Original Article

Lung Oscillometry: A Practical Solution for Overcoming Spirometry Challenges

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Abstract

Background: Lung oscillometry is an alternative pulmonary function test in patients unable to perform spirometry due to cough or dyspnea. **Objective:** The objective of the study was to study the characteristics of lung oscillometry parameters in patients with cough or dyspnea and who are unable to perform spirometry. **Methodology:** A retrospective cross-sectional study Was conducted in a pulmonology outpatient clinic. Patients during the study period were selected for lung oscillometry after fulfilling the inclusion and exclusion criteria. The resistance and reactance parameters were measured along with the demographic variables. Statistical calculations were done. **Results:** Forty-two percent patients were found to have airway obstruction if the recommended cutoff for resistance at 5 hertz (R5) was followed. However, reactance parameters were abnormal in most of the cases. The area of reactance (Ax) had a very good coefficient of correlation with R5 (0.867, $P = 0.001$). **Conclusions:** Ax is a suitable lung oscillometric parameter for identifying airway obstruction in asthmatics.

Keywords: *Forced oscillation technique, impulse oscillometry, lung oscillometry, spirometry*

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Introduction

Obstructive airway diseases represent a significant portion of outpatients seen in pulmonary medicine departments. Spirometry is widely accepted as a reliable tool for their diagnosis, assessment, and follow-up. Forced expiratory maneuvers were introduced in the 1950s,[1] more than a century following John Hutchinson's invention of the spirometer.[2] During forced expiration, airflow depends entirely on airway resistance and lung elasticity, the parameters for evaluating various lung diseases, primarily obstructive diseases. Spirometry has very good reproducibility, solidifying its position in international guidelines.[3]

In a clinical context, the popularity of spirometry increased with the availability of various handheld devices and affordable models. However, in primary care settings, the procedure often does not meet its acceptability criteria which could impact the clinical diagnosis.[4] About 30% of elderly patients are not able to perform good spirometry.[5] Furthermore, spirometry is impractical in extreme age groups, in patients with various physical disabilities, and has a list of contraindications.[6]

In addition to its numerous contraindications and limitations with small children, clinicians encounter challenges when patients exhibit symptoms such as a persistent cough or dyspnea. Obstructive airway diseases, which require spirometry, frequently manifest with these symptoms. These limitations can not only hinder diagnosis but can also pose ethical problems related to patient discomfort and safety during the test. Despite being a problem frequently encountered by clinicians, it appears to have been largely overlooked by researchers. The challenges associated with performing spirometry seem to be accepted as a given.

Lung oscillometry offers a promising alternative to spirometry for assessing lung function.[7] It is a noninvasive technique to assess the mechanical

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properties of the respiratory system. During oscillometry, a stimulus is administered to the respiratory system via the mouth. The stimulus signal can be either pressure or flow oscillations, or the resulting response, be it flow or pressure, is gauged accordingly. The proportion of oscillatory pressure to oscillatory flow resulting from this stimulus is utilized to compute input impedance, which encapsulates the comprehensive mechanical characteristics of the respiratory system. Thus, oscillometry assesses the mechanical impedance of the respiratory system (Zrs), encompassing the resistive (Rrs) and reactive (Xrs) forces necessary to propel an oscillating flow signal through the respiratory system.

A tidal volume breathing is sufficient for this test and this minimal patient effort makes it more tolerable for patients with respiratory symptoms like cough or dyspnea. There are two types of oscillometry devices – impulse oscillometry (IOS) and forced oscillation technique (FOT). In the IOS, a low-frequency square wave is transmitted which is mathematically decomposed into different frequencies. FOT transmits sound waves of different frequencies sequentially and the pressure oscillations are sinusoidal. In the pseudorandom noise type of FOT, several frequencies are applied simultaneously at prime numbers.

In addition, lung oscillometry gives a broader picture of airway mechanics by measuring both resistance and reactance.[8] Resistance parameters (R5, R19, and R5–R19) indicate airway narrowing, and reactance parameters (X5, area of reactance [Ax], and Fres) reflect elastic recoil of the peripheral lung units. Oscillometry can identify whether the large airway or the small airway is affected from the above parameters.[9] Studies also suggest that oscillometry is more sensitive than spirometry in detecting early asthma and small airway disease asthma.[10] Al-Mutairi *et al*.[11] observed comparable results between oscillometry and spirometry. Nikkhah *et al*.[12] found oscillometry superior in patients with acute respiratory symptoms, where spirometry was impractical. Oscillometry also performed well in assessing asthma control in a clinical setting.[13] It is a viable alternative for diagnosing asthma.[11]

In outpatient settings like those in Kerala, where patients frequently present symptoms directly to specialist doctors, an easily accessible screening method for airway obstruction is useful. Spirometry may not always be practical. A peak flow meter is easy to use, however, studies indicate that peak expiratory flow rate (PEFR) might not consistently align with forced expiratory volume in 1 s, potentially leading to inaccuracies in the assessment of airway obstruction.[14,15] Oscillometry testing holds potential promise in this context, offering a more effective alternative to PEFR estimation and is easy to perform.[16] Oscillometry offers valuable insights into airflow obstruction in par with or more than spirometry.

