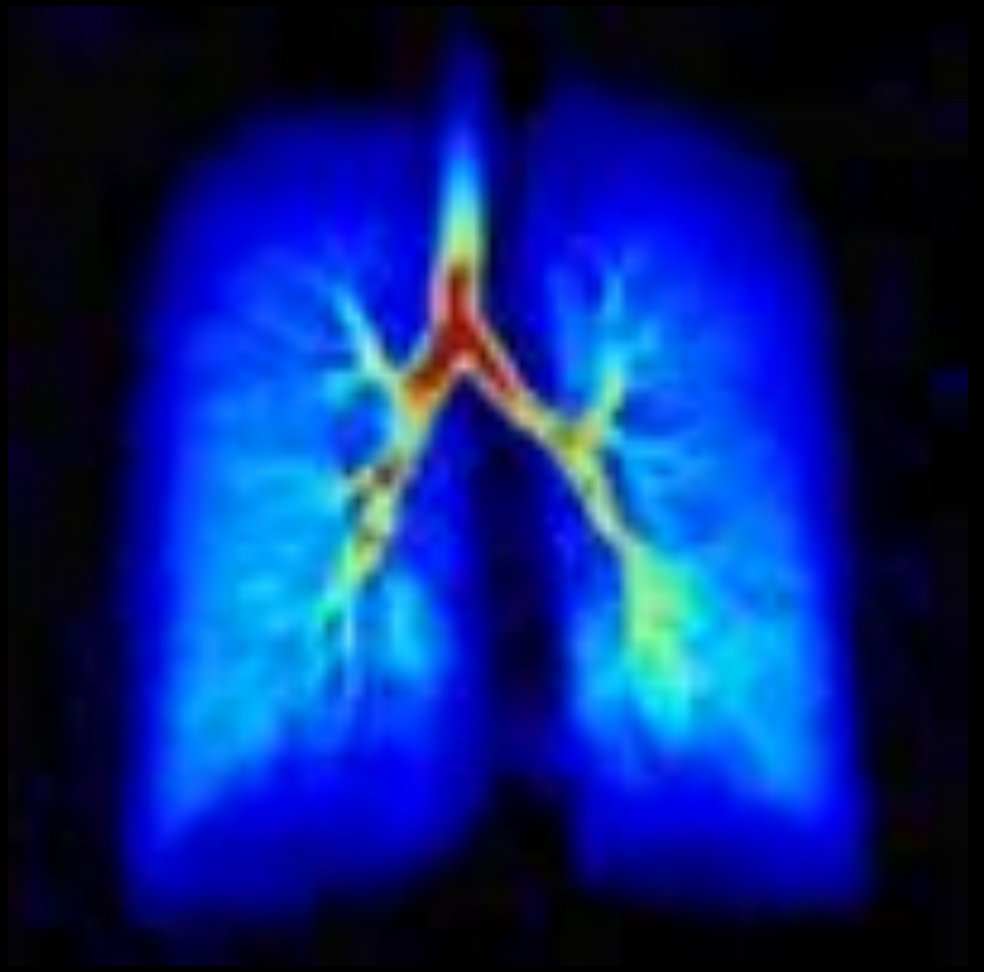
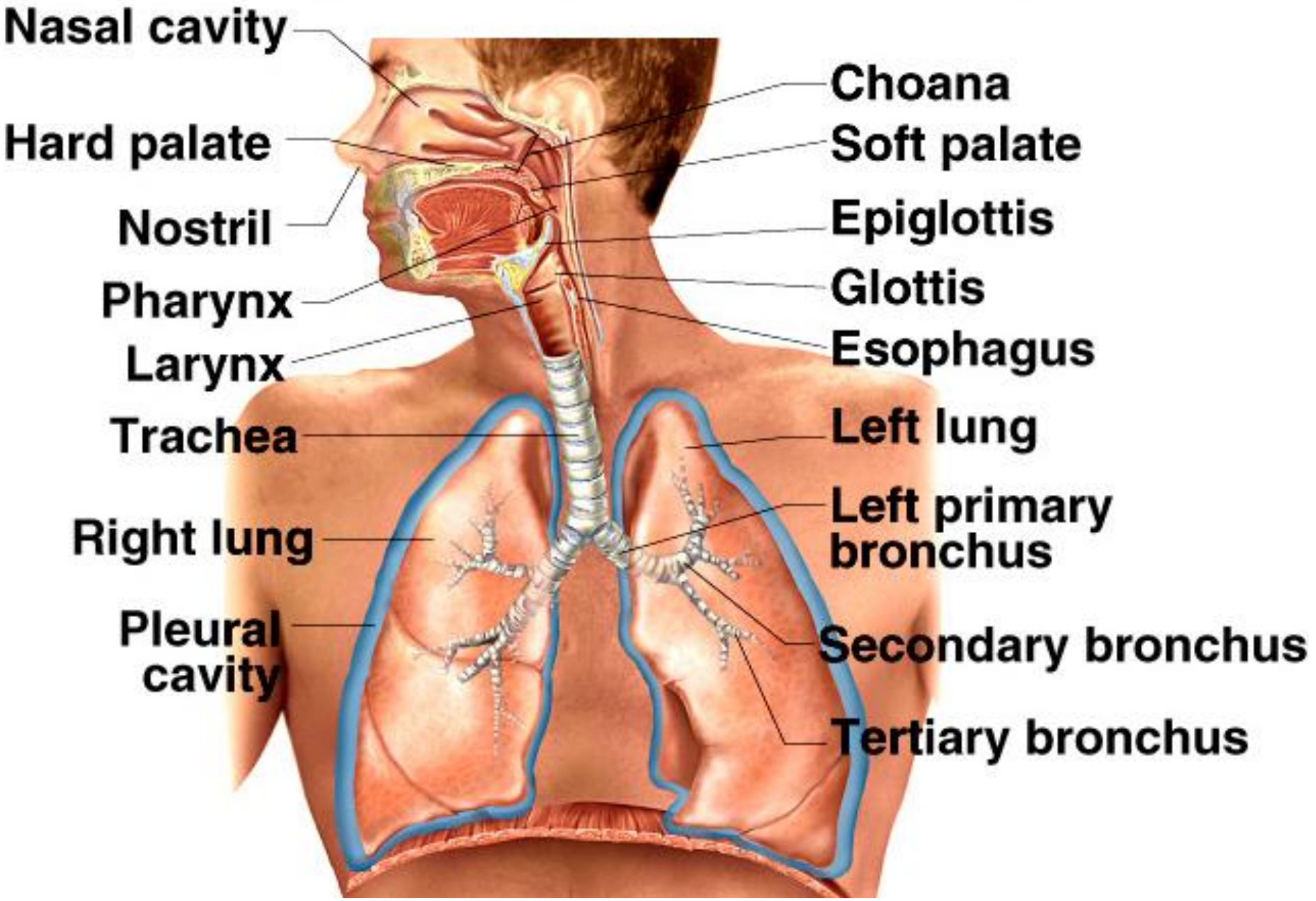
Respiratory System

Chapter 22

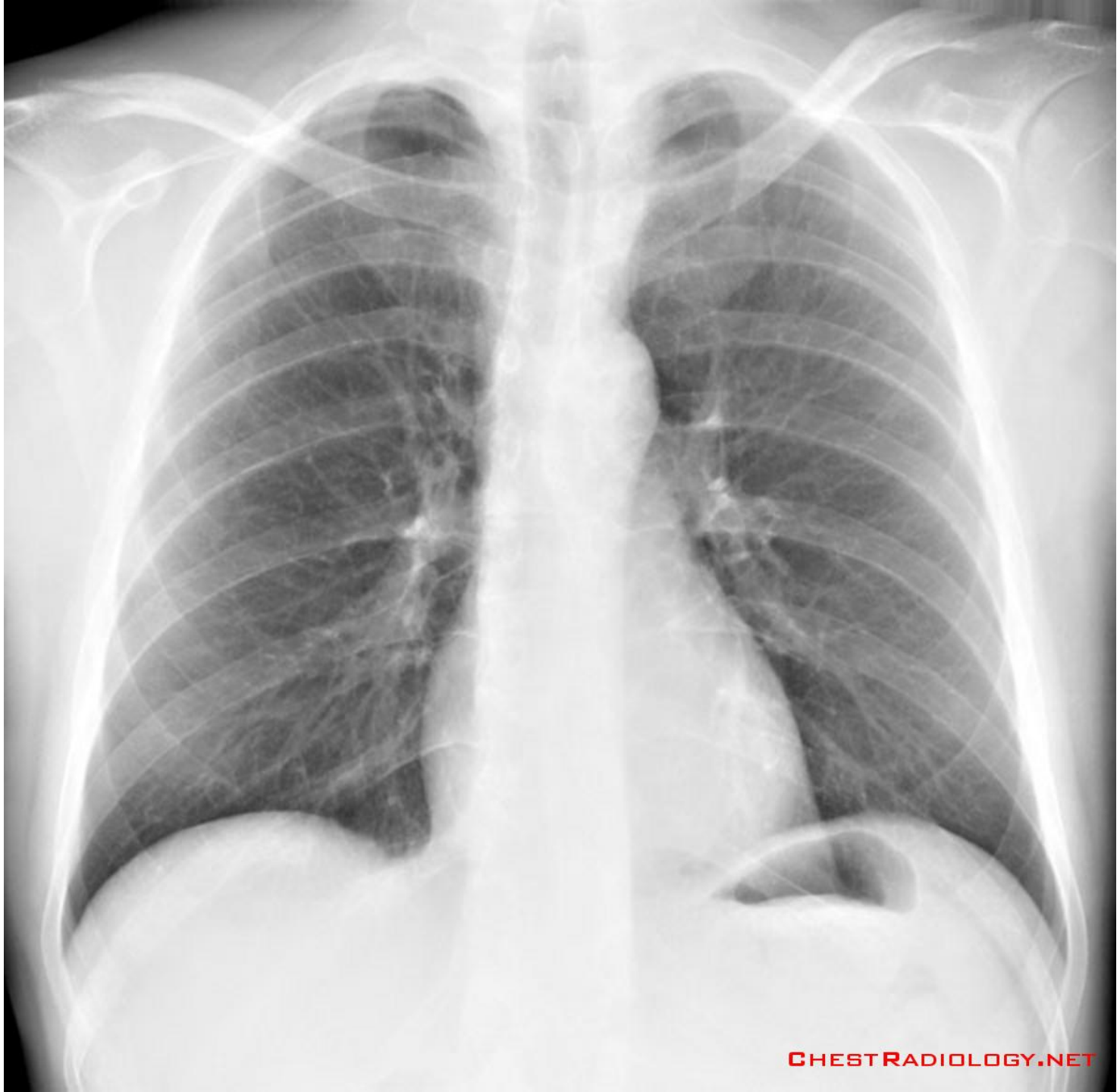
- Anatomy of the Respiratory System
- Mechanics of Ventilation
- Neural control of Ventilation
- Gas Exchange and Transport



