

Impulse Oscillometry (IOS)

Hans-Jürgen Smith



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Impulse Oscillometry is an attractive method for the determination of respiratory resistance of the lung as only simple tidal breathing is required [1, 2] – without the need for a shutter, body plethysmography cabin, or measurement gases.

Test results are derived from small pressure impulses which are superimposed during quite tidal breathing. Thus, allowing measurements in patients groups who would struggle using conventional methods. These include children under the age of five, obese, geriatric patients, patients with limitations of their respiratory drive, severe diseased and patients with neuromuscular abnormalities.



Fig. 1
Performing an oscillometric measurement. To avoid loss of pressure, the palms of the hands should stabilize the cheeks.

Every **Vyntus® IOS** system incorporates innovative Impulse Oscillometry and **full spirometry with flow volume display**. Both in accordance with the latest national and international recommendations.

Impulse Oscillometry allows a **detailed analysis of tidal breathing** deriving clinically relevant results of changes in chest mechanics caused by disease and intervention that complement spirometry. The additional data from oscillometry provide a greater insight into possible changes and enhance observations in spirometry.

Methodology of Impulse Oscillometry

An impulse generator is used to apply small measurement oscillation pressure impulses to the respiratory system of a **patient breathing normally**. These impulses are multifrequency oscillations in nature ranging from 5 Hz to 50 Hz [3]. Numerous studies demonstrate that especially frequencies below 20 Hz provide clinically relevant information for the differential diagnosis of the respiratory tract.

The precise measurements of the flow signal generated by the impulse (V'_I) and the resulting pressure response of the lung-thorax system (P_I) directly at the patient's mouth represent the **respiratory impedance Z_{RS}** . It can be considered as primary parameter.

$$Z_{RS} = \frac{P_I}{V'_I} = R_{RS} + j \cdot X_{RS}$$

The clinical interpretation of the measurements is usually based on the two components of respiratory impedance Z_{RS} , **respiratory resistance R_{RS}** and **lung reactance X_{RS}** .

In a normal lung, R_{RS} represents the equivalent of the flow resistance in the (large) central airways, whereas X_{RS} represents the small, peripheral airways in addition to the retraction capacity of the lungs. See Fig. 2.

Unique features of Impulse Oscillometry

The respiratory resistance R_{RS} measured by oscillometry differs slightly from the airways resistance measured using body plethysmography (R_{aw}) and the resistance acquired by interrupter technique (R_{int} , R_{occ}), which is due to differences in the measurement principles [4].

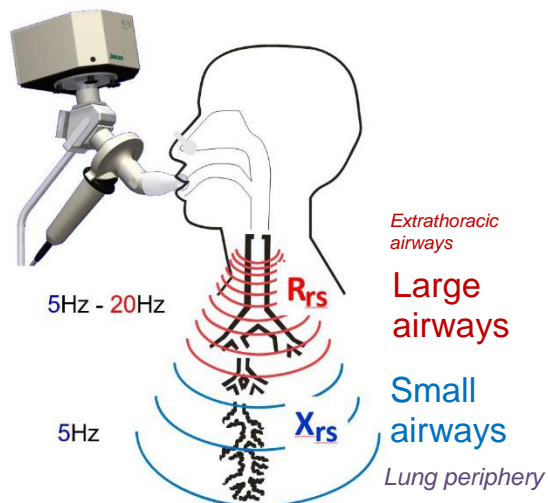


Fig. 2

The oscillations of the impulse-shaped measurement signal penetrate the respiration tract at varying depths. Whereas 20 Hz signals are absorbed (shunted) in the large airways, 5 Hz oscillations pass the entire lung. Thus, the respiratory resistance R_{rs} of the large airways can be differentiated from the lung reactance X_{rs} of the small airways.

For a comprehensive clinical interpretation of oscillometry, an interpretation concept that incorporates the specific properties of the methodology based on the R_{rs} and X_{rs} data is recommended. This allows the reliable classification of possible limitation, as well as verification of the different respiratory symptoms.

