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Nonlinear Relationship Between Body Mass Index Z-Scores and Lung Function Parameters in Asthmatic Children: A Cross-Sectional Study

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Introduction: To assess the relationship between body mass index (BMI) and BMI z-scores with lung function parameters in children with asthma, aiming to provide scientific evidence for individualized treatment and management strategies.

Methods: We enrolled 328 children with asthma during acute exacerbation. The BMI and BMI z-scores were analyzed in relation to lung function parameters, including maximum vital capacity (VCmax), forced vital capacity (FVC), forced expiratory volume in the first second (FEV1), peak expiratory flow (PEF), maximal mid-expiratory flow rate (MMEF), and instantaneous flows at 25%, 50%, and 75% of maximal expiratory flow (MEF25, MEF50, MEF75). Both linear regression and piecewise regression models were used to identify linear associations and potential threshold effects.

Results: BMI showed significant positive linear correlations with VCmax, FVC, FEV1, MEF50, MEF75, and MMEF, while BMI z-scores demonstrated positive linear associations with VCmax, FVC, FEV1, MEF25, MEF50, and MMEF. After adjusting for age, sex, immunoglobulin E (IgE), eosinophil count (EOS), fractional exhaled nitric oxide (FeNO), and asthma severity, both BMI and BMI z-scores remained positively associated with VCmax, FVC, and FEV1. Piecewise regression analysis revealed significant threshold effects in the relationships between BMI z-scores and VCmax, FVC, FEV1, PEF, MEF25, MEF50, MEF75, and MMEF. Below a z-score of ~2.3–3.9, BMI z-score was positively associated with pulmonary function. Above this threshold, the association reversed; for instance, FEV1 decreased by 9.7% ($\beta = -9.69$, 95% CI: −18.93 to −0.46) and PEF decreased by 12.2% ($\beta = -12.17$, 95% CI: −21.12 to −3.22) for every unit increase in BMI z-score beyond 3.945.

Conclusion: A nonlinear relationship exists between BMI z-scores and lung function parameters in children with asthma. Weight-guided interventions may enhance lung function and asthma control.

Keywords: asthma, children, body mass index z-score, lung function, threshold effect

Introduction

As a predominant chronic pulmonary condition in pediatric populations, bronchial asthma is characterized by sustained inflammatory processes in the bronchial tubes, airflow obstruction that is physiologically reversible, and exaggerated airway reactivity to various stimuli. Asthma not only causes recurrent symptoms such as wheezing, coughing, chest tightness, and dyspnea but also poses life-threatening risks during severe exacerbations.[1] Its chronic nature and recurrent acute episodes significantly impair the quality of life of affected children and impose a substantial burden on families and healthcare systems.[2] Globally, asthma affects over 300 million individuals, with notable regional disparities in childhood prevalence—particularly higher in developed countries and urbanized areas, where rates exceed 15% in some regions.[3,4] In China, alongside environmental changes and lifestyle shifts, the prevalence of childhood asthma has shown a continuous upward trend over the past three decades, emerging as a major public health concern. Epidemiological surveys indicate that the

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prevalence of asthma among urban children in China has risen from 1.09% in 1990 to 7.9% in 2020.[5] Asthma not only leads to recurrent wheezing, coughing, and dyspnea but is also closely associated with impaired lung function development, with approximately 30%-50% of asthmatic children exhibiting persistent airflow limitation into adulthood.[6,7]

Notably, the epidemiological trends of asthma exhibit a complex interplay with another global health crisis—childhood obesity.[8] According to the Global Burden of Disease Study 2021, the total prevalence of overweight and obesity among children and adolescents doubled between 1990 and 2021, and obesity alone tripled.[9] While asthma prevalence has risen by approximately 50% during the same period, with significant spatial and temporal overlap between the two conditions.[10] Numerous epidemiological studies suggest that obesity may be an independent risk factor for asthma development and progression.[11,12] Overweight and obesity can impair pulmonary function. In obese children, fat deposition in the chest wall, abdominal wall, and lung tissue restricts the descent of the thoracic cage and diaphragm, leading to reduced lung compliance. On the other hand, the abnormal secretion of various pro-inflammatory factors in obese children further adversely affects pulmonary function.[13]

Prospective cohort studies demonstrate that each unit increase in body mass index (BMI) is associated with a 55% higher risk of childhood asthma.[14] Research indicates that the prevalence of asthma is 17% and 26% higher in overweight and obese children, respectively, compared to their normal-weight counterparts, with obesity severity positively correlated with poor asthma control, emergency visits, and hospitalization risks.[15,16] A study of preschool-aged children (6–11 years) revealed that overweight/obese children had significantly lower FEV1 and FVC compared to those with normal weight.[17] However, studies on the relationship between childhood asthma and obesity have also reported conflicting findings. A large-scale cross-sectional study identified a nonlinear inflection point in the BMI-asthma risk association—asthma risk increased significantly with BMI below 21 kg/m^2, whereas the risk plateaued beyond this threshold.[15] Both low body weight and extreme obesity correlate with impaired lung function, whereas moderate obesity may have a protective effect on respiratory health.[18] Exploring the relationship between lung function and body weight in children with asthma is of great significance for the management.

The correlation between body weight and lung function parameters is a complex field influenced by various factors such as age, sex, and body composition. Although some studies have identified significant associations, the impact of body weight on lung function in individuals with respiratory diseases requires further investigation. Such observations indicate a possible curvilinear link between BMI and lung capacity. Developed from WHO growth norms for children, the BMI z-score is a standardized measure that more reliably quantifies weight deviations across growth periods.[19] The nonlinear relationship between BMI z-scores and lung function parameters has not been thoroughly explored. Therefore, the present study aimed to bridge these gaps by: (1) utilizing BMI z-scores for a more accurate assessment of weight status; (2) employing advanced piecewise regression analysis to identify potential threshold effects rather than assuming linearity; and (3) comprehensively evaluating this relationship across a spectrum of lung function parameters, with particular attention to the small airways, in a sizable cohort of children with acute asthma exacerbations while adjusting for key clinical confounders.

