Forced Oscillatory Technique
An Excellent Airway Caliber Test, Particularly In Children

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Objectives

- Explain the underlying physiology behind the forced oscillation technique
- Review published literature
- Present case examples
Flow

Volume

Static mechanics, Muscle force, Effort

Stress relaxation

Upper airway dimensions, Muscle force, Effort

Airflow limitation

Static mechanics, Muscle force, Effort, Gas trapping

Inspiratory resistance, Muscle force, Effort
Forced Oscillatory Technique (FOT)
Basic Lung Mechanics
Basic Mechanical Model

\[ F_{app} \quad R \text{(oil)} \quad \text{Mass} \quad F_{opp} \quad \text{Spring} \]
Equation of motion

Newton’s Law (third law of motion)
For every action there is an equal and opposite reaction.

\[ F_{\text{app}} = F_{\text{opp}} \]

\[ F_{\text{opp}} = F_{\text{el}} + F_{\text{res}} + F_{\text{in}} \]

Elastance (E)
Resistance (R)
Inertance (I)
Basic Principles

If you measure the pressure, flow and volume generated at the mouth during breathing, one can solve for the parameters R, E, and I that define the mechanical characteristics of the model.

\[ P = EV + RV' + I V'' \]
If the flow alternates between inflow and outflow, single compartment model (SCM) then additional pressure is also required to accelerate and decelerate the mass of gas in the pipe, known as the inertance (I).

\[ P = EV + RV' + I V'' \]

This is the “equation of motion” for this SCM system.
Basic Principles: Impedance

\[ Z_{rs} = \frac{|\Delta P|}{|\Delta V|} \]

- Elastance
- Resistance
- Inertance
Impedance (Z) can be conceived as a generalization of resistance, since it embodies both the in-phase and out-of-phase relationships between P and V. The in-phase component is called the real part of Z (or resistance (R)), whereas the out-of-phase relationship is expressed by the imaginary part (or reactance (X)).

ERS Task Force 2003
Forced Oscillations: theory
In oscillating flow, the total opposition to flow, or the net sum of forces that must be overcome, is termed impedance (Z).

Z is determined not only by R, E and I, but also by the frequency of oscillation, since the tissues have time-varying mechanical properties (known as viscoelastance).
Basic Principles

peripheral  central

Z5Hz, Rrs5Hz, Rrs20Hz, X5Hz,
Airway resistance (Raw) is measured using body plethysmography by using a panting technique to keep volume oscillations low (E not significant) and frequency low (I not significant). The equation of motion therefore is governed by Raw alone.

\[ P = EV + RV' + TV'' \]
Forced Oscillation Technique
Forced Oscillation Technique

Guidelines and Statements

ERS TASK FORCE

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

- European Resp J. 2003 (22) 1026-1041

ATS/ERS Working Party

History

Mayo Clinic
Dr. Hyatt’s lab
circa. 1960’s

Forced Oscillatory Techniques

Input impedance

- test signal applied at airway opening
  mono- or multi-frequency (usual 2-40 hz)
- multi-frequency:
  - pseudorandom noise impulse

Mottram CD Ruppel’s Manual of Pulmonary Function Testing 10th Ed. Chp. 10
Forced Oscillatory Techniques
Forced Oscillation Technique

### Calibration

- **Volume calibration prior to testing in accordance with ATS/ERS recommendations**
- **Known reference impedance with a magnitude of 1.5 kPa/s/L and 4 kPa/s/L are suggested for calibration in adult and infant studies**
  - a maximum error of 10% or 0.01 kPa/s/L, whichever is greater, is allowed over the frequency range of interest.

ERS Task Force 2003
Forced Oscillation Technique

Subject preparation

- Performed in the sitting position
- Head in a neutral or slightly extended position. Flexion of the head should be avoided
- The subject (or technician) firmly supports the cheeks and the floor of the mouth using both hands
- Noseclip is required
Forced Oscillation Technique

- Subject simply breaths normally (quietly)
- Distractors

Walsh B, Perinatal and Pediatric Respiratory Care 4th Ed. 2014
Hynes KM, Motttram CD. Chp5 Fig 5-14
Forced Oscillation Technique

Data collection
- Minimum 3 minutes of quiet breathing after an FVC maneuver
- Minimum of 20-30 seconds of data collection

Measurement acceptance criteria
- Swallowing, glottis closure, leak around the mouthpiece, improper seal with the nose-clip, irregular breathing or acute hyperventilation during the measurement are reasons to discard the measurement.
- Flow signal should be displayed on the screen during the measurement to assist in artifact detection
- If artifact detected than should be rejected.
Forced Oscillation Technique

• A total of three to five technically acceptable measurements should be performed.
• The subject should come off the mouthpiece in between successive measurements.
• The short term intra-individual CV of FOT indices in healthy adults range 5–15%.
Clinical Applications

- 12 normal subjects
- Rrs greater increase in the low frequency range

Advantages
- Non-invasive
- Little subject cooperation required
- Deep inspirations that affect bronchoconstrictor agents are avoided.

