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OSCILLOMETRY (FOT and IOS) definition and application

PG11 Assessing respiratory system resistance in children and adults

Prof. Waldemar TOMALAK
Dept. Physiopathology of Respiratory System, Institute for TBC & Lung Dis. Rabka Branch, Poland
I declare no conflict of interest related to this presentation
The forced oscillation technique

- The forced oscillation technique uses external pressure signals (generated by loudspeaker) to evoke flow response of the respiratory system. Pressure and resulting flow are then analysed yielding to parameters of oscillatory mechanics (resistances and reactances or parameters of the model of respiratory system).
The forced oscillation technique – two approaches

• „classic” (FOT) – with the excitation wave being the sum of several sinusoidal waves
• Impulse oscillometry (IOS) – using pressure pulses
The forced oscillation technique – the principle

\[ p_{ao}(t) + p(t) \]

\[ 10 \text{ Hz} \]

\[ V'_{ao}(t) \]

\[ p_{ao} \]

\[ Z = \frac{p_{ao}}{V'_{ao}} \]

\[ R_{10} \]

\[ X_{10} \]

\( Z \) – respiratory impedance; \( R \) – resistance; \( X \) - reactance
Multifrequency oscillations

Typical frequency range: 2..4 – 32 Hz

\[ p(t) = p_1 + p_2 + p_3 + p_4 + \ldots \]
„classic” FOT realisations

Pulmosfor (SEFAM)

Ros (Sensormedics)

Cosmed
The measurements

• Oscillatory measurement are distorted by the so called upper airways shunt (influence of the impedance of the cheeks and mouth floor). Therefore, the subject has to support cheeks with palms during the measurements.

• Interesting modification was put into practice with PULMOSFOR (SEFAM, F) where the pressure wave was applied around the head rather than at the mooth (the head generator technique) to minimize this.
Head generator of PULMOSFOR
Analysis of data

Data can be interpreted as values resistance or reactance at given frequency (e.g. R10, X10) or using a simple model of respiratory system with frequency dependent resistance $R_{rs}$, compliance od respiratory system $C_{rs}$ and respiratory system inertance $I_{rs}$.

Resonant frequency $F_n$ is a frequency where $X_{rs}$ equals 0.
Correlation of FOT indices with classic measurements

W. Tomalak et al. Pneumonologia i Alergologia Polska, 1995
Reference values for FOT

Many publications; especially for children. For different age ranges. Some examples:

• Solymar L et al. Pediatric Pulmonology 1985; 1; 134-140.


Reference values for FOT

Adults:


• Age range: 18-80; frequency range: 4-26 Hz; number of subjects: 368.

• Suggestion: „new reference equations based on different setups are recommended to replace those established with a single device.”
Mechanical Respiratory Impedance: the forced oscillation method

Contributions to the workshop held for the European Commission on 18-19 June 1990, Antwerp, Belgium

Mechanical Respiratory Impedance by Forced Oscillation

Edited by A. Zwart and K.P. Van de Woestijne

Contributions to the workshops held for the European Commission on 2-3 December 1991 and 8-9 March 1993, Zeist, The Netherlands
ERS TASK FORCE

The forced oscillation technique in clinical practice: methodology, recommendations and future developments

E. Oostveen*, D. MacLeod†, H. Lorino*, R. Farré†, Z. Hantos§, K. Desager‡, F. Marchal**, on behalf of the ERS Task Force on Respiratory Impedance Measurements
IOS


The realisation of measurements using IOS (impulse oscillometry system) uses pressure pulses instead of sum of several sinusoidal waves.

The analysis of data is the same as in classic FOT realisations.
IOS – the measuring head

loudspeaker

pneumotach

\[ V' \quad P_m \]
An example of IOS measurement
The data are analysed as resistances and reactances at different frequencies (5, 10, 15, 20, 25, 35 Hz)

The results may be also analysed with built-in 7-element model (not frequently used)
Correlation of IOS indices with classic measurements

Correlation of R5 with FEV1: $r=-0.66$ (the same study)

Reference values for children (IOS)

B. Nowowiejska, W. Tomalak et al. Pediatric Pulmonology 2008
Reference Values of Impulse Oscillometric Lung Function Indices in Adults of Advanced Age

