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Clinical usefulness

The Forced Oscillation Technique in Paediatric Respiratory Practice

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EDUCATIONAL AIMS

After reading this article the reader will be able to:

- Understand the physiological principles and the procedure of the FOT.
- Interpret the commonly reported FOT parameters.
- Understand the advantages and limitations of the method.
- Discuss the current indications of the FOT in paediatric respiratory practice.

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SUMMARY

The Forced Oscillation Technique (FOT) is a lung function modality based on the application of an external oscillatory signal in order to determine the mechanical response of the respiratory system. The method is in principal noninvasive and requires minimal patient cooperation, which makes it suitable for use in young paediatric patients. The FOT has been successfully applied in various paediatric respiratory disorders, such as asthma, cystic fibrosis, and chronic lung disease of prematurity, in order to assess airway obstruction, bronchodilator response, and airway responsiveness after bronchoprovocation challenge. This technique may be more sensitive than spirometry in identifying disturbances of peripheral airways and assessing the level of asthma control or the effectiveness of therapy at the long term. Further research is required to determine the exact role of the FOT in paediatric lung function testing and to incorporate the method in specific diagnostic and management algorithms.

INTRODUCTION

Accurate lung function testing in young or uncooperative children remains a significant challenge in routine paediatric practice. Although spirometry represents a simple and widely available technique, its use in such populations is limited due their inability to perform reliable and reproducible forced respiratory maneuvers. The Forced Oscillation Technique (FOT) is a lung function modality which requires minimal patient cooperation and, therefore, is particularly suitable for use in young children. In recent years, technological advancements and ongoing research has led to the standardization of the measuring procedures and the rapid expansion of the FOT in both clinical and research settings.

PHYSIOLOGIC PRINCIPLES AND TECHNICAL ASPECTS

The FOT was originally described by Dubois et al. in 1956 [1] and its fundamental principles remain unchanged to date [2]. The method is based on the application of an external oscillatory signal to the airway opening (input oscillometry) in order to determine the mechanical behavior of the respiratory system in terms of changes in pressure (P) and flow (V').

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Abbreviations: FOT, forced oscillation technique; Rrs, respiratory resistance; Xrs, respiratory reactance; Zrs, respiratory impedance.

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The signal generator consists of a computer-controlled loudspeaker which produces harmonic sound waves (impulses) which travel through the airways superimposed to tidal breathing. A transducer measures P and V' changes at the airway opening (Figure 1A), and from the relationship between P and V' the *impedance of the respiratory system* (Z_{rs}) is calculated. The Z_{rs} represents the sum of all forces which oppose impulse propagation, and comprises a 'true' resistive component that opposes friction (termed *respiratory resistance* – R_{rs}) and an 'imaginary' component that opposes the elastic and inertial forces within the respiratory system (termed *respiratory reactance* – X_{rs}) [2]. The contribution of these two components is expressed by the equation:

$$Z_{rs} = R_{rs} + jX_{rs} = R_{rs} + j(\omega In - 1/\omega Ca)$$

where $j = \sqrt{-1}$ (imaginary number), $\omega = 2\pi f$, f is the impulse frequency, *In* is the inertance, and *Ca* the capacitance of the respiratory system [2]. Capacitance can be conceptualized as reflecting the elasticity of the lungs (airways and pulmonary parenchyma), while inertance as expressing the inertive forces within the respiratory system (moving column of gas and expansible tissues). R_{rs} and X_{rs} can be calculated by analyzing the frequency-dependent relationship between P and V' using specific mathematical transformations [2]. In simple terms, R_{rs} represents the component of Z_{rs} where changes in V' are in phase with changes in P, while X_{rs} the component where changes in V' are out of phase with changes in P (Figure 1B).

Current FOT technologies use composite signals in the frequency domain of 2 to 50 Hz, that can take two forms: (1) *square wave signals* generated at a fixed frequency (usually 5 Hz) from which all other frequencies can derive; this represents the classical approach in impulse oscillatory systems (IOS), and (2) *pseudorandom noise*, which allows for simultaneous application of broad-band frequencies [2,8]. The frequency of the applied signal is of critical importance in order to explore the mechanical properties of various lung tissues [2,9]: lower frequency impulses travel deeper into the lung and reflect the mechanical behavior of smaller airways, while higher frequencies are more sensitive to upper airway pathology.