Methods

Study Design

This single-center cross-sectional study aimed to evaluate the nonlinear relationship between BMI z-scores and lung function parameters in children with asthma. The study period from January 2019 to December 2023 was selected to ensure a sufficient sample size for robust statistical analysis of the nonlinear relationships under investigation. Although this is a cross-sectional analysis, the extended enrollment period captures a wide spectrum of BMI z-scores (−2.47 to 7.18) and asthma severity levels (mild to severe) within our target population. A one-time data collection approach was employed to explore the associations between variables.

Ethics Statement

The study protocol was reviewed and approved by the Institutional Ethics Committee of Children's Hospital Affiliated to Shandong University (Approval No.: SDFE-IRB/P-2024028). This study was performed in line with the principles of the

Declaration of Helsinki. The Ethics Committee granted a waiver of written informed consent as the study was a retrospective analysis of anonymized clinical data, posing no more than minimal risk to participants. All patient data were de-identified to protect confidentiality and were used solely for the purpose of this research.

Study Participants

Inclusion Criteria

(1) Meeting the diagnostic criteria for acute exacerbation of bronchial asthma in children;
(2) Aged 5–15 years, regardless of sex;
(3) Ability to cooperate with lung function tests, bronchial dilation tests, fractional exhaled nitric oxide (FeNO) measurement, complete blood count, allergen testing, and other examinations;
(4) Complete clinical data, including age, height, weight, lung function parameters, FeNO, eosinophil count (EOS), immunoglobulin E (IgE), etc.

Exclusion Criteria

(1) Comorbidities such as growth disorders or other chronic endocrine diseases, such as pneumonia, bronchopulmonary dysplasia, or recent (<4 weeks) upper respiratory tract infection.
(2) Concurrent respiratory diseases such as bronchopulmonary dysplasia or pneumonia;
(3) Uncontrolled or severe asthma with persistent lung function impairment.
(4) A history of severe, uncontrolled asthma with persistent lung function impairment even during clinical stability, as this might represent a fixed obstructive defect confounding our analysis.

Lung Function Testing

Pulmonary ventilation function was assessed using the MasterScreen lung function testing system (Master screen, JAEGER, Germany) by performing maximal expiratory flow-volume curve (MEFV) measurements in children aged ≥5 years, according to the American Thoracic Society/European Respiratory Society (ATS/ERS) standards.[20] Prior to testing, each child received detailed instructions and a demonstration of the forced expiratory maneuver. Tests were performed in a seated position with a nose clip applied. A minimum of three acceptable maneuvers were required for each participant. The testing protocol required the child to stand straight with the head in a neutral position and the jaw relaxed. A nose clip was used to occlude the nostrils. The child was instructed to gently bite the mouthpiece with their teeth and seal their lips tightly to prevent air leakage. The tongue was positioned below the mouthpiece without obstructing it. The right hand held the sensor handle or the support arm of the device. The test began with quiet expiration to residual volume (RV), followed by rapid and deep inspiration to total lung capacity (TLC). Immediately afterward, the child exhaled with maximal effort to achieve peak expiratory flow (PEF) and continued exhaling forcefully to RV without interruption. After complete exhalation, the child rapidly inhaled again to TLC before returning to tidal breathing, completing one cycle. The test was repeated at least three times, and the best values were selected and recorded. Measured parameters included maximum vital capacity (VCmax), forced vital capacity (FVC), forced expiratory volume in the first second (FEV1), peak expiratory flow (PEF), maximal mid-expiratory flow rate (MMEF), and instantaneous flows at 25%, 50%, and 75% of forced vital capacity (MEF25, MEF50, and MEF75, respectively).

Quality control of pulmonary function tests. Technician Training: All operators were certified and received standardized training on the testing procedures and coaching techniques for children. Performance Criteria: A minimum of three acceptable and reproducible maneuvers were required for each participant. Acceptability: Maneuvers were deemed acceptable if they met the following criteria: a rapid, forceful start (with a sharp peak on the flow-volume curve); no cough or glottic closure during the first second of expiration; no early termination of effort (exhalation time of at least 6 seconds or a clear plateau on the volume-time curve for ≥1 second); and no air leakage. Reproducibility: The test was considered reproducible if the two best FVC and FEV1 values from the acceptable maneuvers were within 150 mL of each other. Visual Inspection: All flow-volume and volume-time curves were visually inspected in real-time by the technician and later by a second independent reviewer to verify that the above criteria were met. Tests that did not meet these quality standards were excluded from the final analysis. Calibration: The spirometer was calibrated daily using a 3-L calibration syringe to ensure measurement accuracy.

Fractional Exhaled Nitric Oxide (FeNO) Measurement

FeNO was measured using an online detection method:

(1) Deep exhalation: The patient exhaled deeply to empty the lungs as much as possible.
(2) Inhalation through a disposable bacterial filter and NO filter: The patient inhaled through the NO filter with lips sealed around the disposable bacterial filter to ensure inhaled NO levels were <5 ppb, reaching TLC.
(3) Steady exhalation through the filter at a flow rate of 50 mL/s: No additional inhalation was permitted during exhalation.

Serological Testing

Venous blood samples were collected upon enrollment to measure IgE and eosinophil levels. Total serum IgE concentration was determined using the Pharmacia UniCAP100 allergen detection system (Sweden). Peripheral blood eosinophil (EOS) counts were measured using an automated hematology analyzer.

Assessment of Asthma Severity in Children

Asthma severity was categorized as mild, moderate, or severe according to the Global Initiative for Asthma (GINA) 2023 guidelines,[21] based on symptom frequency, nighttime awakenings, rescue medication use, and lung function (FEV1% predicted). Mild: Symptoms occur intermittently, FEV1 $\geq$ 80% of the predicted value. Moderate: Symptoms occur weekly, FEV1 60–79% of the predicted value. Severe: Symptoms persist, FEV1 < 60% of the predicted value, or high-dose ICS/LABA control may be required.

