Original Article

Risk of asthma associated with energy-dense but nutrient-poor dietary pattern in Taiwanese children

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Childhood asthma has rapidly increased over the past few decades, possibly due to changes in lifestyle and dietary patterns. We aimed to determine associations between dietary patterns and asthma in schoolchildren in Taiwan. The Nutrition and Health survey in Taiwan Elementary School Children was carried out by using a multistaged complex sampling design. A total of 2,082 elementary school children with complete data on dietary, lifestyle, demographics and asthma were included in the analysis. We used a Chinese version of the International Study of Asthma and Allergies in Childhood questionnaire to generate an asthma symptom score and to define asthma outcomes. Dietary intake was assessed by a food frequency questionnaire. Reduced rank regression (RRR) was used to identify the dietary pattern associated with the asthma symptoms score. Asthma outcomes included; current asthma, current severe asthma, nocturnal cough, exercise-induced wheeze and asthma ever. The RRR-derived dietary pattern was characterized by high consumption of fast foods, high-fat snacks, candy, and cheese; and low consumption of fruit, vegetables and rice. The RRR-derived dietary pattern was associated with an increased risk of current asthma (OR [95% CI]) (2.42 [1.19-4.93] for Q4/Q1, *p*-for-trend=0.01), current severe asthma (3.21 [1.11-9.25] for Q3/Q1, 4.45 [1.59-12.5] for Q4/Q1; *p*-for-trend=0.003), and nocturnal cough (1.79 [1.06-3.05] for Q2/Q1, 1.74 [1.02-2.97] for Q3/Q1, 1.82 [1.07-3.11] for Q4/Q1; *p*-for-trend=0.049). Our results suggest that a diet with a high intake of fat and simple sugars and low intake of fruit, vegetables and rice is associated with an increased risk of asthma in Taiwanese children.

Key Words: asthma, children, dietary pattern, risk factors, reduced rank regression

INTRODUCTION

Asthma is a respiratory disease characterized by increased airway responsiveness, inflammation and variable airflow obstruction. Its prevalence in children has drastically increased over the past few decades around the world.[1] Although the prevalence rate of 'current wheeze' in Taiwan is 9.7%, lower than that of English speaking countries, Latin America, Western Europe, and Asia-Pacific countries such as Japan, Singapore, and South Korea; it is increasing by a rate of 0.04% per year.[1] Lifestyles have been changing rapidly around the globe and the increasing prevalence of asthma symptoms may be related to dietary factors and their complex interactions with genes and the environment.[2,3] Numerous cross-sectional and case-control observational studies have suggested that individual foods such as egg, seafood, milk, soy products, liver, deep fried foods, fruit, vegetables and rice are associated with asthma risk or lung function.[3-6] In addition, much research has related asthma to a variety of nutrients such as beta-carotene, vitamin C and E[7,8] which were abundantly contained in vegetables, fruit and seeds. However, trials of supplementation of single nutrients such as vitamin A, C, E, selenium, and magnesium have been unable to show a beneficial effect on asthma symptoms, lung function or reduced inflammatory responses.[3] The above results may indicate that the effects of foods are beyond a simple combination of individual nutrients and components. Studying dietary patterns instead of specific foods or nutrients is an alternative approach in nutritional

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epidemiology and can be used to assess the relationship between diet and asthma.

Few studies had focused on the relationship between dietary patterns and asthma in children. The Mediterranean diet which is rich in fish, fruits, vegetables, legumes, nuts and cereals, but low in red meat, margarine and junk foods, was the only dietary pattern reported to have a protective effect for asthma in children.[9] In adults, only two prospective studies have reported an association between dietary patterns and asthma. In a study of French women, a Western dietary pattern (pizza/salty pies, desserts and cured meats) was associated with an increased risk of reported "frequent asthma attacks", whereas there was no statistically significant association between a "prudent" dietary pattern (fruit and vegetables) and asthma attacks.[10] In another study of Chinese Singaporeans, a "meat-dim sum" dietary pattern (pork and chicken dim sum foods and noodle dishes) was positively associated with new-onset cough with phlegm, whereas a weak inverse association was found for the "fruit-vegetable-soy" dietary pattern.[11]

