Low Vegetable Intake is Associated With Allergic Asthma and Moderate-to-Severe Airway Hyperresponsiveness

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Summary. Background: In recent decades, children's diet quality has changed and asthma prevalence has increased, although it remains unclear if these events are associated. Objective: To examine children's total and component diet quality and asthma and airway hyperresponsiveness (AHR), a proxy for asthma severity. Methods: Food frequency questionnaires adapted from the Nurses' Health Study and supplemented with foods whose nutrients which have garnered interest of late in relation to asthma were administered. From these data, diet quality scores (total and component), based on the Youth Healthy Eating Index (YHEI adapted) were developed. Asthma assessments were performed by pediatric allergists and classified by atopic status: Allergic asthma ($\geq$1 positive skin prick test to common allergens $>$3 mm compared to negative control) versus non-allergic asthma (negative skin prick test). AHR was assessed via the Cockcroft technique. Participants included 270 boys (30% with asthma) and 206 girls (33% with asthma) involved in the 1995 Manitoba Prospective Cohort Study nested case-control study. Logistic regression was used to examine associations between diet quality and asthma, and multinomial logistic regression was used to examine associations between diet quality and AHR. Results: Four hundred seventy six children (56.7% boys) were seen at 12.6 $\pm$ 0.5 years. Asthma and AHR prevalence were 26.2 and 53.8%, respectively. In fully adjusted models, high vegetable intake was protective against allergic asthma (OR 0.49; 95% CI 0.29–0.84; $P < 0.009$) and moderate/severe AHR (OR 0.58; 0.37–0.91; $P < 0.019$). Conclusions: Vegetable intake is inversely associated with allergic asthma and moderate/severe AHR. **Pediatr Pulmonol.** © 2012 Wiley Periodicals, Inc.

Key words: nutrition; children; wheeze; atopy.

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INTRODUCTION

Asthma is the most common chronic disease in children, affecting approximately 12% of Canadian children, a prevalence which is significantly higher than less than a decade ago.[1] A nutrition transition has occurred over a similar time period, from a prudent or traditional diet, which is high in fresh produce and n-3 fatty acids,[2] to a western diet, characterized by high glucose-fructose, and saturated-, trans,- and n-6 fats.[3] Many diet components and nutrients have been considered individually as risk factors for asthma (reviewed in Reference 4). Yet, most people eat a reasonably diverse diet, not a single food or nutrient.[5] Inferences made from a single food or nutrient may be quite different than those drawn from dietary assessments.[6]

Although there has been focus placed on maternal diet during pregnancy and subsequent allergic outcomes in offspring,[7–10] little attention has been given to children's dietary patterns and asthma. Some,[11–14] but not all[15–18] studies have identified differences in dietary patterns between individuals with asthma and without asthma. Intakes of high fat and sodium, and low fiber and carbohydrates are linked with bronchial reactivity[16] and asthma,[17] while traditional[15] and vegetarian diets[18] are associated with lower rates of self-reported asthma in women. These findings suggest that Western dietary

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patterns may be associated with a higher prevalence of asthma. As asthma is believed to have origins in childhood[19] or earlier,[20] it is logical to address associations between diet quality and asthma in young people. We also report on associations between diet and airway hyperresponsiveness (AHR), which may be used to characterize asthma particularly among individuals with asthma-like symptoms but who do not exhibit obvious airflow obstruction.[21]

The term ''diet quality'' remains elusively defined, as its interpretation is influenced by the interests of those considering it.[6] Herein, diet quality is defined as *an indicator of risk of nutrition-mediated disease based on food and beverage intake that is reflective of one's typical intake patterns*. It is an assessment of total food intake, rather than specific individual foods or nutrients. Thus, the present study considers associations between diet quality and asthma, rather than asthma and a particular nutrient. The aim of this analysis was to determine if dietary patterns of 11–14 year old children are associated with asthma. The hypotheses were (1) that an inverse association exists between asthma and diet quality, particularly among those with allergic asthma, and (2) that an inverse association exists between AHR and diet quality.

