Accurately Measuring Airway Resistance in the PFT Lab

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Disclaimer

The views in this lecture are those of the presenter and not those of the Department of Veterans Affairs or any other agency of the United States Government.

I have no vested interests in any of the manufacturers of the equipment referenced in this presentation.
Objectives

- Evaluate quality of Airway Resistance Measurements through graphic analysis
- The participant will identify corrective actions based on graphical analysis
Basic Physiology

In a most basic expression:
Raw = ΔPressure / Δ Flow

Unit of measurement: cmH$_2$O/L/sec

Students? Straws
\( \Delta P / \Delta \text{Flow} \)

The gas flow resistance caused by friction between the gas molecules and the airway wall.

Think of Poiseuille’s Law in terms of the factors that go into it.

– Pressure, flow, airway radius, airway length, gas viscosity
Factors that DECREASE Raw

- ↑ airway diameter
- Bronchodilation
- ↓ airway length
- ↓ gas viscosity
- Laminar flow
- ↑ lung volume
Factors that **INCREASE** $\text{Raw}$

- $\downarrow$ airway diameter
- Bronchoconstriction
- $\uparrow$ airway length
- $\uparrow$ gas viscosity
- Turbulent flow
- $\downarrow$ Lung volume
Gaw

- Conductance (Gaw) is the inverse of Raw.
- It is a measure of airflow generated per unit pressure.
- \( \text{Gaw} = \frac{\text{Flow}}{\text{Pressure}} \)
- Unit of Measurement: L/sec/cmH\(_2\)O
- 1/Raw
Relationship Between Lung Volume and Raw/Gaw

- Raw has a linear and hyperbolic relationship with Lung Volume
- Gaw has a direct relationship with lung volume

<table>
<thead>
<tr>
<th>Increase lung volume</th>
<th>Decrease lung volume</th>
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<tbody>
<tr>
<td>Decrease Raw</td>
<td>Increase Raw</td>
</tr>
<tr>
<td>Increase Gaw</td>
<td>Decrease Gaw</td>
</tr>
</tbody>
</table>
sRaw and sGaw Correct for Lung Volume

\[ s\text{Raw} = \text{Raw} \times \text{Lung volume} \]

\[ s\text{Gaw} = \frac{\text{Gaw}}{\text{Lung volume}} \]
Tests to Measure Airway Resistance

- Esophageal balloon
- Impulse oscillometry (IOS)
  - Rrs: lung volume independent
- Body plethysmography
  - Raw
  - Gaw
Indications

From ATS PFLM&P 3rd edition

- “Further evaluation of airflow limitation beyond spirometry”
- “Determining the response to bronchodilator”
- “Determination of bronchial hyperreactivity in response to methacholine; mannitol or isocapnic hyperventilation”
Indications (cont)

– “Distinguishing respiratory muscle weakness from obstruction as the cause of low flow rates”

– “Following the course of disease and response to treatment”
Patient Preparation

- Wear non-restrictive clothing
- Test at least 1 hour after eating
- Test at least 1 hour after exercise/physical activity (affect bronchial tone)
Patient preparation

If reversibility to be assessed use the following schedule regarding meds (same as spirometry):

- SABA 4-6 hours  albuterol
- SAMA 6 hours  ipratropium
- LABA 12 hours  formoterol, salmeterol, arformoterol
- Ultra-long acting agents: 24 hours  tiotropium, indacaterol, vilanterol
Technique

- Patients should be seated in pleth box.
- During panting patient should place fingertips on cheeks
- Traditionally patients are asked to begin panting with the valve open at FRC
- Current ATS guidelines state pt may pant at a comfortable volume
- Computer corrects for lung volume
Technique

- Panting should be small breaths between 50 – 100ml / breath at a frequency of 1.-2.0 breaths / second
- All efforts should appear in the graph within the pressure range
- After 2-3 acceptable open-shutter loops obtained, close shutter and continue panting for TGV data
Technique
The inspiratory portion of the Flow-Volume curve has the shape of a crescent. The expiratory portion of the curve is triangle-shaped and shows a linear decrease in flow. All dynamic lung volumes (FEV1, PVC, VC, ...), flow values (FEFx, PEF, ...), static lung volumes (TLC, ITGV, RV, ERV, ...) and the resulting airway resistance (Raw) are within the individual normal range. The loops of specific resistance (tan Beta) and the occlusion pressure curves (tan Alpha) show a normal angle of inclination.
Airway Resistance

[LRT, Reff, R0.5]

Lung Volume

[ITGV]

Normal

Increased

Specific resistance loops

Occlusion pressure curves

From Carefusion
Obstruction

Obstructive ventilatory disorders produce a concave Flow-Volume curve representing the impaired expiratory flows (FEF50) via the entire expiratory portion. As compared to the predicted value, the bar diagram reveals a slight increase in residual volume (RV). The airway resistance (Raw) is increased. The open and flat specific resistance loops indicate an obstruction, which is partially reversible after having administered a spasmolytic.