Calculation of BMI Z-Score

BMI z-scores is a standardized indicator used to assess the weight status of children and adolescents relative to their same-age and same-sex peers. The formula for BMI Z-scores is: Z-score= (BMI - P_{50}) / SD.[22]

Statistical Analysis

Statistical analysis and figure generation were performed using R software (version 4.2.2). Descriptive statistics included frequencies (n, %) for categorical variables, mean ± standard deviation (Mean ± SD) for normally distributed data, and median (interquartile range, IQR) for non-normally distributed data. The primary outcomes were lung function parameters (VCmax, FVC, FEV1, PEF, MEF25, MEF50, MEF75, and MMEF). Covariates included sex, age, disease severity, IgE, EOS, and FeNO. Linear regression and piecewise logistic regression analyses were used to explore potential threshold effects of BMI and BMI z-scores on outcome measures. The segmented package in R was employed to identify potential thresholds, with specific values determined based on model fit indices and statistical tests. In the piecewise model, different linear slopes were fitted according to the identified thresholds.

While an a priori power analysis for the specific piecewise regression model was not performed, our final sample size (N=328) is substantially larger than those in previously published studies examining similar nonlinear relationships in pediatric respiratory research.

Results

Baseline Characteristics

A total of 328 participants were included in this study (Table 1). The mean age of the study population was 8.20 ± 2.12 years (range: 5.00–15.75 years), with 66.2% being male. Regarding weight distribution, 59.5% had a healthy weight, while 10.7% were classified as severely obese. Asthma severity was predominantly mild (68.6%), with 18.0% classified as severe. Laboratory findings showed median (IQR) values for IgE (273 [115, 649] IU/mL), EOS (0.33 [0.11, 0.64] $\times 10^9$/L),

Table 1 Baseline Characteristics of Enrollments

Characteristic	**N = 328**[1]	**Characteristic**	**N = 328**[1]
Age (years old)		VCmax (mL)	
Mean ± SD	8.20 ± 2.12	Mean ± SD	90 ± 15
Min, Max	5.00, 15.75	Min, Max	48, 137
Gender, n (%)		FVC (mL)	
Male	217 (66.2%)	Mean ± SD	92 ± 15
Female	111 (33.8%)	Min, Max	51, 138
BMI z score		FEV_1 (%)	
Median (Q1, Q3)	0.57 (−0.39, 1.91)	Mean ± SD	87 ± 18
Min, Max	−2.47, 7.18	Min, Max	38, 132
BMI z score group		FEV_1/FVC	
Under weight (<-2)	4 (1.2%)	Mean ± SD	92 ± 14
Health weight (−2 to +1)	195 (59.5%)	Min, Max	61, 118
Overweight (+1 to +2)	54 (16.5%)	FEV_1/VC_{Max}	
Obese (+2 to +3)	40 (12.2%)	Mean ± SD	92 ± 9
Severe Obese (>+3)	35 (10.7%)	Min, Max	66, 118
Severity of asthma		PEF	
Mild	225 (68.6%)	Mean ± SD	79 ± 18
Moderate	44 (13.4%)	Min, Max	39, 125
Severe	59 (18.0%)	MEF25	
IgE (IU/mL)		Mean ± SD	50 ± 23
Median (Q1, Q3)	273 (115, 649)	Min, Max	12, 125
Min, Max	3, 2,587	MEF50	
EOS ($\times 10^9$/L)		Mean ± SD	63 ± 23
Median (Q1, Q3)	0.33 (0.11, 0.64)	Min, Max	14, 127
Min, Max	0.00, 3.80	MEF75	
FeNO (ppb)		Mean ± SD	74 ± 23
Median (Q1, Q3)	13 (8, 21)	Min, Max	22, 137
Min, Max	3, 126	MMEF	
		Mean ± SD	60 ± 24
		Min, Max	16, 131

Notes: [1]n (%).

Abbreviations: IgE, Immunoglobulin E; EOS, Eosinophil count; FeNO, Fractional exhaled nitric oxide; VCmax, maximum vital capacity; FVC, Forced vital capacity; FEV1, Forced expiratory volume in the first second; PEF, Peak expiratory flow; MEF, Maximal expiratory flow; MMEF, Maximal mid-expiratory flow rate.

and FeNO (13[8,21] ppb). Lung function test results indicated mean values of VCmax (90 ± 15%), FVC (92 ± 15%), FEV1 (87 ± 18%), and FEV1/FVC (92 ± 14%). Additionally, PEF (79 ± 18%), MEF25 (50 ± 23%), MEF50 (63 ± 23%), MEF75 (74 ± 23%), and MMEF (60 ± 24%) were recorded.

Linear Relationship Between BMI/BMI z-Score and Lung Function

Linear regression analysis was employed to assess the linear association between BMI/BMI z-score and lung function parameters. Before adjusting for confounders, BMI showed a positive linear correlation with VCmax, FVC, FEV1, MEF50, MEF75, and MMEF, while BMI z-score was positively correlated with VCmax, FVC, FEV1, MEF25, MEF50, and MMEF.

After adjusting for age, sex, IgE, EOS, FeNO, and asthma severity, both BMI and BMI z-score remained positively associated with VCmax, FVC, and FEV1, suggesting that higher BMI and BMI z-scores were linked to improved lung function in these parameters. The linear relationships are detailed in Tables 2 and 3.