Principal component analysis (PCA) and reduced rank regression (RRR) are commonly used methods to identify dietary patterns.[12] In the above prospective studies, the dietary patterns were derived by PCA which produces a linear combination of food groups that explains maximal variation in food group intake in the study population. PCA may not achieve the full potential of dietary pattern analysis because it relies solely on intercorrelations among dietary variables, which may not optimally represent the diet qualities most relevant to the disease of interest.[12] RRR is superior to PCA analysis[12] in its context linking capacity. RRR produces several linear combinations of food groups (eg dietary patterns) that maximally explain variation of investigator-specified intermediate phenotypes of a given disease (ie asthma symptom score in this study).

In the present study, we used RRR to derive a dietary pattern factor that explains most of the variation in asthma symptom score in Taiwanese children, aged 7-12 years. We then investigated the relationship between this dietary pattern and asthma symptoms.

MATERIALS AND METHODS

Study population

This study used data obtained from the Nutrition and Health Survey of Taiwan Elementary School Children 2001-2002 (NAHSIT Children). The NAHSIT Children investigated the nutritional status, influential dietary and non-dietary factors, health and development, and school performance of children in Taiwan. The survey adopted a two-staged, stratified, clustered probability sampling scheme. Towns and districts in Taiwan with particular ethnic and geographical characteristics were designated into 13 strata including Hakka areas, mountain areas, Penghu islands, eastern Taiwan regions, 3 northern regions, 3 central regions and 3 southern regions. Eight schools were selected from each stratum using the probabilities proportional to size method. Twenty-four children were randomly selected within each school. A total of 2,419 face-to-face interviews were completed with a response rate of 78.8%. A detailed description of the study design, sampling methodology and contents has been described elsewhere.[13] Informed consent was signed by one of the parents of all school children. The study was approved by reviewers from the Department of Health in Taiwan.[13] For the present study, we excluded 17 schools that did not have nearby air quality monitoring stations leaving a remaining 87 schools. A total of 2,082 children (1,111 boys and 971 girls) with data on socio-demographics, anthropometrics, food frequency, asthma and air pollution indices were included in the analyses.

Asthma symptom assessment and asthma symptom score

Asthma symptoms were assessed by a Chinese version of the International Study of Asthma and Allergies in Childhood (ISAAC) questionnaire[14] (see Figure 1) which was administered at home to one parent or guardian. The number of the asthma symptoms was added up to create an asthma symptom score (0 = no symptoms, 1 = one symptom and so on). The asthma symptom score was used as the dependent variable in the RRR analysis for deriving dietary pattern factors (described further below).

The outcomes [15] included: current asthma, current severe asthma, nocturnal cough, exercise-induced wheeze and asthma ever were then associated with dietary patterns. Current asthma was defined as "having wheezing attacks more than one time during the last 12 months". Current severe asthma was defined as ≥4 wheezing attacks in the last 12 months, or when sleep was disturbed ≥1 nights/per week, or dyslogia occurred caused by wheezing in the last 12 months. Nocturnal cough was defined as "having a dry cough at night, apart from a cough associated with a cold or a chest infection during

1. Has your child ever had wheezing or whistling in the chest at any time in the past? Y/N (then to Q6)
2. Has your child had wheezing or whistling in the chest in the last 12 months? Y/N (then to Q6)
3. How many attacks of wheezing has your child had in the last 12 months?
4. In the last 12 months, how often, on average, has your child's sleep been disturbed due to wheezing?
5. In the last 12 months, has wheezing ever been severe enough to limit your child's speech to only one or two words at a time between breaths? Y/N
6. Has your child ever had asthma? Y/N
7. In the last 12 months, has your child's chest sounded wheezy during or after exercise? Y/N
8. In the last 12 months, has your child had a dry cough at night, apart from a cough associated with a cold or a chest infection? Y/N

Figure 1. The International Study of Asthma and Allergies in Childhood questionnaire (modified Chinese version).

the last 12 months". Exercise-induced wheeze was defined as "having wheezing during or after exercise during the last 12 months". Asthma ever was defined when a positive answer was given to the question "Has your child ever had asthma?".

