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Sleep disordered breathing is associated with asthma severity in children

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Abstract

Objective—To examine the relationship between obesity, sleep disordered breathing (SDB), and asthma severity in children. We hypothesized that obesity and SDB (intermittent nocturnal hypoxia and habitual snoring) are associated with severe asthma at one year of follow-up.

Study design—Children (4 to 18 years) were recruited sequentially from a specialty asthma clinic, and underwent physiological, anthropometric, and biochemical assessments at enrollment. Asthma severity was determined after one year of follow-up and guidelines-based treatment, using a composite measure of level of controller medication, symptom burden, and health care utilization. Multivariable logistic regression was used to examine adjusted associations of SDB and obesity with asthma severity at 12-month follow-up.

Results—Among 108 participants (mean age 9.1 ± 3.4 years, 45.4% African-American, 67.6% male), obesity and SDB were common, affecting 42.6% and 29.6% of participants respectively. After adjusting for obesity, race, and sex, children with SDB had a 3.62-fold increased odds of having severe asthma at follow up (95% CI: 1.26, 10.40). Obesity was not associated with asthma severity.

Conclusions—We identify SDB as a modifiable risk factor for severe asthma after one year of specialty asthma care. Future studies are needed to determine if treating SDB improves asthma morbidity.

Keywords

sleep disordered breathing; obesity; asthma

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Childhood obesity is a risk factor for the development of asthma [1], but the influence of obesity on asthma severity is less clear. There are conflicting reports in the literature, some supporting a relationship between obesity and more severe asthma [2, 3], and others finding no relationship [4, 5]. The contradictory nature of work in this area may be due to inadequate assessment of obesity-related co-morbidities. We found obesity and obesity related co-morbidities, including sleep disordered breathing (SDB), to be highly prevalent in children referred to a specialty asthma clinic[6]. Although SDB has been shown to partially explain the increased risk of wheezing and asthma in obese children[7], the influence of SDB on childhood asthma severity has not been studied.

The objective of this study was to examine the relationship between obesity, SDB, and asthma severity in a cohort of children referred for specialty asthma care. We hypothesized that both obesity and SDB (characterized by intermittent nocturnal hypoxia with snoring) are associated with severe asthma, defined after one year of care in a specialty asthma clinic. We further sought to examine whether SDB modified or confounded the relationship between obesity and severe asthma. Defining the role of sleep abnormalities in the relationship between obesity and asthma severity may impact patient care by directing personalized adjunct therapies.

Methods

This was a prospective observational study performed at Rainbow Babies and Children's Hospital in Cleveland, OH. Children ages 4 to 18 years initially seen between August 2006 and November 2008 who were diagnosed with asthma by pediatric pulmonologists were sequentially enrolled. Asthma was diagnosed based on chronic or recurrent symptoms of cough, wheeze, and/or shortness of breath that responded to inhaled bronchodilators and/or inhaled corticosteroids. Additional eligibility requirements included the ability of the parent or guardian to provide informed consent, and plans to have follow-up for asthma in the clinic for the duration of the study. Exclusion criteria included cystic fibrosis, bronchopulmonary dysplasia, sickle cell anemia, and other chronic lung diseases. Informed consent was obtained from the parent/guardian or the participant. Assent was obtained from children ages 7 to 17 years. The study was approved by the local Institutional Review Board.

Participants underwent physiological, anthropometric, and biochemical assessments at enrollment as previously described[6]. Allergic sensitization was defined as at least 1 positive skin test or specific IgE to a perennial or seasonal allergen, described in more detail previously [6]. Participants were followed prospectively approximately every 6 months for 1 year at regularly scheduled clinical visits for asthma. Participants who were not seen within 1 month of their scheduled follow-up clinic visit were contacted by telephone to collect follow-up information. Data collected included the name and dose of asthma and allergy medications, the score of the Asthma Control Test (ACT, age appropriate version[8, 9]), asthma related missed school days, number of courses of prednisone, number of unscheduled physician visits, number of emergency department visits, and number of hospitalizations since the last visit.

Asthma severity

No single asthma outcome completely captures morbidity or severity. We therefore used multiple measures assessed over time, including symptom burden, medication use, and exacerbations to examine severity. Lung function data were not used as more than 25% of our population was too young to be able to perform spirometry adequately. Children were classified as having either severe or not severe asthma after 12 months of follow up based on the criteria described below.

