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Interaction of Body Mass Index and Sex on Pulmonary Function Tests among patients with Chronic Obstructive Respiratory Disease: An Observational study from a Tertiary Centre in India

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Abstract

Introduction: Obesity has unique role in chronic disease like Chronic Obstructive Respiratory Disease; Patients with higher obesity have been reported to have better life expectancy than underweight patients. But this particular obesity paradox has been studied very less among the Indian population. The interaction of obesity with sex is an important factor as the fat distribution varies differently among male and females. **Methods:** Hospital based observational study. Here the anthropometric parameters and pulmonary function testing were recorded from 951 chronic respiratory disease patients. The relation and association were studied through Correlation, Regression and MANOVA. **Results:** A significant interaction effect between sex and BMI was observed for both FVC and FEV1, indicating that the impact of BMI on pulmonary function differs by Sex. Specifically, underweight males had disproportionately lower FVC and FEV1 values compared to their female counterparts. This suggests a possible synergistic vulnerability of respiratory function in underweight males **Conclusion:** In summary, this study reinforces the significant influence of sex on pulmonary function and highlights the nuanced role of BMI, particularly in its interaction with sex. These findings underline the importance of individualized interpretation of PFTs that account for both anthropometric and sex-based physiological differences. Further research is needed to explore underlying mechanisms and potential clinical implications in diverse populations.

Keywords: Pulmonary Function Test, BMI, Obesity, Sex, Chronic respiratory disease

Resumen

Introducción: La obesidad desempeña un papel fundamental en enfermedades crónicas como la enfermedad respiratoria obstructiva crónica (ERC). Se ha reportado que los pacientes con mayor obesidad tienen una mayor esperanza de vida que los pacientes con bajo peso. Sin embargo, esta paradoja de la obesidad se ha estudiado muy poco en la población india. Además, la interacción de la obesidad con el sexo es un factor importante, ya que la distribución de la grasa varía de forma diferente entre hombres y mujeres. **Métodos:** Estudio observacional hospitalario. Se registraron los parámetros antropométricos y las pruebas de función pulmonar de 951 pacientes con ERC. La relación y la asociación se estudiaron mediante correlación, regresión y MANOVA. **Resultados:** Se observó un efecto de interacción significativo entre el sexo y el IMC tanto para la CVF como para el VEF1, lo que indica que el impacto del IMC en la función pulmonar difiere según el sexo. Específicamente, los hombres con bajo peso presentaron valores de CVF y VEF1 desproporcionadamente más bajos en comparación con las mujeres. Esto sugiere una posible vulnerabilidad sinérgica de la función respiratoria en varones con bajo peso. **Conclusión:** En resumen, este estudio refuerza la influencia significativa del sexo en la función pulmonar y destaca el papel matizado del IMC, en particular en su interacción con el sexo. Estos hallazgos subrayan la importancia de la interpretación individualizada de las pruebas de función pulmonar (PFP) que tengan en cuenta las diferencias fisiológicas tanto antropométricas como basadas en el sexo. Se necesita más investigación para explorar los mecanismos subyacentes y las posibles implicaciones clínicas en diversas poblaciones.

Palabras Clave: Prueba de función pulmonar, IMC, Obesidad, Sexo, Enfermedad respiratoria crónica

Introduction

Pulmonary function tests (PFTs) become an indispensable tool for clinical tools for assessing respiratory health and diseases (Liang, 2012). Spirometry is one of the robust, non-invasive method for measuring the volume of air in the lungs at maximal inhalation (Ferguoson, 2000). The key parameters for this test include the forced expiratory volume in one second (FEV_1), forced vital capacity (FVC), and the ratio of the two volumes and forced expiratory flow (FEF 25-75 L/sec) (Ranu, 2011). FEV_1 is the amount of air that is blown out in one second after maximal deep inhalation. FVC is the maximum volume of air one can forcibly exhale from the lungs after fully inhaling. The FEV_1-to-FVC ratio measures airflow obstruction. FEF 25-75 measures 25-75% of forced vital capacity (Talaminos, 2018).Several physiological and anthropometric variables, including age, sex, height, and body mass index (BMI), have been shown to influence pulmonary function. Lung volumes are generally higher in males compared to females due to differences in thoracic dimensions, lung size, and hormonal influences on respiratory musculature (Quanjer, 2012). Height, in particular, is a strong determinant of lung volumes, as taller individuals possess proportionally larger lung capacities (Quanjer, 2012; Miller, 2005). Conversely, age is associated with a decline in lung function owing to reduced chest wall compliance, diminished elastic recoil, and loss of alveolar surface area (Miller, 2005).

Numerous studies have consistently demonstrated that males and females differ in several aspects of lung structure, thoracic mechanics, and ventilatory function, which are reflected in key spirometric indices such as FVC, FEV_1, FEV_1/FVC, and FEF25–75 (Solanki, 2016; Zakaria, 2019). The role of BMI in modulating pulmonary function remains complex and controversial. Obesity may mechanically restrict lung expansion due to increased abdominal and thoracic fat deposition, leading to a reduction in FVC and FEV_1 (Salome, 2010). There are other studies too which suggest that obesity significantly influenced FEV1/FVC and other parameters too (Stier, 2014; Littleton, 2004) due to difference in body fat distribution (Harik Khan, 2001).