Oscillometry, however, presents certain limitations.[17] First, due to a lack of extensive publications (compared to spirometry), there are gaps in our understanding and interpretation of its results. This means further studies are needed to unlock its full potential. Second, international guidelines still rely on spirometry. Finally, oscillometry devices are not as commonly available as spirometry and this impacts their availability, especially in resource-limited settings. Normal oscillometric values vary between IOS and FOT devices.[18] Minor variations in values may occur among different FOT devices.

Study objectives

1. To explore the distribution and characteristics of lung oscillometry parameters (R and X) in adult asthmatics unable to perform spirometry
2. To assess the correlation between resistance parameters (R_5, R_{19}, and R_5–R_{19}) and reactance parameters (X_5, Ax, and Fres).

Study design

A retrospective cross-sectional study.

Methodology

Study population

All the patients aged 18 years or older, clinically diagnosed with asthma by a pulmonologist, and who were unable to perform spirometry due to cough or dyspnea during their outpatient visit at the pulmonary outpatient care facility between January 18, 2024, and April 30, 2024.

Study setting

This study was conducted at a pulmonary outpatient care facility in Kerala, South India.

Inclusion criteria

1. Patients diagnosed with asthma by a pulmonologist clinically. Criteria used for diagnosis were symptoms of wheezing and/or cough, at least of 1-year-duration, and bilateral rhonchi on examination
2. Age 18 years or older
3. Unable to perform spirometry.

Exclusion criteria

1. Current smokers or ex-smokers of more than 5 pack years
2. Patients with heart failure, chronic kidney disease, or chronic obstructive pulmonary disease
3. Patients with clinical features of acute or lower respiratory tract infection

4. Patients with an abnormal chest X-ray
5. Unacceptable oscillometry test.

Sampling technique

Data were collected from all patients who attended the outpatient care facility during the study period and who met the inclusion and exclusion criteria. An oscillometry test was carried out in the study group using the FOT device, Antlia Pro, Icaltech, India. It was carried out as per European Respiratory Society (ERS) specifications and standards.[8]

Study procedure

Patients coming to the pulmonary outpatient care facility with dyspnea, wheezing, or cough were evaluated by clinical examination, chest X-ray, and other indicated tests. Then, they were advised a pulmonary function test. For those patients not able to perform spirometry, oscillometry was done. Patients were given an account of the test procedure before commencing the test. The test was done in the sitting position. The FOT device with the mouthpiece connected was placed in the patient's mouth. The bacterial filter was used in the mouthpiece to ensure patient's safety. The patient was instructed to breathe normally through his/her mouth with a nose clip, ensuring all airflow goes through the device during the test. The test took <5 min to complete.

Records of oscillometry test results from the pulmonary outpatient care facility were screened to identify adult asthmatic patients who visited between January 18, 2024, and April 30, 2024. Identified patients were assessed against the inclusion and exclusion criteria. Once eligible patients were identified, their electronic medical records were viewed to collect the following data: age, gender, height, weight, body mass index (BMI), and FOT parameters [Table 1]: resistance (R5, R19, and R5–R19) and reactance (X5, Ax, and Fres). The collected data were analyzed after the study period using SPSS for Windows, version 20; SPSS Inc., Chicago, IL, USA.

Results and Analysis

Table 2 shows the characteristics of the demographic and oscillometric parameters. The total number of participants was 100. The mean age was 43.18 years, with a standard deviation (SD) of 15.503. There were 77 female participants and 23 male participants. The mean BMI was 27.4, with an SD of 4.6475. The mean values of the reactance parameters were twice or more than the cutoff value (in the case of X5, it was more negative), whereas the mean values of the resistance parameters were just below the cutoff values.

Airway obstruction is defined as an increase in R5 above the cutoff value of 4 cm H_2O/L/s.[19] Only 42 patients had R5 values above this value. However, 51 patients had R19 values above the cutoff of 3 cm H_2O/L/s, and 35 patients had R5–R19 values above the cutoff of 1 cm H_2O/L/s [Table 3]. If airway obstruction is defined in terms of any one of the resistance parameters above the cutoff value, then 71 out of 100 patients have obstruction [Table 4].

The reactance parameters appeared abnormal in most patients [Table 3]. Fres exceeded the cutoff value in all 100 patients, Ax in 99 patients, and X5 in 94 patients (n = 100).

