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Evaluating Asthma Severity Using Forced Oscillation Technique: A Non-Invasive Insight Into Pulmonary Impedance

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HIGHLIGHTS

1. Non-invasive tool for asthma evaluation
2. Measures respiratory resistance and reactance
3. Detects small airway dysfunction early
4. Useful in pediatric and elderly patients
5. Complementsspirometryinasthma monitoring

Key words:
Bronchial asthma
Forced Oscillation Technique
Pulmonary impedance
Airway resistance
Reactance
Asthma severity
Non-invasive lung function test.

ABSTRACT

Background: Bronchial asthma is a chronic inflammatory respiratory disorder characterized by variable airflow limitation and airway hyperresponsiveness. Accurate assessment of disease severity is crucial for optimal management. Conventional pulmonary function tests (PFTs) such as spirometry are effort-dependent and may be challenging for certain populations. The Forced Oscillation Technique (FOT) offers a non-invasive, effort-independent alternative for evaluating respiratory mechanics, particularly airway resistance and reactance. **Aims:** To evaluate and compare the Pulmonary Impedance in Different Severity Stages of Bronchial Asthma using Forced Oscillation Technique in a Tertiary Hospital. **Materials and Methods:** A hospital-based analytical cross-sectional study was conducted in the Department of Respiratory Medicine, Adesh Institute of Medical Sciences and Research (AIMSR), Bathinda, involving 150 patients aged 18–65 years diagnosed with bronchial asthma. Participants were stratified into mild, moderate, and severe asthma groups based on NAEPP-EPR 3 guidelines. FOT parameters resistance at 5 Hz (Rrs5), resistance at 19 Hz (Rrs19), difference (Rrs5–Rrs19), reactance at 5 Hz (Xrs5), and impedance at 5 Hz (Zrs5)—were recorded using the Resmon Pro device. Statistical analysis was performed using SPSS v25.0, with $p < 0.05$ considered significant. **Results:** The mean age of participants was 41.46 ± 13.9 years, with a female predominance (60%). Allergies (51.3%) and dust/fume exposure (50.7%) were prevalent risk factors. FOT parameters demonstrated a significant correlation with asthma severity. Rrs5, Rrs19, Rrs5–Rrs19, and Zrs5 values increased progressively from mild to severe asthma ($p < 0.01$), while Xrs5 became more negative with increasing severity ($p = 0.043$), indicating reduced lung compliance. **Conclusion:** FOT effectively reflects changes in airway resistance and reactance across varying asthma severities, offering a reliable and non-invasive tool for asthma evaluation and monitoring, especially in patients unable to perform traditional spirometry.

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INTRODUCTION

Breathing is a vital function that sustains life by ensuring a continuous exchange of oxygen and carbon dioxide. This process relies on the seamless coordination of several body systems, including the respiratory, nervous, muscular, and cardiovascular systems. However, various diseases can disrupt this harmony, leading to impaired ventilation and, in severe cases, respiratory failure. Respiratory dise ases are broadly classified into obstructive and restrictive lung diseases. Obstructive conditions, such as asthma, bronchitis, and COPD, restrict airflow by narrowing or blocking the airways. In contrast, restrictive diseases, like pulmonary fib - rosis, limit lung expansion, reducing the volume of air that can be inhaled.

Accurate diagnosis is essential for the effective management of these conditions. Pulmonary Function Tests (PFTs) play a crucial role in identifying respiratory abnormalities, evaluating disease severity, monitoring progression, and guiding therapy [1]. While spirometry remains the most widely used PFT due to its validity and reliability, its dependence on patient cooperation makes it less ideal for certain populations, especially the elderly and very young [2].

Alternative diagnostic methods have been developed to overcome these limitations. Tests like nitrogen washout and whole body plethysmography offer valuable insights but often require expensive equipment, are time consuming, and still rely on active patient participation.

One emerging technique gaining attention is the Forced Oscillation Technique (FOT). First introduced by DuBois in 1956, FOT is a non-invasive, effort-independent method for assessing lung function during quiet, tidal breathing [3]. It involves the application of small pressure oscillations to the airways and measures the resulting pressure-flow relationships to determine pulmonary impedance, comprising resistance (Rrs) and reactance (Xrs) [4]. These parameters offer a detailed picture of airway mechanics, including both central and peripheral airway involvement.

