Lung Mechanics: Theory and Practice I

The Basics of Measuring Lung Mechanics

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What are lung mechanics?

• The lungs have to breathe, but this takes pressure.
• Pressure is required to drive gas along the pulmonary airways.
• Pressure is required to stretch the tissues of the respiratory system (i.e. the lungs and thorax).
In a *spontaneously breathing* subject at rest these pressures are provided by the *respiratory muscles* during inspiration, and by the tendency of stretched respiratory tissues to *recoil* to their resting configurations during expiration.

In a *mechanically ventilated* patient the pressures required to produce inspiration are provided by a machine.
Lung mechanics...

• reflect the *physical properties* of the components of the lung.

• is a general term to describe all those things that determine the *relationships* between *pressures*, *flows* and *volumes* in the lung.
Lung mechanics are important because...

- they are determinants of the breathing process (e.g. how much *effort* it takes, how *comfortable* it feels).

- they reflect specific *disease states*. *For example…*
• **During an asthma attack:** The pulmonary airways become narrowed, so more pressure than normal is required to force air through them.

• **In a patient with emphysema:** Parenchymal destruction makes the lungs more easily inflated than normal, so less pressure than normal is required to inflate them.
Question: How can we relate structure to function in the lung?

Answer: By using a mathematical model.
How are mathematical models used?

Input $V(t)$

Respiratory System

Model of System

Output $P(t)$

Compare $P(t) - P(t)$

Adjust parameters
The mathematical model should have...

- easily identifiable and important physiological counterparts.

- an equation of motion which states how pressure is related to flow and volume.
The equation of motion...

• tells us exactly how the model will behave under every conceivable circumstance.

• contains *variables*, which are measurable things that vary in time (typically pressures, flows and volumes).

• contains *parameters* which have fixed values, and which characterize *physical attributes* of the model (such as airway resistance).
The investigative paradigm...

Experimental measurement of lung function

Anatomic evaluation of lung structure

Mathematical/computational model linking structure to function
What do we need to measure?

- Pressure
- Flow
- Volume
Measuring pressure

Pressure ($P$) transduction relies on converting the deformation of an elastic element into a proportional electrical signal.
Airway opening pressure

$Lateral pressure$ is easiest to measure in a flowing stream of gas. However, this pressure is less than $static pressure$ due to the $Bernoulli effect$ (which may be substantial if the tube radius is small).
Esophageal pressure
(a surrogate for pleural pressure)

Diagram:
- Pressure transducer
- Plastic catheter
- Latex balloon

10 cm 100 cm
Alveolar pressure

Diagram showing:
- Pleural surface
- Capsule
- Sub-pleural alveoli
- Terminal airways
- Pressure transducer
Flow ($\dot{V}$) transduction typically involves measuring the pressure drop ($\Delta P$) across a calibrated resistance ($R$).

$$\dot{V} = \frac{\Delta P}{R}$$
Measuring Volume

A. Direct measurement with a *spirometer*

B. Integration of flow

\[ V = \int_{0}^{t} \dot{V} \, dt \]
A measurement scenario in humans...
A measurement scenario in animals...

- Alveolar pressure
- Tracheal pressure and flow
Measurement of lung mechanics provides tools for diagnosing pulmonary diseases.
Clinical tests of lung function: Forced expiration
Expiratory flow limitation
Clinical tests of lung function: Plethysmography

Thoracic gas volume ($V_{tg}$)

\[
\frac{\Delta P_{ao}}{\Delta P_{box}} = \frac{V_{box}}{V_{tg}}
\]

(Boyle’s law)
Airway resistance ($R_{aw}$)

\[
R_{aw} = \frac{\Delta P_{box} \left( \frac{V_{box}}{V_{tg}} \right)}{\dot{V}}
\]
Summary 1

- **Lung mechanics** embody the dynamic relationships between pressure, flow and volume in the lung.
- Our ultimate goal is to link lung mechanical function to lung structure.
- This requires a **mathematical model** of lung mechanics.
Summary 2

• To assess lung mechanics, we need to measure pressure, flow and volume of gas.

• Clinical tests of lung function are mostly based on forced expired flow and body plethysmography.

http://mbi.osu.edu/2006/tut1materials/Mechanics%20Course%201.ppt