Impulses in the range of 4-10 Hz have been shown to be of particular clinical relevance in pediatric practice [3–7]. Very low frequencies (i.e., Below 2 Hz) may contain valuable information on lung periphery, but the interference with spontaneous breathing limits their applicability in practice [10,11]. Similarly, very high frequencies (over 100 Hz) have been applied specifically for the evaluation of the mechanical properties of the airway wall in small infants [12,13].

A series of modeling studies have permitted detailed insight in the significance of R_{rs} and X_{rs} changes in various lung disorders [2]. Although R_{rs} would be expected to reflect airway pathology more accurately, X_{rs} at low frequencies is also considered as an equally sensitive parameter [2–6]. At low frequencies, the energy requirement to overcome lung capacitance dominates and X_{rs} becomes negative. Conversely, at high frequencies the energy loss is attributed mainly to the inertive forces and X_{rs} acquires positive values [2,14]. The frequency at which the energy loss due to the capacitive component is equal to that attributed to the inertial component (therefore the value of X_{rs} is zero), is called the *resonant frequency* (f_{res}). Since lung capacitance is mainly determined by the physical properties of the small distensible airways, X_{rs} at frequencies below the f_{res} is thought to provide important information on the mechanical behavior of lung periphery [2,14].

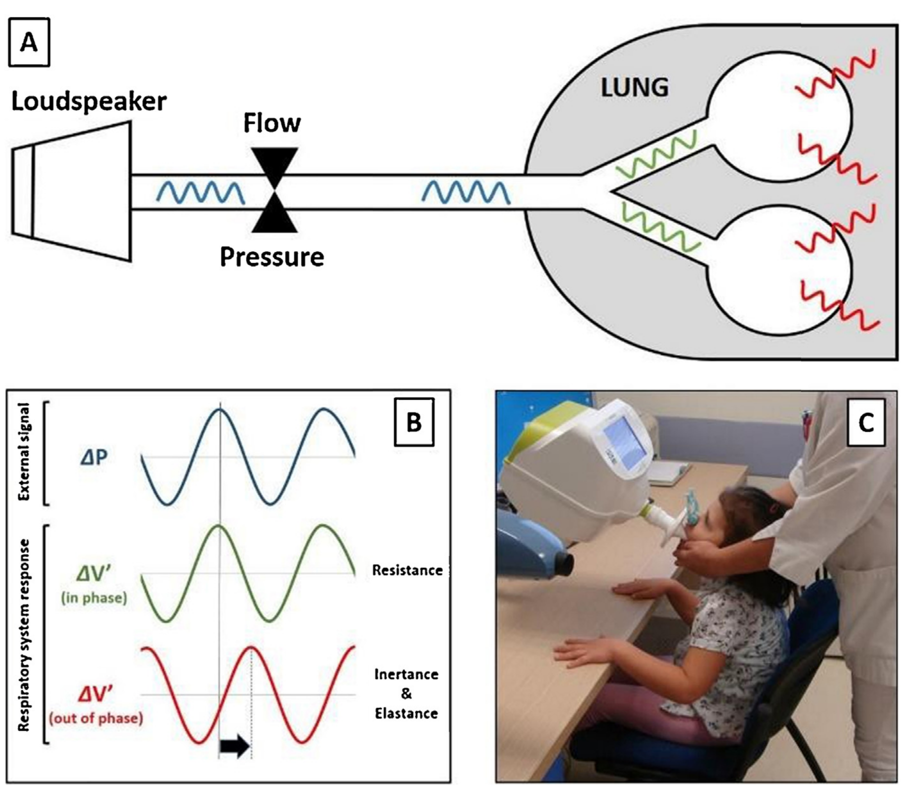

Figure 1. A: Schematic presentation of an input oscillometry setup. **B:** Relationship between changes in pressure (ΔP – external signal) and flow (ΔV' – respiratory system response). Changes in flow that are in phase with changes in pressure represent the component of the respiratory impedance which is attributed to airway resistance, while changes in flow that are not in phase with pressure represent the component which is attributed to elastance and inertance. **C:** Procedure of FOT measurement.
FOT: forced oscillation technique.