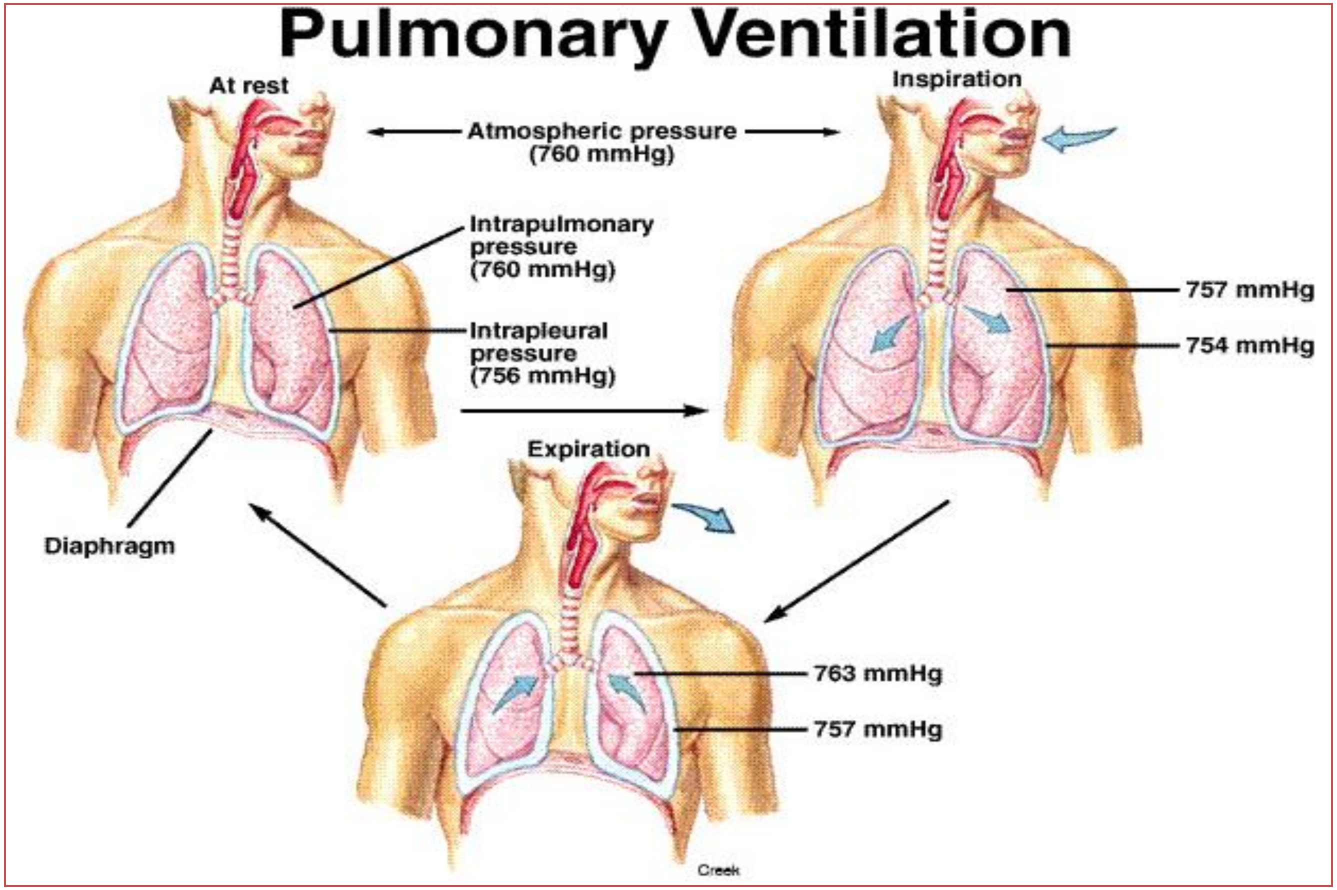
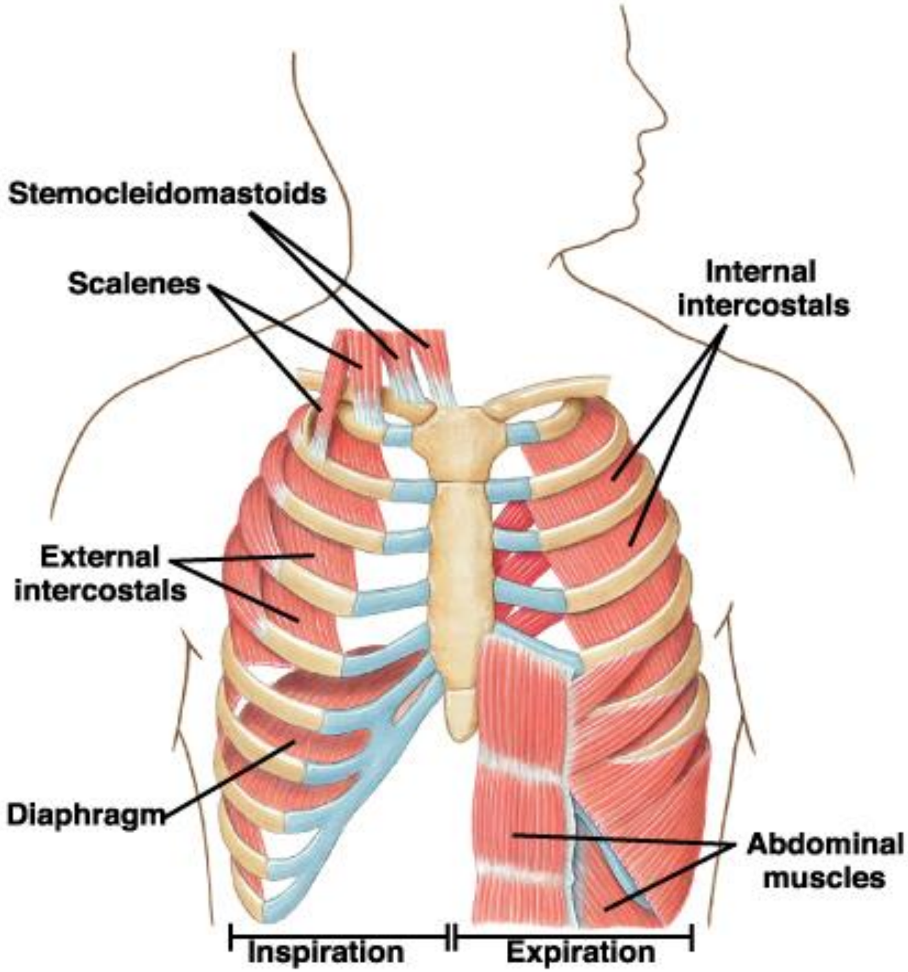
Mechanics of Breathing (Pulmonary Ventilation)