METHODS

Study Design

This was a nested case-control study of the 1995 Manitoba Prospective Cohort Study of Allergy, Genes and the Environment (SAGE), detailed elsewhere.[22] Briefly, study participants were recruited via surveys from ~12,000 children born in 1995 and who remained in the province in 2002. Based on the ~3,500 returned surveys, 12% of children had parental-reported asthma. Those children with a parent-report of asthma, along with controls at a ratio of approximately 1:2 were invited to participate in this study. This yielded a nested case-control study of 723 children. A flow chart detailing recruitment to the SAGE cohort has been previously published.[22] Although the ethnic and geographic distribution of the participants was comparable to that of Manitoba overall, most participants recruited to this nested case-control study reported being of a higher income bracket than the overall Manitoba population. As a result, we acknowledge the possibility of selection bias, that may ultimately alter the measurement of an association in the study and the true magnitude between the exposure and outcome.[23]

Participants and their families have attended clinical visits every 2 years since 2003. This report is based on data collected at ages 8–10 years (2003–2005; retrospective maternal reports of breastfeeding only) and at 11–14 years (in 2007–2009). Four hundred eighty-nine children were reassessed at 11–14 years old. Pediatric allergist assessments for asthma and PC_{20} measurement were available for 470 and 460 children, respectively. All children had been involved in the 1995 Manitoba Prospective Cohort Study since its inception in 2002–03. Thus, they were familiar with the research tools and clinical assessments involved in this study.

Assessment of Diet Quality

Diet quality was ascertained via an adapted version of the Youth Healthy Eating Index (YHEI).[24] The YHEI is derived from the United States' Department of Agriculture's Dietary Guidelines for Americans.[25] These guidelines[25] are similar to those outlined in Canada's Food Guide to Healthy Eating.[26] The FFQ used in the present study was not originally designed to assess diet quality using the YHEI. Thus, some adaptations to component and overall scores were necessary (Table 1).

Information on children's diets was at 11–14 years old collected via parent-/guardian- and child report using a 39-item FFQ (Table 1). All questions were closed-ended; parents and children could select frequency of consumption for each of the foods from various options, depending on the food items. This FFQ was adapted from the validated 72-item FFQ used in the Nurses' Health Study (NHS).[27] Some items included in the NHS FFQ were excluded in our FFQ (Table 2). These included cottage cheese, hard cheese, and liver (attempts to reduce number of questions and thus participant burden; not anticipated to greatly alter diet quality scores; n = 3 questions), coffee and tea (comparable aged children consume only modest amounts (<250 ml) of such beverages per day[28]; n = 2 questions), and both alcoholic (n = 3 questions) and sugar-sweetened (n = 4) beverages. Other food items were collapsed into single categories, such as margarine and butter (n = 2 in the NHS FFQ), green vegetables other than lettuce (n = 4 in the NHS FFQ), orange vegetables (n = 3 in the NHS FFQ) and cakes, cookies and pie (n = 4 in the NHS FFQ). These food items were collapsed into single categories as each single food detailed in the NHS FFQ contributes equally to overall diet quality. Thus, the individual foods are less important than their contributions to diet quality. In contrast, we disaggregated some of the food groups which contribute differently to diet quality. For example, the NHS FFQ considered only ''fish.'' Given the recent interest in n-3 fatty acids and asthma, we divided this food group into two: Salmon and tuna, and other fish.

The FFQ were completed primarily by the children, although there were some questions that the parent/guardian and child were asked to complete together. Although it is not possible to say definitively, some of the questions may have been completed solely by the

parents. These would have included questions regarding the types of oil used for cooking, use of n-3 enriched eggs, and intake of calcium-fortified orange juice. Notably, parental recall of adolescents' diets via FFQ has been validated, albeit modestly [r = 0.30 (range 0.10–0.61) for foods; higher for nutrients].[29]

Given the food items that were contained in this FFQ, the following components were excluded from our adaptation of the YHEI: Soda and drinks, consumption of visible animal fat (fat on meat; skin on poultry), regularity of breakfast consumption, and regularity of eating dinner with family. We included food items that were not part of the NHS FFQ, such as calcium-fortified orange juice, vitamin D-fortified orange juice, n-3 enriched eggs, as well as queries of vegetarianism or veganism. These foods were included given the recent interest in asthma and the role of these foods, nutrients, and dietary patterns.[14,30–32] These exclusions and additions resulted in an adapted YHEI maximum possible score of 85; this is 15 points less than the total

