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Association between the Body Roundness Index and spirometric parameters among U.S. Adolescents from NHANES 2007–2012

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Abstract

Background Obesity is an important factor affecting pulmonary function. The Body Roundness Index (BRI) is a new method of assessing body and visceral adiposity, but its association with spirometric parameters in adolescents has not been previously reported.

Methods Cross-sectional data were obtained from the 2007 to 2012 National Health and Nutrition Examination Survey (NHANES), with participants having complete data on BRI and spirometric parameters. A generalized linear regression was conducted to explore the independent relationship between BRI and spirometric parameters. Smoothing curve fitting, subgroup analysis, and interaction tests were also performed.

Results A negative correlation was observed between BRI and pulmonary function. In the fully adjusted model, an increase of one unit in BRI was associated with an increase of 0.08 L in FVC, an increase of 0.04 L in FEV1, an increase of 5.17 L/min in PEF, and a decrease of 0.62% in FEV1/FVC.

Conclusion The results suggest an inverse association between BRI and pulmonary function. However, the clinical significance of this finding warrants further study.

Clinical trial number Not applicable.

Keywords Body roundness index, Spirometric parameters, National health and nutrition examination survey, Cross-sectional study

Introduction

Pulmonary function tests are essential in evaluating respiratory health and diagnosing diseases. In recent years, with the establishment of pulmonary function testing guidelines, these tests have gained broader clinical applicability across various clinical settings [1]. In pediatric practice, they have increasingly contributed to the diagnosis and monitoring of various pulmonary diseases [2]. The commonly used pulmonary function parameters in clinical practice include Forced Vital Capacity (FVC), Forced Expiratory Volume in the first second (FEV1), the FEV1/FVC ratio, and Peak Expiratory Flow (PEF).

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The Body Roundness Index (BRI) is a novel measure derived from an elliptical body shape model, which employs eccentricity to estimate the proportion of visceral and total body fat [3]. Unlike Body Mass Index(BMI), which does not distinguish between central and peripheral fat distribution and fails to account for body shape or composition [4], BRI has been shown to more effectively reflect visceral adipose tissue and overall body fat percentage [3]. Increasing evidence from studies suggests a correlation between BRI and various health issues [5–7], and BRI holds potential for enhancing obesity classification and management in both clinical and research settings. Research has shown that BRI is inversely U-shaped related to FEV1 and FVC in individuals aged 18 and above [8]. However, the relationship between BRI and pulmonary function in adolescents remains unclear.

We used data from the National Health and Nutrition Examination Survey to examine potential associations between BRI levels and spirometric parameters in adolescents aged 12–19, thereby addressing this gap in knowledge. These findings may assist in the management of spirometric parameters in adolescents aged 12–19 years.

Methods

Study population

The NHANES program is a nationally representative survey of U.S. civilians, approved by the Ethics Review Board of the National Center for Health Statistics, with informed consent obtained from all participants. We downloaded three cycles of NHANES from 2007 to 2012, and all participants ($n = 30,442$) were first included. The final analysis included 3,166 participants, after excluding individuals with missing height and waist circumference data ($n = 4,768$), incomplete pulmonary function metrics or low-quality data (grades D and F) ($n = 6,279$), and those outside the 12 to 19 years age range ($n = 16,229$) (Fig. 1).

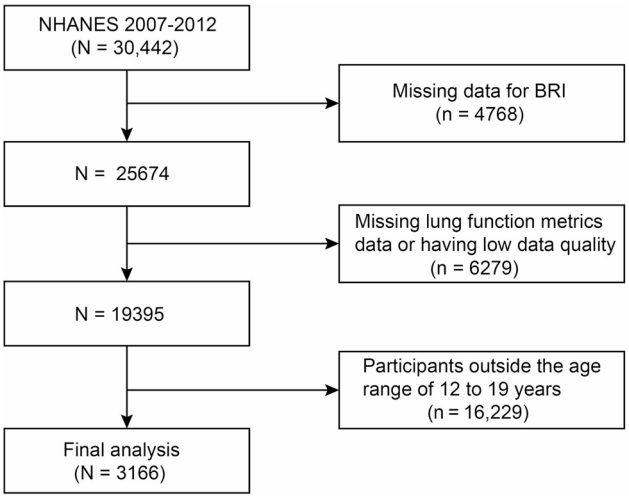

Fig. 1 Flowchart of study participants

Assessment of BRI

BRI is an emerging body size assessment index, calculated using the participant's height (cm) and waist circumference (cm). Height was measured using a stadiometer to the nearest 0.1 cm. WC was measured to the nearest 0.1 cm using a flexible steel tape placed at the midpoint between the lowest rib and the iliac crest. For all measurements, participants were requested to remove their footwear and thick clothing, and measurements were taken at the end of a normal expiration while standing. BRI is defined by the following Eq. [3]:

$$\mathrm{BRI} = 364.2 - 365.5 \times \sqrt{1 - \frac{\left(\frac{\mathrm{WC}}{2\pi}\right)^2}{0.5 * \mathrm{height}^2}}$$