Collapse

The expiratory portion of the Flow-Volume curve shows the typical bend of severely impaired expiratory flow. The bar diagram indicates a considerably increased residual volume (RV), intrathoracic gas volume (ITGV), and total lung capacity (TLC). The airway resistance (Raw) is clearly increased. Typically club-shaped specific resistance loops give evidence of an expiratory airway collapse. Very flat occlusion pressure curves indicate an increased intrathoracic lung volume. The curves cannot be reversed after having administered a spasmolytic.

Restriction

Flow-Volume curves produced by restrictive ventilatory disorders have an almost normal shape. However, the vital capacity (VC) is considerably reduced and flows (FEFs) are restricted. The curves obtained by bodyplethysmography have a shape typical for restrictive ventilatory disorders: normal airway resistance (Raw), steep specific resistance loop and a reduced total lung volume (TLC) as well as a decreased intrathoracic gas volume (steep occlusion pressure curve (ITGV)).

Stenosis

The degree of deformation of the Flow-Volume curve depends on the kind of stenosis. Often, both inspiration and expiration are impaired (FEF50, MIPx, and FEV1 are considerably reduced). Airway resistance (Raw) is always clearly increased and the specific resistance loops exhibit a typical S-shape.
Relationship between change in FEV1 following surgery versus inspiratory lung resistance at baseline in patients undergoing lung volume reduction surgery.

David A Kaminsky Respir Care 2012;57:85-99
Relationship of mouth pressure (Pmo) and box pressure (Pbox) by body plethysmography under closed-loop panting conditions (left) and open-loop panting conditions (right).

\[ \frac{\Delta P_{mo}}{\Delta \text{Vol}} \times \frac{\Delta \text{Vol}}{\Delta \dot{V}} = \frac{\Delta P}{\Delta \dot{V}} \]

David A Kaminsky Respir Care 2012;57:85-99

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Relationship between airway resistance (Raw) and lung volume, the reciprocal of Raw (conductance of the airways [Gaw]) and lung volume, and Gaw/TGV (thoracic gas volume) (specific airway conductance [sGaw]) and lung volume.
Impedance data from patients with asthma (left) and COPD (right) according to severity of underlying disease.
Body Plethysmography

- Must analyze graphics to determine acceptability of efforts (as well as observing technique)
- As with F-V loops and IOS, graphics play a role in interpreting results
Panting: Valve Open
Flow on y-axis; Volume on x-axis
Panting: Valve Closed
Pressure on y-axis; volume on x-axis
72 y/o male with COPD

- FVC: 1.28 L (41%)
- FEV1: 0.63 L (26%)
- FEV1/FVC 49%
- Raw 2.74 (189%)
- Gaw 0.37 (36%)
- sGaw 0.07 (34%)
FVL and Raw Measured in the Same Patient
65 y/o male with numerous admissions for asthma, past history of intubations, steroid dependent

- FVC: 2.40 L 63%
- FEV1: 1.39 L 47%
- FEV1/FVC: 58%
- FEF 50% 22%
- FEF25-75% 26%
- Raw 150%
- Gaw 45%
- sGaw 50%
FVL and Raw Measured in the Same Patient
FVL and Raw Measured in the Same Patient
51 y/o Asthmatic Male

- Current smoker, 35 years of 1 ppd
- Hx of childhood asthma, no attacks during adulthood
- Received anesthesia for a cervical laminectomy and had a severe asthma attack
- PFTs obtained prior to discharge
51 y/o asthma post anesthesia

- FVC: 4.38L 89%
- FEV1: 3.21L 82%
- FEF 50% 60%
- FEF25-75% 60%
- PEFR 88%
- Raw 149%
- Gaw 45%
- sGaw 58%
51 y/o Asthma post anesthesia
Diagnosis: Asthma  
Dyspnea: After severe exertion  
Tobacco Prod: Never Smoked  
Medications: Albuterol  
Pre Test Comments: Worsening Dyspnea  
Post Test Comments: 2 PUFFS ALBUTEROL MDI GIVEN VIA SPACER.  
Occ Expos:  

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<tr>
<td>FEV1 (L)</td>
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<td>FEV1/FVC (%)</td>
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<td>81</td>
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<td>FEF 25% (L/sec)</td>
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<td>FEF 75% (L/sec)</td>
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<td>FEF Max (L/sec)</td>
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<td>FIVC (L)</td>
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<tr>
<td>FIF Max (L/sec)</td>
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---- LUNG VOLUMES ----
SVC (L)        | 2.57       | 3.15        | 82    | 0.49| 2.63|
IC (L)         | 2.29       | 2.18        | 105   | 0.49| 2.63|
ERV (L)        | 0.28       | 0.97        | 29    | 0.39| 0.81|
TGV (L)        | 2.51       | 2.72        | 92    | 0.52| 2.18|
RV (Pleth) (L) | 2.23       | 1.64        | 136   | 0.38| 1.31|
TLC (Pleth) (L)| 4.80       | 4.90        | 98    | 0.54| 3.92|
RV/TLC (Pleth) | 46         | 33          | 141   | 5   | 26  |
Trapped Gas (L)|            |             |       |     |     |