Numerous clinical studies have shown the strengths of Impulse Oscillometry that it can provide differential and highly sensitive data in the diagnosis of pulmonary obstructive diseases. Oscillometric parameters support clinicians in the diagnosis and classification of the severity of pulmonary obstruction, analyzing the extent of reversibility, and evaluating nonspecific and specific provocation tests.

Oscillometry has advantages over spirometry allowing the investigating of lung functionality under normal quiet breathing conditions. Furthermore, the bronchodilator effects associated with spirometry that can occur from maximal inspiratory maneuvers are eliminated. Additional, patients can usually comply better with measurements using tidal breathing compared to maximal inspiratory and expiratory maneuvers.

The analysis of the peripheral small airways based on lung reactance X_{rs} measured by Impulse Oscillometry surpasses that of conventional methods.

Due to its potential to differentiate between central and peripheral abnormalities, Impulse Oscillometry supports individualized patient management, independent of other functional examinations or as part of additional diagnostic measurements.

Measurement including quality control

The entire examination is primarily automated and even quality control of the test results is fully supported by the system.

After the operator has launched data recording, the patient can then start to breathe through the measuring head with their lips tightly closed on the mouthpiece. During measurement, the cheeks must be stabilized using the palms of the hands to prevent a possible loss of pressure via the cheeks. See Fig. 1.

As soon as the measurement application detects respiration, the Z5Hz impedance recordings are displayed for each trial and stored after a preset recording time of 20 s.

The operator repeats this procedure until the quality indicator shows “good quality.”



Fig. 3

The quality indicator shows the status of the quality control.

At least three trials are required to finalize the measurement. Artefact affected trials are automatically deactivated and can be repeated. The averaging of all accepted trials generates a quality of the test result that exceeds the extent of any individual trial.

Oscillometric key parameters

Oscillometric parameters that represent specific and independent characteristics of functionality can be derived from the resistance $R_{rs}(f)$ and reactance $X_{rs}(f)$ outlined within a spectral graphic.

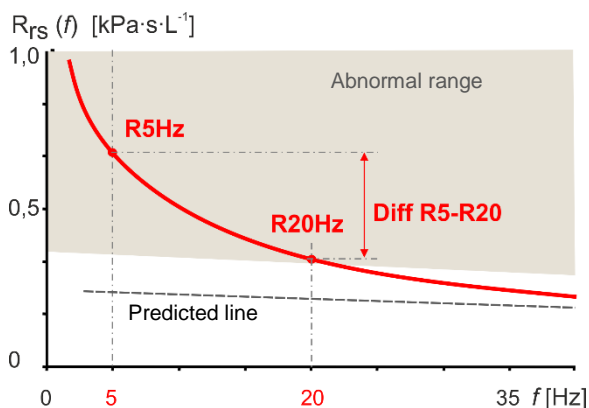


Fig. 4

The respiratory resistance $R5Hz$, central airway resistance $R20Hz$, and small airways index $Diff\ R5-R20$ are derived from the resistance spectrum $R_{rs}(f)$.

The **(total) respiratory resistance $R5Hz$** assesses the airway resistances of the large, central airways as well as the resistive component of the small airways, but also incorporates the extrathoracic airways like the oropharynx and larynx. In contrast, the **central airway resistance $R20Hz$** assesses only the extrathoracic and central airway components. **$Diff\ R5-R20$** , the difference between the two foregoing parameters, is used as the **small airways index**. Figure 4 shows the resistance spectrum with the predicted line and the abnormal range in the usual form.

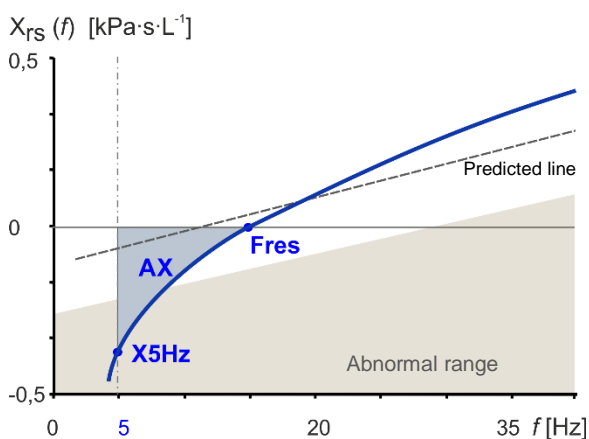


Fig. 5

The reactance spectrum $X_{rs}(f)$ yields the lung reactance $X5Hz$, the resonant frequency $Fres$, and the reactance area AX . Exclusively parameters of the lung periphery.