Spirometric parameters

Participants aged 6–79 years were invited to perform spirometry tests. The testing procedures adhere to the guidelines established by the American Thoracic Society (ATS), with all healthcare technicians undergoing formal training. Key exclusion criteria included recent chest pain, breathing difficulties, supplemental oxygen use, ongoing surgeries involving the chest, abdomen, or eyes, and recent stroke or heart attack, as outlined in the NHANES spirometry procedure manual. We utilized baseline spirometry data obtained from the initial trials, with essential spirometric parameters measurements including forced expiratory volume in 1 s (FEV1), forced vital capacity (FVC), the FEV1/FVC ratio, and peak expiratory flow (PEF). To ensure data accuracy, spirometry results with quality grades D and F were excluded. In addition, the percent predicted values were derived by converting the measured values using the ethnic-neutral reference equations of the Global Lung Function Initiative [9].

Covariates

Covariates were selected based on published literature and clinical experience to minimize their potential impact on the final results [10, 11]. Sociodemographic characteristics, including age, sex, race/ethnicity, and poverty-to-income ratio (PIR) were gathered through self-report questionnaires. Questionnaires identified diabetes, asthma, thoracic/abdominal surgery, presence of respiratory disease and second-hand smoke exposure. Presence of respiratory disease was defined based on the following questionnaire item: "In the past 7 days, have you had a cough, cold, phlegm, runny nose, or other respiratory illness?" In addition, data were collected through laboratory measurements, including alanine

transaminase (ALT, U/L), total calcium (mmol/L), cholesterol (mmol/L), creatinine (mmol/L), serum globulin (g/L), serum albumin (g/L), and triglycerides (mmol/L). Serum cotinine levels were categorized as > 1 ng/mL and ≤ 1 ng/mL.

Statistical analysis

In line with the guidelines set by the U.S. Centers for Disease Control and Prevention guidelines, we used the "survey" package to perform weighting calculations in R. When describing study groups, Continuous variables are presented as weighted means, while categorical variables are expressed as weighted percentages, along with their corresponding confidence intervals (CI). BRI was divided into tertiles. Differences between participants grouped by tertiles were assessed using weighted t-tests for continuous variables and weighted chi-square tests for categorical variables. To explore the relationship between BRI and adolescent spirometric parameters, a weighted generalized linear model analysis was conducted to calculate beta values and 95% confidence intervals. Three models were employed for multivariate analysis: Model 1 was not adjusted for any variables. Model 2 adjusted for age, gender, race, and poverty-to-income ratio. In Model 3, we further adjusted for diabetes, asthma, thoracic/abdominal surgery, presence of respiratory disease, second-hand smoke, serum cotinine levels, alanine transaminase, total calcium, cholesterol, creatinine, serum globulin, serum albumin, and triglycerides. Collinearity among the variables included in the models was assessed using the variance inflation factor (VIF). Smoothed curve fitting was used to identify nonlinear associations and combined with a segmented linear regression model to examine potential threshold effects. Subgroup analyses and interaction tests were performed according to gender, race, PIR, diabetes, second-hand smoke exposure, asthma, thoracic/abdominal surgery, presence of respiratory disease. The discriminative ability of BRI, BMI, and WC for poor lung function was evaluated using receiver operating characteristic (ROC) curve analysis. Multiple interpolation of missing covariates using the MICE package in R. Statistical analyses were conducted using R (version 4.3.3) and Empower Stats software, and *p*-values less than 0.05 were regarded statistically significant.

Results

Table 1 presents the demographic characteristics of the participants and other variables. Our study included 3166 participants aged 12–19 years based on strict selection standards. The average age of the participants was 15.45 years, and 48.4% were female. Non-Hispanic whites comprised the majority of the study population. The corresponding mean and standard deviation of BRI for each BMI category were summarized (Table. S1). The mean BRI was 3.34 ± 1.73 and the mean FEV1/FVC was 0.86 ± 0.07. FEV1/FVC values tended to be lower in subgroups of the higher BRI tertiles (Tertile1: 0.87 ± 0.07, Tertile2: 0.87 ± 0.06, Tertile3: 0.84 ± 0.06, $p < 0.001$). In the three quartile BRI groups, differences in age, gender, race, poverty-to-income ratio, second-hand smoke exposure, alanine transaminase, total calcium, cholesterol, creatinine, serum globulin, serum albumin, and triglycerides were statistically significant ($P < 0.05$). Serum cotinine levels, asthma, diabetes mellitus, respiratory disease, and aspartate aminotransferase were not statistically significant. Participants in the higher BRI group (Tertile 3) were typically female, had low family incomes, were exposed to secondhand smoke, and exhibited higher levels of albumin, globulin, ALT, cholesterol, triglycerides, as well as lower levels of total calcium and creatinine.