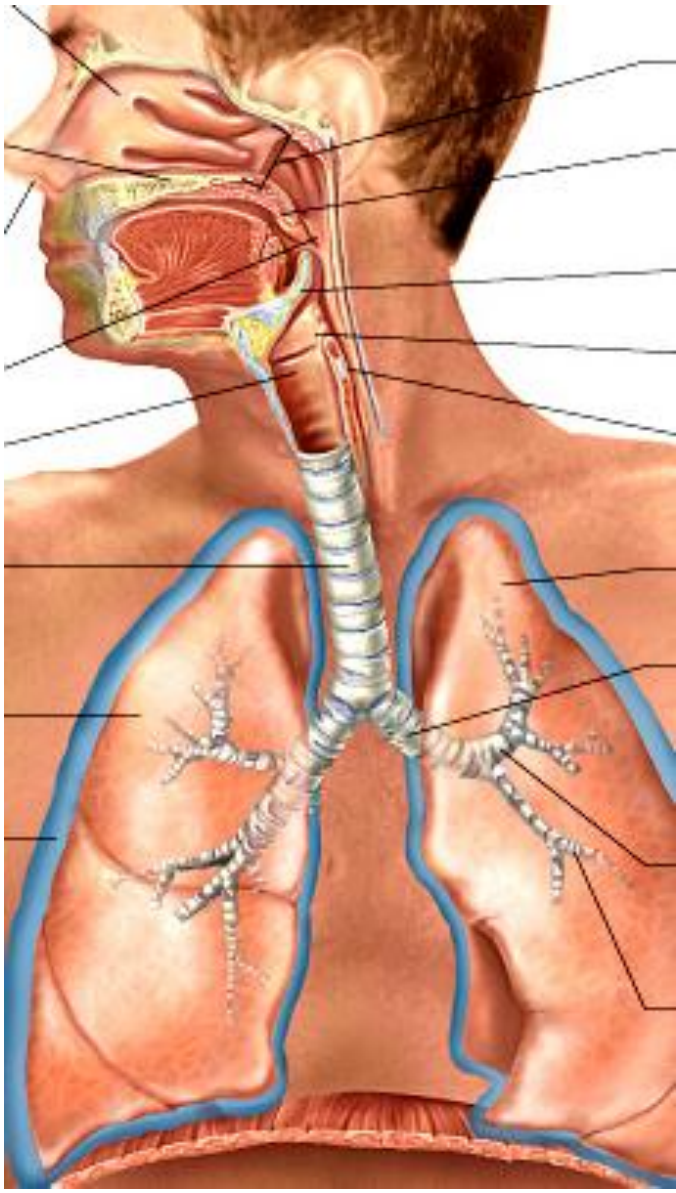
Organs of the Respiratory System



Normal Frontal Chest X-ray



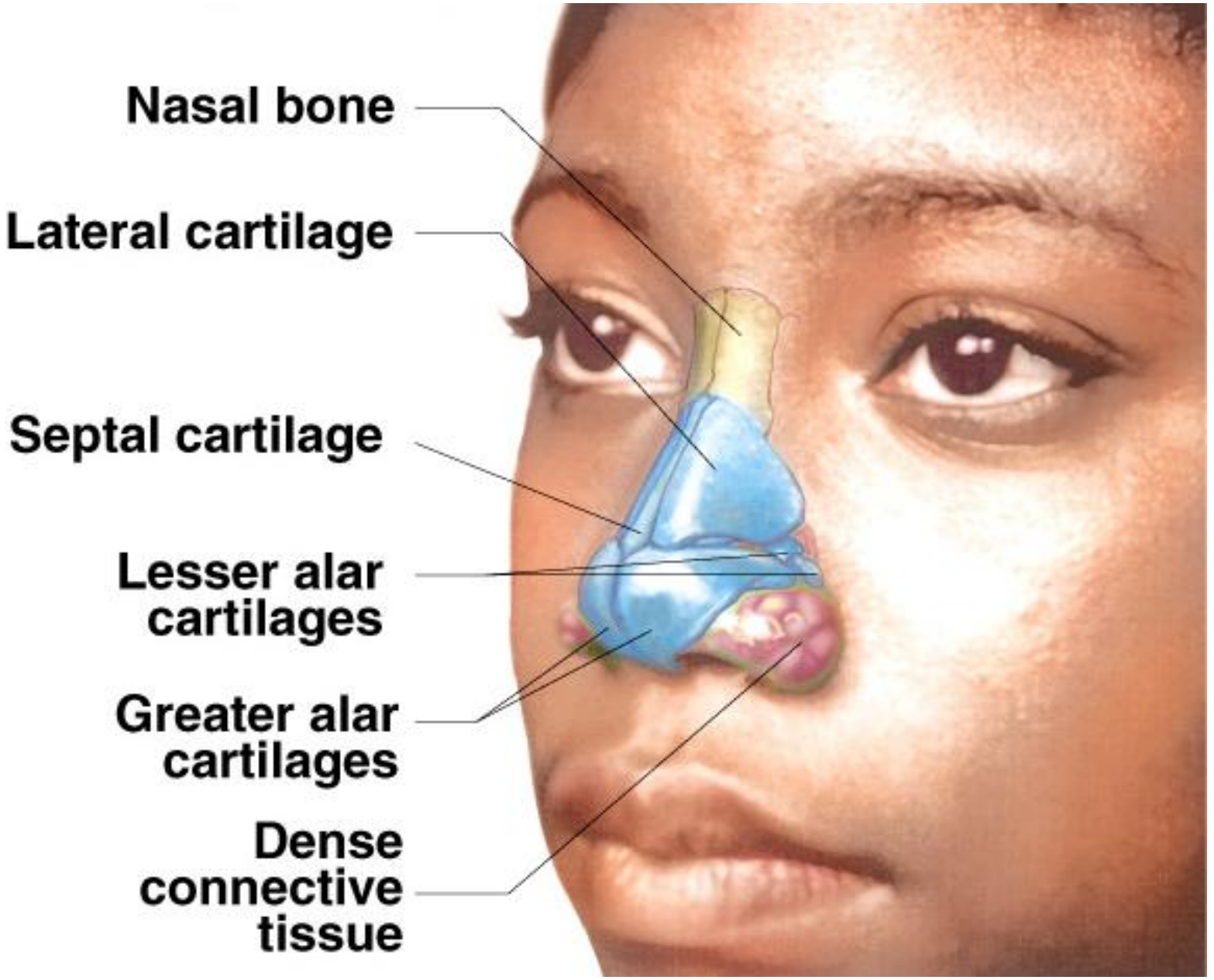
- Airflow
  - nasal/oral cavity ←→ trachea ←→ bronchi ←→ bronchioles ←→ alveoli
- Conducting Part