Dietary assessment

Dietary intake was assessed by a food frequency questionnaire (FFQ) with 21 food groups. The FFQ was carried out at home with parents assisting children to respond to the questions. Children were asked to estimate the average frequency (days/per week) of intake of 21 food groups within the 1 month prior to the interview. Food groups included vegetables, fruits, milk, yogurt, Yakult (lactic acid beverages with low dairy protein and high sugar), cheese, meat, fish, shellfish, organ meat (eg heart, liver, kidney and stomach of poultry and livestock), soybean milk, soy products, eggs, fast foods (eg hamburgers, pizza, French fries, fried chicken, and fried Asian delicacies), high-fat snacks (eg potato chips, flour-based and rice flour-based crisps), sweet drinks (eg cola and soda), candy (eg chocolate and candy), desserts (eg cakes, cookies and sweet pastries), instant noodles, rice and flour. Intake frequencies of the 21 food groups were used as independent variables in RRR analysis for the derivation of dietary pattern factors.

The NAHSIT FFQ validity has been previously assessed by 24-hour recalls in the elderly.[16] In our study, in order to understand the performance of FFQ used in children, the food items gathered from the 24-hour recall were grouped according to the food groups of the FFQ. The Spearman ranked correlations was used to examine how closely frequency data obtained from FFQ is associated with the food weight calculated from 24-hour recall for each food group. The highest correlation coefficient was observed for dairy products (0.95) and the lowest for meat (0.13) with an average 0.60 (data not shown). These results indicate that our FFQ has reasonable validity, considering that 24-hour recall records dietary information for just one day.

Assessment of non-dietary information

Information on participants' characteristics including age, sex, parental education level, parental asthma history, number of siblings, and vigorous exercise (that produces sweating) was obtained at home from parents or parents assisting children to respond to the questions. Parental asthma history was defined as a reported history of physician diagnosed asthma in one or more parents. Vigorous sweat-inducing exercise was defined as performing exercise that induced sweating more than three times a week. We also asked about parental education level and the number of siblings. Body mass index (BMI; in kg/m^2) was calculated from measured height and weight.

Air pollution data was collected from 2001-2002 by air quality monitoring stations which were set up by the Environmental Protection Administration (EPA) throughout the main island of Taiwan. Indices of air pollution included sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), nitrogen oxides (NO_X) and particles with an aerodynamic diameter of 10μm or less (PM_{10}). The concentration of these air pollution indices was measured continuously and reported hourly. SO_2 was measured by ultraviolet fluorescence, CO by non-dispersive infrared absorption, O_3 by ultraviolet absorption, NO_X by chemiluminescence, and PM_{10} by β-gauge.[17] Pollution parameters used in the statistical analysis were annual arithmetic mean concentrations, calculated from the daily averages. The average concentration per hour was retrospectively extracted for each student from the time of the interview to one year prior to the interview.

Statistical analysis

We used RRR[12] to derive dietary pattern factors. In the RRR model, the asthma symptom score was the dependent variable and consumption frequencies of the 21 food groups were the independent variables. The RRR model identifies a linear combination of the predictors (ie food groups) which explains a substantial amount of variation in the response variable (ie asthma symptom score). One dietary pattern factor was identified, which was constructed by including food groups with large factor loadings values. The 90^{th} percentile (≥0.24) and 10^{th} percentile values (≤-0.27) of the loadings were used as the cut-off. Therefore, high-fat snack (0.44), cheese (0.31), fast food (0.25), candy (0.24), rice (-0.27), fruit (-0.34) and vegetables (-0.44) were included in this factor. Individual scores for the RRR-derived dietary pattern factor were calculated as the weighted sum of the food frequencies where weights were factor loadings. All of the loadings between 0.24 and -0.27 were set to zero.

Weighting was carried out to calculate and compare prevalence rates of asthma among various subgroups using SUDAAN version 10.0. Others data analyses were conducted using SAS version 9.2. Participant characteristics were described using percentages or means and standard deviations. We examined mean food frequencies across quartiles of the RRR-derived dietary pattern score. The linear trend between RRR-derived dietary pattern score and food frequency was evaluated by using linear regression. Finally, we used logistic regression to estimate odds ratios for the derived dietary pattern and asthma symptoms, adjusting for age, sex, BMI z-score, older sibling number (0, 1 and 2+), parental education level (<high school, high school, and college+), parental asthma status (yes and no), ambient NOx concentration and seasonal effect (spring and summer versus fall and winter).