What makes FOT particularly appealing is its simplicity, speed, and minimal patient cooperation requirement, making it ideal for use in children, elderly, and critically ill patients. FOT measurements, such as resistance (Rrs) and reactance (Xrs), reflect various components of airway and tissue mechanics, including compliance, inertance, and elastic recoil.

Asthma, a highly prevalent chronic respiratory condition affecting both adults and children, is characterized by reversible airway obstruction, inflam mation, and remodeling. According to the GINA 2020 guidelines, asthma is a heterogeneous disorder marked by variable respiratory symptoms and airflow limi - tation. Asthma management is based on disease severity, but traditional methods often lack sensitivity in distinguishing between severity stages, especially in subclinical presentations [5].

Despite the potential of FOT, there remains a paucity of data comparing pulmonary impedance values across different asthma severity levels. This study aims to bridge that gap by evaluating and comparing FOT-derived pulmonary impedance parameters in patients with varying severity stages of bronchial asthma in a tertiary care setting. By doing so, we hope to assess the utility of FOT as a supportive tool in asthma classifi - cation and management.

MATERIALS AND METHODS

Study Design and Setting

This hospital based analytical cross sectional study was conducted over a period of 1.5 years in the Department of Respiratory Medicine at Adesh Institute of Medical Sciences and Research (AIMSR), Bathinda, Punjab to evaluate and compare the Pulmonary Impedance in Different Severity Stages of Bronchial Asthma using Forced Oscillation Technique in a Tertiary Hospital.

Study Population

The study included patients diagnosed with bronchial asthma presenting to the Department of Respi - ratory Medicine. A total of 150 patients were enrolled based on a calculated sample size derived from a reported asthma prevalence of 10.3% (CDC, 2020), with 5% precision using an online sample size calculator.

Inclusion Criteria

- Patients of either sex aged between 18 and 65 years.
- Clinically diagnosed cases of bronchial asthma.
- Willingness to participate with informed written consent.

Exclusion Criteria

- Patients with other coexisting major respiratory conditions (e.g., COPD, interstitial lung disease, tuberculosis, chest wall diseases).
- Patients with serious cardiac comorbidities.
- Disoriented or critically ill patients unable to undergo testing.
- Patients unwilling to give consent.

Methodology

A detailed explanation of the study and its proce - dures was provided to all participants. After obtaining informed written consent, relevant patient data were recorded using a predesigned proforma. This included demographic details, clinical history, comorbidities, exposure history, and laboratory investigations.

Asthma severity was classified based on NAEPP-EPR 3 guidelines into three groups:

- **Group 1:** Mild Persistent Asthma
- **Group 2:** Moderate Persistent Asthma
- **Group 3:** Severe Persistent Asthma

Measurement of Forced Oscillation Parameters

Pulmonary impedance was assessed using the Resmon Pro device (Restech SRL, Italy), in accordance with the ATS/ERS guidelines. Patients were instructed to breathe normally through a mouthpiece while seated upright, with nasal clips in place and cheeks supported.

Each patient performed tidal breathing for 30–45 seconds, and artifacts such as coughing or leaks were excluded. The following FOT parameters were recorded:

- **Rrs5** (Resistance at 5 Hz): Total airway resistance.
- **Rrs19** (Resistance at 19 Hz): Resistance of large airways.
- **Rrs5–Rrs19:** Reflects small airway resistance.
- **Xrs5** (Reactance at 5 Hz): Reflects compliance and viscoelastic properties of the lung.
- **Zrs5** (Impedance at 5 Hz): Overall impedance.

Statistical Analysis

Categorical variables were expressed as frequencies and percentages, while quantitative variables were presented as mean ± SD or median (IQR), depending on distribution assessed via Shapiro Wilk test.