- Completely mechanical process
- Depends on volume changes in the thoracic cavity
- Volume changes lead to pressure changes, which lead to the flow of gases to equalize pressure
- Two phases
  - Inspiration – flow of air into lung
  - Expiration – air leaving lung

Muscles used for ventilation

The muscles of inspiration include the diaphragm, external intercostals, sternocleidomastoids, and scalenes. The muscles of expiration include the internal intercostals and the abdominals.



Pressure Relationships in the Thoracic Cavity

- Respiratory pressure is always described relative to atmospheric pressure
- Atmospheric pressure (P_{atm})
  - Pressure exerted by the air surrounding the body
  - Negative respiratory pressure is less than P_{atm}
  - Positive respiratory pressure is greater than P_{atm}

Pressure Relationships in the Thoracic Cavity

- Intrapulmonary pressure (P_{pul}) – pressure within the alveoli
- Intrapleural pressure (P_{ip}) – pressure within the pleural cavity

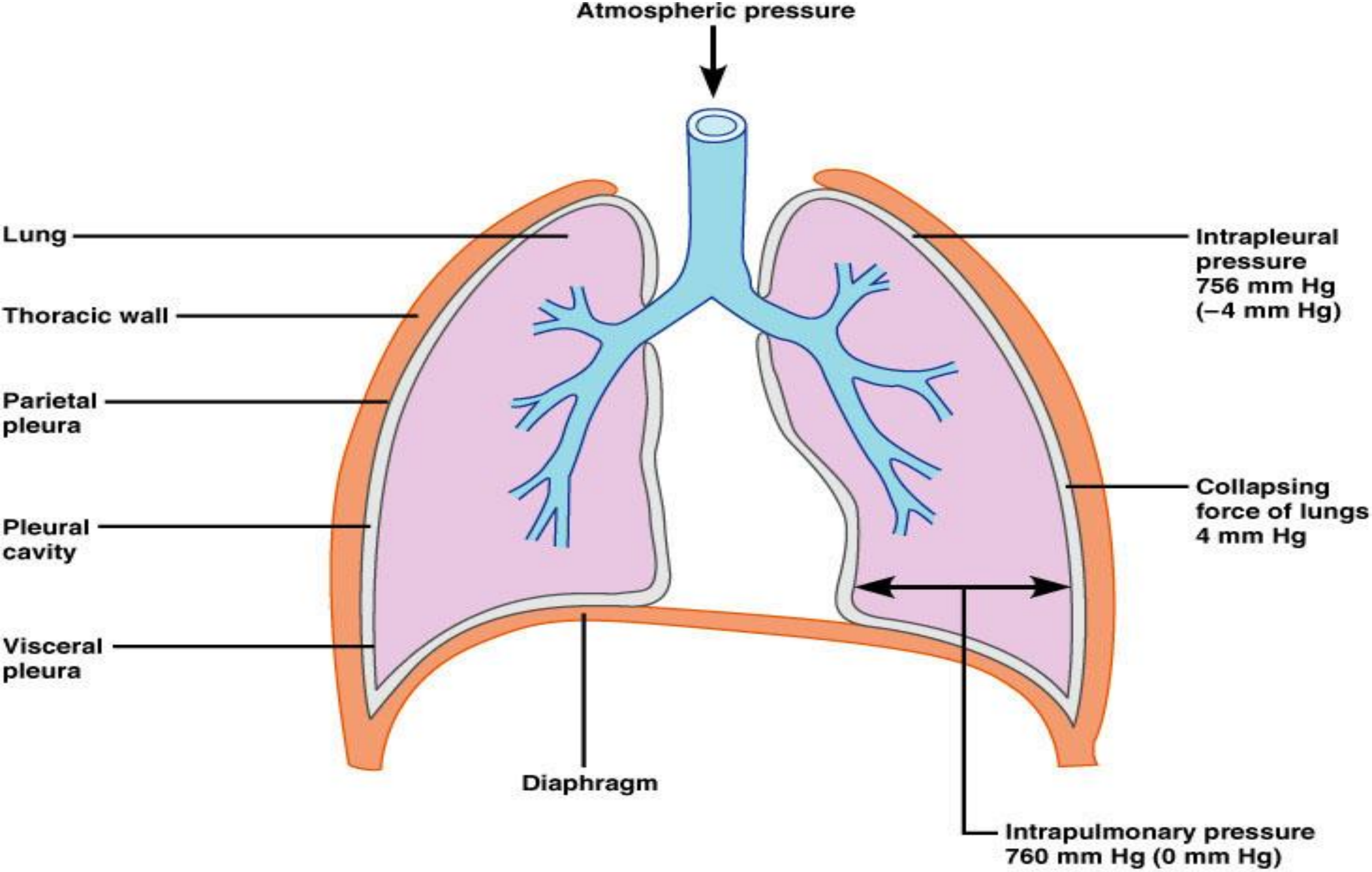
Pressure Relationships

- Intrapulmonary pressure and intrapleural pressure fluctuate with the phases of breathing
- Intrapulmonary pressure always eventually equalizes itself with atmospheric pressure
- Intrapleural pressure is always less than intrapulmonary pressure and atmospheric pressure

