

Extreme BMI Predicts Higher Asthma Prevalence and Is Associated With Lung Function Impairment in School-Aged Children

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Summary. Background: The prevalence of obesity and asthma has increased in recent decades. We investigated the relationship between body mass index (BMI) and lung function, and also tried to determine if asthma prevalence differs between obese and non-obese children. Methods: An International Study of Asthma and Allergies in Childhood (ISAAC) video questionnaire survey that included 170,457 students in junior high school was conducted during a 1-year period. Using random selection, 15,761 students were selected for lung function testing; 14,654 (93.0%) completed the lung function tests. Multiple logistic regression analysis was used to analyze the risk factor of asthma, such as atopic diathesis, BMI, exercise habits, smoking and secondary smoking. The detailed comparison in lung functions was plotted by asthmatic versus non-asthmatic, and between both sexes. Results: The risk factor of ISAAC-identified asthma were male sex, atopy, elevated BMI, higher education levels of the parents (higher than senior high school), family smoking ≥ 1 pack/day, self-reported smoking. The prevalence of asthma increased as BMI elevated in both sex. The FEV1/FVC declined as BMI elevated in both sex. The thin and underweight male students had declined FEF 25–75% and PEF. Conclusions: Extreme BMI is associated with different lung function impairment. This study showed that high BMI in both sexes was associated with low FEV1/FVC and low BMI in males are associated with poor PEF and FEF 25–75% and contributed to the symptoms of asthma. **Pediatr Pulmonol.** © 2009 Wiley-Liss, Inc.

Key words: asthma; lung functions; obesity; body mass index; atopy; gender.

INTRODUCTION

Obesity is a growing health issue throughout the whole world.^{1–3} In Native Americans, about 11–40% of school-aged children are obese.⁴ The prevalence of overweight or obese school children were 15.0–15.8% in Australia.⁵ And in Taiwan the prevalence of obesity increased approximately from 10% to 15.6% during last 2 decades.⁶ Obesity is a known risk factor for type II diabetes,⁷ hypertension, arteriosclerosis,⁸ sleep apnea,⁹ and some forms of cancer.¹⁰ Evidence for an association between obesity and asthma has been recently reported.^{2,11–13} In some reports, a correlation between body mass index (BMI) and lung function has been found.^{14,15} Longitudinal studies on body weight reduction have shown benefits for lung function and asthmatic symptoms.^{16,17} On the other hand, gaining weight predisposes individuals to a diagnosis of asthma.¹⁸ These studies suggest that impairment of lung function in obese individuals may play a role in the linkage between obesity and asthma.

The purpose of this study was to determine the relationship between asthma, lung function, and BMI in a large pediatric population.

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SUBJECTS AND METHODS

Study Population

Our population sample included 170,457 students representing all grades in a total of 123 junior high schools in southern Taiwan (Kaohsiung and Pintong) between 1995 and 1996. Details of the study design and site selection were reported earlier.¹⁹ In brief, each student completed the International Study of Asthma and Allergies in Childhood (ISAAC) video questionnaire²⁰ and a parent or guardian of each student completed a written questionnaire. The video questionnaire by ISAAC consisted of five sequences of teens displaying signs of asthma. The scenes represented for:

- 1. Moderate wheezing at rest.
- 2. Wheezing and shortness of breath after exercise.
- 3. Nocturnal waking with wheezing or whistling.
- 4. Nocturnal waking with cough.
- 5. Severe wheezing and shortness of breath at rest.

After each sequence, the children were asked to specify whether their breathing had been like the person in the video. Following each scene a question was asked, which was similar in format to the following:

Has your breathing ever been like this at any time in your life? Yes/No
If yes: In the past 12 months? Yes/No
If yes: How many time in every month?

About 10% of the students (N = 15,761) were randomly selected for lung function study 6 months later. In order to avoid recall bias, the subjects were considered to have asthma if they reported having symptoms during the previous 12 months before completing the baseline ISAAC questionnaire. There were 643 students who were excluded because on an incomplete response on the ISAAC or family questionnaires. In order to control for difference in age groups, the age was restricted to students aged 13–16 years, which excluded 79 students. A total of 15,039 students were enrolled in lung function tests.