Statistical tests used included:

- Independent t-test / ANOVA for normally distributed quantitative variables.
- Mann-Whitney U / Kruskal-Wallis test for non-normally distributed variables.
- Post hoc analysis: Bonferroni correction (normal data) or Dunn's test (non-normal data).
- Chi-square or Fisher's exact test for categorical variables.

RESULTS AND OBSERVATIONS

This study included a total of 150 patients diagnosed with bronchial asthma at the Department of Respiratory Medicine, Adesh Institute of Medical Sciences and Research (AIMSR), Bathinda. The mean age of the study population was 41.46 ± 13.9 years, with the majority of patients falling within the 44–53-year age group (26.7%), followed by 20.7% in the 36–44-year group. Of the 150 participants, 60% were female and 40% were male. A history of smoking was reported in 42.7% of cases, while 51.3% had known allergic conditions. Occupational or environmental exposure to dust or fumes was noted in 50.7% of the participants.

Based on the NAEPP-EPR 3 guidelines, patients were stratified into three clinical severity groups: 37.3% had mild persistent asthma, 44% had moderate persistent asthma, and 18.7% had severe persistent asthma.

The Forced Oscillation Technique (FOT) parameters demonstrated significant variation across the different asthma severity stages. The mean respiratory resistance at 5 Hz (Rrs5), which reflects total airway resistance, increased with disease severity: 6.06 ± 2.24 cmH□O·s/L in mild asthma, 7.22 ± 1.46 cmH□O·s/L in moderate asthma, and 8.19 ± 1.69 cmH□O·s/L in severe asthma ($p = 0.001$). Similarly, resistance at 19 Hz (Rrs19), representing large airway resistance, showed an increase from 3.99 ± 1.42 in mild cases to 4.97 ± 1.22 cmH□O·s/L in severe cases ($p = 0.001$).

The difference between Rrs5 and Rrs19 (Rrs5–Rrs19), indicative of small airway involvement, also increased significantly across groups: from 2.06 ± 1.57 in mild asthma to 3.23 ± 1.68 cmH□O·s/L in severe asthma ($p = 0.001$). Respiratory reactance at 5 Hz (Xrs5), which reflects pulmonary compliance and elastic recoil, became more negative with increasing severity: −3.30 ± 1.49 in mild, −3.85 ± 1.56 in moderate, and −4.13 ± 1.79 cmH□O·s/L in severe asthma ($p = 0.043$), indicating worsening lung elasticity and compliance. Likewise, the overall impedance at 5 Hz (Zrs5) rose progressively from 3.49 ± 1.17 in mild to 4.39 ± 1.90 cmH□O·s/L in severe asthma ($p = 0.002$).

Table 1: Age distribution

Age	Frequency	Percentage
18 to 26 years	22	14.7
27 to 35 years	27	18
36 to 44 years	31	20.7
44 to 53 years	40	26.7
54 to 62 years	21	14
63 to 71 years	9	6
Mean ± SD	41.46 ± 13.9	