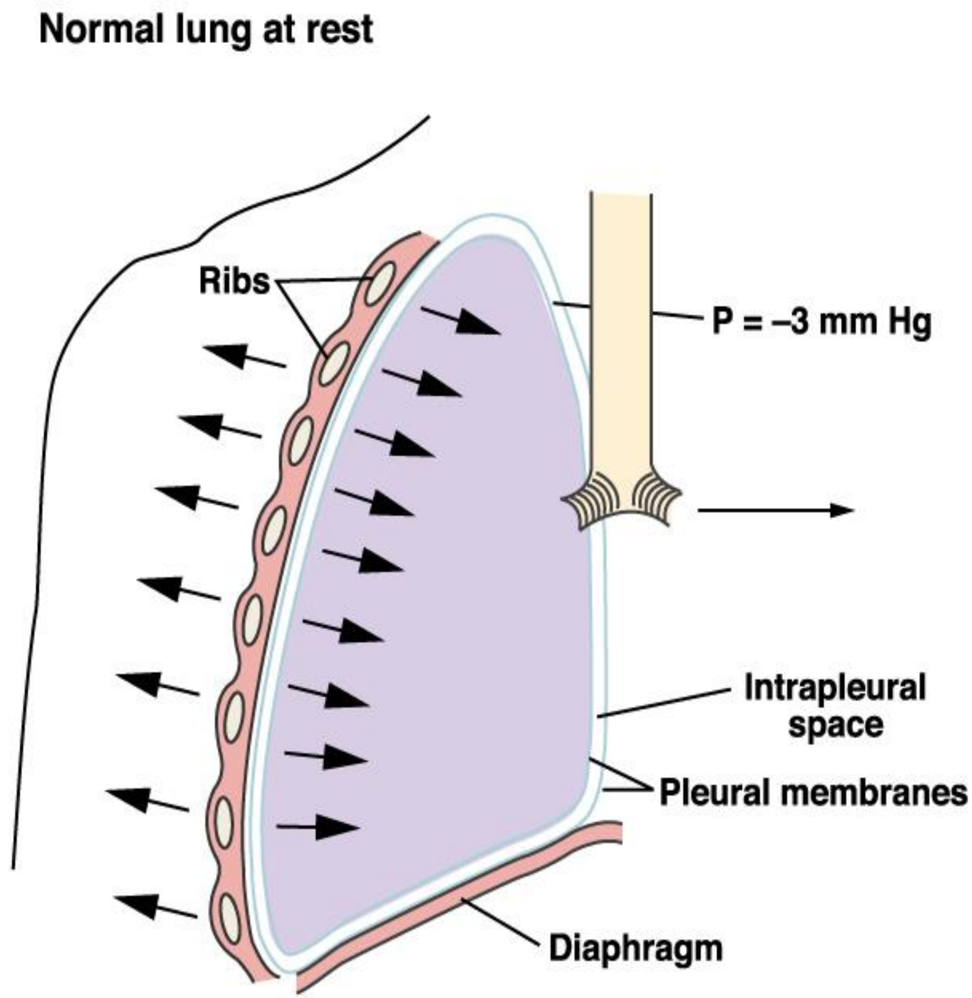
Pressure Relationships

- Two forces act to pull the lungs away from the thoracic wall, promoting lung collapse
  - Elasticity of lungs causes them to assume smallest possible size
  - Surface tension of alveolar fluid draws alveoli to their smallest possible size
- Opposing force – elasticity of the chest wall pulls the thorax outward to enlarge the lungs.
- Lymphatic system drains the pleural fluid, generating a negative pressure (- 5cm H_2O pressure)

