

Lung Oscillometry: New hope in asthma diagnosis in children

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Abstract

Asthma is the most common chronic respiratory disease in children, with a rising prevalence in Bangladesh. The diagnosis of asthma in young children is always challenging. Spirometry, the gold standard test for asthma is suitable only for older children as its applicability is limited in young children due to the need for active cooperation and forced respiratory manoeuvres. Lung oscillometry, is an emerging non-invasive method that evaluates the mechanical properties of the respiratory system during tidal breathing. It is a simple, non-invasive test where a pressure wave generated by external source is given to the airway through the mouth and pressure-flow relationship is analysed to calculate impedance of the respiratory system. Oscillometry is particularly advantageous in children above 3 years of age and in patients unable to perform spirometry, as it requires minimal cooperation and tidal breathing. Key indices such as resistance (Rrs), reactance (Xrs), resonant frequency (Fres), and reactance area (AX) provide information on subtle changes of small airway dysfunction and bronchodilator reversibility. Despite its strengths, challenges remain, including lack of standardized reference values, inter-device variability and the need for validated cut-off thresholds for bronchodilator responsiveness. Further research is required to establish regional normative data, standardize equipment and interpretation protocols. This review summarizes the principles, historical development, procedure, measured parameters, quality control criteria, reference values, bronchodilator response and clinical utility of lung oscillometry in paediatric practice.

Keywords: Lung Oscillometry, Asthma, Children.

Introduction

Asthma is reported to be the most common chronic respiratory disease in children and its prevalence is increasing over last few decades in Bangladesh.¹ The diagnosis of asthma in young children remains challenging because no single confirmatory test is available. Therefore, in children with a suggestive history and compatible clinical findings, the diagnosis is often supported by a favourable response to a therapeutic trial of inhaled corticosteroids administered for approximately 2–3 months.² Spirometry remains the gold-standard objective test for the diagnosis of asthma because standardized protocols for its performance and interpretation are well established, despite several limitations in children, particularly younger children who may have difficulty performing the manoeuvres correctly.³ Lung oscillometry is an emerging technique that is increasingly being incorporated into clinical pulmonary function laboratories and serves as a generic term encompassing both the forced oscillation technique (FOT) and impulse oscillometry (IOS).⁴ Lung oscillometry measures airway resistance by transmitting sound waves of different frequencies (5–20 Hz) into the lungs during normal tidal breathing. Forced oscillation technique (FOT) and impulse oscillometry (IOS) are closely related, non-invasive methods used to assess the mechanical properties of the respiratory system. The main difference between them lies in the type of sound wave used. FOT applies sinusoidal waves of a single frequency, whereas IOS uses pressure impulses containing multiple frequencies simultaneously.⁵

Lung Oscillometry uses pressure wave generated by external source, given to the airway through the mouth. The pressure-flow relationship is analyzed to find out impedance of the respiratory system. The resistance to flow is sum of frictional losses in the airway, compliance and inertia of the lung tissue. The measurement therefore can be performed in children who are above the age of three years.⁶

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History

Oscillometry was first described by DuBois and colleagues in 1956 as a method for measuring the mechanical properties of the lungs and chest wall. Although the technique was largely overlooked for several years, it gained clinical recognition during the 1990s and has become an important tool for diagnosing and monitoring asthma, particularly in children.⁷

Advantages over spirometry

Oscillometry is more sensitive than spirometry for detecting peripheral airway obstruction and may better reflect changes in the elastic properties of the respiratory system associated with restrictive lung diseases. In comparison with spirometry, oscillometry generates fewer aerosols and requires only quiet tidal breathing with minimal patient cooperation, making it particularly useful in young children, elderly individuals, postoperative patients, and patients with neuromuscular or intellectual disabilities.⁸

Procedure

In the forced oscillation technique (FOT), pressure waves are applied at the mouth and travel through the airways, causing the lung tissues to expand and recoil. The returning signals are then analysed to assess airway function. Low-frequency waves (around 5 Hz) reach the peripheral airways, whereas high-frequency waves (around 20 Hz) mainly assess the larger, proximal airways because of the structural properties of the respiratory tract.⁹

Preparation and calibration

The oscillometry device should be calibrated according to the manufacturer's recommendations, and a daily load test should be performed to ensure optimal performance. Bronchodilator medications should be withheld before the procedure (short-acting β_2 -agonists for at least 4 hours and long-acting β_2 -agonists for at least 24 hours). The procedure should be explained clearly to the patient and caregivers, and demographic and anthropometric data should be entered into the system.^{5,10}

Patient positioning

The patient should sit comfortably in an upright position with the head slightly extended and the feet resting on the floor. A nose clip is applied, and the patient is instructed to seal the lips firmly around the mouthpiece to prevent air leakage. The cheeks should be supported by either the patient or a caregiver because movement of the cheeks can affect the measurements, particularly in children.^{1,11}