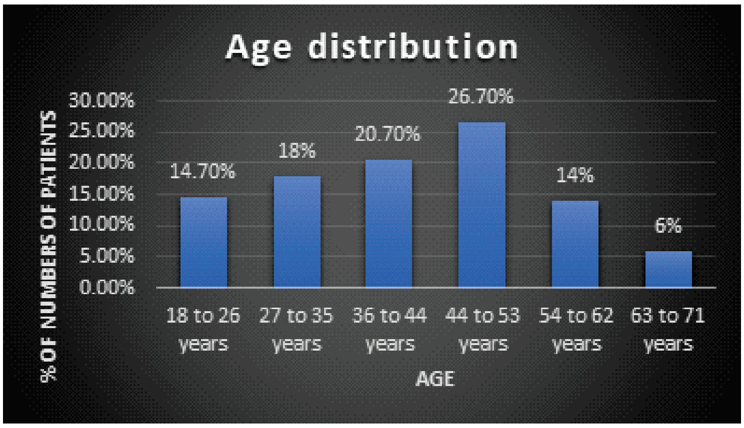

Figure 1: Age distribution

Table 2: Gender distribution

Gender	Frequency	Percentage
Male	60	40.00%
Female	90	60.00%
Total	150	100.00%

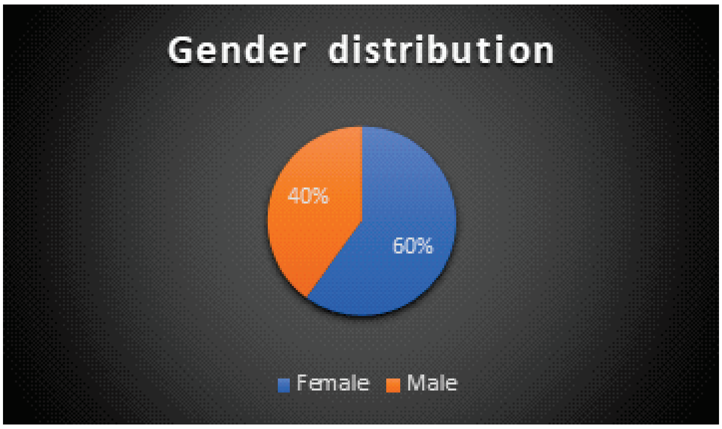

Figure 2: Gender distribution

Smoking	Frequency	Percentage
Present	64	42.7%
Absent	86	57.3%
Total	150	100.00%

Table 3: Smoking distribution

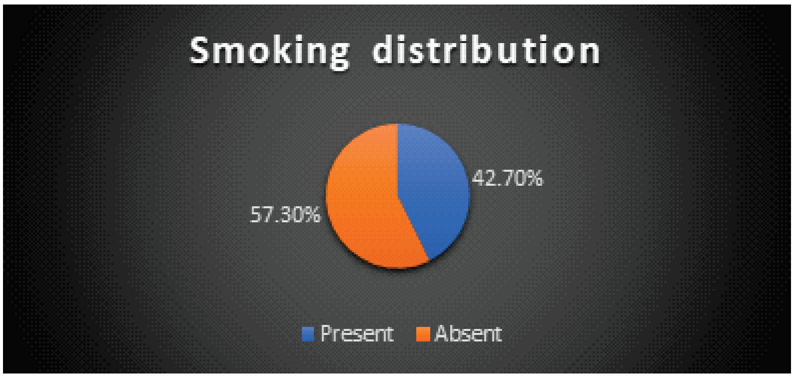

Figure 3: Smoking distribution

Table 4: Allergic distribution

Allergies	Frequency	Percentage
Present	77	51.3%
Absent	73	48.7%
Total	150	100.00%

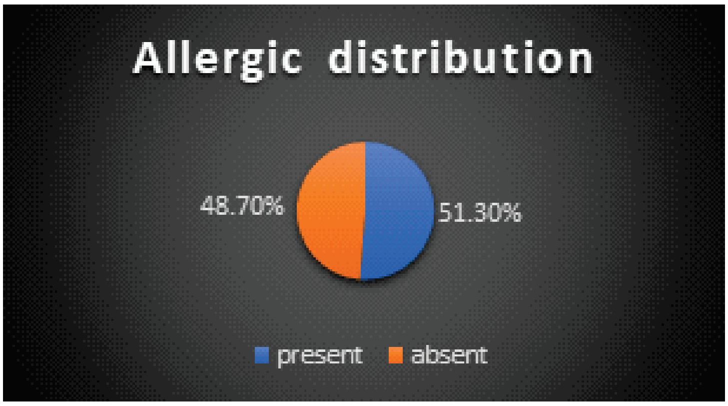

Figure 4: Allergic distribution

Table 5: Dust/ fumes exposure distribution

Dust/fumes exposure	Frequency	Percentage
Present	76	50.7%
Absent	74	49.3%
Total	150	100.00%