We also used a statistical permutation procedure to validate the association between dietary pattern score and asthma symptoms. We randomly permuted the asthma symptom scores of 2,082 school children. The data of other variables remained unchanged to create a new permutation dataset. The procedure aimed to create data sets mimicking the null distribution "no association between dietary pattern score and asthma symptoms". The permutation procedure was repeated for 10,000 times to create 10,000 independent permutation datasets. With each permutation-generated dataset, we performed RRR to define a dietary pattern and then use multivariate logistic regression to examine association between dietary pattern score and asthma symptoms. Therefore, it yielded 10,000 new tables similar to Table 4 in the manuscript based on the permutation datasets. Finally, empirical *p*-values of the

Table 1. Participant characteristics and air pollution indices (n=2,082).

Variables	Total	Boys (n=1,111)	Girls (n=971)	
	N (%) or Mean±SD			*p* value†
Age, yrs	8.5±1.7	8.5±1.7	8.5±1.7	0.21
BMI, kg/m^2	18.1±3.5	18.6±3.7	17.6±3.2	<0.0001
Father's education, yrs				
<9	674 (33.0)	369 (33.8)	306 (32.2)	0.61
9-12	785 (38.5)	421 (38.5)	364 (38.3)	
>12	581 (28.5)	302 (27.7)	280 (29.5)	
Mother's education, yrs				
<9	677 (33.0)	367 (33.4)	311 (32.4)	0.47
9-12	998 (48.6)	539 (49.1)	460 (48.0)	
>12	380 (18.5)	192 (17.5)	188 (19.6)	
Number of older siblings				
0	865 (42.1)	460 (41.8)	406 (42.4)	0.91
1	768 (37.4)	410 (37.3)	359 (37.5)	
2	423 (20.6)	230 (21.0)	193 (20.2)	
Vigorous exercise				
No	1110 (53.6)	514 (46.4)	596 (61.8)	<0.0001
Yes	961 (46.4)	595 (53.7)	368 (38.2)	
Parental asthma history				
No	1992 (96.3)	1067 (96.3)	927 (96.3)	0.96
Yes	77 (3.7)	41 (3.7)	36 (3.7)	
Air pollution				
SO_2, ppb	3.8±2.6	3.9±2.6	3.8±2.6	0.46
CO, ppm	0.7±0.1	0.7±0.1	0.7±0.1	0.26
O_3, ppb	25.4±4.3	25.4±4.3	25.4±4.4	0.79
PM10, μg/m3	57.4±16.4	57.2±16.0	57.6±16.8	0.60
NOx, ppb	26.6±8.8	26.8±8.7	26.5±9.0	0.50
Food consumption frequency, days/week				
Vegetables	6.1±1.7	6.0±1.7	6.2±1.6	0.004
Fruit	4.7±2.1	4.6±2.1	4.8±2.1	0.05
Rice	6.3±1.0	6.3±1.0	6.2±1.0	0.02
Cheese	0.4±1.1	0.4±1.1	0.4±1.1	0.70
Fast food	1.1±1.4	1.2±1.5	1.0±1.2	<0.0001
High-fat snacks	1.7±1.8	1.6±1.8	1.7±1.8	0.60
Candy	2.0±2.0	1.9±1.9	2.1±2.1	0.02

† Significant differences between boys and girls were assessed using a chi-square test for categorical variables and student's t-test for continuous variables.

Table 2. The prevalence of asthma symptoms in school children in Taiwan (n=2082)

Variable	All		Boys		Girls		
	N	%	N	%	N	%	*p* value
Asthma ever	106/2082	5.4	66/1111	5.8	41/971	5.0	0.45
Current asthma	74/2082	3.5	55/1111	4.9	19/971	2.1	0.001
Current severe asthma	47/2082	2.3	35/1111	3.0	12/971	1.5	0.03
Exercise-induced wheeze	56/2082	3.1	37/1111	3.8	20/971	2.2	0.12
Nocturnal cough	145/2082	6.9	81/1111	7.2	64/971	6.6	0.61

statistical tests in Table 4 are estimated by calculating the proportion that 10,000 realizations of test statistics from permutation datasets were greater than the result from the real data.