  - are passages for airflow
- Respiratory Part
  - alveoli are the only place where significant gas-exchange takes place
- Upper respiratory tract
  - organs in head and neck including the nose to the larynx
- Lower respiratory tract
  - organs of the thorax: trachea to alveoli in the lungs



Nose and Nasal Cavity

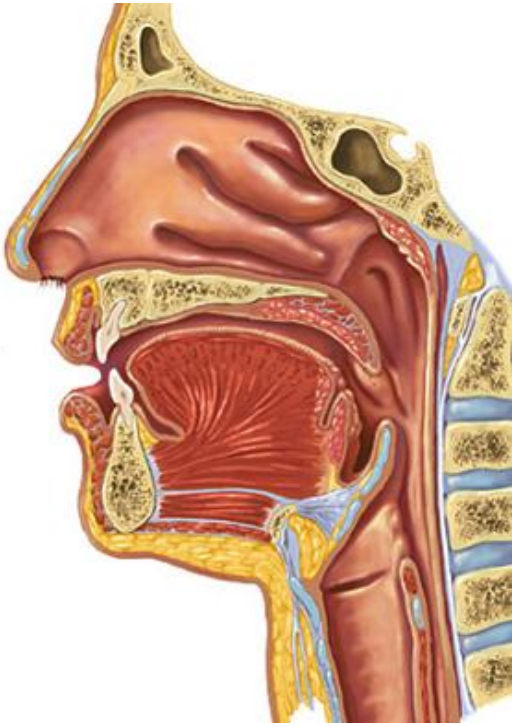
- Functions
  - warms, cleanses, humidifies inhaled air
  - detects odors
  - resonating chamber that affects tone and amplifies the voice
- Bony and Cartilaginous parts of the Nose
  - Nasal Bones of the skull
  - Nasal Cartilages are composed of hyaline cartilage which is less flexible than the elastic cartilage of external ear or epiglottis
  - Ala Nasi: flared portion around external nares (nostrils) are composed of dense connective tissue.

