergy symptoms or attacks in the past year (yes/no), the occurrence of hay fever symptoms in the past year (yes/no), and eczema (itchy rash coming and going for at least 6 months in the past year) (yes/no). In addition, weight was examined in relation to each allergen individually.

The association between continuous BMI percentile-for-age and total IgE (logbase 10) was examined using linear regression. Data were plotted using a scatterplot smoothing technique.[19]

Potential modification of the effect of overweight on atopy and allergic outcomes was examined for sex, age, and race/ethnicity. A p-value for the interaction term < 0.10 was considered evidence of interaction. Stratified models were used to explore associations where evidence for interaction was found.

The potential for confounding was first examined by looking at the strength of the univariate associations between potential available confounders and the exposure and the outcome. Age, sex, race/ethnicity, poverty income ratio, and household smoking were retained in the adjusted models based on these associations and findings from previous studies. Results for both simple age-adjusted and fully adjusted models are shown. C-reactive protein was found to be associated with both weight and atopy, but cannot be treated as a confounder in this relationship as it may be on the causal pathway. Instead, a model that assessed the relationship between CRP and atopy and potential confounding by BMI examined this possibility.

All analyses were performed using SAS survey sampling procedures to adjust for the NHANES complex sampling design (Version 9.1.3, Cary, NC). Figures were generated using the R system for statistical computing (version 2.7.0), which also can account for the sampling design.[19]

Results

Table I shows the distribution of the allergic outcomes in the NHANES 2005–2006 population age 2–19 by demographic characteristics and other potential confounding variables. Total IgE increased with age and was higher among boys. By race/ethnicity, IgE was highest in non-Hispanic blacks and lowest in non-Hispanic whites. Total IgE was higher with a lower poverty income ratio. There is also a strong relationship between CRP levels and total IgE. Total IgE was not related to smoking, birthweight, or physical activity.

The proportion classified as atopic based on at least one positive allergen-specific IgE result follows a similar pattern, with boys being more likely than girls to be atopic and non-Hispanic blacks and Mexican-Americans being more likely than non-Hispanic whites to be atopic. Children whose mothers smoked during pregnancy were somewhat less likely to be atopic than children of non-smoking mothers. Atopy was also related to the child's CRP level.

Odds of current allergy symptoms were increased at older ages, but reduced for Mexican Americans. Children whose household reference person had less than a high school education and for those in the lowest quartile of poverty income ratio also had a reduced odds of recent allergy symptoms. Otherwise, report of recent allergy symptoms was not highly associated with any of the socio-demographic characteristics.

The relationships of the same characteristics to obesity are shown in Table E1 in the online supplement. Overweight was associated with older age, being non-Hispanic black or Hispanic, lower education, smoking, and lower physical activity levels, especially the number of hours of television watching. As expected, there is a moderate relationship of obesity with CRP levels. The correlation between the continuous BMI z-score and the log 10 CRP level is 0.39 (95% CI: 0.37, 0.41).

Table II shows the age-adjusted and fully adjusted association of the overweight categories with total IgE, atopy, sensitization to food and inhalant allergens, and reported allergy symptoms, hay fever, and eczema. Both weight categories were associated with higher total IgE in both models. Being in the obese category was associated with higher odds of atopy (OR 1.26; 95% CI: 1.03–1.55). The odds ratio for sensitization to foods was particularly elevated (OR 1.59; 95% CI: 1.28–1.98), whereas the odds for inhalant allergen sensitization were not elevated in the fully-adjusted model. Odds for allergy symptoms, hay fever, and itchy rash were also not different by weight category in adjusted models. Examination of the specific foods tested shows a large association with sensitization to milk in both weight categories, an association with sensitization to egg in the overweight category only, and an association with sensitization to shrimp in the obese category only. There was no association observed for sensitization to peanut. With the exception of total IgE, significant gender differences were not observed; however, data are presented by sex in Table E2 in the online supplement. Although no significant effect modification was seen by age group for these outcomes (see Table E3 in the online supplement), the food sensitization association in the 2 to 5 year old children was particularly strong (OR 2.58; 95% CI: 1.45–4.60).

