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APICON 2025 Workshop Manual

Pulmonary Function Test



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CHAPTER 3

Impulse Oscillometry

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INTRODUCTION TO IMPULSE OSCILLOMETRY

Historical Background and Development

Impulse oscillometry (IOS) is a non-invasive pulmonary function test developed to measure airway resistance and reactance. The technique utilizes oscillatory pressure signals to assess mechanical properties of the respiratory system. The early conceptualization of forced oscillation techniques can be traced back to the 1950s and 1960s, with foundational studies by researchers such as Dubois, Botnick, and Mead. These pioneering studies sought to explore the mechanical properties of the lungs under different conditions of airflow and pressure.

Impulse oscillometry, as it is used today, was developed more comprehensively in the 1980s and 1990s. Initially, forced oscillation methods were used in research settings to study respiratory mechanics in animals. Over time, advancements in sensor technology, signal processing, and computational models made it possible to adapt this method for human use. Modern IOS technology utilizes high-frequency oscillatory signals that are sent into the respiratory system and then measured to determine the mechanical characteristics of the lungs and airways.

Key Features and Principles of IOS

Impulse oscillometry involves applying small pressure oscillations to the airway at different frequencies and measuring how these oscillations are transmitted through the respiratory system. The response of the respiratory system to these oscillations provides valuable information about lung mechanics, particularly airway resistance and reactance.

Key parameters measured in IOS include:

- *Resistance (R)*: Reflects the opposition to airflow in the airways. Higher resistance typically indicates narrowing or obstruction of the airways.
- *Reactance (X)*: Represents the elasticity or compliance of the airways. Negative reactance values indicate increased stiffness of the airways, often seen in obstructive lung diseases.
- *Resonant frequency*: The frequency at which the airway reactance equals zero and is useful in determining the overall mechanical properties of the lungs.

IOS tests typically involve generating pressure oscillations at frequencies between 5–30 Hz. The resulting data is then analyzed to produce an impedance spectrum, from which resistance and reactance values are extracted.

Importance of IOS in Modern Pulmonary Diagnostics

In clinical practice, IOS has become increasingly recognized for its ability to assess small airway function—something that traditional pulmonary function tests, such as spirometry, often fail to measure effectively. Small airways (those smaller than 2 mm in diameter) play a critical role in overall lung function, and dysfunction in these areas can be a sign of early respiratory disease.

IOS is non-invasive and offers several advantages over traditional methods. Unlike spirometry, which measures airflow during forced exhalation, IOS provides a comprehensive assessment of both the large and small airways, even when the patient cannot perform forced maneuvers. As such, IOS is highly beneficial in diagnosing early-stage airway disease, especially in conditions such as asthma, chronic obstructive pulmonary disease (COPD), and interstitial lung diseases (ILDs).

The non-invasive nature of IOS makes it suitable for repeated measurements, enabling clinicians to monitor disease progression and response to treatment over time without subjecting patients to the discomfort of traditional invasive procedures.

PHYSIOLOGY OF AIRWAYS AND RESPIRATORY SYSTEM

Anatomy and Function of the Respiratory System

The human respiratory system is divided into two primary sections: The conducting zone and the respiratory zone. The conducting zone includes the trachea, bronchi, and bronchioles, which function primarily to transport air to the alveoli. The respiratory zone consists of the alveoli, where gas exchange occurs.

Airway resistance is mainly determined by the caliber of the airways, their length, and the viscosity of the air. In healthy individuals, the majority of airway resistance comes from the larger airways. However, in diseases such as asthma or COPD, smaller airways (which constitute a much smaller percentage of total airway volume) can become critically involved in airflow obstruction.

Airway resistance and lung compliance are essential for maintaining optimal ventilation and gas exchange. Any dysfunction in these properties can lead to impaired respiratory mechanics, which is why accurate measurement of airway resistance is crucial in diagnosing and managing respiratory diseases.

Airway Mechanics and Lung Physiology

Lung compliance refers to the ability of the lungs to expand in response to pressure changes. It is influenced by the elastic properties of lung tissues and the surface tension in the alveoli. Decreased compliance is seen in conditions such as pulmonary fibrosis and acute respiratory distress syndrome (ARDS), where the lungs become stiffer and less able to expand.