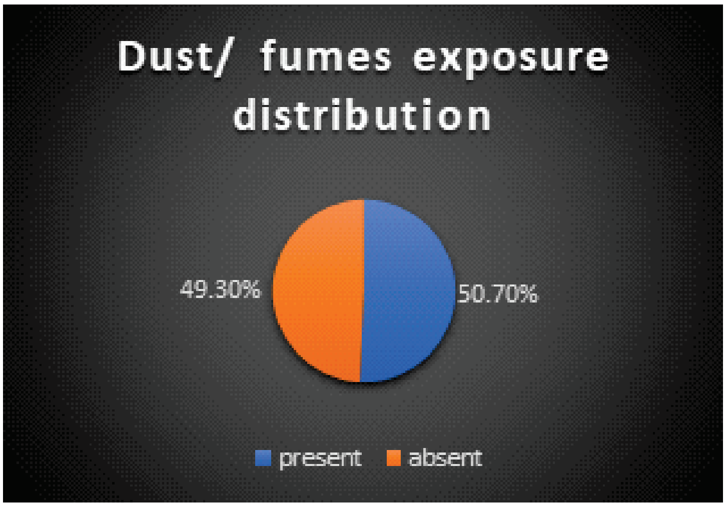

Figure 5: Dust/ fumes exposure distribution

Table 6: Asthma severity distribution

Asthma severity	Frequency	Percentage
Mild asthma	56	37.3%
Moderate asthma	66	44%
Severe asthma	28	18.7%

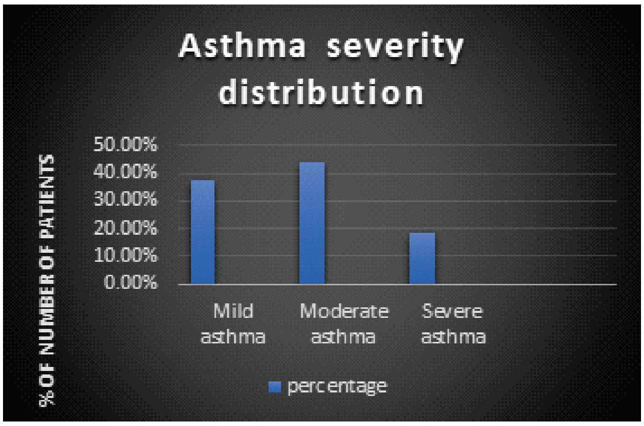

Figure 6: Asthma severity distribution

Table 7: Overall distribution of patients according to their demographic data and clinical severity of Bronchial asthma

CHARACTERSTICS	VALUE
Total subjects	150
Sex(n), (Male/Female)	60/90
Age mean± SD (years)	41.46 ± 13.9
Smoking(n), Present/Absent	64/86
Allergies(n), Present/Absent	77/73
Exposure to dust or fumes(n), Present/Absent	76/74
Clinical severity(n), Mild/Moderate/Severe	56/66/28

Table 8: Comparison of FOT parameters in various severity groups of Bronchial asthma

Clinical severity	Mild asthma (mean±SD) n=56	Moderate asthma (mean±SD) n=66	Severe asthma (mean±SD) n=28	P value
Rrs5, $cmH_2O.s/l$	6.06±2.24	7.22±1.46	8.19±1.69	0.001 (significant)
Rrs19, $cmH_2O.s/l$	3.99±1.42	4.22±1.00	4.97±1.22	0.001 (significant)
Rrs5- Rrs19, $cmH_2O.s/l$	2.06±1.57	3.00±1.64	3.23±1.68	0.001 (significant)
Xrs5, $cmH_2O.s/l$	-3.3±1.49	-3.85±1.56	-4.13±1.79	0.043 (significant)
Zrs5, $cmH_2O.s/l$	3.49±1.17	4.18±0.95	4.39±1.90	0.002 (significant)

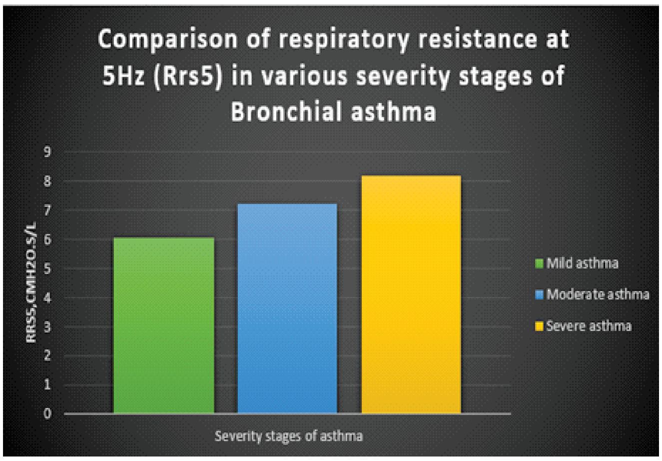

Figure 7: Comparison of respiratory resistance at 5Hz (Rrs5) in various severity stages of Bronchial asthma