Lung oscillometry distinguishes large airway obstruction from small airway obstruction based on the changes in

Table 1: Resistance and Reactance parameters

Abbreviation	Description
R5	Resistance at 5 Hz
R19	Resistance at 19 Hz
R5–R19	Difference between R5 and R19
X5	Reactance at 5 Hz
Ax	Area of reactance
Fres	Resonant frequency

Table 2: Characteristics of the demographic and oscillometric parameters

Characteristics	Mean±SD	Range
Age (years)	46.18±15.503	19–83
Gender (male:female)	23:77	
Height (cm)	156.60±8.080	137–180
BMI (kg/m^2)	27.379±4.6475	19.4–42.25
R5 (cmH_2O/L/s)	3.9344±1.02719	2.04–8.36
R19 (cmH_2O/L/s)	2.9838±0.71438	1.27–4.68
R5–R19 (cmH_2O/L/s)	0.9537±0.71081	0.01–4.99
X5 (cmH_2O/L/s)	−2.1860±1.44912	−0.3–−13.69
Ax (cmH_2O/L)	21.2291±14.51151	3.75–108.87
Fres (Hz)	23.4492±4.22644	14.96–34.75

BMI: Body mass index, SD: Standard deviation

Table 3: Number and percentage of patients whose resistance and reactance values exceeding the recommended cutoffs[19] (n=100)

	Cutoff value	n (%)
R5 (cmH_2O/L/s)	4	42 (42)
R19 (cmH_2O/L/s)	3	51 (51)
R5–R19 (cmH_2O/L/s)	1	35 (35)
X5 (cmH_2O/L/s)	−1	94 (94)
Ax (cmH_2O/L)	4	99 (99)
Fres (Hz)	12	100 (100)

Table 4: Airway obstruction defined in terms of any one of the resistance parameters exceeding the cutoff value

	n (%)
Airway obstruction (n=100)	71 (71)

R5, R19, and R5–R19. If R5 and R19 are increased equally, it indicates large airway obstruction. If R5 is increased but R19 is not, resulting in a high R5–R19, it indicates small airway obstruction. If all parameters are increased, it indicates both large and small airway obstruction.[20]

Table 5 shows the number of patients with each of the three types of airway obstruction in this study group based on the above classification.

Table 6 shows the percentage of patients detected by abnormal R5 when the cutoff value is set lower (3.5 and 3).

Table 7 presents the correlation and significance between each of the resistance parameters and each of the reactance parameters. X5 exhibits a strong negative correlation (−0.812, P = 0.001), while Ax shows a strong positive correlation (0.852, P = 0.001) with R5–R19. However, the correlation of X5 and Ax with R19 is notably less. There is a mild correlation between R5 and R19 and Fres (0.270, P = 0.007), as well as between R19 and Fres (0.266, P = 0.007). The correlation between R5 and X5 demonstrates a strong negative correlation, and that between R5 and Ax [Diagram 1] displays a strong positive correlation (−0.725 and 0.867, respectively, P = 0.001). The correlation between R5 and Fres shows a moderate strength (0.376, P = 0.001).

Table 8 illustrates the correlation between R5 and the reactance parameters in patients with low R5–R19 values (0.5 or less). This examines the correlation of R5 with the reactance parameters independently of an increased R5–R19. Ax demonstrates a good correlation with R5, although to a lesser extent than in the entire study group (0.613, P = 0.002). The negative correlation between R5 and X5 in this group is minimal (−0.151), although not statistically significant.

Table 5: Types of airway obstruction according to the recommended cutoff values[19] (*n*=42)

	n (%)
Large airway obstruction	18 (42.86)
Small airway obstruction	8 (19.05)
Large and small airway obstruction	16 (38.09)

Table 6: Airway obstruction defined by lowering the cutoff value for R5 (*n*=100)

	n (%)
4 (cmH_2O/L/s)	42 (42)
3.5 (cmH_2O/L/s)	66 (66)
3 (cmH_2O/L/s)	84 (84)

Table 7: Correlation between resistance and reactance parameters among the study population (*n*=100)

	X5	Ax	Fres
R5	−0.725 (0.001)	0.867 (0.001)	0.376 (0.001)
R19	−0.241 (0.016)	0.410 (0.001)	0.266 (0.007)
R5–R19	−0.812 (0.001)	0.852 (0.001)	0.270 (0.007)

Table 8: Correlation between R5 and reactance parameters in patients with R5–R19 value of 0.5 or lower (*n*=23)

	X5	Ax	Fres
R5	−0.151 (0.490)	0.613 (0.002)	0.468 (0.024)