Measurement

After correct positioning has been achieved, the patient is asked to breathe normally and quietly through the

mouthpiece. Measurements are generally obtained during tidal breathing, and at least three technically acceptable recordings are recommended. In children younger than 12 years of age, a recording period of approximately 16 seconds is considered adequate, whereas a recording time of about 30 seconds is recommended for adults.^{12,13}

Table 1: Acceptability criteria for FOT: All of the following are required¹⁰

Domain	Criteria
Patient position	Sitting position at comfortably Back straight with slightly extended neck Legs uncrossed Cheek firmly supported
Patient-machine interface	Tight seal around mouthpiece No artefact due to irregular breathing efforts, tongue obstruction, swallowing, speaking or coughing during maneuver or glottis closure

Only measurements that meet the acceptability criteria are included in the analysis. Recordings affected by coughing, swallowing, crying, irregular breathing, tongue obstruction, glottic closure, air leakage, or poor technique are excluded. At least three acceptable manoeuvres are obtained, and the coefficient of variation (CoV) is assessed to ensure reproducibility. Parameters such as respiratory resistance, reactance, resonant frequency, and reactance area are then recorded. The test is repeated approximately 15 minutes after administering an inhaled short-acting β_2 -agonist to assess bronchodilator responsiveness.^{5,11}

Parameters measured

Lung oscillometry measures respiratory impedance using sound waves of different frequencies (5–20 Hz). Resistance and reactance measured at 5 Hz are termed R5 and X5, respectively. Low-frequency waves (5 Hz) reach the peripheral airways and reflect the function of the entire respiratory system, whereas high-frequency waves (20 Hz) mainly assess the central airways. Consequently, abnormalities in the peripheral airways affect R5 and X5, while central airway obstruction is usually indicated by an increased R20.^{14,15}

Respiratory impedance (Zrs): Lung oscillometry measures respiratory impedance (Zrs), which consists of two components: resistance (R) and reactance (X). Resistance reflects the degree of airway narrowing, whereas reactance reflects the elastic and inertial properties of the lungs and chest wall.^{6,9,16}

Resistance (R): Resistance is a measure of airflow limitation within the respiratory system and includes the contribution of both the central and peripheral airways. It is calculated from the pressure and airflow signals generated during normal breathing. An increase in resistance generally indicates airway obstruction.^{6,9,16}

Reactance (X): Reactance reflects the ability of the lungs to expand and recoil. It is influenced by the elasticity of the lung tissue and the inertia of the moving air column. At lower frequencies, reactance is particularly useful for assessing peripheral airway function. More negative values usually indicate greater airway obstruction.^{6,9,16}

Resonant frequency (Fres): The resonant frequency (Fres) is the frequency at which the elastic and inertial forces of the respiratory system balance each other, resulting in a reactance value of zero. An increase in Fres is often associated with airway disease.^{6,9,16}

Area of reactance (AX): The area of reactance (AX), also known as the Goldman triangle, represents the area under the reactance curve between 5 Hz and the resonant frequency. It is considered a sensitive marker of small-airway dysfunction and is useful for assessing the response to bronchodilator therapy.^{6,9,16} (Figure 1,2,3)

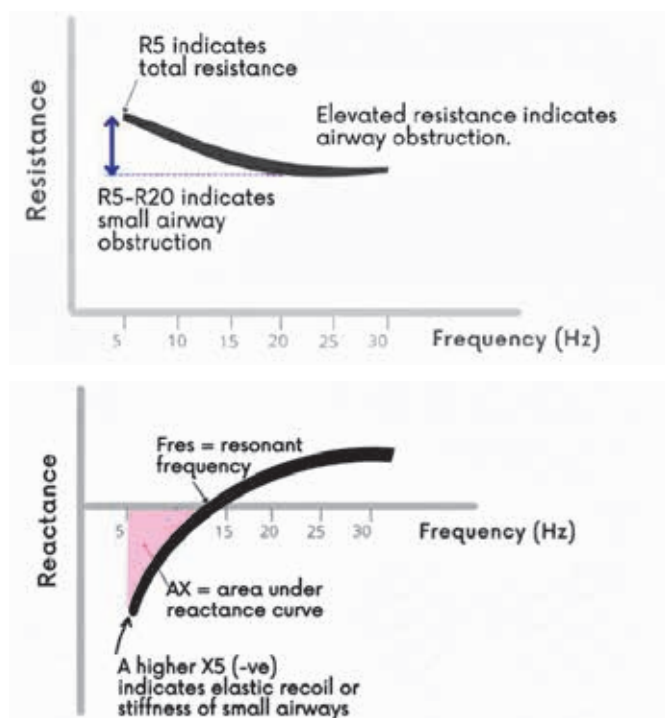


Figure 1 & 2: Showing resistance, reactance curve, resonant frequency (Fres) and area of reactance (Ax)

