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To cite this article: Matthew R. Nagy, Kellye C. McGlumphy, Richard Dopp, Toby C. Lewis & Rebecca E. Hasson (2019): Association between asthma, obesity, and health behaviors in African American youth, Journal of Asthma, DOI: [10.1080/02770903.2019.1571083](https://doi.org/10.1080/02770903.2019.1571083)

To link to this article: <https://doi.org/10.1080/02770903.2019.1571083>



Published online: 31 Jan 2019.



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Association between asthma, obesity, and health behaviors in African American youth

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ABSTRACT

Background: There is a clear relationship between obesity and asthma, with obesity recognized as a risk factor for asthma. There is mounting evidence, however, that asthma may predict obesity risk via behavioral pathways. **Objectives:** The purpose of this study was to assess the cross-sectional relationships between asthma, body mass index (BMI) percentile, and behavioral factors including caloric intake, dietary inflammatory index, moderate-vigorous physical activity (MVPA), and sedentary time (SED) among African American adolescents. **Methods:** A community-based sample of 195 African American youth (ages 11–18 years) were included in this analysis. Asthma status was based on self-report using the International Study of Asthma and Allergies in Children's Phase Three questionnaire. MVPA and SED were measured via accelerometry, and caloric intake and dietary inflammatory index were evaluated with the Food Frequency Questionnaire. Weight status was assessed via BMI percentile using measured weight, height, and CDC growth charts. **Results:** Adolescents with a history of asthma were significantly more overweight (62% vs. 43%, $p = 0.04$) and consumed a higher inflammatory diet (1.6 ± 0.3 vs. 1.0 ± 0.2 , $p = 0.02$) than their peers who never had asthma. After adjusting for all covariates, activity and dietary variables, odds ratio analysis revealed adolescents who reported ever having asthma were 3.1 ± 1.5 times as likely to be overweight or obese than adolescents with no asthma history ($p = 0.02$). **Conclusions:** Presence of asthma history was associated with increased obesity risk in African American adolescents, independent of behavioral factors. Longitudinal studies are needed to better understand the relationship between asthma and obesity in African American adolescents.

ARTICLE HISTORY

Received 24 August 2018
Revised 11 January 2019
Accepted 12 January 2019

KEYWORDS

Asthma; obesity; nutrition; physical activity; sedentary behavior; adolescents

Introduction

African American adolescents are one and a half times more likely to be diagnosed with asthma than white adolescents [1]. Similarly, 40% of African American adolescents are overweight or obese compared to 31% of white adolescents [2]. There is a clear relationship between obesity and asthma, and it is widely accepted that obesity is a risk factor for asthma through pathways such as low-grade inflammation and altered airway mechanics [3]. There is also evidence that asthma is a risk factor for developing obesity, but it is unclear if this is via behavioral pathways including physical inactivity and poor nutrition [3–5].

Many researchers have observed that children and adolescents diagnosed with asthma engage in significantly less physical activity than their non-asthmatic

peers, which may be a mechanism by which asthma is a risk factor for obesity [6,7]. McPherson et al. (2006) observed that children and adolescents with asthma reported engaging in less physical activity than those without asthma. In addition, 60% of parents of children with asthma perceived that asthma inhibited their child's ability to be active [8]. Jones et al. (2006) also observed that irrespective of physical activity levels, adolescents with asthma were significantly more likely than their healthy peers to use a computer for three or more hours a day during leisure time [9]. Because African American youth engage in less physical activity and more screen time compared to their white peers, these behavioral patterns may play an important role in the relationship between asthma and obesity in African American adolescents [10].

Pro-inflammatory diets may also contribute to increased obesity risk in children with asthma, as asthma is considered a chronic inflammatory disease [11]. It has been observed that typical “westernized” dietary patterns, consisting of high-fat foods and low levels of fruits and vegetables, are associated with increased circulating cytokines, which are present in adults with asthma as well as obese individuals [12]. These inflammatory cytokines are not only associated with body mass index (BMI), but Engström et al. (2003) observed that circulating inflammatory proteins, which are regulated by cytokines, predict future weight gain [13]. African American youth are more likely to consume a high inflammatory diet, take-out food, as well as be exposed to fast food restaurants and advertising, compared to their white and Latino peers [14,15]. As such, it is possible that diet may play a moderating role in the relationship between asthma and obesity in African American adolescents.