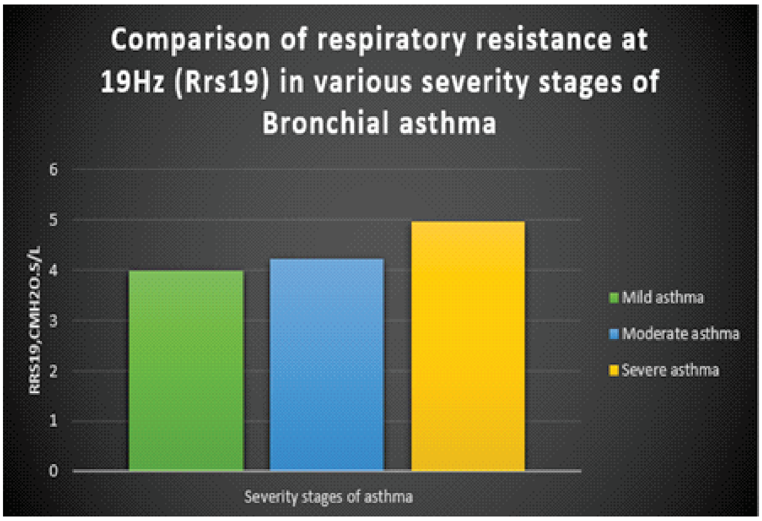

Figure 8 : Comparison of respiratory resistance at 19Hz (Rrs19) in various severity stages of Bronchial asthma

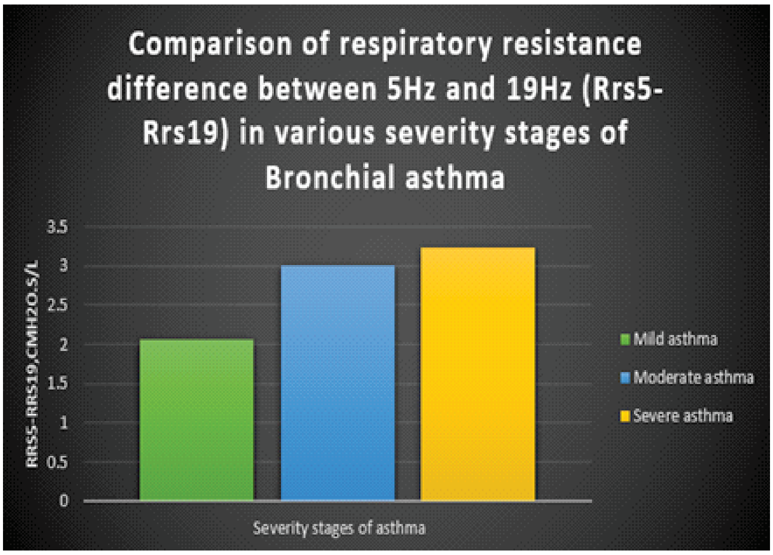

Figure 9 : Comparison of respiratory resistance difference between 5Hz and 19Hz (Rrs5-Rrs19) in various severity stages of Bronchial asthma