TABLE 1— Food Frequency Questionnaire

The following questions are for parent and child to complete:
1. What type of milk does your child mostly consume?
   (A) Regular cow's milk (any variety)
   (B) Farm fresh (unpasteurized) milk
   (C) Soymilk
2. Does your child drink Calcium fortified orange juice?
   (A) No (B) Yes
3. Does your child drink vitamin D fortified orange juice?
   (A) No (B) Yes
4. Does your child eat omega-3 enriched eggs?
   (A) No (B) Yes
5. What type of cooking oil do you use at home? (Please choose the one(s) you use most often.)
   (A) Lard or Butter
   (B) Vegetable/olive oil
   (C) Vegetable shortening
   (D) Margarine
   (E) Non-fat cooking spray
6. How often does your child take a multivitamin or mineral supplement?
   (A) Often (once a day or more)
   (B) Sometimes (once a week or more)
   (C) Rarely (<1 week)
   (D) Never
7. How often does your child take a Vitamin D supplement?
   (A) Often (once a day or more)
   (B) Sometimes (once a week or more)
   (C) Rarely (<1 week)
   (D) Never
8. How often does your child take a Vitamin C supplement?
   (A) Often (once a day or more)
   (B) Sometimes (once a week or more)
   (C) Rarely (<1 week)
   (D) Never
9. How often does your child take flax seed oil or fish oil?
   (A) Often (once a day or more)
   (B) Sometimes (once a week or more)
   (C) Rarely (<1 week)
   (D) Never

The following questions are for child to complete:
Please select the correct response to your intake of the following:
10. In the past year, on average, how often did you eat fast food?
   (A) Never/less than once per month
   (B) 1–3 times per month
   (C) 1–2 times per week
   (D) 5–6 times per week
   (E) At least once per day
11. Are you a vegetarian? (no meat, chicken or fish; eat some dairy and/or eggs)
   (A) No (B) Yes
12. Are you a vegan? (no animal products including eggs, dairy, or honey)
   (A) No (B) Yes

TABLE 1—(*Continued*)

For each food listed below, please indicate how often (on average) you ate the food over the course of the past year. If the amount eaten varies depending on the time of the year, please indicate how many times on average the food was eaten over the course of a year:

		Average number times eaten in past year								
	Food and amounts	6+ per day	4–6 per day	2–3 per day	1 per day	5–6 per week	2–4 per week	1 per week	1–3 per month	Almost never
13	Skim or low fat (1% or 2%) milk	A	B	C	D	E	F	G	H	I
14	Whole (homogenized) milk	A	B	C	D	E	F	G	H	I
15	Yogurt	A	B	C	D	E	F	G	H	I
16	Ice cream/frozen yogurt	A	B	C	D	E	F	G	H	I
17	Butter or Margarine	A	B	C	D	E	F	G	H	I
18	Tofu	A	B	C	D	E	F	G	H	I
19	Green vegetables other than lettuce	A	B	C	D	E	F	G	H	I
20	Vegetables with added cheese sauce or butter	A	B	C	D	E	F	G	H	I
21	Orange vegetables [carrots, sweet potatoes, yellow squash (acorn, butternut, spaghetti)]	A	B	C	D	E	F	G	H	I
22	Tomatoes or tomato juice	A	B	C	D	E	F	G	H	I
23	Fruit Citrus fruit [oranges, grapefruit, lemons]	A	B	C	D	E	F	G	H	I
24	Orange or grapefruit juice	A	B	C	D	E	F	G	H	I
25	Berries (blueberries, strawberries, etc.) including cherries	A	B	C	D	E	F	G	H	I
26	Salmon, Tuna	A	B	C	D	E	F	G	H	I
27	Other fish excluding fish sticks	A	B	C	D	E	F	G	H	I
28	Hamburgers or hotdogs	A	B	C	D	E	F	G	H	I
29	Pizza	A	B	C	D	E	F	G	H	I
30	Sandwich meats (salami, bologna, sausage, ham, corned beef, soy slices)	A	B	C	D	E	F	G	H	I
31	Eggs	A	B	C	D	E	F	G	H	I
32	Canned legumes (soybeans, lentils, chick peas, black eyed peas, etc.)	A	B	C	D	E	F	G	H	I
33	Hot breakfast cereal (not instant), Hot breakfast cereal (instant), Cold breakfast cereal	A	B	C	D	E	F	G	H	I
34	Dark or whole grain bread	A	B	C	D	E	F	G	H	I
35	French fries	A	B	C	D	E	F	G	H	I
36	Nuts	A	B	C	D	E	F	G	H	I
37	Potato or corn chips	A	B	C	D	E	F	G	H	I
38	Canned soup, canned vegetables or instant noodles	A	B	C	D	E	F	G	H	I
39	Cookies or 1 slice of a 9'' pie/cake	A	B	C	D	E	F	G	H	I

possible score of the original YHEI.[25] From these totals, two dichotomous groups (low vs. high consumption) were created using the median of total and component diet scores as cut-offs (Table 2).