However in cases with chronic respiratory disease the relation of obesity and pulmonary function, mortality is quite complicated. The 'obesity paradox' (Elagizi, 2018) refers to improved pulmonary function and better outcome in obese as compared to underweight. However obesity had been defined on the basis of body mass index and mostly in western population. As the obesity pattern is different in Indian or south asian population compared to western population a detailed study on the anthropometric parameters and pulmonary function among patients with chronic respiratory disease may be helpful particularly in perspective of different ethnicity. Also this may reveal important risk factors among Indian population. Unfortunately, there are very few studies on this aspect.

Objective

To investigate the effect of Sex and Body mass index on pulmonary function test parameters among patients suffering from chronic respiratory diseases

Materials and Methods

Participants and setting

A total of 951 participants were included in this cross-sectional study. They were referred to the Pulmonary function testing laboratory for evaluation and follow up of pulmonary function testing after an established diagnosis of chronic respiratory disease from other departments like Medicine, Surgery and Cardiovascular OPD. Data were collected from the Pulmonary Function Laboratory, Department of Physiology, All India Institute of Medical Sciences (AIIMS), Kalyani, West Bengal, India, between March 2024 and January 2025 (Ethical No.: IEC/AIIMS/KALYANI/CERTIFICATE/2024/420). Data collection was carried out daily using the Epicollect5 digital platform.

Anthropometric Assessment

Standing height was measured to the nearest 0.1 cm using a SECA 213 portable stadiometer, and body weight was recorded to the nearest 0.1 kg using a SECA 803 digital weighing scale (SECA GmbH & Co. KG., Hamburg, Germany). Measurements were taken with participant's barefoot, wearing light indoor clothing, and standing upright in accordance with the Frankfurt horizontal plane.All anthropometric assessments were performed by trained personnel certified at ISAK Level 1, following standard protocols (Marfell-Jones, 2012). Equipment was calibrated prior to data collection as per the manufacturer's instructions.

Body Mass Index (BMI) Classification

BMI was calculated using Quetelet's Index: BMI = Weight (kg) / Height (m^2)

Participants were categorized using the WHO Asia-Pacific BMI classification (WHO Expert Consultation, 2004):

Underweight: BMI < 18.5 kg/m^2

Normal weight: 18.5–22.9 kg/m^2

Overweight: 23.0–24.9 kg/m^2

Obese: BMI ≥ 25.0 kg/m^2

Pulmonary Function Test

The following parameters were measured-

Forced Vital Capacity (FVC): The total volume of air forcibly exhaled after a maximal inhalation.

Forced Expiratory Volume in 1 second (FEV_1): The volume of air exhaled during the first second of forced expiration.

FEV_1/FVC Ratio: Used to distinguish between obstructive and restrictive lung conditions.

Forced Expiratory Flow at 25–75% (FEF_{25-75}) which reflects small airway function.

Testing was performed using a turbine-based spirometer (Universal Medical Instruments, Delhi, India), operated via Spiromin Software version 18.0.3. The device was calibrated daily using a 3-liter calibration syringe, as per manufacturer guidelines. Spirometry was conducted in accordance with ATS/ERS 2005 and 2019 standards (Graham, 2019; Miller, 2005).All tests were performed in a seated position, and at least three acceptable and repeatable efforts were recorded. The best maneuver was used for analysis.

Inclusion and Exclusion Criteria:

All patients referred for PFT with a diagnosis of Chronic obstructive respiratory problem like bronchitis, emphysema, interstitial lung disease, asthma etc from departments such as General Medicine, Pulmonology, ENT, Cardiology, Gastroenterology, and Pre-operative Evaluation were eligible for inclusion, with no restrictions based on age or sex.

Participants were excluded if they had any of the following conditions before testing, based on ATS/ERS contraindications (Miller, 2005):

1. Myocardial infarction (within the last 6 weeks)
2. Hemoptysis of unknown origin (last 6 weeks)
3. Recent pneumothorax (last 6 weeks)
4. Eye, chest, or abdominal surgery (within the past 6 weeks)
5. Exacerbation of respiratory illness requiring antibiotics (past 6 weeks)
6. COVID-19 symptoms or positive test (within the last 4 weeks)

These criteria ensured patient safety and reliability of test results.

Statistical analysis:

Statistical analysis was performed using IBM SPSS software version 23. Participants were categorized by sex and BMI group (underweight, normal, overweight, and obese). Chi-square tests were used to compare categorical variables (e.g., sex, smoking status). Independent t-tests were used to compare pulmonary function and demographic variables between males and females. One-way ANOVA assessed differences in pulmonary and demographic variables across BMI categories, followed by Tukey's post hoc test to determine pairwise differences. Pearson correlation analysis explored associations between BMI, sex, height, weight, and lung function parameters. Linear regression was performed to identify significant predictors of lung function. A p-value ≤ 0.05

was considered statistically significant. Data visualization and graphical representations were generated using R software version (version 4.4.3).