Figure 1 shows the relationship between continuous BMI percentile-for-age and total IgE, stratified by sex. There is a significant linear trend (for a 1 standard deviation increase in the BMI z-score on the log-10 value of total IgE) that is stronger for girls (slope=0.104, 95% CI: 0.064–0.143) than for boys (slope=0.042, 95% CI: 0.010–0.075; p-value for interaction=0.04). Race/ethnicity modified the relationship between overweight and atopy in girls (see Table E3 in the online supplement). Figure 2 displays the percent of atopy among girls by ethnicity and weight category. The association of obesity with atopy was only significant among non-Hispanic white and non-Hispanic black girls.

To examine whether CRP (i.e. systemic inflammation) might be on the pathway between obesity and atopy, we examined whether CRP was related to total IgE, atopy, and food allergy with and without adjustment for BMI (Table III). CRP and total IgE were correlated in age-adjusted analysis. Further adjustment for race, SES, and smoking attenuated the relationship. Adjusting for BMI in addition to socio-demographic factors decreased the model estimate by 31% (12% in boys and 70% in girls). Thus, the relationship of CRP to total IgE was confounded by BMI. Conversely, the odds ratio for atopy was not significantly attenuated when adjusting for BMI, and the odds ratio for food sensitization was reduced by more than 10% only in girls.

Discussion

We found a relationship between overweight and atopy in this population of American children age 2–19. Sensitization to foods appeared to be responsible for the overall relationship with atopy. For most of the outcomes, the associations were stronger for the obese weight category than the overweight category, providing evidence of a dose-response for weight. The analysis of continuous BMI with total IgE supports the concept that increased weight is associated with increased allergic predisposition.

A relationship between obesity and atopy has been observed before, but not consistently, and food sensitization has rarely been examined in relation to body weight. Huang et al. found that Taiwanese teenage girls in the highest quintile of BMI were more likely to be atopic than girls in the middle 3 quintiles (OR 1.77, 95% CI: 1.15, 2.73).[6] Xu et al. found atopy to be associated with current BMI among Finnish adults.[8] Schachter et al. combined data from 7 epidemiological studies in Australian children and found that BMI was associated with atopic status among girls only.[7] In all of these studies, prick skin tests were used rather than allergen-specific serum IgE, and only the Huang study included a food allergen (shellfish mix) among the allergens tested. In contrast, the European Community Respiratory Health Survey used allergen-specific IgE (dust mite, grass or cat) to define atopy and did not find a relationship with BMI among young adults.[9]

Previous work using NHANES III data also did not find a significant relationship between overweight and atopy in children age 6–17.[12] Comparative analyses using both datasets suggest that the main reasons for this difference are the inclusion of younger children and the inclusion of the food-specific IgE tests in NHANES 2005–2006. While a significant interaction effect was not seen overall across age groups, the largest odds ratio was observed among the 2–5 year-old children (2.58; 95% CI: 1.45–4.60). Additionally our findings were strongest for food-specific IgE. The 2005–2006 NHANES includes IgE levels for milk, egg, peanut and shrimp, whereas NHANES III included only a skin test for peanut. Sensitization to milk (more common in younger children) and to shrimp (only tested in those age 6 and above) were both strongly associated with overweight and obesity. The association with sensitization to shrimp suggests that the relationship is not limited to egg and milk allergy or to younger children.

Conversely, no association was seen between obesity and reported allergy symptoms and hay fever. The symptom outcomes and IgE levels are weakly correlated in these data. This could be in part because the symptom data relate to only the 12 months prior to the survey, whereas serum IgE reflects overall allergic predisposition. In addition, the persons with the most allergy symptoms may take regular medication and thus may not report having an allergy attack. Information on over-the-counter allergy medication, however, is not available in the NHANES 2005–2006 dataset.

Effect modification by sex was observed for total IgE but not the other allergic outcomes. Total IgE was elevated for girls (but not boys) in the overweight category, whereas it was elevated for boys (but not girls) in the obese category. In addition, the relationship of BMI examined

as a continuous variable with total IgE was stronger in girls than in boys. In girls, the effect on atopy was present among non-Hispanic white and black girls, but not Mexican American girls. The mechanism for this difference among racial/ethnic groups remains enigmatic, especially given that obesity and atopy were strongly associated among Mexican-American boys.