Table 2 shows the associations between BRI and spirometric parameters. In the Model 3, adjusting for all covariates, BRI was found to be positively associated with FVC, FEV1, and PEF, and negatively associated with FEV1/FVC. Specifically, for each unit rise in BRI, there was a corresponding increase of 0.08 L in FVC (β = 0.08, 95% CI: 0.06, 0.10), 0.04 L in FEV1 (β = 0.04, 95% CI: 0.03, 0.06), and 5.17 L/min in PEF (β = 5.17, 95% CI: 3.12, 7.22), and FEV1/FVC decreased by 0.62% (β = -0.62%, 95% CI: -0.82%, -0.43%). These connections were still statistically significant after tertiary treatment of the BRI. The highest tertile of BRI was associated with higher FVC, FEV1 and PEF and lower FEV1/FVC levels compared to the lowest tertile group.

Additionally, the associations between BRI and spirometric variables reported as predicted percent values (FEV1pred, FVCpred, and FEV1/FVCpred) were analyzed. After adjustment for covariates, BRI was positively associated with FVCpred (β = 2.03, 95% CI: 1.63, 2.44) and FEV1pred (β = 1.25, 95% CI: 0.91, 1.58), and negatively associated with FEV1/FVCpred (β = -0.69, 95% CI: -0.90, -0.48). These findings are consistent with the results obtained from the original spirometric values(Table. S2).

To assess multicollinearity among the covariates included in the regression models, the variance inflation factor (VIF) was calculated for each variable (Table. S3). All VIF values were less than 5, suggesting that multicollinearity was not present.

Smoothed curve fitting findings confirmed the negative correlation between BRI and FEV1/FVC. A turning point was observed at 10.3 (Table 3; Fig. 2), with a significant negative association present to the left of the turning point, while no statistically significant association was found to the right of the turning point. Additionally, we observed an inverse U-shaped relationship between BRI and FVC, FEV1, and PEF (Table 3; Fig. 2). We further conducted a sex-stratified analysis of the nonlinear

Table 1 Baseline characteristics of participants stratified by BRI tri-sectional quantiles

Characteristic	Overall (*N* = 3166)	Low (*N* = 1054)	Middle (*N* = 1056)	High (*N* = 1056)	*P*-value
BRI	3.34 ± 1.73	1.93 ± 0.27	2.83 ± 0.31	5.26 ± 1.69	< 0.001
BMI	23.74 ± 5.76	19.18 ± 2.01	22.23 ± 2.27	29.82 ± 5.51	< 0.001
Age (years)	15.45 ± 2.24	15.15 ± 2.20	15.56 ± 2.22	15.64 ± 2.27	0.001
Gender, (%)					< 0.001
Male	51.6	65.2	42.1	47.4	
Female	48.4	34.8	57.9	52.6	
Race/ethnicity, (%)					< 0.001
Mexican American	13.2	7.9	13.2	18.4	
Other Hispanic	6.4	5.5	5.7	8.0	
Non-Hispanic White	59.3	60.3	63.5	54.0	
Non-Hispanic Black	14.3	17.5	11.2	14.2	
Other Race	6.9	8.8	6.4	5.4	
PIR, (%)					< 0.001
≤ 1	23.1	17.4	22.8	28.9	
> 1	76.9	82.6	77.2	71.1	
Asthma, (%)					0.123
No	79.5	81.5	79.9	77.0	
Yes	20.5	18.5	20.1	23.0	
Thoracic/ abdominal surgery, (%)					0.502
No	97.6	97.6	98.1	97.1	
Yes	2.4	2.4	1.9	2.9	
Respiratory disease, (%)					0.071
No	75.7	77.8	76.7	72.7	
Yes	24.3	22.2	23.3	27.3	
Diabetes, (%)					0.485
No	99.4	99.7	99.1	99.4	
Yes	0.6	0.3	0.9	0.6	
Albumin(g/L)	44.51 ± 3.04	45.22 ± 3.04	44.82 ± 2.87	43.50 ± 2.94	< 0.001
Globulin(g/L)	27.54 ± 3.65	27.03 ± 3.51	27.30 ± 3.66	28.30 ± 3.67	< 0.001
ALT(U/L)	19.60 ± 13.83	17.46 ± 6.84	18.14 ± 13.48	23.22 ± 18.06	< 0.001
Total calcium (mmol/L)	2.41 ± 0.08	2.42 ± 0.08	2.41 ± 0.08	2.39 ± 0.08	< 0.001
Cholesterol (mmol/L)	4.11 ± 0.76	4.02 ± 0.73	4.15 ± 0.72	4.15 ± 0.82	0.008
Triglycerides (mmol/L)	1.08 ± 0.73	0.91 ± 0.53	1.05 ± 0.73	1.29 ± 0.84	< 0.001
Creatinine (mmol/L)	65.36 ± 18.32	67.75 ± 24.49	64.92 ± 14.04	63.43 ± 14.17	0.003
Second-hand smoke, (%)					0.001
No	86.2	89.0	87.5	81.9	0.001
Yes	13.8	11.0	12.5	18.1	
Serum cotinine levels, (%)					0.711
≤ 1 ng/mL	79.2	80.2	78.7	78.6	
> 1 ng/mL	20.8	19.8	21.3	21.4	
FVC(L)	4.09 ± 0.98	4.00 ± 0.98	4.02 ± 0.92	4.23 ± 1.00	0.002
FEV1(L)	3.50 ± 0.80	3.47 ± 0.85	3.47 ± 0.75	3.55 ± 0.80	0.200
FEV1/FVC	0.86 ± 0.07	0.87 ± 0.07	0.87 ± 0.06	0.84 ± 0.06	< 0.001
PEF(L/min)	468 ± 109	467 ± 110	462 ± 104	475 ± 111	0.200