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Table 2 Linear Relationship Between BMI and Lung Function Parameters

	Univariate					Multivariate *				
	β	SE	t	P	β (95% CI)	β	SE	t	P	β (95% CI)
VCmax	0.70	0.18	3.83	<0.001	0.70 (0.34 ~ 1.05)	0.70	0.21	3.39	<0.001	0.70 (0.30 ~ 1.11)
FVC	0.51	0.19	2.69	0.008	0.51 (0.14 ~ 0.89)	0.67	0.22	3.07	0.002	0.67 (0.24 ~ 1.09)
FEV_1	0.48	0.23	2.07	0.039	0.48 (0.03 ~ 0.93)	0.61	0.26	2.31	0.021	0.61 (0.09 ~ 1.12)
PEF	0.38	0.22	1.70	0.090	0.38 (−0.06 ~ 0.82)	0.02	0.26	0.08	0.938	0.02 (−0.48 ~ 0.52)
MEF25	0.53	0.29	1.82	0.069	0.53 (−0.04 ~ 1.11)	0.33	0.34	0.97	0.331	0.33 (−0.33 ~ 0.99)
MEF50	0.76	0.29	2.61	0.009	0.76 (0.19 ~ 1.33)	0.48	0.34	1.42	0.158	0.48 (−0.18 ~ 1.14)
MEF75	0.68	0.28	2.39	0.017	0.68 (0.12 ~ 1.24)	0.26	0.33	0.78	0.437	0.26 (−0.39 ~ 0.90)
MMEF	0.70	0.30	2.36	0.019	0.70 (0.12 ~ 1.28)	0.44	0.34	1.28	0.203	0.44 (−0.23 ~ 1.11)

Notes: * Adjusted for age, sex, IgE levels, eosinophil count (EOS), fractional exhaled nitric oxide (FeNO), and asthma severity.

Table 3 Linear Relationship Between BMI z-Scores and Lung Function Parameters

	Univariate					Multivariate *				
	β	SE	t	P	β (95% CI)	β	SE	t	P	β (95% CI)
VCmax	1.64	0.47	3.48	<0.001	1.64 (0.72 ~ 2.57)	1.48	0.47	3.13	0.020	1.48 (0.55 ~ 2.40)
FVC	1.38	0.50	2.78	0.006	1.38 (0.41 ~ 2.35)	1.41	0.49	2.86	0.004	1.41 (0.45 ~ 2.38)
FEV_1	1.52	0.60	2.54	0.012	1.52 (0.35 ~ 2.69)	1.50	0.59	2.52	0.012	1.50 (0.33 ~ 2.66)
PEF	0.60	0.58	1.04	0.300	0.60 (−0.54 ~ 1.75)	0.20	0.58	0.34	0.731	0.20 (−0.94 ~ 1.33)
MEF25	1.69	0.76	2.23	0.026	1.69 (0.20 ~ 3.17)	1.32	0.76	1.73	0.084	1.32 (−0.17 ~ 2.82)
MEF50	1.94	0.75	2.58	0.010	1.94 (0.46 ~ 3.41)	1.49	0.76	1.96	0.051	1.49 (−0.00 ~ 2.99)
MEF75	1.27	0.74	1.72	0.087	1.27 (−0.18 ~ 2.72)	0.82	0.75	1.10	0.274	0.82 (−0.64 ~ 2.28)
MMEF	1.91	0.77	2.49	0.013	1.91 (0.40 ~ 3.41)	1.46	0.77	1.88	0.061	1.46 (−0.06 ~ 2.98)

Notes: * Adjusted for age, sex, IgE levels, eosinophil count (EOS), fractional exhaled nitric oxide (FeNO), and asthma severity.

Threshold Effect Analysis of BMI/BMI z-Score on Lung Function

A piecewise regression model was used to examine potential threshold effects of BMI on lung function. While a threshold effect was observed between BMI and PEF, neither the associations below nor above the inflection point reached statistical significance. No threshold effects were found between BMI and other lung function parameters (Table 4).

Subsequently, BMI z-score was analyzed for threshold effects. Significant threshold effects were identified for VCmax, FVC, FEV1, PEF, MEF25, MEF50, MEF75, and MMEF (all *P* for likelihood ratio test < 0.05). Specifically: Below the threshold, BMI z-score exhibited a significant positive correlation with all measured lung function parameters; Above the threshold, this positive association disappeared for VCmax, FVC, MEF25, MEF75, and MMEF, while it reversed to a negative correlation for FEV1, PEF, and MEF50. The threshold effect analysis for BMI z-score is presented in Table 5 and illustrated in Figure 1.

Discussion

This study focused on the linear and nonlinear relationships between BMI/BMI z-scores and lung function parameters in children with asthma, aiming to provide more precise evidence for asthma treatment and management. By analyzing 328 children with acute exacerbation of bronchial asthma, we revealed a complex nonlinear association between BMI z-scores and lung function. Our findings demonstrated a linear positive correlation between BMI/BMI z-scores and certain lung function parameters. Furthermore, piecewise regression analysis identified a threshold effect in the relationship between BMI z-scores and lung function: below a specific threshold, BMI z-scores showed a significant positive correlation with lung function, whereas above this threshold, the correlation disappeared or even became negative. This provides new insights into the complex physiological and pathological links between obesity and asthma.

Table 4 Threshold Effect Analysis of BMI on Lung Function Parameters

	Break-Point	*Adjusted β (95% CI)	P	P for Likelihood Test
VCmax	<17.800	1.78 (0.40, 3.15)	0.011	0.106
	≥17.800	0.26 (−0.43, 0.95)	0.453	
FVC	<14.900	3.38 (−0.83, 7.59)	0.115	0.136
	≥14.900	0.47 (−0.01, 0.95)	0.055	
FEV_1	<16.700	2.59 (0.27, 4.92)	0.029	0.060
	≥16.700	0.13 (−0.60, 0.86)	0.725	
PEF	<16.500	2.20 (−0.29, 4.69)	0.084	0.041
	≥16.500	−0.45 (−1.13, 0.24)	0.198	
MEF25	<16.700	2.51 (−0.48, 5.51)	0.100	0.129
	≥16.700	−0.20 (−1.14, 0.75)	0.684	
MEF50	<23.800	0.92 (−0.01, 1.85)	0.053	0.245
	≥23.800	−1.03 (−3.45, 1.39)	0.402	
MEF75	<16.595	2.54 (−0.51, 5.59)	0.102	0.109
	≥16.595	−0.26 (−1.17, 0.65)	0.573	
MMEF	<16.930	2.50 (−0.32, 5.31)	0.082	0.139
	≥16.930	−0.11 (−1.09, 0.87)	0.822	

Notes: *Adjusted for: gender, age, severity, IgE, EOS, FeNO.