Outcome Measures

The primary outcome measure in this study was a pediatric allergist diagnosis of asthma at 11–14 years old. This definition of asthma is more robust than self-/parental-report or general practitioner diagnosis, which tends to over- and under-report asthma, respectively.[33,34] Children diagnosed with asthma were further dichotomized as having allergic versus non-allergic asthma. This dichotomization was made based on a skin prick test to one or more common allergens $\geq$3 mm in diameter compared to the negative control. Pediatric asthma has several phenotypes. As the presence of atopy may influence the association between diet and asthma/wheeze,[35] the phenotypes considered herein were allergic versus non-allergic asthma.

The secondary outcome measure was AHR. This was measured via the provocative concentration of methacholine required to decreases participants' FEV_1 by 20% (PC20), using the Cockcroft technique.[36] A 20% drop in FEV_1 yields a measure of the provocative concentration (PC_{20}) that can be classified as mild (2.1–8.0 mg/ml), moderate (0.25–2.0 mg/ml), or severe (<0.25 mg/ml) AHR as compared to normal (>8 mg/ml) controls. An inhaled bronchodilator (albuterol) was

TABLE 2— Adaptation of the Youth Healthy Eating Index (YHEI) and Dichotomization of Low Versus High Scores

YHEI component	Criteria for maximum score	Criteria for minimum score	Maximum score	Stratification threshold for low vs. high scores[1]	Mean	IQR[2]
Total YHEI score	Maximum for all components	0	85	33.45	33.85	29.85–38.12
1. Whole grains	>2×/day	0	10	6.50	5.53	4.00–6.50
2. Vegetables	>2×/day	0	10	4.60	4.59	3.60–5.60
3. Fruits	>2×/day	0	10	5.33	5.47	4.33–7.00
4. Dairy	>2×/day	1–3×/month or less	10	4.50	4.33	3.50–5.25
5. Meat ratio[3]	>2×/day	0	10	0.36	0.48	0.11–0.71
6. Snack foods[4]	Never	≥2×/day	10	4.25	4.35	2.50–5.94
7. Soda and drinks	NA	NA	—	—	—	—
8. Multivitamin use	Daily	Never	5	0.25	0.8	0.00–1.25
9. Margarine and butter	Never	≥2×/day	5	2.83	2.74	2.00–3.33
10. Fried foods outside home[3]	Never or <1×/month	≥1×/day	5	3.00	3.09	3.00–3.00
11. Visible animal fat	NA	NA	—	—	—	—
12. Eat breakfast	NA	NA	—	—	—	—
13. Dinner with family	NA	NA	—	—	—	—
14. Fish	>2×/week	Never	10	1.50	2.65	0.00–3.50

[1]Stratified at median score.
[2]Interquartile range.
[3]Lean meat + vegetable protein/dark meat.
[4]Salty snacks (e.g., potato chips, nachos, pretzels, crackers, canned soup) and snacks with added sugar (e.g., cakes, doughnuts, cookies). Adapted from references 26 and 28.

subsequently administered if required to reverse any continued fall in FEV1 following the methacholine challenge. This assessment was conducted by trained research nurses and research assistants.

Ethics

This study received ethical approval from The University of Manitoba's Health Research Ethics Board. Parents/guardians provided written consent and children provided written assent.

Statistical Analysis

Descriptive statistics were used to describe the study population. Binary logistic regression analyses were used to identify potential relationships between total and component diet scores (exposure variable; categorical) and asthma (dichotomous outcome variable; categorical). Multivariate, multinomial logistic regression was used to identify relationships between total and component diets scores and AHR [trichotomous outcome variable (normal, mild, moderate/severe); categorical].

Results are presented as odds ratios (95% confidence intervals). Potential a priori confounders were identified via x^2 tests for association. Significant covariates ($P < 0.05$) included weight status at 11–14 years old (lean vs. overweight; further described below), region of residence (urban, southern rural, northern), income (≥ or <$30000 Canadian annually), physical activity at 8–10 years old (>2 or ≤2 days per week), and maternal history of asthma.