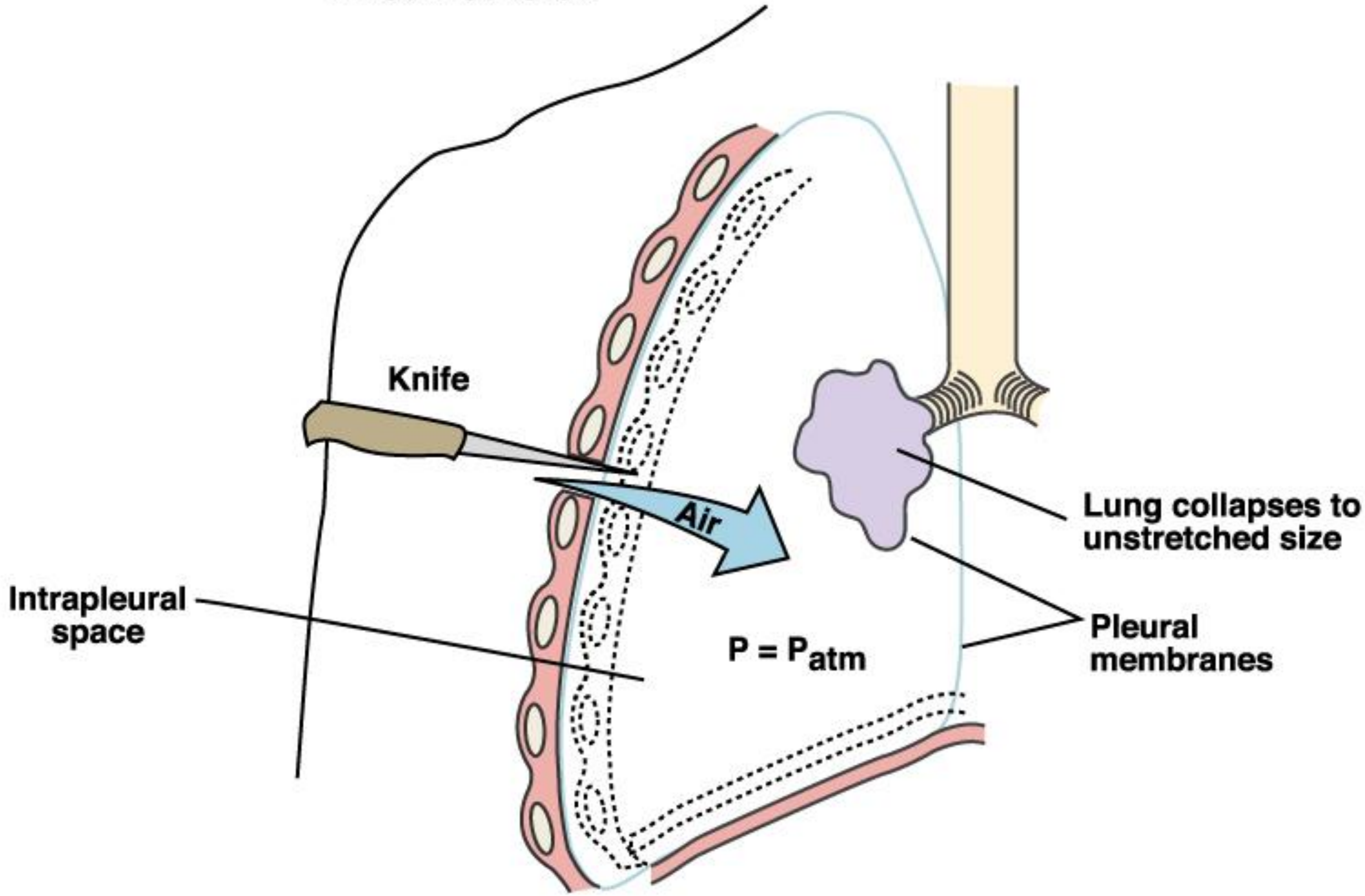
Pressure Relationships



- The negative intrapulmonary pressure is what keeps the lungs from collapsing (atalectasis) due to their natural elasticity.
- Any condition where $P_{ip} = P_{alv}$ causes lung collapse.
- The difference btwn P_{ip} and P_{alv} is the transpulmonary pressure.
- Pneumothorax is the presence of air in the intrapleural space.



Pneumothorax



Lung Collapse

- Caused by equalization of the intrapleural pressure with the intrapulmonary pressure
- Transpulmonary pressure keeps the airways open
  - Transpulmonary pressure – difference between the intrapulmonary and intrapleural pressures ($P_{pul} - P_{ip}$)

Pulmonary Ventilation

- A mechanical process that depends on volume changes in the thoracic cavity
- Volume changes lead to pressure changes, which lead to the flow of gases to equalize pressure

Boyle's Law

- Boyle's law – the relationship between the pressure and volume of gases

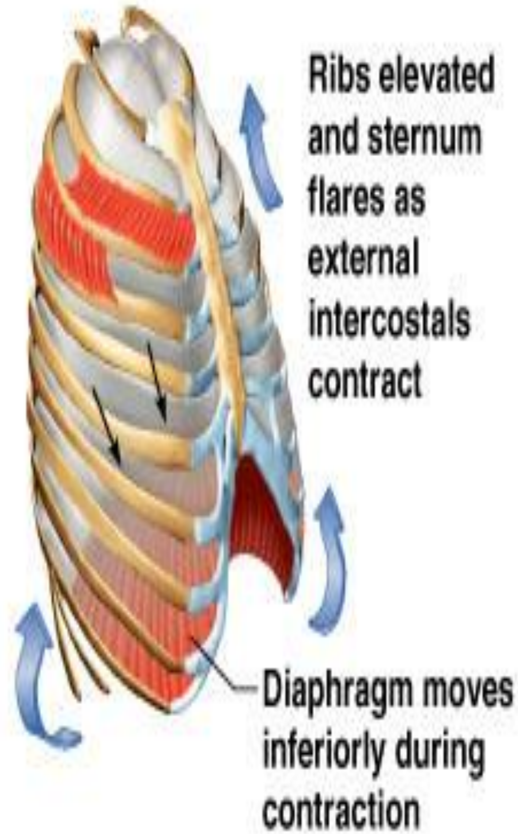
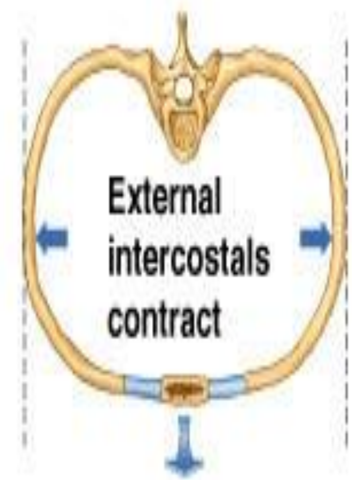
$$P_1V_1 = P_2V_2$$

  - P = pressure of a gas in mm Hg
  - V = volume of a gas in cubic millimeters
  - Subscripts 1 and 2 represent the initial and resulting conditions, respectively