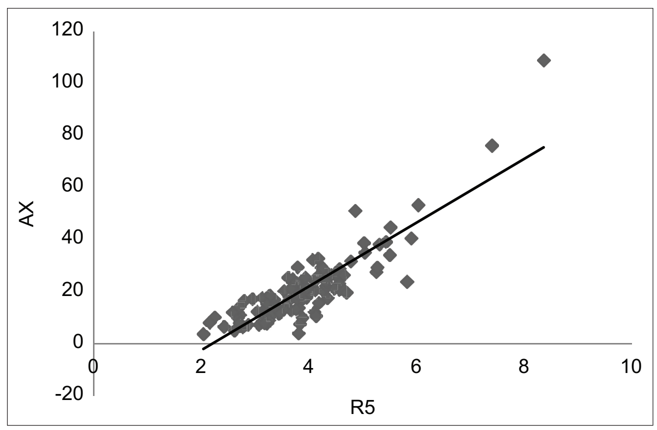

Diagram 1: Strong correlation (0.867 P = 0.001) between R5 and Ax

Discussion

In this study group of 100 patients, 77 were female and 23 were male. The literature describes a female preponderance among adult asthmatics, attributed to sex hormones, socioeconomic factors, and indoor air pollution.[21] The mean BMI was 27.4, and asthma prevalence has been found to be higher in obese adults compared to lean adults.[22]

Regarding airway obstruction, only 42% of patients met the cutoff criteria for R5.[19,20] Salvi *et al*.[19] suggested a cutoff value of 4 cm H_2O/L/s for R5, but remarked that further fine-tuning may be needed based on additional data. Based on these study data, lowering the cutoff to 3.5 increased obstruction detection to 66%, while lowering it to 3 raised detection to 84%. However, a conclusive assessment requires a study involving normal healthy adults and patients with varying pulmonary diseases.

Among the 42 patients with R5 above 4, 18 (42.86%) had large airway obstruction, 8 (19.05%) had small airway obstruction, and 16 (38.09%) had both. In an IOS study, R20 (similar to R19 in this study) demonstrated the strongest correlation with asthma severity.[23]

Considering either R19 or R5–R19 exceeding the cutoff as obstruction (without considering the cutoff for R5) improves the detection rate in this study to 71%.

Statistically significant correlations between the resistance parameters and each of the reactance parameters are found in this study. Ax, reflecting the elastic properties of lung parenchyma and peripheral airways, showed abnormal values in 99% of the 100 patients studied. Notably, Ax exhibited a strong correlation with R5 (0.867, P = 0.001). In contrast, although Fres was abnormal in all patients, its correlation with R5 was only moderate (0.376, P = 0.001). Eddy *et al*.[24] found that Ax is a sensitive indicator for airway obstruction, although it lacks specificity. Through multiple logistic regression analysis, Kim *et al*.[25] showed that Ax could indicate asthma even in patients with preserved lung function. Ax has also been found to be useful in monitoring treatment response in asthma.[26]

X5, abnormal in 94% of patients (more negative than the cutoff of -1), correlated well with R5 (−0.725, P = 0.001), albeit less than Ax.

The study revealed a strong correlation between R5 and R19 with both X5 and Ax (correlation coefficients of −0.812 and 0.852, respectively, both with P = 0.001). However, the correlation with Fres (resonant frequency) was 0.270 only (P = 0.007). R5–R19, X5, and Ax are closely related to small airway obstruction.[7]

R19 (resistance at 19 Hz) moderately correlated with Ax (0.410, P = 0.001) and slightly with X5 (−0.241, P = 0.016). As expected, large airway narrowing is less likely to affect the reactance parameters.

A subgroup of patients with R5–R19 values of 0.5 or less was also analyzed to mitigate the impact of abnormal R5–R19 on the reactance parameters. The correlation remained strong with Ax (0.613, P = 0.002), while the correlation with X5 was only −0.151, but this was not statistically significant.

Limitations of the study

1. This is a retrospective cross-sectional study without a calculated sample size
2. Healthy subjects or patients with other respiratory diseases were not included in this study. The aim is to present oscillometric data and determine if the available cutoffs, based on the study by Salvi *et al*.,[19] are useful for this group of clinically diagnosed asthma patients, who would otherwise be managed without a spirometry test
3. Bronchodilator reversibility testing was not done as definite guidelines are not available for oscillometry[8]
4. Spirometry was not conducted. It was either impractical or the patients were having symptoms of cough and/or dyspnea, making an acceptable spirometry test impossible.

Conclusions

1. Adult asthmatic patients may not always be able to perform spirometry due to symptoms such as cough and breathlessness
2. A technically acceptable lung oscillometry is easy to perform in these situations
3. Resistance parameters are specific for airway obstruction and can distinguish between large and small airway obstruction. The sensitivity for detecting obstruction depends on the cutoff value of R5. Further studies are needed to determine this value
4. Reactance parameters, though not specific for airway obstruction, are very sensitive. Among these, Ax is found to be the most useful parameter for the clinician treating patients with asthma. Further studies are needed in this area.

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Conflicts of interest

There are no conflicts of interest.

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