Statistical models were built by sequentially adding significant covariates in each regression analysis. In fully adjusted models which were not stratified by breastfeeding and fast food, these variables were considered as confounders. Height and weight measurements were collected in triplicate, and body mass index [BMI; weight (kilograms)/height (m^2)] was calculated from the mean of these measures. Each participant was then categorized as normal weight (<85th percentile for age and sex) or overweight (≥85th percentile for age and sex), based on the accepted criteria of the Canadian Pediatric Society.[37] Other confounding variables included sex, region of residence, SES, and maternal history of asthma. In order to add elements of temporality, breastfeeding duration (never breastfed vs. ever breastfed, and <3 months vs. ≥3 months) and children's fast food intake at 8–10 years old (never/occasionally vs. ≥1 time per week) were also considered.

For all analyses, significance was defined as $P < 0.05$. Analyses were conducted using Statistical Package for Social Sciences (SPSS) 17.0.

RESULTS

Participants' characteristics are noted in Table 3. Four hundred seventy-six children [270 (56.7%) boys] were seen at this assessment. This represents 65.8% of the original nested case-control study, which began in

TABLE 3— Clinical and Demographic Characteristics of Participants at the Time of the Index Visit

	n	%[1]
Sex	476	100.0
Age[2] (n = 474)	12.6 ± 0.5	—
Asthma (n = 465)		
No	343	73.8
Yes	122	26.2
AHR[3] (n = 460)		
Normal	204	42.9
Mild	108	22.7
Moderate	123	25.8
Severe	25	5.3
Breastfeeding (n = 471)		
Yes	410	87.0
≥3 months	340	82.9
Fast food consumption (n = 471)		
Never/occasionally	217	46.1
≥1 time per week	254	53.9
Physical activity (n = 473)		
≤2 times per week	96	20.3
Most/all days	377	79.7
Weight status[4] (n = 476)		
Lean	342	71.8
Overweight	134	28.2
Region of residence (n = 476)		
Urban	265	55.7
Southern rural	177	37.2
Northern	34	7.1
Socio-economic status[5] (n = 476)		
<$30,000	70	14.7
≥$30,000	406	85.3
Maternal history of asthma (n = 475)		
No	343	72.1
Yes	122	25.6

[1]Percentages may not total 100% due to rounding.
[2]Mean ± standard deviation.
[3]Airway hyperresponsiveness based on methacholine challenge.
[4]Weight status based on BMI< or ≥ 85th percentile for age and sex.[37]

2002–03. Those identifying as Caucasians, as well as higher income families and urban dwellers were more likely to remain in the study at 11–14 years old. The prevalence of moderate/severe AHR was higher at 11–14 years (57.9%) compared to baseline (50.0%), although the prevalence of mild AHR was lower (41.1% vs. 50.0% at baseline). At ages 11–14 years, nutritional data were available for 476/489 children. At a mean age 12.6 ± 0.5 years, approximately 26% of children had asthma, while 53.8% had AHR. There were no differences in rates of breastfeeding, breastfeeding duration, fast food consumption, or breastfeeding + fast food consumption (all $P > 0.05$) between those with and those without asthma. No differences were identified between sexes, except for AHR; girls were significantly more likely to have normal AHR than boys. Nearly three-quarters of the children had a BMI within the healthy range. Most lived in urban areas and were from middle-class families. Approximately one in four mothers of participating children had a history of asthma.

The median diet score in this cohort was 33.45/85 (Table 2), indicating that overall diet quality was relatively poor. Children scored around the 50th percentile for several diet components (whole grains, vegetables, fruit, dairy, snack foods, margarine and butter, fried foods). In contrast, scores for meat ratios, multivitamins, and fish were very low. Two hundred thirty children (48.3%) reported a multivitamin supplement at least rarely, with fewer children reporting supplementation of vitamin C (n = 162), vitamin D (n = 64), and n-3 fatty acids (n = 59).

Few associations were made between diet scores and asthma for all participants collectively (Table 4) in either partially or fully adjusted models.

TABLE 4— Associations between Total and Component Diet Scores and Asthma in Manitoba Children

	Unadjusted		Fully adjusted[1]	
	OR	95% CI	OR	95% CI
Total diet score	1.02	0.84–1.24	1.06	0.67–1.70
YHEI component				
Whole grains	0.99	0.77–1.24	0.99	0.65–1.51
Vegetables	0.99	0.82–1.20	1.15	0.75–1.76
Fruits	0.94	0.77–1.14	1.44	0.93–2.22
Dairy	0.93	0.76–1.14	1.23	0.80–1.91
Meat ratio	1.07	0.88–1.31	1.86	0.77–1.83
Snack foods	0.91	0.75–1.11	1.23	0.80–1.89
Multivitamin use	0.89	0.73–1.08	1.01	0.66–1.56
Margarine and butter	0.88	0.72–1.08	0.75	0.48–1.16
Fried foods outside of home	0.86	0.68–1.10	0.15	0.65–2.02
Fish	1.06	0.87–1.30	0.74	0.47–1.17

Reference group is children with high total diet/diet component scores.
[1]Adjusted for breastfeeding, fast food consumption, weight status, region of residence, family income, physical activity, and maternal history of asthma.