One limitation of this analysis is that it used BMI to characterize obesity, which is not a direct measure of fatness and may misclassify some children, particularly adolescent males, who can be heavier than average due to a larger bone structure or more muscle mass.[20] Nevertheless, BMI has been shown to correlate well with other measures of adiposity. Mei et al. compared BMI to dual x-ray absorbtiometry (DXA) in a pooled dataset of 3 studies in children and found correlations that ranged from 0.78 to 0.88, and that the area under the receiving operating characteristics curve was 0.952.[21] DXA to directly measure percent body fat was performed in the 2005–2006 NHANES, but those data are not available at this time. In order to assess the potential for bias, we examined the correlation between percent body fat, measured by DXA, and BMI in the available NHANES data from 1999–2004. We found the correlation between BMI z-score and percent body fat to be 0.78 overall. The correlation was somewhat weaker (0.73) for adolescent boys, but otherwise did not differ significantly by gender, race, or age. BMI was observed to perform poorly as a proxy for percent body fat only among children below the 50th percentile, suggesting that the potential for misclassification of weight status when using the CDC BMI-percentile-for-age categories at the upper end of the distribution is minimal.

Odds ratios, as presented in this study, always overestimate the true relative risk, but are a reasonably good estimate for rare outcomes.[22] Because the prevalence of atopy is high in U.S. children (46%), the estimated odds ratio is considerably farther from the null than the relative risk. Nonetheless, reported p-values and confidence intervals remain valid.

The relationship between CRP levels and atopy has not been previously examined. Because we found a relationship between CRP levels and atopy in this study, we explored the possibility that inflammation (CRP) could be on the pathway between obesity and atopy. As it is inappropriate to control for such an intermediate variable as a confounder,[22] we tested whether the intermediate (CRP) was related to total IgE, atopy, and food sensitization, and whether that relationship was confounded by BMI. We found that CRP was positively correlated to total IgE, and that confounding of this relationship by BMI was indeed present. This suggests that there could be an inflammatory component to the association between BMI and IgE levels. We were not able, however, to demonstrate the same level of confounding for atopy or food sensitization, except for girls in the latter case.

Importantly, because these NHANES data come from a cross-sectional survey, it is not possible to assign causality to these associations. Other explanations for our findings are possible, such as the presence of an unmeasured confounder, e.g. gut microbiota,[23] which is known to be associated with both increased allergy and obesity. Given that some gender differences were observed, hormonal influences may also be at play. Reverse causation could also be possible if milk-allergic children drink more juice or sweetened beverages, which have been shown to increase obesity in children.[24, 25] In order to understand the true causal mechanisms that underlie the relationships between adiposity and development and manifestation of atopy and allergic symptoms, it will be necessary to examine inter-relationships among overweight, systemic inflammation, atopy, and asthma in a prospective fashion.

NHANES 2005–06 is the largest dataset of serum IgE levels that has ever been collected, and it comes from a sample that is generalizable to the population of the U.S. The NHANES employs standardized data collection methods, with strict quality control, and contains a wealth of data regarding every study subject. Our analysis, using an objective assessment of atopy,

shows that overweight in children is associated with allergic predisposition, especially to food. Childhood obesity may be the most important health issue facing U.S. children today. While an increase in allergy may not be the most consequential health risk faced by overweight children, it does provide additional motivation for undertaking the difficult challenge to reduce childhood obesity.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Abbreviations