Asthma severity was determined using symptom burden (quantified using the ACT), the level of controller therapy prescribed, and exacerbations. After 12 months of follow and treatment, children who met threshold levels of severity in one or more of the following measures during the previous 6 months were considered to have severe asthma. *Symptom burden.* We assessed symptom burden using the age appropriate Asthma Control Test (ACT) score[8, 9]. Scores of 14 or less were classified as severe. *Controller therapy use.* Controller medications were recorded and classified as steps 1 through 6 using national guidelines[10]. Children using high dose inhaled corticosteroids (ICS) alone or in combination with long acting beta agonists, or daily or every other day systemic corticosteroids (steps 5–6), were classified as severe. Children using only short acting bronchodilators, low dose ICS, leukotriene antagonists alone (steps 1–2), moderate dose ICS, or low to moderate dose ICS in combination with long acting beta agonists (steps 3–4) were classified as not severe. *Exacerbations/health care utilization.* Exacerbation rates and healthcare utilization were also considered in categorizing patients as severe or not severe. Participants with 2 or more hospitalizations, 3 or more courses of systemic corticosteroids, or 3 or more unscheduled doctor visits or emergency department visits due to asthma were classified as severe.

Predictors

Obesity—Height and weight were obtained and BMI calculated as previously described[6]. BMI was normalized for age and sex using Centers for Disease Control (CDC) growth percentiles and z-scores. For descriptive statistics, participants were categorized as normal weight (BMI < 85th percentile), overweight (BMI 85th to <95th percentile), or obese (BMI 95th percentile). Extreme obesity was defined as BMI 99th percentile.

Sleep disordered breathing—SDB was defined as habitual loud snoring (parental report of snoring “louder than talking” 3 to 4 times per week or more on a written questionnaire), and 3 or more desaturations of a least 3% per hour during overnight oximetry monitoring. To measure desaturations, home overnight finger pulse oximetry monitoring (RAD-8 Masimo oximeter with cable monitor 1006 and finger sensor) was performed for 2 nights at enrollment while the child was well[6]. These data were analyzed with Profox software (Profox Associates, Inc, Escondido, CA) calculating the average desaturation rate per hour, averaged across all valid nights of sleep.

Statistical methods

Participant characteristics were summarized using frequencies and proportions for categorical variables, means and standard deviations for normally distributed measures, and medians and the inter-quartile range for non-normally distributed variables. Univariable logistic regression analyses were used to examine bivariate associations with asthma severity at 12-month follow-up as well as SDB status at baseline. Multivariable logistic regression was used to examine adjusted associations of SDB and BMI z-score with asthma severity at 12-month follow-up; the two-way interaction between SDB and BMI z-score was fitted to examine whether SDB moderated the association between obesity and asthma severity. Due to small event size, the primary analyses were adjusted for two strongest confounders: African-American race and sex. In secondary analyses, propensity scores were used to adjust for these confounders as well as the season in which the participant was enrolled. Propensity scores were created by regressing SDB status on the covariates of interest. In exploratory analyses, the logistic regression models were refitted stratifying by race to examine the consistency of the associations for African-Americans and non African-Americans. The results of the logistic regression analyses are summarized using odds ratios (OR) and 95% confidence intervals (95% CI). SAS version 9.2 was used for all analyses.

Some of the findings in this manuscript were previously reported in the form of an abstract[11].

Results

At the time of our analysis, out of 477 children eligible for participation, 201 children were enrolled. Reasons for refusal were similar to those described in our previous report, with not having enough time being the most commonly cited reason[6]. Enrolled children did not differ from those who did not enroll in terms of age, sex, raw BMI, or BMI category (data not shown). Enrolled children had a higher BMI percentile than the 229 non-enrolled children for whom these data were available (77.5 ± 25.4 vs 72.1 ± 28.2 , $p=0.04$). At the time of these analyses, 131 children had been enrolled in the study for at least one year. 108 (82%) had at least 2 nights of overnight pulse oximetry, height/weight measurements, and asthma outcome data at 12-month follow-up allowing us to determine level of obesity, SDB status, and asthma severity. Children with and without follow up data available were similar with respect to age, sex, race, household income, BMI, BMI percentile, and ACT score (data not shown). The mean age at baseline was 9.1 ± 3.4 years, almost half of participants were African-American, and approximately two-thirds were male (Table I). Obesity and extreme obesity were common, affecting 42.6% and 13.0% of children, respectively. SDB was present in 32 children (29.6%). Twenty-nine participants were classified as having severe asthma at follow up, 23 due to a severe score in one dimension: high symptom burden ($n=6$), step 5 or 6 controller therapy ($n=7$), or frequent exacerbations ($n=10$). Four children met severe criteria in two categories ($n=2$ frequent exacerbations and symptom burden; $n=2$ frequent exacerbations and step 5–6 therapy), and 2 children met criteria in all three categories.

