Pulmonary ventilation-1

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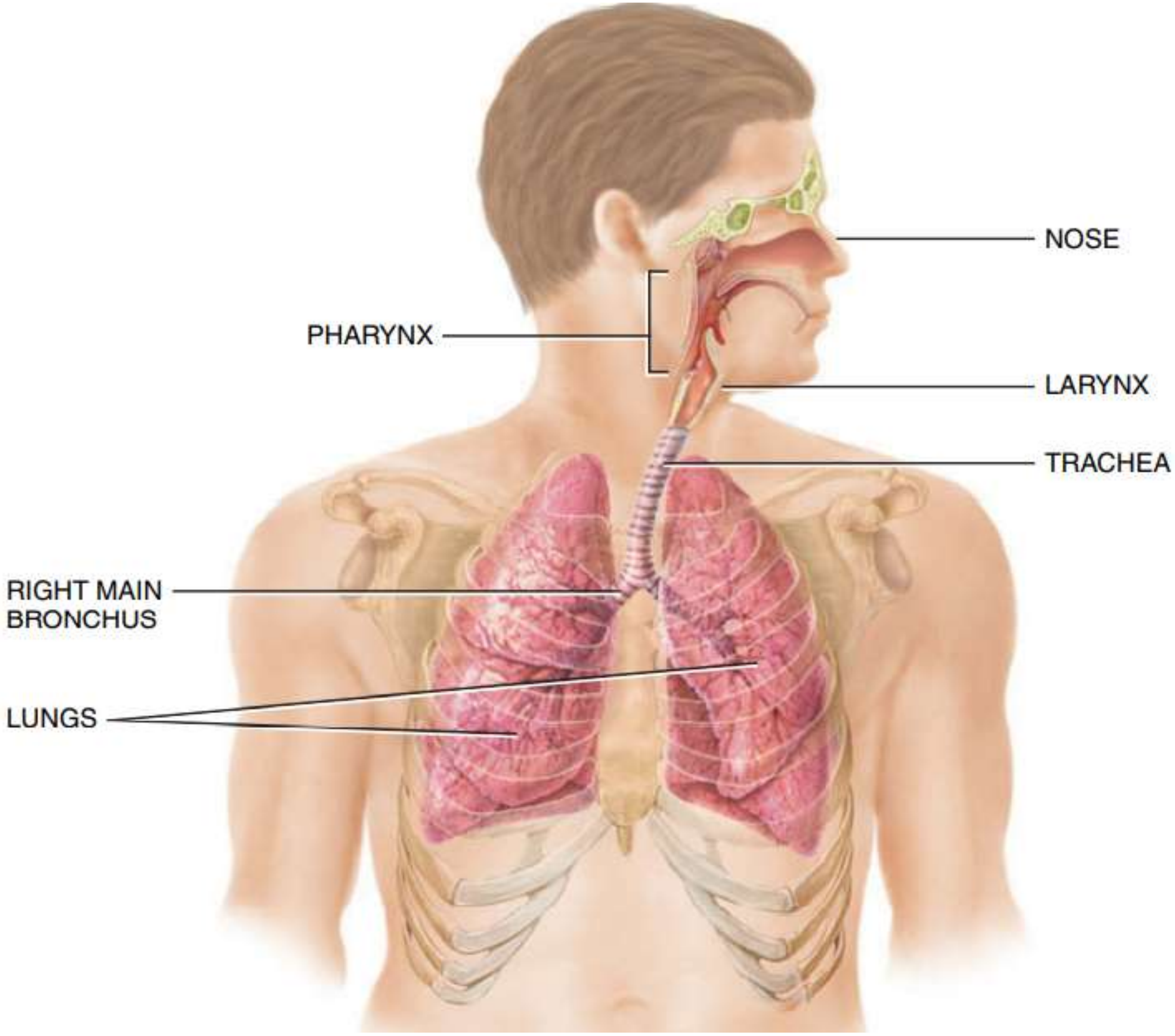
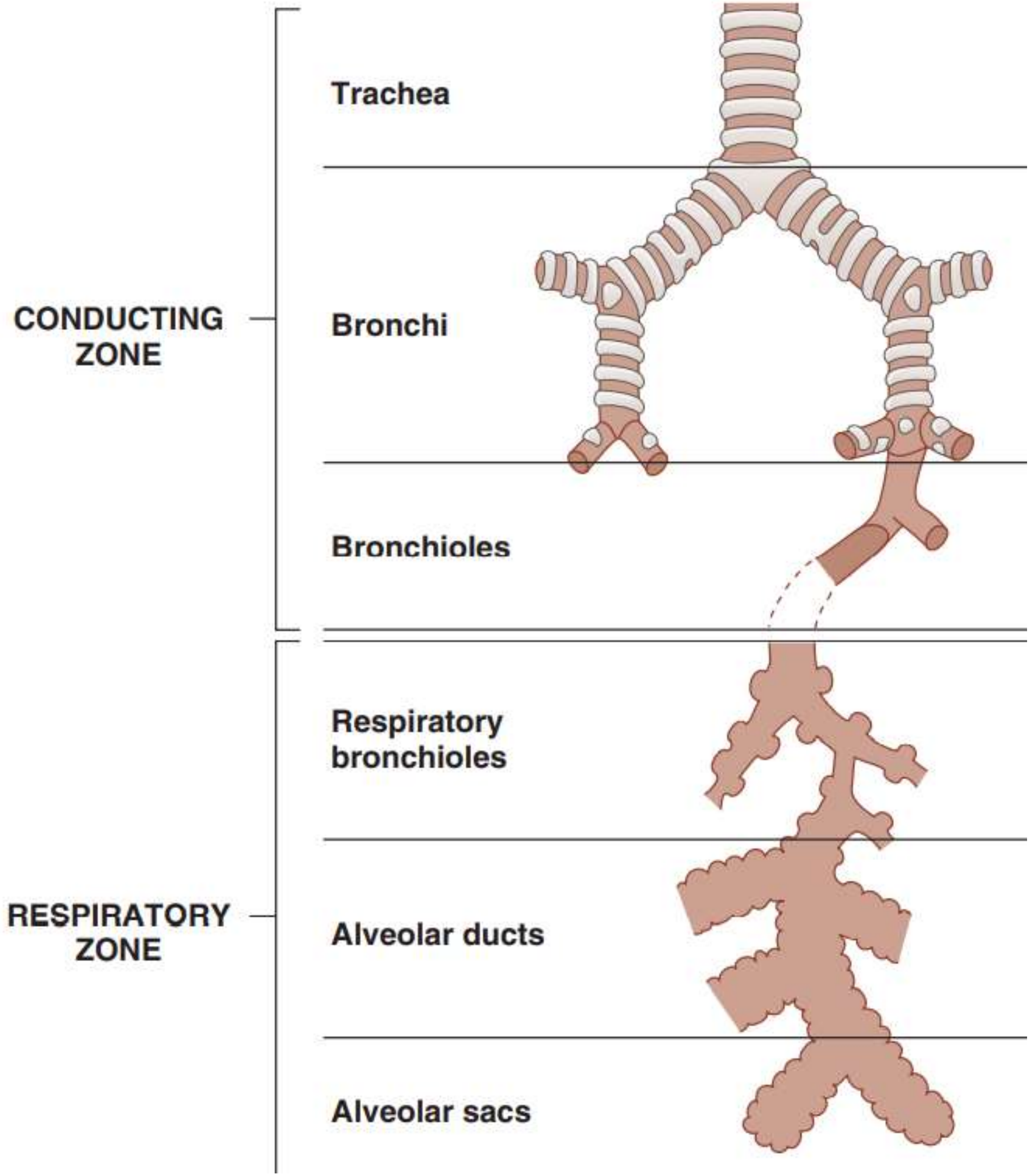
Overview of the respiratory system

