(measurement of) airway resistance

Prof. Ellie Oostveen
Dept. of Pulmonary Medicine
Antwerp University Hospital
Ellie.Oostveen@uza.be
Introduction: spontaneous breathing

A pressure gradient (negative/positive) between alveoli and airway opening leads to airflow ($V'$) (inspiration/expiration)
Introduction

Resistance = relationship between pressure and flow = $P/V'$
Resistance

Definition:

- Literally: resistance is frictional loss due to movement
- Respiration: \( R = \frac{\Delta P}{\Delta V'} \)
  
  (However: elastic properties (C) and inertial components (I) also resist against movement (flow))

Resistance is the in-phase component between (applied) pressure gradient and resulting respiratory airflow
Resistance

- Airway resistance
  - $Raw = \frac{P_A - P_B}{V'}$ (body plethysmography)

- Respiratory resistance
  - $Rrs = \frac{P_{rs}}{V'}$ (forced oscillations, interruptor technique)
Respiration: \( R = \Delta P / \Delta V' \)

\[ R = \frac{\eta 8 \pi l}{(\pi r^2)^2} \]

\[ R \propto l/A^2 \]
Distribution of Raw along the respiratory tree
Airway resistance: Raw

Raw-measurement

\[ \text{Raw} = \frac{P_A}{V'} \]
\[ R = \frac{P}{V'} = \frac{1}{0.5} = 2 \text{ cm H}_2\text{O/L/s} \]
Breathing cycle

normal vs. obstructive
Airway resistance

- Large airways determine Raw
- Raw is dependent on lung volume
- normal value:
  - $\text{Raw} \leq 0.2 - 0.3 \text{ kPa/l/s}$
- Significant change:
  - $\Delta \text{Raw} \geq 30\%$ baseline
Resistance measurement by F.O.T.

Superposition of small pressure oscillations and measurement of the flow response
Introduction

Superposition of small pressure oscillations and measurement of the flow response

Ratio $P/V'$ (=$Z_{rs}$) is dependent on $R_{rs}$, $C_{rs}$
Forced Oscillations
Forced Oscillation Technique

- Definition:
  
  F.O.T. is a measurement technique where small external pressure oscillations (P) lead to airflow variations (V’).

  The relationship between P/V’ is the total “resistance” (impedance, Zrs) of the patient.
Respiration + external pressure oscillation

spontaneous breathing + external oscillation (5 Hz)
Basics

FFT

Pressure
Flow

FFT
Forced Oscillation Technique (F.O.T.)

- Clinical potential of the method:
  - minimal patient cooperation
  - measurement during quiet breathing (no forced expiratory manoeuvres)
  - fast measurement
Recommendations for measurement

- Sitting position, nose clip, cheeks supported
- Quiet breathing at FRC
- Measurement duration 8-16 s, covering several breathing cycles
- No artifacts: swallowing, glottis closure, no leak, irregular breathing etc..
- 3-5 measurements: $Z_{rs} = \text{average (SD)}$
Forced Oscillation Technique

Homogeneous lung:

\[ P = \left( \frac{1}{Crs} \right) \times V + Rrs \times V' + Irs \times V'' \]

sinusoidal excitation:

\[ \frac{P}{V'} = Rrs + j(\omega Irs - \frac{1}{\omega Crs}) \]
FOT: healthy adult

- $R \propto 1/\omega C$
- $\omega l$

Graph showing $R$ and $X_{rs}$ over frequency.
FOT: obstructive patient

Graphs showing changes in Rrs and Xrs with frequency (Hz).
Relationship $\text{FEV}_1$ - Rrs: 125 COPD patients
Relationship $\text{FEV}_1$ - $\text{Rrs}$: 125 COPD patients
Bronchoconstriction

53 patients with asthma: BHR: baseline and at $\Delta FEV_1 \geq 15$

van Noord et al. 1992
Reversibility in adult asthmatic patients: FOT versus spirometry

Acute effect of inuvair: formoterol & beclometasone dipropionate: LABA + ICS

24 (documented) asthmatic patients:

- 16F: 8M; 51 (14) yrs [range: 19-73 yrs]
- $\text{FEV}_1 = 93$ (20) %pred [range: 50-130 %pred]
- $\text{FVC} = 110$ (15) %pred [range: 82-138 %pred]
- $\text{FEV}_1/\text{FVC} = 70$ (8) % [range: 54% - 85%]
Acute effect of Inuvair

- 48 hrs no medication (washout)
- Baseline LF measurement (FOT, spirometry)
- Inuvair administration
- 4 hrs later: post-bronchodilator LF measurements (FOT, spirometry)
#7: \( \Delta \text{FEV}_1 = 1.12 \text{ L} (=34\%) \)
\( \Delta \text{FVC} = 0.36 \text{ L} \)

<table>
<thead>
<tr>
<th></th>
<th>pred</th>
<th>pre</th>
<th>%pred</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC (L)</td>
<td>4.71</td>
<td>3.27</td>
<td>115 %</td>
</tr>
<tr>
<td>FEV1 (L)</td>
<td>3.86</td>
<td>5.42</td>
<td>85 %</td>
</tr>
<tr>
<td>FEV1/VC (%)</td>
<td>80</td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>
#7: ΔR4 = -1.36 hPa/L/s
Reversibility: FEV1

Pearson correlation coefficient

$r = -0.79$ (p < 0.01)
Reversibility: FEV1

![Graph showing FEV1 reversibility](image-url)
Reversibility: FOT

Pearson correlation coefficient

$r = -0.94$ (p< 0.01)
Reversibility: FOT

![Graph showing Δ R4 (hPa.s/L) vs. R4 baseline (hPa.s.L⁻¹) for normal and obstructive cases.](image)

- **Δ R4 (hPa.s/L)**
- **R4 baseline (hPa.s.L⁻¹)**

- **normale R4**
- **obstructief**
Reversibility: $\text{FEV}_1$

Pearson correlation coefficient

$r = -0.81$ (p < 0.01)

$\bigcirc$ : FOT - nonresponder
Reversibility: FOT

Pearson correlation coefficient
\[ r = -0.94 \quad (p < 0.01) \]
Merits of F.O.T.

- Fast measurement
- Non-invasive
- No (hardly any) cooperation needed
- Measurement during spontaneous breathing
- (no change in bronchomotor tone)

high time resolution
(using 5 Hz: every 200 ms information on Zrs !!)
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
FOT setup (during sleep)
Application of FOT during sleep/CMV

spontaneous breathing + external oscillation (5 Hz)
Interruptor resistance

- **Rint**: Measurement of resistance by
  - (fast) interruption of the respiratory airflow and simultaneous measurement of the driving pressure gradient:
  - \[ R_{\text{int}} = \frac{\text{Pressure (after interruption)}}{\text{Flow (before interruption)}} \]
Rint
Degree of obstruction: adults

FEV$_1$ (%pred) vs. Rint (kPa/l/s)
$\Delta \text{FEV}_1$ and $\Delta \text{Rint}$ in BHR-testing
Advantages compared to forced expiration

Minimal need for patient cooperation

Deep inspiration is not required (this can lead to bronchoconstriction or dilatation)

Fast measurement
Raw, Rrs, Rint

- Disadvantages compared to spirometry
- No one-to-one relationship (?)

⇒ Alternative methods or additive ?