Bivariate associations between baseline characteristics and asthma severity at follow-up are also shown in Table I. Severe asthmatics were more likely to be African American (69.0% vs. 36.7%, $p<0.01$), male (86.2% vs. 60.8%, $p=0.01$), and from lower income homes (69.0% vs. 43.0%, $p=0.02$), consistent with previous studies of asthma severity [12–14]. BMI z-score at baseline was not associated with asthma severity at follow-up (OR=1.21, 95% CI: 0.84, 1.72, $p=0.31$), and there was no statistically significant difference in the proportion of children with extreme obesity in children with non-severe and severe asthma (21% vs 10%, $p=0.20$). SDB was more prevalent in participants with severe asthma (55.2% vs 20.3%, $p<0.01$; unadjusted OR = 4.85, 95% CI: 1.94, 12.10).

Bivariate associations with baseline SDB are shown in Table II. A higher proportion of children with SDB were African American (62.5% vs. 38.2%, $p=0.02$) and male (81.3% vs. 61.8%, $p=0.05$) compared with those without SDB. Additionally, children with SDB had higher BMI z scores than children without SDB (mean BMI z score 1.77 ± 1.33 vs. 0.86 ± 1.06 , $p<0.01$). There was no difference in rates of allergic sensitization, although rates were high among participants with and without SDB (89.3% vs. 81.1%, $p=0.39$).

The findings from the main effects multivariable logistic regression analyses were consistent with the results from the unadjusted bivariate analyses. BMI z-score was not significantly associated with asthma severity at 12-month follow-up, and SDB did not appreciably confound the association (OR = 0.96, 95% CI: 0.65, 1.42; Table III, Model 1). In contrast, children who had SDB at baseline had a 5.02-fold increased odds of having severe asthma at the 12 month follow-up visit after adjusting for BMI z-score (Model 1: OR = 5.02, 95% CI: 1.88, 13.44). The association between SDB and severe asthma was modestly attenuated after adjusting for race and sex (Model 2: SDB OR=3.62, 95% CI: 1.26, 10.40). Similar results were observed when the propensity score was included as a covariate to additionally adjust for the effect of season of enrollment (SDB OR=3.43, 95% CI 1.21, 9.72; results not

shown). Unadjusted and propensity-score adjusted logistic regression models provided some evidence that BMI z-score modified the association between SDB and asthma severity (p-values for interaction=0.07 and 0.08, respectively). The findings show that as BMI increases, the association between SDB and severe asthma increases (Figure). For example, among asthmatic children with a BMI z-score 2 standard deviations above the mean (BMI z-score=2) those with SDB had 6.7-fold increased odds of severe asthma compared with those without SDB (95% CI: 1.74, 25.55). In contrast, among average weight asthmatic children (BMI z-score=0), those with SDB did not have significantly increased odds of severe asthma compared with those without SDB (OR 1.40, 95% CI: 0.31, 6.42).

Secondary unadjusted analyses stratified by race also suggests that the association between SDB and asthma severity is stronger among African-Americans (OR=8.44, 95% CI: 2.16, 32.99) compared with non African-Americans (OR=1.21, 95% CI: 0.19, 7.75) (results not shown). However, the small number of non African-American children with severe asthma (n=9) or with SDB (n=12) limited our ability to fully examine racial differences.