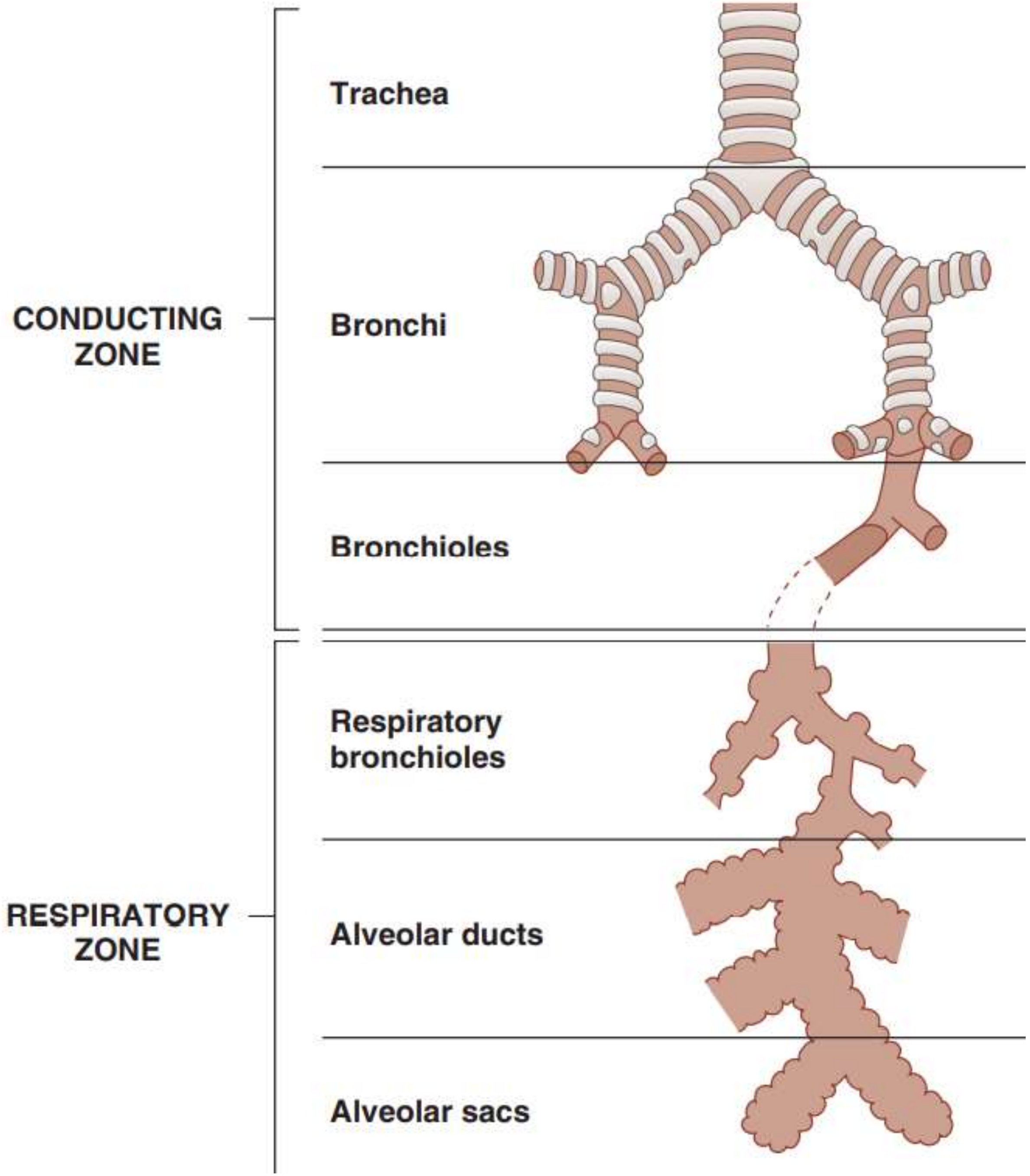
- The main functions of respiration are to provide oxygen to the tissues and remove carbon dioxide.
- The four major components of respiration are the following:
- (1) pulmonary ventilation, which means the inflow and outflow of air between the atmosphere and the lung alveoli.
- (2) diffusion of O_2 and CO_2 between the alveoli and the blood.
- (3) transport of O_2 and CO_2 in the blood and body fluids to and from the body's tissue cells.
- (4) regulation of respiration.


NOSE
PHARYNX
LARYNX
TRACHEA
RIGHT MAIN BRONCHUS
LUNGS


CONDUCTING ZONE
Trachea
Bronchi
Bronchioles
RESPIRATORY ZONE
Respiratory bronchioles
Alveolar ducts
Alveolar sacs

brings air into and out of the lungs

lined with alveoli, where gas exchange occurs



Conducting zone

- These structures function to bring air into and out of the respiratory zone for gas exchange and to warm, humidify, and filter the air before it reaches the critical gas exchange region.

- The conducting airways are lined with mucus-secreting and ciliated cells that function to remove inhaled particles.

Conducting zone

- The walls of the conducting airways contain smooth muscle. This smooth muscle has both sympathetic and parasympathetic innervations:

- (1) Sympathetic adrenergic neurons activate β2 receptors on bronchial smooth muscle, which leads to relaxation and dilation of the airways. In addition, these β2 receptors are activated by β2-adrenergic agonists such as albuterol used to in the treatment of asthma.

- (2) Parasympathetic cholinergic neurons activate muscarinic receptors, which leads to contraction and constriction of the airways.

Respiratory zone

- The respiratory bronchioles, like the conducting airways, they have cilia and smooth muscle, but they also are considered part of the gas exchange region because alveoli occasionally bud off their walls.

- The alveolar ducts are completely lined with alveoli, but they contain no cilia and little smooth muscle.

- The alveolar ducts terminate in alveolar sacs, which also are lined with alveoli.