Results

Descriptive Characteristics of the Patient Population

A total of 951 participants were included in the study, categorized into four BMI groups: Underweight (n = 84), Normal weight (n = 435), Overweight (n = 316), and Obese (n = 116). The demographic characteristics, anthropometric data, and smoking status by BMI category are presented in Table 1. Independent t-test was performed to see any significant changes in demographic characteristics and smoking status between males and females. One-way ANOVA followed by post-hoc Tukey test was performed to explore any association between BMI categories (Underweight, Normal, Overweight and Obese) and demographic characteristics and smoking status.

Sex Distribution

Out of the 951 participants, 561 were male (58.99%) and 390 were female (41%) and it was significantly increased (χ^2 test, p = 0.001), indicating a disproportionate distribution of males and females across BMI groups. Males were predominantly represented in the underweight (78.6%) and normal BMI groups (66.7%). In contrast, females comprised the majority in the overweight (48.7%) and obese groups (62.1%). This suggests that underweight and normal BMI are more common in males, whereas overweight and obesity are relatively more common in females within this sample.

Age Distribution

The mean age varied across BMI categories and between sexes, though no statistically significant differences were observed (p = 0.283 for males). Among males, age ranged from 49.25 ± 15.13 years (obese) to 54.48 ± 19.59 years (underweight). Among females, age increased steadily with BMI, ranging from 36.58 ± 16.77 years (underweight) to 47.63 ± 11.72 years (obese). Although the pattern suggests that increasing BMI is associated with older age in females, but the results were not statistically significant (p=0.283) in between the sexes. One-way ANOVA also showed no statistically significant difference in age between four BMI categories.

Height and Weight

Both height and weight showed significant variation across BMI categories for both sexes.

In male, height was increased slightly from underweight (158.59 ± 11.63 cm) to obese (162.77 ± 6.78 cm). In female, minimal difference across groups, ranging from 149.84 ± 7.77 cm to 150.84 ± 6.40 cm. Independent t-test revealed a significant increase in height was observed (p<0.001) in males as compared to females. When compared across the BMI categories, we observed significant difference in height in normal BMI category as compared to overweight (p=0.049) and Obese category (p=0.002) across the study population.

In male, weight was increased from 42.73 ± 6.45 kg (underweight) to 85.80 ± 9.80 kg (obese), p = 0.001, whereas, females showed an increased from 38.84 ± 4.81 kg to 75.31 ± 7.90 kg. These findings confirm the expected upward trend in weight with increasing BMI classification, with males consistently weighing more than females in each BMI group which was statistically significant (p<0.001). Post-hoc analysis done by Tukey test revealed a significant increase (p<0.001) in weight from underweight to obese category. Therefore, both sex and BMI categories have a significant effect on weight.

Body Mass Index (BMI)

The mean values in males were 16.90 (Standard deviation 1.32), 22.06 (Standard deviation 1.87), 26.90 (Standard deviation 1.37), 32.32 (Standard deviation 2.36) in underweight, normal, overweight and obese categories respectively. The mean values in females were 17.24 (Standard deviation 0.98), 22.51 (Standard deviation 1.76), 27.18 (Standard deviation 1.40), 33.36 (Standard deviation 2.79) in the underweight, normal, overweight and obese categories respectively. Females showed significant higher (p<0.001) BMI values as compared to males. However, in our study population post-hoc analysis done by Tukey test revealed a significant increase (p<0.001) in weight from underweight to obese category.

Smoking Status

There was a highly significant association between smoking status and BMI category (χ² test, $p < 0.001$). Male smokers constituted 29.75% of the total population (n = 283), and were most commonly found in the normal BMI group (n = 156). Female smokers were rare (only 5 out of 390), but were present in all BMI categories except underweight.

Most female participants were non-smokers (98.7%). These findings underscore a sex difference in smoking behavior, with a substantial portion of males being smokers, and very few females reporting smoking history.

The distribution of sex, anthropometric characteristics, and smoking status across BMI categories showed statistically significant differences, particularly in terms of sex and smoking prevalence. Males were more likely to be normal or overweight and were more frequently smokers, while females were more often overweight or obese. BMI and weight showed expected trends across categories, supporting the internal validity of group classification.

Effect of Sex and BMI categories on pulmonary function test parameters

A total of 951 participants were analyzed and stratified into four BMI categories: underweight (n = 84), normal weight (n = 435), overweight (n = 316), and obese (n = 116). Pulmonary function was assessed through FVC, FEV1, FEV1/FVC ratio, and FEF 25–75, and comparisons were made between BMI groups using ANOVA and post hoc Tukey tests. Comparisons were also made between male and female using Independent t-test (Table 2).

Forced Vital Capacity (FVC) (L)

Among males, FVC increased progressively with BMI. Underweight males had a mean FVC of 2.21±0.77 L, whereas obese males had the highest FVC at 2.68±0.85 L.