Discussion

In this prospective observational study, we assessed whether obesity and SDB were associated with asthma severity after one year of follow-up in a specialty asthma clinic. After one year of follow-up and treatment in a specialty-based asthma clinic, over one quarter of participants in our study had high exacerbation rates, high symptom burden, or required high doses of inhaled corticosteroids to manage their asthma. We found that traditional risk factors for asthma, including male sex and African American race, were associated with severe asthma. In addition, we found a strong association between SDB and severe asthma. Contrary to our hypothesis, obesity was not associated with asthma severity. Although not statistically significant, there were clinically relevant differences in the rates of severe asthma in children with severe obesity. Extreme obesity (BMI 99th percentile) was twice as prevalent in children subsequently found to have severe asthma compared with those with non-severe asthma (20.7 vs 10.1%, p=0.20). The lack of statistical significance may have related to the relatively modest sample size and reduced power to detect small effects.

SDB is characterized by snoring and intermittent upper airway obstruction, with more severe disease associated with intermittent hypoxia. Previous work suggests SDB is a risk factor for incident wheezing and asthma in children[15]. Obstructive sleep apnea (OSA), defined by abnormal polysomnography or habitual snoring with witnessed apneas, has been identified as a risk factor for exacerbations in adults with severe asthma[16]. Asthma guidelines recommend that clinicians consider evaluating poorly controlled asthmatics for OSA, particularly when they are also obese, but do so based on panel consensus judgment due to insufficient literature on the subject[10]. Previous work has shown a relationship between asthma severity and obstructive sleep apnea in adults[17]. To our knowledge, this is the first study demonstrating a relationship between SDB and asthma severity in children, providing evidence to support current asthma guidelines.

SDB is a treatable condition. Strategies include weight management if the child is obese, nasal steroids, adenotonsillectomy, and continuous positive airway pressure (CPAP). Small studies in adults with asthma and OSA show improved asthma outcomes after treatment with CPAP[18, 19]. In an uncontrolled study, sixteen adult asthmatics with moderate to severe OSA and persistent nocturnal asthma symptoms were treated with CPAP for 2 months. CPAP was not associated with changes in lung function, but there was a reduction in nocturnal symptom scores [18]. In another uncontrolled study of twenty adult asthmatics with moderate to severe OSA, 6 weeks of treatment with CPAP was associated with an

improvement in asthma related quality of life[19]. These studies targeted adults with moderate to severe OSA, for whom CPAP was indicated based on the severity of upper airway obstruction. To our knowledge, there are no studies examining whether pediatric asthma improves with OSA treatment. Although all children in our study with SDB were referred for polysomnography (PSG) and clinical evaluation for OSA, referrals were made as part of clinical care and not as part of the research program, limiting the available information on potential treatment effects. Further work is needed to determine if a structured approach for diagnosing and managing SDB in asthmatic children would alter asthma outcomes.

There are several biologically plausible mechanisms by which SDB could adversely influence asthma, including mechanical, inflammatory, metabolic, and effects on the autonomic nervous system. Asthma and SDB may co-exist in children due to a shared relationship with atopy. Over 80% of the children in our population had at least one skin or in vitro blood test demonstrating sensitization to a food or aeroallergen, and nasal obstruction and adenoidal hypertrophy associated with allergic disease is a treatable cause of SDB in children [20–22]. Exploratory analyses in sensitized children did not show a significant relationship between SDB and asthma severity, but we were unable to test for an association in children with clinical allergic rhinitis or adenoidal hypertrophy, which may have been more relevant. Mouth breathing in children with SDB may lead to airway drying, which has been linked to airway reactivity in mathematical[23] and animal models[24], although a clear relationship between airway drying and airway reactivity has not been confirmed in humans [25, 26]. Gastroesophageal reflux may also be precipitated by recurrent episodes of upper airway obstruction as may occur with SDB, and may trigger bronchoconstriction through altered parasympathetic tone or other mechanisms.