Respiratory zone

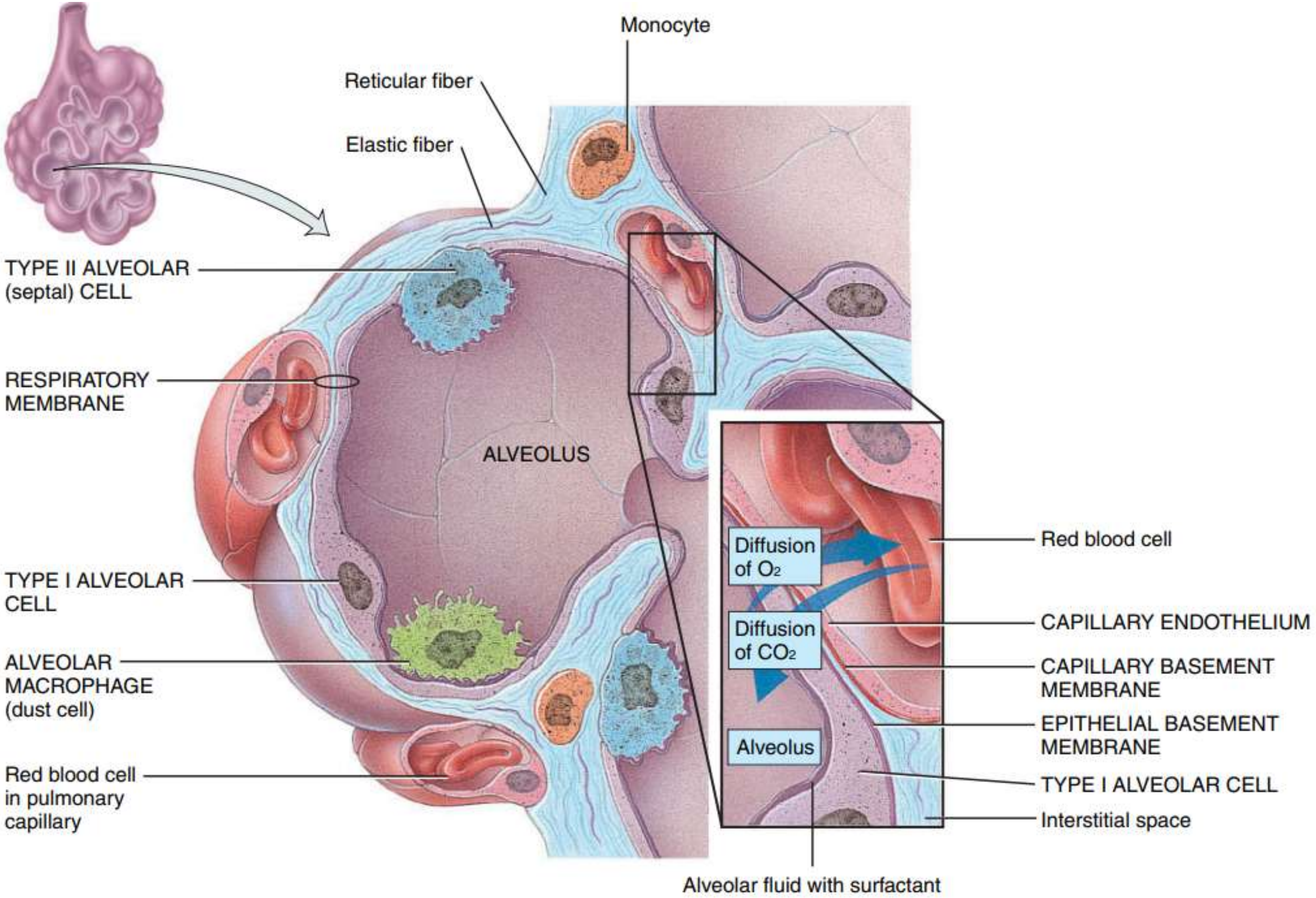
- The Exchange of O_2 and CO_2 between alveolar gas and pulmonary capillary blood can occur rapidly and efficiently across the alveoli because alveolar walls are thin and have a large surface area for diffusion.

- The alveolar walls are rimmed with elastic fibers and lined with epithelial cells, called type I and type II pneumocytes (or alveolar cells).

Respiratory zone

- Type II pneumocytes synthesize pulmonary surfactant (necessary for reduction of surface tension of alveoli).

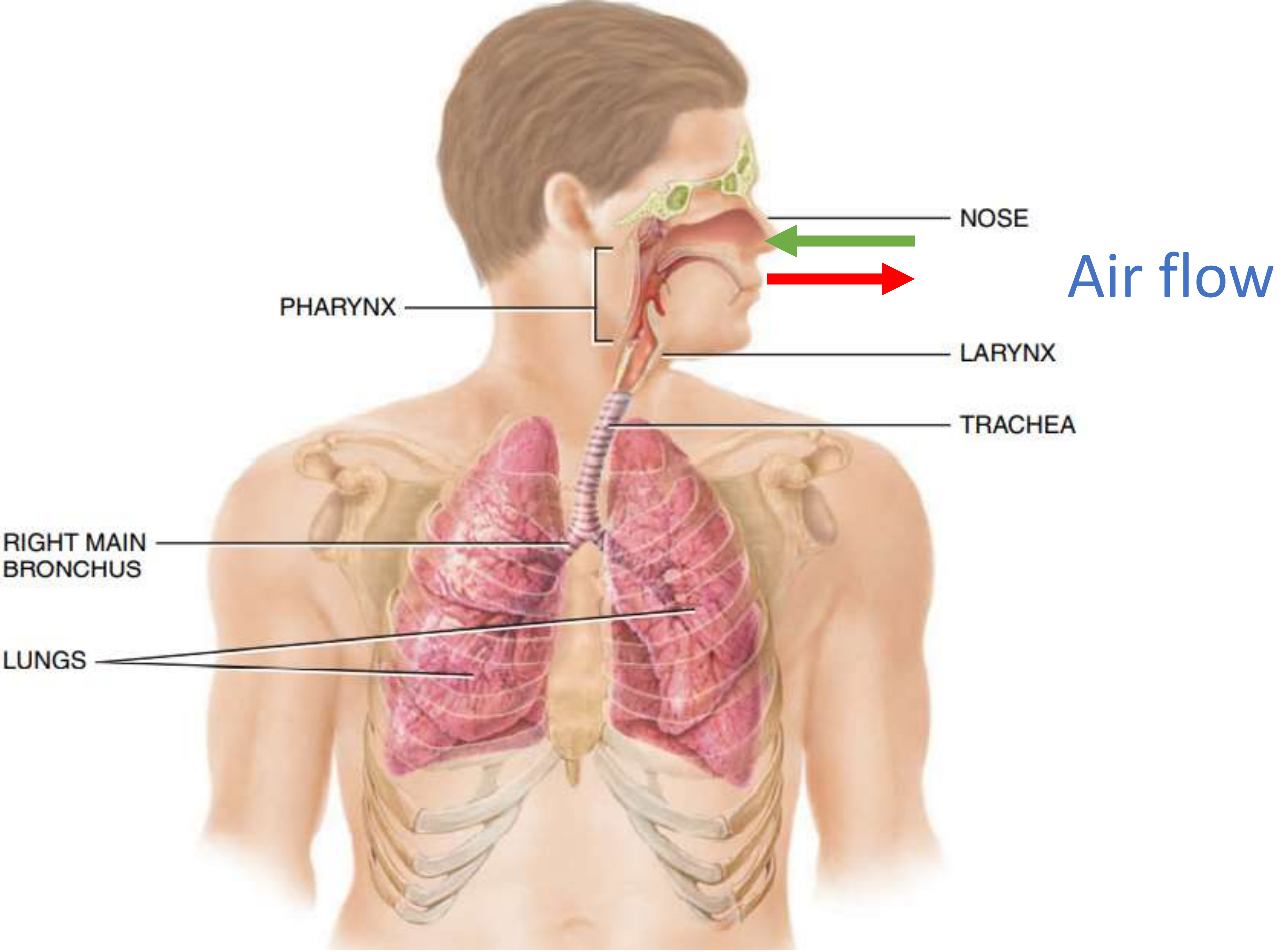
- The alveoli contain phagocytic cells called alveolar macrophages. Alveolar macrophages keep the alveoli free of dust and debris because the alveoli have no cilia.