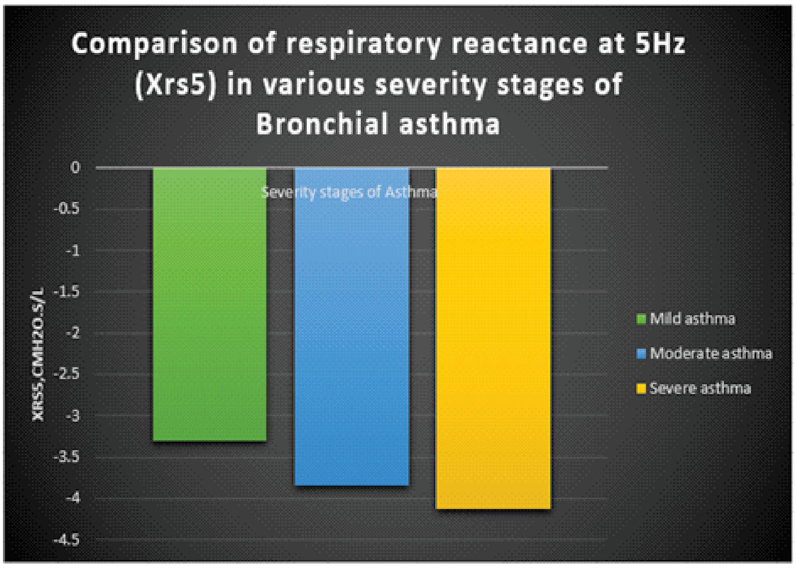

Figure 10 : Comparison of respiratory reactance at 5Hz (Xrs5) in various severity stages of Bronchial asthma

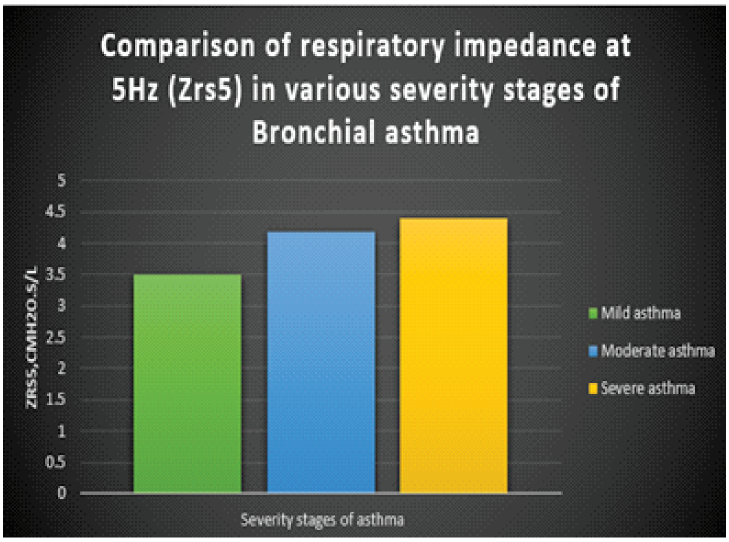

Figure 11 : Comparison of respiratory impedance at 5Hz (Zrs5) in various severity stages of Bronchial asthma

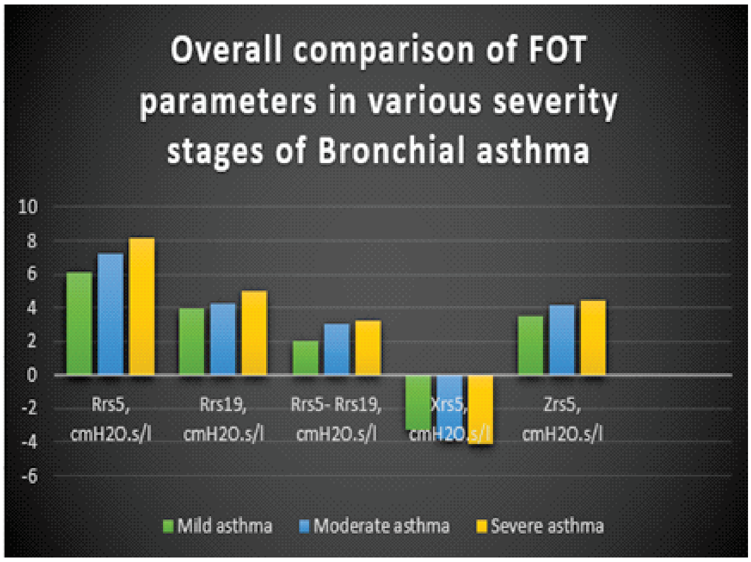

Figure 12 : Overall comparison of FOT parameters in various severity stages of Bronchial asthma

DISCUSSION

This study evaluated pulmonary impedance parameters using the Forced Oscillation Technique (FOT) across varying severity stages of bronchial asthma in a cohort of 150 patients. The mean age of participants was 41.46 years, with the highest representation in the 44–53-year age group. This suggests that middle-aged adults may be more likely to experience symptomatic asthma or seek medical care, consistent with findings by Kanani et al. (2005), who reported a similar age distribution [6]. These patterns underscore the importance of targeting this demographic for early screening and intervention.