Multiple metabolic abnormalities are associated with SDB, including hyperinsulinemia [27] and lipid dysregulation [28, 29]. Two cross-sectional studies suggest that components of metabolic syndrome are associated with asthma-like symptoms in adults[30, 31], and hypercholesterolemia has been implicated as a risk factor for asthma [32]. SDB is also associated with increased levels of leptin[33] [34] and reduced levels of adiponectin [34], two adipokines implicated in asthma [35–37]. Leptin, an appetite regulator produced by adipocytes, also regulates the proliferation, activation, and cytokine secretion of T lymphocytes, an important cell in asthma [38]. Leptin levels increase as fat mass increases, but several studies have shown that leptin is further increased in SDB independent of BMI [33, 34]. Leptin negatively correlates with lung function in adults [39] and children [40] independent of BMI, suggesting that changes in leptin may influence asthma morbidity. Adiponectin levels decrease as fat mass increases, and reduced adiponectin is correlated with visceral adiposity and predicts the development of metabolic syndrome and type 2 diabetes. There is more limited data on the relationship between SDB and adiponectin, but one study suggests that adiponectin levels are further reduced in obese children with SDB compared with those with similar BMI but no SDB[34]. There is also evidence for a role for adiponectin in asthma; in an animal model of allergic asthma, exogenous administration of adiponectin prevented the development of airway reactivity and allergic airway inflammation [36]. Future studies will be needed to determine if alterations in metabolic or inflammatory pathways such as these mediate the relationship between sleep disorders and asthma.

One of the strengths of our study is the way asthma severity was defined. Because asthma symptoms may be variable over time, asthma severity was determined after one year of care by an asthma specialist, rather than at a single time point. Asthma was classified as severe based on high symptom burden, high controller therapy requirements, and/or high health care utilization.

A study limitation is the lack of attended PSG to diagnose SDB. Although our definition may lack some of the specificity and sensitivity of multi-channel PSG, we defined SDB based on both habitual snoring and intermittent nocturnal hypoxia with at least 2 nights of home pulse oximetry. Even though oximetry has important limitations as a diagnostic tool for OSA [41, 42], the strategy of using a combination of questionnaire data plus in-home pulse oximetry has been used to screen for or predict sleep-disordered breathing in several pediatric prevalence studies [43–48]. Although most of these prevalence studies used a 4% desaturation criterion typical of adult criteria to identify a sleep-disordered breathing events, we selected a 3% desaturation threshold to better align with the newer recommendation by the AASM to specifically use a 3% desaturation to identify respiratory events in children [49, 50].

We acknowledge that the possibility that nocturnal desaturations were due to lower airway disease, reflecting asthma severity rather than upper airway obstruction. To our knowledge, there are no data on patterns of overnight oximetry in children with asthma at any level of severity. However, children were studied when clinically stable with normal resting oximetry, reducing the likelihood that the intermittent hypoxemia reflected asthma severity. In addition, there were no differences in desaturation rates among non-snoring children with nonsevere and severe asthma. The combination of both desaturations and habitual loud snoring was necessary to see a relationship with asthma severity, suggesting that the relationship we found was more likely due to upper airway obstruction rather than lower airway disease.

Although outside the context of our study, we were able to obtain results of PSG from twelve of the children defined with SDB by our definition. Ten of these children met pediatric criteria for SDB. The two normal studies were limited by minimal supine sleep time and were characterized by the parents as atypical nights in terms of sleep and breathing, suggesting they may have been false negatives.

Although a directional relationship between SDB and asthma cannot be determined based on the study design, our results suggest the need to determine if treatment of SDB can improve asthma outcomes. Although several children in our study were referred for surgical or CPAP treatment of SDB, we do not have sufficient follow-up data to comment on whether asthma was improved following treatment. Further studies will be needed to determine the role of in-home screening for SDB in children with poorly controlled asthma, and what treatment strategies are most appropriate.

We identify SDB (habitual loud snoring along with nocturnal desaturations on home overnight oximetry) as a modifiable risk factor for having severe asthma after one year of specialty asthma care. Additionally, SDB may be highly prevalent in African American and obese children referred for specialty asthma care. Our findings support existing guideline recommendations based on expert consensus to screen difficult to control asthmatics for SDB. Future studies are needed to better understand the signaling mechanisms underlying this relationship, and to determine if treating childhood SDB improves asthma morbidity.

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Abbreviations

SDB	Sleep disordered breathing
BMI	Body mass index
ACT	Asthma Control Test

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Figure 1.

BMI z-score modifies the association between SDB and severe asthma at 12-month follow-up. Adjusted model: propensity-score adjusted for race, sex and season of enrollment.