The purpose of this study was to assess the cross-sectional relationships between asthma, obesity, and health behaviors including moderate-vigorous physical activity (MVPA), sedentary time (SED), diet, and diet quality in African American youth. It was hypothesized that asthma would be associated with increased BMI percentile in African American adolescents, and that MVPA, SED, diet, and diet quality would modify this relationship, thus accounting for the relationship between asthma and BMI percentile.

Methods

Sample population, recruitment, and procedure

Male and female adolescents ages 11–18 years were recruited to participate in this study. Individuals were excluded from participating in this study if they had participated in a weight loss or exercise program within the previous 6 months, were taking any medications known to effect body weight, or were diagnosed with any syndrome or disorder that would affect body weight or any other major illness. Children were also excluded if they were diagnosed with clinical depression or any other mental health disorder that may influence mood, emotions, or stress perception. Adolescent participants were recruited from communities in southeast Michigan to participate in the Health & Culture Project, a two-component study investigating social, psychological, and cultural predictors of obesity. The first component involved adolescents completing questionnaires assessing psychological stress, socioeconomic status, culture, dietary habits, and other environmental factors, and

included objective measures of physical activity via accelerometry and anthropometric measurements. The second component provided information to youth about their own health behaviors, which was followed by a researcher led discussion with participants about ways in which they could integrate healthy eating and physical activity into their lives. Flyers were posted in school nurses offices and community centers, and previous participants recruited peers via word of mouth. A total of 273 participants (11–18 years) from after-school programs (17%), middle schools (31%), high schools (11%), community centers (11%), and the general community of Washtenaw County, Michigan (30%) participated in this study. Data collection occurred at the Childhood Disparities Research Laboratory or off-site at a school, after-school program, or community center. All data collection was performed by the same research personnel and with the same equipment across locations. Participants were excluded from this analysis for the following reasons: 19 participants did not self-identify as African American, 24 participants did not complete at least half of the study questionnaires, and 35 participants were outliers for caloric intake [16]. Overall, 78 participants were excluded from the analysis. Therefore, a total of 195 African American adolescents (118 female, 77 male) were included in this analysis. When the included participants ($n = 195$) were compared to the excluded participants, the two groups were similar in sex, weight, height, BMI, BMI percentile, waist-hip ratio, weight status, SED, MVPA, pubertal development, and asthma (data not shown, all p 's > 0.05). Included participants were, however, older (14.6 vs. 13.8 years, $p = 0.002$) and had caregivers with higher education (College degree or more: 58% vs. 24%, $p = 0.001$), compared to excluded participants. Written consent from the adolescent and the caregiver (if participant was younger than 18 years old) was obtained before participation in the study began. This study was reviewed and approved by the University of Michigan Institutional Review Board Health Sciences and Behavioral Sciences.

Body mass index

BMI percentiles were calculated using guidelines via the Centers for Disease Control and Prevention [17]. Body weight (kg) and height (cm) were measured to the nearest 0.1 kg, and 0.1 cm, respectively, using ShorrBoard® (Weigh and Measure, LLC., Olney, MD) and an electronic scale (Doran Scales, Inc., Batavia, IL) using standardized procedures [17]. Adolescents were then classified as healthy

weight (BMI: ≤ 85 th percentile) or overweight/obese (BMI > 85 th percentile).

Asthma

Asthma history was measured via one question from the International Study of Asthma and Allergies in Children's Phase Three [18]. This questionnaire has been used in many contexts to track the prevalence and severity of asthma across the globe [19]. Participants were classified as having asthma in their lifetime if they had an affirmative response to the question "Have you ever had asthma?".

Sedentary behavior and Moderate-Vigorous physical activity

Habitual SED and MVPA were assessed over a 7-day period for each participant via accelerometry (GT3X ActiLife, ActiGraph, Pensacola, FL). The frequency at which the devices collected raw data was 30 Hz. The raw data obtained from the accelerometer were retrieved and integrated into 10 s epochs using ActiLife software, version 6.11.8. Sleep time was entered manually by the participants via self-report logs and was considered non-wear time. Additionally, time periods of > 60 min of zero activity counts were similarly defined as non-wear time [20]. At least 4 days of valid (> 600 min/day) accelerometer data was required for SED and MVPA to be recorded. Cut points determined by Puyau et al. (2002), which are commonly utilized for adolescent populations, were used to determine activity intensity and calculate respective wear time (sedentary: < 799 counts/min; light: 800–3199 cuts/min; moderate: 3200–8199 cuts/min; vigorous: > 8200 counts/min) [21,22].