BMI
: Body mass index

CI
: Confidence interval

CRP
: C-reactive protein

DXA
: Dual x-ray absorbtiometry

IgE
: Immunoglobulin E

NHANES
: National Health and Nutrition Examination Survey

OR
: Odds ratio

PIR
: Poverty income ratio

PSU
: Primary sampling unit

SES
: Socio-economic status

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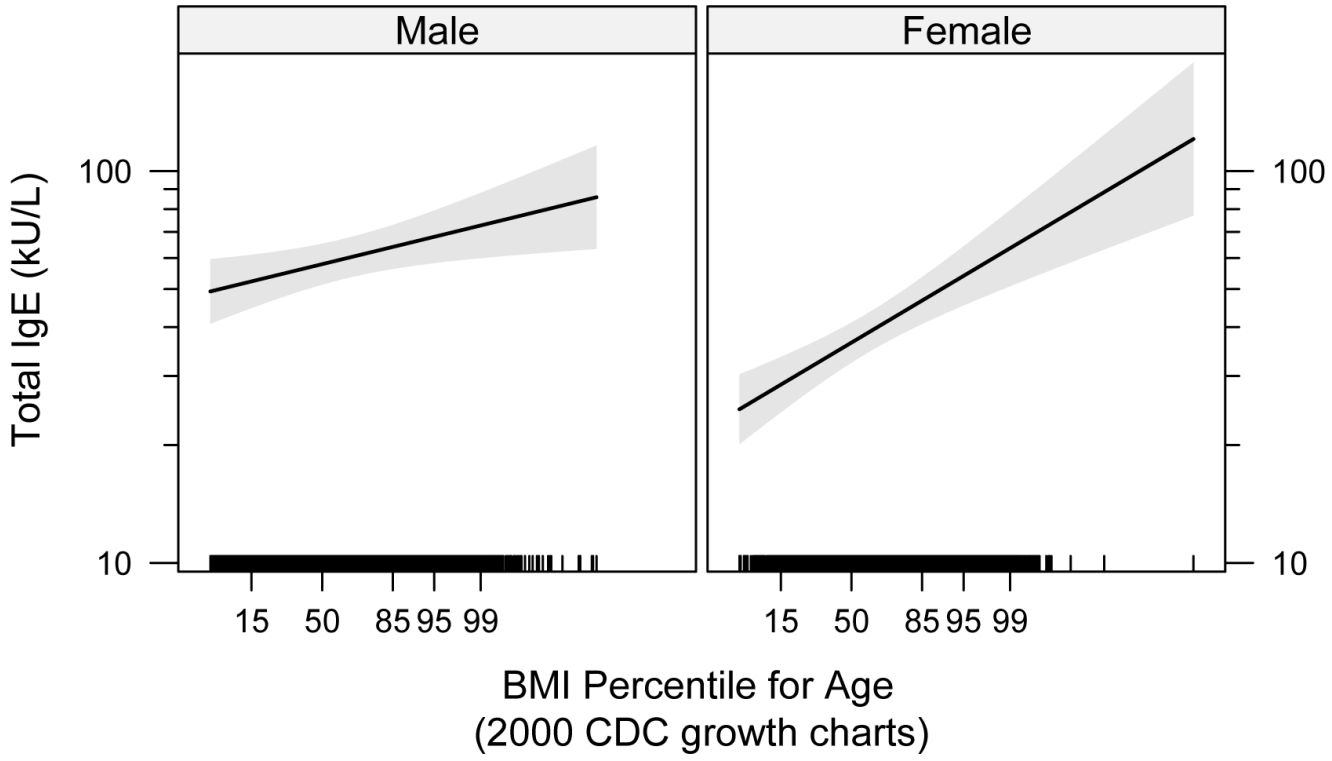

Figure 1.
Association between BMI percentile-for-age and total IgE by sex, NHANES 2005–2006, children age 2–19. The shaded region represents the 95% confidence limits of the data. The black lines represent observations and show where the data lie on the BMI distribution. The x axis is plotted as the z-score for BMI-for-age and labeled with the transformation of z-scores to percentiles.