Mean ± SD for continuous variables: the *P* value was calculated by the weighted linear regression model; (%) for categorical variables: the *P* value was calculated by the weighted chi-square test. Abbreviation: BRI, Body Roundness Index; PIR, the ratio of income to poverty; ALT, alanine aminotransferase; AST, aspartate aminotransferase; FVC: forced vital capacity; FEV1: forced expiratory volume in one second; PEF: peak expiratory flow; FEV1/FVC: the FEV1/FVC ratio

Table 2 The associations between BRI and FVC, FEV1, PEF, FEV1/FVC

Exposure	Model 1[β (95% CI)*P*]	Model 2[β (95% CI)*P*]	Model 3[β (95% CI)*P*]
Y = FVC(L)			
BRI	0.05(0.02, 0.09)0.0018	0.07(0.05, 0.09)<0.0001	0.08(0.06, 0.10)<0.0001
BRI tertile			
Low	Reference	Reference	Reference
Middle	0.02(-0.09, 0.14)0.6986	0.14(0.06, 0.23)0.0014	0.15(0.07, 0.23)0.0007
High	0.23(0.11, 0.35)0.0003	0.33(0.25, 0.40)<0.0001	0.36(0.28, 0.44)<0.0001
P for trend	0.0002	<0.0001	<0.0001
Y = FEV1(L)			
BRI	0.02(-0.01, 0.04)0.1410	0.03(0.01, 0.04)0.0029	0.04(0.03, 0.06)<0.0001
BRI tertile			
Low	Reference	Reference	Reference
Middle	0.00(-0.10, 0.10)0.9893	0.07(0.00, 0.15)0.0386	0.09(0.02, 0.16)0.0147
High	0.08(-0.01, 0.17)0.0825	0.14(0.07, 0.20)<0.0001	0.20(0.13, 0.26)<0.0001
P for trend	0.0825	<0.0001	<0.0001
Y = PEF(L/min)			
BRI	1.72(-1.16, 4.59)0.2360	2.45(0.44, 4.46)0.0182	5.17(3.12, 7.22)<0.0001
BRI tertile			
Low	Reference	Reference	Reference
Middle	-5.08(-16.92, 6.75)0.3920	7.88(-0.74, 16.50)0.0721	10.39(1.66, 19.13)0.0215
High	7.94(-4.47, 20.35)0.2040	16.50(7.16, 25.84)0.0010	25.73(17.04, 34.42)<0.0001
P for trend	0.2044	0.0010	<0.0001
Y = FEV1/FVC(%)			
BRI	-0.65(-0.82, -0.48)<0.0001	-0.78(-0.94, -0.61)<0.0001	-0.62(-0.82, -0.43)<0.0001
BRI tertile			
Low	Reference	Reference	Reference
Middle	-0.40(-1.11, 0.31)0.2590	-1.12(-1.85, -0.40)0.0032	-1.00(-1.77, -0.23)0.0130
High	-2.68(-3.61, -1.74)<0.0001	-3.37(-4.30, -2.45)<0.0001	-2.78(-3.79, -1.77)<0.0001
P for trend	<0.0001	<0.0001	<0.0001

Model 1: unadjusted

Model 2: adjusted for age, gender, race and PIR

Model 3: adjusted for age, gender, race, PIR, diabetes, asthma, thoracic/abdominal surgery, presence of respiratory disease, second-hand smoke, serum cotinine levels, alanine transaminase, total calcium, cholesterol, creatinine, serum globulin, serum albumin, and triglycerides

relationship between BRI and FEV1/FVC. In both males and females, a nonlinear association was observed, with an inflection point at 9.8 (Table. S4; Fig. S1). Before this threshold, BRI was significantly negatively correlated with FEV1/FVC.