Lung Function Tests

A calibrated, computerized spirometer (Model 2130; SensorMedics; Yorba Linda, CA) was used to measure

lung function. The forced vital capacity (FVC), forced expiratory flow in 1 sec (FEV1), FEV1/FVC, peak expiratory flow (PEF), forced expiratory flow in 25–75% FVC (FEF 25–75%) were recorded and compared. These parameters were chosen due to clinical implication and article reviews. Lung function was tested three times and was graded as A, B, or C. “A” was defined as all data compatible with the standard of the American Thoracic Society, with five “zeros” in the error code, and there were at least two compatible graphic features. “B” was defined as all data compatible with the American Thoracic Society standard, at least one “zero” in the first two error codes, no compatible graphic features, but the result was still reliable. “C” (2.3% in 15,039) was excluded from the analysis of lung function due to inconsistency in lung function tests. A total of 14,654 students (93.0% of 15,761) were included in the data analysis.

Definition of ISAAC-Identified Asthma

The definition of asthma in our study was a positive response to any of the questions in the ISAAC video questionnaire during the 12-month period of 1996 (1-year prevalence). The definition of non-asthma was no positive response to questions one to five during this period of time. The risk factors of asthma such as the education level of the family, exercise, self-smoking, family smoking numbers, and incense burning were entered into multiple regression analysis.

Definition of Atopy

Two questions asking “Has your child ever been diagnosed to have allergic rhinitis by a doctor?” and “Has your child ever been diagnosed to have atopic dermatitis by a doctor?” were listed in the family questionnaire. If the answer was “yes” to either question, the child was categorized as “atopic.”

Body Mass Index

The body weight and height were measured at the time when the lung functions were taken. Body weight was measured in light clothing to the nearest 0.1 kg, and height without shoes was measured to the nearest 0.5 cm using a vertical ruler. The BMI was calculated by dividing the weight in kilograms by the square of the height in meters (kg/m²). We defined the following BMI groups according to the definition of CDC classification: Those who was defined as “overweight” when they had BMI in 85–95% of the same age population, and “obese” when the BMI is over 95%. In the mean while, those who had BMI in 5–15% was classified as “thin” and those BMI below 5% as “underweight”. Table 1 illustrated the cutoff point of BMI in each age and sex group.

ABBREVIATIONS	
BMI	Body mass index
FEF 25–75%	Forced expiratory flow in 25–75% forced vital capacity
FEV1	Forced expiratory flow in 1 sec
FEV1/FVC	Forced expiratory flow in 1 sec divided by forced vital capacity
FVC	Forced vital capacity
ISAAC	International Study of Asthma and Allergies in Childhood
PEF	Peak expiratory flow

TABLE 1—Demographic Data

	Asthma	Non-asthma	OR _{adj} (95% CI)
N (%)	1829 (12.5)	12825 (87.5)	
Male, N	969	6,257	1.134 (1.020–1.261)*
Age, mean ± SD	14.21 ± 0.92	14.30 ± 0.92	0.091 (0.860–0.959)**
Atopy (N)	748	3039	2.106 (1.899–2.335)**
BMI (mean ± SD)	21.24 ± 3.98	20.69 ± 3.72	1.034 (1.022–1.048)**
Highest education level of the parents			
Below senior high school	691	5,832	1
Senior high school and above	1,138	6,993	1.242 (1.119–1.378)**
Family smoking (packs/family)			
None or <1 pack	1,680	11,907	1
>1 packs	149	918	1.242 (1.034–1.492)*
Self-reported smoking (N)	48	264	1.435 (1.045–1.972)*
Incense burning (N)	778	6,152	0.857 (0.775–0.949)*
Exercise habit			
None/sometimes	1,176	7,907	1
Usually	653	4,918	0.880 (0.789–0.982)*

Multivariate analysis of the relationship between ISAAC-identified asthma and non-asthma participants. Data express in age as years and BMI as kg/m². Adjusted odds ratio (OR_{adj}) is shown using multiple logistic regressions for risk of asthma.