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Airway resistance, on the other hand, refers to the opposition to airflow within the airways. It is influenced by several factors, including the diameter of the airways, the viscosity of the air, and the airway smooth muscle tone. The resistance is higher in smaller airways, making them particularly susceptible to obstruction in diseases such as asthma and COPD.

Impulse oscillometry measures these resistances and reactances in both large and small airways. By understanding the mechanical properties of the airways and lung tissue, IOS can provide critical insights into the pathophysiology of respiratory diseases.

WHY SMALL AIRWAYS MATTER IN RESPIRATORY MEDICINE?

Small airways are the first to be affected in many common pulmonary diseases. These airways contribute to the total resistance to airflow, and even minor changes in their function can have significant effects on overall lung performance. Diseases such as asthma, COPD, and ILD can cause early changes in the small airways, leading to difficulty in breathing, exercise intolerance, and decreased gas exchange efficiency.

In asthma, for instance, the small airways are often affected by bronchoconstriction and inflammation. Similarly, in COPD, the small airways can undergo remodeling and narrowing due to chronic inflammation and fibrosis. Identifying dysfunction in the small airways early in the disease process is crucial for preventing progression to more severe disease and managing symptoms effectively.

Traditional pulmonary function tests like spirometry are often unable to detect early changes in small airway function. Spirometry measures the flow of air through larger airways during forced exhalation, but small airways contribute relatively little to overall airflow during such tests. This limitation has led to a growing interest in alternative diagnostic methods, such as IOS, which can evaluate both large and small airways.

CURRENT METHODS FOR MEASURING SMALL AIRWAY OBSTRUCTION

Spirometry and Its Limitations in Assessing Small Airways

Spirometry is one of the most commonly used methods for assessing lung function in clinical practice. It measures *forced expiratory volume in 1 second (FEV_1)* and *forced vital capacity (FVC)* during a maximal forced exhalation. These parameters are key indicators of *large airway function* and overall lung volume. However, spirometry is *limited* in assessing the function of small airways. FEF25–75 is often used as a marker of small airway dysfunction, however, it lacks sensitivity and is affected by other parameters.

Small airways—those with a diameter of less than 2 mm—play a significant role in overall airway resistance but are not directly measured by spirometry. In

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conditions such as *asthma*, *COPD*, and *bronchitis*, small airways can become *obstructed or narrowed* without affecting the larger airways significantly enough to alter FEV_1 or *FVC* readings. This is especially problematic in early-stage diseases, where changes in *small airway function* can be the *first sign of pathology*.

Furthermore, spirometry requires *maximal effort* from the patient, which may be difficult for children, the elderly, or patients with severe disease. For these reasons, *alternative methods* are necessary to assess small airway dysfunction early and more accurately.

Lung Volume Measurements

Lung volume measurements are conducted using *body plethysmography* or *helium dilution* to assess the total lung capacity (TLC), functional residual capacity (FRC), and residual volume (RV). These measurements help provide insight into the overall condition of the lung and can highlight *hyperinflation* or *air trapping*.

While lung volume measurements can provide indirect clues about small airway function, they are *not specific* to small airway pathology. For example, increased *RV* or *FRC* may suggest *air trapping*, which can be a consequence of *small airway obstruction*; however, these methods do not provide a direct measurement of small airway resistance or reactance, which is where *IOS* excels.

Multiple Breath Nitrogen Washout Test

The *multiple breath nitrogen washout (MBW)* test is another advanced method used to assess small airway function. During the MBW test, a patient inhales a washout gas (typically *100% oxygen*), and the nitrogen concentration is measured as the subject exhales. The test identifies areas of the lung that are poorly ventilated or have impaired gas exchange. This technique is especially useful for detecting *early-stage small airway dysfunction*.

Although the MBW test can provide valuable information about lung ventilation and distribution, it is complex, requires specific equipment, and is not as widely available as *IOS*. Additionally, the MBW test requires *cooperation* from the patient and is more time-consuming, which can limit its practicality in certain settings, especially for pediatric or elderly patients.

