Breathing and respiration

5.3.2024

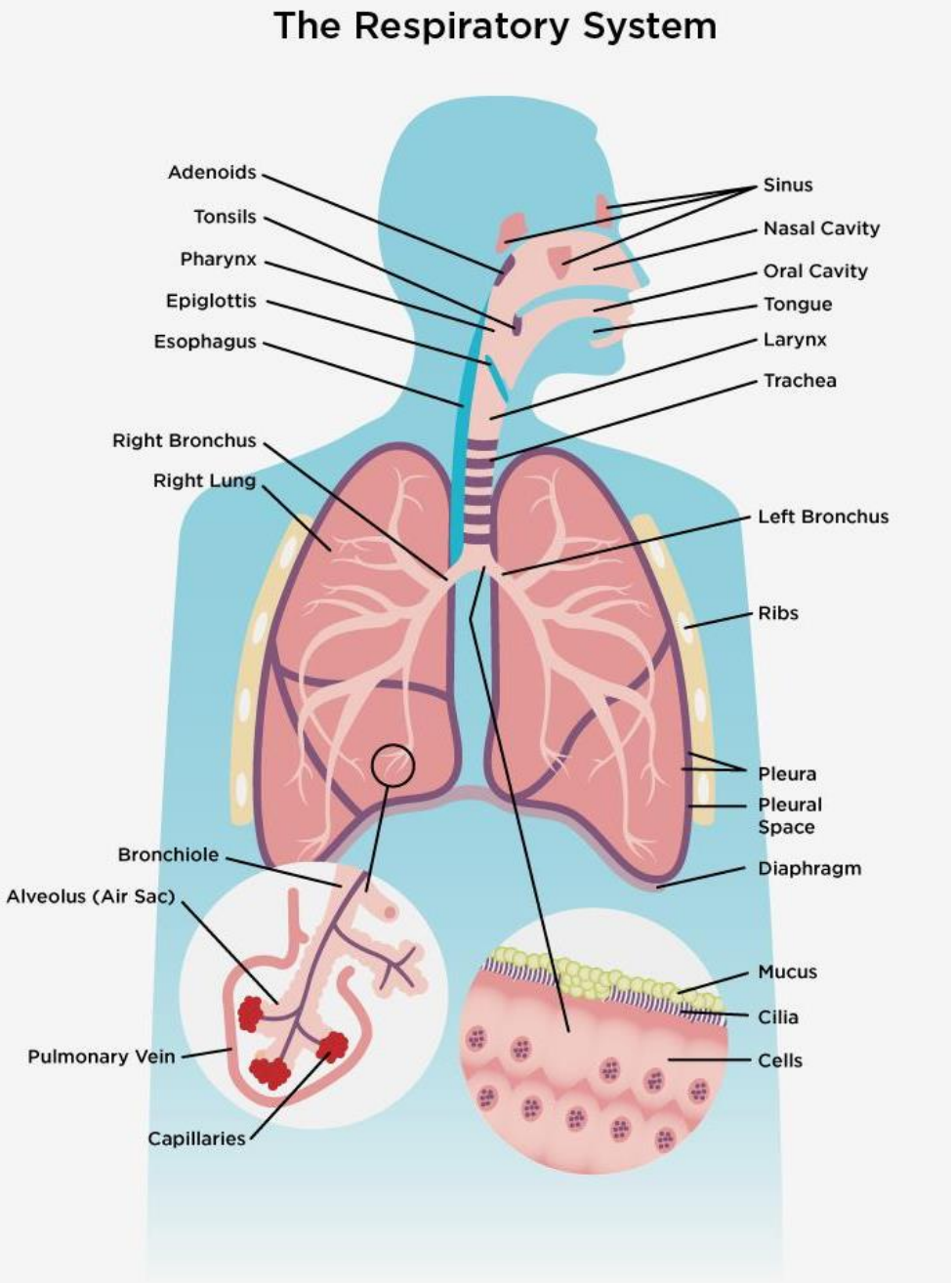
Learning outcomes

Recognize the essential anatomical structures of the respiratory system

Understand the physiological principles of oxygen and carbon dioxide exchange

Understand the principles in control on breathing

Recognize the essential investigations related to pulmonary functions



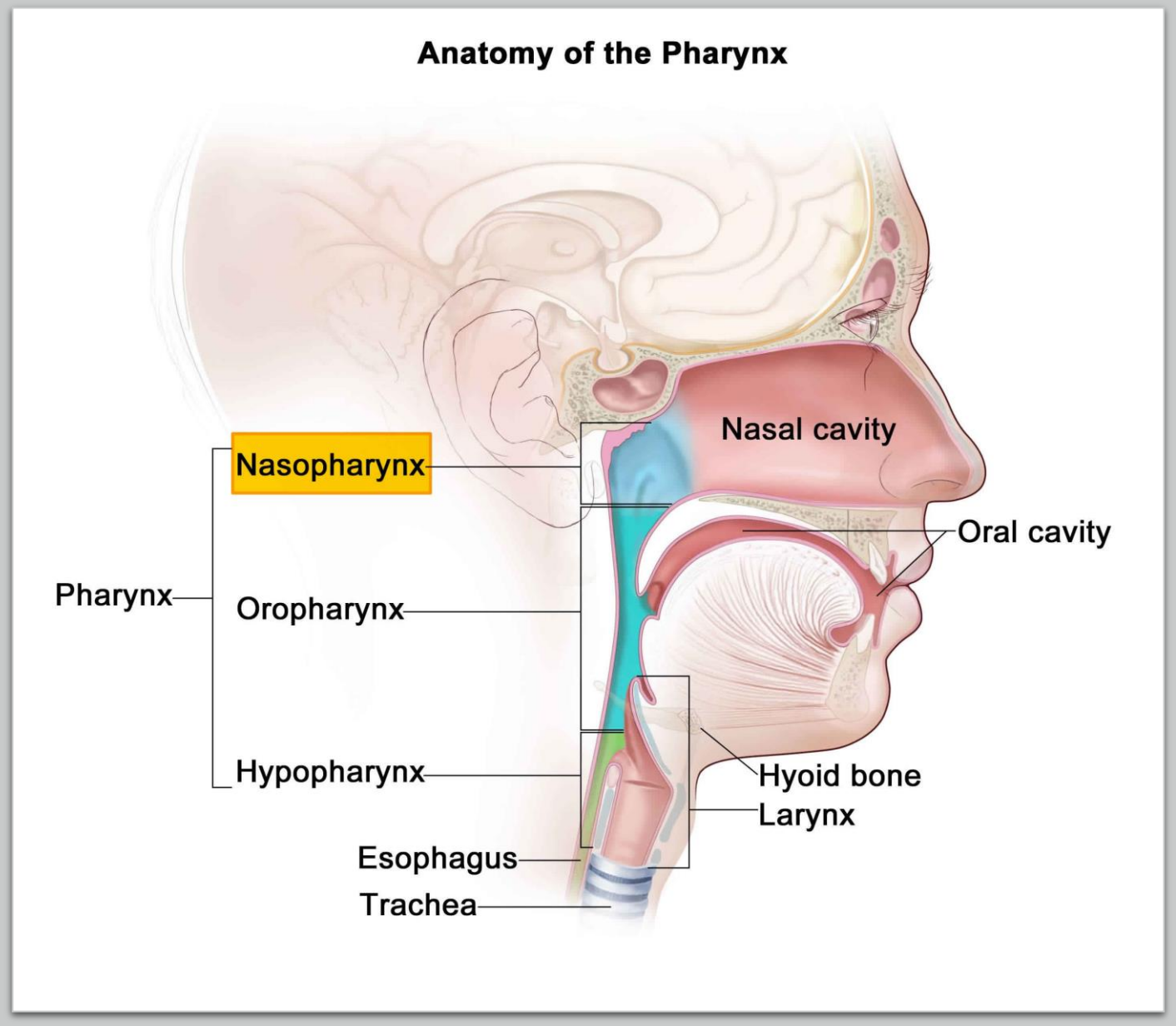
https://www.lung.ca/

Anatomy of respiratory system

- The upper respiratory system: Nose and paranasal sinuses, pharynx
- The lower respiratory system: Larynx, trachea, bronchi
- Smallest bronchi (bronchioles) terminate in alveolar sacs which form most of the lung tissue

Nasal cavity cleans, moistens and warms the air

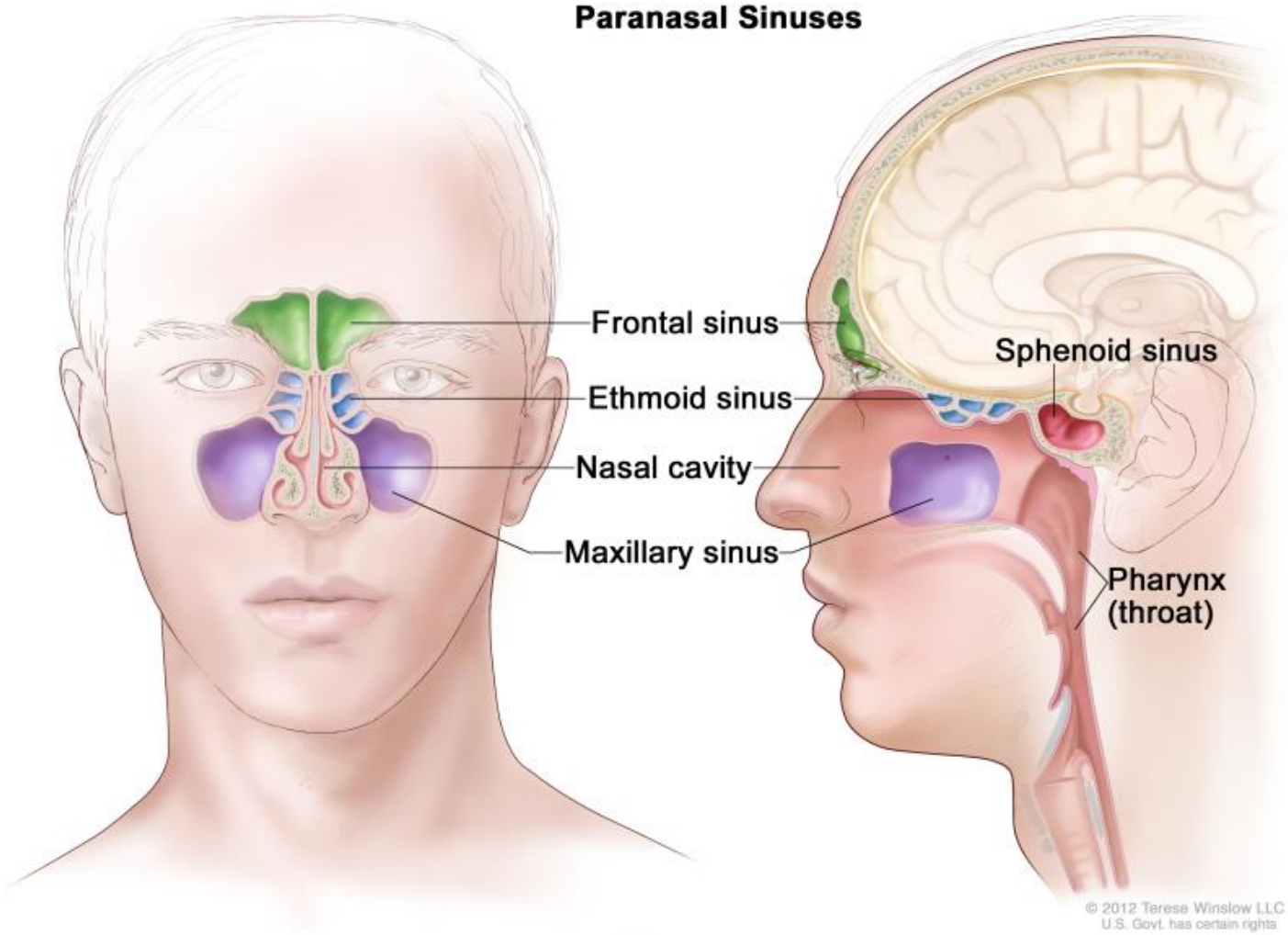
- Mucosa with ciliated pseudostratified columnar epithelium
- Pollutants to stomach via pharynx and esophagus
- Rich vasculature
- Olfactory epithelium in the floor of nasal cavity