Holger Schulz1, Claudia Flexeder1, Jürgen Behr2,8, Margit Heier3, Rolf Holle3, Rudolf M. Huber5,9, Rudolf A. Jörres6,7, Dennis Nowak6,9, Annette Peters3, H.-Erich Wichmann7,8,9, Joachim Heinrich1,9, Stefan Karrasch6, for the KORA Study Group

1Institute of Epidemiology I, Helmholtz Zentrum München, Munich, Germany, 2Department of Internal Medicine V, Comprehensive Pneumology Center Munich, Ludwig-Maximilians-University, Munich, Germany, 3Institute of Epidemiology II, Helmholtz Zentrum München, Munich, Germany, 4Institute of Health Economics and Health Care Management, Helmholtz Zentrum München, Munich, Germany, 5Division of Respiratory Medicine and Thoracic Oncology, Department of Medicine, Innerstedt, Ludwig-Maximilians-University, Munich, Germany, 6Institute and Outpatient Clinic for Occupational, Social and Environmental Medicine, Ludwig-Maximilians-University, Munich, Germany, 7Institute of Medical Data Management, Biometrics and Epidemiology, Ludwig-Maximilians-University, Munich, Germany, 8Klinikum Großhadern, Ludwig-Maximilians-University, Munich, Germany, 9Comprehensive Pneumology Center Munich (CPC-M), Member of the German Center for Lung Research, Munich, Germany

Table 2. Age distribution of the combined sample from KORA-F4L and KORA-AGE.

<table>
<thead>
<tr>
<th>Age, years</th>
<th>Men included</th>
<th>Men excluded</th>
<th>Women included</th>
<th>Women excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td>45–54</td>
<td>36 (23.4)</td>
<td>247 (85.4)</td>
<td>43 (17.7)</td>
<td>255 (83.1)</td>
</tr>
<tr>
<td>55–64</td>
<td>32 (20.8)</td>
<td>249 (87.1)</td>
<td>51 (21.0)</td>
<td>293 (82.6)</td>
</tr>
<tr>
<td>65–74</td>
<td>45 (29.2)</td>
<td>207 (78.3)</td>
<td>69 (28.4)</td>
<td>209 (66.8)</td>
</tr>
<tr>
<td>75–84</td>
<td>36 (23.4)</td>
<td>227 (84.1)</td>
<td>70 (28.8)</td>
<td>215 (67.4)</td>
</tr>
<tr>
<td>≥85</td>
<td>5 (3.2)</td>
<td>44 (88.6)</td>
<td>10 (4.1)</td>
<td>45 (77.8)</td>
</tr>
</tbody>
</table>
CHAPTER 5

Forced oscillation technique and impulse oscillometry

H.J. Smith*, P. Reinhold†, M.D. Goldman‡

*Research in Respiratory Diagnostics, Berlin, Germany. †Friedrich-Loeffler-Institute, Jena, Germany. ‡David Geffen School of Medicine, University of California, Los Angeles, USA.

Correspondence: H.J. Smith, Research in Respiratory Diagnostics, Bahrendorfer Str. 3, 12555 Berlin, Germany.
Reliability of FOT (IOS) data

• As natural breathing may interfere with excitation pressure waves (especially in lower frequencies) a coherence function values (calculated from power spectra of flow and pressure signals) are calculated for each frequency of interest. The value of coherence is within 0 and 1; the higher the value the 'better' is the measurement.
Reliability of FOT (IOS) data

- It is assumed that for classic measurements the value of coherence should be $\geq 0.95$ to have the coefficient of variation of impedance data $<10\%$ (Landser et al., 1976.)
- For IOS coherence $>0.6$ at 5 Hz is an acceptable threshold (Smith et al., 2005.)
Difference between IOS and FOT (n=79 subjects)

\[ \frac{R_{\text{IOS}}}{hPa \cdot \text{ls}} - \frac{R_{\text{PULM}}}{hPa \cdot \text{ls}} = \frac{R_{\text{PULM}} + R_{\text{IOS}}}{hPa \cdot \text{ls}} \]

J. Radliński, W. Tomalak et al. Comparison of measuring system used to evaluate input respiratory impedance by forced oscillation technique – pilot study
Eur. Respir. J 2002; 20; suppl 38; 32
## Difference between FOT and IOS

<table>
<thead>
<tr>
<th>f</th>
<th>Correlation</th>
<th>differences (mean \pm sd)</th>
<th>BA graphs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td></td>
<td>R</td>
</tr>
<tr>
<td>5</td>
<td>0.82 (***</td>
<td>0.56 ± 0.91</td>
<td>0.24 (*)</td>
</tr>
<tr>
<td>10</td>
<td>0.81 (***</td>
<td>0.37 ± 0.65</td>
<td>0.24 (*)</td>
</tr>
<tr>
<td>20</td>
<td>0.74 (***</td>
<td>0.22 ± 0.55</td>
<td>0.16 (NS)</td>
</tr>
</tbody>
</table>

The analysis showed high correlation between PULMOSFOR and IOS resistances; but also systematic differences at lower frequencies, which can be attributed to differences in pressure signal energy.