Forced Oscillatory Techniques and Impulse Oscillometry

Forced oscillatory techniques (FOT) refer to a class of methods that involve applying a *small oscillating pressure* to the airway to measure the *resistive* and *reactive properties* of the respiratory system. IOS is one of the most prominent methods within FOT. It involves *small pressure waves* of varying frequencies applied to the airways, with the corresponding *response* measured to assess airway resistance and reactance.

The *impulse oscillation* method differs from traditional spirometry in that it can be performed without the need for forced exhalation. This makes it *ideal*

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for young children, *elderly patients*, or those with ***severe obstructive diseases*** who may be unable to produce forced exhalations. Moreover, IOS can be used to assess both the *large and small airways*, providing more *detailed information* about airway dysfunction than spirometry or lung volume measurements.

The development of IOS is the result of advancements in *signal processing*, allowing for the use of *high-frequency oscillations* that can measure small airway resistance across a *range of frequencies*, giving detailed insights into the mechanical properties of the entire respiratory system.

THE FORCED OSCILLATION TECHNIQUE AND IMPULSE OSCILLOMETRY

Overview of Forced Oscillation Technique

In *FOT*, the lung impedance is measured across a wide range of frequencies (typically from 5 to 20 Hz). The response to these oscillations is analyzed to differentiate between the effects of *resistance* and *reactance*. Higher frequency oscillations primarily reflect *large airway resistance*, while lower frequency oscillations provide insights into *small airway resistance* and the *elastic properties* of the lungs.

What is Impulse Oscillometry?

Impulse oscillometry is a method within the FOT that specifically uses *short bursts of oscillatory signals* to assess the mechanical properties of the airways. IOS allows for *continuous measurement* of *airway resistance* and *reactance* across various frequencies, providing a *detailed picture* of both large and small airway function.

The process of *IOS* involves sending a short *impulse* into the respiratory system and measuring the response as the signal travels through the airways. This method can measure *resistance* at both high and low frequencies (R5 for high-frequency resistance and R20 for low-frequency resistance), which gives clinicians valuable information about *both central and peripheral airways*.

Technological Advancements in IOS Devices

Over the years, IOS technology has undergone significant advancements. Modern *IOS devices* are compact, portable, and capable of performing real-time measurements with high precision. These devices often use sophisticated *signal processing algorithms* to extract meaningful data from the complex oscillatory signals, enabling precise assessments of *airway resistance* and *reactance* at different frequencies.

The development of *user-friendly interfaces* for IOS devices has made the technique more accessible and practical for routine use in clinical practice. Additionally, improvements in *calibration*, *accuracy*, and *reproducibility* have enhanced the reliability of IOS as a diagnostic tool for respiratory diseases.

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ADVANTAGES OF IMPULSE OSCILLOMETRY OVER TRADITIONAL METHODS

Comparing IOS with Spirometry

Spirometry, while an essential tool for diagnosing and monitoring pulmonary diseases, is *limited* in assessing small airway dysfunction. *Small airways*—those with diameters smaller than 2 mm are responsible for a significant portion of *airway resistance*, but their function is often overlooked in spirometry testing, which primarily assesses large airway function.

In contrast, IOS can assess airway resistance and reactance across both large and small airways. As *small airway disease* is often an early indicator of *chronic respiratory conditions* such as *asthma* and *COPD*, the ability to detect changes in small airway function is crucial for early diagnosis and treatment. Moreover, *IOS is non-invasive*, *quick*, and requires less patient effort compared to spirometry, making it ideal for use in children, the elderly, and patients with severe respiratory conditions.

IOS and Its Ability to Measure Small Airway Resistance

Impulse oscillometry is particularly valuable because it directly measures *resistance in small airways*, an area traditionally difficult to assess. Unlike spirometry, which requires maximal effort from the patient, *IOS is less affected by patient cooperation* and does not require forced maneuvers. As a result, IOS can detect *small airway dysfunction* in the *early stages of disease*, often before more overt symptoms such as *dyspnea* (shortness of breath) or *wheezing* appear.