Table 1. Characteristics of Anthropometric data, Age, BMI, smoking status of the patients on the basis of Sex and BMI categories

Variables		BMI categories (Total = 951)				p-value
		Underweight (n= 84)	Normal (n= 435)	Overweight (n= 316)	Obese (n= 116)	
Sex	Male (58.99%) n= 561	66	290	162	44	0.001***
	Female (41%) n= 390	19	145	154	72	(X2)
Age (years)	Male	54.48±19.59	53.57±15.19	50.36±14.36	49.25±15.13	0.283
	Female	36.58±16.77	43.17±15.66	45.59±13.32	47.63±11.72	
Height (cm)	Male	158.59±11.63	162.05±6.61	162.61±6.90	162.77±6.78	<0.001
	Female	149.84±7.77	150.84±6.40	150.43±5.84	150.20±5.77	
Weight (Kg)	Male	42.73±6.45	58.09±7.33	71.19±7.17	85.80±9.80	0.001
	Female	38.84±4.81	51.30±5.74	61.61±5.79	75.31±7.90	
BMI (kg/m^2)	Male	16.90±1.318	22.06±1.87	26.90 ± 1.375	32.32±2.36	0.001
	Female	17.24±0.980	22.51±1.76	27.18±1.40	33.36±2.79	
Smoking status	Smoker Male (29.75%) n= 283	35	156	74	18	<0.001** (X2)*
	Non-Smoker Male (29.23%)	30	134	78	26	

	n= 278					
	Smoker	0	1	2	2	
	Female (0.52%)					
	n= 5					
	Non-smoker	19	144	152	70	
	Female (40.48%)					
	n= 385					

Note: Chi-square test was done for sex and smoking status (categorical variables) across BMI categories. Independent t-test was performed to assess the significant difference in Age, Height, Weight, BMI compared between male and female. One way ANOVA followed by post-hoc Tukey test was done to check significant difference on Age, Height, Weight and BMI to compare between underweight, normal, overweight and obese groups. P-value less or equal to 0.05 was considered as significant. *p<0.05, **p<0.01, ***p<0.001.

For females, the FVC remained relatively stable between the underweight and normal groups (2.13±0.64 L vs. 2.13±0.58 L), but declined slightly in overweight (2.05±0.57 L) and obese (1.98±0.50 L) categories. The difference between male and females was statistically significant ($p < 0.001$) (Table 2).

Post hoc Tukey analysis revealed a significant difference in FVC between underweight and normal weight females ($p = 0.035$) (Table 2).

Forced Expiratory Volume in 1 Second (FEV_1) (L)

In males, FEV1 significantly increased with BMI. Underweight males had the lowest mean value (1.64±0.76 L), while obese males had the highest (2.12±0.75 L), with a significant overall difference ($p < 0.001$).

Among females, the highest FEV1 was observed in the underweight group (1.81±0.62 L), with values decreasing slightly across the higher BMI categories: normal (1.73±0.54 L), overweight (1.72±0.51 L), and obese (1.66±0.43 L). Tukey analysis identified significant differences between Underweight vs. normal weight ($p = 0.044$), Underweight vs. overweight ($p = 0.025$).

However, t-test revealed significant change in FEV1 between males and females (p<0.001) (Table 2).

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FEV_1/FVC Ratio

For males, the FEV_1/FVC ratio showed an increasing trend with higher BMI from 72.14±15.73 in the underweight group to 78.46±11.28 in the obese group ($p < 0.001$). In females, the highest ratio was observed in the underweight group (84.05±8.70), followed by slight decreases in the normal (80.83±9.34), overweight (83.58±8.07), and obese (83.83±6.25) groups. Tukey test results indicated a significant difference between normal weight and overweight ($p = 0.001$) and between normal weight and obese groups ($p < 0.001$). A highly significant effect was also found in between males and females (p<0.001) (Table 2).

Forced Expiratory Flow at 25–75% (FEF 25–75) (L/sec)

Male participants demonstrated a consistent increase in FEF 25–75 with increasing BMI from 1.57±1.14 L/sec in underweight to 2.12±1.09 L/sec in obese individuals ($p < 0.001$).

Among females, the values fluctuated slightly without a clear trend underweight (2.07±1.05 L/sec), normal (1.89±0.91 L/sec), overweight (2.03±0.82 L/sec), and obese (1.95±0.79 L/sec). A significant difference was observed in between underweight and overweight groups (p = 0.039) (Table 3).

