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Impulse oscillometry

Abstract

Pulmonary function testing involves a battery of tests from the simple pulse oximetry to the cardiopulmonary exercise testing. Impulse oscillometry (IOS) is one of the newly described pulmonary function tests. It is based on the old principle of forced oscillatory technique modified and refined as per research and advances. It involves the use of sound waves during normal tidal breathing, which gives information on oscillatory pressure-flow relationships and eventually resistance and reactance. The resistance at 20 Hz (R20) represents the resistance of the large airways. The resistance at 5 Hz (R5) means the total airway resistance. (R5–R20) reflects resistance in the small airways. The reactance at 5 Hz (X5) indicates the elastic recoil of the peripheral airways. Resonant frequency and area of reactance are also measured. IOS has major uses in diagnosis and control of asthma in children and the elderly, where spirometry is otherwise normal. IOS has been studied in other respiratory diseases like COPD, ILD and supraglottic stenosis.

Key words: R5, R20, X5, impedance, resistance, reactance

Adv Respir Med. 2019; 87: 235–238

Introduction

Conventional spirometry has been in use since many decades. Newer applications of alternative technologies to measure lung functions which were postulated in the same era have come into practice now. Impulse oscillometry system is one of such pulmonary function tests. In 1956, Dubois *et al.* described the forced oscillation technique (FOT) to measure lung functions using single frequency sound waves, which was easy to perform and provided more insight into the lung mechanics as compared to the simple spirometry [1]. In 1975, Michaelson *et al.* improvised the technique to use multiple frequency sound waves which was named impulse oscillometry (IOS) [2]. However, it was not until 1998 when Jaeger could make computerised IOS commercially available [3–5].

Principle of impulse oscillometry

Impulse oscillometry is defined as a variant of FOT described by Dubois over 50 years ago, which permits passive measurement of lung mechanics. The principle of IOS is based on superimposition of sound waves on normal tidal breathing, which leads to disturbances in flow and pressure across the airways, leading to an ultimate output of respiratory resistance, reactance and impedance using the fast fourier transform (FFT) technique. This principle of IOS is derived from the Ohm's law which states that resistance is a product of division of pressure and flow. The IOS involves the use of sound waves which give information about oscillatory pressure-flow relationships and eventually **resistance** and **reactance**.

Respiratory resistance is the in-phase component of lung impedance and reflects information about the forward pressure of the conducting airways. With the use of multiple frequencies, the characteristics of the different section of the airways can be studied. Sound waves with higher frequencies (20 Hz) travel shorter distances and generally till the large airways. Hence, the resistance at 20 Hz (R20) represents the resistance of the large airways. Sound waves with

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DOI: 10.5603/ARM.a2019.0039
Received: 04.02.2019

ISSN 2451–4934

lower frequencies (5 Hz) travel larger distances and generally till the small airways. Hence, the resistance at 5 Hz (R5) represents the total airway resistance. Subtracting R20 from R5 (R5–R20) reflects resistance in the small airways. Further higher frequencies than 20 Hz cause discomfort and lower ones are influenced by breath dynamics and hence not used. Respiratory reactance is the out-of-phase component (imaginary part) of lung impedance and reflects the capacitive and inertive properties (opposite forces) of the airways. The reactance at 5 Hz (X5) reflects the elastic recoil of the peripheral airways (capacitive energy of the lungs). The diseases of the lung that reduce the elasticity of the lung (fibrosis, hyperinflation) lead to higher or more negative X5.

Respiratory **impedance** is the sum of all forces which oppose the generated impulse, i.e. real respiratory resistance and imaginary respiratory reactance. **Resonant frequency** (Fres) indicates the frequency at which the inertial properties of the airways and capacitance of lung periphery are equal. Total reactance at this point is zero. Normal Fres is 6–11 Hz. Fres increases in peripheral airway obstruction and fibrosis. **Area of reactance** (AX) is the integrated low frequency respiratory reactance magnitude between 5 Hz and Fres. AX relates to respiratory compliance, small airway patency and correlates with R5–R20.

In IOS quality assurance is measured by coherence (CO). It reflects reproducibility of impedance measurements. Coherence at 5 Hz (CO 5) is > 0.8 cm H_2O. Coherence at 20 Hz (CO 20) is between 0.9 to 1.0. Coherence can be decreased due to improper technique, irregular breathing, glottis closure, swallowing [3–5].