By using multiple frequencies, IOS can assess *frequency-dependent resistance*, enabling clinicians to identify changes in *airway reactance* and *resistance* that might otherwise go undetected. This level of detail makes IOS a highly sensitive and reliable tool for diagnosing and monitoring diseases such as *asthma*, *COPD*, and *pulmonary fibrosis*.

HOW TO PERFORM IMPULSE OSCILLOMETRY?

Patient Preparation for IOS Testing

IOS is a relatively straightforward test to perform and requires minimal patient preparation. However, to ensure accurate and reliable results, there are a few considerations to keep in mind:

- *Pre-test instructions*: Patients should avoid consuming food or drinks that could increase airway resistance, such as caffeine or alcohol, for several hours before the test. It is also advisable to avoid using bronchodilators before the test unless otherwise instructed by a healthcare provider.
- *Equipment calibration*: IOS devices must be calibrated according to the manufacturer's instructions before use. Regular calibration is essential to ensure the accuracy of the results.
- *Positioning*: The patient should be seated comfortably in an upright position to allow optimal airway function during testing. A proper *nose clip* may be used to prevent airflow through the nostrils and ensure that the patient is breathing through their mouth.

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- *Breathing instructions*: Patients should be instructed to breathe *normally* through the mouthpiece during the test, which typically takes only a few minutes. It is crucial that the patient remains *relaxed* and *comfortable* to avoid any unnecessary stress that could impact the results.

Step-by-step Procedure for IOS Measurements

- *Patient calibration*: Before the actual test begins, the device is calibrated, and the patient's respiratory impedance is measured at baseline. This step ensures that the device is working properly.
- *Oscillatory signal application*: The test begins by applying a series of oscillatory signals at varying frequencies. The patient continues to breathe normally while the device measures how the oscillations are transmitted through the airways.
- *Data collection*: As the patient breathes normally, the device collects data on both airway resistance and reactance. This data is then processed using sophisticated algorithms to generate a detailed impedance spectrum.
- *Test duration*: The entire test typically takes about 5–10 minutes, with only a few minutes of actual oscillatory signal exposure. The test is non-invasive and generally well-tolerated by patients.
- *Post-test evaluation*: After the test, the clinician evaluates the results, which include airway resistance (R) and reactance (X) at different frequencies. The data can be compared to normative values and used to identify any abnormalities.

WHEN TO PERFORM IMPULSE OSCILLOMETRY?

Indications for IOS in Clinical Practice

Impulse oscillometry has become an essential tool for assessing lung function, especially in diseases where *small airway dysfunction* is a key feature. While traditional methods like spirometry are commonly used for diagnosing obstructive lung diseases, IOS offers more nuanced and sensitive measurements of *airway resistance* and *reactance*, particularly in the *small airways*.

Some specific indications for performing IOS include:

- *Early detection of obstructive lung diseases*: IOS can identify changes in airway function before spirometry reveals any abnormal results. In conditions such as *asthma* or *COPD*, where small airway involvement is common, IOS can detect *small airway obstruction* even in the early stages of disease. This is critical for initiating early intervention before irreversible damage occurs.
- *Evaluation of asthma*: Asthma is characterized by *bronchoconstriction* and *airway hyperreactivity*, which often involves the small airways. IOS can help assess the degree of obstruction and monitor response to *bronchodilators* or *steroid therapy*. It can also be used to track *bronchial responsiveness* over time, making it valuable for disease management and progression.
- *Assessment of COPD*: In *COPD*, the progressive narrowing of the airways leads to *airflow limitation*, especially in the small airways. IOS can help assess *small airway function* early in the disease course, even before changes in FEV_1

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become noticeable. Regular monitoring with IOS can guide the management of *COPD* and help assess the effectiveness of treatment strategies.