Table 2. Effect of Sex and Body Mass Index on Pulmonary Lung Function

Variables		**BMI categories (Total = 951)**				**p-value**
		Underweight	Normal	Overweight	Obese	**(t-test)**
		(n= 84)	(n= 435)	(n= 316)	(n= 116)	
FVC (L)	Male	2.21±0.77	2.56±0.78	2.68±0.71	2.68±0.85	**<0.001*****
	Female	2.13±0.64	2.13±0.58	2.05±0.57	1.98±0.50	
p-value (Tukey test)		**0.035 (Underweight vs normal)**				
FEV_1 (L)	Male	1.64±0.76	1.95±0.75	2.08±0.68	2.12±0.75	**<0.001*****
	Female	1.81±0.62	1.73±0.54	1.72±0.51	1.66±0.43	
p-value (Tukey Test)		**0.044* (Underweight vs normal)**				
		0.025* (Underweight vs overweight)				
FEV_1/FVC	Male	72.14±15.73	74.72±13.12	76.72±10.39	78.46±11.2	**<0.001*****
	Female	84.05±8.70	80.83±9.34	83.58±8.07	83.83±6.25	
p-value (Tukey Test)		**0.001*** (Normal vs overweight)**				
		<0.001* (Normal vs obese)**				
FEF 25-75 (L/Sec)	Male	1.57±1.14	1.92±1.16	2.02±1.06	2.12±1.09	**<0.001*****
	Female	2.07±1.05	1.89±0.91	2.03±0.82	1.95±0.79	
p-values (Tukey test)		**0.039* across all the categories**				

*Note: Independent t-test was done to assess the significant difference in lung function parameters to compare between male and female. One way ANOVA followed by post-hoc Tukey test was done for BMI categories to check significant difference to compare between underweight, normal, overweight and obese groups. P-value less or equal to 0.05 was considered as significant. *p<0.05, **p<0.01, ***p<0.001.

Table 3. Correlation analysis

Predictors		**FVC (L)**	**FEV_1 (L)**	**FEV_1/FVC**	**FEF2575 (L/Sec)**
Sex	Pearson Correlation	-.327**	-.181**	.307**	0.016
	Sig. (2-tailed)	**0**	**0**	**0**	0.613
	Pearson Correlation	0	0.058	.196**	.096**
BMI	Sig. (2-tailed)	0.998	0.073	**0**	**0.003**
Height	Pearson Correlation	.575**	.451**	-.158**	.219**
	Sig. (2-tailed)	**0**	**0**	**0**	**0**
Weight	Pearson Correlation	.322**	.305**	.090**	.206**
	Sig. (2-tailed)	**0**	**0**	**0.005**	**0**
Age	Pearson Correlation	-.430**	-.489**	-.311**	-.451**
	Sig. (2-tailed)	**0**	**0**	**0**	**0**

Note: Pearson's correlation analysis was conducted to explore the relationships between pulmonary function parameters and variables such as Sex, BMI, height, weight, and age. All correlations reported are based on two-tailed significance tests, with significance levels set at p < 0.01 (highly significant) and p < 0.05 (significant).

Figure 1. Correlation matrix: The bubble plot reflects the strength and direction of relationships between sex, age, height, weight and BMI with the PFT parameters FVC, FEV_1, FEV_1/FVC, FEF_{25-75}. The size of each bubble corresponds to the value of rho (Pearson correlation coefficient). Bubble are colored by blue indicating positive correlation between the variables and red indicating negative correlation between the variables. Larger bubbles correspond to stronger correlations, indicating a greater degree of association between the variables and smaller bubbles or very small or no bubbles indicate weak or negligible correlation among the variables.

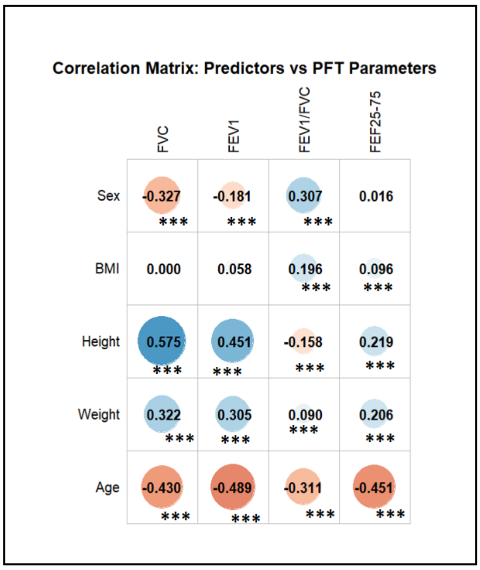

Figure 1. Correlation matrix: Predictors vs PFT Parameters

Pearson's correlation analysis was conducted to explore the relationships between pulmonary function parameters and variables such as sex, BMI, height, weight, and age. All correlations reported are based on two-tailed significance tests, with significance levels set at $p < 0.01$ (highly significant) and $p < 0.05$ (significant).

Bubble plot illustrates that FVC, FEV_1, FEV_1/FVC are significantly correlated with Sex, height, weight. BMI showed significant correlation with FEV_1/FVC and FEF 25-75. FEF 25-75 showed significant correlation with height, weight and age, not with sex and BMI (Figure 1).