Table 1

Baseline Subject Characteristics By Asthma Severity at 12 Month Follow-up

Baseline Characteristics	Analytic Sample (n=108)	Asthma Severity at 12 Month Follow-up		
		Mild/Mod (n=79)	Severe (n=29)	Unadjusted OR (95% CI)
Age	9.1 ± 3.4	9.5 ± 3.4	8.2 ± 3.2	0.89 (0.77, 1.02)
Older age group (12 – 17 yrs)	26 (24.1%)	19 (24.1%)	7 (24.1%)	1.01 (0.37, 2.72)
Male sex	73 (67.6%)	48 (60.8%)	25 (86.2%)	4.04 (1.28, 12.72)
African-American Race	49 (45.4%)	29 (36.7%)	20 (69.0%)	3.83 (1.54, 9.52)
Atopy (n=102)	85 (83.3%)	66 (86.8%)	19 (73.1%)	0.41 (0.14, 1.23)
Adiposity				
BMI z-score	1.13 ± 1.21	1.06 ± 1.20	1.33 ± 1.26	1.21 (0.84, 1.72)
BMI category				
Normal	49 (45.4%)	36 (45.6%)	13 (44.8%)	-ref-
Overweight	13 (12.0%)	11 (13.9%)	2 (6.9%)	0.50 (0.10, 2.58)
Obese	46 (42.6%)	32 (40.5%)	14 (48.3%)	1.21 (0.50, 2.96)
Extreme obesity (BMI 99 th %tile)	14 (13.0%)	8 (10.1%)	6 (20.7%)	2.32 (0.73, 7.37)
Lung function / inflammation				
FEV ₁ % predicted (n=78)	96.5 ± 17.8	97.2 ± 18.3	94.3 ± 16.5	0.99 (0.96, 1.02)
FVC % predicted (n=78)	104.3 ± 16.3	103.9 ± 17.1	105.5 ± 14.0	1.01 (0.97, 1.04)
FEV ₁ to FVC ratio (n=78)	92.5 ± 8.7	93.6 ± 8.2	89.2 ± 9.5	0.94 (0.89, 1.00)
Sleep Characteristics				
SDB: habitual loud snoring & 3 desaturations per hr at 3%	32 (29.6%)	16 (20.3%)	16 (55.2%)	4.85 (1.94, 12.10)
Habitual Loud snoring	45 (43.3%)	27 (35.1%)	18 (66.7%)	3.70 (1.47, 9.36)
Insufficient nocturnal sleep [†]	58 (54.2%)	40 (51.3%)	18 (62.1%)	1.55 (0.65, 3.72)
Parent/family characteristics				
Household size (number of individuals)	4.0 (3.0, 5.0)	4.5 (4.0, 5.0)	4.0 (3.0, 5.0)	0.78 (0.57, 1.05)
Low household income (<\$30,000)	54 (50.0%)	34 (43.0%)	20 (69.0%)	2.94 (1.19, 7.26)
Household income (n=104)				
<\$20,000	45 (43.3%)	28 (36.4%)	17 (63.0%)	8.20 (1.73, 38.91)

Baseline Characteristics	Analytic Sample (n=108)	Asthma Severity at 12 Month Follow-up		
		Mild/Mod (n=79)	Severe (n=29)	Unadjusted OR (95% CI)
\$20,000 to < \$50,000	30 (28.9%)	22 (28.6%)	8 (29.6%)	4.91 (0.94, 25.53)
\$50,000 to < \$75,000	8 (7.7%)	6 (7.8%)	2 (7.4%)	
\$75,000 to < \$100,000	11 (10.6%)	11 (14.3%)	0 (0%)	ref
\$100,000	10 (9.6%)	10 (13.0%)	0 (0%)	
Maternal BMI 30 (n=88)	52 (59.1%)	37 (55.2%)	15 (71.4%)	2.03 (0.70, 5.86)
Maternal waist circumference (n=87)	100.1 ± 18.5	98.1 ± 17.7	106.2 ± 20.0	1.02 (1.00, 1.05)
Maternal history of asthma (n=95)	33 (34.7%)	22 (31.9%)	11 (42.3%)	1.57 (0.62, 3.96)
Current maternal smoking	25 (23.2%)	17 (21.5%)	8 (27.6%)	1.39 (0.52, 3.68)