Caloric intake and dietary inflammatory index

Total daily caloric intake was collected using the 2012 Adolescent Food Frequency Questionnaire (FFQ) developed by Harvard University. This questionnaire was designed, validated and calibrated for use in adolescents [16]. Total calories consumed were obtained as a measure of self-reported caloric intake of various food items reported on the questionnaire. Specific grams of nutrients consumed were multiplied by a weighted inflammatory score developed by Cavicchia et al. [23]. For example, the individual score for saturated fat was calculated as such: (grams saturated fat consumed) $\times$ (weighted saturated fat inflammatory score) = (individual score). Individual scores were summed to create a dietary inflammatory index score, with a lower score signifying a higher inflammatory diet [23,24]. For ease of interpretation, the values

were reversed so that a higher dietary inflammatory index score represents a more inflammatory diet.

Because underreporting of total calories is a common occurrence among adolescents who are overweight and obese, we took additional efforts to minimize this problem [25]. Daily intake of calories below 500 kcals and above 3500 kcals were considered outliers and were excluded from the analysis ($n = 27$). Additionally, the Harris-Benedict equation was used to calculate estimated total daily energy requirements [26]. These values were then compared to children's recorded caloric intake. Children who reported consuming less than 25% of estimated energy requirements (under-reporters) or reported consuming more than 175% of estimated energy requirements (over-reporters) were considered outliers and excluded from the analysis ($n = 8$), resulting in 35 participants being excluded from the analysis based on dietary reporting factors, as previously described.

Covariates

Given the confounding effect of pubertal development and socioeconomic status on the relationships between asthma and BMI percentile, these variables were also included in the models [27, 28]. Pubertal development was assessed via the Pubertal Development Scale [29]. Adolescents were classified as pre-pubertal, early-pubertal, mid-pubertal, late-pubertal, or post-pubertal based on self-reported completion of developmental stages [29]. Household education was used as a proxy for socioeconomic status. Household education was assessed with a 3-category variable: (1) less than high school degree, (2) high school and some college, (3) college graduate and beyond. If the participant had multiple caregivers in one household, the caregiver who reported the highest educational attainment was used.

Statistical analyses

All data analyses were conducted using Stata Special Edition 14.0 (StataCorp LLC, College Station, TX). Baseline characteristics between adolescents with and without asthma history were compared via *t*-tests and chi-squared tests. Data are expressed as mean $\pm$ standard error. Multiple imputation was used to account for missing data via chained regression equations with 100 data sets imputed. Statistical analyses represent an average amongst all imputed data sets [30]. A majority of study variables had $< 10\%$ missing data. The variable that had the highest fraction of missing data was household education (35%). When participants who had household education data ($n = 127$) were compared with participants who had missing household

education data ($n=68$), there were no differences in sex, age, weight, height, BMI, BMI percentile, weight status, pubertal development, caloric intake, dietary inflammatory index, MVPA, SED, asthma history, or recent asthma symptoms (all p 's > 0.05).

Following imputation, five multiple linear regression models were used to examine the relationship between the independent variables (asthma, MVPA, SED, caloric intake, and dietary inflammatory index), covariates (household education and pubertal development) and dependent variable (BMI percentile) in African American adolescents. Model 1 included the covariates (pubertal development and household education) to determine the lone influence of these covariates on BMI percentile. Model 2 included asthma in addition to the covariates, to assess the relationship between asthma and BMI percentile. Model 3 included asthma, MVPA and SED, and covariates, to assess the influence of activity behavior on the relationship between asthma and BMI percentile. Model 4 included asthma, caloric intake, dietary inflammatory index, and covariates, to assess the influence of dietary behaviors on the relationship between asthma and BMI percentile. Model 5 included asthma, MVPA, SED, caloric intake, dietary inflammatory index, and covariates, to assess the combined influence of activity and dietary behaviors on the relationship between asthma and BMI percentile. Standardized beta coefficients from -1.00 to 1.00 were developed for each linear regression model in order to compare the relative effect of each dependent variable on BMI percentile.