J. Radliński, W. Tomalak et al. Comparison of measuring system used to evaluate input respiratory impedance by forced oscillation technique – pilot study Eur. Respir. J 2002; 20; suppl 38; 32
Oscillometric measurements in obstructive diseases
Impedance data in obstructive diseases.

Fig. 7. Impedance data from patients with asthma (left) and COPD (right) according to severity of underlying disease. Notice the consistent relationship between diseases of the changes in respiratory system resistance ($R_{res}$) and respiratory system reactance ($X_{res}$) with increasing severity. In both cases, as severity increases, $R_{res}$ rises and becomes more frequency dependent, especially at lower frequencies ($< \sim 16$ Hz), and $X_{res}$ falls to more negative values, with an increase in the resonant frequency (point at which $X_{res}$ crosses zero). (Left from Reference 47, with permission. Right from Reference 48, with permission.)
IOS (FOT) allows measurements of inspiratory and expiratory resistances.

Fig. 8. Comparison of change in respiratory system resistance at 5 Hz ($R_{RS5}$) and respiratory system reactance at 5 Hz ($X_{RS5}$) between inspiration and expiration in healthy control subjects, and subjects with asthma and COPD. Notice that only the patients with COPD had significant differences in $X_{RS5}$ between inspiration and expiration, differentiating them from both control subjects and subjects with asthma. (From Reference 63, with permission.)
Main advantages of FOT and IOS

- Requires only passive cooperation (natural breathing)
- Fast, easy to perform and reproducible
- Useful especially in children (from 2 yrs of age.), older adults and patients unable to perform spirometry
- Useful in bronchodilator tests and bronchial challenges
- Standardisation documents
- Allows analysis of respiratory resistance in real time
Performance of IOS/FOT in youngest children

• IOS: Own experience: among 133 children aged 3-4 years, 6 were unable to perform the measurements; 27 refused to make examination. Overall cooperation success rate: 61%

• Spirometry: (also own experience) age group 3-4 yrs. Cooperation yielding to interpretable results: 3.6%

Tomalak W et al. Pneumonologia i Alergologia Polska 2008
IOS (FOT) in assessing small airway properties
Results: Small-airway IOS measurements, including the difference of R5 and R20 [R5-20], X5, Fres, and AX, of AX and the difference R5-R20 are regarded as small airway status indices.

Figure 1 – Sample impulse oscillometry result illustrating key impulse oscillometry attributes. F = frequency; R5 = resistance at 5 Hz; R20 = resistance at 20 Hz; X5 = reactance at 5 Hz.
Respiratory system impedance with impulse oscillometry in healthy and COPD subjects: ECLIPSE baseline results

Courtney Crim, Bartolome Celli, Lisa D. Edwards, Emiel Wouters, Harvey O. Coxson, Ruth Tal-Singer, Peter M.A. Calverley, on behalf of the ECLIPSE investigators

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Baseline IOS (impulse oscillometry) impedance parameters in ECLIPSE subjects.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NSC (n = 233)</td>
</tr>
<tr>
<td>R5 (kPa/L/s)</td>
<td>0.33 (0.10)</td>
</tr>
<tr>
<td>R20 (kPa/L/s)</td>
<td>0.26 (0.07)</td>
</tr>
<tr>
<td>R5 - R20 (kPa/L/s)</td>
<td>0.07 (0.05)</td>
</tr>
<tr>
<td>X5 (kPa/L/s)</td>
<td>-0.10 (0.06)</td>
</tr>
<tr>
<td>AX (Hz·kPa/L/s)</td>
<td>0.38 (0.40)</td>
</tr>
<tr>
<td>FRes (Hz)</td>
<td>12.4 (3.4)</td>
</tr>
</tbody>
</table>

Data expressed as mean (SD) unless otherwise specified; Impedance parameters are post-bronchodilator. NSC = non-smoker controls; CS = control smokers; COPD = chronic obstructive pulmonary disease; GOLD = Global Initiative for Chronic Obstructive Lung Disease; R5, R20, X5, AX, and FRes refer to the related impedance parameters at the given frequencies. Differences between study groups were assessed using ANOVA with post-hoc comparisons with Bonferroni correction. *p ≤ 0.001 compared with NSC and CS.