- *Children and infants*: IOS has a significant advantage over spirometry in pediatric populations, especially in younger children and infants who may not be able to perform forced expiratory maneuvers. IOS testing requires *minimal cooperation*, and the procedure is quick and non-invasive. It is particularly useful in *diagnosing asthma* and *tracking airway resistance* in children with respiratory symptoms.
- *Monitoring airway disease progression*: IOS can be used to monitor the progression of diseases such as *bronchiectasis*, *cystic fibrosis*, and *pulmonary fibrosis*, where small airway involvement plays a key role in disease development. Regular monitoring with IOS allows clinicians to evaluate changes in *airway function* and *lung mechanics*, helping to assess disease severity and response to treatment.
- *Evaluation of response to therapy*: One of the key advantages of IOS is its ability to assess the *immediate response* to bronchodilators, corticosteroids, or other therapeutic interventions. For example, a reduction in *airway resistance* after a bronchodilator administration is a key indicator of effective therapy. IOS can be used to evaluate bronchodilator reversibility, providing real-time feedback on the effectiveness of treatment regimens.
- *Preoperative assessment*: In patients undergoing *thoracic surgery* or *lung transplantation*, IOS can be used to evaluate *preoperative airway function*. Since small airway dysfunction can influence postoperative recovery, measuring small airway resistance can provide useful information to guide *perioperative care*.
- *Assessment of respiratory conditions with limited spirometry utility*: In patients who are unable to perform traditional spirometry, such as those with *neuromuscular diseases*, *severe COPD*, or *pediatric patients*, IOS can be a valuable alternative. It does not require forced exhalation or patient effort, making it more accessible for these populations.

HOW TO INTERPRET RESULTS FROM IMPULSE OSCILLOMETRY?

Key Parameters Measured in IOS

To interpret IOS results effectively, it is crucial to understand the various parameters generated during the test. These parameters provide insights into the *mechanical properties* of the respiratory system. The main parameters that are typically analyzed in IOS are:

- *Airway resistance (R) at multiple frequencies*:
  - R5 (high-frequency resistance): Represents resistance in the large airways.
  - R20 (low-frequency resistance): Reflects the overall resistance across the entire respiratory system, including the small airways.
  - R10, R15: Intermediate frequencies that can give more detailed information about both the large and small airways.

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- *Airway reactance (X)*: Reactance refers to the elastic properties of the airways, such as *compliance* (ability to expand and contract). Negative values of reactance typically indicate airway constriction or increased *stiffness* in the lungs. Reactance is measured at low frequencies (e.g., X5, X10) and provides information about *small airway compliance*.
- *Resonance frequency (fres)*: Resonance frequency is the frequency at which the respiratory system exhibits the maximum response to oscillatory forces. The *fres* can be used to assess overall lung compliance and help in identifying abnormal lung mechanics.

Interpreting Increased Resistance

When resistance measurements, particularly *R5* and *R20*, are elevated, it suggests that there is *obstruction* or *narrowing* of the airways. An increase in *R20* is typically seen in patients with *obstructive pulmonary diseases* such as *asthma* or *COPD*, where inflammation and bronchoconstriction lead to increased airway resistance. *Elevated R5* indicates that the *larger airways* are also affected, but *increased R20* is a more specific indicator of *small airway dysfunction*.

The key to interpretation lies in understanding the *frequency dependence* of resistance. In cases of *small airway obstruction*, resistance often increases disproportionately at *lower frequencies* (e.g., R5 > R20), indicating *more pronounced changes in the smaller airways* compared to the larger ones.

Using Prime Numbers for Impulse Oscillometry Interpretation

Using prime numbers is based on the principle that resistance measurements taken at odd-numbered frequencies provide better resolution in detecting changes in *small airway resistance*. R20 may be sensitive to harmonic variability. As such, *R19* is considered to be a more accurate representation of *peripheral airway resistance*, allowing for more precise diagnostic interpretation.

Interpretation of Reactance (X) Values

Reactance provides insight into the *elastic properties* of the airways. A *negative reactance* value (i.e., when X < 0) is indicative of increased *airway stiffness*, which may be due to *airway remodeling*, *fibrosis*, or *inflammation* in diseases such as *asthma*, *COPD*, or *pulmonary fibrosis*.

Changes in *reactance* can also be used to evaluate *bronchodilator response*. A reduction in *reactance* following bronchodilator administration suggests a positive response to the medication, as the airways become less stiff and more compliant.

Bronchodilator Reversibility Criteria

IOS is a valuable tool for assessing bronchodilator reversibility, particularly in conditions like asthma. It is more sensitive than spirometry in detecting changes in small airways.