Five odds ratio analyses were conducted to observe the likelihood that an individual who reported a history of asthma would be classified as overweight/obese. BMI percentile was dichotomized into healthy weight (BMI percentile $< 85^{\text{th}}$ ile) or overweight/obese (BMI percentile $\geq 85^{\text{th}}$ ile). Model 1 was unadjusted, including only the dependent variable (healthy weight/overweight or obese) and the predictor variable (asthma/no asthma). Model 2 adjusted for household education and pubertal development. Model 3 adjusted for household education, pubertal development, caloric intake, and dietary inflammatory index. Model 4 adjusted for household education, pubertal development, MVPA, and SED. Model 5 adjusted for household education, pubertal development, caloric intake, dietary inflammatory index, MVPA, and SED. The significance level for all analyses was $\alpha < 0.05$.

Results

Overall participant characteristics are displayed in Table 1. Participants were a majority female (61%)

Table 1. Participant characteristics.

	<i>n</i>	Mean $\pm$ SE	%
Sex (% female)	195	–	61
Pubertal Development	194	–	–
Pre-pubertal	2	–	1
Early-pubertal	10	–	5
Mid-pubertal	40	–	21
Late-pubertal	126	–	65
Post-pubertal	16	–	8
Age (years)	195	14.6 $\pm$ 0.1	–
Weight (kg)	195	66.3 $\pm$ 1.3	–
Height (cm)	195	162.9 $\pm$ 0.7	–
BMI (kg/m ²)	195	24.9 $\pm$ 0.5	–
BMI Percentile	195	73.7 $\pm$ 1.9	–
Parent Education	127	–	–
Less than high school degree	6	–	5
High school and some college	47	–	37
College graduate and beyond	74	–	58
SED (min)	129	760.3 $\pm$ 7.9	–
MVPA (min)	129	12.4 $\pm$ 1.2	–
Caloric Intake (Kcals)	133	1809.2 $\pm$ 69.4	–
Dietary Inflammatory Index	133	1.1 $\pm$ 0.1	–
Asthma History (% ever had asthma)	144	–	29

with an average age 14.6 years and a BMI percentile of 73.7. Each day, participants engaged in an average of 12.4 min of moderate-to-vigorous physical activity and consumed 1809 calories. There were 29% of adolescents who reported ever having asthma. When comparing adolescents with a history of asthma to those who reported no asthma, adolescents with asthma history had a higher average BMI percentile (80th vs. 70th, $p=0.04$) with a greater percentage classified as overweight and obese (62% vs 43%, $p=0.04$), compared to those who never had asthma. Adolescents with asthma history also had a higher dietary inflammatory index (1.6 vs 1.0, $p=0.03$) compared to those who never had asthma. Otherwise, the two groups were similar for sex, pubertal development, age, weight, height, household education, caloric intake, SED, and MVPA (all p 's > 0.05).

Asthma history

Table 2 displays the results of the five linear regression models run. Model 1 examined the associations between household education, pubertal development, and BMI percentile. Pubertal development was positively associated with BMI percentile ($\beta=7.8 \pm 2.5$, $p < 0.01$) with higher BMI percentiles observed in adolescents who were further along in pubertal development. There were no significant associations of BMI percentile with household education ($\beta=-6.0 \pm 4.0$, $p=0.13$).

Model 2 examined the associations between BMI percentile, asthma, household education, and pubertal development. Asthma was positively associated with BMI percentile, with adolescents with asthma history

Table 2. Unstandardized beta coefficients (95% CI) for five regression models examining the relationships of body mass index percentile with covariates (household education and pubertal development), asthma, diet (caloric intake and dietary inflammatory index) and activity (moderate-vigorous physical activity and sedentary behavior) in African American adolescents * $p < 0.05$.

	Model 1	Model 2	Model 3	Model 4	Model 5
Household Education	−6.0 (−13.8, 1.9)	−5.6 (−13.4, 2.2)	−6.4 (−14.6, 1.7)	−7.0 (−15.1, 1.0)	−8.0 (−16.5, 0.6)
Pubertal Development	7.8 (2.9, 12.7)*	8.8 (4.0, 13.7)*	8.1 (3.1, 13.1)*	7.1 (1.8, 12.3)*	6.5 (1.1, 11.9)*
Asthma	—	10.9 (2.1, 19.8)*	12.6 (3.3, 21.8)*	10.2 (0.9, 19.5)*	12.0 (2.3, 21.8)*
Caloric Intake	—	—	−0.004 (−0.01, 0.001)	—	−0.003 (−0.01, 0.003)
Dietary Inflammatory Index	—	—	−0.9 (−4.4, 2.6)	—	−1.5 (−5.2, 2.1)
MVPA	—	—	—	−0.4 (−0.8, −0.1)*	−0.4 (−0.8, −0.3)*
Sedentary Behavior	—	—	—	−0.01 (−0.07, 0.05)	−0.02 (−0.8, 0.05)

having a higher BMI percentile than those who never had asthma ($\beta = 10.9 \pm 4.5$, $p = 0.02$). Pubertal development remained positively associated with BMI percentile ($\beta = 8.8 \pm 2.5$, $p < 0.01$) and there were no significant associations of BMI percentile with household education ($\beta = -5.6 \pm 3.9$, $p = 0.16$).