RESULTS

Characteristics of study participants are shown in Table 1. The study included data from 1111 boys (53.4%) and 971 girls (46.6%) aged 7-12 years. The mean age was 8.5 ± 1.7 years. There were more parents with "senior high school education" than either those with "college education" or those with "less than senior high school education". A total of 3.7% of students had at least one parent with a history of asthma. About 58% of children had one or more siblings. Boys had a higher BMI (18.6±3.7 vs 17.6±3.2) and were more likely to engage in sweating exercise (53.7% vs 38.2%) than girls. With regard to food consumption, boys had a lower weekly frequency of intake of fruits (4.6 vs 4.8 days), vegetables (6.0 vs 6.2 days), and candy (1.9 vs 2.1 days); but had higher intakes of fast food (1.2 vs 1.0 days) and rice (6.3 vs 6.2 days) than girls.

Asthma symptoms prevalence (Table 2)

Table 3. Corresponding loadings† of food groups, and average consumption frequency by quartiles of dietary pattern score in school children in Taiwan (n=2,082)

Food groups	Corresponding loading	Mean food frequency by dietary pattern score quartiles				
		Q1	Q2	Q3	Q4	*p* for trend‡
High-fat snacks	0.44	0.60±0.94	0.99±1.01	1.82±1.51	3.28±2.25	<0.0001
Cheese	0.31	0.16±0.50	0.32±0.86	0.45±1.18	0.57±1.46	<0.0001
Fast food	0.25	0.56±0.87	0.89±1.03	1.21±1.25	1.90±1.76	<0.0001
Candy	0.24	1.00±1.28	1.63±1.70	2.13±1.88	3.25±2.30	<0.0001
Shellfish	0.22	1.20±1.35	1.06±1.24	1.26±1.28	1.33±1.44	0.03
Meat	0.19	6.05±1.86	5.84±1.90	5.62±1.89	5.41±2.07	<0.0001
Soy products	0.14	1.74±1.46	1.84±1.51	1.70±1.38	1.69±1.42	0.33
Desserts	0. 14	4.40±3.04	4.75±2.97	5.35±3.22	6.10±3.27	<0.0001
Soybean milk	0.11	1.23±1.66	1.13±1.53	1.27±1.67	1.20±1.68	0.89
Organ meat	0.06	0.28±0.77	0.24±0.63	0.29±0.67	0.36±0.81	0.05
Sweet drinks	0.01	2.60±2.39	3.12±2.44	3.61±2.42	4.41±2.43	<0.0001
Yakult	-0.01	1.55±1.82	1.42±1.57	1.62±1.72	1.74±1.81	0.03
Instant noodles	-0.02	0.52±1.08	0.65±1.01	0.97±1.34	1.63±1.81	<0.0001
Milk	-0.06	4.29±2.62	3.68±2.79	3.60±2.63	3.47±2.67	<0.0001
Yogurt	-0.06	1.05±1.52	1.00±1.53	1.03±1.63	1.00±1.61	0.63
Egg	-0.12	4.18±2.06	3.90±2.16	3.85±2.07	3.99±2.18	0.11
Flour	-0.13	4.87±2.06	4.50±2.19	4.64±2.12	4.75±2.12	0.54
Fish	-0.17	4.26±2.13	3.67±2.17	3.53±2.11	3.29±2.09	<0.0001
Rice	-0.27	6.45±0.84	6.37±0.86	6.18±1.02	6.10±1.09	<0.0001
Fruit	-0.34	6.27±1.40	4.67±1.98	4.21±2.07	3.48±1.90	<0.0001
Vegetables	-0.44	6.89±0.54	6.73±0.80	5.95±1.57	4.73±2.18	<0.0001

† Corresponding loadings of 0.24 or more were included in the model of dietary pattern score.
‡ Tests for trend were conducted by entering the exposure variable (quartiles of dietary pattern score) as a continuous term in the regression model.