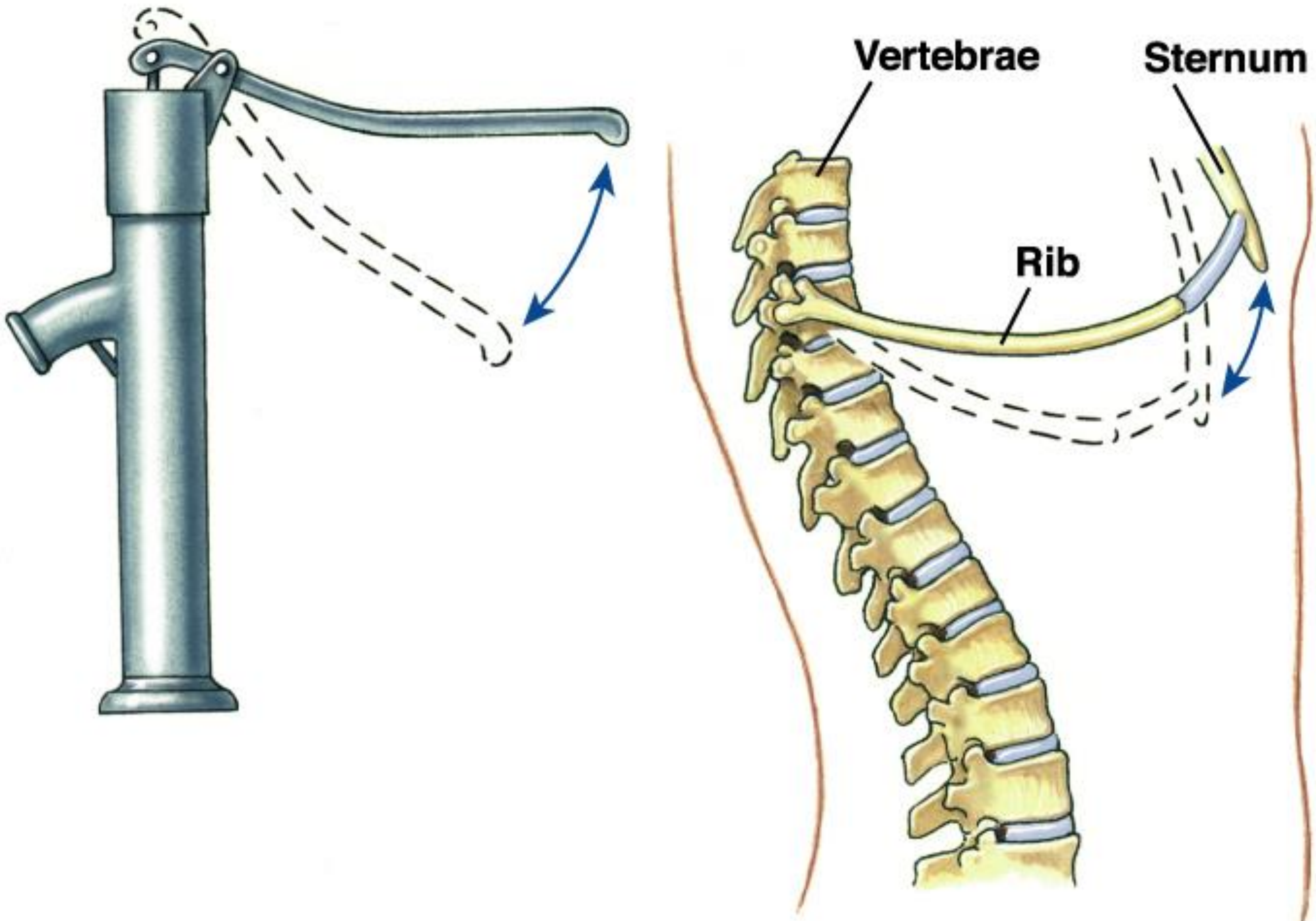
Inspiration

- The diaphragm and external intercostal muscles (inspiratory muscles) contract and the rib cage rises
- The lungs are stretched and intrapulmonary volume increases
- Intrapulmonary pressure drops below atmospheric pressure (–1 mm Hg)
- Air flows into the lungs, down its pressure gradient, until intrapleural pressure = atmospheric pressure

