NORMAL BREATHING
How Do We Breath?

- Inspiration is normally active
-Expiration is normally passive.
Muscles of Respiration

- **Inspiratory muscles**
  - Diaphragm.
  - External intercostals.
  - Accessory muscles.
    - Include sternomastoids, scalene muscles, and alae nasi.

- **Expiratory muscles**
  - Abdominal muscles.
  - Internal intercostals.
Figure 1: Respiratory Pressures
Important Respiratory Pressure Differences.

- **Airway pressure gradient:**
  \[ P_M - P_{ALV} \]

- **Transpulmonary pressure:**
  \[ P_{TP} = P_{ALV} - P_{Pl} \]

- **Transchest wall pressure:**
  \[ P_{TC} = P_{Pl} - P_{bs} \]

- **Transmural respiratory system pressure:**
  \[ P_{RS} = P_{ALV} - P_{bs} \]
Balance of Static Forces

Increase to Inflate

\[ P_{RS} + P_{MUS} = P_L + P_{CW} \]

inspiratory lung elastic recoil
muscle
contraction

Increase with Inflation

\[ P_{ALV} - P_{bs} + P_{MUS} = P_L + P_{CW} \]

Chest wall elastic recoil

Outward Acting forces when positive

Inward acting forces when positive
Three Ways to Inflate the Lungs

- Increase alveolar pressure
  - Positive pressure respirators.
- Decrease body surface pressure
  - “Iron lungs”
- Activate inspiratory muscles
  - Normal way to breath.
Transmural pressure must overcome:
- Elastic recoil forces
- Airway resistance to flow.
MECHANICS OF BREATHING

Part 2
ELASTIC CHARACTERISTICS OF THE LUNG
Inflation Hysteresis

![Graph showing hysteresis between saline and air inflation.](image)
Compliance

\[ \Delta V \]

Transmural Pressure

\[ \Delta P \]

Volume

\[ V_o \]

\[ P_{in} \]

\[ P_{out} \]
Lung Compliance vs. Volume

\[ C = \frac{\Delta V}{\Delta P} \]
Two Major Forces affect Lung Compliance

- Tissue elastic forces
- Surface tension forces.
Air vs. Saline Inflation

More Compliant
Saline Inflation

Less Compliant
Air Inflation
Surface Tension.

- At every gas-liquid interface surface tension develops.
- Surface Tension is a liquid property
- LaPlace’s Law:

\[ P = \frac{2 \cdot T}{r} \]

\[ T = \frac{P_1 \cdot r_1}{2} = \frac{P_2 \cdot r_2}{2} \]

If \( r_1 > r_2 \) Then, \( P_2 > P_1 \)

**Result:** Small Bubble Collapses
Surface Tension.

- At every gas-liquid interface surface tension develops.
- Surface Tension is a liquid property
- LaPlace’s Law:

\[ P = \frac{2 \cdot T}{r} \]

\[ T = \frac{P_1 \cdot r_1}{2} = \frac{P_2 \cdot r_2}{2} \]

If \( r_1 > r_2 \) Then, \( P_2 > P_1 \)

**Result:** Small Bubble Collapses
Surfactant

- Secreted by Type II alveolar cells
- Dipalmitoyl phosphatidyl choline
- Lines alveoli
- Unique surface tension properties:
  - Average surface tension low.
  - Surface tension varies with area:
    - Surface tension rises as area gets bigger
    - Surface tension falls as area gets smaller.
Figure 4: Surfactant

![Surfactant Diagram]

- **Surfactant**
- **Detergent**
- **Water**

**Axes:**
- Y-axis: Surface Tension (dynes/cm)
- X-axis: Relative Area (%)

The graph shows the surface tension values for different relative areas, with distinct regions for water, surfactant, and detergent, indicating their different behaviors in terms of surface tension.
Physiological Importance of Surfactant

- Increases lung compliance (less stiff)
- Promotes alveolar stability and prevents alveolar collapse
- Promotes dry alveoli:
  - Alveolar collapse tends to “suck” fluid from pulmonary capillaries
  - Stabilizing alveoli prevents fluid transudation by preventing collapse.
Infant Respiratory Disease Syndrome (IRDS)