https://healthjade.net/nasopharynx/

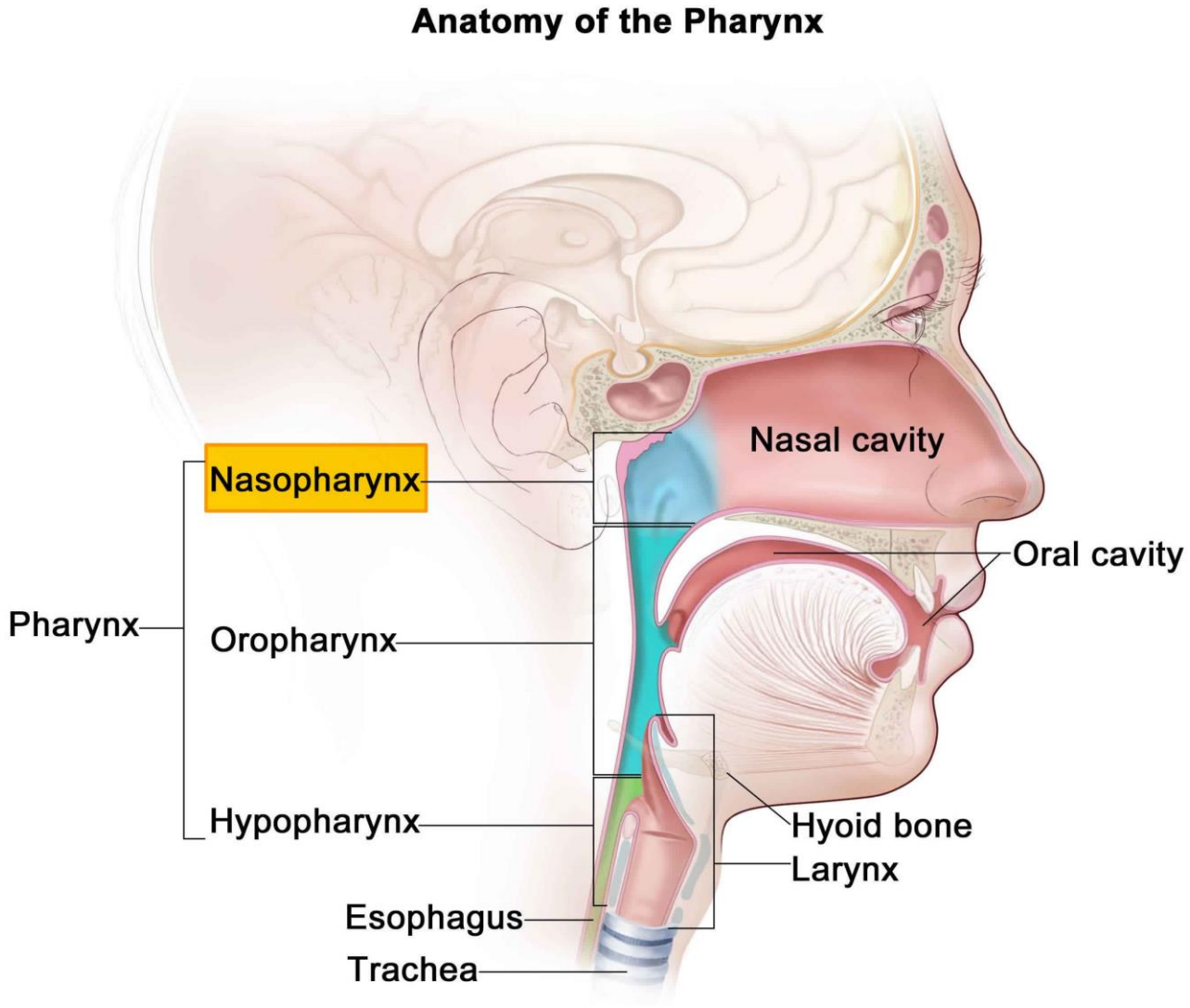
Paranasal sinuses

- Frontal, maxillary, sphenoid, ethmoidal sinuses
- Increase the space for moistening and warming up the air
- Sound board for voice production
- Lightens the weight of the skull
- More space for olfactory functions



Pharynx

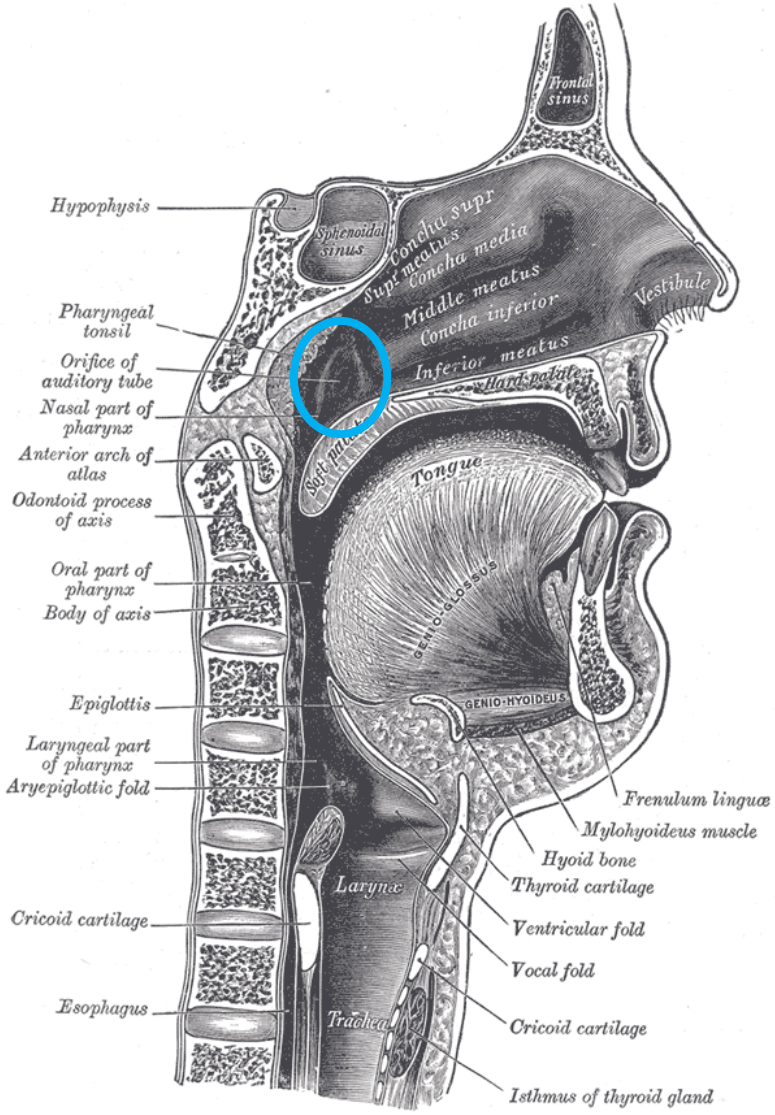
- Belongs to both respiratory and gastrointestinal system
- Divides into naso-, oro-, and hypophranx

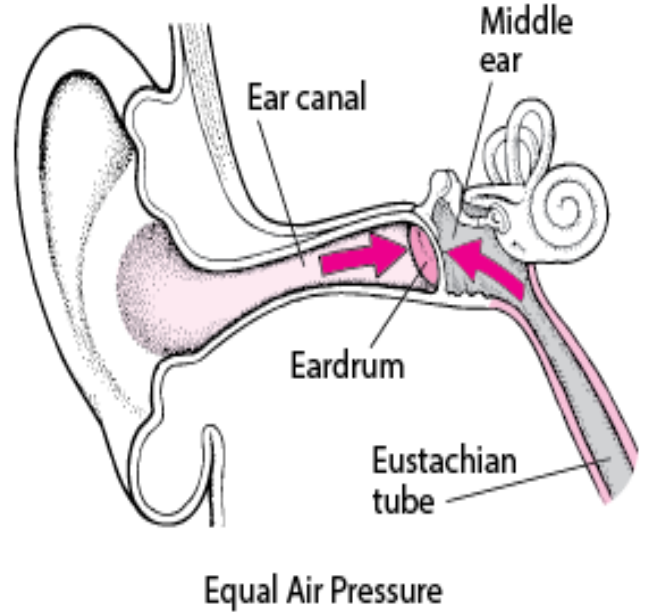


https://healthjade.net/nasopharynx/

- Nasopharynx
  - Ciliated epithelium
  - Eustachian tube runs from the middle ear to pharynx and equalizes pressure