Table 5 Threshold Effect Analysis of BMI z-Scores on Lung Function Parameters

	Break-Point	*Adjusted β (95% CI)	*P*	*P* for Likelihood Test
VCmax	<3.945	2.43 (1.27, 3.60)	<0.001	0.006
	≥3.945	−6.63 (−13.99, 0.73)	0.077	
FVC	<3.945	2.35 (1.13, 3.58)	<0.001	0.011
	≥3.945	−6.56 (−14.28, 1.15)	0.095	
FEV_1	<3.945	2.82 (1.36, 4.28)	<0.001	0.002
	≥3.945	−9.69 (−18.93, −0.46)	0.040	
PEF	<3.945	1.66 (0.24, 3.07)	0.022	<0.001
	≥3.945	−12.17 (−21.12, −3.22)	0.008	
MEF25	<3.945	2.69 (0.80, 4.57)	0.005	0.019
	≥3.945	−10.24 (−22.18, 1.70)	0.093	
MEF50	<3.945	3.09 (1.20, 4.97)	0.001	0.005
	≥3.945	−12.02 (−23.93, −0.11)	0.048	
MEF75	<2.294	3.23 (0.76, 5.70)	0.011	0.012
	≥2.294	−4.58 (−9.51, 0.35)	0.068	
MMEF	<2.256	4.22 (1.63, 6.80)	0.001	0.006
	≥2.256	−4.52 (−9.54, 0.49)	0.077	

Notes: *Adjusted for: gender, age, severity, IgE, EOS, FeNO.

The relationship between BMI and lung function is complex, with conflicting results across different populations. A study of 3077 healthy adults found that underweight individuals exhibited lower FVC compared to normal-weight and overweight subjects.[23] Conversely, studies involving healthy pediatric populations have indicated that higher BMI or BMI z-scores correlate with diminished lung capacity, which may signal compromised respiratory efficiency, elevated symptom burden, and poorer functional outcomes.[24] A systematic meta-analysis corroborated these findings, demonstrating that obesity negatively impacts pulmonary volumes and vital capacity in children and adolescents, with the most pronounced reductions observed in functional residual capacity, expiratory reserve volume, and residual volume.[25] Further analysis of 62 studies revealed an inverse relationship between excess weight (overweight/obesity) and FVC/FEV1 in adults, though this association was not statistically significant in younger populations. Interestingly, the magnitude of effect on FEV1 and FVC was substantially greater in non-asthmatic individuals compared to those with

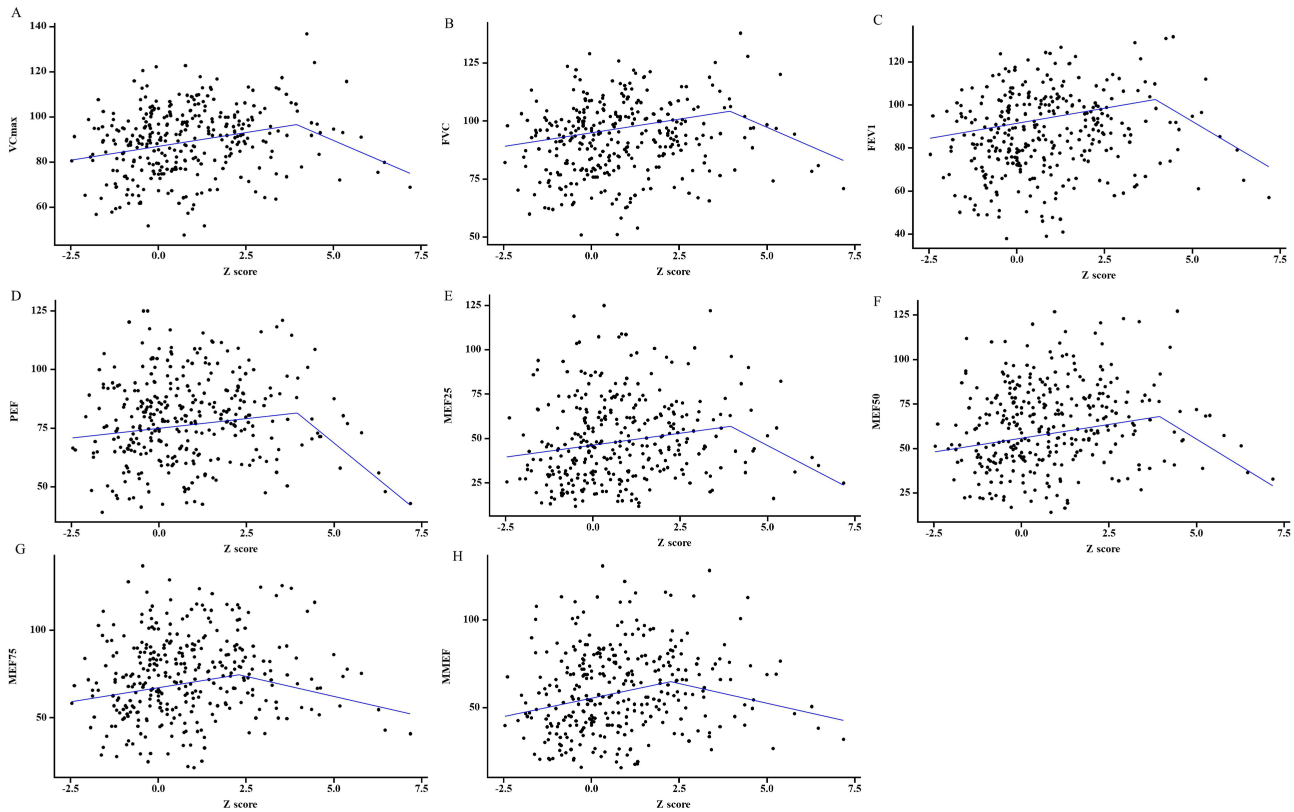

Figure 1 Threshold effect analysis of BMI z-scores on lung function parameters (piecewise linear regression) (**A**) VCmax, (**B**) FVC, (**C**) FEV1, (**D**) PEF, (**E**) MEF25, (**F**) MEF50, (**G**) MEF75, (**H**) MMEF.