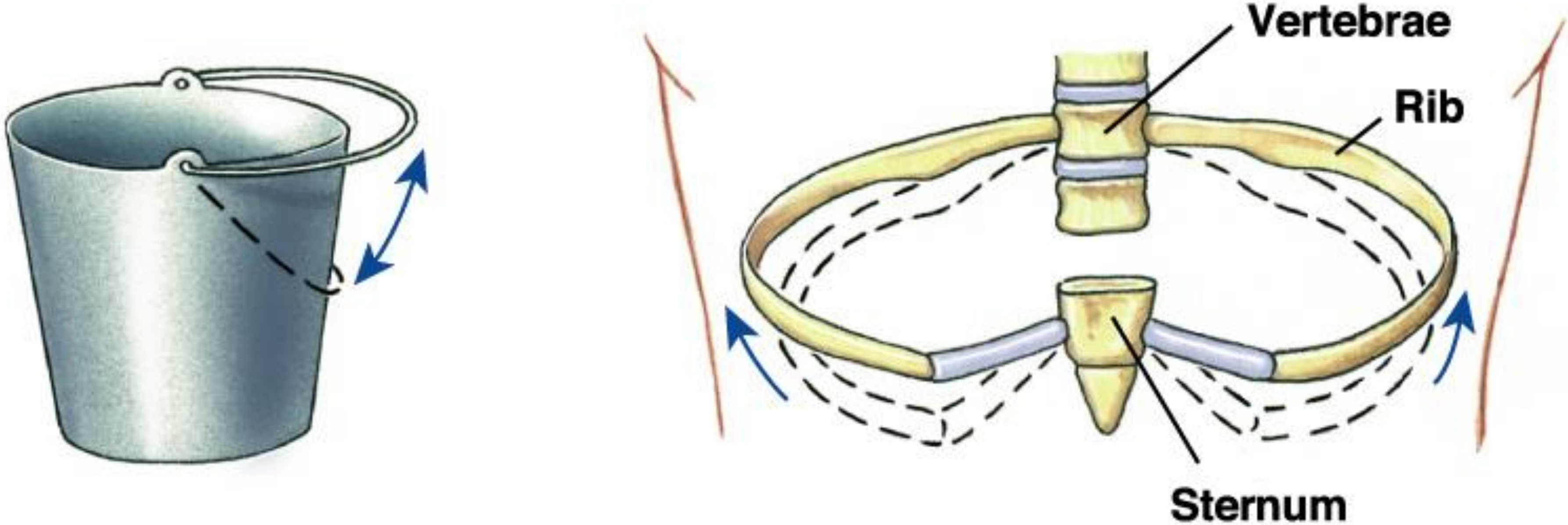
Inspiration

	Sequence of events	Changes in anterior-posterior and superior-inferior dimensions	Changes in lateral dimensions
Inspiration	① Inspiratory muscles contract (diaphragm descends; rib cage rises) ↓ ② Thoracic cavity volume increases ↓ ③ Lungs stretched; intrapulmonary volume increases ↓ ④ Intrapulmonary pressure drops (to −1 mm Hg) ↓ ⑤ Air (gases) flows into lungs down its pressure gradient until intrapulmonary pressure is 0 (equal to atmospheric pressure)		

“Pump handle" motion increases anterior-posterior dimension of rib cage



"Bucket handle" motion increases lateral dimension of rib cage



Expiration

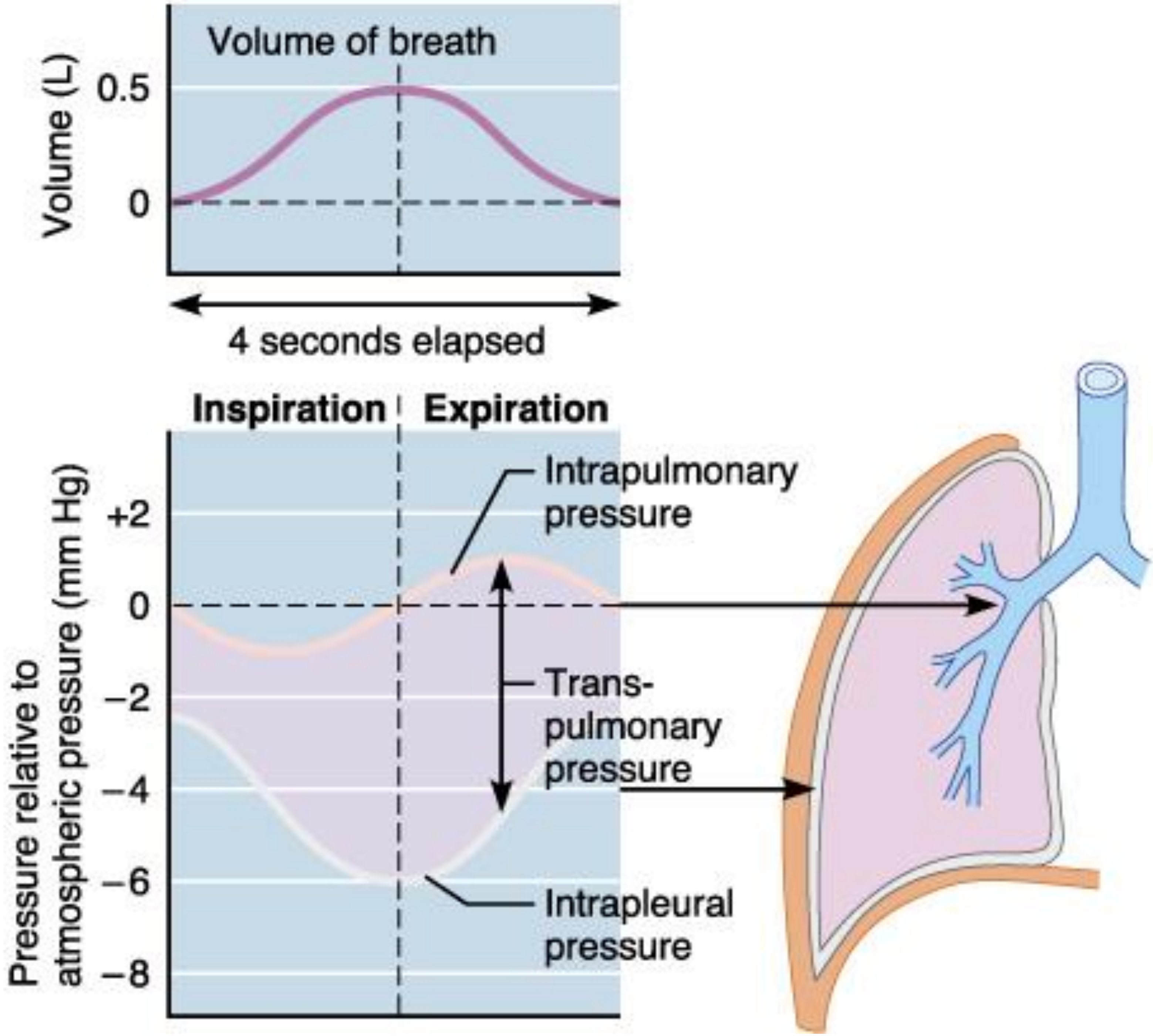
- Inspiratory muscles relax and the rib cage descends due to gravity
- Thoracic cavity volume decreases
- Elastic lungs recoil passively and intrapulmonary volume decreases
- Intrapulmonary pressure rises above atmospheric pressure (+1 mm Hg)
- Gases flow out of the lungs down the pressure gradient until intrapulmonary pressure is 0