- Surfactant starts late in fetal life
  - Total gestation: 39 wks
  - Surfactant: 23 wks → 32-36 wks

- Infants with immature surfactant (IRDS)
  - Stiff, fluid-filled lungs
  - Atelectatic areas (alveolar collapse)
    - Collapsed alveoli are poorly ventilated
    - Effective right to left shunt (Admixture)

- \([\text{lecithin}] / [\text{sphingomyelin}]\) ratio
  → Gestational Maturity
Dependent Lung—\textbf{the lung in the lowest part of the gravitational field}
- base when in the upright position
- dorsal portion when supine.
Gravity and Lung Inflation

\[ P_{TP} = 0 - (-10) = +10 \text{ cmH}_2\text{O} \]

\[ P_{PL} = -10 \text{ cm H}_2\text{O} \]

\[ P_{PL} = -2.5 \text{ cm H}_2\text{O} \]

\[ P_{TP} = 0 - (-2.5) = +2.5 \text{ cmH}_2\text{O} \]
Figure 5: Regional Compliance Differences During Inflation
Regional Lung Volume vs. Regional Lung Ventilation

- In the upright posture:
  - Relative lung volume is greater at the apex
  - Lung is less compliant (stiffer) at the apex
  - Regional lung ventilation is greatest at the base
Time Constants for Emptying

- Important regional inhomogeneities:
  - regional differences in airway resistances
  - regional differences in elastic characteristics
- High resistance and high compliance cause slow emptying.

\[ \text{Time Constant} \propto RC \]
Specific Compliance

- Normalization allows comparison of tissue elastic characteristics
- **Question**: How would compliance differ in a child and an adult, both with normal lungs?

\[
\text{Specific Compliance} = \frac{\text{Compliance}}{\text{FRC}}
\]
INTERACTIONS BETWEEN LUNGS AND CHEST WALL
The lungs and chest wall operate in series

Lung and chestwall compliances add reciprocally:

\[
\frac{1}{C_{\text{Total}}} = \frac{1}{C_{\text{Chestwall}}} + \frac{1}{C_{\text{Lung}}}
\]
Figure 6: Chest Wall Mechanics
Chest Wall Mechanics Summary

- **Negative $P_{TT}$**: Found at RV and FRC.
  - Normal tidal breathing in this condition
  - chest wall below its unstressed volume
  - chest tends to spring out

- **Unstressed Volume**: 65% of TLC
  - No net recoil

- **Positive $P_{TT}$**: Above 65% of TLC
  - volumes above 65% TLC
  - Chest tends to collapse (spring in)
Figure 7: Lung Mechanics

Transpulmonary Pressure

\[ P_{TP} = P_{ALV} - P_{Pl} \] cm H\textsubscript{2}O
Lung Mechanics Summary

- Always above unstressed volume (minimal volume = 10% TLC).
- $P_{TP}$ is positive from RV to TLC.
- Lungs always tends to collapse.
Figure 8: Combined Mechanics

- TLC
- CHEST $V_0$
- FRC
- RV
- MIN. VOL.
- 10% TLC
- 25% TLC
- 45% TLC
- 65% TLC
- 100% TLC

LUNG VOLUME

Volume liters:

CW
L
RS

TRANSMURAL RESPIRATORY SYSTEM PRESSURE

($P_{RS} = P_{ALV} - P_{BS}$) cm H$_2$O
**Combined Mechanics Summary**

- **Functional residual capacity**
  - Respiratory system unstressed volume
  - Chest and lung recoil equal and opposite

- **Pneumothorax**
  - Uncouples lungs and chest wall
  - Lungs and chest wall move to their unstressed volume
    - lungs *always* recoil inward
    - chest wall springs outward below 65% TLC
    - chest wall springs inward above 65% TLC
Lung Compliance in Disease

- Diseases **increasing compliance**: 
  - natural aging
  - emphysema.