**P* < 0.05.

***P* < 0.001.

Statistical Analysis

Data were analyzed using the SPSS 12.0 software package for computation. For all analysis a *P* value of <0.05 was taken as significant. Chi-square test was used to determine the difference in prevalence and 95% confidence intervals were reported. Chi-square test-for-trend was used to test the relationship between increase in BMI and asthma prevalence. Multiple logistic regression analysis was used for the odds ratio analysis for asthma adjusted for sex, age, obesity, family or self-reported tobacco smoking, exercise habits, and incense burning. The *t*-test and one-way ANOVA were used to analyze the lung function data. Bonferonni post-hoc analysis was used for multiple comparisons between groups (*P* value setting at 0.0025). Lung function values were presented in mean ± SD.

RESULTS

Demographic Data and Risk-Factor Analysis

In Table 1, demographic data are presented for the total of 14,654 students who were enrolled for risk-factor analysis. By using multiple logistic regression analysis, the significant risk factors for ISAAC-identified asthma were male sex, atopy, elevated BMI, higher education levels of the parents (higher than senior high school), family smoking ≥ 1 pack/day, self-reported smoking. The protective factors were age, incense burning, and exercise habits. The BMI was an independent factor predicting ISAAC-identified asthma.

Prevalence of ISAAC-Identified Asthma in Different BMI Groups

By using definition in Table 2, the boys and girls were divided into five groups. The prevalence of ISAAC-identified asthma was higher in males in each BMI group. In both sex, the prevalence of asthma was elevated as BMI increased (chi-square for trend, male: *P* < 0.05; female: *P* < 0.001). The prevalence of asthma in the “underweight” was about twice higher than the girls and the “thin” boys about 1.5 times higher than the girls in the same BMI composition.

Lung Function Analysis in Different BMI and Sex Groups

The FVC, FEV1, FEV1/FVC, FEF 25–75%, and PEF were chosen due to clinical implication. These parameters were plotted by the original values in order not to be biased by the calculated predicted values. All the figures were presented with mean value with standard errors. The FVC and FEV1 inclined as BMI elevated in both sex groups despite asthma or not (Fig. 2A–D). There was no significant difference between asthma or non-asthma groups. The FVC and FEV1 in girls were significantly lower than those in boys (Fig. 3A–D). On the contrary, the FEV1/FVC declined as BMI elevated in both sex groups (Fig. 2E,F). The female students had higher FEV1/FVC than the males in both non-asthmatic and asthmatic groups, especially at normal, overweight, and obese groups (Fig. 3E,F, “#”). The FEV1/FVC was significantly lower in the obese and overweight group in both sexes in the non-asthmatic group (solid lines “*”, Fig. 2E,F). The

TABLE 2—The Cutoff Value of BMI and Case Numbers in Different Age and Sex Groups

Male		13Y		14Y		15Y		16Y	
Underweight	<5%	<15.45	80	<16.00	124	<16.59	119	<16.76	33
Thin	5–15%	15.45–16.73	168	16.00–17.19	252	16.59–17.71	235	16.76–18.14	67
Normal	15–85%	16.73–24.54	1,153	17.19–24.74	1,768	17.71–24.84	1,676	18.14–24.64	464
Overweight	85–95%	24.54–27.85	166	24.74–28.03	253	24.84–29.00	239	24.64–29.40	67
Obese	≥95%	≥27.85	82	≥28.03	126	≥29.00	120	≥29.40	34
Female		13Y		14Y		15Y		16Y	
Thin	<5%	<15.58	87	<16.16	127	<16.61	125	<16.82	32
Underweight	5–15%	15.58–16.81	176	16.16–17.36	249	16.61–17.92	251	16.82–18.08	69
Normal	15–85%	16.81–23.50	1,202	17.36–24.16	1,765	17.92–24.31	1,757	18.08–24.50	474
Overweight	85–95%	23.50–27.59	172	24.16–27.41	250	24.31–27.94	251	24.50–28.35	69
Obese	≥95%	≥27.59	86	≥27.41	127	≥27.94	125	≥28.35	34

FEV1/FVC was significantly low the overweight and obese male groups (Fig. 2E, dash line, “*”).