Expiration

	Sequence of events	Changes in anterior-posterior and superior-inferior dimensions	Changes in lateral dimensions
Expiration	① Inspiratory muscles relax (diaphragm rises; rib cage descends due to recoil of costal cartilages) ↓ ② Thoracic cavity volume decreases ↓ ③ Elastic lungs recoil passively; intrapulmonary volume decreases ↓ ④ Intrapulmonary pressure rises (to +1 mm Hg) ↓ ⑤ Air (gases) flows out of lungs down its pressure gradient until intrapulmonary pressure is 0		

Forced Expiration

- Forced expiration is an active process due to contraction of oblique and transverse abdominus muscles, internal intercostals, and the latissimus dorsi.
- The larynx is closed during coughing, sneezing, and Valsalva's maneuver
- Valsalva's maneuver-Forced expiration against closed glottis .
  - Air is temporarily held in the lower respiratory tract by closing the glottis
  - Causes intra-abdominal pressure to rise when abdominal muscles contract.
  - Helps to empty the rectum.
  - Child birth .


Volume of breath
Volume (L)
0.5
0
4 seconds elapsed
Inspiration
Expiration
Pressure relative to atmospheric pressure (mm Hg)
+2
0
−2
−4
−6
−8
Intrapulmonary pressure
Trans-pulmonary pressure
Intrapleural pressure

Lung Compliance

- The ease with which lungs can be expanded
- Specifically, the measure of the change in lung volume that occurs with a given change in transpulmonary pressure
- Determined by two main factors
  - Distensibility of the lung tissue and surrounding thoracic cage
  - Surface tension of the alveoli

Lung Compliance

- A. Compliance of Lungs and Thoracic wall:0.13 liters/cm of H_2O
- B. Compliance of the Lungs only: 0.22 litre/cm H_2O

Regional Lung Volume

- In the upright posture:
  - Relative lung volume is <u>greater at the apex</u>
  - Lung is less compliant (stiffer) at the <u>apex</u>

