Body Plethysmography

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Boyle-Marriott’s Law

• The absolute pressure exerted by a given mass of an ideal gas is inversely proportional to the volume it occupies if the temperature and amount of gas remain unchanged within a closed system.

\[ P \propto \frac{1}{V} \]

\( P = \text{pressure} \)
\( V = \text{volume} \)
(assumes temperature constant and closed system)
Shift volume

- Inspiration is initiated from end expiration by inspiratory muscles T.V increases.
- Airflow does not start immediately → pressure gradient is required for mass movement.
- Airflow lags behind the changes in lung volume due to airway resistance.

\[
\text{Resistance} = \frac{\text{Change in pressure}}{\text{Flow}} = \frac{\{\text{Zero}\}}{\{\infty\}}
\]

- If the airway is occluded during inspiration, there is decrease in alv. Pressure but no flow → Closed compartment → Boyle law
• During inspiration the thoracic volume excursion is slightly ahead of the equilibrating mass flow.

• When thoracic & lung volume ceases to increase alveolar and box pressure will reach equilibrium.

• However as long as air is flowing, the increase in lung vol > vol of air that passed through the airways into lung.

• This small discrepancy in mass flow is called “shift volume”
• *Shift volume* is the tiny pressure generating fraction of the tidal volume, tiny → ~ 1/100

• Volume defect in the lung is equal in magnitude but opposite in sign to the volume defect in the box.

• Volume of box = Tot box vol - Body vol (est. from weight)

• Why shift volume?  
  – Provides the link to box pressure  
  – Allows determination of TGV & sRaw
Alveolar $\Delta P$ = Alveolar $\Delta V$

$P_{mouth} = P_{alv}$

How to achieve 'zero flow' or occlusion maneuver?

Shutter mechanism prevents entry or exit of air to lungs, therefore normal inspiratory or expiratory efforts cause compression and decompression of the lung volume. This movement is transmitted to box as in normal flow.

$\Delta P_{mo}$

Alveolar $\Delta P \propto$ Shift volume
• Pm plotted on y axis, shift vol on x axis.
• Inspiratory efforts causes neg Pm & positive S.V
• Little deviation in both inspiratory & expiratory efforts.
• Expiratory efforts causes visa- versa
• The slope Pm vs shift volume $\propto$ to FRCpleth.

Lung volume and shift volume

- When moving a plunger a equivalent distance in a short vs. long syringe, the pressure change will be greater in the short cylinder.
- Larger the lung volume for a given shift vol, the smaller the pressure change.
- Greater the pressure change, the smaller lung vol. relative to shift volume.
- In a large lung occlusion pressure curve will be more flat, in a small lung more steep.
FRC - TGV at occlusion
ERV - maximal expiration
IVC - maximal inspiration
RV - FRC-ERV
TLC - IVC + RV
• Specific airway resistance ($s_{Raw}$)
• Airway resistance (Raw)
• Conductance (Gaw)
Specific airway resistance

- Resistance is defined as \( \frac{\text{driving pressure}}{\text{Flow}} = \frac{\text{Palv}-\text{Pmo}}{\text{Flow rate}} \rightarrow \frac{\text{Shift vol}}{\text{Flow}} \)

- The more the driving pressure for a given flow, the greater the resistance.
- \( \text{Pmo} \) - constant during unimpeded breathing
- \( \text{Palv} \) - not available during free breathing.
- Shift volume represents the thoracic excursions which is needed to establish the driving pressure to the lung.
- Though not identical, closely related to driving pressure.
- Ratio of shift vol to flow rate is called specific airway resistance or \( s\text{Raw} \)

• If airflow is plotted on the vertical axis and shift vol on the horizontal axis, closed loops are obtained.
• The reciprocal slope of the breathing loop represents the sRAW.
• Normally the curves are straight lines
• A more flat curve indicates an elevated shift volume relative to airflow and therby an increase of sRaw.
• Various respiratory diseases provide different patterns.
• The contents of the sRaw loop is often complex not always uniform, or straight lines esp in obstructive diseases.
• sRaw loop involves varying flows throughout the cycle.
• Where to calculate the plot of sRaw?
• sRaw total
• sRaw effective
• sRaw at .5Ls$^{-1}$
Total specific resistance.

- The sRtot is determined by a straight line between maximal inspiratory and maximal expiratory shift volume points.
- The outstanding characteristic of sRtot is its sensitivity to partial obstruction of peripheral airways.
- The potential disadvantage of sRtot would appear to be a greater variability from test to test, as a consequence of using only two points at the extremes of inspiratory and expiratory shift volume.