There was significant difference in FEF 25–75% in the normal BMI group between asthmatic and non-asthmatic students (both sex; Fig. 2G,H, “#”). The FEF 25–75% dropped significantly in the male group in those BMI <15%, both the asthmatic and non-asthmatic groups (Fig. 2G, “*”). This phenomenon was also true for the female, non-asthmatic group (Fig. 2H, “*”). But FEF 25–75% did not show drop significantly in female “underweight” asthma group as compare with the non-asthmatic group whereas the male “underweight” asthma group showed significantly lower FEF 25–75% as compared with the “thin” non-asthmatic group (Fig. 2G,H, see “@” in the lowest BMI group). In the Figure 3G, the FEF 25–75% showed significant differences in the normal, overweight, and obese groups between sexes. But the FEF 25–75% female asthma students showed relative high and cross-over in the thin and underweight groups as compared with male students (Fig. 3H). This finding was also true for the PEF in Figures 2I,J and 3I,J.

DISCUSSION

The randomized selection in our study of 14,654 students from junior high schools of southern Taiwan was representative because the male–female ratio and the prevalence of asthma (12.5%) were nearly identical to that of the original 170,457 students in a previously published article.¹⁹

Lung function impairment in asthmatic children may persist into the teens and even into adulthood.²¹ Reports noted below have proposed that obesity further impairs lung function and secondarily increases the prevalence of asthma. Schachter et al.²² reported that obesity was a significant risk factor for recent asthma, and that FEV1 and FVC were significantly reduced in the group with severe obesity. Aaron et al.¹⁷ showed that FVC improved by 92 ml ($P=0.05$) and that FEV1 improved by 73 ml ($P=0.04$) in 58 obese women with or without asthma

during weight reduction over 6 months. Stenius-Aarniala¹⁶ reported that FEV1% and FVC% increased and symptoms decreased significantly in the treatment group compared with the controls during weight reduction in a study of 38 obese patients with asthma. However, airway hyper-responsiveness was not altered during weight reduction in some reports.^{17,22} King et al.¹⁴ reported that obesity is associated with reduced lung volume, which is linked with airway caliber narrowing. Due to the pitfall in the “predicted” values of pulmonary function in the adolescents, who are under rapid and sex-specific changes, we use original pulmonary data in order to analyze the true difference. Our data showed that only FEV1/FVC declined as the BMI increased. Obese students had poor FEV1/FVC and therefore were prone to be more symptomatic when they had an attack (Fig. 2E,F). The possible explanation is that those who had high BMI, although had higher FEV1 and FVC than normal population, had disproportional or “fragile” FEV1 (to FVC). The longitudinal study (CARDIA study) provided a 10-year follow-up and suggested FEV1 decreased with increasing weight gain in all participants, with maximum decline in obese individuals who gained the most weight

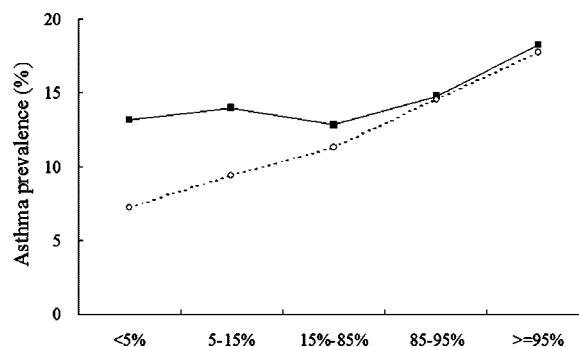


Fig. 1. The prevalence of asthma in different sex and BMI groups. The prevalence of asthma increases with BMI elevation (Chi-square for trend, male: $P<0.05$; female: $P<0.001$). The prevalence of asthma was higher in males than in females. Closed box: male, open circle: female.