Table 4a. Forced Vital Capacity (FVC)

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	R value	R^2 value	Adjusted R^2
	B	Std. Error	Beta					
(Constant)	-3.168	0.399		-7.939	0	0.748	0.559	0.557
Sex	-0.189	0.044	-0.125	-4.296	**.000*** **			
Height	0.041	0.003	0.499	15.85	**.000*** **			
Weight	0.004	0.001	0.066	2.655	**.008** **			
Age	-0.023	0.001	-0.489	-21.865	**.000*** **			

Note: Dependent Variable: FVC, p-values less or equals to 0.05 considered as significant predictors (Sex, Height, Weight and Age) **p<0.01; ***p<0.001

Table 4b. Forced Expiratory capacity in 1 sec (FEV_1)

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	R value	R^2 value	Adjusted R^2
	B	Std. Error	Beta					
(Constant)	-2.327	0.393		-5.924	0	0.692	0.479	0.477
Height	0.032	0.003	0.424	12.387	**.000*** **			
Weight	0.005	0.001	0.092	3.426	**.001*** **			
Age	-0.022	0.001	-0.52	-21.36	**.000*** **			

Note: Dependent Variable: FEV_1, *p-values less or equals to 0.05 considered as significant predictors (Height, Weight and Age) **p<0.01; ***p<0.001*

Table 4c. FEV1/FVC

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	R value	R^2 value	Adjusted R^2
	B	Std. Error	Beta					
(Constant)	90.297	8.634		10.46	0	0.408	0.166	0.164
Sex	5.358	0.954	0.225	5.62	**.000*** **			
Weight	0.124	0.031	0.134	3.94	**.000*** **			
Age	-0.185	0.023	-0.248	-8.06	**.000*** **			

Note: Dependent Variable: FEV_1, *p-values less or equals to 0.05 considered as significant predictors (Sex, Weight and Age) ***p<0.001*

Table 4d. FEF 25-75:

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	R value	R^2 value	Adjusted R^2
	B	Std. Error	Beta					
(Constant)	-1.82	.733		-2.49	.013	0.522	0.272	0.269
Sex	.173	.080	.082	2.158	**.031** **			
Height	.030	.005	.257	6.298	**.000*** **			
Weight	.007	.003	.082	2.590	**.010** **			
Age	-.029	.002	-.439	- 15.22	**.000*** **			

*Note: Dependent Variable: FEV_1, p-values less or equals to 0.05 considered as significant predictors (Sex, Height, Weight and Age) **p=0.010 ***p<0.001*

Furthermore, significant predictors according to Pearson correlation analysis, linear regression was performed for each parameter to explore the association with Sex, age, height, weight and BMI. However, for all lung function parameter BMI showed non-significant association. Sex, height, weight and age are significant predictors for FVC and FEF 25-75 (Table 4a, 4d). For FEV_1 only height, weight and age are significant predictors (Table 4c). For FEV_1/FVC sex, weight and age are found as significant and potent predictors.

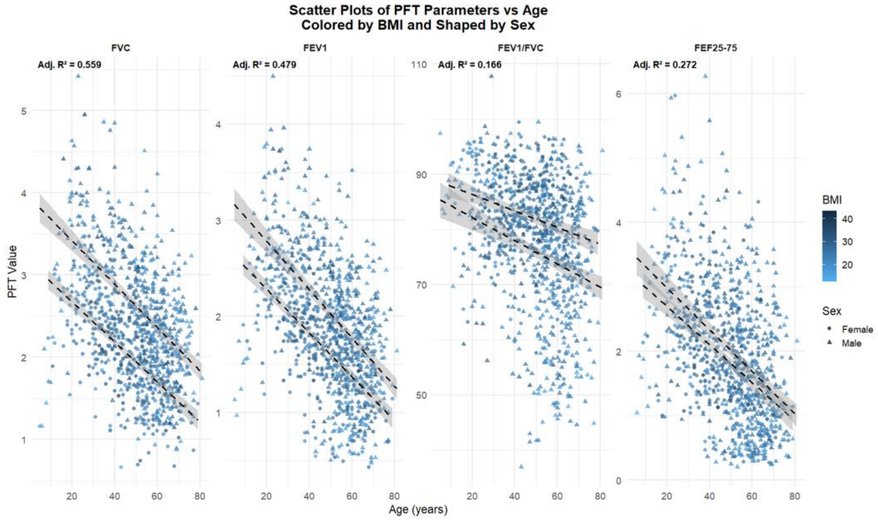

Figure 2. Scatter plot of Adjusted R^2 visualizing the relationship between PFT parameters, age and body mass index (BMI). BMI represented in color (color gradient shown in figure indicating different categories of BMI); Age represented in shape where Circle shape indicates Female subjects and Triangle shape indicates Male subjects.

Table 5. Multivariate and Univariate Effects of Sex and BMI Categories on Pulmonary Function Parameters

(**A) Multivariate Tests (Pillai's Trace)**

Effect	Pillai's Trace	F	Hypothesis df	Error df	p-value	Partial η²
Sex	0.159	44.353	4	940	< .001	0.159
BMI Category	0.024	1.928	12	2826	.027	0.008
Sex × BMI	0.025	1.991	12	2826	.021	0.008