A subgroup analysis was conducted to examine the relationship between BRI and spirometric parameters

Table 3 Analysis of threshold and saturation effects

Outcomes	β(95% CI)*P*-value
FVC(L)	
Breakpoint (k)	8.9
< k-segment effect 1	0.106 (0.089, 0.123) < 0.001
> k-segment effect 2	-0.245 (-0.357, -0.133) < 0.001
Log likelihood ratio	< 0.001
FEV1(L)	
Breakpoint (k)	8.1
< k-segment effect 1	0.062 (0.047, 0.077) < 0.001
> k-segment effect 2	-0.088 (-0.159, -0.017) 0.015
Log likelihood ratio	< 0.001
PEF(L/min)	
Breakpoint (k)	9.9
< k-segment effect 1	5.978 (4.005, 7.951) < 0.0001
> k-segment effect 2	-21.955 (-42.575, -1.334) 0.0370
Log likelihood ratio	0.010
FEV1/FVC(%)	
Breakpoint (k)	10.3
< k-segment effect 1	-0.6 (-0.8, -0.5) < 0.001
> k-segment effect 2	1.4 (-0.5, 3.3) 0.149
Log likelihood ratio	0.037

(Table 4). No significant interactions were identified for gender, race, PIR, diabetes, thoracic/abdominal surgery, or respiratory disease (all p values for interaction > 0.05). However, statistically significant interactions were found for asthma (p for interaction = 0.007) and exposure to second-hand smoke (p for interaction = 0.039). In the population without asthma, a stronger negative correlation was observed between BRI and FEV1/FVC. Among individuals not exposed to second-hand smoke, the positive correlation between BRI and PEF was more pronounced.

To compare the diagnostic ability of BRI, BMI, and WC for predicting poor lung function, we performed receiver operating characteristic (ROC) curve analyses. Based on relevant cutoff values applicable to children [12–14], poor lung function was defined as observed FVC < 85% predicted value, FEV1 < 85% predicted value, or FEV1/FVC < 85%. As shown in Fig. 3, BRI demonstrated a higher area under the ROC curve (AUC) compared to both BMI and WC for the prediction of poor lung function(BRI, AUC = 0.589; BMI, AUC = 0.559; WC, AUC = 0.553).

Discussion

This cross-sectional study included 3,166 participants and aimed to assess the relationship between BRI and spirometric parameters in the U.S. adolescent population. We observed that participants with higher BRI had lower levels of lung function, as indicated by a decreased FEV1/FVC ratio. Although BRI was positively correlated with both FEV1 and FVC, the increase in FVC was greater than that of FEV1, leading to a decline in the