Monocyte
Reticular fiber
Elastic fiber
TYPE II ALVEOLAR (septal) CELL
RESPIRATORY MEMBRANE
ALVEOLUS
TYPE I ALVEOLAR CELL
ALVEOLAR MACROPHAGE (dust cell)
Red blood cell in pulmonary capillary
Diffusion of O2
Diffusion of CO2
Alveolus
Red blood cell
CAPILLARY ENDOTHELIUM
CAPILLARY BASEMENT MEMBRANE
EPITHELIAL BASEMENT MEMBRANE
TYPE I ALVEOLAR CELL
Interstitial space
Alveolar fluid with surfactant

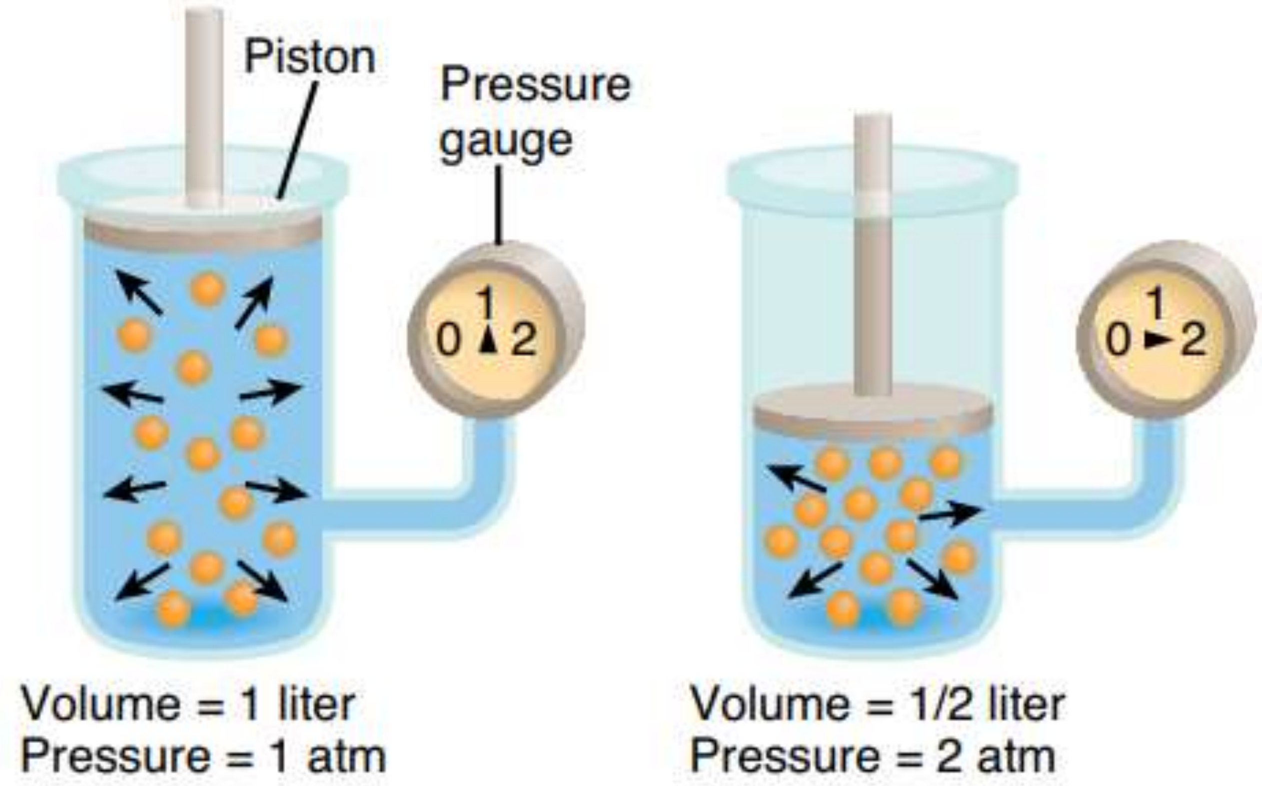
Before inspiration:

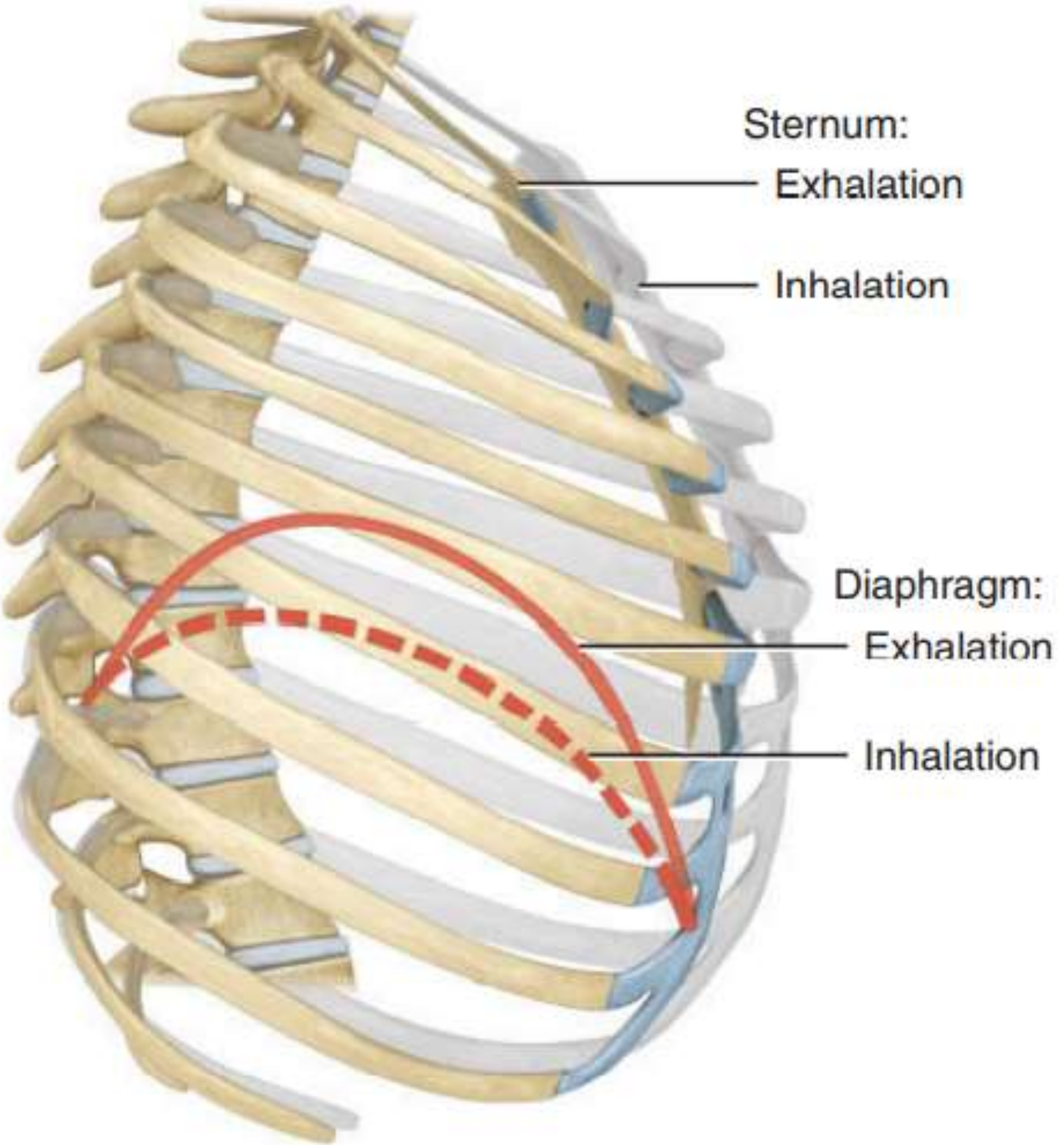
P atm= P alv = 760 mmHg



Boyle’s law

The volume of a gas varies inversely with its pressure.