- Oro- and hypopharynx take part mainly in digestion

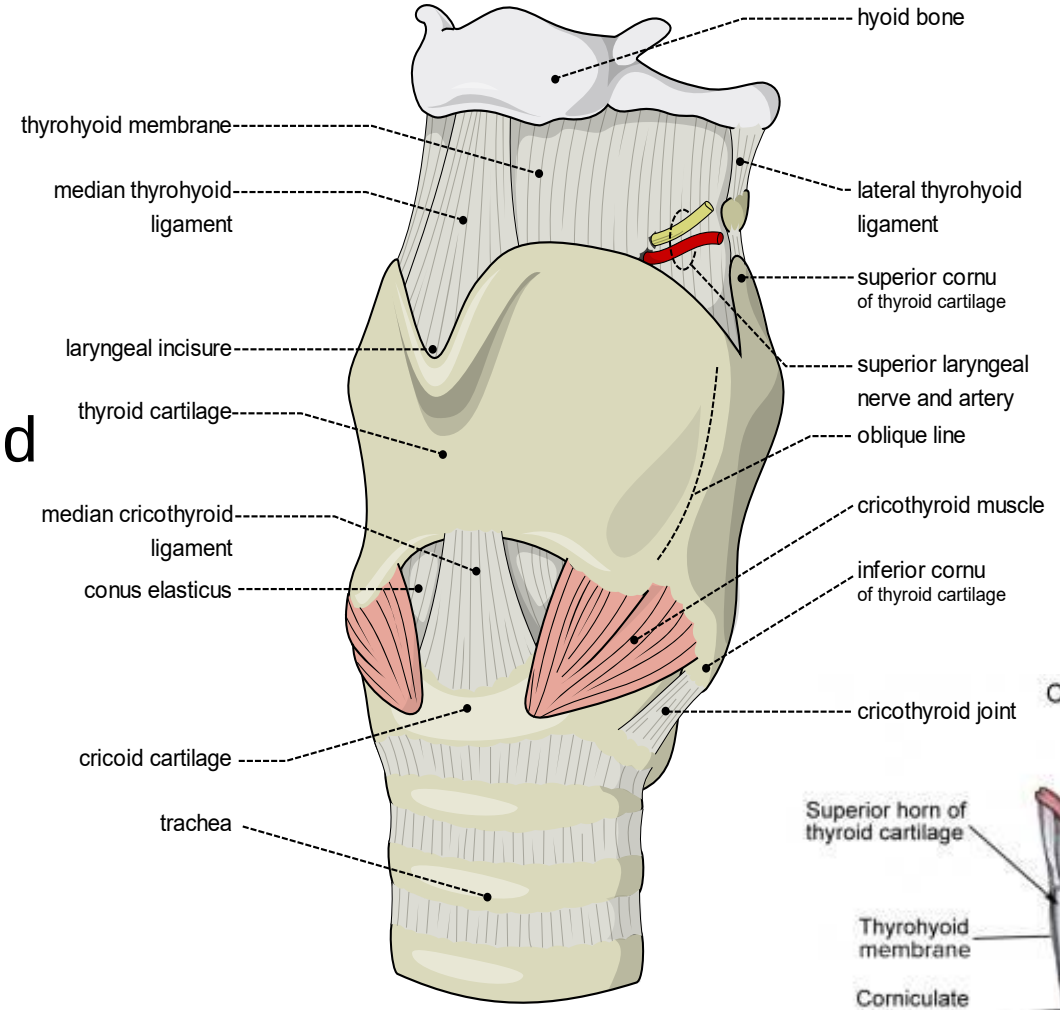


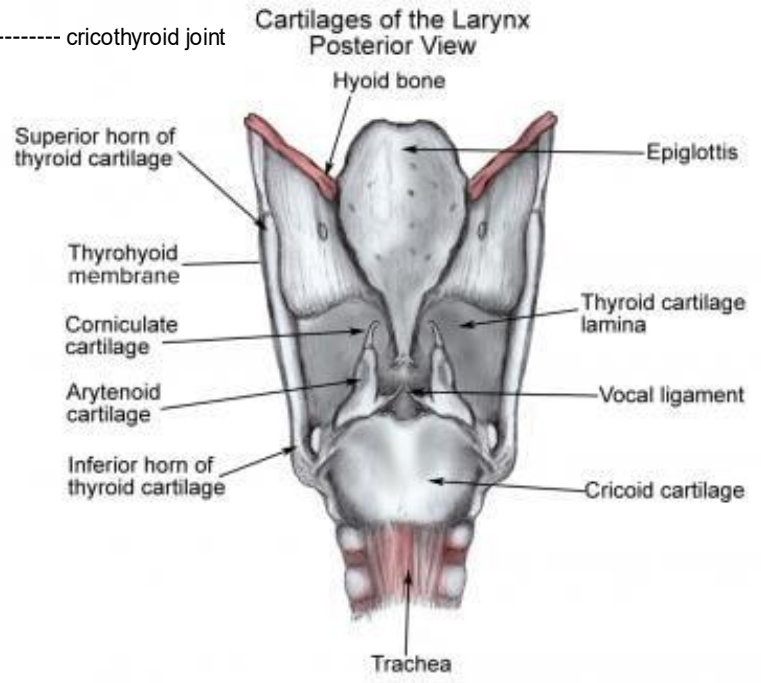


Wikipedia; msdmanuals.com

Larynx

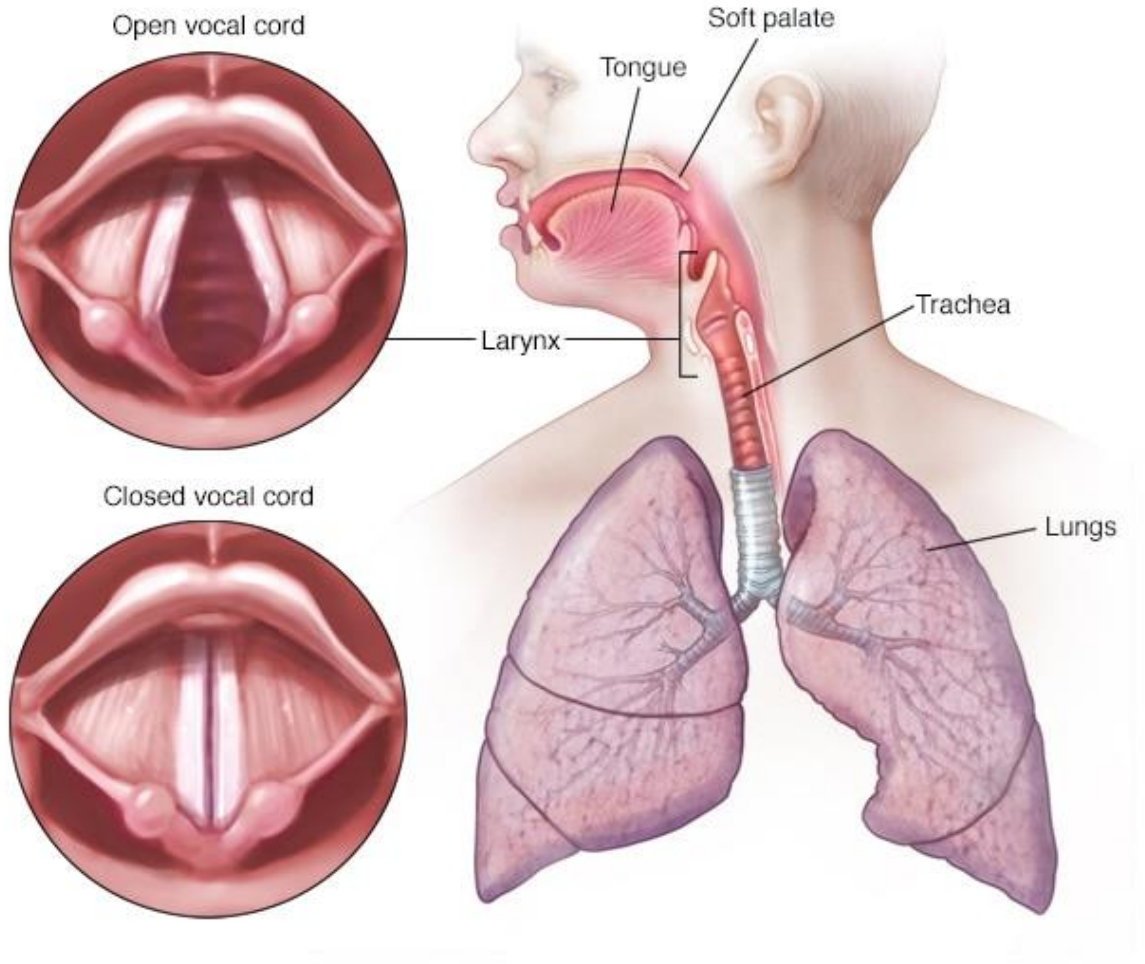
- Cartilage, connective and muscle tissues
- *Thyroid cartilage* is connected with a ligament to the hyoid bone: moves during swallowing
- *Cricoid cartilage* is below the thyroid cartilage
- Above the back of cricoid cartiage resides *arytenoid cartilage* which connects to vocal ligaments