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Criteria for Bronchodilator Response

- *Resistance (R)*:
  - A decrease in R_5 of ≥40% from baseline indicates significant improvement in total airway resistance.
  - A reduction in R_5 - R_{20} of ≥50% suggests significant improvement in small airway function.
  - In the odd numbers method, a similar threshold applies to R_5 - R_{19}.
- *Reactance (X)*:
  - An increase in X_5 (i.e., less negative) of ≥50% from baseline suggests improved compliance and reduced small airway obstruction.
  - A significant reduction in AX (≥50%) indicates decreased hyperinflation and improved distal airway function.

Advantages of IOS in Bronchodilator Testing

- *Small airway sensitivity*: IOS can detect small airway improvement even when spirometric changes (e.g., FEV_1) are minimal.
- *Effort-independent testing*: Particularly useful in patients who struggle to perform forced maneuvers required in spirometry.

Introduction to Intra-breath Oscillometry

Intra-breath oscillometry (IBO) is an advanced modification of traditional IOS that allows for the continuous measurement of respiratory mechanics during a natural tidal breathing cycle. Unlike conventional IOS, which measures airway resistance and reactance during forced breathing maneuvers, *IBO* integrates respiratory impedance measurements within the *breathing cycle* itself, enabling more dynamic and real-time data collection during normal, unforced *tidal breathing*. This method enhances the ability to assess airway function under more physiological conditions, making it particularly valuable in both clinical and research settings where forced maneuvers may be difficult to obtain or less representative of everyday lung function.

The key feature of IBO is its ability to measure *airway resistance*, *reactance*, and other respiratory parameters during different phases of the breathing cycle, providing more granular insights into the *temporal variability* of airway function. This can be crucial for understanding *small airway dynamics*, *airway responsiveness*, and *ventilation distribution* in a more representative, non-invasive manner.

Technical Principles of Intra-breath Oscillometry

Intra-breath oscillometry builds upon the principles of standard IOS but operates with some key modifications. In both IOS and IBO, oscillations are generated and delivered into the airways, but the main difference lies in the timing and how the signals are recorded.

- *Oscillatory signal generation*: In IBO, a set of *high-frequency pressure oscillations* (typically ranging from 5 to 35 Hz) is introduced into the airways

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during the *inspiratory* and *expiratory phases* of the *tidal breathing cycle*. These oscillations are delivered continuously, allowing for measurement of respiratory impedance throughout the breath. This contrasts with traditional IOS, where oscillations are applied only during forced exhalation, typically at a constant frequency.

- *Measurement of respiratory impedance*: IBO measures *airway resistance* (R), *reactance* (X), and *impedance* (Z) continuously throughout the breathing cycle. The impedance can be analyzed at various frequencies, with the most significant values typically being at the low-frequency end (representing large airway contributions) and high-frequency end (reflecting small airway function). The primary goal of IBO is to capture real-time changes in *airway mechanics* during *natural breathing* and assess how these change from one breath to another.
- *Phase-specific measurements*: A significant advantage of IBO is its ability to measure changes in *airway mechanics* across different phases of a single breath (i.e., during *inspiration*, *expiration*, and *breath holding*). This provides a more detailed picture of how the airways behave under normal physiological conditions. For example, by analyzing *impedance* during the expiratory phase, clinicians can identify any changes or resistance caused by *airway narrowing*, *bronchoconstriction*, or *increased airway viscosity*, which might not be evident during forced maneuvers

CLINICAL APPLICATIONS OF IMPULSE OSCILLOMETRY

Impulse oscillometry has proven to be a valuable tool in clinical settings, offering more precise and comprehensive insights into airway mechanics than traditional methods. The clinical applications of IOS extend across a wide range of respiratory conditions, including asthma, COPD, pulmonary fibrosis, and more.

Asthma Management

IOS is particularly useful in *asthma management*, where small airway obstruction plays a key role. Asthma exacerbations are often caused by *bronchoconstriction*, which affects the *small airways*. By regularly assessing *airway resistance* and *reactance*, clinicians can detect *early signs of airway narrowing* and track the effectiveness of *bronchodilator therapy*. IOS also helps identify patients who might benefit from *inhaled corticosteroids* or *long-acting beta agonists*.