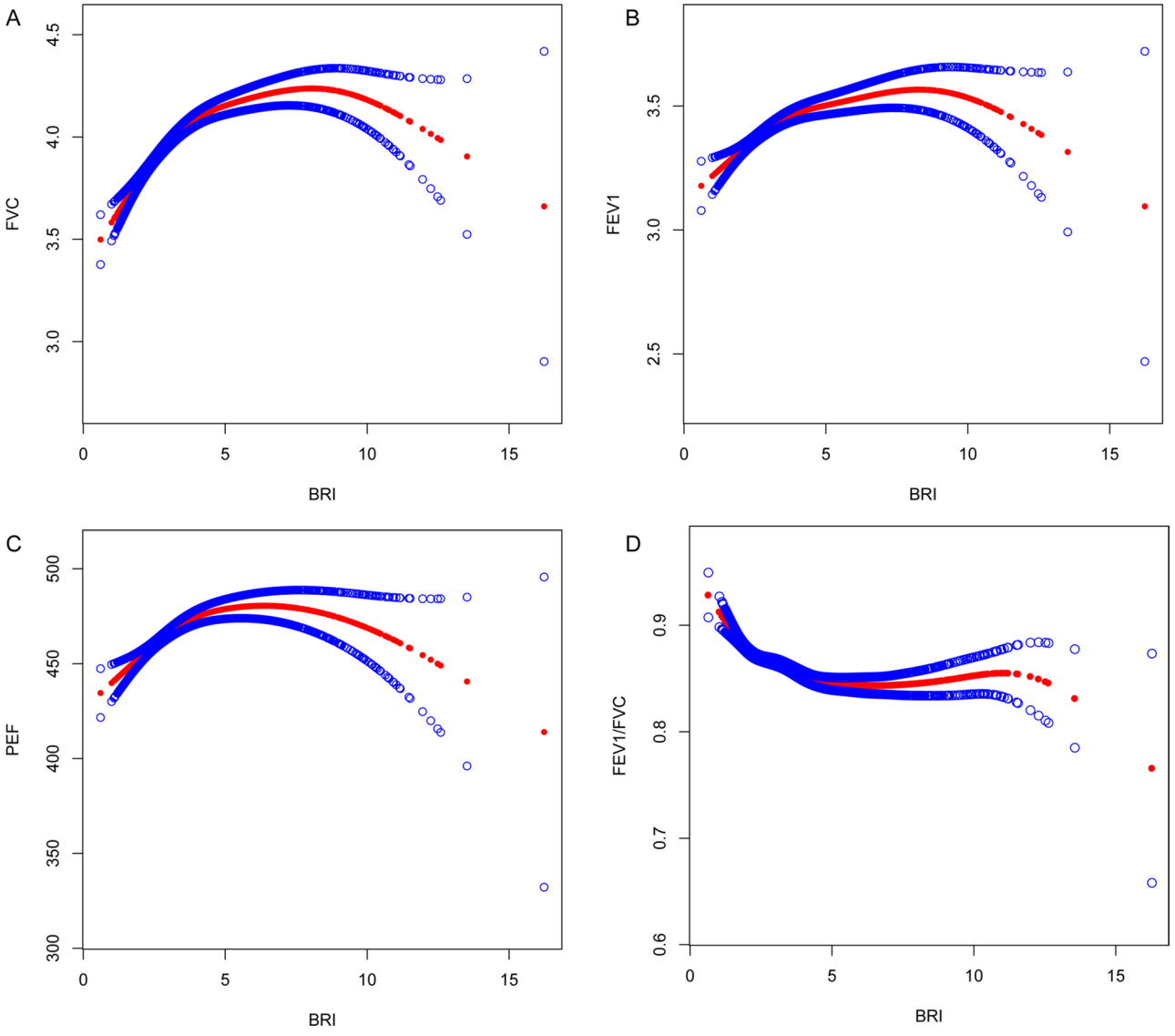

Fig. 2 The relationship between BRI and FVC, FEV1, PEF, FEV1/FVC. The solid red line represents the smooth curve fit between variables. Blue bands represent the 95% of confidence interval from the fit. (**A**) BRI and FVC; (**B**) BRI and FEV1; (**C**) BRI and PEF; (**D**) BRI and FEV1/FVC

FEV1/FVC ratio. This result remained consistent after adjusting for all confounding factors. Subgroup analyses indicated that this association did not vary significantly across different populations. Although previous studies have suggested potential sex differences in lung function, we found that sex did not have a significant impact on the relationship between BRI and spirometric parameters in our study population. Additionally, a non-linear notable correlation was found between BRI and FEV1/FVC, with a significant negative correlation on the left side of the breakpoint (BRI = 10.3), while no statistically significant correlation was observed on the right side of the breakpoint. Our study demonstrates a statistically significant association between BRI and lung function among adolescents. However, the clinical relevance of these findings remains uncertain, and further longitudinal studies are warranted to clarify these associations.

Childhood obesity is becoming an increasingly significant global health concern, and research has demonstrated its role in raising the risk of type 2 diabetes, cardiovascular diseases, mental health issues, and obesity in adulthood [15]. In addition, numerous studies support the relationship between obesity and impaired pulmonary function. A previous longitudinal research involving 9059 Asians showed that high BRI values were associated with better lung function at baseline and rapid decline in lung function at follow-up [16]. Zhang et al. found an inverted U-shaped relationship between BRI and both FEV and FVC in adults aged 18 and above in America [8]. A study conducted on Australian school children revealed that the adjusted FEV1 and FVC

Table 4 Subgroup analysis of the association between BRI and FVC(L), FEV1(L), PEF(L/min), FEV1/FVC