Effective specific resistance

- Introduced to integrate the effects of variable flows and non-linearity of mouth flow shift volume loops during tidal breathing.
- Calculated from the quotient of integrated shift volume loop and integrated flow-volume loop.
Advantages over sRtot

- Better assessment of the airway behaviour
- Reflects larger central airways than sRtot
- Improved SNR.
sRaw at .5 Ls$^{-1}$

- Dubois initially measured the slope of sRaw at a fixed flow of 1Ls$^{-1}$
- Subsequently for standardization purposes for calculation of resistance, the flow range at which sRaw is measured has been limited to .5Ls$^{-1}$
- Denoted larger more proximal airways.
Conductance

• The reciprocal of resistance is denoted as specific conductance

• $s_{Gaw} = \frac{1}{s_{Raw}}$
Resistance

- To obtain airway resistance $Raw$, Palv is indispensable.
- It is seen that, $sRaw$ can be changed to $Raw$ by dividing $sRaw/FRC_{pleth}$.
  \[ Raw = \frac{sRaw}{FRC_{pleth}} \]
- However, breathing loops are obtained at a higher lung volumes than $FRC_{pleth}$, so to correct for this $Vt/2$ is added.
  \[ Raw = \frac{sRaw}{FRC_{pleth} + Vt/2} \]
  \[ Gaw = \frac{1}{Raw} \]
Interpretation

• Numerical values of $s_{Raw}$, $s_{Gaw,Raw,Gaw}$ and TGV can be compared with the normative data to define obstructive, restrictive or mixed defects.

• Graphical or based on the appearance of the loop.
Restrictive lung diseases

- Can be suspected when FVC is reduced and FEV1/FVC is normal or elevated.
- However can be confirmed only by demonstration of a reduced TLC by plethysmography.
- TLC below 5th percentile of normal value is considered as restrictive lung disease.
Obstructive diseases

- Characterized by a normal or elevated FRC, TLC, and RV, and elevated Raw and sRaw.
- Additionally determination of RV and RV\%TLC allows to determine the degree of hyperinflation.

<table>
<thead>
<tr>
<th></th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV/TLC</td>
<td>&gt;95\textsuperscript{th} percentile - &lt; 140%</td>
<td>140 -170 %</td>
<td>&gt;170 %</td>
</tr>
</tbody>
</table>

- In the presence of severe defect, plethysmographic volumes tends to overestimated, as pressure changes are not properly transmitted to the mouth.
• Body plethysmography can also demonstrate the effects of Rx on hyperinflation
  – Decrease in FRC following bronchodilator Rx
  – Decrease following successful Rx of AE-COPD

• These determination’s are not influenced by the patient effort, which may be substantially decreased in the presence of hyperinflation.

• Body plethysmography directly measures the FRC.
<table>
<thead>
<tr>
<th>Condition</th>
<th>FRC</th>
<th>RV</th>
<th>TLC</th>
<th>Raw</th>
<th>sRaw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obstructive airway diseases</td>
<td>Normal or elevated</td>
<td>Normal or elevated</td>
<td>Normal</td>
<td>Elevated</td>
<td>Elevated</td>
</tr>
<tr>
<td>Hyperinflation</td>
<td>Elevated</td>
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<td>Normal or elevated</td>
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<tr>
<td>Restrictive disorders</td>
<td>Reduced</td>
<td>Reduced or normal</td>
<td>Reduced</td>
<td>Normal</td>
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</tr>
</tbody>
</table>
Interpretation

• Numerical values of sRaw, sGaw, Raw, Gaw and TGV can be compared with the normative data to define obstructive, restrictive or mixed defects.

• Graphical or based on the appearance of the loop.
Normal

- Normal subjects manifest a steep linear loop during tidal breathing without hysteresis, ie no “openness”
- Flattening = increased ‘Ω’, Openness = localised resistance!
- During panting the upper and lower extremities of the loop become curvilinear- ‘s’ shape
Large airway obstruction

- There is uniformly increased airway resistance and not localised, there is little hysteresis or “openness”
- Linear $\text{sRaw}$ loop that is tilted clockwise, manifesting a slope less steep than normal reflects increased Raw
Small airway obstruction

• In patients with non-homogeneous airway obstruction, there is
  – “opening” / hysteresis in the loop
  – Alinerierity

• This represents the expiratory flow limitation or the dynamic
  compression which occurs in expiration.

• Denotes the large changes in shift volume that occurs at mid-expiration without comparable increases in flow.
Fixed localised central airway obstruction

• Seen in fixed or functional stenosis of the airways like laryngeal abnormality or VC palsy

• Flow limitation during inspiration, in that at sufficiently high flows further increases in driving pressure does not increase in airflow.