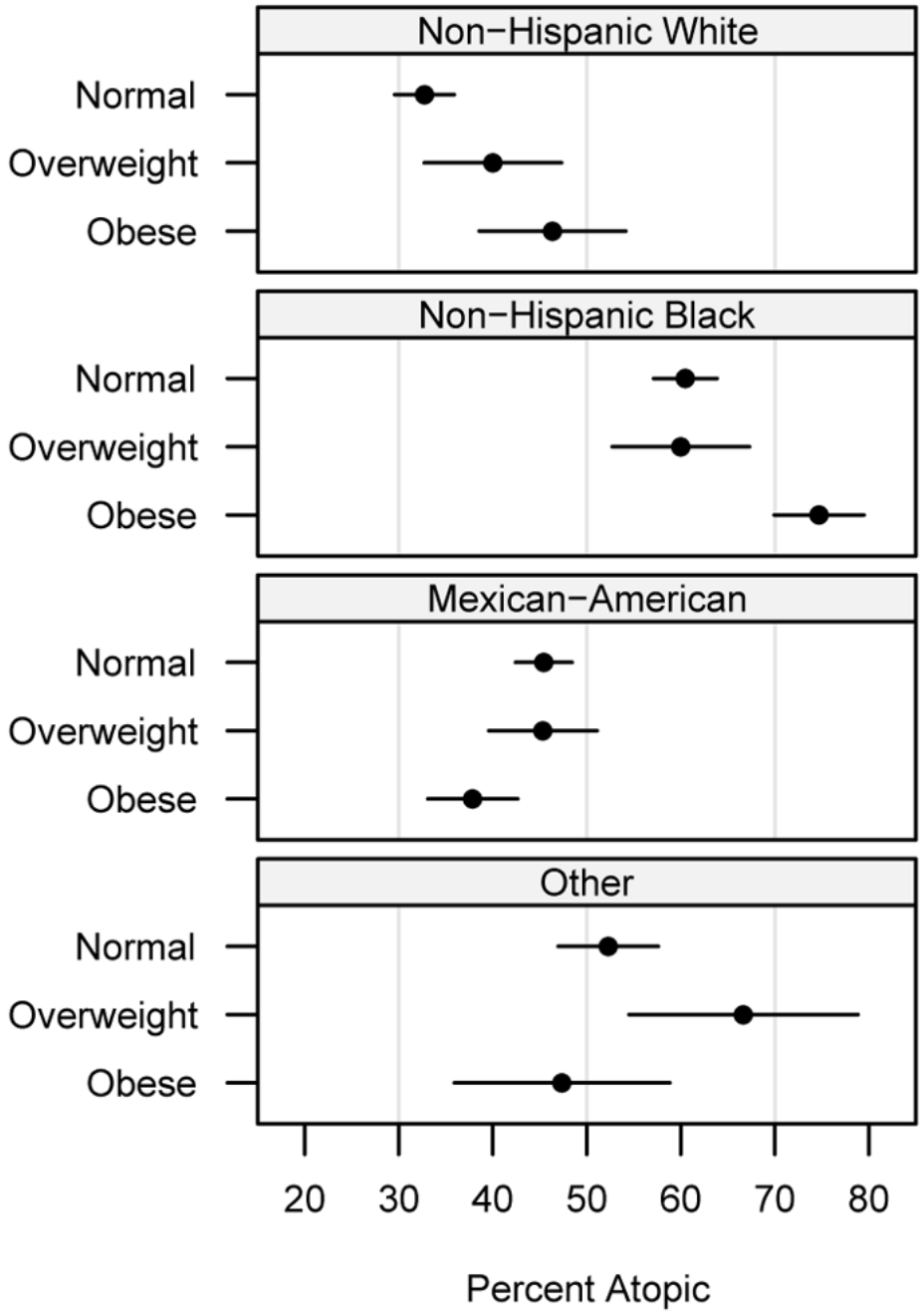

Figure 2.
Prevalence of atopy by race and weight status among girls NHANES 2005–2006, children age 2–19. The dots reflect the mean prevalence of atopy and the bars represent the 95% confidence interval.

Table I

Distribution of total serum IgE, atopy, and recent allergy symptoms by population characteristics, NHANES 2005–2006, children age 2–19.