- Diseases **decreasing compliance** (stiffer lung): 
  - pulmonary fibrosis
  - edema (e.g. rheumatic heart disease)
Chestwall Compliance in Disease

- **Actually less compliant (stiffer):**
  - chest wall deformation (eg. kyphoscoliosis)
- **Functionally less compliant (stiffer):** (Abdominal cavity changes)
  - displacement of the diaphragm (eg. pregnancy)
  - ascites
AIRWAY RESISTANCE
Resistive Forces and Breathing

- Quiet breathing -- Air flow laminar
  - Resistance -- Poiseuille’s Law
  - Pressure gradient proportional to flow.

- High airflow (e.g. exercise)
  - Turbulence and eddy flow
  - Extra pressure gradient proportional to flow rate squared
Distribution of Airway Resistance

- Major portion larger airways
  - specifically medium size bronchi
- Small airways (< 2 mm)
  - Only 20% of total airway resistance
  - Resistance increases may foretell coming problems
  - $\text{FEF}_{25-75}$ supposedly sensitive
Airway Resistance
--Smooth Muscle

- Bronchoconstrictors
  - Vagal tone
  - Histamine

- Bronchoconstrictors
  - Beta agonists → Bronchodilation
  - Anti-cholinergics
Airways and V/Q Matching

- ↑ $P_A CO_2$  → Bronchodilation
  - Find high $P_A CO_2$ in poorly ventilated regions
  - These airways tend to dilate.
  - Promotes homogeneous ventilation
Homeostatic Summary

- **Low V/Q units**
  - Alveolar hypoxia
  - Alveolar hypercapnia

- **Homeostasis**
  - Alveolar hypercapnia tends to raise ventilation
  - Alveolar hypoxemia tends to lower blood flow

- **Result:** V/Q tends back towards normal
Airway Resistance -- Minimized by High Elastic Recoil

- Radial traction normally holds bronchi open

- **Low elastic recoil forces** causes less radial traction and higher airway resistances:
  - Lower lung volumes
  - Chronic obstructive disease (eg. Emphysema)
Maximum Forced Expiration

Effort Independent Limb

Peak Flow

Volume vs. Time

Flow vs. Volume

TLC, RV
Summary of Forced Expiration

- Peak flow occurs early
- Envelope of **effort-independence**:
  - Flow depends only on elastic recoil.
  - Flow falls as expiration continues
- Envelope is eventually joined independent of:
  - Starting volume
  - Initial effort.
Figure 10: Flow Limitation and EPP

\[ P_{alv} = P_{pl} + P_{el} \]

\[ P_{EPP} = P_{pl} \]
Mechanism of Flow Limitation

Summary

- Force expiration: $P_{PL}$ is positive outside the airways.
- Equal pressure point (EPP).
  - Point at which $P_{airway}$ falls just enough to equal $P_{PL}$
  - Bronchi collapse
- Flow proportional to: $P_{ALV} - P_{EPP}$
Effort Independence of Flow-Volume Envelope

- Increased effort
  - Similar increases in $P_{\text{ALV}}$ and $P_{\text{EPP}}$.
  - Pressure difference unchanged
  - Therefore, Flow unchanged.
Figure 11: Flow Limitation at Various Lung Volumes

High Lung Volume

Medium Lung Volume

Low Lung Volume
Flow Limitation in COPD (Emphysema)

\[ P_{el} = 10 \text{ mmHg} \]

\[ P_{el} = 5 \text{ mmHg} \]

Normal Lung Medium Volume

Emphysematous Lung Medium Volume
Forced Inspiration: is Effort-Dependent

- $P_{PL}$ is Negative
- Airways are held open.
Clinical Flow-Volume Loops

Obstruction

A. Fixed Obstruction Intra or Extra Thoracic

B. Extra Thoracic Obstruction (variable)

C. Intra Thoracic Obstruction (variable)
Reference

http://www.ursa.kcom.edu/Department/SlideSets/Summer/MechBreathing/PPMechBreathing.ppt