Diet scores of children with allergic asthma (n = 107; 22.5%) and non-allergic asthma (n = 38; 8.0%) were compared to those of healthy children (n = 181; 38.0%) (Table 5). This excluded 150 (31.5%) children from the prospective cohort, who were atopic but who did not have asthma. Only high vegetable intake (OR 0.49; 95% CI 0.29–0.84; $P < 0.009$) was associated with reduced odds of allergic asthma in a fully adjusted model.

Two hundred four children (44.3%) had normal airway responsiveness, 108 (23.5%) had mild AHR, 123 (26.7%) had moderate AHR, and 25 (5.4%) had severe AHR. These latter two groups were collapsed to create a moderate/severe AHR category. Only high vegetable intake remained protective against moderate/severe AHR in a fully adjusted model (OR 0.58; 0.37–0.91; $P < 0.019$) (Table 6).

DISCUSSION

In this study, total diet scores were not associated with asthma or AHR. In a fully adjusted model, high vegetable intake was inversely associated with allergic asthma, as well as moderate/severe AHR. Vegetables queried in the FFQ included green and orange vegetables. Canada's Food Guide[26] suggests both dark green

TABLE 5— Associations between Total And Component Diet Scores[1] and Non-Allergic and Allergic Asthma Phenotypes Compared to Healthy Manitoba Children

	Unadjusted		Fully adjusted[2]	
	OR	95% CI	OR	95% CI
Total diet score				
Non-allergic asthma[3]	1.10	0.55–2.21	0.98	0.46–2.06
Allergic asthma[4]	0.90	0.56–1.45	0.94	0.56–1.59
By YHEI component				
High intake of whole grains				
Non-allergic asthma	0.68	0.31–1.45	0.73	0.32–1.66
Allergic asthma	1.28	0.71–2.30	1.36	0.71–2.59
High intake of vegetables				
Non-allergic asthma	0.88	0.44–1.77	0.74	0.35–1.58
Allergic asthma	**0.55***	**0.34–0.90**	**0.49**[4]	**0.29–0.84**
High intake of fruits				
Non-allergic asthma	0.83	0.41–1.67	0.87	0.41–1.85
Allergic asthma	0.94	0.59–1.53	1.06	0.63–1.79
High intake of dairy				
Non-allergic asthma	1.36	0.65–2.83	1.35	0.62–2.94
Allergic asthma	1.10	0.67–1.78	0.98	0.57–1.67
High meat ratio				
Non-allergic asthma	1.00	0.50–2.02	0.94	0.45–1.98
Allergic asthma	0.96	0.59–1.55	1.00	0.59–1.69
Low intake of snack foods				
Non-allergic asthma	1.20	0.59–2.41	1.26	0.60–2.66
Allergic asthma	1.29	0.80–2.09	1.34	0.79–2.28
High intake of multivitamin use				
Non-allergic asthma	1.52	0.75–3.08	1.17	0.55–2.49
Allergic asthma	**1.62****	**1.00–2.63**	1.51	0.89–2.57
Low intake of margarine and butter				
Non-allergic asthma	0.89	0.44–1.78	1.01	0.48–2.14
Allergic asthma	1.16	0.71–1.87	1.22	0.72–2.06
Low intake of fried foods outside of home				
Non-allergic asthma	0.93	0.39–2.20	1.15	0.45–2.97
Allergic asthma	0.84	0.47–1.50	0.91	0.48–1.73
High intake of fish				
Non-allergic asthma	1.48	0.73–3.03	1.48	0.69–3.19
Allergic asthma	1.04	0.65–1.69	1.10	0.65–1.86

The bold text indicates statistically significant results.
[1]Adapted from the Youth Healthy Eating Index.[24]
[2]Adjusted for breatfeeding, fast food consumption, weight, region of residence, family income, physical activity, and maternal history of asthma.
[3]Non-allergic asthma (n = 38).
[4]Allergic asthma (n = 107).
*$P < 0.02$.
**$P < 0.05$.