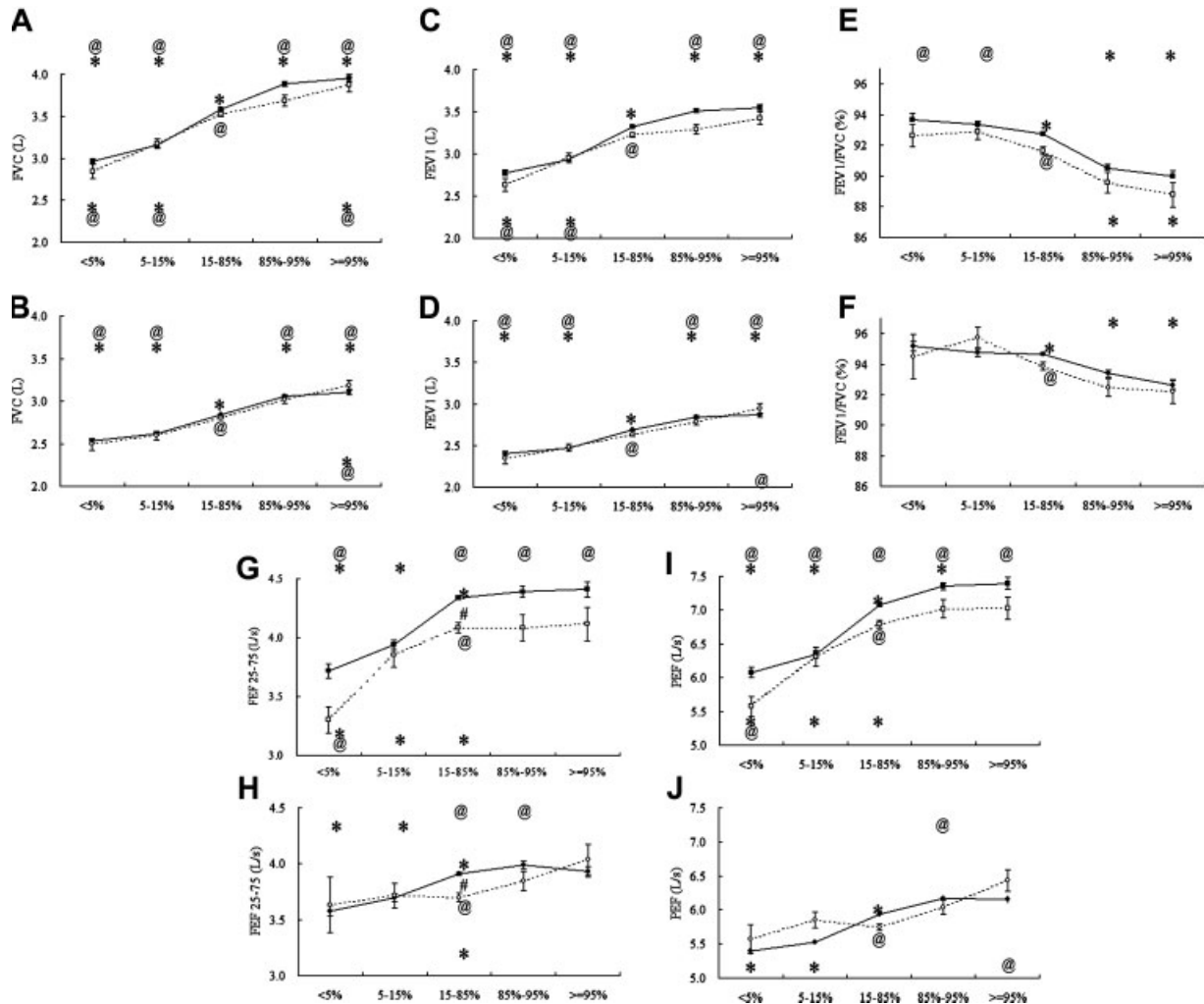


Fig. 2. The FVC and FEV1 increased as the BMI elevated in both sex (A–D). There was no significant FVC and FEV1 difference between asthma and non-asthma groups in both sexes. The FEV1/FVC decreased in non-asthma, overweight, and obese groups in both sex (E,F). The FEF 25–75% was significant different between asthma and non-asthma in both sex (G,H, “#”). The FEF 25–75% and PEF had decreased significantly in the male, underweight, asthma or non-asthma group (I). But the FEF 25–75% and PEF did not decrease in the female underweight asthma group (J). *, @: significant difference from the reference marked as the “*” or “@” nearby. The normal BMI groups were chosen as reference. (Bonferonni post hoc analysis, $P < 0.0025$); #: significant difference between non-asthma and asthma in indicated BMI group (Bonferonni post hoc analysis, $P < 0.0025$). A,C,E,G, and I: lung function of the male sex. B,D,F,H, and J: lung function of the female sex. Closed box: non-asthmatic-male, open box: asthmatic male. Closed circle: non-asthmatic female, open circle: asthmatic female.