(B) Univariate Tests of Between-Subjects Effects

Dependent Variable	Effect	F	df	p-value	Partial η²	Dependent Variable
FVC	Sex	55.053	1	< .001	0.055	**FVC**
	BMI Category	1.280	3	.280	0.004	
	Sex × BMI	3.714	3	.011	0.012	
FEV_1	Sex	13.746	1	< .001	0.014	**FEV_1**
	BMI Category	1.343	3	.259	0.004	
	Sex × BMI	3.656	3	.012	0.011	
FEV_1/FVC	Sex	58.580	1	< .001	0.058	**FEV_1/FVC**
	BMI Category	4.219	3	.006	0.013	
	Sex × BMI	1.313	3	.269	0.004	
FEF25–75%	Sex	0.615	1	.433	0.001	**FEF25–75%**
	BMI Category	1.298	3	.274	0.004	
	Sex × BMI	1.447	3	.228	0.005	

A) Multivariate analysis

A one-way multivariate analysis of variance (MANOVA) was conducted to examine the effects of Sex, BMI categories, and their interaction on four pulmonary function test parameters: forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), FEV_1/FVC, and forced expiratory flow at 25–75% (FEF_{25-75}) (Table 5). Box's M test indicated a significant violation of the assumption of equality of covariance matrices, *Box's M* = 686.69, *p* .001.

Therefore, Pillai's Trace was used for interpreting multivariate results, as it is more robust to assumption violations.

The MANOVA revealed a significant multivariate effect of Sex on the combined dependent variables, *Pillai's Trace* = .159, $F(4, 940) = 44.35$, $p < .001$, partial $\eta^2 = .159$. There was also a significant multivariate effect of BMI category, *Pillai's Trace* = .024, $F(12, 2826) = 1.93$, $p = .027$, partial $\eta^2 = .008$. Additionally, the Sex × BMI interaction was statistically significant, *Pillai's Trace* = .025, $F(12, 2826) = 1.99$, $p = .021$, partial $\eta^2 = .008$.

B) Univariate Effects

Follow-up univariate ANOVAs revealed the following effects (Table 5) for each dependent variable:

- **FVC**: Significant main effect of Sex, $F(1, 943) = 55.05$, $p < .001$, partial $\eta^2 = .055$; and significant Sex × BMI interaction, $F(3, 943) = 3.71$, $p = .011$, partial $\eta^2 = .012$. The main effect of BMI category was not significant, $F(3, 943) = 1.28$, $p = .280$.
- **FEV_1**: Significant main effect of Sex, $F(1, 943) = 13.75$, $p < .001$, partial $\eta^2 = .014$; and significant Sex × BMI interaction, $F(3, 943) = 3.66$, $p = .012$, partial $\eta^2 = .011$. The main effect of BMI category was not significant, $F(3, 943) = 1.34$, $p = .259$.
- **FEV_1/FVC**: Significant main effects of Sex, $F(1, 943) = 58.58$, $p < .001$, partial $\eta^2 = .058$; and BMI category, $F(3, 943) = 4.22$, $p = .006$, partial $\eta^2 = .013$. No significant Sex × BMI interaction was observed, $F(3, 943) = 1.31$, $p = .269$.

FEF_{25-75}: No significant main effects or interaction were found (all $p > .05$).

Discussion

This cross-sectional study investigated the influence of Sex and BMI categories (Underweight, Normal, Overweight and Obese) on anthropometric data (height, weight), demographic data (age, smoking status) and pulmonary function parameters (FVC, FEV1, and FEV1/FVC) in a large hospital-based Indian population. Our findings emphasize that sex, anthropometry, and age are significant determinants of pulmonary function, while the effect of BMI appears to be more nuanced and dependent on sex. Age emerged as a consistently strong negative predictor of all pulmonary function parameters, in agreement with global data indicating that pulmonary function peaks in early adulthood and declines with age due to structural and physiological changes in the lungs (Miller, 2005; Sharma and Goodwin, 2006). These changes include loss of elastic recoil, decreased chest wall compliance, and degeneration of alveolar attachments, contributing to reduced ventilatory capacity and expiratory flow rates.

Effect of Sex on Pulmonary Function

Consistent with existing literature, our study demonstrated that male participants had significantly higher mean values for FVC and FEV1 across BMI categories compared to females. These differences can be attributed to anatomical and physiological variations between sexes, including larger lung volumes, thoracic dimensions, and airway calibers in males (Quanjer, 2022)

Interestingly, the FEV1/FVC ratio was significantly higher in females, which aligns with studies suggesting that although women have lower absolute lung volumes, they may exhibit relatively preserved airflow (LoMauro, 2018)**.**

The observed sex differences in pulmonary function align with previous literature demonstrating higher lung volumes (FVC and FEV_1) in males compared to females, likely due to larger thoracic dimensions, greater lung surface area, and respiratory muscle mass (Quanjer, 2012; Becklake and Kauffmann, 1999). Hormonal influences such as the anabolic effects of testosterone in males may also contribute to enhanced pulmonary mechanics (LoMauro and Aliverti, 2018).

Interestingly, the higher FEV_1/FVC observed in females corroborates findings from the previous study, which also found better preserved expiratory flows in females despite lower absolute lung volumes (Jithoo, 2013). This highlights the need for sex-specific reference equations in interpreting spirometric data to avoid misclassification of restrictive or obstructive defects.