Characteristic	FVC	FEV1	PEF	FEV1/FVC
	β(95%CI)	β(95%CI)	β(95%CI)	β(95%CI)
Gender				
Male	0.08(0.06,0.11)	0.04(0.02,0.06)	3.56(0.82,6.30)	-0.01(-0.01, -0.01)
Female	0.06(0.05,0.08)	0.04(0.02,0.05)	5.00(2.59,7.41)	-0.01(-0.01, -0.00)
P for interaction	0.190	0.912	0.624	0.101
Race				
Mexican American	0.07(0.04,0.10)	0.03(0.01,0.05)	1.32(-2.21,4.86)	-0.01(-0.01, -0.00)
Other Hispanic	0.04(0.01,0.08)	0.01(-0.02,0.04)	-1.08(-5.79,3.63)	-0.01(-0.01, -0.00)
Non-Hispanic White	0.10(0.07,0.13)	0.06(0.04,0.08)	6.04(3.06,9.02)	-0.01(-0.01, -0.00)
Non-Hispanic Black	0.06(0.04,0.09)	0.03(0.01,0.06)	5.32(1.92,8.73)	-0.01(-0.01, -0.00)
Other Race	0.10(0.06,0.15)	0.06(0.02,0.10)	11.25(3.50,19.00)	-0.01(-0.01, -0.01)
P for interaction	0.254	0.184	0.08	0.230
PIR				
≤ 1	0.07(0.04,0.09)	0.03(0.01,0.05)	3.33(0.21,6.45)	-0.01(-0.01, -0.01)
> 1	0.08(0.06,0.09)	0.04(0.03,0.06)	4.83(2.62,7.05)	-0.01(-0.01, -0.00)
P for interaction	0.387	0.347	0.260	0.718
Asthma				
No	0.08(0.06,0.10)	0.04(0.02,0.05)	3.84(1.72,5.97)	-0.01(-0.01, -0.01)
Yes	0.06(0.03,0.09)	0.05(0.02,0.07)	5.54(1.80,9.28)	-0.00(-0.00,0.00)
P for interaction	0.494	0.459	0.399	0.007
Thoracic/abdominal surgery				
No	0.07(0.06,0.09)	0.04(0.03,0.05)	4.38(2.42,6.34)	-0.01(-0.01, -0.01)
Yes	0.07(-0.01,0.15)	0.04(-0.03,0.10)	1.40(-6.86,9.65)	-0.01(-0.01,0.00)
P for interaction	0.111	0.086	0.944	0.612
Respiratory disease				
0	0.08(0.06,0.09)	0.04(0.03,0.06)	4.26(2.06,6.47)	-0.01(-0.01, -0.00)
1	0.07(0.04,0.09)	0.03(0.01,0.05)	4.35(1.04,7.66)	-0.01(-0.01, -0.00)
P for interaction	0.785	0.673	0.610	0.940
Diabetes				
No	0.07(0.06,0.09)	0.04(0.02,0.05)	4.22(2.28,6.17)	-0.01(-0.01, -0.01)
Yes	0.21(0.10,0.33)	0.18(0.08,0.27)	9.14(-1.00,19.29)	-0.00(-0.02,0.01)
P for interaction	0.514	0.052	0.738	0.365
Second-hand smoke				
No	0.08(0.06,0.09)	0.04(0.03,0.05)	4.98(2.87,7.08)	-0.01(-0.01, -0.01)
Yes	0.06(0.02,0.09)	0.03(0.00,0.06)	1.49(-2.45,5.43)	-0.00(-0.01, -0.00)
P for interaction	0.183	0.100	0.039	0.478

values, accounting for age, gender, and height, significantly increase with higher weight and BMI [17]. A cross-sectional study in the South African region indicated that adolescent BMI is positively correlated with FVC, FEV1, and PEF, but negatively correlated with the FEV1/FVC ratio [18]. A study involving 68 obese children and adolescents showed that changes in waist circumference or waist-to-height ratio for abdominal obesity were negatively correlated with changes in FEV1/FVC, FEF25-75% /FVC, and FEF25-75% in obese children and adolescents after 1 year of follow-up, and pointed to the need to use waist circumference and/or waist-to-height ratio, apart from body weight (BW) and BMI, to monitor obesity [19]. Similarly, Feng et al. reported that the ratio of waist circumference to chest circumference is inversely associated with lung function in Chinese children and adolescents, reflecting the association between abdominal obesity and respiratory health [20]. The BRI considers both weights and provides a more precise reflection of body shape and fat distribution, which enhances its sensitivity in evaluating risks linked to abdominal obesity [21]. Consistent with previous studies, our findings emphasize the importance of BRI in spirometric parameters management.

While the exact mechanisms by which the BRI impacts lung functions remain unclear, some theories have been put forward. A study shows that excess body fat in the chest and abdomen restricts respiratory muscle activity, limiting diaphragm mobility and rib cage movement [22]. Adipose tissue deposits in the thoracic and abdominal areas could potentially reduce total lung volume and lower expiratory reserve capacity, likely due to a decrease