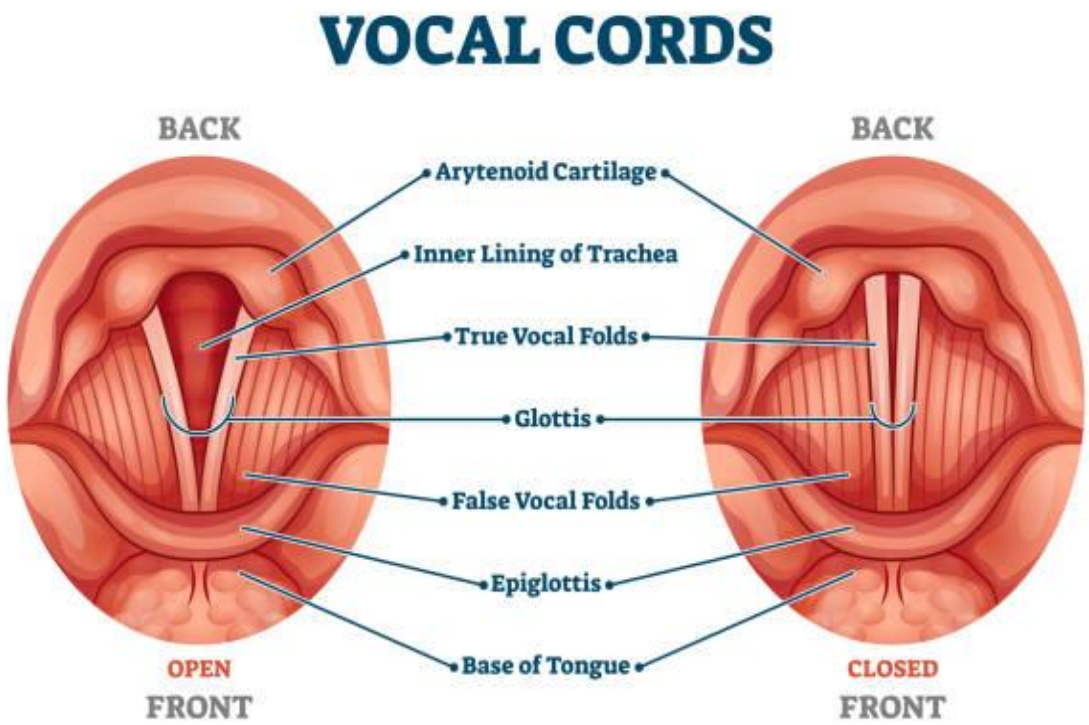




Wikipedia, https://emedicine.medscape.com/article/866384-overview

Larynx and upper respiratory system participate in vocal production

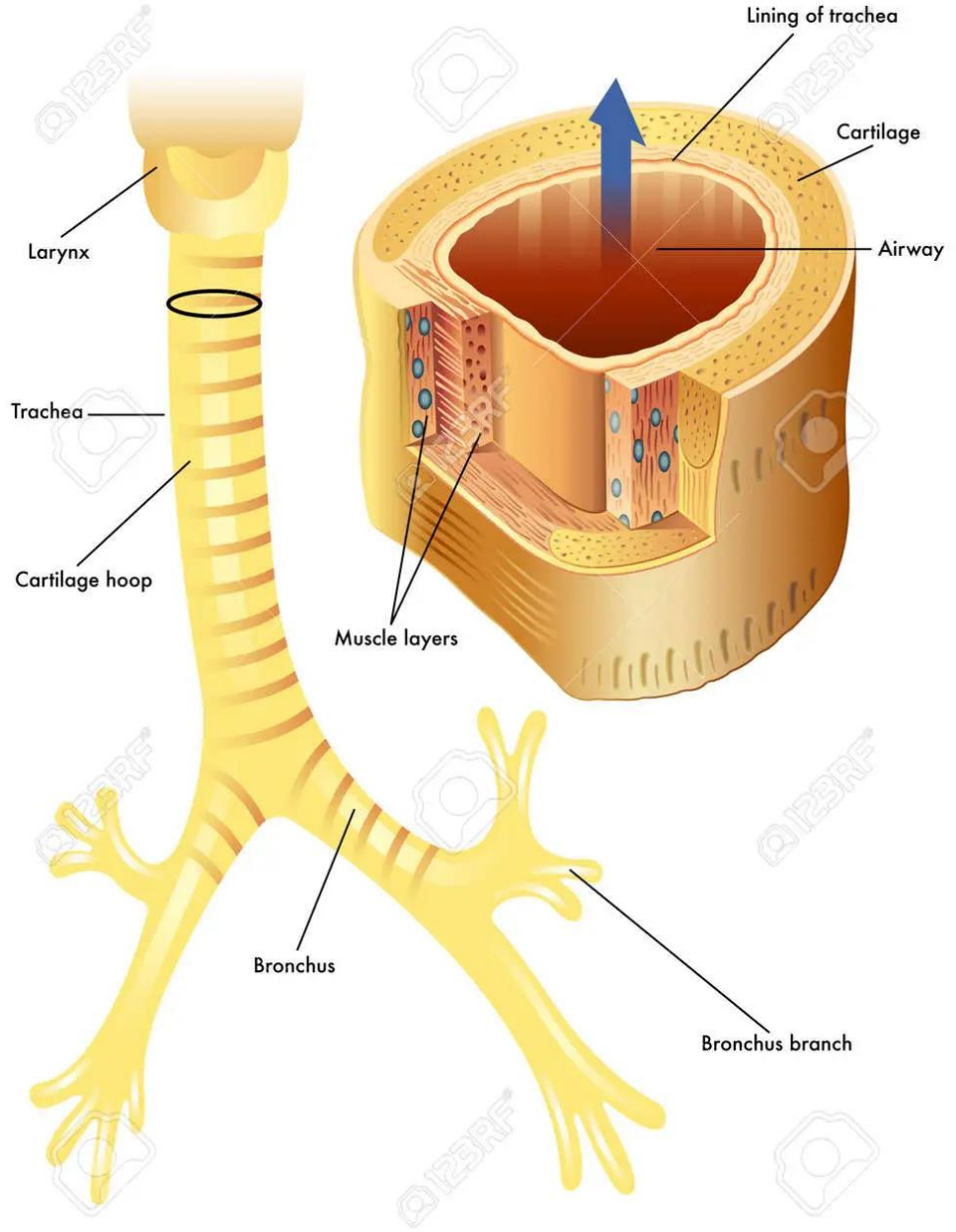




Mayoclinic.com, istockphoto.com

Trachea

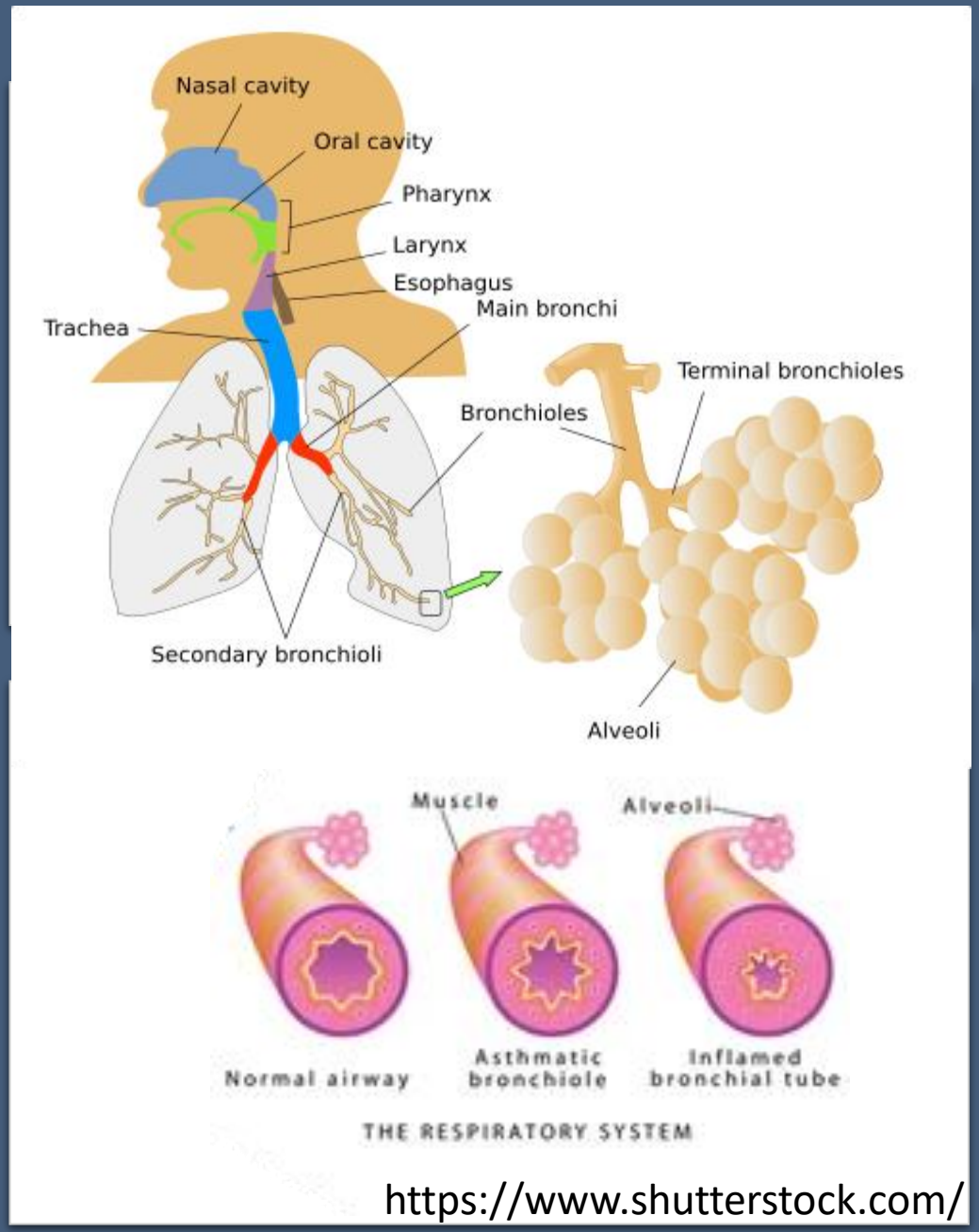
- Cartilaginous tube that connects the larynx to the bronchi
- 15-20 U-shaped cartilages that support the anterior side; the backside consists of smooth muscle and connective tissue
- Ciliated epithelium
- Remains constantly open due to its structure



https://www.123rf.com/photo_17438472_anatomy-of-the-trachea.html

Bronchi

- Primary bronchi divide into smaller bronchi
- Bronchi divide finally into ~1 mm diameter *bronchioles* of only smooth muscle
- In asthma, the smooth muscle cells tend to constrict

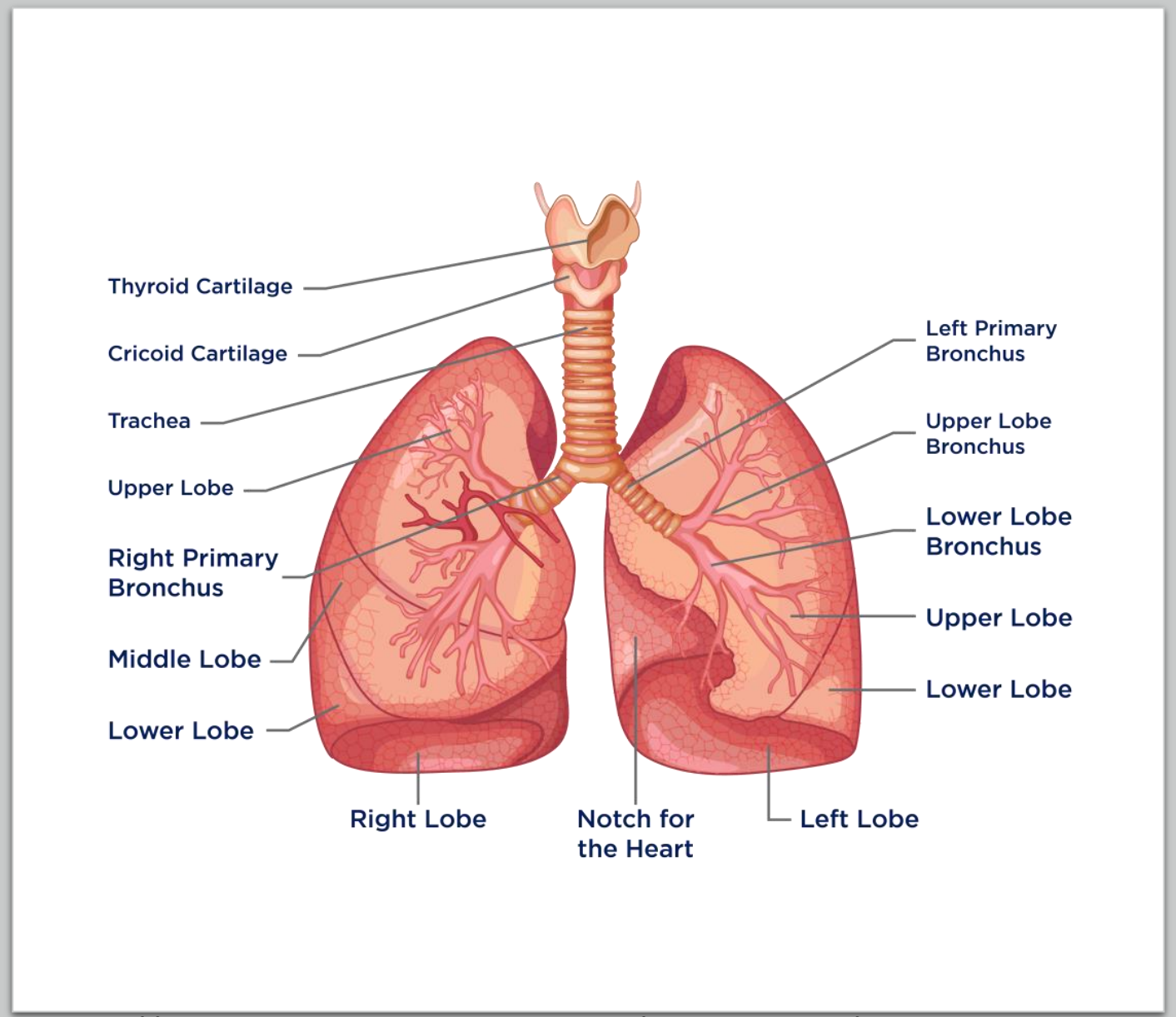


https://www.shutterstock.com/

https://mmegias.webs.uvigo.es/

Lungs

- Pairwise organ inside the thoracic cavity
- Right side consists of three, and left side of two lobes
- Lobes divide further into 10 segments per side, each with own (tertiary) bronchus
- Bronchus – bronchiole – terminal bronchioles – respiratory bronchioles – alveoli



https://diagnosis101.welchallyn.com/auscultation/educational-topics/anatomy-of-the-heart-and-lungs/

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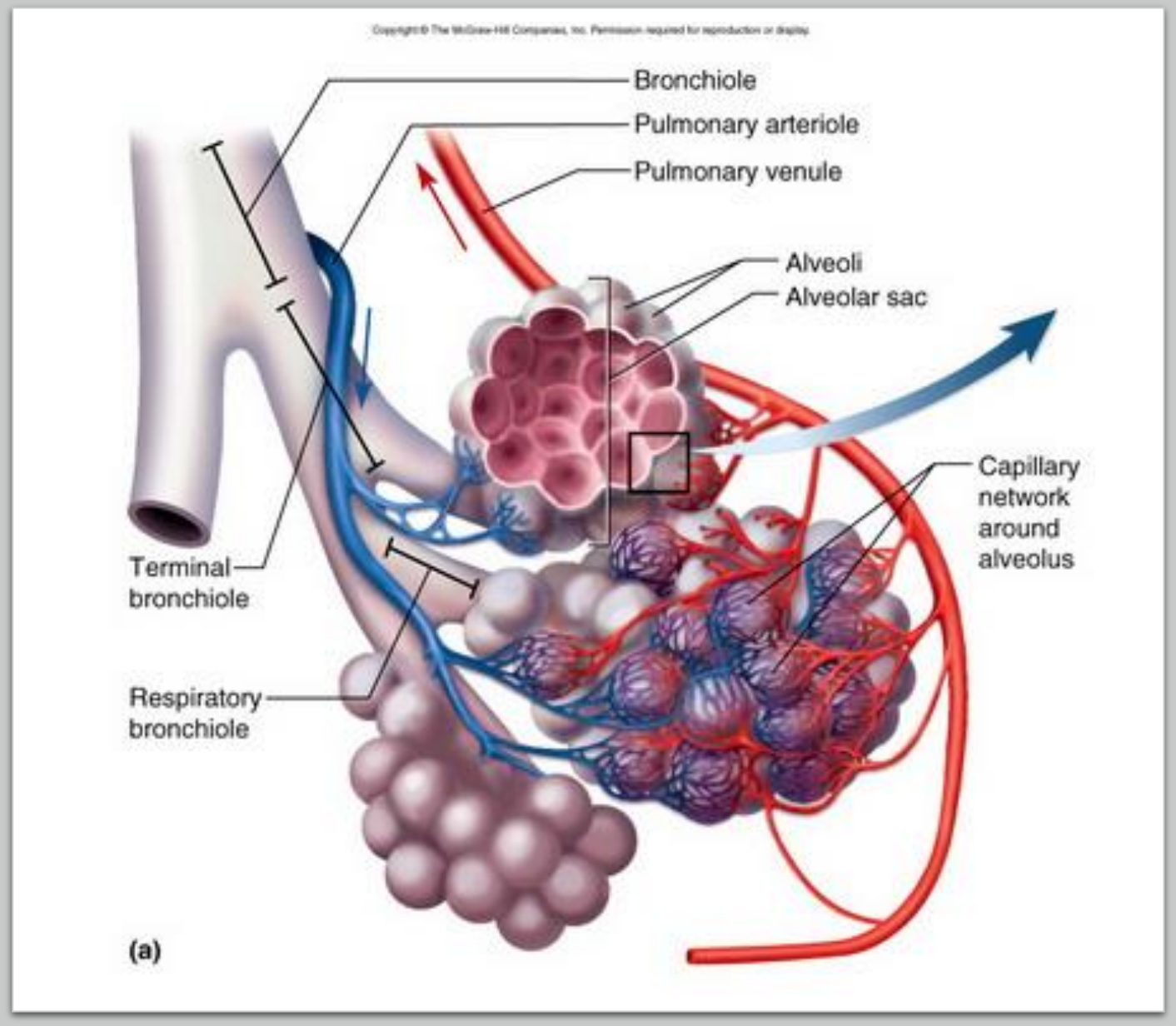
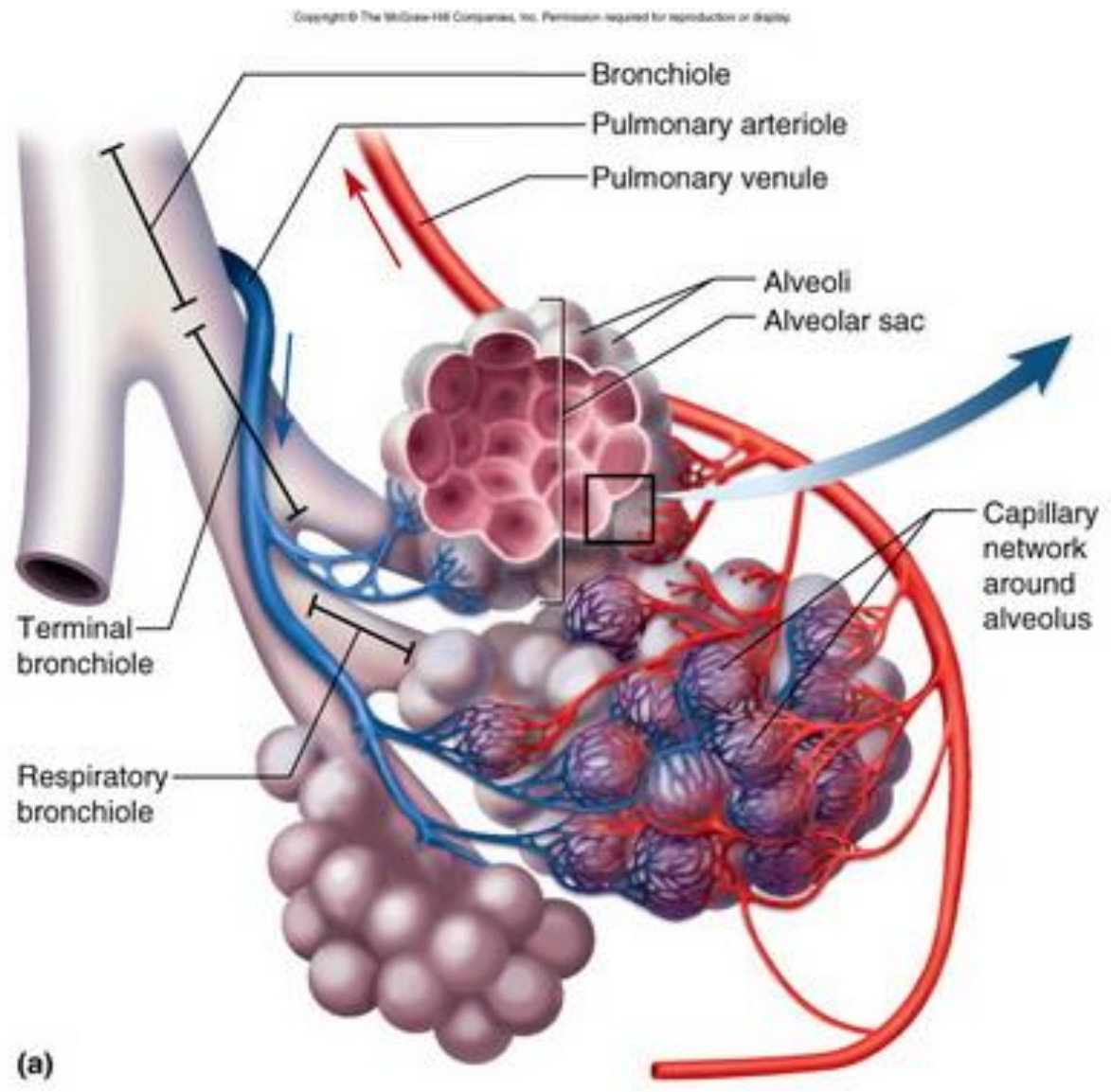