Table 4. Multivariate logistic regression† of dietary pattern score and asthma symptoms in school children in Taiwan (n=2082)

	Current asthma	Current severe asthma	Nocturnal cough	Exercise-induced wheeze	Asthma ever
Dietary pattern score					
Q1	1	1	1	1	1
Q2	1.33 (0.62-2.86)	2.28 (0.77-6.81)	1.79 (1.06-3.05)	0.98 (0.44-2.20)	1.45 (0.84-2.53)
Q3	1.81 (0.87-3.77)	3.21 (1.11-9.25)	1.74 (1.02-2.97)	1.10 (0.49-2.47)	0.93 (0.50-1.74)
Q4	2.42 (1.19-4.93)	4.45 (1.59-12.5)	1.82 (1.07-3.11)	1.52 (0.72-3.22)	1.44 (0.81-2.55)
p for trend	0.01	0.003	0.049	0.25	0.46

† Adjusted for age, BMI z-score, sex, mother's education level, older sibling number, parental asthma history, ambient NOx concentration and seasonal effect.

The prevalence of asthma ever was 5.4%, current asthma 3.5%, current severe asthma 2.3%, exercise-induced wheeze 3.1%, and that for nocturnal cough was 6.9%. Boys had a higher prevalence of current asthma (4.9% vs 2.1%) and current severe asthma (3.0% vs 1.5%) than girls.

RRR-derived dietary factor

One major dietary pattern associated with asthma symptom score was identified by RRR. The dietary pattern score was calculated via weighting frequency by the factor loading values of the selected food group items with factor loading values ≥0.24 or ≤-0.27 (Table 3). The higher the score, the higher the consumption of fast foods (hamburgers, pizza, french fries and fried chicken), high-fat snacks (potato chips, flour-based crisps and rice flour-based crisps), candy and cheese; and the lower the consumption of fruits, vegetables and rice. The upper quartiles correspond to an energy-dense/nutrient-poor dietary pattern. The consumption frequency of desserts, sweet drinks, instant noodles, shellfish, Yakult and organ meat were positively associated with the dietary pattern score, and the frequency of milk, meat and fish were negatively associated with this dietary pattern score.

Dietary pattern and asthma

We used multivariate logistic regression modeling to assess the association between the RRR-derived dietary pattern and asthma symptoms (Table 4). We found that the energy-dense, nutrient-poor food pattern was positively associated with current asthma (OR=2.42, 95% CI: 1.19-4.93 for Q4/Q1; *p* for trend =0.01), current severe asthma (OR=3.21, 95% CI: 1.11-9.25 for Q3/Q1; 4.45, 95% CI: 1.59-12.5 for Q4/Q1; *p* for trend =0.003) and

nocturnal cough (OR=1.79, 95% CI: 1.06-3.05 for Q2/Q1; 1.74, 95% CI: 1.02-2.97 for Q3/Q1; 1.82, 95% CI: 1.07-3.11 for Q4/Q1; *p* for trend =0.049), after adjusting for potential confounders, including: age, BMI-z score, sex, mother's education level, number of older siblings, parental asthma history, ambient NOx concentration and seasonal effect. No statistically significant association between the dietary pattern and asthma ever and exercise-induced wheeze was observed. The associations between dietary pattern and asthma symptoms of our study were further confirmed in the analysis with 10,000 permutation replications.

DISCUSSION

We found in this national survey that an energy-dense/nutrient poor dietary pattern was positively associated with current asthma, current severe asthma and nocturnal cough, but not asthma ever and exercise-induced wheeze, after adjustment for demographic and non-dietary confounders. This dietary pattern features a high consumption of fast foods, high-fat snacks, cheese, and candy, and a low consumption of fruits, vegetables and rice. This finding implies that a dietary pattern that is rich in fat and simple sugars but nutrient poor may be contributing to the increase in asthma prevalence in Taiwanese children.

Previous epidemiological studies in non-Asian regions have found that a higher consumption of fast foods [18] or a lower consumption of vegetables,[19] fruit [3] and rice [6] increases asthma risk in children, and we found in an earlier study that greater intake of deep-fried foods was associated with increased risk of childhood asthma [4]. However, to the best of our knowledge, no previous studies have explored the relationship, in children, between asthma and dietary patterns identified by RRR or PCA. The use of RRR maximizes the variation explained not only for the disease of interest but also for dietary factors. Therefore, the asthma-associated dietary pattern which we obtained reflects a coupling of the abundance of energy-dense westernized fast foods and a lack of fruits, vegetables and complex carbohydrate. The findings from studies in adults using PCA are consistent with ours for children. In adults, a dietary pattern identified using PCA, such as that with "greater intake of pizza/salty pies, desserts and cured meats" in French women [10] and that with "more pork and chicken dim sum foods and noodle dishes" in Chinese Singaporeans [11] increased the risk of asthma. In contrast, "the more fruits, vegetables and soy pattern" in Chinese Singaporeans [11] was protective.