Chronic Obstructive Pulmonary Disease

Impulse oscillometry has become a valuable diagnostic tool for assessing *small airway dysfunction* in *COPD*. While traditional methods such as spirometry typically focus on large airway function, IOS enables clinicians to detect abnormalities in the *small airways* early on, even before spirometry shows a reduction in FEV_1.

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- *Detecting small airway involvement*: In *COPD*, small airway dysfunction is thought to play a crucial role in disease progression. Changes in the *R5* and *R20* parameters measured by IOS reflect *airway resistance* in both the small and large airways, making it easier to assess the *severity of small airway involvement*. The detection of increased *frequency dependence of resistance*, characterized by a higher *R5/R20* ratio, is often an early sign of *airway remodeling* and *obstruction* in COPD.
- *Monitoring disease progression*: IOS can help track the progression of *COPD* by measuring subtle changes in *airway resistance* and *reactance* over time. Since small airway dysfunction can precede large airway changes, IOS allows clinicians to assess early functional decline, even before overt symptoms or spirometric changes occur. It can also be used to monitor the response to interventions such as *bronchodilators*, *corticosteroids*, or *pulmonary rehabilitation*.
- *Assessing bronchodilator response*: One of the most important applications of IOS in COPD is its ability to assess *bronchodilator reversibility*. After administering a bronchodilator, IOS can measure how the airway resistance and reactance change in response. In *COPD*, bronchodilator responses tend to be less pronounced than in asthma, but significant improvements in *R5* or *R20* following treatment may indicate a *reversible component* of the disease. This information can help tailor treatment plans and determine the effectiveness of bronchodilators.
- *Evaluating impact of therapy*: IOS can be used to assess the effectiveness of various treatments, including *inhaled bronchodilators*, *steroids*, and *anticholinergic agents*. In patients with *moderate-to-severe COPD*, where airway remodeling may lead to irreversible changes, IOS can provide valuable information on the degree of *small airway involvement* that might still be reversible with pharmacological interventions.

Pulmonary Fibrosis and Interstitial Lung Diseases

Pulmonary fibrosis and other *ILDs* often involve changes in the *small airways*, leading to *restrictive patterns* and *reduced gas exchange*. While *spirometry* may indicate a reduction in *lung volumes*, it does not provide a complete picture of *small airway function*. IOS, by assessing both *airway resistance* and *reactance*, provides additional insights into the condition of the *small airways* in patients with ILD.

- *Detecting early changes*: In *pulmonary fibrosis*, early changes in *airway resistance* and *reactance* often occur before changes in **spirometry**. IOS can detect early *small airway dysfunction*, even in the absence of overt *airflow limitation* or *restrictive patterns* in conventional tests. Increased *frequency dependence of resistance* is often observed in *ILDs*, indicating early alterations in small airway function.
- *Monitoring disease progression*: Since *pulmonary fibrosis* and other ILDs involve ongoing *fibrosis* and *scarring* of the lung tissue, monitoring small airway function with IOS can help assess the *progression* of the disease. Increased airway resistance and reactance values over time can signal

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worsening disease, providing early indicators of worsening *lung function*. This allows for timely interventions to prevent further decline.

Children and Infants

One of the most significant advantages of IOS is its ability to evaluate lung function in populations where traditional pulmonary function tests, such as spirometry, are difficult to perform. *Children*, particularly *infants and toddlers*, may not be able to perform forced expiratory maneuvers, making conventional tests unsuitable. IOS, however, requires minimal cooperation and can provide valuable data on *airway resistance* and *reactance*.

- *Diagnosing asthma in children*: Asthma is the most common chronic respiratory disease in children. IOS provides an effective means of diagnosing asthma in younger patients who may have difficulty completing spirometry. Increased *R5* and *R20* values are indicative of *bronchoconstriction* in asthma. Tracking these values over time can also help assess treatment efficacy and adjust asthma management strategies.
- *Assessing airway function in infants*: In infants, especially those under the age of two, performing spirometry can be technically challenging or even impossible. IOS, however, can be conducted in infants as young as *6 months old*, making it an ideal tool for assessing early airway resistance and tracking the progress of diseases such as asthma, *bronchiolitis*, or *cystic fibrosis*.
- *Monitoring response to treatment*: In pediatric patients, especially those with *asthma*, IOS can help monitor how the airways respond to treatment. Following bronchodilator administration, a reduction in *airway resistance* is expected, and IOS provides real-time feedback on whether the airways are responding appropriately. This helps guide therapeutic decisions and ensures that children receive the most effective interventions for their condition.