https://socratic.org/questions/what-are-structure-and-function-of-alveoli

Lung tissue consists mainly of alveolar sacs



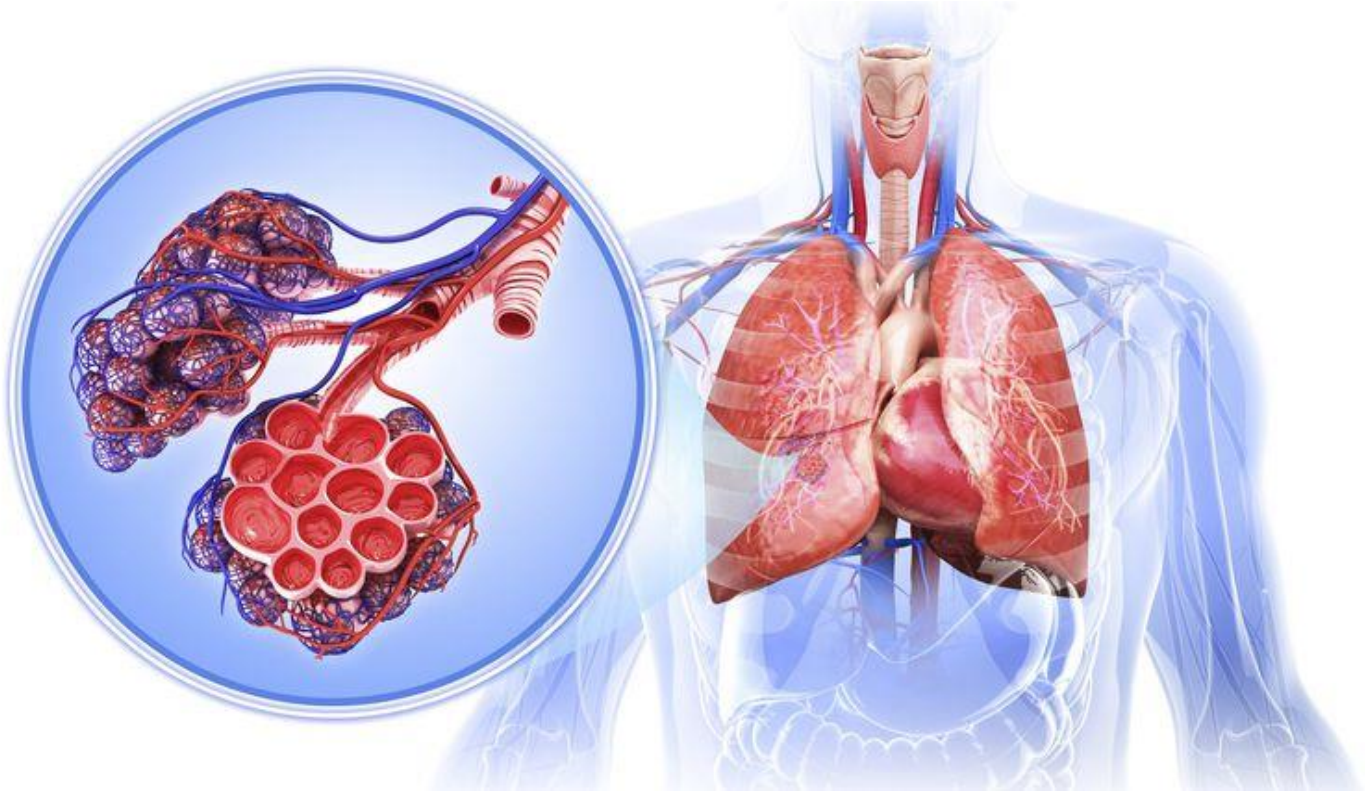
https://socratic.org/questions/what-are-structure-and-function-of-alveoli

Alveoli

- Hundreds of millions
- Diameter during exhaling 0.1-0.2 mm; during inhaling 2x
- Rich vasculature
- Inside covered with fluid

→Tendency to collapse

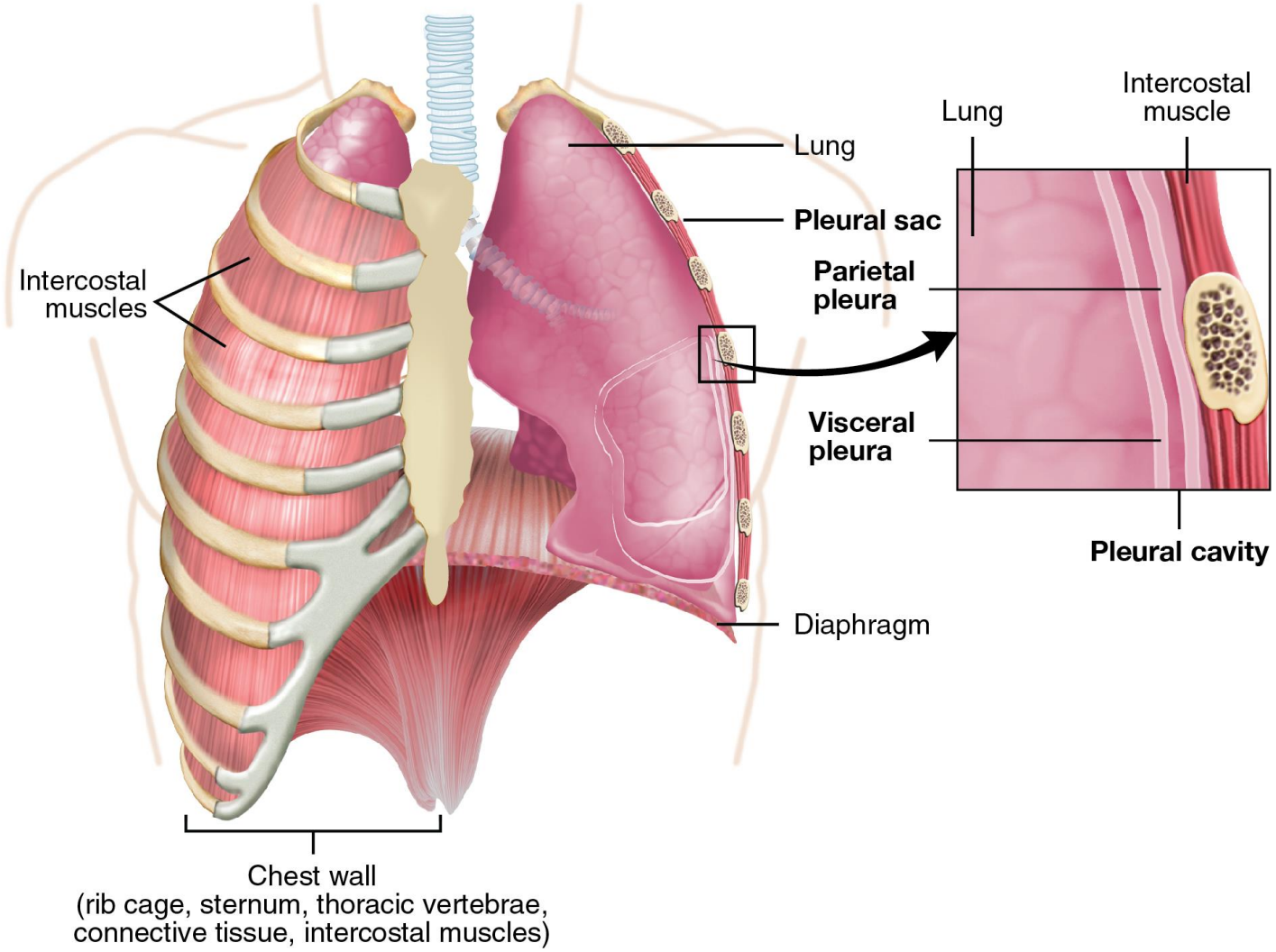
→ Surface tension lowered by surfactant enzyme



https://fi.approby.com/kuinka-hengitys-toimii-fysiologisesti/

Pleural sac

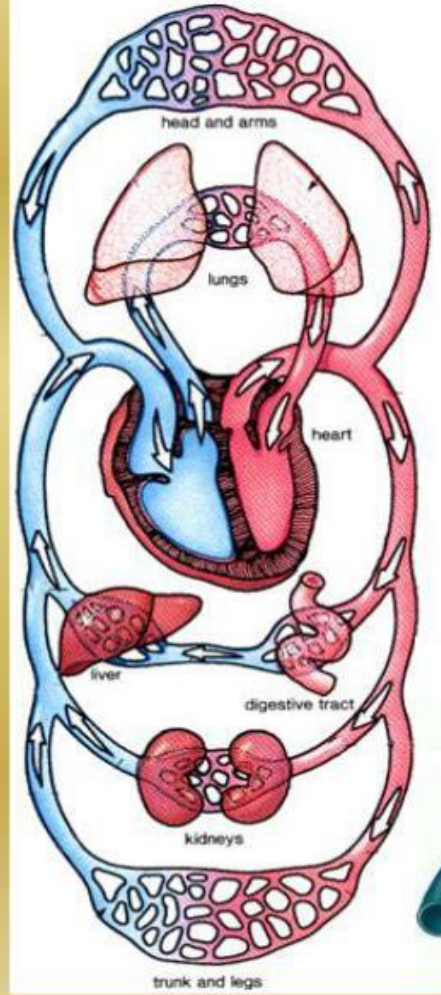
- Surrounds each lung
- Two membranes: visceral pleura and parietal pleura
- Fluid in the pleural cavity enables lubrication between the membranes