The RRR-derived dietary pattern in our study corresponds to an unhealthy diet. As the dietary pattern score increased, children consumed less nutritious foods such as fruits, vegetables, rice, milk, meat and fish (*p* for trend <0.05), and consumed more energy-dense, nutrient-poor foods such as fast foods, high-fat snacks, cheese, candy, desserts, instant noodles, sweet drinks and Yakult (*p* for trend <0.05). In an Australian study, Webb *et al*. consistently observed that the intake of "extra" foods was inversely associated with the intake of "core" foods among children aged 1-2 yr [20] and adults aged 19-24 yr.[21] "Extra" foods referred to sugar-sweetened soft drinks, fried potatoes, meat pies and savory pastries, pizza, crisps, lollies and chocolate. "Core" foods referred to traditional foods such as fruits, vegetables, meat, fish, pasta, porridge and bread. The American Dietetic Association [22] has published a dietary guidance for healthy children aged 2 to 11 years. This guidance points out that over consumption of energy-dense, nutrient-poor foods and beverages increases childhood obesity and diet-related risk of chronic degenerative diseases, such as cardiovascular disease, type 2 diabetes, cancer, and osteoporosis. Our study extends the risks associated with an unhealthy diet to include childhood asthma.

A high fat intake typically rich in saturated fatty acid [23], n-6 polyunsaturated fatty acid [24,25] or trans fatty acid [23] can activate an NFκB-mediated innate immune response, resulting in airway inflammation. A low antioxidant dietary intake indicated by low intake of fruits and vegetables can also increase oxidative damage of airways by reactive oxygen species generation.[25] These studies and mechanisms may explain why we found that an energy-dense but nutrient-poor dietary pattern with high fat and simple sugar and low antioxidant intakes increased the risk of asthma prevalence. Acylamide accumulation in the foods have been linked to inflammation and oxidative stress. Studies found that a high level of acrylamide can be detected in deep-fried Asian delicacies (Chinese Dim Sum) (30-190 μg/kg), French fries (100-340 μg/kg), high-fat snacks such as potato chips (1500-1700 μg/kg) and Asian snacks (61-460 μg/kg).[26] Acrylamide is formed during food processing procedures such as grilling, roasting, baking, frying and deep-frying.[26] A study with 14 healthy volunteers found that chronic ingestion of potato chips (consuming equivalent to 157 mg of Acrylamide daily) for 28 days significantly increased reactive oxygen radical production by monocytes, lymphocytes and granulocytes, and increased CD14 expression in macrophages which may contribute to NFκB activation.[27]

In our study, an energy-dense, but nutrient poor dietary pattern was not significantly associated with asthma ever. This phenomenon may be due to the changing dietary habits after physician diagnosis.[28] In addition, exercise-induced wheeze was not significantly associated with dietary pattern, indicating that this question may lack sensitivity. Children living in Taiwan are more sedentary than their western counterparts [29] due to societal emphasis on intellectual performance and grades. A substantial proportion may not be exposed to the level of exercise which induces wheeze (see Table 1).