FUTURE DIRECTIONS AND INNOVATIONS IN IMPULSE OSCILLOMETRY

Impulse oscillometry has undergone significant advancements over the past few decades, and ongoing research is expanding the potential applications of this technique. As technology improves, IOS may play an even greater role in clinical practice, offering more sensitive, specific, and accessible methods for assessing *small airway dysfunction* and *lung mechanics*.

Development of More Advanced Algorithms

As data collection and analysis techniques improve, more advanced algorithms could be developed to analyze IOS measurements. For example, incorporating machine learning and *artificial intelligence (AI)* could enable more accurate prediction of disease progression, response to treatment, and even early diagnosis of conditions such as *COPD* or *asthma*. These algorithms could help clinicians make *better-informed decisions* based on patient-specific data, improving both diagnostics and treatment outcomes.

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Pulmonary Function Test

Explore the science and clinical application of pulmonary function testing in this authoritative guide, authored by experienced pulmonologists and educators. This book is an essential resource for physicians, respiratory therapists, and healthcare professionals seeking to enhance their understanding of modern diagnostic techniques used in respiratory medicine. Covering a wide array of topics, the book delves into the fundamentals and advanced methodologies of pulmonary function testing. Key chapters include an in-depth exploration of spirometry, the cornerstone of lung function assessment, along with impulse oscillometry, a cutting-edge technique for evaluating airway mechanics. Dedicated sections on fractional exhaled nitric oxide (FeNO) provide insights into assessing airway inflammation, while the diffusing capacity of the lungs for carbon monoxide (DLCO) chapter unpacks critical concepts in gas exchange and alveolar function. Written in an engaging and accessible style, pulmonary function test balances theoretical principles with clinical insights. Scientifically written and supported by latest research publications, it offers a comprehensive reference for both novice practitioners and seasoned experts looking to refine their diagnostic skills. Whether you are in training or practice, this book is a vital tool to unlock the full potential of pulmonary diagnostics. Prepare to deepen your expertise and transform your approach to respiratory care with this indispensable guide.



Aloke Gopal Ghoshal MD DNB FCCP Ex-WHO Fellow, Fellow ICS FICP is presently the Medical Director, National Allergy Asthma Bronchitis Institute (NAABI), Kolkata, West Bengal, India. He is Past-President, Indian Chest Society, and Founder-Secretary, Association of Chest Physicians (ACP), West Bengal (presently President, ACP). He has more than 40 years of experience as a revered teacher, researcher, and master clinician with more than 225 national and international publications, book chapters, and books. He first recognized the silent global epidemic in obstructive airway diseases hitherto neglected in mainstream medicine. His students and colleagues pioneered office spirometry and revolutionized the practice of pulmonology in Eastern India. He devised a bedside lung function test and the current regression equation for population in East India. He has been bestowed with Lifetime Achievement Award from multiple national societies for his contribution in upbringing the specialty from its nascent stage and NAABI is the ICS accredited center of excellence for pulmonary function training in India.



Indranil Halder MBBS DCH MD FRCP (Glasgow) FCCP(USA) FICP European Diploma in Adult Respiratory Medicine is an eminent teacher of pulmonary medicine. He is presently Associate Professor and Head, Department of Pulmonary Medicine at College of Medicine and JNM Hospital, Kalyani, West Bengal, India. He has been a passionate proponent of early screening to pick up lung diseases since the beginning of his career. He spearheaded the efforts to dissipate knowledge of spirometry and other respiratory innovations among physicians and respiratory therapists, and even now he has been carrying on the trend with newer technologies like oscillometry. Dr Halder is a researcher, spearheading several research projects with his contemporaries and students. He has several impactful publications, in the sphere of respiratory medicine.

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