Model 3 examined the associations between BMI percentile, asthma, caloric intake, dietary inflammatory index, household education, and pubertal development. Asthma remained positively associated with BMI percentile after the inclusion of the dietary variables ($\beta = 12.6 \pm 4.7$, $p < 0.01$). Pubertal development remained positively associated with BMI percentile ($\beta = 8.1 \pm 2.5$, $p < 0.01$) and there were no significant associations of BMI percentile with household education ($\beta = -6.4 \pm 4.1$, $p = 0.12$), caloric intake ($\beta = -0.004 \pm 0.003$, $p = 0.13$), and dietary inflammatory index ($\beta = -0.9 \pm 1.7$, $p = 0.61$).

Model 4 examined the linear associations between BMI percentile, asthma, MVPA, SED, household education, and pubertal development. Asthma remained positively associated with BMI percentile after the inclusion of the activity variables ($\beta = 10.2 \pm 4.7$, $p = 0.03$). MVPA was negatively associated with BMI percentile ($\beta = -0.4 \pm 0.2$, $p = 0.02$), with adolescents who engaged in more MVPA having a lower BMI percentile. Pubertal development remained positively associated with BMI percentile ($\beta = 7.1 \pm 2.7$, $p < 0.01$) and there were no significant associations of BMI percentile with household education ($\beta = -7.0 \pm 4.0$, $p = 0.09$) or SED ($\beta = -0.01 \pm 0.03$, $p = 0.67$).

Model 5 examined the linear associations between BMI percentile, asthma, caloric intake, dietary inflammatory index, MVPA, SED, household education, and pubertal development. Asthma remained positively associated with BMI percentile after the inclusion of all behavioral variables ($\beta = 12.0 \pm 4.9$, $p = 0.02$). Pubertal development remained positively associated with BMI percentile ($\beta = 6.5 \pm 2.7$, $p = 0.02$) and MVPA remained negatively associated with BMI percentile ($\beta = -0.4 \pm 0.2$, $p = 0.03$). There were no significant associations of BMI percentile with household

education ($\beta = -8.0 \pm 4.3$, $p = 0.07$), caloric intake ($\beta = -0.003 \pm 0.003$, $p = 0.38$), dietary inflammatory index ($\beta = -1.5 \pm 1.9$, $p = 0.41$), or SED ($\beta = -0.02 \pm 0.03$, $p = 0.63$). Standardized beta coefficients and R^2 values for all five models are displayed in Table 3.

Table 4 displays the odds ratio analysis. Model 1 examined the unadjusted odds of being overweight/obese if an adolescent reported ever having asthma, and observed that adolescents who ever reported asthma tended to be 2.0 ± 0.7 times as likely to be overweight/obese as those who reported no history of asthma ($p = 0.05$). Model 2 adjusted for household education and pubertal development, and observed that adolescents who ever reported asthma were 2.9 ± 1.2 times as likely to be overweight/obese as those who reported no history of asthma ($p = 0.01$). Model 3 adjusted for household education, pubertal development, caloric intake, and dietary inflammatory index, and observed that adolescents who ever reported asthma were 3.2 ± 1.4 times as likely to be overweight/obese as those who reported no history of asthma ($p = 0.01$). Model 4 adjusted for household education, pubertal development, MVPA, and SED, and observed adolescents who ever reported asthma were 2.8 ± 1.3 times as likely to be overweight/obese as those who reported no history of asthma ($p = 0.03$). Model 5 adjusted for household education, pubertal development, caloric intake, dietary inflammatory index, MVPA, and SED and observed adolescents who ever reported asthma were 3.1 ± 1.5 times as likely to be overweight/obese as those who reported no history of asthma ($p = 0.02$).