asthma, implying that obesity's detrimental influence on lung function may be more pronounced in otherwise healthy subjects.[26]

In asthma patients, higher BMI is associated with worse lung function, indicating that increased BMI leads to reduced lung function and airway reversibility, particularly in severely obese individuals.[27] However, in COPD patients, higher BMI correlates with better lung function, including higher FEV1 and FVC, suggesting a protective effect of increased BMI in this population.[18] These findings highlight the importance of maintaining a healthy nutritional status to improve respiratory function and immune responses in children.

Given these conflicting results, we hypothesized that the relationship between lung function and weight in asthmatic children might not be purely linear—a conclusion supported by our study. Several existing studies have reported non-linear associations between weight and lung function. A cross-sectional study revealed a non-linear relationship between respiratory function and visceral adiposity index (VAI) in the overall and male cohorts. Specifically, among males with VAI scores below 14, both FEV1% and FVC% predicted values showed positive associations with increasing VAI, whereas in those with VAI > 15, the correlation became negative.[28] Another study observed an inverted L-shaped nonlinear relationship between BMI and lung function in high-risk COPD patients hospitalized for severe acute exacerbation, further influenced by hemoglobin (Hb) levels.[29] Additionally, research has shown that both underweight and overweight (compared to normal BMI: 20–24.9 kg/m²) are associated with reduced lung function.[30] Our findings of a nonlinear relationship between BMI z-scores and lung function parameters in children with asthma are consistent with a growing body of literature suggesting that the association between adiposity and respiratory health is complex and context-dependent. Farhat et al[31] reported that atopy was associated with lower lung function in healthy-weight asthmatic children but not in overweight/obese asthmatics, suggesting that obesity may alter the inflammatory phenotype of asthma. Similarly, Ying et al[32] observed reduced FEV1/FVC and FEF25–75% in overweight/obese children with newly diagnosed asthma, supporting the notion that obesity exacerbates airway obstruction. Moreover, several studies in non-

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asthmatic children have also demonstrated a negative impact of obesity on lung function. Charoensittisup et al[33] found that increases in waist circumference were negatively associated with FEV1/FVC and mid-expiratory flows in obese children over a 1-year follow-up, highlighting the role of abdominal adiposity in lung function decline. Similarly, a meta-analysis by Forno et al[26] indicated that obesity was associated with reduced FEV1 and FVC in both asthmatic and non-asthmatic children, though the effect was more pronounced in the latter.

From a physiological perspective, the impact of weight on lung function likely results from multiple interacting factors. Parameters such as FVC and VCmax primarily reflect lung volumes and the overall force-generating capacity of the respiratory muscles, while parameters such as MEF50, MEF75, and MMEF are more sensitive indicators of small airway function. In healthy adults, small airway resistance accounts for only 10%–20% of total airway resistance. However, in infants and young children, whose airway diameter is approximately half that of adults, small airway resistance is significantly higher. Following infection, the potential for increased airflow resistance becomes more pronounced. In children with asthma, segmental or widespread inflammation of the tracheal wall, combined with mucus secretion, leads to luminal obstruction and predisposes to airflow limitation in the small airways[34] Due to a reduction in end-expiratory volume, the support provided by the pulmonary parenchyma to the peripheral small airways is diminished, which increases the likelihood of peripheral airway collapse and elevates airway resistance.[35] The accumulation of adipose tissue in thoracic, abdominal, and upper airway regions creates biomechanical constraints on respiratory function, leading to modified pulmonary volumes, altered airway dynamics, and uneven ventilation patterns].[36,37] Furthermore, obesity induces a pro-inflammatory state through adipose tissue-derived cytokines and immune cells, contributing to pulmonary dysfunction and exacerbating conditions like asthma and COPD.[38,39] During exercise, obese individuals experience increased respiratory load and oxygen cost, leading to greater dyspnea and reduced exercise capacity.[40] Studies suggest that lean body mass (LBM) and fat-free mass—rather than fat mass—are positively correlated with lung function, indicating that muscle mass plays a more critical role in maintaining respiratory efficiency.[30,41–43] Thus, the relationship between weight and lung function requires reevaluation.

Our study also found that the threshold effects of BMI z-scores varied across different lung function parameters, possibly due to their distinct physiological implications. For instance, VCmax and FVC primarily reflect ventilatory capacity, whereas FEV1 is more indicative of airway obstruction.[44,45] This suggests that different lung function measures may have varying sensitivities to obesity, emphasizing the need for comprehensive multi-parameter assessments in clinical evaluations of asthmatic children.

This study has several strengths. First, the large sample size, consisting exclusively of pediatric patients with strictly diagnosed acute asthma exacerbations, ensures the reliability and representativeness of the findings. This study is the first to demonstrate a nonlinear relationship between body weight and lung function in children with asthma. Second, the inclusion of multiple potential confounding factors—such as sex, age, IgE, EOS, and FeNO—and their adjustment in the analysis help mitigate the impact of confounding bias on the results.