during the study.²³ The female had higher FEV1/FVC as compared with male students in various BMI groups, no matter asthmatic or non-asthmatic (Fig. 3E,F). This data echoed the prevalence of both sex in Figure 1.

The FEF has been taken as the measure of small airway caliber in various reports.^{24–26} Schachter et al.²² have reported that the prevalence of recent wheeze was increased in those with BMI <18.5 which might be explained by reduced FEV1, FVC, PEF, and FEF 25–75%, and an increase in airway responsiveness. Juan

et al. reported that underweight (low BMI group) males had a higher probability of asthma or airway hyper-responsiveness.²⁷ It is of interest to see that those “thin” or “underweight” boys had decreased FEF 25–75% and PEF. This implies the male group had hyper-responsive airways and prone to be asthmatic, which also echoed the higher prevalence in male students in those “thin” and “underweight” BMI groups (Fig. 1). The female asthma patients may have less hyper-responsive airways and therefore had better small airway functions.

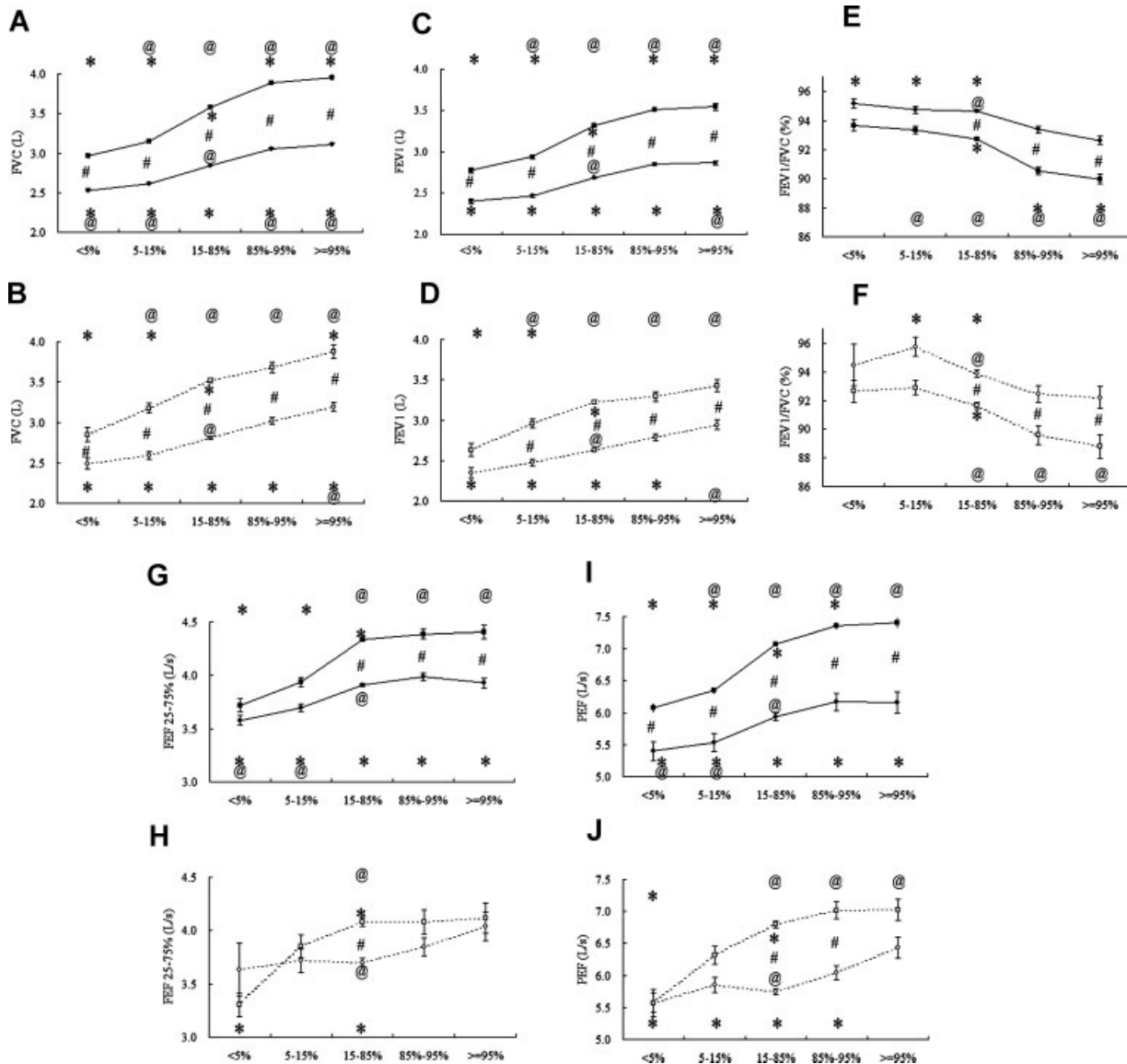


Fig. 3. The FVC and FEV1 increased as the BMI elevated in both sex (A–D). There were significant FVC and FEV1 difference between sex in non-asthmatic (A,C) and asthmatic (B,D) groups. There were significant difference in FEV1/FVC between sexes, especially in the normal, overweight, and obese groups (E, F, “#”). In figure H and J, the female underweight asthmatic group had significant higher FEF 25–75% and PEF as compared with the male group. *, @: significant difference from the reference marked as the “*” or “@” nearby. The normal BMI groups were chosen as reference. (Bonferonni post hoc analysis, $P < 0.0025$), #: significant difference between non-asthma and asthma in indicated BMI group (Bonferonni post hoc analysis, $P < 0.0025$). A,C,E,G, and I: lung function of the non-asthmatic. B,D,F,H, and J: lung function of the asthmatic. Closed box: non-asthmatic-male, open box: asthmatic male. Closed circle: non-asthmatic female, open circle: asthmatic female.