All parameters derived from the reactance spectrum primarily characterize the lung periphery and its ventilatory inhomogeneity.

The **lung reactance $X5Hz$** is an important parameter in the clinical interpretation as it assesses not only the retraction capacity of the lungs but, also the degree of peripheral obstruction.

The **resonant frequency $Fres$** , i.e., the zero crossing of the reactance spectrum and the **reactance area AX** , are used as indirect markers of the lung periphery, especially for pre-post examinations and provocation tests. The integrative, quantitative index AX is especially sensitive. Figure 5 shows their interrelationships.

In clinical practice, it is always helpful to compare the measured parameter results to their predicted values. Corresponding references for nearly all age ranges are available for both spirometry and Impulse Oscillometry. They allow following recommendations for classifying the severity of the disease as well as applying standards on differentiating the lung function.

Simple clinical interpretation

Respiratory resistance $R5Hz$ and lung reactance $X5Hz$ from normal tidal breathing recordings relative to their predicted values enables grading the lung function. However, it is important to always include BOTH parameters in the assessment. Normal lung function can be stated only if both parameters are in the normal range.

Normal lung function	
Respiratory resistance	$R5Hz < 140\%$ predicted
Lung reactance	$(Predicted - X5Hz) < 0.15\ kPa \cdot s \cdot L^{-1}$

Classification incorporating both $R5Hz$ and $X5Hz$ is presented automatically by the measurement application [5].



Fig. 6

Classification of the test results on the basis of $R5Hz$ and $X5Hz$ compared to their reference values.

Differential diagnostic assessment of lung function

Interpreting the two frequency responses $R_{RS}(f)$ and $X_{RS}(f)$ allows for more advanced and conclusive differentiation of the pulmonary obstruction.

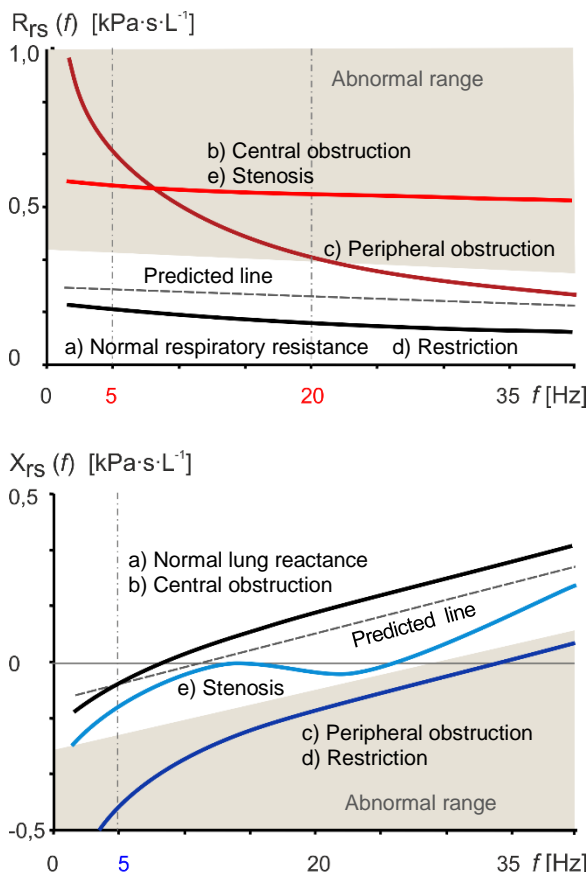


Fig. 7
Characteristic pattern of healthy and abnormal resistance and reactance spectra.

a) Normal lung function

Respiratory resistance R_{5Hz} and lung reactance X_{5Hz} are in the normal range. The resistance spectrum $R_{RS}(f)$ shows a linear, nearly frequency-independent response. The pattern of the reactance spectrum $X_{RS}(f)$ is normal, i.e. continually decreases towards lower frequencies.

b) Central obstruction

Respiratory resistance R_{5Hz} is elevated compared to its reference and abnormal, whereas X_{5Hz} still lies in the normal range. The resistance spectrum $R_{RS}(f)$ shows no frequency dependence and runs parallel to the predicted line in the abnormal range. The reactance spectrum $X_{RS}(f)$ remains normal.