The findings of this study hold significant clinical implications. For asthmatic children with a BMI z-score below the threshold, appropriate weight gain may contribute to improved lung function, though this does not imply advocating excessive weight increase. Conversely, for overweight and obese asthmatic children, maintaining weight within a reasonable range could be a key measure to enhance lung function and asthma control. Additionally, the results suggest that weight status should be carefully considered when developing asthma treatment plans, with individualized adjustments to medication dosages and therapeutic strategies. For obese children, higher drug doses or more suitable administration routes may be required to ensure effective drug concentrations in vivo.

However, this study also has some limitations. First and most importantly, the cross-sectional design of our study captures data at a single point in time, which precludes any inference of causality in the observed relationships between BMI z-scores and pulmonary function parameters. While we identified significant associations and threshold effects, we cannot definitively conclude that changes in BMI z-score cause changes in lung function; the reverse causality or influence of unmeasured confounding factors cannot be ruled out. Furthermore, we acknowledge that we did not collect data such as preterm birth, smoking exposure, and maternal status, medication use, physical activity, which could act as residual confounders and influence the observed associations between BMI z-scores and pulmonary function. Third, the single-center source of participants may introduce selection bias, limiting the generalizability of the results.

Conclusion

In children with asthma, the relationship between body weight and lung function is not simply linear. For those with a BMI z-score below the threshold, appropriate weight gain may help improve lung function, whereas for overweight and obese asthmatic children, maintaining weight within a reasonable range could be a key measure to enhance lung function and asthma control.

Data Sharing Statement

The data that support the findings of this study are available from the corresponding author (Email: maxiang0176@163.com) upon reasonable request.

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Disclosure

The authors report no conflicts of interest in this work.

References

1. Savin IA, Zenkova MA, AV S. Bronchial asthma, airway remodeling and lung fibrosis as successive steps of one process. *Int J Mol Sci*. 2023;24(22). doi:10.3390/ijms242216042
2. Yuan L, Tao J, Wang J, et al. Global, regional, national burden of asthma from 1990 to 2021, with projections of incidence to 2050: a systematic analysis of the global burden of disease study 2021. *EClinicalMedicine*. 2025;80:103051. doi:10.1016/j.eclinm.2024.103051
3. Dharmage SC, Perret JL, Custovic A. Epidemiology of asthma in children and adults. *Front Pediatrics*. 2019;7(246). doi:10.3389/fped.2019.00246
4. Choi EJ, Hong SJ. The trend of childhood asthma prevalence decreased in 2022: true or not? *Allergy Asthma Immunol Res*. 2025;17(3):285–287. doi:10.4168/aair.2025.17.3.285
5. Li X, Song P, Zhu Y, et al. The disease burden of childhood asthma in China: a systematic review and meta-analysis. *J Global Health*. 2020;10(1):010801. doi:10.7189/jogh.10.010801
6. Hamelmann E, von Mutius E, Bush A, Szefler SJ. Addressing the risk domain in the long-term management of pediatric asthma. *Pediatric Allergy Immunol*. 2020;31(3):233–242. doi:10.1111/pai.13175
7. Lanz MJ, Gilbert I, Szefler SJ, Murphy KR. Can early intervention in pediatric asthma improve long-term outcomes? A question that needs an answer. *Pediatric Pulmonology*. 2019;54(3):348–357. doi:10.1002/ppul.24224
8. Smith JD, Fu E, Kobayashi MA. Prevention and management of childhood obesity and its psychological and health comorbidities. *Ann Rev Clin Psychol*. 2020;16(1):351–378. doi:10.1146/annurev-clinpsy-100219-060201
9. Kerr JA, GC P, Cini KI, et al. Global, regional, and national prevalence of child and adolescent overweight and obesity, 1990–2021, with forecasts to 2050: a forecasting study for the global burden of disease study 2021. *Lancet*. 2025;405(10481):785–812. doi:10.1016/S0140-6736(25)00397-6
10. Mao Z, Zhu X, Zheng P, et al. Global, regional, and national burden of asthma from 1990 to 2021: a systematic analysis of the global burden of disease study 2021. *Chin Med J Pulmonary Critic Care Med*. 2025;3(1):50–59. doi:10.1016/j.pccm.2025.02.005
11. Marko M, Pawliczak R. Obesity and asthma: risk, control and treatment. *Postepy dermatologii i alergologii*. 2018;35(6):563–571. doi:10.5114/ada.2018.77607
12. Bantulà M, Roca-Ferrer J, Arismendi E, Picado C. Asthma and Obesity: two Diseases on the Rise and Bridged by Inflammation. *Journal of Clinical Medicine*. 2021;10(2):169. doi:10.3390/jcm10020169
13. Jinhong WU, Chunhong PAN, Yufen, WU, et al. The effect of body weight on lung function in children aged 6-17 years *J Clin Pediatr*. 2019;37(12):932.
14. Granell R, Henderson AJ, Evans DM, et al. Effects of BMI, fat mass, and lean mass on asthma in childhood: a Mendelian randomization study. *PLoS Med*. 2014;11(7):e1001669. doi:10.1371/journal.pmed.1001669
15. Fang C, Jiang Z, Su X, Fan W. The association between body mass index and asthma in children: a cross-sectional study from NHANES 1999 to 2020. *Sci Rep*. 2025;15(1):9448. doi:10.1038/s41598-025-92619-z
16. Lang JE, Bunnell HT, Hossain MJ, et al. Being overweight or obese and the development of asthma. *Pediatrics*. 2018;142(6). doi:10.1542/peds.2018-2119
17. Spathopoulos D, Paraskakis E, Trypsianis G, et al. The effect of obesity on pulmonary lung function of school aged children in Greece. *Pediatr Pulmonol*. 2009;44(3):273–280. doi:10.1002/ppul.20995
18. Tang X, Lei J, Li W, et al. The relationship between BMI and lung function in populations with different characteristics: a cross-sectional study based on the enjoying breathing program in China. *Int J Chronic Obstr*. 2022;17:2677–2692. doi:10.2147/COPD.S378247
19. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ*. 2000;320(7244):1240–1243. doi:10.1136/bmj.320.7244.1240
20. Miller MR, Hankinson J, Brusasco V, et al. Standardisation of spirometry. *Europ Resp J*. 2005;26(2):319–338. doi:10.1183/09031936.05.00034805
21. Venkatesan P. 2023 GINA report for asthma. *Lancet Respir Med*. 2023;11(7):589. doi:10.1016/S2213-2600(23)00230-8