Our study has several strengths. First, it is advantageous to study the relationship between dietary pattern and asthma, since no individual dietary factor repeatedly stands out as a risk factor. Secondly, we used RRR to identify the dietary pattern, which was superior to PCA analysis. We found 4 dietary pattern factors with PCA: energy dense dietary pattern (higher consumption of fast foods, high-fat snack, candy, sweet drinks, instant noodles and desserts), nutrient rich dietary pattern (higher consumption of meat, fish, fruit, vegetable, egg and soybean products), allergen food dietary pattern (higher consumption of organ meat, shellfish, Yakult and soybean milk) , and western dietary pattern (higher consumption of flour, yogurt, cheese and milk; and lower consumption of rice). However, none of the above 4 dietary pattern

factors were associated with asthma. In contrast, the energy-dense/nutrient-poor dietary pattern we identified was significantly associated with asthma risk. Thirdly, we used the accumulated number of asthma symptoms as the intermediate response variable to guide us finding the asthma associated dietary pattern. A previous study [30] indicated that the asthma symptoms score was a good tool to assist asthma diagnose. Fourthly, asthma symptoms of our study were defined by the ISAAC (International Study of Asthma and Allergies in Childhood) questionnaire enabling comparison with other international research. Fifthly, our study used data from the NAHSIT Children 2001-2002, a representative sample of Taiwanese children. The finally advantage of our study is that we examined and adjusted for a comprehensive list of confounders, including environmental (particularly air pollution) and genetic factors.

Limitations of our study are discussed as follows: The cross-sectional design of this study hindered our ability to investigate causal relations. We excluded 14% of the children due to missing air pollution data. However, there were no differences in asthma prevalence estimates, dietary pattern content, and the association strength between the RRR-derived dietary pattern and asthma with or without exclusion. Adjusting air pollution parameters improved the precision of odds ratios (data not shown). The indoor environmental factors such as exposure to airborne mouse allergen, home smoking, particulate matter and nitrogen dioxide have been associated with asthma [31]. However, we did not have this information. Finally, high correlation among food items forbids us to pin point the culprit foods. For example, we observed that cheese was positively associated with asthma risk. Yet, cheese may represent those cheese containing fast foods, since cheese is not common in traditional Taiwanese food culture, and Taiwanese children primarily ingest cheese from cheese containing foods such as hamburgers, pizzas, sandwiches, pasta, breads, desserts and high-fat snacks. This speculation is supported by our analysis (data not shown). Among those children who ate cheese in more than two days a week, a significantly higher proportion of them ate fast foods more frequently than their counterpart (29.0% vs 18.0%; p value = 0.0139). In addition, children frequently consuming cheese had a reduced rice intake.

CONCLUSION

In conclusion, we reported the first study on dietary pattern and asthma risk in children aged 7-12 year in Asia. One major asthma-associated dietary pattern was identified, and featured by high consumption of fast foods, high-fat snacks, candy and cheese, and low consumption of fruit, vegetables and rice. This dietary pattern was positively associated with increased risk of current asthma, current severe asthma and nocturnal cough. These results indicate that a diet rich in fat and simple sugars but nutrient poor may increase the risk of asthma in children. Longitudinal or intervention studies are needed to confirm our findings.

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AUTHOR DISCLOSURES

Conflict of Interest: None in all authors

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Original Article

Risk of asthma associated with energy-dense but nutrient-poor dietary pattern in Taiwanese children

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高熱量與營養素貧乏的飲食型態會增加學童的氣喘罹患風險

小兒氣喘盛行率在過去幾十年間快速增加，研究認為可能與生活形態與飲食習慣的改變有關。本研究目的在探討台灣國小學童之飲食與氣喘的相關性。研究分析的資料來源為臺灣國小學童營養健康狀況調查(2001-2002)，共 2082 位具有完整飲食、生活形態、社會人口學及氣喘資料的學童資料納入分析。使用中文版的國際兒童氣喘過敏研究標準問卷產生氣喘症狀分數，並定義氣喘狀況，包括：目前有氣喘、嚴重氣喘、深夜乾咳、運動後誘發氣喘及曾經被診斷有氣喘。飲食的攝取狀況則以飲食頻率問卷進行評估。以減維度迴歸分析法來找尋與氣喘症狀分數有關的飲食型態。本研究歸納出與氣喘最有相關的飲食型態特徵為：攝取高頻率的速食、高脂零食、糖果及乳酪，及低頻率的蔬菜、水果與米飯。分析結果顯示此飲食型態會增加氣喘、嚴重氣喘及深夜乾咳的罹患風險。因此，本研究指出多攝取油脂及精緻糖、少攝取蔬菜水果及米飯的飲食型態，可能增加台灣學童罹患氣喘的風險。

關鍵字：氣喘、兒童、飲食型態、危險因子、減維度迴歸分析