Discussion

The present study sought to better understand the cross-sectional relationships between asthma and obesity in African American adolescents, and the influence of activity (MVPA and sedentary behaviors), diet and diet quality (caloric intake and dietary inflammatory index) on this relationship. Adolescents who had ever had asthma were more likely to have a

Table 3. Standardized beta coefficients (95% CI) for five regression models, with accompanying R^2 coefficients, examining the relationships of body mass index percentile with covariates (household education and pubertal development), asthma, diet (caloric intake and dietary inflammatory index) and activity (moderate-vigorous physical activity and sedentary behavior) in African American adolescents * $p < 0.05$.

	Model 1 $R^2 = 0.07$	Model 2 $R^2 = 0.11$	Model 3 $R^2 = 0.14$	Model 4 $R^2 = 0.16$	Model 5 $R^2 = 0.18$
Household Education	−0.14	−0.13	−0.15	−0.16	−0.18
Pubertal Development	0.22*	0.25*	0.23*	0.20*	0.19*
Asthma	—	0.19*	0.22*	0.18*	0.21*
Caloric Intake	—	—	−0.13	—	−0.08
Dietary Inflammatory Index	—	—	−0.05	—	−0.08
MVPA	—	—	—	−0.22*	−0.22*
Sedentary Behavior	—	—	—	−0.04	−0.05

Table 4. Odds ratio (95% CI) of being classified as overweight/obese (BMI percentile $\geq 85\%$) if reported ever having asthma.

	Model 1	Model 2	Model 3	Model 4	Model 5
Asthma	2.0 (1.0, 4.2)	2.9 (1.3, 6.6)*	3.2 (1.3, 7.7)*	2.8 (1.1, 6.8)*	3.1 (1.2, 8.0)*
No Asthma (Reference)	—	—	—	—	—

Model 1: unadjusted. Model 2: adjusted for covariates (household education and pubertal development) Model 3: adjusted for covariates + dietary variables (caloric intake and dietary inflammatory index). Model 4: adjusted for covariates + activity variables (moderate-vigorous physical activity and sedentary time). Model 5: adjusted for covariates + dietary variables + activity variables. * $p < 0.05$.

higher BMI percentile than their peers who reported never having asthma, even after accounting for the confounding effects of pubertal development and household education. When activity and dietary behaviors were added to the model, asthma remained significantly associated with BMI percentile. Additionally, adolescents who reported ever having asthma were more than three times as likely to be classified as overweight or obese than those with no history of asthma, even after accounting for the pubertal development, household education, activity behaviors, and dietary behaviors, suggesting that the relationship between asthma and BMI percentile may be mediated through factors other than physical activity and diet in African American youth.

Mounting evidence has observed asthma as an independent risk factor in becoming obese. In a 10-year prospective cohort study following over 2000 5–8 year old children into adolescence, those diagnosed with asthma at cohort entry were one and a half times more likely to develop obesity than their non-asthmatic counterparts [4]. This risk was independent of caloric intake and physical activity levels. This relationship has similarly been observed in adults. Hasler et al. (2006) conducted a longitudinal study with 591 adults and found that asthma predicted subsequent weight gain after accounting for physical activity, but being overweight or gaining weight did not predict the development of asthma [31]. The present study similarly suggests that current dietary and physical activity behaviors do not play significant roles in the mechanism by which ever having asthma is associated with BMI percentile.

Previous research regarding the relationship between physical activity behaviors with obesity in adolescents with asthma are mixed. Consistent with the present study, Westergren et al. (2016) observed no difference in self-reported or objective levels of MVPA between adolescents with or without asthma [32]. Ekström et al. (2017) found a positive association between asthma and BMI in Swedish children, however, the children diagnosed with asthma unexpectedly exhibited higher levels of physical activity than their non-asthmatic counterparts [33]. The higher physical activity participation in children with asthma was attributed to exercise being a useful treatment to relieve asthma symptoms [34]. It is also important to note that Ekström et al. (2017) studied a Swedish birth cohort and there are several differences in terms of population, culture, and built environment as it relates to our cohort of African American youth. Jones et al. (2006), observed no differences in MVPA, but adolescents with asthma were 1.3 times more likely to engage in 3 h or more of screen time per day and 1.5 times more likely to be overweight [9]. In contrast, Groth et al. (2016) noted that adolescents with lifetime asthma participated in significantly fewer days of both low- and high-intensity exercise than their non-asthmatic counterparts, though neither their sedentary behavior nor BMI significantly differed [35]. While MVPA was associated with lower BMI in the present study, this did not account for the higher BMI percentile observed in adolescents with a history of asthma, and there was no difference in MVPA between the two groups. These findings paired with previous research suggest that physical inactivity may not necessarily be the route by which asthma is related to higher BMI.