The reason whether the BMI is associated with asthma is still under debate. Somehow more evidence showed this association do exist.²⁸ Some claimed the non-inflammatory effects such as sleep apnea, acid regurgitation and airway limitations, the others reported the obese groups may have cytokine changes such as TNF- α , IL-6, and adipokines.²⁹ Our study provided evidence that BMI

may alter the FEV1/FVC, PEF, and FEF 25–75% and impose influence on the prevalence of asthma. In addition, the sex differences modulated the changes in PEF and FEF 25–75% in lower BMI groups and contribute to the prevalence in asthma.

The limitations of our study are listed as follows: First, the definition of BMI when applied to children may not

truly reflect their adiposity, therefore further parameters should be developed for adiposity in this age group.³⁰ Second, in this cross-sectional study, only correlations could be studied; therefore, this study cannot be used to answer cause-and-effect questions. Third, this study was focused on school teens that may have no or only mild asthma symptoms; those with severe symptoms may be hospitalized or resting and therefore lost to the study. This selection bias could hardly be eliminated. Fourth, in this study, diet was not included, and therefore, it cannot address the effect of diet on BMI and asthma prevalence. Further study on this topic should focus on the adequacy of asthma diagnosis, the definition of obesity, the measurement of fat mass, clinically usable lung parameters, the differences between the sexes, and a possible molecular marker that could be monitored during a weight reduction study. The ISAAC-based asthma diagnosis may be adequate for a large population, cross-sectional study such as this one, but may not be sufficient for a weight loss study.

CONCLUSION

In this population-based survey of school children in southern Taiwan, we found that higher BMI is associated with lung function impairment, as demonstrated by parameters such as FEV1/FVC. Higher BMI also predicted higher asthma incidence in both sexes. However, underweight male children may have problems with regard to FEF 25–75% and PEF, and thus have more asthma symptoms. This study shows that high BMI in children of both sexes and low BMI in male children predicts poor lung function and may contribute to the symptoms of asthma.

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