A notable female predominance (60%) was observed, aligning with data from the 2012 National Health Interview Survey (CDC), which noted higher asthma prevalence among females post-puberty [7]. This gender difference may also explain the relatively lower prevalence of smoking (42.7%) observed in our cohort, as smoking rates tend to be lower in females. Engelkes et al. (2020) and Jaakkola et al. (2019) also highlighted that allergic tendencies and exposure to dust or fumes reported by 51.3% and 50.7% of participants in our study, respectively are significant exacerbating factors in asthma [7-8].

Patients were stratified into three clinical categories based on the NAEPP-EPR 3 guidelines: mild (37.3%), moderate (44%), and severe (18.7%) asthma. This distribution mirrors findings by Zureik et al. (2002), who reported that the majority of asthmatic patients fell within mild to moderate severity, emph - asizing the chronic and often underdiagnosed nature of the condition [10].

The core objective of this study was to evaluate pulmonary impedance parameters—specifically resistance (Rrs), reactance (Xrs), and impedance (Zrs)—in relation to asthma severity. Rrs5 and Rrs19 represent total and large airway resistance, respe - ctively, while the difference (Rrs5–Rrs19) indicates small airway involvement. Xrs5 reflects the elastic and inertial properties of the lungs, and Zrs5 represents overall impedance.

FOT data demonstrated a clear and statistically significant increase in airway resistance with advancing asthma severity. Resistance at 5 Hz (Rrs5) rose progressively from mild to severe asthma, paralleled by a similar trend in Rrs19. This suggests worsening obstruction in both central and peripheral airways as the disease becomes more severe. These findings are consistent with the results of Balasun daran et al. (2023), who also reported a rise in resistance values across asthma severity grades [11].

Reactance at 5 Hz (Xrs5) showed a significant decline with increasing disease severity, indicating diminished lung compliance and elastic recoil. The trend observed more negative Xrs5 values in severe asthma highlights worsening lung mechanics and altered viscoelastic properties. These observations are corroborated by Kanda et al. (2010), who similarly noted declining Xrs5 values in patients with more severe forms of asthma [12].

Furthermore, impedance (Zrs5), which reflects the total opposition to airflow, increased signifi cantly from mild to severe asthma. This supports the interpretation that the overall respiratory system mechanics deteriorate with disease progression. The graphical data presented in Figure 12 effectively illustrated these trends, with Rrs5 and Zrs5 highest in severe asthma and Xrs5 most negative in severe cases, thus reinforcing the role of FOT in objectively assessing asthma severity.

In conclusion, this study demonstrates that FOT is a sensitive, non-invasive tool capable of detecting and differentiating airway mechanical changes across asthma severity levels. The significant corre - lation between clinical severity and FOT parameters suggests its potential value not only in diagnosis but also in monitoring treatment response and disease progression in bronchial asthma.

CONCLUSION

This study highlights the clinical utility of the Forced Oscillation Technique (FOT) in evaluating pulmonary impedance across different severity stages of bronchial asthma. The findings demon strated a clear and statistically significant association between increasing asthma severity and worsening FOT parameters, including elevated airway resistance (Rrs5, Rrs19), reduced lung reactance (Xrs5), and increased overall impedance (Zrs5). These changes reflect progressive deterioration in airway mechanics, particularly involving both central and peripheral airways as well as lung compliance. Given its non-invasive nature and minimal patient effort requirement, FOT emerges as a valuable diagnostic and monitoring tool, especially for patients who may not be able to perform conve-ntional pulmonary function tests. Incorporating FOT into routine asthma assessment may enhance early detection, guide severity-based management, and improve long-term outcomes in asthma care.

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