TABLE 6— Associations Between Total and Component Diet Scores[1] and Mild and Moderate/Severe Airway Hyperresponsiveness Compared to Healthy Manitoba Children

	Unadjusted		Fully adjusted[2]	
	OR	95% CI	OR	95% CI
Total diet score				
Mild AHR	0.98	0.61–1.56	1.07	0.66–1.72
Moderate/severe AHR	0.92	0.60–1.40	0.97	0.62–1.51
By YHEI component				
Whole grains				
Mild AHR	1.51	0.84–2.69	1.40	0.78–2.53
Moderate/severe AHR	0.89	0.55–1.44	0.90	0.54–1.49
Vegetables				
Mild AHR	0.074	0.47–1.19	0.68	0.42–1.11
Moderate/severe AHR	**0.62***	**0.40–0.94**	**0.58***	**0.37–0.91**
Fruits				
Mild AHR	0.78	0.49–1.24	0.77	0.48–1.25
Moderate/severe AHR	0.93	0.61–1.43	0.98	0.63–1.53
Dairy				
Mild AHR	0.83	0.51–1.34	0.83	0.51–1.36
Moderate/severe AHR	**0.63***	**0.41–0.98**	0.66	0.42–1.04
Meat ratio				
Mild AHR	1.05	0.66–1.67	1.00	0.62–1.62
Moderate/severe AHR	1.01	0.66–1.55	0.99	0.63–1.55
Snack foods				
Mild AHR	1.28	0.80–2.06	1.37	0.84–2.23
Moderate/severe AHR	0.95	0.62–1.45	0.99	0.63–1.55
Multivitamin use				
Mild AHR	0.85	0.53–1.35	0.86	0.53–1.39
Moderate/severe AHR	0.86	0.56–1.31	0.92	0.59–1.44
Margarine and butter				
Mild AHR	1.10	0.69–1.77	1.11	0.68–1.79
Moderate/severe AHR	1.24	0.81–1.91	1.39	0.88–2.18
Fried foods outside of home				
Mild AHR	1.34	0.76–2.36	1.13	0.63–2.04
Moderate/severe AHR	1.32	0.79–2.21	1.38	0.79–2.41
Fish				
Mild AHR	1.16	0.72–1.85	1.12	0.69–1.82
Moderate/severe AHR	0.88	0.57–1.35	0.94	0.60–1.47

The bold text indicates statistically significant results.
Reference group is children with low total diet/diet component scores.
[1]Adapted from the Youth Healthy Eating Index.[24]
[2]Adjusted for breastfeeding, fast food consumption, weight, region of residence, family income, physical activity, and maternal history of asthma.
*$P < 0.02$.

and orange vegetables ought to be consumed at least once daily. Our findings suggest that intake of orange and green vegetables may protect against particular asthma phenotypes or severities only. The reasons for phenotype-specific protection remain unclear. However, vegetables may protect against asthma in two different ways. First, vegetables are abundant in antioxidants. The ''antioxidant hypothesis'' was first described by Soutar, Seaton, and Brown[16] nearly two decades ago. Vitamin C, a potent antioxidant, is known to act on the airways by affecting arachidonic acid metabolites, including prostaglandins. In animal models, Prostaglandin F2α induces bronchoconstriction; vitamin C mitigates this reaction. Additionally, vitamin C is the most abundant antioxidant in the extracellular fluid of the lungs.[38] Alternatively, vegetable intake may be a proxy for lifestyle factors, including but not limited to variables identified as confounders at Visit 3.

Much of the related literature focuses on fruits, including a recent report in which regular fruit intake over the preceding month reduces the risk of persistent asthma.[38] We were unable to identify a protective effect of fruit intake on asthma outcomes. Nonetheless, this report provides evidence that high vegetable intake, also a proxy for antioxidant intake, may protect against allergic asthma and increasingly severe AHR. Similarly, an inverse association has been reported for

green vegetable intake and self-reported wheeze among those living in low/middle income nations, but not high income nations.[39] The lack of association between vegetable intake and asthma in developed nations may be due to differences in preparation methods or the variety of available vegetables compared to developing nations.[39] However, findings from other work,[39–41,42] including the present study, suggest that vegetable intake may be protective against asthma in children from more affluent nations. Also consistent with the present study is work from Menorca, Spain, which was indicative that ''fruity vegetables'' (tomatoes, green beans, eggplant, zucchini, cucumber) protected against atopic (or allergic) wheeze.[35] These types of vegetables were collectively grouped with other vegetables in the present study. The related protective mechanisms of vegetables remain unclear. However, it is plausible that antioxidants, particularly vitamins C and E, and ß-carotene play a role.