Advantages and disadvantages

Advantages of IOS include the use of simple tidal breathing manoeuvres against forced manoeuvres applied in spirometry and thus require less effort. Hence, it can be used in children, the elderly, special patient population groups. It can be employed to study lung functions in patients on ventilators as well as during sleep, post-surgery, acute coronary syndromes. It reflects lung mechanics and provides a more "real-world" assessment of respiratory function. Humans do not use forced manoeuvres in daily activity, artefacts from gas compression, closure of the small airway are limitations of conventional spirometry which are overcome with IOS. It has greater sensitivity to diagnose peripheral airway obstruction, i.e. small airway disease. It gives a better insight into lung mechanics and demonstrates a change in early disease wherein spirometry is normal. Disadvantages of IOS include a newer less standardised methodology, limited reference standard values and high intra-subject variability. More research/studies are required for validation and formulation of predicted equations. Major studies have reported its role in obstructive airway diseases like asthma. Cost and portability issues also prove an hindrance to IOS use in resource limited setting [3–5].

Indications of IOS

1) Measurement of lung functions in children aged < 5 years, elderly people and those with physical and cognitive limitations who cannot perform spirometry easily; 2) Diagnosis of bronchial asthma with normal spirometry; 3) Measurement of lung functions in special patient groups- ventilated, post-transplant; 4) IOS is also used for demonstration of bronchodilator response and in bronchoprovocation testing (lower doses required); 5) Small airway disease.

How to perform the test?

Impulse oscillometry machine has a pneumotach and pressure transducer connected in series, with a speaker at one end and a mouthpiece at the other. Figure 1 depicts the machine assembly. Calibration is done using a 3 litre syringe. In a relaxed sitting position with a nose clip applied, the patient is asked to make a tight seal between the mouth piece and lips with the cheeks firmly held by both hands. The patient is informed about the procedure. When sound impulses are emitted and pushed into the lungs it may make the patient feel little uncomfortable. The patient is asked to perform normal tidal breathing for 30–45 seconds when sound impulses are pushed into the lungs. At least three reproducible efforts are recorded. Bronchodilator reversibility is assessed with repeated testing 20 minutes post administration in a similar fashion [3–5].

Multiple researchers attempted to document equations for IOS. Consensus recommendations were published in 2003 and also reviewed the limitations of existing reference equations [6]. The Jaeger system used equations published by Vogel and Smidt [7]. Alternative equations were given by Oostveen *et al* in 2013 in white adults [8].

IOS result and its implications

The IOS reports R5, R20, X5, AX, Fres as the available output. Proximal airway obstruction mani-

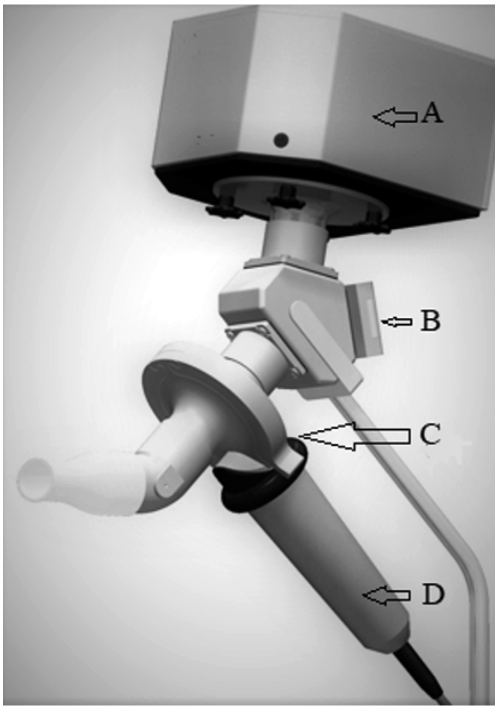

Figure 1. Impulse oscillometry assembly consisting of sound emitter (**A**), screen flap (**B**), Y-adapter with a mouthpiece (**C**), pneumotach (**D**)

fests as increased R5, increased R20, normal X5 and normal Fres. Peripheral airway obstruction results in increased R5, normal R20, increased X5 and increased Fres. Lung restriction manifests as normal R5, normal R20, increased X5, increased Fres [3–6, 9–11].