Subject Characteristics	N	% in category	Geometric mean total IgE (SE)	p-value*	Percent SE) atopic†	OR (95% CI)	Percent SE) with allergy symptoms	OR (95% CI)
Overall	4111		50.4 (2.5)		46.4 (0.9)		18.7 (1.4)	
Age								
2–5	918	21.0	35.2 (3.9)	<0.0001	37.5 (2.1)	1.00	14.8 (2.1)	1.00
6–10	904	28.4	52.9 (3.7)		46.3 (2.5)	1.44 (1.02–2.02)	20.8 (2.3)	1.51 (1.01–2.23)
11–14	929	21.6	50.6 (4.0)		45.2 (2.1)	1.38 (1.07–1.77)	17.4 (1.9)	1.21 (0.81–1.81)
15–19	1360	29.0	59.2 (6.3)		52.1 (2.4)	1.82 (1.32–2.49)	20.6 (2.2)	1.49 (1.09–2.04)
Sex								
Male	2031	51.0	60.8 (3.7)	0.0002	49.4 (1.7)	1.29 (1.09–1.52)	19.1 (1.9)	1.05 (0.82–1.35)
Female	2080	49.0	41.4 (2.7)		43.2 (1.1)	1.00	18.4 (1.6)	1.00
Race-ethnicity								
Non-Hispanic white	1074	59.6	41.4 (3.0)	<0.0001	42.2 (1.5)	1.00	21.8 (2.4)	1.00
Non-Hispanic black	1291	14.9	83.9 (5.9)		62.2 (1.8)	2.26 (1.82–2.79)	17.5 (1.7)	0.76 (0.50–1.16)
Mexican American	1371	13.3	55.6 (3.2)		47.4 (1.7)	1.23 (1.01–1.51)	10.7 (0.9)	0.43 (0.30–0.63)
Other	375	12.2	66.6 (8.7)		47.6 (3.7)	1.24 (0.90–1.72)	14.0 (2.4)	0.58 (0.34–0.98)
Education (family referent)								
< 12^{th} grade	1280	18.9	62.6 (4.9)	0.02	46.7 (2.2)	0.99 (0.84–1.17)	9.3 (1.4)	0.38 (0.23–0.62)
12^{th} grade/GED	930	24.7	45.4 (4.6)		46.2 (1.6)	0.97 (0.77–1.22)	19.5 (1.8)	0.88 (0.63–1.24)
> 12^{th} grade	1722	52.9	49.0 (3.4)		46.9 (1.7)	1.00	21.5 (2.2)	1.00
Poverty Income Ratio (quartiles)								
1st	1474	24.2	62.9 (3.1)	0.003	49.0 (1.8)	1.11 (0.88–1.39)	13.7 (1.2)	0.52 (0.39–0.69)
2nd	1064	24.2	51.3 (6.0)		44.9 (2.2)	0.94 (0.68–1.29)	19.1 (2.2)	0.77 (0.53–1.12)
3rd	755	24.2	45.4 (3.2)		45.5 (2.1)	0.96 (0.78–1.19)	18.5 (2.5)	0.74 (0.52–1.07)
4th	617	24.1	43.5 (3.2)		46.5 (2.6)	1.00	23.4 (3.0)	1.00
Missing/unknown	201	3.3	54.0 (9.5)		43.2 (6.0)		19.8 (3.4)	
Any smokers in household								
Yes	667	16.3	53.5 (5.6)	0.61	44.3 (3.1)	0.90 (0.64–1.25)	20.4 (1.7)	1.13 (0.91–1.40)
No	3398	83.7	49.9 (3.0)		47.0 (1.4)	1.00	18.5 (1.5)	1.00