Clinical Applications

- 313 children: 132 could not do spirometry Baseline and post-bronch spiro and FOT Baseline: Rrs correlated with FEV1, MEF50
  Increased peripheral resistance (MEF50) correlated with increased frequency-dependence of Rrs at low frequencies

J Asthma (Delacourt, 2000)
Clinical Applications

- 73 children 4 years of age
  - Childhood Asthma Prevention Study (NIH/National Institutes of Allergy and Infectious Diseases)
  - Conclusion: IOS was better than spirometry at discriminating between young children with and without asthma on the basis of their bronchodilator response.
  - Marotta, et.al J ALLERGY CLIN IMMUNOL AUGUST 2003
49 school-aged children born prematurely with (n=15) or without (n=34) chronic lung disease (CLD), and 18 healthy children born at full term.

Compared to an increase in Rrs, a decrease in Xrs appears to be more sensitive and specific indicator of intrathoracic obstruction.

Malmberg et al. ERJ 2000 (16) 598-603
Forty-eight children (5.3 ± 0.9 years) were challenged to compare the FEV1 and FOT responses.

Conclusion: An increase in Rrs5 of 45.2% showed the optimal combination of sensitivity and specificity to detect a 20% reduction in FEV1.
51 subjects (20-82 yrs.) clinically ordered MCT
Clinical Cases
Case 1

- 4 y.o. male
- HPI
  - Mother reports that he coughs every night
  - Worse in winter and with exercise
- Impression/plan:
  - CXR
  - Allergy testing
  - Assessment of lung function
  - Spirometry and/or forced oscillation
Case 1

- Negative skin testing
- Negative CXR
Case 1 “could not perform spirometry”

- Started Asthma Action Plan.
  - Albuterol 90 mcg/Act HFA Aerosol 2 puffs by inhalation every 4 hours as needed.
- Additional instruction on use if Aerochamber
Case 2

- 6 y.o. female

**PMH:**

- RSV at age 18 mos., but she did not require hospitalization.
- She was wheezy then, with labored breathing. She was treated with nebulized albuterol.
- Since then, she has had random episodic dry cough, every few month, lasting 2-3 days.
Case 2

CURRENT MEDICATIONS

- Ventolin 90 mcg/actuation HFA Aerosol by inhalation as directed by prescriber as needed.
- Accolate (Zafirlukast - leukotriene receptor antagonist) 10 mg tablet 1 TABLET by mouth two times a day.
### Case 2

6 y.o. Female  
Wt: 23.3 KG, BMI: 15.1  
Ht: 124.4 cm  
Previous test: Desk: RC: 1.00

<table>
<thead>
<tr>
<th>SPIROMETRY</th>
<th>PREDICTED</th>
<th>NORMAL</th>
<th>RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC</td>
<td>1.65</td>
<td>&gt;1.29</td>
<td></td>
</tr>
<tr>
<td>FVC</td>
<td>1.65</td>
<td>&gt;1.29</td>
<td></td>
</tr>
<tr>
<td>FEV1</td>
<td>1.56</td>
<td>&gt;1.20</td>
<td></td>
</tr>
<tr>
<td>FEV1/FVC</td>
<td>94.7</td>
<td>&gt;74.9</td>
<td></td>
</tr>
<tr>
<td>FEF25-75</td>
<td>2.1</td>
<td>&gt;1.1</td>
<td></td>
</tr>
<tr>
<td>FEFmax</td>
<td>4.0</td>
<td>&gt;2.8</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>CONTROL</th>
<th>POST-DILATOR**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FOUND %PRED.</td>
<td>FOUND %CHANGE</td>
</tr>
<tr>
<td>VC</td>
<td>1.05*</td>
<td>1.12* +6%</td>
</tr>
<tr>
<td>FVC</td>
<td>1.05*</td>
<td>1.12* +11%</td>
</tr>
<tr>
<td>FEV1</td>
<td>1.01*</td>
<td>1.12* +11%</td>
</tr>
<tr>
<td>FEV1/FVC</td>
<td>95.4</td>
<td>100.0</td>
</tr>
<tr>
<td>FEF25-75</td>
<td>1.1*</td>
<td>1.6</td>
</tr>
<tr>
<td>FEFmax</td>
<td>1.7*</td>
<td>3.2 +83%</td>
</tr>
</tbody>
</table>