In asthma, IOS can help in diagnosis on a background of normal spirometry if 1) R > 150% (R is resistance at all frequencies); 2) R5–R20 ≥ 20%; 3) Reduction in R > 20% suggesting significant post-bronchodilator reversibility; 4) Increase in R on bronchoprovocation testing. Control of asthma is said to be poor if associated with increased R5–R20, X5, AX, even in the background of normal spirometry. In small airway disease, the R5 is increased with normal R20 and a rise in R5–R20. In chronic obstructive pulmonary disease (COPD), a decrease in X5 suggests dynamic hyperinflation. Difference in inspiratory reactance (X_I) and expiratory reactance (X_E) correlate with COPD severity, although the clinical relevance is unknown. In interstitial lung disease, IOS changes are similar to those in severe COPD and require clinicoradiological correlation for interpretation. New inhaler drug delivery mechanisms measured by IOS are more representative of the mechanical and physiological properties of the lung. IOS can quantify changes with therapy in non-invasive assessment of supraglottic diseases, such as vocal cord dysfunction. Figure 2 depicts graphically changes on IOS in obstructive and restrictive abnormality.

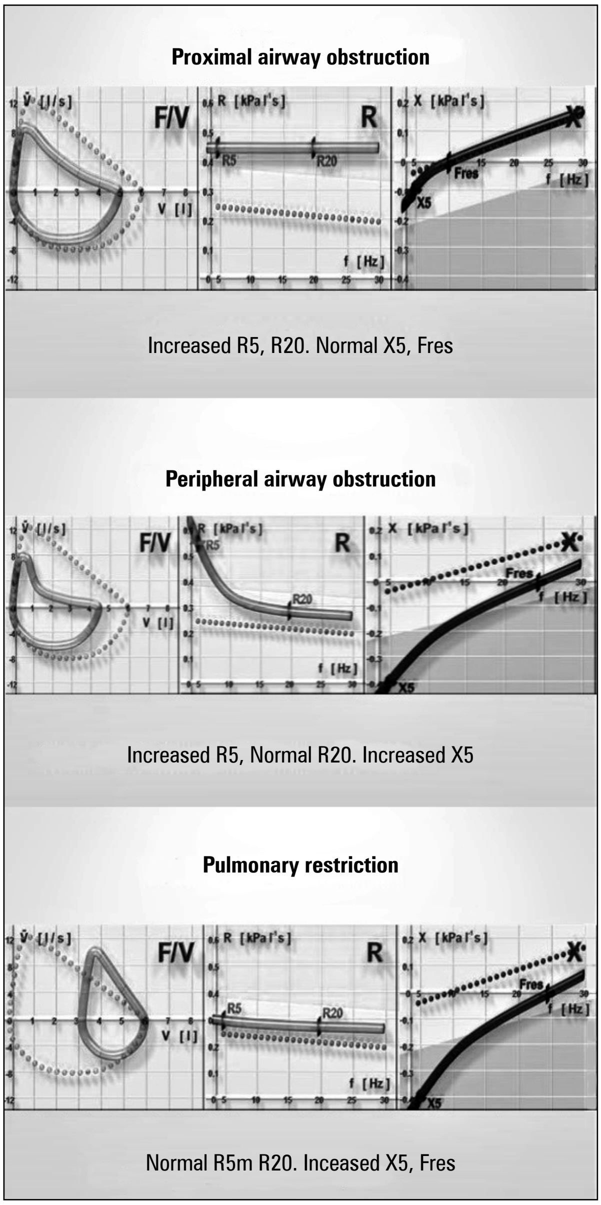

Figure 2. Graphical depiction of impulse oscillometry in obstructive and restrictive abnormality

Children are a group of patients in whom conventional spirometry is challenging as it requires active patient cooperation and is effort dependent. The predicted equations for them are less standardised, making it difficult to differentiate normal and diseased states with the help of adult reference values. Studies have utilised IOS in healthy children to obtain normal reference values for further use in view of the difficulty in performing and interpreting conventional spirometry [12]. IOS has been used to diagnose and manage airway diseases in children [13, 14]. IOS has correlated with spirometry values in COPD, asthma and bronchiectasis to help review and manage therapy [15–18]. It correlated with lung functions in some rare diseases like sickle cell disease, gastro-oesophageal reflux disease without airway disease [19, 20].

To summarise, the IOS is an alternative to spirometry in special situations. Although the technique needs further refinement, it is based on an established principle with wide application to future research. IOS can serve as an adjunct to conventional spirometry in special situations.

Conflict of interest

The authors declare no conflict of interest.

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