While physical activity limitations due to asthma are a genuine concern for both adolescents and parents, and may cause exercise-induced bronchoconstriction at high intensities, it is important to note that exercise may in fact provide relief of asthma symptoms [34]. Ornstein et al. (2002) concluded in a literature review that exercise can have positive effects on asthma that are both subjective (decreased intensity of wheezing attack, increased activity participation, and improved emotional status) and objective (improved aerobic fitness and running performance) [36]. In the present study, there were no objective differences in MVPA participation between adolescents with and without asthma. Furthermore, we observed that higher levels of MVPA was associated with a lower BMI percentile, suggesting physical activity may be a useful intervention to improve weight status in African American adolescents with and without asthma. Future research should seek to better understand the ideal duration and intensity of physical activity to best improve physical and cardiopulmonary fitness, while not triggering exercise-induced asthma episodes.

The literature regarding the influence of diet and diet quality on the relationship between asthma and obesity in adolescents is similarly mixed. Bueso et al. (2011) observed that adolescent girls with asthma consumed significantly lower levels of magnesium and folate, which are classified as anti-inflammatory nutrients, though they did not differ in BMI [37]. Wood et al. (2015), however, observed that university students who were clinically diagnosed with current asthma had higher BMI and consumed diets with a significantly greater dietary inflammatory index than their healthy counterparts [24]. When the inflammatory index of the diets was split into tertiles, a pattern of increasing BMI was observed, though this trend was not significant. In the present study, the diets of adolescents with diagnosed asthma history consisted of foods with high inflammatory properties, such as cholesterol, carbohydrates, and saturated fats compared to those without diagnosed asthma, despite similar total daily caloric intake in both groups. Interestingly, however, neither caloric intake nor dietary inflammatory index was associated with BMI percentile, and neither accounted for the relationship between asthma and BMI. Taken together these findings suggest that while adolescents with asthma seem to consume more inflammatory diets, this may not be the driving factor in the relationship between asthma and obesity in African American adolescents.

While diet accounts for some level of inflammation, other factors influence inflammation levels such as exposure to pollution, vitamin D deficiency, and psychological stress. Previous research has demonstrated that these factors can influence the inflammatory response present in uncontrolled asthma [38,39]. Engström et al. (2003) observed in a prospective cohort study of over 2000 men that individuals who had elevated levels of inflammation sensitive plasma proteins (ISP) in their system at baseline gained more weight over the following 3–9 years [13]. ISP's are regulated by pro-inflammatory cytokines, some of which influence fat storage via upregulation of the hypothalamic-pituitary-adrenal (HPA) axis [40]. The HPA axis may also be upregulated in ethnic minority teens with asthma, as this group has been observed to have elevated levels of psychological stress compared to their peers without asthma. [41]. Inflammation may also be mediated by alterations in gut and respiratory microbiota, both of which have been shown to have interconnected influences on each other. Consistent with this hypothesis, obese individuals have an altered microbiome, which has been shown to be associated with both the development and onset of asthma [42,43]. This inflammation connection is further supported by a prospective cohort study conducted by Chen et al. (2017) in which adolescents with asthma were less likely to develop obesity if they regularly used a rescue inhaler to control their symptoms [4]. Inhaled corticosteroid functions primarily by reducing the number of inflammatory cells in the airways and thus downregulating the production of pro-inflammatory proteins [44].

African Americans have higher rates of undiagnosed asthma and are likely to have fewer opportunities to receive the necessary anti-inflammatory medications and treatments for this condition, putting them at increased risk for asthma-related weight gain [45]. Accordingly, Hossain et al. (2015) demonstrated in a cohort of children diagnosed with asthma that African Americans had a more rapid weight gain after asthma diagnosis as compared to white children [46]. Taken together these findings suggest efforts should be made to both increase asthma screening amongst African American adolescents as well as to provide education, asthma control resources, and controlled physical activity opportunities to help adolescents have better control of their symptoms.