*Outside normal range.  
**Bronchodilator was Albuterol

**COMMENTS:** This was the patient’s first effort, and the pre-bro not technically satisfactory. Post-bronchodilator spirometry

### Bronchoprovocation challenge by forced oscillation since she is unable to perform spirometry adequately.
Case 2

Diagnosis: Cough variant asthma

<table>
<thead>
<tr>
<th>AIRWAY REACTIVITY</th>
<th>PREDICTED NORMAL</th>
<th>RANGE</th>
<th>CONTROL FOUND</th>
<th>%PRED.</th>
<th>POST-CHALLENGE** FOUND</th>
<th>%CHANGE</th>
<th>POST-DILATOR*** FOUND</th>
<th>%CONTROL</th>
</tr>
</thead>
<tbody>
<tr>
<td>R5Hz</td>
<td>2.2</td>
<td>&lt; 2.6</td>
<td>0.71</td>
<td>32%</td>
<td>1.14</td>
<td>+62%</td>
<td>0.61</td>
<td>86%</td>
</tr>
<tr>
<td>R10Hz</td>
<td>2.1</td>
<td>&lt; 2.5</td>
<td>0.58</td>
<td>28%</td>
<td>0.88</td>
<td>+52%</td>
<td>0.52</td>
<td>89%</td>
</tr>
</tbody>
</table>

**COMMENTS**: Normal respiratory resistance at baseline. Positive methacholine challenge, indicating airway hyperresponsiveness. The patient developed cough and complained that it was harder to breathe. Resistance returned to baseline following bronchodilator, and symptoms improved.
Case 2

Mayo Asthma Plan
Pediatric Allergy Immunology Pulmonology

Provider: Pianosi, Paolo T, MD
Service Date/Time: 07-Jun-2013 16:16

### Triggers
- [ ] Pull

### Peak Flow Meter Device:
- [ ]

### Best Peak Flow based on
- [ ]

### Asthma Severity Classification:
- [ ]

### Tobacco exposure:
- [ ]

### Sreen Zone (Controlled)

#### Your asthma is under control if:
- [ ] You have no cough, wheeze, chest tightness, or shortness of breath during the day or at night
- [ ] You can work, play, and exercise without asthma symptoms

#### Take these maintenance medications:

<table>
<thead>
<tr>
<th>Medication</th>
<th>Dose / Route</th>
<th>Times / Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alvesco 80 mcg</td>
<td>1 Inhalation</td>
<td>2 times a day</td>
</tr>
</tbody>
</table>

#### Take these quick-relief / rescue medications:

<table>
<thead>
<tr>
<th>Medication</th>
<th>Dose / Route</th>
<th>Times / Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albuterol HFA</td>
<td>2 puffs</td>
<td>every 4-6 hours as needed</td>
</tr>
</tbody>
</table>

#### Before exercise / activity, if needed take:

<table>
<thead>
<tr>
<th>Medication</th>
<th>Dose / Route</th>
<th>Times / Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albuterol HFA</td>
<td>2 puffs</td>
<td>15 minutes prior to exercise / activity</td>
</tr>
</tbody>
</table>

### Instructions
This is the zone Kinsey should be at everyday, symptoms free. Your triggers are: rhinitis, respiratory infections and exercise. Please use Optichamber spacer with mask when administering your asthma medications. Please brush teeth or rinse mouth after administering daily controller medication to avoid oral thrush. Administer Albuterol for cough, wheeze, or shortness of breath. Patient can repeat administration of Albuterol once during or after exercise.
Forced Oscillations: Interpretation

\[ R_{rs} \neq \text{FEV}_{1} \]
How are FEV₁ and FOT parameters different?

- FOT obtained during quiet breathing vs. FEV₁ during forced exhalation
- Variable volumes during FOT (esp. acute BC or BD)
- Effect of deep inhalation on airflow during FEV₁
Conclusions

Disadvantages

- Volume-dependence, physiologic noise
- Limits of knowledgeable practitioners/interpretation
- Problem with upper airway shunt in FOT
Conclusions

Advantages

• Noninvasive
• Rapid, real-time
• No influence on measurements
• Very sensitive to airway resistance
• Cost

Clinical uses

• Assess airflow limitation (peripheral and central), bronchodilator response, bronchoprovocation testing
• *Children*, elderly, neuromuscular disease, sleep, mechanical ventilation
Pulmonary Function Testing and Bedside Pulmonary Mechanics

KATRINA M. HYNES, CARL D. MOTTRAM