Subject Characteristics	N	% in category	Geometric mean total IgE (SE)	p-value*	Percent SE) atopic†	OR (95% CI)	Percent SE) with allergy symptoms	OR (95% CI)
Mother smoked during pregnancy‡								
Yes	436	18.0	50.1 (2.6)	0.74	39.2 (2.7)	0.75 (0.59–0.96)	21.1 (1.9)	1.27 (1.00–1.62)
No	2555	82.0	47.9 (2.6)		46.1 (1.1)	1.00	17.3 (1.6)	1.00
Birthweight‡								
<2500 g	278	8.0	49.0 (6.3)	0.87	41.4 (3.9)	0.86 (0.60–1.24)	12.9 (2.6)	0.65 (0.37–1.13)
≥2500 g	2692	92.0	48.0 (2.5)		45.2 (1.2)	1.00	18.6 (1.7)	1.00
Physical Activity								
0–3 times/wk	1454	32.9	48.2 (4.4)	0.33	45.9 (1.7)	0.85 (0.65–1.10)	19.5 (1.7)	1.08 (0.83–1.40)
4–6 times/wk	730	19.0	49.8 (5.1)		48.2 (2.4)	0.93 (0.71–1.21)	19.7 (2.0)	1.09 (0.89–1.34)
7 times/wk	1100	17.9	49.7 (4.9)		43.6 (2.1)	0.77 (0.61–0.97)	17.9 (2.4)	0.98 (0.66–1.43)
8+ times/wk	752	18.3	57.1 (5.8)		50.1 (2.4)	1.00	18.3 (2.1)	1.00
Average hours of TV/videos								
0 hours/day	531	15.5	49.6 (5.1)	0.29	49.9 (2.5)	1.00	19.0 (2.5)	1.00
1–2 hours/day	2002	54.9	47.0 (2.7)		45.2 (1.4)	0.83 (0.66–1.04)	18.4 (2.1)	0.96 (0.66–1.40)
3+ hours/day	1508	29.7	58.2 (5.2)		46.9 (2.5)	0.89 (0.67–1.16)	19.8 (1.8)	1.05 (0.80–1.39)
Average hours of computer use								
0 hours/day	1300	36.6	50.1 (2.8)	0.89	46.0 (1.8)	1.00	20.0 (2.0)	1.00
1–2 hours/day	1155	29.9	52.2 (4.0)		46.8 (1.7)	1.03 (0.82–1.29)	20.2 (2.3)	1.01 (0.72–1.42)
3+ hours/day	1581	33.5	49.6 (3.9)		46.6 (1.5)	1.02 (0.90–1.17)	16.4 (2.0)	0.78 (0.53–1.16)
C-reactive protein§								
Not detectable	860	23.9	42.2 (2.6)	0.0008	42.8 (1.9)	1.00	17.1 (2.3)	1.00
0.2 – 0.4 mg/L	834	20.8	49.2 (4.7)		42.5 (2.7)	0.99 (0.79–1.24)	18.1 (2.9)	1.07 (0.67–1.69)
0.4 – 1.4 mg/L	804	18.7	55.0 (3.2)		51.7 (2.6)	1.43 (1.07–1.92)	18.5 (2.1)	1.10 (0.73–1.65)
>1.4 – 13.6 mg/L	888	19.1	62.5 (5.9)		50.8 (2.4)	1.38 (1.11–1.72)	20.7 (2.3)	1.26 (0.93–1.72)
Missing/unknown	725	17.6	30.6 (8.0)		35.6 (6.0)		19.8 (2.1)	

*Test for linear trend, except chi-square test used for sex and race/ethnicity. Tests do not include missing data.

†Atopy defined as at least one positive allergen-specific IgE result.

‡Only available for subjects up to age 15.

[§] Values represent tertiles above detection.

Table II

Allergic outcomes by weight category (BMI percentile for age), NHANES 2005–2006, children and young adults age 2–19.