22. Li H, Ji CY, Zong XN, Zhang YQ. [Height and weight standardized growth charts for Chinese children and adolescents aged 0 to 18 years]. *Zhonghua er ke za zhi*. 2009;47(7):487–492.
23. Elsaidy WH, Alzahrani SA, Boodai SM. Exploring the correlation between body mass index and lung function test parameters: a cross-sectional analytical study. *BMC Res Notes*. 2024;17(1). doi:10.1186/s13104-024-06967-6
24. Davidson WJ, Mackenzie-Rife KA, Witmans MB, et al. Obesity negatively impacts lung function in children and adolescents. *Pediatr Pulmonol*. 2014;49(10):1003–1010. doi:10.1002/ppul.22915
25. Winck AD, Heinzmann-Filho JP, Soares RB, da Silva JS, Woszezenki CT, Zanatta LB. Effects of obesity on lung volume and capacity in children and adolescents: a systematic review. *Revista paulista de Pediatria*. 2016;34(4):510–517. doi:10.1016/j.rpped.2016.02.008
26. Forno E, Han YY, Mullen J, Celedón JC. Overweight, obesity, and lung function in children and adults-a meta-analysis. *J Allergy Clin Immunol Prac*. 2018;6(2):570–581.e510. doi:10.1016/j.jaip.2017.07.010
27. Xu L, Huang X, Yang M, Duan M, Deng J. Correlation between body mass index and pulmonary function indexes in patients with bronchial asthma and suggestions for patient management. *Chin J Health Manage*. 2023;17(8):579–583.
28. Wang Y, Li Z, Li F. Nonlinear relationship between visceral adiposity index and lung function: a population-based study. *Respir Res*. 2021;22 (1):161. doi:10.1186/s12931-021-01751-7
29. Zhang C, Ling W, Pan H, Bai R, He L. Body mass index and lung function in hospitalized severe AECOPD patients: investigating nonlinear associations and the role of hemoglobin. *Int J COPD*. 2025;20:1309–1320. doi:10.2147/COPD.S521112
30. Fogarty AW, Lewis SA, McKeever TM, Britton J. The association of two different measures of body habitus with lung function: a population-based study. *Respir Med*. 2011;105(12):1896–1901. doi:10.1016/j.rmed.2011.07.024
31. Farhat L, de Vos G, De A, Lee DS, Rastogi D. Atopy and pulmonary function among healthy-weight and overweight/obese children with asthma. *Pediatr Pulmonol*. 2021;56(1):34–41. doi:10.1002/ppul.25005
32. Ying X, Lin J, Yuan S, et al. Comparison of pulmonary function and inflammation in children/adolescents with new-onset asthma with different adiposity statuses. *Nutrients*. 2022;14(14):2968. doi:10.3390/nu14142968
33. Charoensittisup P, Udomittipong K, Mahoran K, Palamit A. Longitudinal effects of obesity on pulmonary function in obese children and adolescents. *Pediatr Res*. 2025;97(5):1644–1649. doi:10.1038/s41390-024-03544-2
34. Carr TF, Altisheh R, Zitt M. Small airways disease and severe asthma. *World Allergy Organ J*. 2017;10(1):20. doi:10.1186/s40413-017-0153-4
35. Peters U, Suratt BT, Bates JHT, Dixon AE. Beyond BMI: obesity and lung disease. *Chest*. 2018;153(3):702–709. doi:10.1016/j.chest.2017.07.010
36. Chapman D, King G, Forno E. Obesity and lung function: from childhood to adulthood. *Mechan Manifestat Obes Lung Dis*. 2018;45–65.
37. Brazzale DJ, Pretto JJ, Schachter LM. Optimizing respiratory function assessments to elucidate the impact of obesity on respiratory health. *Respirology*. 2015;20(5):715–721. doi:10.1111/resp.12563
38. Dixon AE, Peters U. The effect of obesity on lung function. *Expert Rev Resp Med*. 2018;12(9):755–767. doi:10.1080/17476348.2018.1506331
39. McNeill JN, Lau ES, EK Z, et al. Association of obesity-related inflammatory pathways with lung function and exercise capacity. *Respir Med*. 2021;183:106434. doi:10.1016/j.rmed.2021.106434
40. Dreher M, Kabitz HJ. Impact of obesity on exercise performance and pulmonary rehabilitation. *Respirology*. 2012;17(6):899–907. doi:10.1111/j.1440-1843.2012.02151.x
41. Pekkarinen E, Vanninen E, Länsimies E, Kokkarinen J, Timonen KL. Relation between body composition, abdominal obesity, and lung function. *Clin Physiol Funct Imaging*. 2012;32(2):83–88. doi:10.1111/j.1475-097X.2011.01064.x
42. Song I, Ryu S, Kim DS. Relationship between obesity, body composition, and pulmonary function among Korean adults aged 40 years and older. *Sci Rep*. 2024;14(1). doi:10.1038/s41598-024-70809-5
43. Gonzalez-Barcala FJ, Takkouche B, Valdes L, et al. Body composition and respiratory function in healthy non-obese children. *Pediatr Int*. 2007;49 (5):553–557. doi:10.1111/j.1442-200X.2007.02420.x
44. Nagarchi K, Ahmed S, Saheb SH. Study of pulmonary function test in asthma patients. *J Pharm Sci Res*. 2015;7(1):37–39.
45. Sacco O. Pulmonary Function Tests. *Thoracic Surg Pediatric Patients*. 2021;81–87.