Central obstruction

Respiratory resistance	$R_{5Hz} \geq 140\%$ predicted
Lung reactance	$(\text{Predicted} - X_{5Hz}) < 0.15 \text{ kPa}\cdot\text{s}\cdot\text{L}^{-1}$

c) Peripheral obstruction

Both R_{5Hz} and X_{5Hz} are abnormal. The resistance spectrum $R_{RS}(f)$ has a marked frequency dependency, i.e., it continually rises as oscillation frequency decreases. The reactance spectrum $X_{RS}(f)$ simultaneously shifts into the lower negative range.

Peripheral obstruction

Respiratory resistance	$R_{5Hz} \geq 140\%$ predicted
Lung reactance	$(\text{Predicted} - X_{5Hz}) \geq 0.15 \text{ kPa}\cdot\text{s}\cdot\text{L}^{-1}$
Small airways index	$\text{Diff } R_5 - R_{20} \geq 0.07 \text{ kPa}\cdot\text{s}\cdot\text{L}^{-1}$

In terms of intrapulmonary inhomogeneity, these obvious dependencies on frequency can be explained as the result of peripheral distribution problems and structural changes in the lung periphery.

d) Restriction

Because of the loss of lung elasticity, the lung reactance X_{5Hz} shows a negative trend, but only in severe degrees of restriction.

More mild forms of restriction, however, are not detected. If a restriction is expected, VC should also be determined via spirometry, and an examination of TLC via body plethysmography or gas dilution is even more advisable.

Restriction

Respiratory resistance	$R_{5Hz} < 140\%$ predicted
Lung reactance	$(\text{Predicted} - X_{5Hz}) \geq 0.15 \text{ kPa}\cdot\text{s}\cdot\text{L}^{-1}$

e) Stenosis

Consider using both spirometry and oscillometry results in the assessment of a possible impact of the extrathoracic airways. In the case of a clinically relevant stenosis, inspiratory and expiratory plateaus occur on the flow volume curve in parallel with horizontal, plateau-like sections in the otherwise continual course of the lung reactance $X_{RS}(f)$ spectrum.

Stenosis	
Respiratory resistance	$R5Hz \geq 140\%$ predicted
Lung reactance	$(\text{Predicted} - X5Hz) < 0.15 \text{ kPa}\cdot\text{s}\cdot\text{L}^{-1}$

In principle, oscillometry noticeably reacts to extrathoracic limitations, even under tidal breathing conditions.

Analysis of bronchial hyperreactivity

The main advantage of the oscillometric determination of bronchial hyperresponsiveness is that no maximal breathing maneuvers are required. Because of the dilatory effect associated with maximal maneuvers, these maneuvers could influence the reaction rate and early forms of hyperresponsiveness stay undetected.

Proven determination / threshold values of the recommended observation parameters are available for both reversibility and provocation testing.

Because of the specificity of the oscillometric parameters, both the resistive (R5Hz) as well as the reactive (Fres, AX) parameters should always be included in the evaluation.

Reversibility testing

The following table summarizes the reaction rate of the most common oscillometric parameters for determining bronchial reversibility. Due to its sensitivity, the reactance area AX is of particular importance.

Reversibility testing	
Observation parameter	Significant reversibility
Respiratory resistance R5Hz	-20% to -25%
Small airways index Diff R5-R20	-0.04 $\text{kPa}\cdot\text{s}\cdot\text{L}^{-1}$
Resonance frequency Fres	-20%
Reactance area AX	-40%

Provocation testing

For specific and nonspecific bronchial challenge testing, clinical studies prove a 20% drop in FEV1 coincides with the following changes in oscillometric values.