As a marker of pulmonary function, a decrease in the forced expiratory volume in one second (FEV_1) has been associated cross-sectionally with a traditional northern European diet, which includes boiled vegetables.[43] Although initially high in anti-oxidants, vegetables lose much of their antioxidant properties in the cooking process, particularly boiling.[44] Thus, it is likely that not all vegetables confer a similar protective effect against allergic asthma, AHR and, more generally, lung function. Consideration must also be given to the methods in which these foods were prepared.

As previously noted, allergic disease may begin in fetal[19] and early life.[20] As such, the protective effect of vegetable intake against allergic disease has been considered among very young children. High maternal vitamin E consumption in pregnancy is seemingly protective against childhood wheeze.[7] While no associations between maternal vegetable intake during pregnancy and asthma in offspring[7,8] have been identified, high maternal vegetable consumption during pregnancy may be protective against wheeze and atopy in school-aged children.[9]

These associations provide further evidence that vegetable intake may confer protection against allergic asthma and moderate-to-severe AHR. Although causality cannot be implied due to the cross-sectional nature of this study, the present findings are in accordance with existing literature. Moreover, the inclusion of breastfeeding data and previous fast food consumption data allowed for temporality as these events provide a reflection of participants' earlier nutritional patterns. However, it warrants mention that pre-clinical symptoms may have also caused participants to alter their eating habits. That stated, determination of dietary changes resulting from an asthma diagnosis was beyond the scope of this investigation.

There are several limitations to this study. The validated YHEI was adapted, based on available data, for this study, thereby necessitating some exclusions. Some excluded foods and beverages were likely rarely consumed (e.g., liver, coffee) or would have been inappropriate to query among children aged 11–14 years (e.g., alcohol) and would likely have had little impact on the total dietary score if they had been included. Other excluded foods (e.g., cottage and hard cheeses) were likely more regularly consumed foods. However, these items were not included as part of the FFQ, and thus by necessity, had to be excluded. Second, selection bias is a concern with all observational studies,[23,45] including the present study. Study participants were predominantly from middle class families in Canada. Thus, they likely had greater access to a wider variety of dietary choices and had fewer food security concerns. For these reasons, the results from this study ought to be generalized with caution. Also, as with all self-reported dietary data, FFQ have intrinsic limitations. Such limitations range from concerns with variations in nutrient composition and portion sizes of the reported foods[28] to participants' reports based on creating an illusion of a more nutritious diet than is actually consumed. These latter three issues may have been further compounded by the fact that participants were asked to complete numerous questionnaires during the study visit and validity may have been reduced due to participant fatigue/burden. But, many participants actually completed the FFQ prior to the study visit, thereby minimizing participant fatigue. Finally, it must be acknowledged that some results (e.g., low intake of fried foods outside the home) were not significantly associated with reduced odds of allergic asthma, even though the results tended in the expected direction. This may be due to a lack of power; larger sample sizes may yield more conclusive results.

There are many strengths to this study. Asthma presence was diagnosed by a pediatric asthma expert and the presence of atopy to further define the asthma phenotype and AHR were measured objectively and are considered to be the gold standards. As well, this is one of the largest population-based descriptions between diet and asthma in an adolescent population. Adolescents tend to have nutritionally inferior diets[46]; this is supported by participants' low total and component diet scores. The sex shift of asthma, from male to female predominance, also occurs during this time.[47] As such, examination of potential associations between diet and asthma in this age group is warranted. And, while an adapted version of a validated FFQ was used, the inclusion of foods typically eaten in Manitoba and by adolescents provide an enhanced representation of participants' diets. Consideration of the intake of both nutrients and food/food groups broadly as well as

specifically to this age- and geographical-group provides an enhanced means by which to consider the complex etiology of asthma.

These findings have implications for future research and clinical work. The ongoing hypothesis that vegetable intake is inversely associated with allergic asthma and AHR warrant further consideration, as cumulative evidence remains unclear. Moreover, associations between diet and asthma should be considered in a more diverse population. This ought to include children from low socioeconomic status and food insecure homes, who are more likely to have a nutritionally inferior diet than children from more affluent families. Lastly, although it would be premature to advise patients that vegetable intake is protective against allergic asthma and increasingly severe AHR, these nutrients have many other well-documented health benefits. Thus, consumption of these foods ought to be encouraged. In youth, vegetable intake is inversely associated with allergic asthma, and may protect against moderate-to-severe AHR.

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