Effect of height on pulmonary function

As anticipated, height was one of the most potent positive predictors of FVC and FEV_1, reflecting the anatomical basis of pulmonary capacity. Taller the individuals possess longer airways and larger lung volumes as previously reported (Quanjer, 2012; Hankinson, 1999). Weight, although positively correlated with FVC and FEV_1, had a more modest impact, particularly in females, possibly due to the confounding effects of adiposity and lean mass proportions.

These findings are in line with the NHANES III study, which also demonstrated height as the strongest predictor of lung volumes, followed by age and weight (Alam, 2021). In our population, the weight-BMI relationship appears more influential in males, suggesting a differential impact of lean versus fat mass on lung mechanics.

Effect of BMI on Pulmonary Function

BMI was found to have a significant effect only on the FEV1/FVC in the univariate analysis. Notably, individuals in the underweight category exhibited significantly lower FVC values compared to those in the normal BMI category. Previous research has shown that undernutrition may lead to decreased respiratory muscle strength and reduced lung volumes (Collins, 1995). In contrast, while obesity is often associated with a restrictive ventilatory pattern, no significant reduction in FVC or FEV1 was observed in the obese group in our cohort. This may be due to the relatively small sample size in extreme BMI categories or compensatory mechanisms in early-stage obesity (Salome, 2010). The relationship between BMI and lung function was complex and sex-dependent. In males, an increase in BMI was associated with improvements in FVC, FEV_1, and FEF25–75, a pattern also noted in earlier studies that proposed improved respiratory muscle strength and thoracic expansion as possible mechanisms (Biring, 1999; Chen, 2007). However, this pattern was not evident in females, where increased BMI was associated with slightly reduced or stagnant lung volumes, suggesting a more pronounced mechanical restriction by deposition of adipose tissue in females (Jones and Nzekwu, 2006).

These contrasting trends support the notion that the distribution of fat, particularly central adiposity, may play a greater role in reducing lung function than BMI alone indicates. Studies have shown that waist-to-hip ratio or visceral adiposity better predicts ventilatory impairment than BMI (Lazarus, 1997). Future studies need to be done to incorporate body composition measures such as waist circumference or dual-energy X-ray absorptiometry (DEXA) scans.

Sex and BMI Interaction

A significant interaction effect between Sex and BMI was observed for both FVC and FEV1, indicating that the impact of BMI on pulmonary function differs by Sex. Specifically, underweight males had disproportionately lower FVC and FEV1 values compared to their female counterparts. This suggests a possible synergistic vulnerability of respiratory function in underweight males, potentially linked to greater loss of muscle mass or differing fat-to-muscle ratios (Harik-Khan, 2001). Such interaction effects emphasize the need to consider both Sex and BMI simultaneously when interpreting PFT results or designing interventions targeting respiratory health.

Factors affecting FEF25-75

Notably, FEF25–75, a measure of small airway function, showed a particularly steep age-related decline, indicating that aging may disproportionately affect peripheral airway patency, as seen in other epidemiological studies (Thomson, 2012).

The behavior of FEF25–75 across BMI groups was inconsistent, particularly in females, possibly due to the high intra-individual variability of this parameter and its sensitivity to early small airway obstruction (Stanojevic, 2008). FEF 25-75 is a marker for small airway functions. Although traditionally less emphasized, literature suggests that FEF25–75 may detect early airway dysfunction even when FEV_1 and FEV_1/FVC are preserved, especially in obese or aging populations (Aaron, 2017).

In our study, FEF25–75 correlated significantly with height, weight, and age, and was moderately influenced by sex. Given its potential role as an early indicator of airway dysfunction, especially in asymptomatic or preclinical stages, its utility in spirometry reporting deserves more attention in clinical settings.

Clinical Implications and Recommendations

Our findings highlight the necessity of incorporating sex, age, height, and weight into pulmonary function test parameters. While BMI has some utility in population-level assessments, its limitations in predicting individual lung function reinforce the need for more precise body composition metrics. Sex-specific responses to increasing BMI also suggest that weight management strategies may have differing respiratory benefits for males and females.

The incorporation of regional anthropometric profiles is particularly important in the Indian context, where body composition and fat distribution differ significantly from Western populations, often leading to underestimation of health risks when using standard BMI thresholds according to WHO guidelines.

Limitations and Future Directions

BMI, as a surrogate for adiposity, may not accurately capture fat distribution or lean mass. Inclusion of more specific body composition indices (e.g., skinfold measurements, bioelectrical impedance, DEXA) in future studies would offer a more nuanced understanding. Moreover, the study population consisted of individuals undergoing routine hospital-based screening, potentially introducing selection bias and limiting generalizability.

Further longitudinal studies are warranted to assess how changes in weight, aging, or physical training influence lung function trajectories, particularly in obese and elderly individuals.

Conclusion

In conclusion, sex, height, weight, and age are significant determinants of pulmonary function, with distinct sex-specific effects of BMI on lung volumes and airflow. The findings underscore the importance of individualized and population-specific reference standards for spirometry, especially in South Asian populations. The role of BMI as an independent predictor of lung function is limited and should be interpreted in conjunction with other anthropometric measures.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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