^f Nocturnal sleep duration < 2nd percentile for age

Table 2

Baseline Subject Characteristics By SDB Status at Enrollment

Baseline Characteristics	Analytic Sample (n=108)	SDB At Baseline*			p-value
		No SDB (n=76)	SDB (n=32)	Unadjusted OR (95% CI)	
Age	9.1 ± 3.4	9.3 ± 3.4	8.7 ± 3.3	0.95 (0.84, 1.08)	0.41
Older age group (12 – 17 yrs)	26 (24.1%)	20 (26.3%)	6 (18.8%)	0.65 (0.23, 1.80)	0.40
Male sex	73 (67.6%)	47 (61.8%)	26 (81.3%)	2.67 (0.98, 7.28)	0.05
African-American Race	49 (45.4%)	29 (38.2%)	20 (62.5%)	2.70 (1.15, 6.33)	0.02
Atopy (n=102)	85 (83.3%)	60 (81.1%)	25 (89.3%)	1.94 (0.51, 7.36)	0.39
Adiposity					
BMI z-score	1.13 ± 1.21	0.86 ± 1.06	1.77 ± 1.33	2.03 (1.34, 3.07)	<0.001
BMI category					
Normal	49 (45.4%)	41 (53.9%)	8 (25.0%)	- ref -	
Overweight	13 (12.0%)	11 (14.5%)	2 (6.3%)	0.93 (0.17, 5.03)	0.002
Obese	46 (42.6%)	24 (31.6%)	22 (68.7%)	4.70 (1.81, 12.19)	
Extreme obesity (BMI 99 th %tile)	14 (13.0%)	4 (5.3%)	10 (31.3%)	8.18 (2.34, 28.67)	<0.001
Lung function / inflammation					
FEV ₁ % predicted (n=78)	96.5 ± 17.8	98.7 ± 17.7	90.9 ± 17.1	0.98 (0.95, 1.00)	0.08
FVC % predicted (n=78)	104.3 ± 16.3	105.6 ± 16.2	100.9 ± 16.6	0.98 (0.95, 1.01)	0.27
FEV ₁ to FVC ratio (n=78)	92.5 ± 8.7	93.4 ± 8.0	90.3 ± 9.9	0.96 (0.91, 1.02)	0.15
Parent/family characteristics					
Household size (individuals)	4.0 (3.0, 5.0)	4.0 (3.0, 5.0)	4.0 (3.5, 5.0)	0.91 (0.70, 1.17)	0.50
Low household income (<\$30,000)	54 (50.0%)	35 (46.1%)	19 (59.4%)	1.71 (0.74, 3.96)	0.21
Household income (n=104)					
<\$20,000	45 (43.3%)	27 (36.5%)	18 (60.0%)	3.20 (1.03, 9.94)	
\$20,000 to < \$50,000	30 (28.9%)	23 (31.1%)	7 (23.3%)	1.46 (0.41, 5.27)	0.10
\$50,000 to < \$75,000	8 (7.7%)	6 (8.1%)	2 (6.7%)		
\$75,000 to < \$100,000	11 (10.6%)	8 (10.8%)	3 (10.0%)	ref	\$50,000
\$100,000	10 (9.6%)	10 (13.5%)	0 (0%)		

Baseline Characteristics	Analytic Sample (n=108)	SDB At Baseline*			p-value
		No SDB (n=76)	SDB (n=32)	Unadjusted OR (95% CI)	
Maternal BMI 30 (n=88)	52 (59.1%)	40 (62.5%)	12 (50.0%)	0.60 (0.23, 1.55)	0.29
Maternal waist circumf (n=87)	100.1 ± 18.5	98.6 ± 17.0	104.0 ± 21.9	1.02 (0.99, 1.04)	0.23
Maternal history of asthma (n=95)	33 (34.7%)	23 (33.3%)	10 (38.5%)	1.25 (0.49, 3.19)	0.64
Current maternal smoking	25 (23.2%)	17 (22.4%)	8 (25.0%)	1.16 (0.44, 3.04)	0.77

Table 3

Association Between SDB, Obesity, and Severe Asthma at 12-Month Follow-up

	Model 1			Model 2		
	aOR*	95% CI	p-value	aOR*	95% CI	p-value
SDB	5.02	1.88, 13.44	0.001	3.62	1.26, 10.40	0.02
BMI z-score	0.96	0.65, 1.42	0.84	0.96	0.64, 1.46	0.86
African-American Race				2.92	1.10, 7.72	0.03
Male sex				3.04	0.91, 10.15	0.07

aOR = adjusted odds ratio (adjusted for the covariates listed in the table)