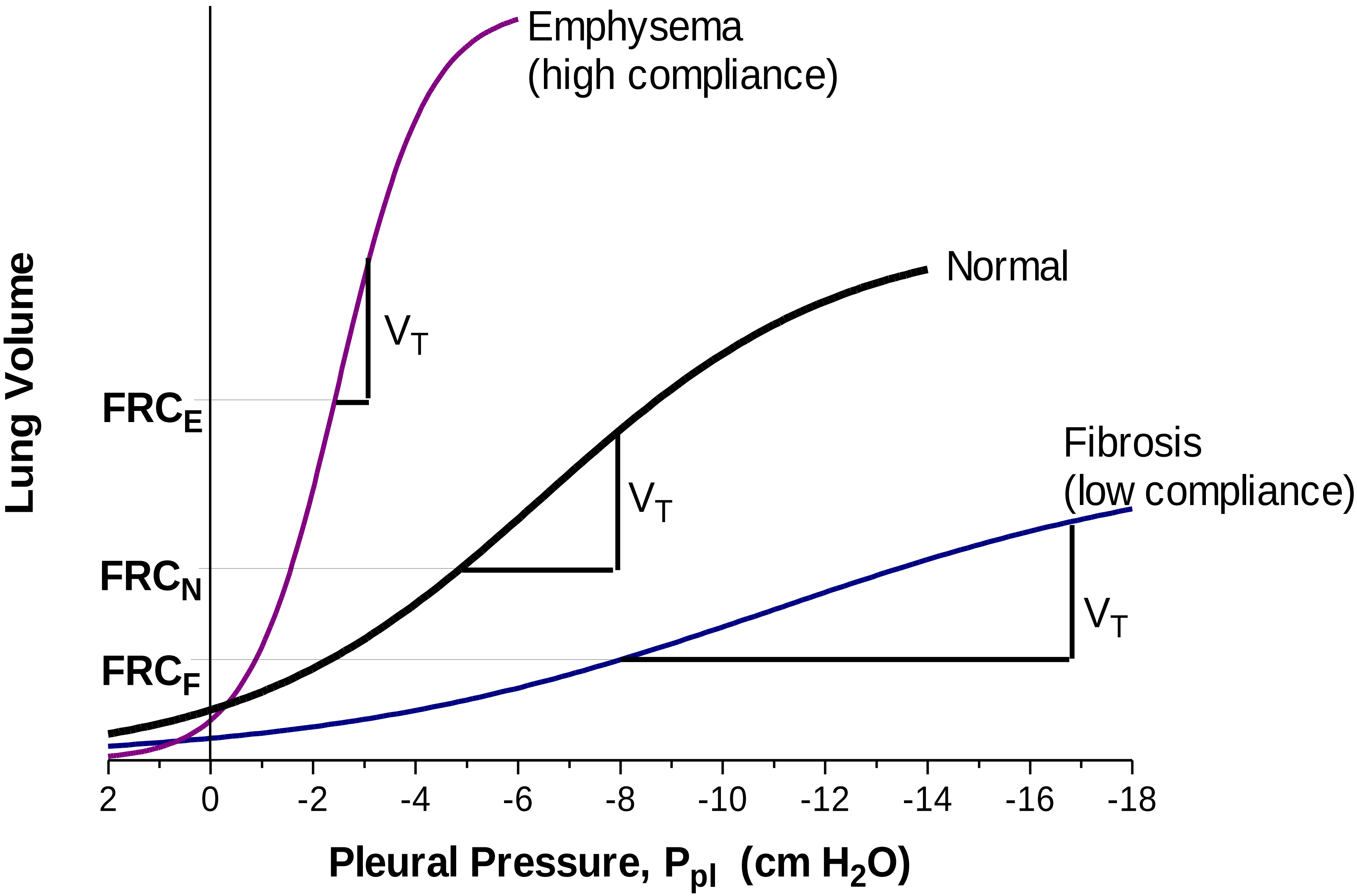
Factors That Diminish Lung Compliance

- Scar tissue or fibrosis that reduces the natural resilience of the lungs
- Blockage of the smaller respiratory passages with mucus or fluid
- Reduced production of surfactant
- Decreased flexibility of the thoracic cage or its decreased ability to expand

Factors That Diminish Lung Compliance

- Examples include:
  - Deformities of thorax
  - Ossification of the costal cartilage
  - Paralysis of intercostal muscles

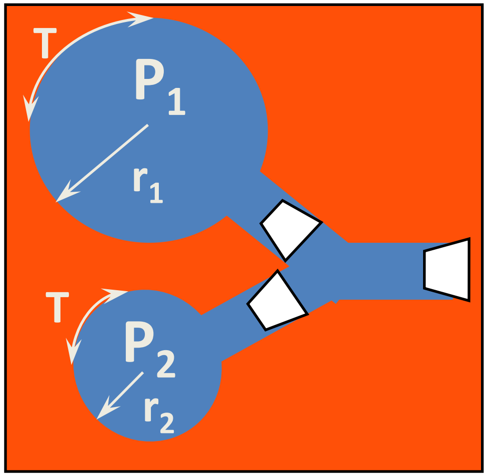
Static Compliance Curves



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

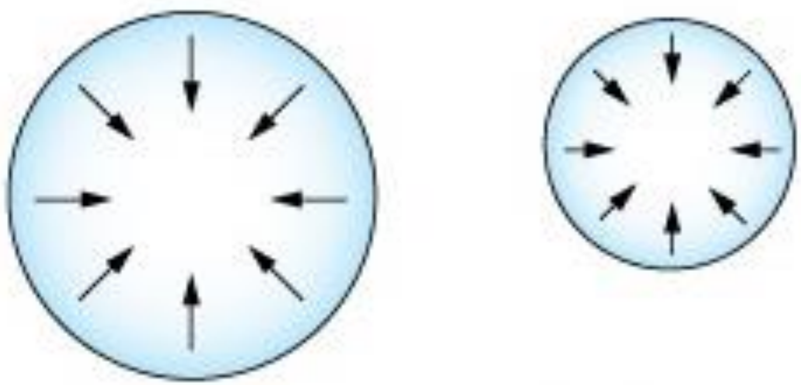
Surfactant Facts

1. Secreted by Alveolar Type II cell.
2. Principal chemicals are dipalmityl phosphatidylcholine (lecithin) and phosphotidylglycerol.
3. Release is stimulated by beta-adrenergic agonists and increased tidal volume.
4. Recirculated into Type II cell and released again.

Functions of Pulmonary Surfactant

1. promote alveolar stability
2. prevent atelectasis
3. reduce opening or inflation pressures in collapsed or small alveoli
4. keep alveoli "dry"
5. decrease the work of breathing

(a) Pressure is greater in the smaller bubble.



Larger bubble	Smaller bubble
$r = 2$	$r = 1$
$T = 3$	$T = 3$
$P = (2 \times 3)/2$	$P = (2 \times 3)/1$
$P = 3$	$P = 6$

Law of LaPlace: $P = 2T/r$

P = pressure
T = surface tension
r = radius

According to the law of LaPlace, if two bubbles have the same surface tension, the small bubble will have higher pressure.

Law of LaPlace: $P = 2T/r$

P = pressure
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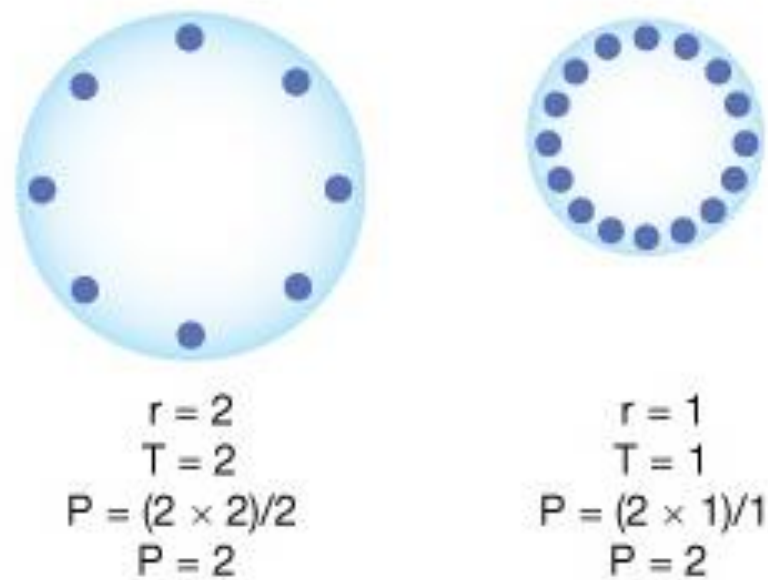
According to the law of LaPlace, if two bubbles have the same surface tension, the small bubble will have higher pressure.

(b) Surfactant reduces surface tension (T). Pressure is equalized in the large and small bubbles.



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
  - 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)