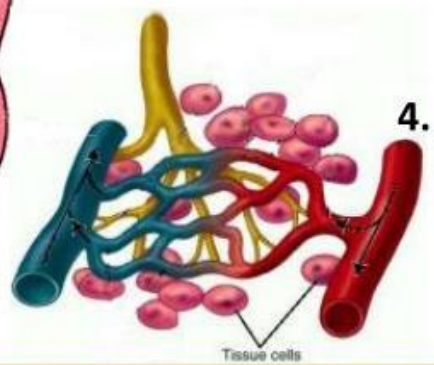


Wikipedia

Phases in respiration

Four phases of Human Respiration



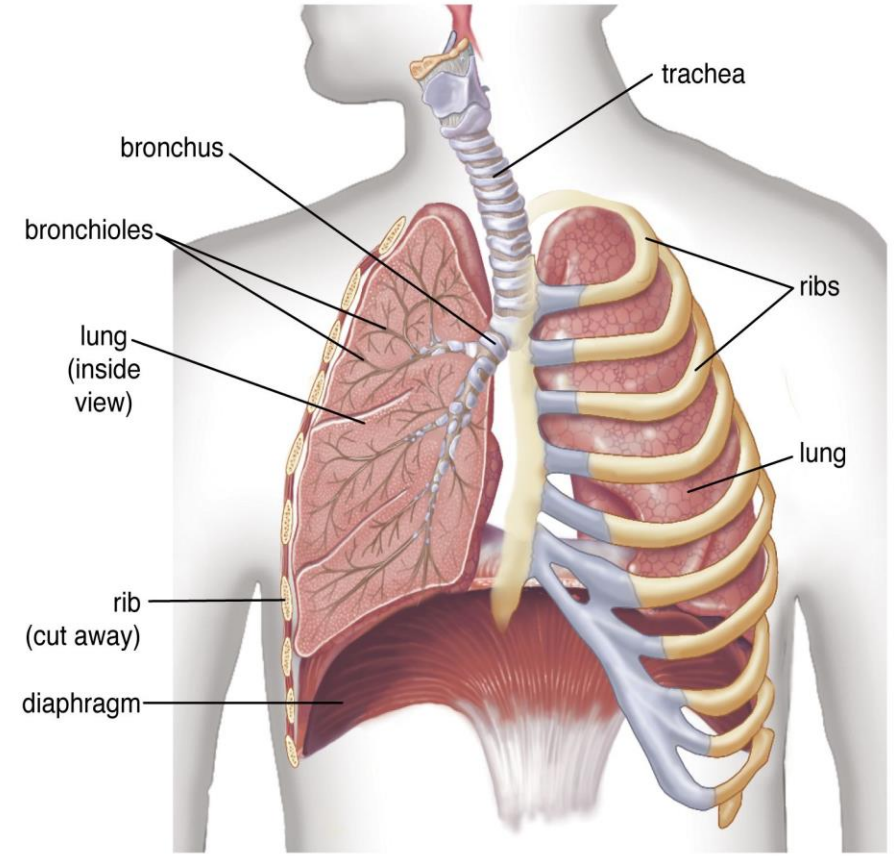


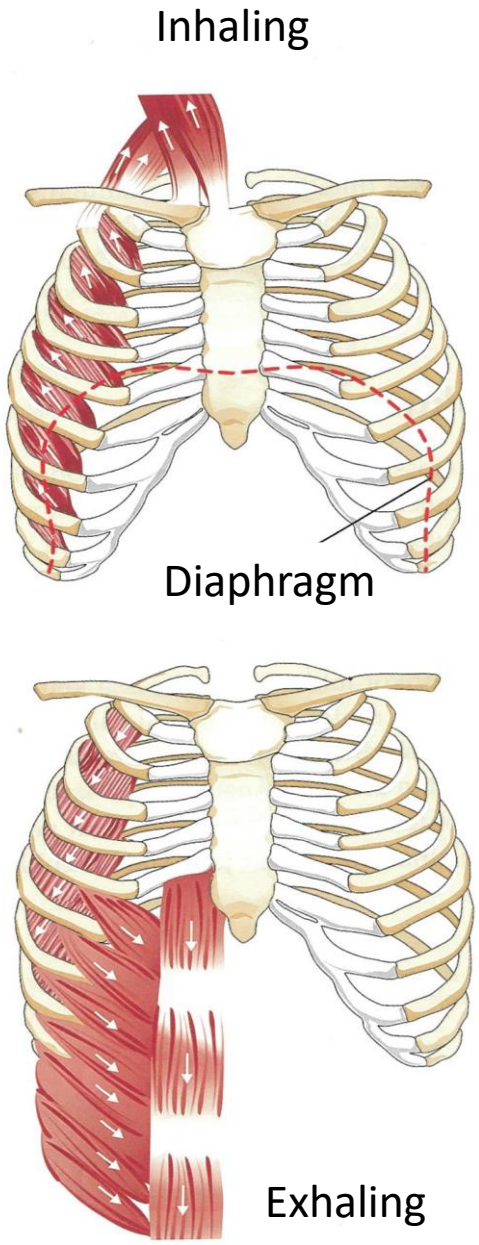
1. **Ventilation** – the movement of air into and out of the lungs
   - → **Inspiration**: breathing in
   - → **Expiration**: breathing out
2. **External respiration** – the exchange of O_2 and CO_2 between the air and the blood in the lungs
3. **Circulation** – the carrying of dissolved gasses by the blood to and from the body cells
4. **Internal respiration** – the exchange of O_2 and CO_2 between blood and the body cells.

https://www.slideserve.com/jethro/respiratory-system

Respiratory muscles

- During normal breathing, only inhaling is active
- Most important respiratory muscles are the diaphragm and the external intercostal muscles
- Accessory inspiratory muscles at the neck
- In a forceful exhaling, internal intercostal muscles and abdominal muscles are active

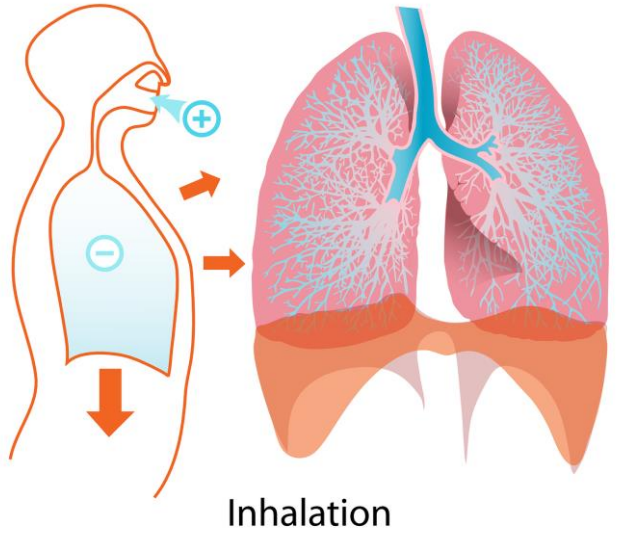


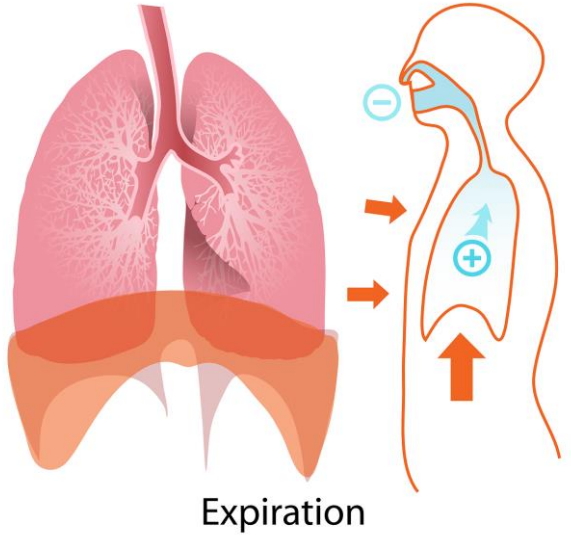


Karhumäki et al. 2017

Respiratory pressures

- Lungs tend to collapse, rib cage to widen → negative pressure inside the pleural sac
  - Connection between air and pleural sac → lung collapses = air breast
- Positive and negative pressure alternates in the bronchi and alveoli

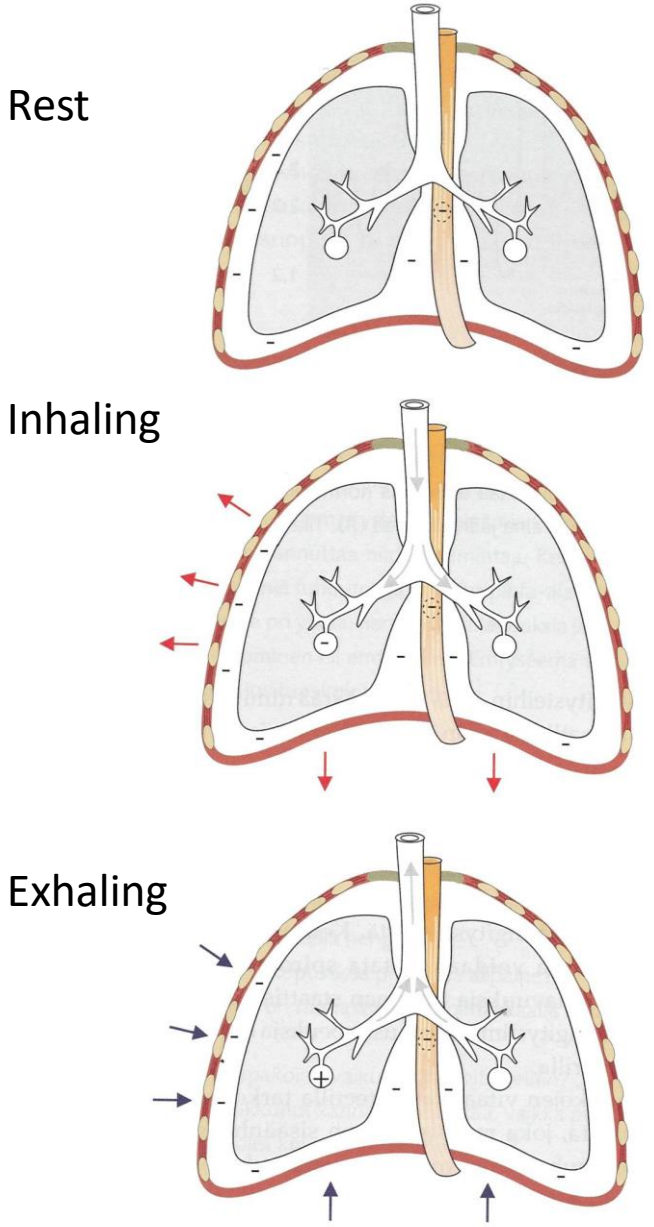




https://courses.lumenlearning.com/boundless-biology/chapter/breathing/

Respiratory volumes

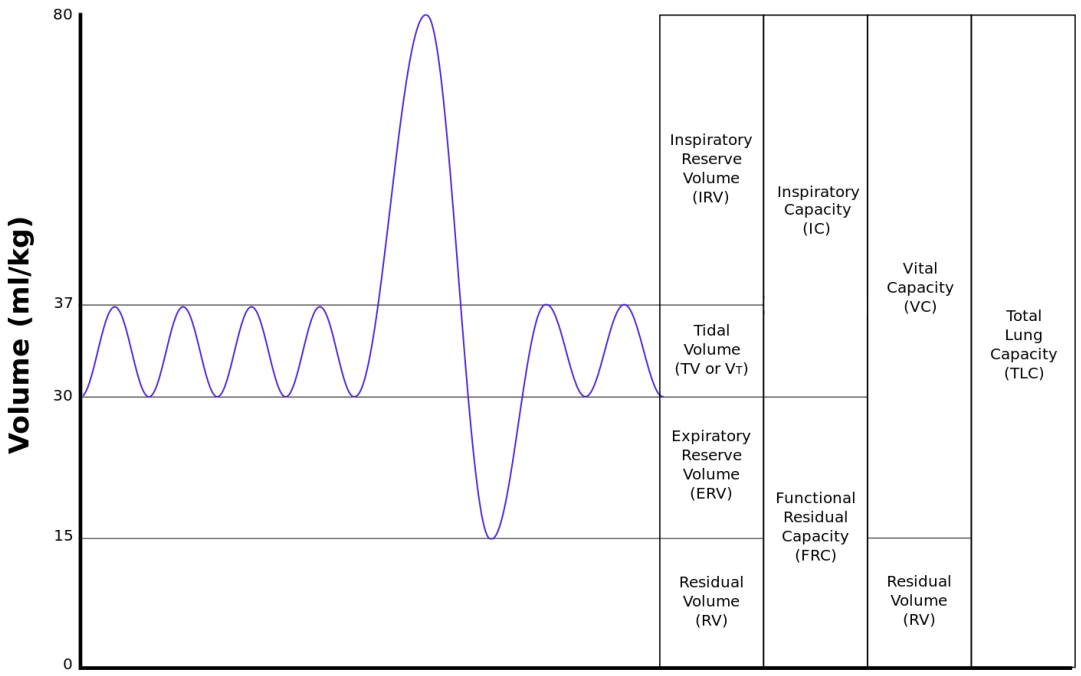
- Normal respiration rate for an adult at rest is 12-15 breaths per minute, more for children
- Appr. 0.5 l of air breathed at each time → minute ventilation appr. 6-7 l
- Muscle exercise increases respiration rate and minute ventilation