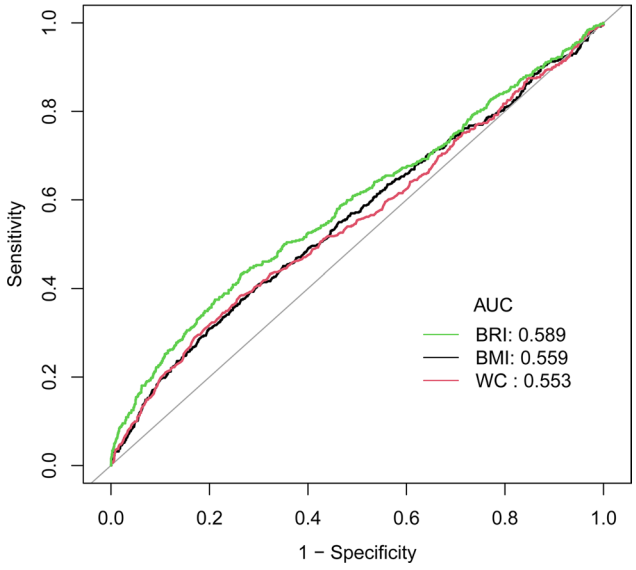

Fig. 3 ROC curves of BRI, BMI, and WC for predicting poor lung function

in lung compliance and changes in respiratory rhythm [23, 24]. Reduced lung compliance may be caused by an increase in pulmonary blood volume, airway closure leading to small atelectatic areas, or elevated alveolar surface tension due to a decrease in functional residual capacity (FRC) [25, 26]. Macrophages derived from adipose tissue produce pro-inflammatory mediators such as C-reactive protein, leptin, tumor necrosis factor-alpha, and interleukin-6 [27], which contribute to both local and systemic inflammation. These changes in adipose tissue can impair immune function, increasing the risk of diseases such as asthma [28]. Besides, we observed an inverted U-shaped relationship between BRI and FEV1, FVC, and PEF. On the breakpoint's left side, BRI was positively correlated with these parameters. Lazarus et al. also demonstrated that, even after adjusting for height, an increase in FEV1 and FVC, along with a lower FEV1/FVC ratio, is associated with childhood obesity [29]. The increase in FVC and FEV1 in obese adolescents may be attributed to airway dysanapsis, a condition where the airway length and lung volume grow more rapidly than the airway caliber. On the other hand, obese children experience accelerated lung growth, resulting in airway dysanapsis, characterized by a disproportionate increase in FVC relative to FEV1. This discrepancy may originate from natural physiological processes early in life [18].

Our study has several limitations. First, due to its cross-sectional design, we cannot draw conclusions about causal relationships between the two factors. Future research will require further prospective validation. Second, some covariates were defined using self-reported questionnaires, which may not fully reflect the true situation. Thirdly, BRI was calculated retrospectively from NHANES 2007–2012 data, collected before the index was introduced, and hence, waist circumference measurements may not have been standardized for BRI, potentially introducing measurement bias. Another limitation of this study is that BRI measurement requires standardized waist circumference assessment, which may involve undressing and physical contact. Although trained staff and private settings can help mitigate these issues, some participants may still feel reluctant to undergo the measurement, possibly affecting participation rates and data quality. Therefore, the ethical implications and acceptability of BRI measurement should be carefully considered in future research and survey design. Notably, 24.3% of our study participants reported respiratory symptoms (such as cough, cold, phlegm, or runny nose) in the past 7 days, and 20.5% had asthma. These conditions may have contributed to lower lung function measurements in our cohort and introduced potential confounding, despite adjustment for major covariates. Their inclusion may limit the generalizability of our findings, and future studies with standardized diagnostic criteria or exclusion of these subgroups are warranted to validate our results. Moreover, studies have indicated that air pollution negatively influences lung function in children and adolescents [30, 31]. However, it was not accounted for in the models due to the unavailability of relevant data. Despite these limitations, our study presents several strengths, including the adjustment for multiple biochemical indicators related to spirometric parameters and the relatively large sample size. Furthermore, we used cotinine levels rather than self-reported smoking status to indicate smoking exposure, as cotinine more accurately reflects the cumulative biological impact of smoking.

Conclusion

BRI is negatively correlated with pulmonary function in adolescents aged 12 to 19. Besides, our findings reveal a nonlinear relationship between BRI and spirometric parameters. Future large-scale, multicenter, prospective clinical studies are required to validate the strength of our results.

Abbreviations

BRI	The Body Roundness Index
BMI	Body Mass Index
NHANES	National Health and Nutrition Examination Survey
FEV1	Forced expiratory volume in 1 s
FVC	Forced Vital Capacity
PEF	The FEV1/FVC Ratio, and Peak Expiratory Flow
PIR	Poverty-to-Income Ratio
ALT	Alanine Transaminase
AST	Aspartate Aminotransferase

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Supplementary Material 5

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Author contributions
W.X. contributed to the original draft, Methodology, and Formal analysis. B.H. contributed to the original draft, Methodology, Supervision, Project administration, and Formal analysis. Y.X. contributed to Conceptualization, Methodology, Validation, Formal analysis, Resources, and Data curation. G.H. was involved in Writing-review & editing, Supervision, Project administration, and Investigation.

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Data availability
All data generated or analyzed during this study is included at this https://www.cdc.gov/nchs/nhanes/Default.aspx.

Declarations

Ethics approval and consent to participate
The research involving human participants underwent review and approval by the National Health and Nutrition Examination Survey (NHANES), sanctioned by the National Center for Health Statistics Research Ethics Review Board. Written informed consent was obtained from all participants before they participated in the survey. Participants under 16 years of age, with informed consent provided by their parents or legal guardians.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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