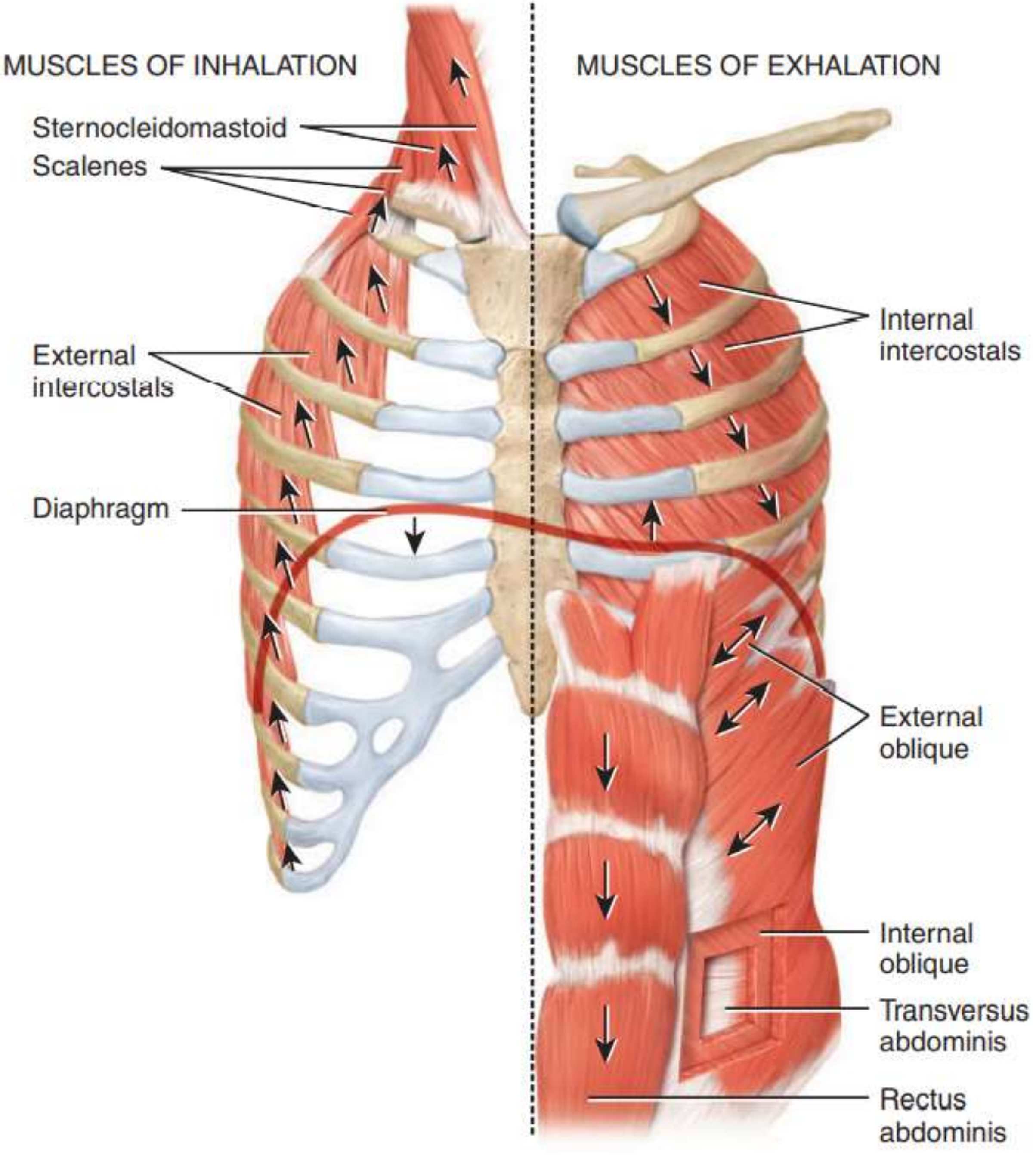

Sternum:
Exhalation
Inhalation
Diaphragm:
Exhalation
Inhalation

Diaphragm

- Contraction of the diaphragm is responsible for about 75% of the air that enters the lungs during quiet Breathing.
- Because both normal quiet inhalation and inhalation during exercise or forced ventilation involve muscular contraction, the process of inhalation is said to be active.
- Normal exhalation during quiet breathing, unlike inhalation, is a passive process because no muscular contractions are involved. Instead, exhalation results from elastic recoil of the chest wall and lungs.
- Exhalation becomes active only during forceful breathing. During these times, muscles of exhalation—the abdominal and internal intercostals contract, which increases pressure in the abdominal region and thorax.

Diaphragm

- During inspiration, contraction of the diaphragm pulls the lower surfaces of the lungs downward. Then, during expiration, the diaphragm simply relaxes, and the elastic recoil of the lungs, chest wall, and abdominal structures compresses the lungs and expels the air.
- During heavy breathing, however, the elastic forces are not powerful enough to cause the necessary rapid expiration, so extra force is achieved mainly by contraction of the abdominal muscles, which pushes the abdominal contents upward against the bottom of the diaphragm, thereby compressing the lungs.


MUSCLES OF INHALATION
Sternocleidomastoid
Scalenes
External intercostals
Diaphragm
MUSCLES OF EXHALATION
Internal intercostals
External oblique
Internal oblique
Transversus abdominis
Rectus abdominis