Karhumäki et al. 2017

Lung volumes

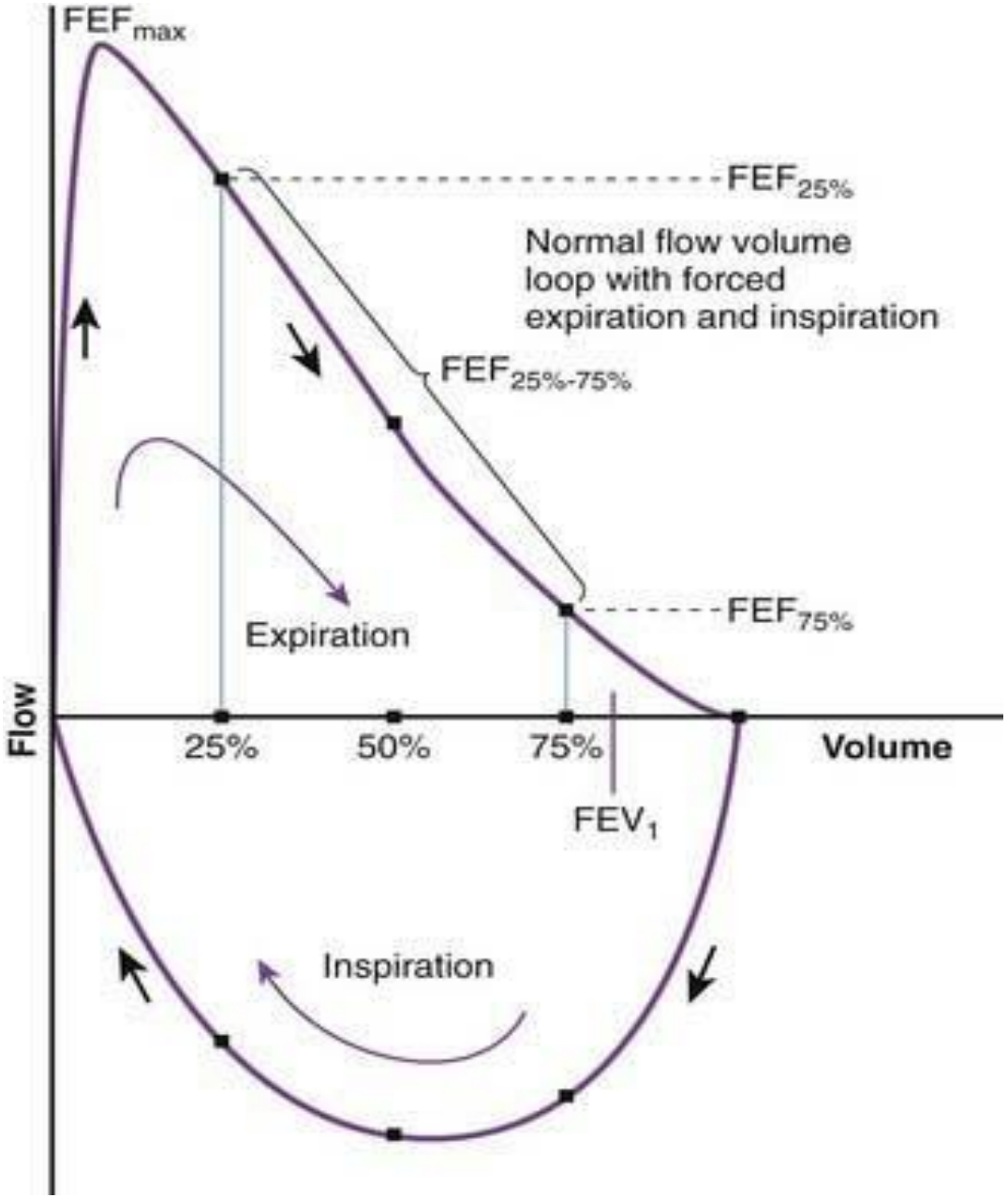
- Ventilation can be studied with spirometry
- After tidal volume (appr. 0.5 l) one can breath in appr. 3 l: Inspiratory reserve volume (IRV)
- Expiratory reserve volume (ERV): the maximal volume of air that can be exhaled (appr. 1 l)
- Residual volume (RV, appr. 1.5 l)



Nhs.uk, Wikipedia

- Vital Capacity = Total amount of air exhaled after maximal inhalation : 0.5 l + 3 l + 1 l = 4.5 l
- Total lung capacity = vital capacity + RV = 6 l
- Dynamic spirometry addresses flow velocities:
  - Forced Expiratory Volume (FEV1): volume of air (l) that one can maximally exhale in 1 s
  - FEV% = FEV1/Vital Capacity
  - PEF = Peak expiratory flow

https://www.youtube.com/watch?v=YwcNbVnHNAo



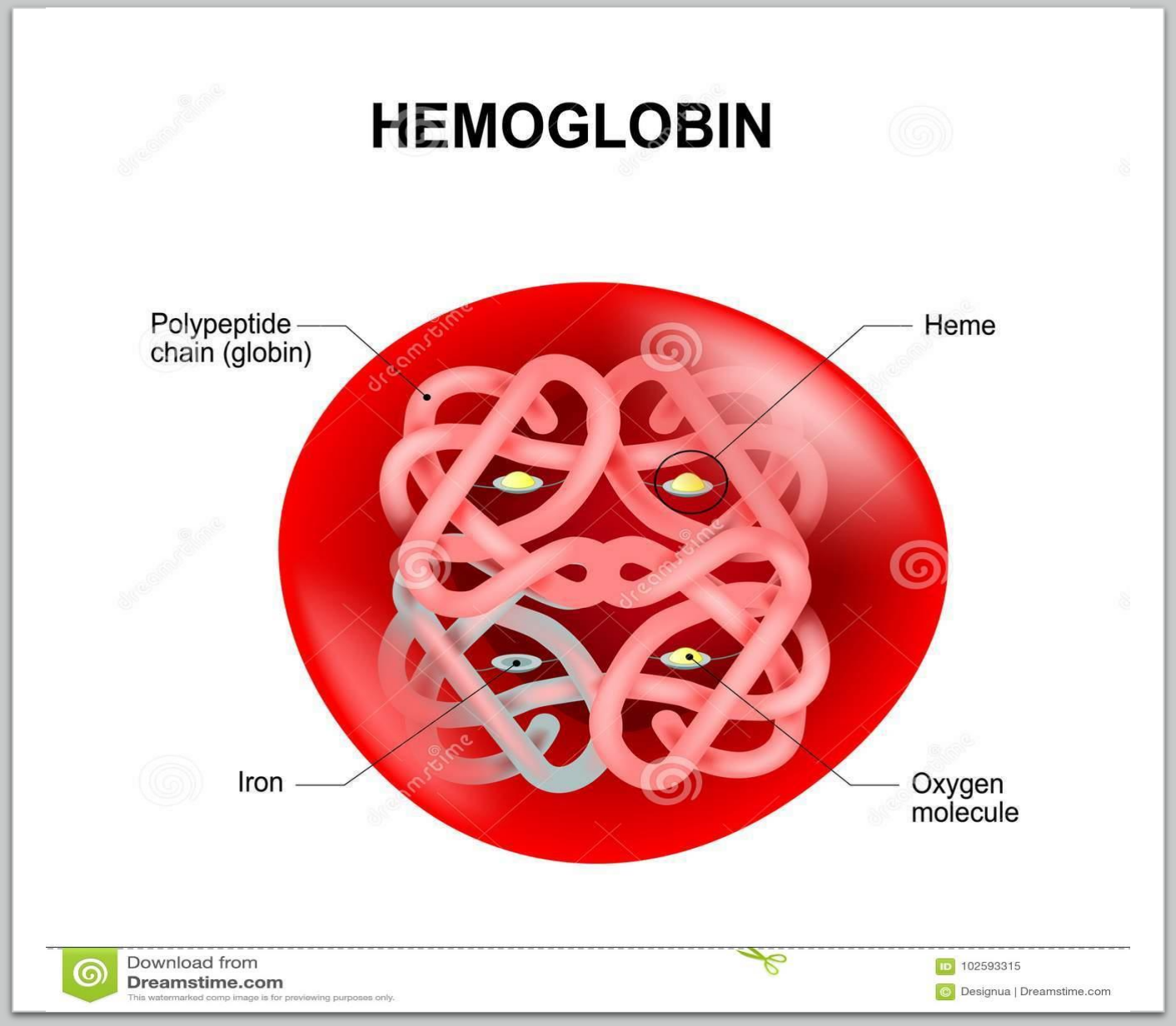
https://clinicalgate.com/respiratory-pathophysiology-and-regulation/

Alveolar ventilation

- Anatomical dead space = appr. 150 ml of the inhaled air which does not enter the alveoles
- Alveolar ventilation: appr. 15 x 350 ml per minute
- Gases move towards their smaller partial pressure
- 1/7 alveolar air changes at each breath
- 250 ml/min of oxygen is transferred to circulation, and 200 ml/min of carbon dioxide to air
- In alveoles, air and circulation are separated by alveolar fluid, alveolar epithelium, capillary endothelium, but the distance is appr. 0.2-1 um and gas exchange happens rapidly

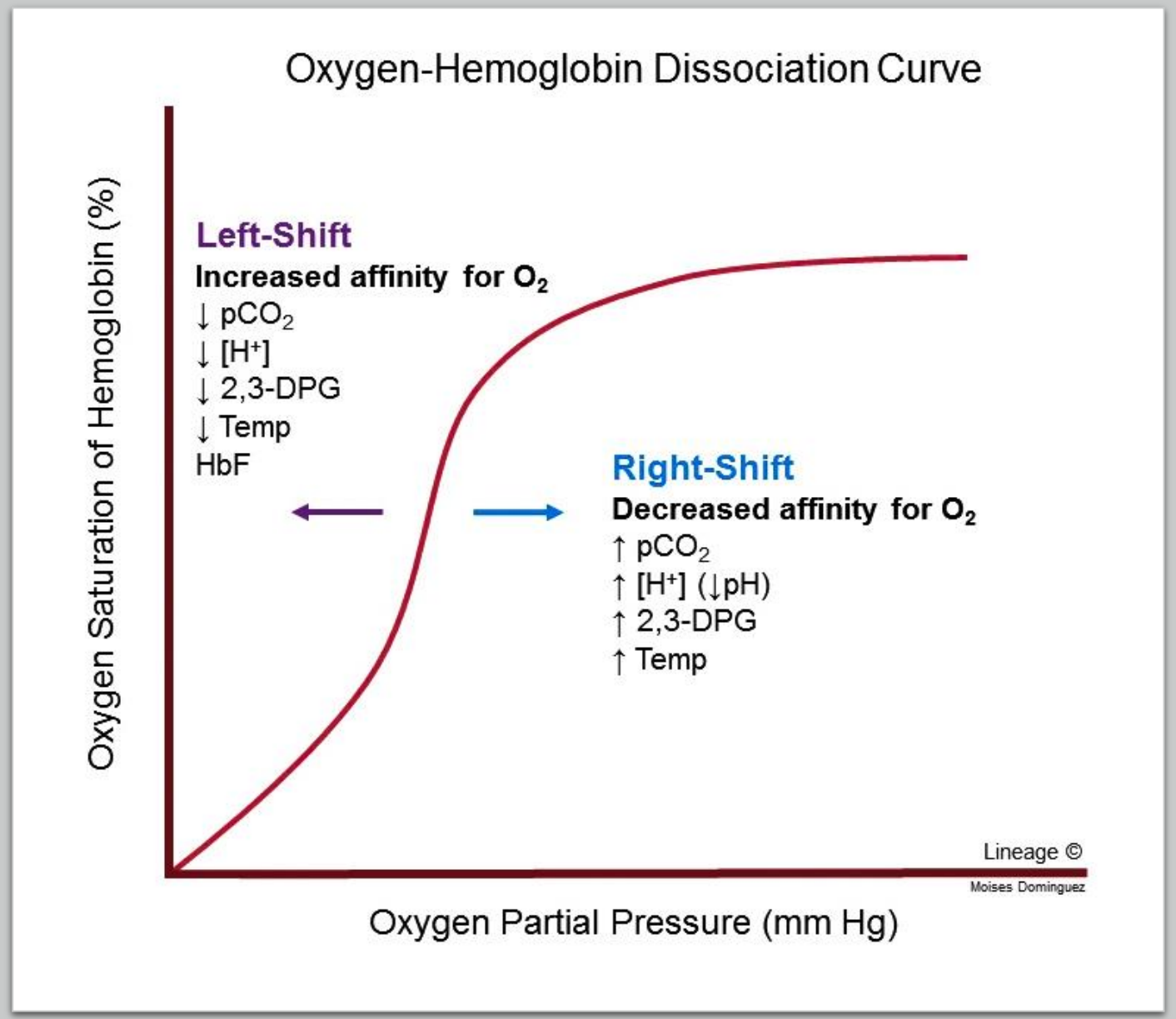
Oxygen transportation in blood

- 99% of oxygen binds to hemoglobin
- Hemoglobin consists of 4 peptide chains, each with an organic compound known as a porphyrin to which an iron atom is attached
- Oxygen binds to iron
- From the capillaries, oxygen moves towards lower partial pressure in interstitial fluids and cells