Provocation testing		
Observation parameter	Baseline measurement	Determination value
R5Hz	$R5Hz < 140\%$ predicted	PD/PC +40 R5Hz
X5Hz	$(\text{Predicted} - X5Hz) < 0.15 \text{ kPa}\cdot\text{s}\cdot\text{L}^{-1}$	-
Fres	-	PD/PC +35 Fres

IOS measurement application from the SentrySuite® system

IOS testing benefits everyone - patients, technicians, and physicians. There is minimal cooperation required from the patients as they perform only quiet, passive breathing.

The technician benefits from simple tidal breathing instructions and the subsequent, automatic quality check.

For the physician, essential clinical questions on lung function, reversibility, and hyperreactivity are answered. The results are automatically classified, based on simple tidal breathing recordings.

Impulse Oscillometry and conventional lung function diagnostics

Impulse Oscillometry is an ideal complement to conventional lung function testing such as spirometry, body plethysmography and diffusion. It shows a comparatively high sensitivity in displaying peripheral obstructions of the respiratory tract (small airways) and detects instabilities in the bronchial system (trapped air), which supports early detection of lung disease.

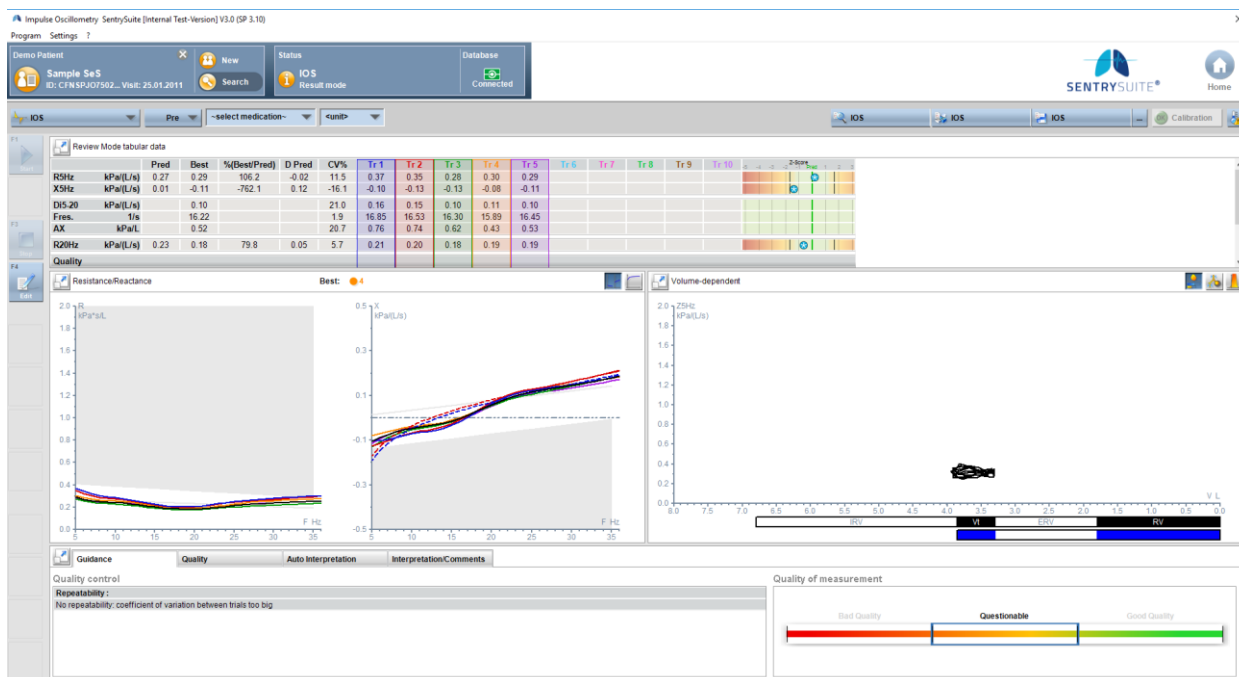


Fig. 8 Impulse Oscillometry application window in the SentrySuite system. The example shows normal lung function with a mild, functional extrathoracic stenosis.

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Vyaire Medical, Inc.
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Vyaire Medical GmbH
Leibnizstrasse 7
97204 Hoechberg, Germany

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