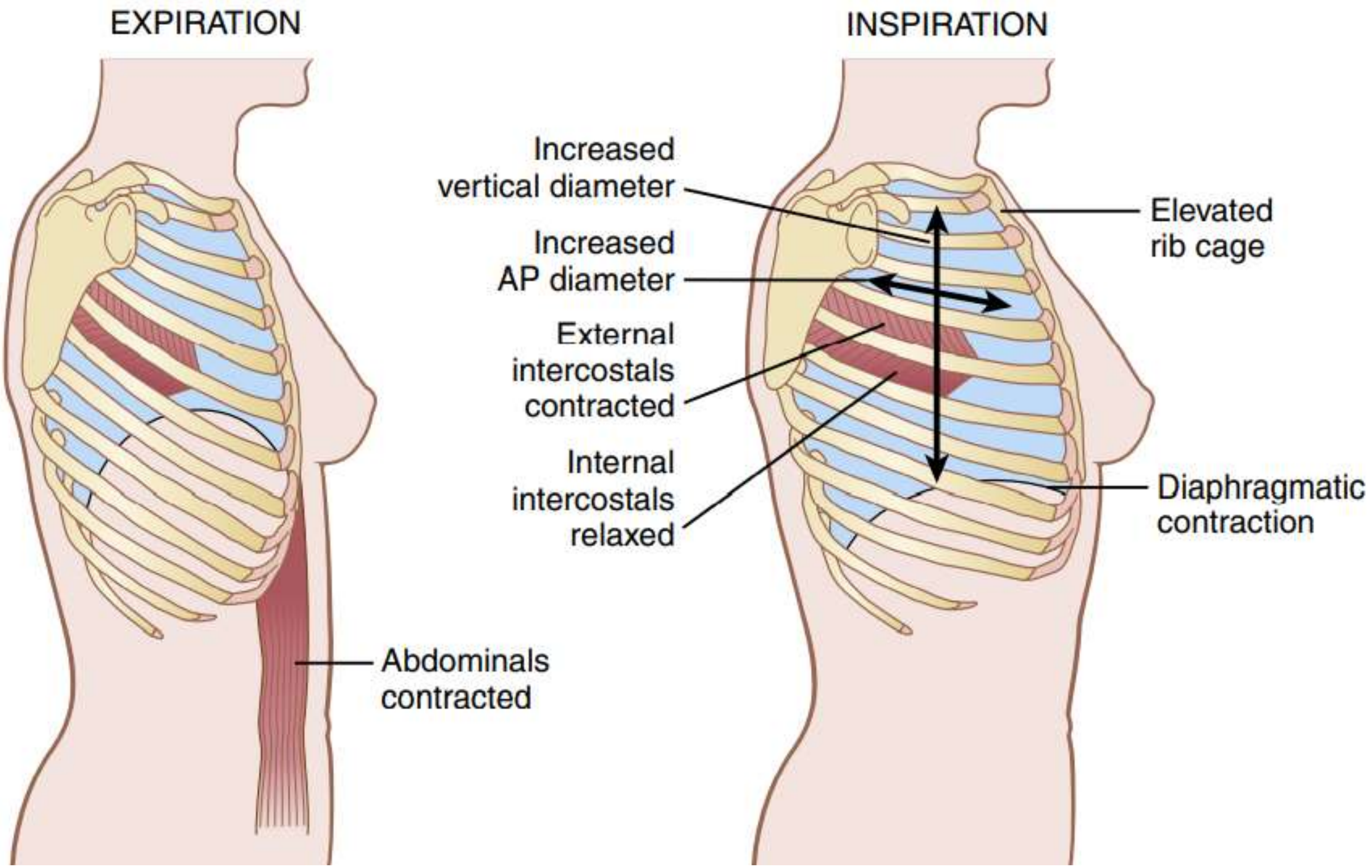
Rib cage

- The second method for expanding the lungs is to raise the rib cage.
- Raising the rib cage expands the lungs because, in the natural resting position, the ribs slant downward, thus allowing the sternum to fall backward toward the vertebral column.
- When the rib cage is elevated, however, the ribs project almost directly forward, so the sternum also moves forward, away from the spine, making the anteroposterior thickness of the chest about 20% greater during maximum inspiration than during expiration.

- Therefore, all the muscles that elevate the chest cage are classified as muscles of inspiration, and the muscles that depress the chest cage are classified as muscles of expiration.

Expiration (Exhalation)

- Expiration normally is a passive process.
- Air is driven out of the lungs by the reverse pressure gradient between the lungs and the atmosphere until the system reaches its equilibrium point again.
- During exercise or in diseases in which airway resistance is increased (e.g., asthma), the expiratory muscles may aid the expiratory process.
- The muscles of expiration include the abdominal muscles, which compress the abdominal cavity and push the diaphragm up, and the internal intercostal muscles, which pull the ribs downward and inward.



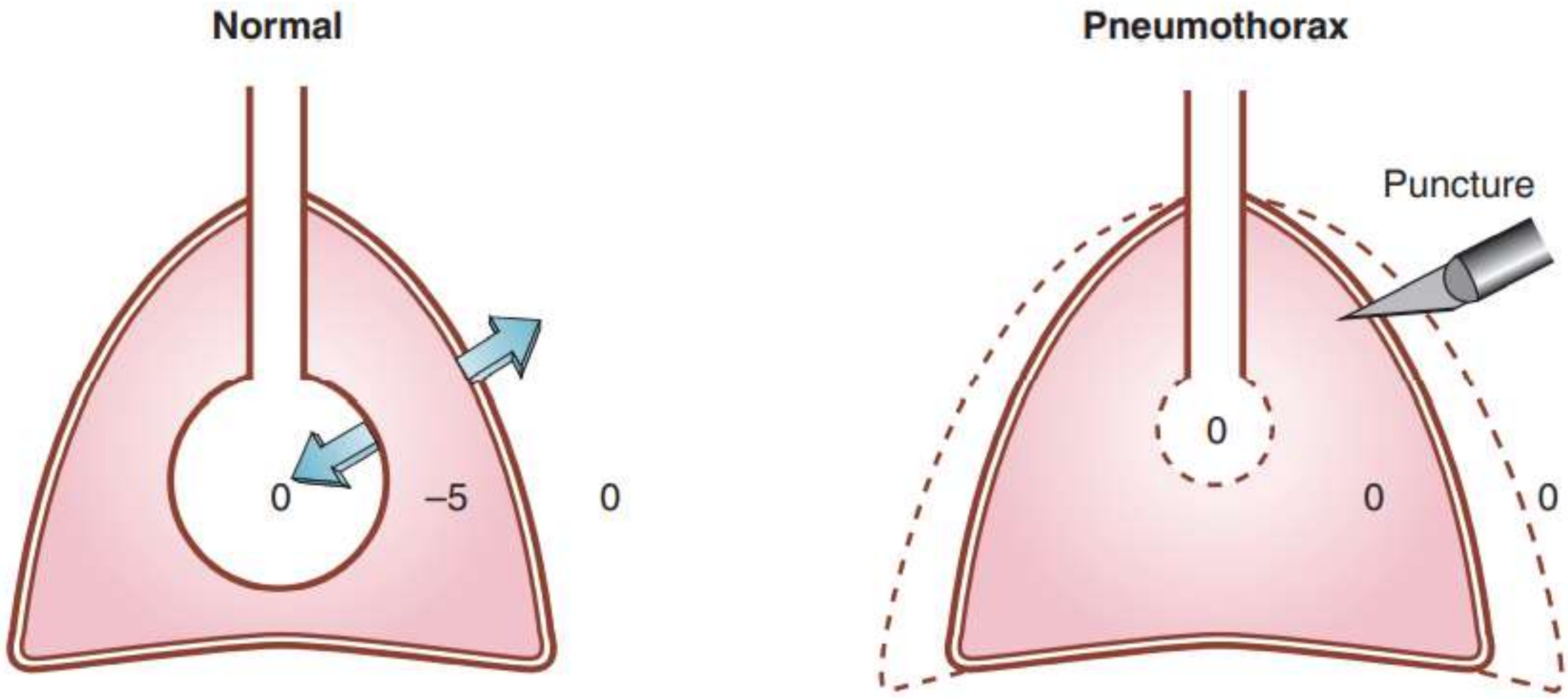
EXPIRATION
INSPIRATION
Increased
vertical diameter
Increased
AP diameter
External
intercostals
contracted
Internal
intercostals
relaxed
Elevated
rib cage
Diaphragmatic
contraction
Abdominals
contracted