---- AIRWAYS RESISTANCE----  
Raw (cmH2O/L/s) | 2.62 | 1.86 | 141 | 0.43 | 1.55 |
Gaw (L/s/cmH2O) | 0.38 | 1.03 | 37  | 0.86 | 0.86 |
sRaw (cmH2O*s)  | 6.97 | <4.76| 3.97| 0.14 | 0.17 |
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<th>SpL</th>
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![Graphs showing data points](image-url)
Technique Errors: Panting too low or volume too big
Technique Errors
Impulse Oscillometry

- Sometimes called “forced oscillation technique” or FOT
- Do not mistake that to mean there are any forceful efforts in the testing maneuver
- A miniature loudspeaker produces a range of frequencies producing “forced” oscillations of flow
Impulse Oscillometry

- The patient breathes in a relaxed manner, tidal breathing
- Time protocols vary: 15-30 seconds or 30-60 seconds (with 15-20 seconds of data collected)
- A special mouthpiece is used: has a ridge to keep the tongue out of the path of airflow
IOS Mouthpiece

Jaeger product
It is a good alternative for children who cannot produce valid, reproducible flow volume loops.

But remember, the child needs to sit still for the maneuver.

Gagging, swallowing, coughing interfere with the results.

Obtain 3-5 trials.
Impulse Oscillometry

- IOS measures both
  - $R_{rs}$: resistance
  - $X_{rs}$: reactance (combined effects of compliance, inertance and frequency)

- Both graphs plot frequency on the x-axis

- Frequency dependence: resistance is higher at lower frequencies in children, not normal in adults
Impulse Oscillometry

- Measures Resistance of the Respiratory system (Rrs)
- Deflection of the membrane of a loudspeaker generate a pulse-shaped pressure impulses.
- Lung mechanics produce characteristic ratios of pressure and flow
Impulse Oscillometry

- Oscillating frequencies vary between 5 Hz and 35 Hz and are referred to as a spectrum.

- Each frequency in the spectrum is produced in cycles: ex 5 cycles per second.

- These cycles of oscillating frequencies between positive and negative mouth pressures have differing resistances depending on lung mechanics.
Impulse Oscillometry

- Patients can breathe “normally”, i.e. in a resting state (not a forced maneuver such as FVC)
- A specific mouthpiece is used to keep the tongue does not obstruct airflow
Impulse Oscillometry

- Can test patients who can not perform spirometry
- Useful in pediatric populations
- Can be more sensitive to changes in challenge testing and EIA asthma testing than spirometry
- Interpretation of graphics important as in FVC graphics
From: Measurement of respiratory impedance by Impulse Oscillometry - effects of endotracheal tubes

Kuhnle et al

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**Trial 3**

- Left graph: Graph showing data points on a linear scale with frequency (Freq) ranging from 0 to 30.
- Right graph: Graph showing a horizontal line at 0 with data points on a linear scale, with frequency (Freq) ranging from 0 to 30.
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**Trial 1**

![Graph 1](image1)

![Graph 2](image2)
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### Trial 2

**Graph 1:**
- X-axis: Frequency (Freq)
- Y-axis: Value (P)
- Data points showing a decreasing trend.

**Graph 2:**
- X-axis: Frequency (Freq)
- Y-axis: Value (X)
- Data points showing a consistent pattern post a single point.
<table>
<thead>
<tr>
<th>IOS</th>
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<td>-476</td>
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- Compared spirometry and IOS with challenge testing for EIB
- Used room temperature and cold temperature exercise challenges
- 6 min exercise challenge with cycle ergometry
- Randomly assigned to inhale 22°C or -1°C (after 48 hours, completed the alternate protocol)
Only the inhaled air was chilled for the cold temp challenge.

One population tested were collegiate female hockey players.

Found IOS detected the same degree of resistance to challenge testing regardless of temperature of inhaled air.
Frequency Dependence of Compliance

- FDC is an invasive technique requiring an esophageal balloon
- Static Compliance (Cst) is measured during exhalation from a SVC
- Dynamic Compliance is measured at increasing respiratory frequencies and is expressed as a ratio to the Cst
- $\frac{C_{\text{dyn}}}{C_{\text{st}}}$
Frequency Dependence of Compliance

- Evaluates distal airway function
- Limited use due to its invasive nature
- Esophageal balloon is advanced into the distal 1/3 of the esophagus
Study of WTC Exposure

- Looked at 174 people with symptoms from WTC exposure
- All tested with Spirometry and IOS
- 43 tested with FDC
Study of WTC Exposure

- All had normal spirometry but were symptomatic
- CXR demonstrated hyperinflation while spirometry was normal
- IOS and FDC demonstrated distal airway obstruction
I got hooked on cigarettes as a youth...

Then I got hooked on chewing tobacco while trying to quit cigarettes...

Then I got hooked on nicotine gum while trying to quit chew...

Then I got hooked on the patch while trying to quit the gum...

Then I got hooked on e-cigarettes while trying to quit the patch...

Now I'm hooked on oxygen...