Allergy Outcome	Measure (SE)	Ratio* (95% CI) Age-adjusted Model†	Ratio* (95% CI) Fully-adjusted Model‡
Total IgE (geometric mean kU/L)			
Normal weight	45.7 (2.6)	1.00	1.00
Overweight	57.8 (5.1)	1.22 (0.99–1.51)	1.25 (1.02–1.54)
Obese	66.6 (5.8)	1.40 (1.19–1.66)	1.31 (1.10–1.57)
Any positive specific IgE (%)			
Normal weight	44.5 (1.3)	1.00	1.00
Overweight	48.9 (2.6)	1.14 (0.91–1.44)	1.16 (0.93–1.45)
Obese	51.8 (2.1)	1.28 (1.05–1.58)	1.26 (1.03–1.55)
Any positive food IgE (%)			
Normal weight	21.1 (0.9)	1.00	1.00
Overweight	24.4 (2.0)	1.26 (0.99–1.60)	1.27 (0.98–1.65)
Obese	29.2 (2.2)	1.61 (1.30–1.98)	1.59 (1.28–1.98)
Positive egg IgE (%)			
Normal weight	5.2 (0.6)	1.00	1.00
Overweight	8.8 (1.5)	2.22 (1.36–3.62)	2.26 (1.35–3.80)
Obese	4.7 (1.1)	1.12 (0.71–1.77)	1.19 (0.74–1.92)
Positive milk IgE (%)			
Normal weight	10.0 (0.9)	1.00	1.00
Overweight	12.5 (2.0)	1.62 (1.22–2.13)	1.54 (1.10–2.15)
Obese	12.1 (1.4)	1.56 (1.20–2.03)	1.52 (1.18–1.98)
Positive peanut IgE (%)			
Normal weight	9.7 (1.1)	1.00	1.00
Overweight	8.4 (1.5)	0.81 (0.52–1.26)	0.83 (0.52–1.33)
Obese	11.8 (1.7)	1.18 (0.78–1.79)	1.12 (0.74–1.72)
Positive shrimp IgE (%)			
Normal weight	5.2 (0.5)	1.00	1.00
Overweight	5.3 (1.7)	0.97 (0.52–1.81)	0.94 (0.49–1.78)
Obese	10.6 (1.3)	2.08 (1.62–2.66)	1.88 (1.36–2.60)
Any positive inhalant IgE (%)			
Normal weight	39.2 (1.4)	1.00	1.00
Overweight	42.7 (3.2)	1.05 (0.80–1.37)	1.08 (0.83–1.42)
Obese	45.6 (2.7)	1.18 (0.95–1.48)	1.17 (0.91–1.50)
Allergy symptoms in previous year (%)			
Normal weight	19.3 (1.5)	1.00	1.00
Overweight	18.1 (2.0)	0.90 (0.73–1.10)	0.96 (0.77–1.20)
Obese	17.0 (1.7)	0.83 (0.68–1.02)	0.90 (0.74–1.10)
Hay fever in previous year (%)			
Normal weight	2.9 (0.7)	1.00	1.00
Overweight	2.0 (0.9)	0.66 (0.24–1.81)	0.68 (0.23–1.99)

Allergy Outcome	Measure (SE)	Ratio* (95% CI) Age-adjusted Model†	Ratio* (95% CI) Fully-adjusted Model‡
Obese	3.5 (0.8)	1.19 (0.61–2.32)	1.37 (0.71–2.62)
Itchy rash in previous year (%)			
Normal weight	6.0 (0.7)	1.00	1.00
Overweight	8.3 (1.7)	1.50 (0.79–2.85)	1.58 (0.82–3.05)
Obese	7.9 (1.7)	1.43 (0.96–2.13)	1.50 (0.96–2.32)

*The effect measure for total IgE is the geometric mean ratio. The effect measure for all percents is an odds ratio.

†Model adjusted for age only.

‡Model adjusted for age, race, sex, poverty income ratio, and household smoking.

Table III

Effect estimate for a log 10 increase in C-reactive protein before and after adjustment for poverty, race, household smoking and BMI Z-score, NHANES 2005–2006, children age 2–19.

	Age-adjusted		+poverty, race, smoking		+ BMI Z-score		
	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Percent Change*
Total IgE							
Overall	0.087	0.036–0.137	0.084	0.032–0.136	0.058	−0.009–0.124	31%
Boys	0.090	0.007–0.172	0.095	0.007–0.183	0.084	−0.010–0.177	12%
Girls	0.091	0.032–0.149	0.066	−0.001–0.133	0.020	−0.070–0.110	70%
Atopy							
Overall	1.22	1.07–1.41	1.26	1.07–1.49	1.22	1.00–1.49	3%
Boys	1.28	1.10–1.47	1.37	1.15–1.64	1.36	1.09–1.70	1%
Girls	1.20	1.02–1.42	1.15	0.96–1.37	1.07	0.89–1.30	7%
Food Allergy							
Overall	1.31	1.11–1.55	1.36	1.13–1.64	1.25	1.01–1.55	8%
Boys	1.26	0.98–1.61	1.34	1.01–1.77	1.26	0.90–1.76	6%
Girls	1.41	1.16–1.71	1.39	1.10–1.74	1.21	0.97–1.52	14%

*Percent change in effect estimate (regression coefficient or odds ratio) when adding BMI z-score to model adjusted for age, poverty income ratio, race, and household smoking.