Lungs

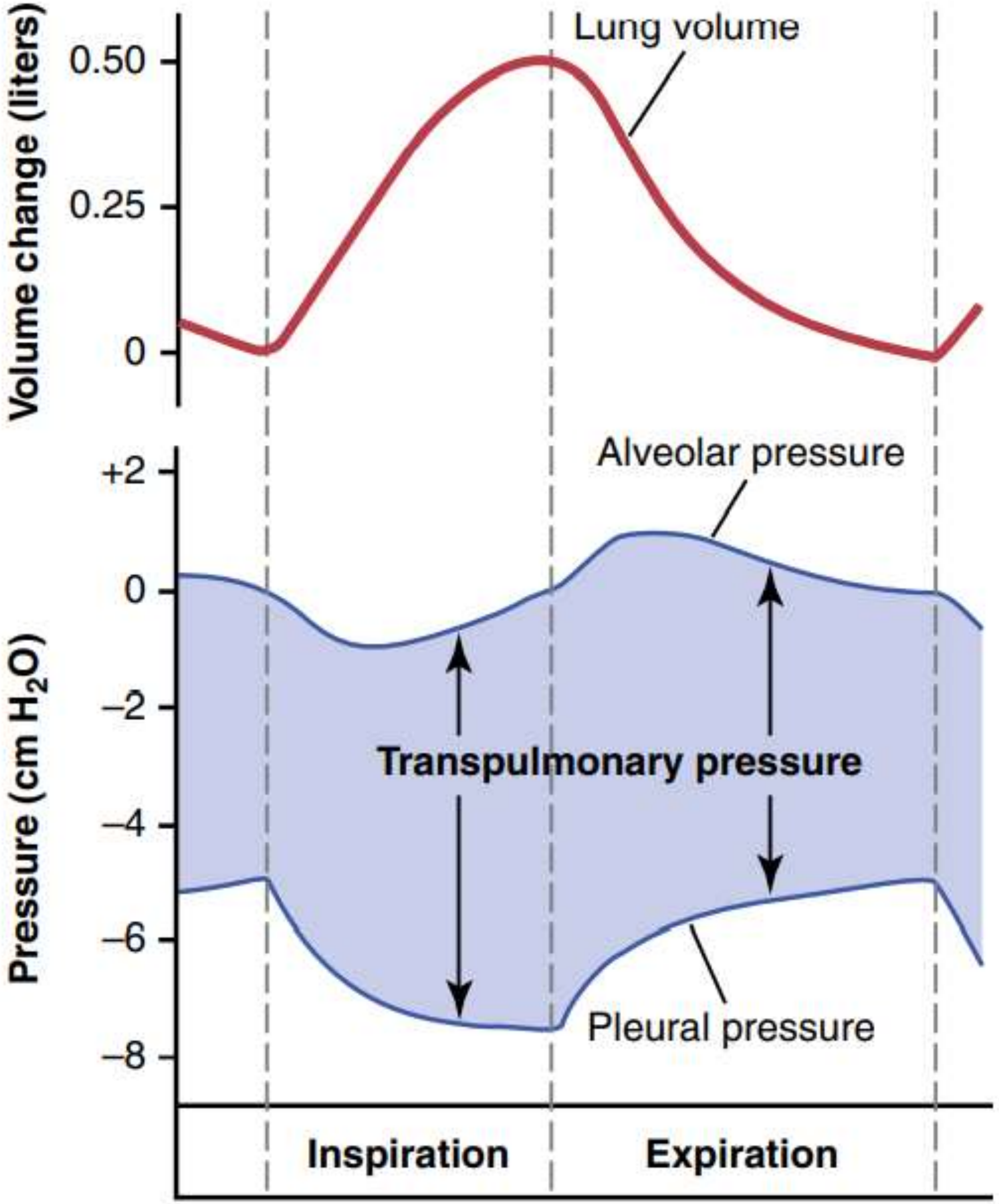
- The lung is an elastic structure that collapses like a balloon and expels all its air through the trachea whenever there is no force to keep it inflated.
- Also, there are no attachments between the lung and walls of the chest cage, except where it is suspended at its hilum from the mediastinum, the middle section of the chest cavity.
- Instead, the lung "floats" in the thoracic cavity, surrounded by a thin layer of pleural fluid that lubricates movement of the lungs within the cavity.

Pleural pressure

- Pleural pressure is the pressure of the fluid in the thin space between the lung pleura and chest wall pleura.
- This pressure is normally a slight suction, which means a slightly negative pressure.
- The normal pleural pressure at the beginning of inspiration is about −5 cm H_2O, which is the amount of suction required to hold the lungs open to their resting level.
- During normal inspiration, expansion of the chest cage pulls outward on the lungs with greater force and creates more negative pressure to an average of about −7.5 cm H_2O.



Normal
0
–5
0
Pneumothorax
Puncture
0
0
0



Volume change (liters)
0.50
0.25
0
Lung volume
Pressure (cm H_2O)
+2
0
–2
–4
–6
–8
Alveolar pressure
Transpulmonary pressure
Pleural pressure
Inspiration
Expiration

Alveolar pressure

- To cause inward flow of air into the alveoli during inspiration, the pressure in the alveoli must fall to a value slightly below atmospheric pressure (below 0).
- during normal inspiration, alveolar pressure decreases to about −1 cm H_2O. This slight negative pressure is enough to pull 0.5 liter of air into the lungs in the 2 seconds required for normal quiet inspiration.
- During expiration, alveolar pressure rises to about +1 cm H_2O, which forces the 0.5 liter of inspired air out of the lungs during the 2 to 3 seconds of expiration.

Transpulmonary pressure

- the transpulmonary pressure is the pressure difference between that in the alveoli and that on the outer surfaces of the lungs (pleural pressure)

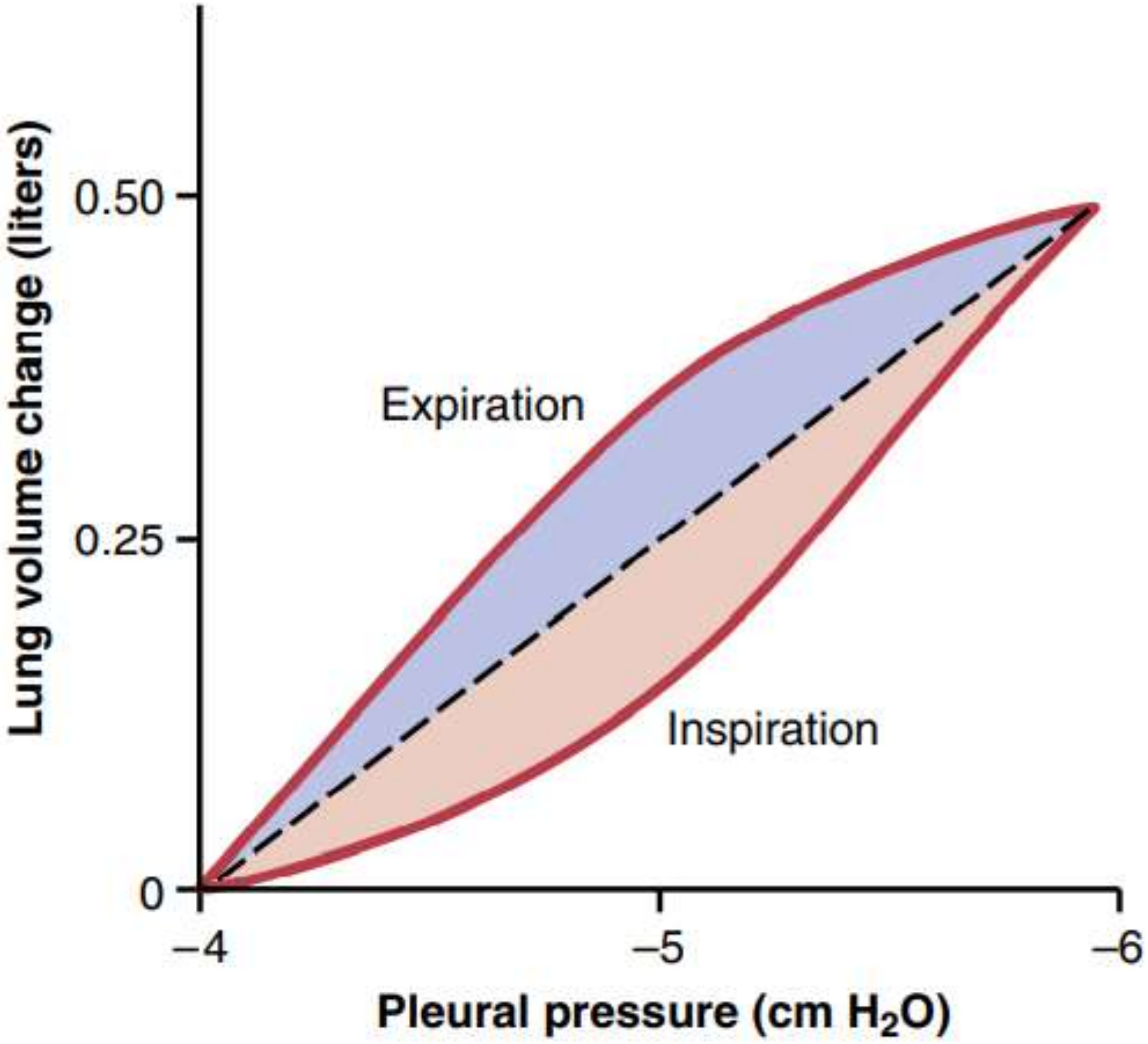
- it is a measure of the elastic forces in the lungs that tend to collapse the lungs at each instant of respiration, called the **recoil pressure**.