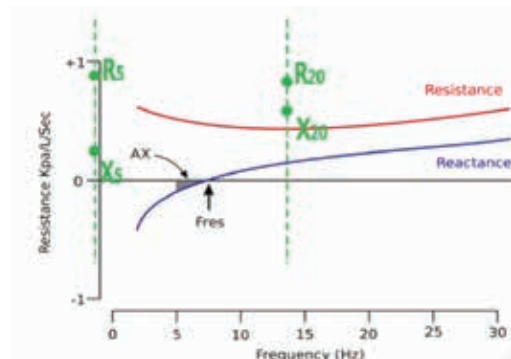


Figure 3: Resistance and reactance curve in normal FOT recording

Quality control and test acceptability

Artefacts: Artefacts can significantly affect the accuracy of oscillometry measurements. Common causes include coughing, swallowing, air leaks, breath-holding, glottic closure, irregular breathing, and incorrect tongue placement. Real-time monitoring of pressure, airflow, and volume curves helps identify these errors. At least three technically acceptable recordings should be obtained.^{5,17}

Coherence: Coherence reflects the relationship between airflow and pressure signals and was previously used to assess the reliability of measurements. Although low coherence values indicate poor-quality recordings, coherence is no longer routinely recommended as a primary quality-control criterion.^{5,17}

Coefficient of variation (CoV): The coefficient of variation (CoV) is an indicator of test reproducibility and is calculated automatically by the oscillometry device. A CoV of $\leq 15\%$ is generally recommended for children, whereas a value of $\leq 10\%$ is recommended for adults. Higher values should be interpreted cautiously.^{5,17}

Reference values

Reference values for oscillometry have been established for both children and adults, but they vary according to the population studied and the device used. Therefore, each laboratory should use reference equations that are appropriate for its own population and equipment.^{5,6}

In children, height is considered the most important determinant of oscillometric parameters, whereas the effects of sex, ethnicity, and body surface area are less consistent. As children grow, airway size increases, resulting in a progressive reduction in respiratory resistance. At the same time, X5 values become less negative, reflecting improved lung compliance and airway function. Because differences exist among devices and study populations, further work is needed to establish standardized, multi-ethnic reference values for oscillometry.^{5,18}

Bronchodilator response

The thresholds for bronchodilator responsiveness are remarkably similar, which for Rrs is around -40% in preschool-aged children at 4-6 Hz forcing frequency, and for Xrs being between 40 – 60% and -80% for AX. In older children, the threshold may be slightly lower for Rrs at around -35% but similar for Xrs and AX being 40% and -80%, respectively. Therefore, it is recommended that the thresholds for defining a positive bronchodilator response, for both adults and children, are -40% decrease in Rrs5, +50% increase in Xrs5 and -80% decrease in AX.^{5,6,12,17}

Table II: Technical standards for Forced Oscillation Technique⁵

Technical parameter	Recommendation
Technically acceptable repeatability criteria	• Minimum 3 maneuvers required • Three replicates should have CoV of R5 at lowest oscillation frequency of <15% in children • Free of artifacts- artifacts detection by machine has to be standardized
Minimum acquisition time	30 s for >12 years and 16 s for <12 years
Reporting of results	• Flexibility in formulation of reports should be offered by all software • Oscillatory parameter included in a report should be determined by the end user
Reference values in children	• Standing height is the dominant predictor of Rrs • There is a large scatter in the prediction of Rrs and Xrs at low frequency in young children • Use of the reference equations from studies in which the devices and population most closely approximate the local situation is recommended
Bronchodilator reversibility (BDR)	Threshold for BDR in children is a change in • R5 of -40% • X5 of +50% • Ax of -80%

Limitations and challenges

1. Although the technique is less effort-intensive than spirometry and tidal breath based, patient related factors such as cooperation, posture and breathing pattern can influence the results.
2. Standardization of the available machines with different manufacturers is needed.
3. Reference values for different populations are not available.
4. Reference cutoff values for bronchodilator reversibility need to be validated with more studies.
5. Poor cheek support can reduce the resistance values.

Conclusion

FOT is a newer and promising technique in measuring the mechanical properties of lung, which helps in diagnosis and monitoring the progress of lung diseases particularly suited for younger children where spirometry is not feasible. The non-invasive nature of oscillometry, easy of performance and minimal requirement for patient cooperation makes it particularly useful. It is more sensitive in detecting small airway pathologies over conventional spirometry. More research is required for generating national/regional reference values and standardization of machines.

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