11 (5%) of NSC were former smokers.

R5-R20/R5

| 15% | 33% | 39% | 44% |
277 persons aged 65-97 yrs; 197 with obstruction (FEV1/FVC<LLN)

(R5-R20)/R5 in patients without obstruction: 33%

(R5-R20)/R5 in patients with obstruction (mainly COPD) 50.7%
Application of IOS (FOT)

- COPD;
- Asthma
- Bronchopulmonary displasia
- OSA
- Central airways obstruction
- Adult interstitial lung diseases
- Occupational and environmental exposure
- Response to bronchodilators;
- Bronchoprovocation testing
Table 1. Characteristics of Different Lung Function Tests Related to Airway Resistance

<table>
<thead>
<tr>
<th>Feature</th>
<th>Spirometry (FEV&lt;sub&gt;1&lt;/sub&gt;)</th>
<th>Plethysmography (sR&lt;sub&gt;aw&lt;/sub&gt;, sG&lt;sub&gt;aw&lt;/sub&gt;)</th>
<th>R&lt;sub&gt;int&lt;/sub&gt;</th>
<th>FOT (R&lt;sub&gt;rs&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient cooperation/effort</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Involves deep inhalation</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Adjusts for lung volume</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>Intra-subject variability (coefficient of variation)&lt;sup&gt;5,6,31,44,69,77,78&lt;/sup&gt;</td>
<td>3–5%</td>
<td>8–13%</td>
<td>5–15%</td>
<td>5–15%</td>
</tr>
<tr>
<td>Sensitivity to airway location</td>
<td></td>
<td>+</td>
<td>+++</td>
<td>+</td>
</tr>
<tr>
<td>Central</td>
<td>++</td>
<td>+</td>
<td>+++</td>
<td>+</td>
</tr>
<tr>
<td>Peripheral</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Cutoff for bronchodilator/&lt;br&gt;bronchocinstrictor&lt;sup&gt;5,6,20,24,69,78,79&lt;/sup&gt;</td>
<td>12/20%</td>
<td>25/40%</td>
<td>35%/3SDw</td>
<td>40/50%</td>
</tr>
<tr>
<td>Insight into mechanics</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td>Standardized methodology</td>
<td>Global, nonspecific</td>
<td>R&lt;sub&gt;aw&lt;/sub&gt;, TGV</td>
<td>Lung + chest wall</td>
<td>+</td>
</tr>
<tr>
<td>Reference equations&lt;sup&gt;2,6,10,69,78&lt;/sup&gt;</td>
<td>+</td>
<td>+</td>
<td>+ (pediatric)</td>
<td>++</td>
</tr>
</tbody>
</table>

+ to +++ = Yes, with increasing strength or prevalence of feature
− = No
sR<sub>aw</sub> = specific airway resistance
sG<sub>aw</sub> = specific airway conductance
R<sub>int</sub> = Interrupter resistance
FOT = forced oscillation technique
R<sub>rs</sub> = respiratory system resistance
SDw = within-subject standard deviation
TGV = thoracic gas volume
To conclude...

FOT and/or IOS measurements:

• Are fast and easy to perform (for the patient, as well as for the technician)
• Need only passive cooperation (tidal breathing)
• Are reproducible (although variability is greater than in spirometry, is comparable to other techniques of respiratory resistance measurements)
• Can be used in bronchodilator and bronchoprovocation tests
To conclude...

- Can be used in patients from 2..3 years of age up to 100 or more (?)
- There exist several reference values sets (much more for children than for adults) for both approaches
- There exist recommendation for performing measurements (ERJ 2003; ERM 2005)
- Offers new possibilities for studying respiratory physiology and pathology
LIMITATIONS

• Much less popular (than spirometry for example according to Cosmed representative >50 RESMONs sold (excluding US); on the other hand, according to Jaeger representatives, >9500 IOS devices were sold throughout the world)

• Difficult theoretical background

• Different models used; not completely verified
THANK YOU FOR YOUR ATTENTION