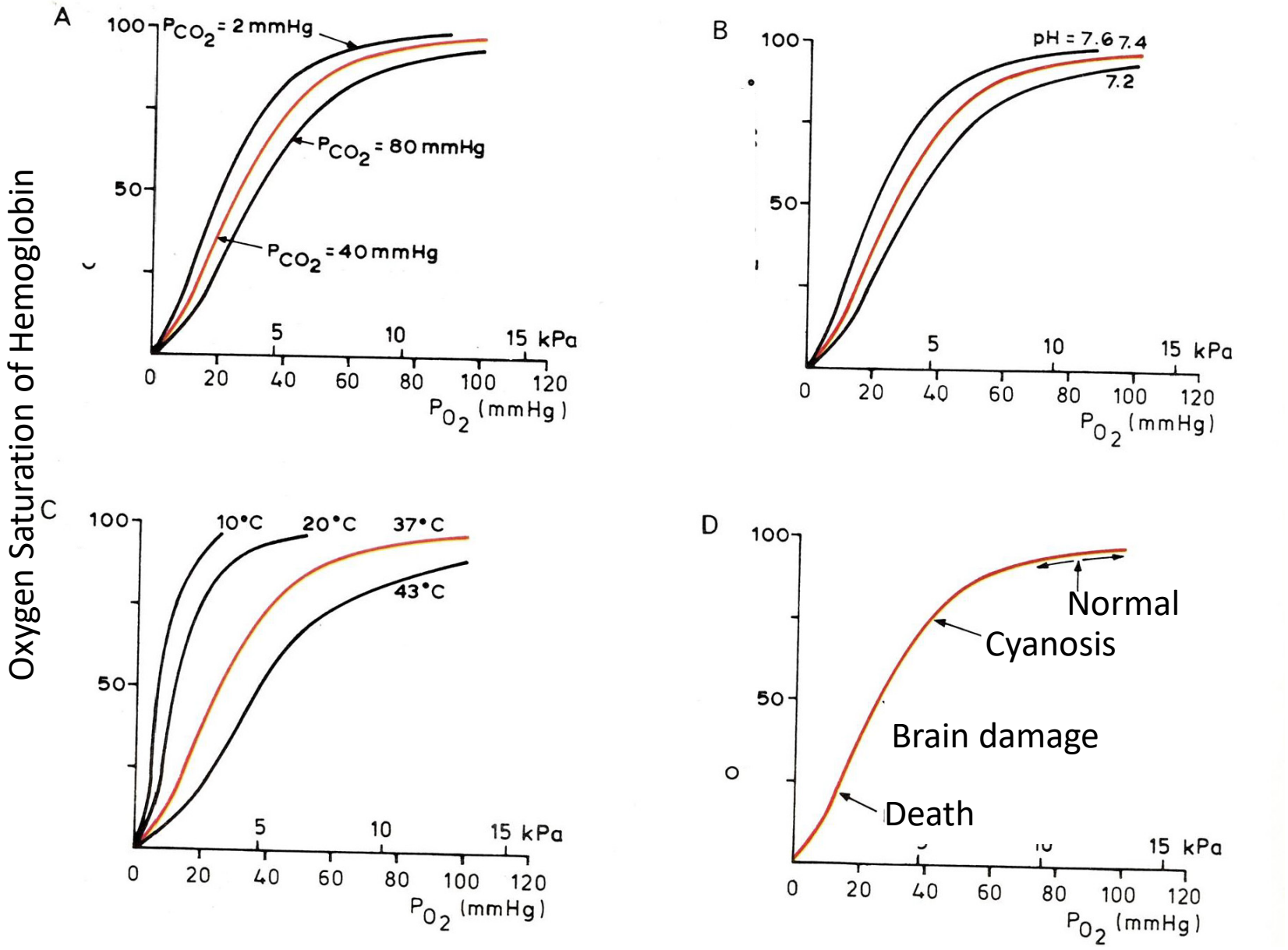
Oxygen transportation in blood

- In the arteries within the great circulation, the oxygen saturation of hemoglobin is appr. 97%
- In veins, the oxygen saturation is appr. 75%
- In the case of increased oxygen consumption, oxygen saturation of hemoglobin goes down rapidly



https://step1.medbullets.com/respiratory/117014/oxygen-hemoglobin-dissociation-curve

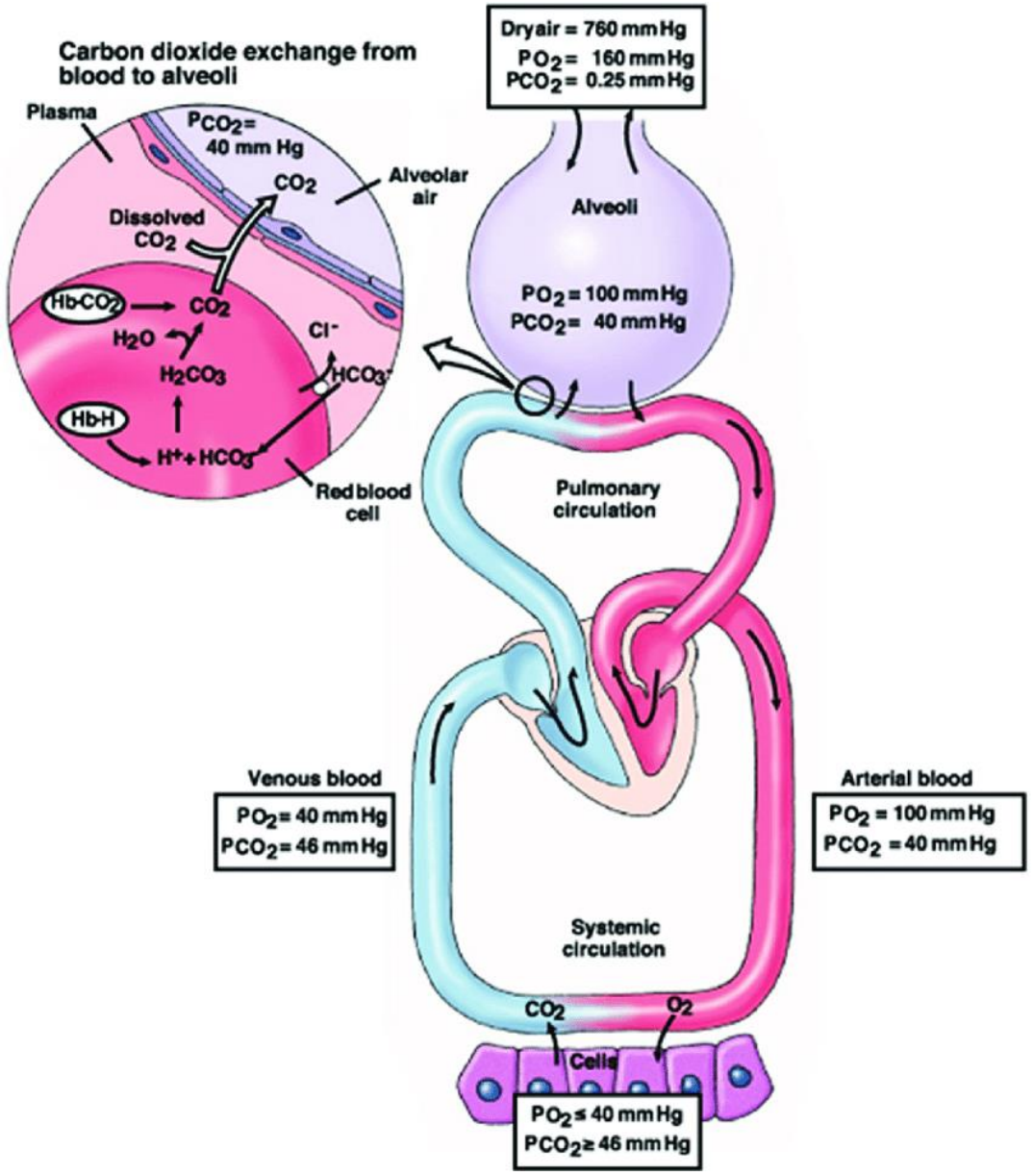
When oxygen consumption increases in tissue, e.g., due to increased CO_2 pressure, lowered pH, or increased temperature, oxygen saturation of hemoglobin decreases rapidly



Transfer of CO_2 in blood

- CO_2 diffuses from cells via interstitial fluid to blood, and it is transported in different forms to the lungs

- 85% reacts with water → H_2CO_3 which dissociates into H^+ and HCO_3
  - 10% binds to hemoglobin → carbamino-hemoglobin ($HbCO_2$)



Godoy et al. 2017

Central control of respiration

- Breathing center in medulla regulates O_2 and CO_2 pressures
- Breathing rhythm is regulated by receptors in bronchi
- *Humoral regulation*: O_2 and especially CO_2 concentrations of blood and interstitial fluids (chemoreceptors in aorta and medulla)
- *Neural regulation* usually more important: information from the motor cortex, muscles, body temperature

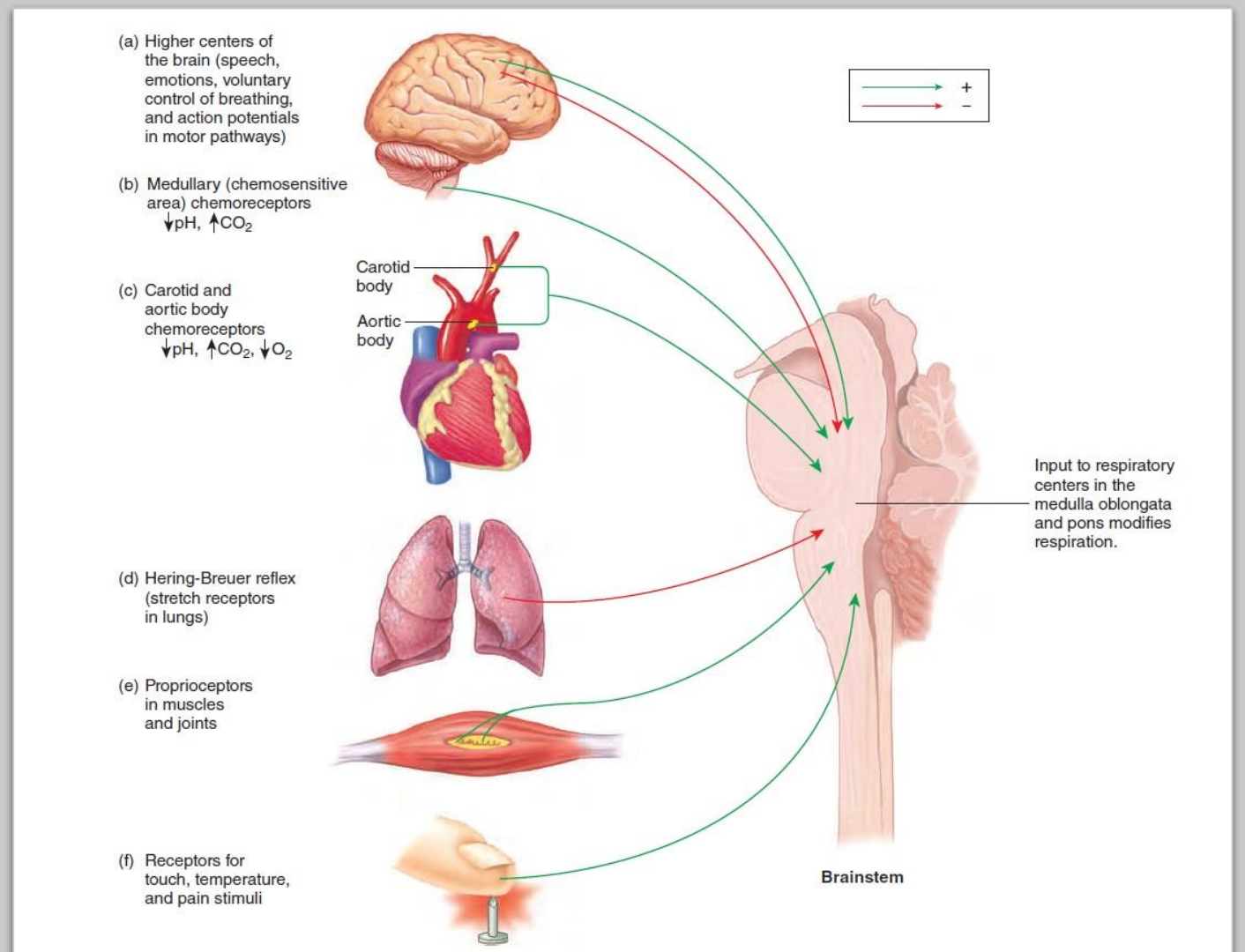


Figure 15.16 Nervous and Chemical Mechanisms of Breathing

Several regulatory mechanisms affect the rate and depth of breathing. A plus sign indicates that the mechanism increases breathing and a minus sign indicates that it results in a decrease in breathing.

https://www.brainkart.com/article/Nervous-and-Chemical-Control-of-Breathing_21927/