Compliance of the lungs

- The extent to which the lungs will expand for each unit increase in transpulmonary pressure (if enough time is allowed to reach equilibrium) is called the lung compliance.

- The total compliance of both lungs together in the normal adult averages about 200 ml of air/cm H_2O transpulmonary pressure.

- That is, every time the transpulmonary pressure increases by 1 cm H_2O, the lung volume, after 10 to 20 seconds, will expand 200 ml.



Lung volume change (liters)
0.50
0.25
0
Expiration
Inspiration
–4
–5
–6
Pleural pressure (cm H_2O)

Compliance of the lungs

- The characteristics of the compliance diagram are determined by the elastic forces of the lungs.

- These forces can be divided into two parts:
- (1) elastic forces of the lung tissue
- (2) elastic forces caused by surface tension of the fluid that lines the inside walls of the alveoli and other lung air spaces.

Compliance of the lungs

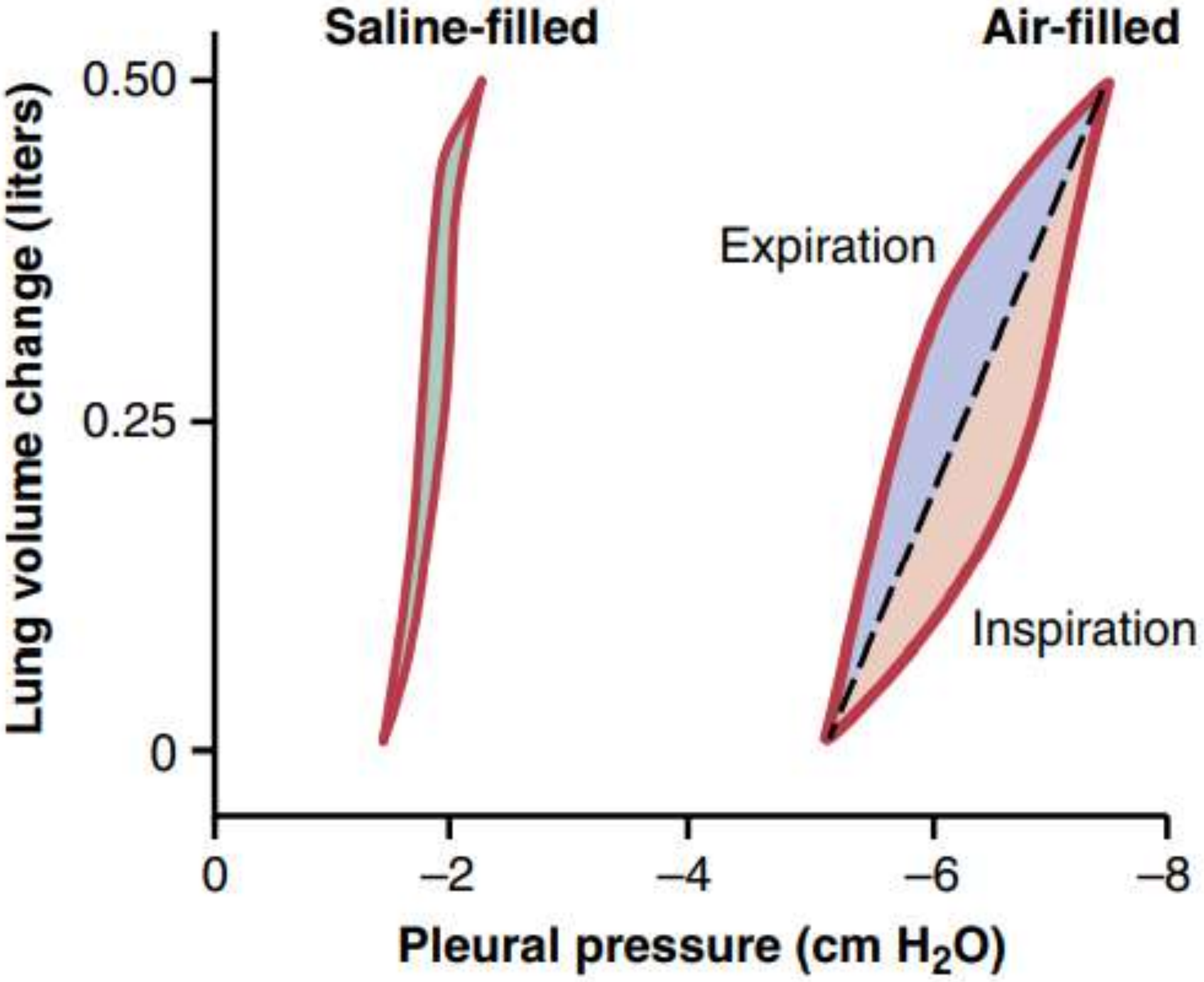
- The elastic forces of the lung tissue are determined mainly by elastin and collagen fibers interwoven among the lung parenchyma.

- In deflated lungs, these fibers are in an elastically contracted and kinked state; then, when the lungs expand, the fibers become stretched and unkinked, thereby elongating and exerting even more elastic force.

Surface tension

- When water forms a surface with air, the water molecules on the surface of the water have an especially strong attraction for one another. As a result, the water surface is always attempting to contract. This is what holds raindrops together.

- In the inner surfaces of the alveoli. Here, the water surface is also attempting to contract. This tends to force air out of the alveoli through the bronchi and, in doing so, causes the alveoli to try to collapse.


Saline-filled
Air-filled
0.50
0.25
0
Lung volume change (liters)
Expiration
Inspiration
0
–2
–4
–6
–8
Pleural pressure (cm H2O)

Surfactant

- Surfactant is a surface-active agent in water, which means that it greatly reduces the surface tension of water.

- It is secreted by special surfactant-secreting epithelial cells called type II alveolar epithelial cells, which constitute about 10% of the surface area of the alveoli.

Surfactant

- Surfactant is a complex mixture of several phospholipids, proteins, and ions.
- They perform this function by not dissolving uniformly in the fluid lining the alveolar surface. Instead, part of the molecule dissolves while the remainder spreads over the surface of the water in the alveoli.
- Without surfactant, small alveoli have increased surface tension and increased pressures and will collapse (**atelectasis**)

Surfactant

- the importance of surfactant in reducing alveolar surface tension and therefore also **reducing the effort required by the respiratory muscles to expand the lungs**.
- **Pressure Caused by Surface Tension Is Inversely Related to Alveolar Radius**.
- This phenomenon is especially significant in small premature infants, many of whom have alveoli with radii less than 25% that of an adult person.
- surfactant does not normally begin to be secreted into the alveoli until between the sixth and seventh months of gestation and, in some cases, even later.
- respiratory distress syndrome of the newborn.

Energy Required for Respiration

- During normal quiet respiration, only 3% to 5% of the total energy expended by the body is required for pulmonary ventilation.

- However, during heavy exercise, the amount of energy required can increase as much as 50-fold, especially if the person has any degree of increased airway resistance or decreased pulmonary compliance.

Work of Breathing

- The work of inspiration can be divided into three fractions:
- (1) that required to expand the lungs against the lung and chest elastic forces, called **compliance work or elastic work**

- (2) that required to overcome the viscosity of the lung and chest wall structures, called **tissue resistance work**

- (3) that required to overcome airway resistance to movement of air into the lungs, called **airway resistance work**.

References

- Guyton and Hall, Textbook of Medical Physiology, 14th edition.

- Costanzo, Physiology Textbook, 6th edition.

- Tortora and Derrickson, Principles of Anatomy and Physiology Textbook, 14th edition.

Thank you