Increasingly, it is understood that there are different asthma subtypes, or endotypes, which have differing clinical manifestations, responses to treatment, and likely biological mechanisms [47]. Obesity-

associated asthma has been characterized as being more prevalent among adults and children with more severe asthma, and being less responsive to some therapies [48]. Obesity-associated asthma itself is complex, with multiple interconnecting biological mechanisms (e.g., altered microbiome, gene-environment interactions) that will likely require novel treatment strategies [3]. Our current study supports the idea that traditional mechanistic views of the relationship between asthma and obesity may be too simplistic.

Some strengths of this study were the objective measures of physical activity via accelerometry, the use of both diet quantity and quality measures, the inclusion of important covariates in the models, and the nested model analysis of the relationship between asthma and BMI. Some important limitations of the present study must be acknowledged. First, caregivers of participants had significantly higher levels of education when compared to the national average, limiting the generalizability of the findings to lower socioeconomic adolescents. While parental education is the most stable indicator of socioeconomic status, other factors including household income and occupation represent important aspects of socioeconomic status of a family that were not measured in the present study. Second, self-report of asthma history was used, which is prone to misclassification. This would, however, likely result in a more conservative estimate as some children may have undiagnosed asthma or be unaware of a prior diagnosis [45]. Asthma history allows evaluation of asthma at any point in the life-span prior to adolescence, which may be helpful for ascertaining asthma that pre-dates the onset of obesity but the tradeoff is that it does not specify current asthma status. While we recognize that a more stringent definition of asthma may have been beneficial for this study, funding limitations precluded our ability to examine lung function and airway constriction objectively. We chose to use self-reported asthma as an alternative as it allowed for assessment by recall of past diagnosis. Third, covariates included had missing data, but data were imputed to help address this issue. Fourth, we relied on self-report of pubertal development and caloric intake which can also result in misclassification. To reduce the likelihood of extreme over- or under-reporting, children with extremely high or low caloric intake were excluded from the study, however, it is possible that some participants excluded for potentially over-reporting did indeed have very high intake and may represent a subgroup with different relationships between the factors of interest. There were insufficient numbers to include in

the present analysis, but this may describe an important subgroup for future investigation. Fifth, cross-sectional data were utilized, so causation and directionality in the present findings cannot be established. Sixth, participation rate of recruited participants was not measured and we acknowledge that our findings may only be applicable to African American youth residing in southeast Michigan. Finally, due to pre-analysis exclusion, the final sample size was smaller than ideal for this type of cross-sectional study. Despite these limitations, we were able to observe a strong and consistent significant relationship between asthma and obesity in our participant sample that was independent of dietary and activity factors.

Much attention has been given to understanding the link between obesity and asthma; however, longitudinal studies that include measurement of potentially mediating factors are clearly needed to better understand the specific pathways by which asthma is associated with obesity in African American youth. This study adds to the literature by demonstrating strong cross-sectional associations between asthma and obesity, irrespective of important activity and dietary considerations related to weight status in African American adolescents. While dietary inflammatory index was not associated with BMI percentile, adolescents with a history of asthma consumed foods that were significantly more pro-inflammatory than their peers who never had asthma. Nevertheless, interventionists should continue to target nutrition as a health-promoting strategy to improve asthma and obesity outcomes in African American youth. Moreover, asthma diagnosis did not limit African American adolescents' participation in MVPA, with both groups of adolescents (with and without asthma) reporting similar levels of MVPA. The American College of Sports Medicine recommends applying "the standard principles of exercise prescription (mode, frequency, intensity, and duration) to patients with respiratory diseases, including asthma," and the American Thoracic Society recognizes physical activity as a key factor in pulmonary rehabilitation [49,50]. As such, developing physical activity interventions may be an effective method to both improve weight status in this population, and control asthma symptoms. Indeed, there are early indications that this approach can be successful, but requires replication and application to African American youth [34]. Providing education, improving asthma screening, and increasing access to asthma control medications and treatment are other preventive measures that can be taken to reduce the burden of asthma and obesity and

improve the quality of life for African American adolescents.

Acknowledgments

The authors would like to thank the Health & Culture Study team and Michigan Consulting for Statistics, Computing and Analytics Research. They are also grateful to their study participants and their families for their involvement.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the article.

Funding

This work was supported by the University of Michigan Office of Research and the University of Michigan School of Public Health Momentum Center. Clinical Trial Registration: This study is registered at www.clinicaltrials.gov (No. NCT02938663). This work was supported by the University of Michigan Office of Research and the University of Michigan School of Public Health Momentum Center.

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