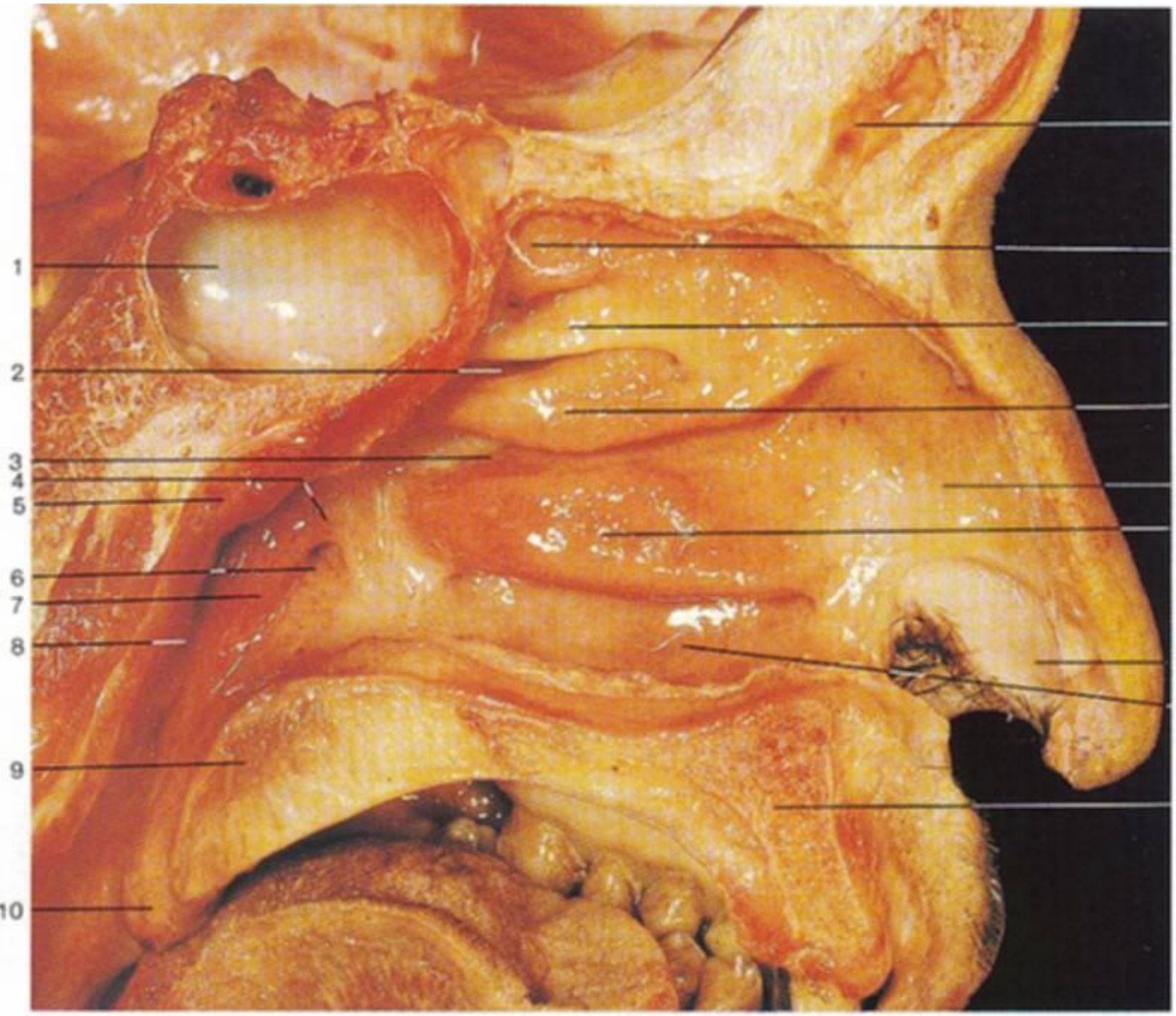
Anatomy of Nasal Region



Nasal Cavity - Conchae and Meatuses

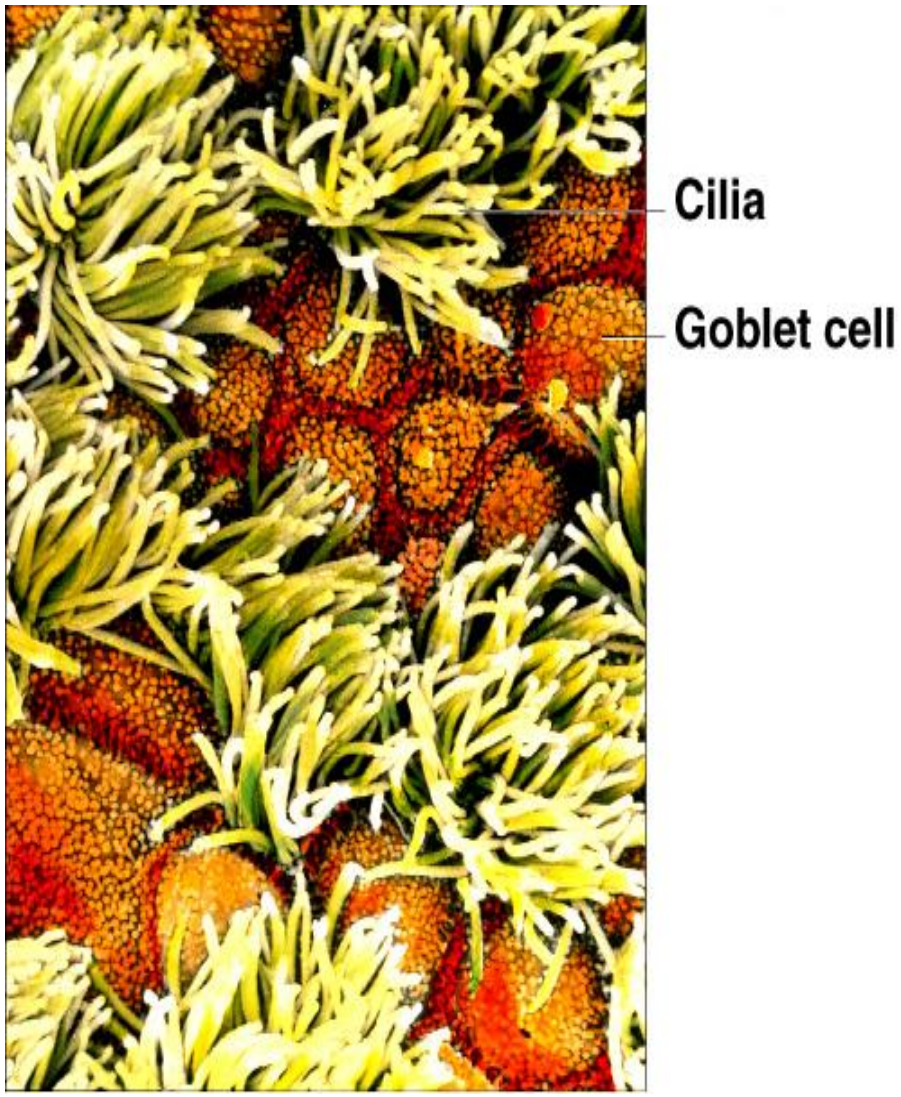
- Superior, Middle, Inferior Nasal Conchae
  - 3 folds of mucous membrane cover the **nasal concha (turbinate bones)**
  - mucus membrane is a ciliated pseudostratified epithelium with goblet cells
  - mucous traps inhaled particles and cilia sweeps it towards the pharynx
  - lysozyme released with mucus destroys many bacteria
  - submucosa over each concha contains a venous plexus called a **swell body** that rhythmically engorges with blood and shifts flow of air from one side to the other once or twice an hour to prevent drying
- Meatuses
  - air passage between the conchae
  - narrowness and turbulence ensures air contacts mucous membranes
    - turbulence and large surface area facilitate cleaning and adjusting the temperature and humidity of the incoming air.

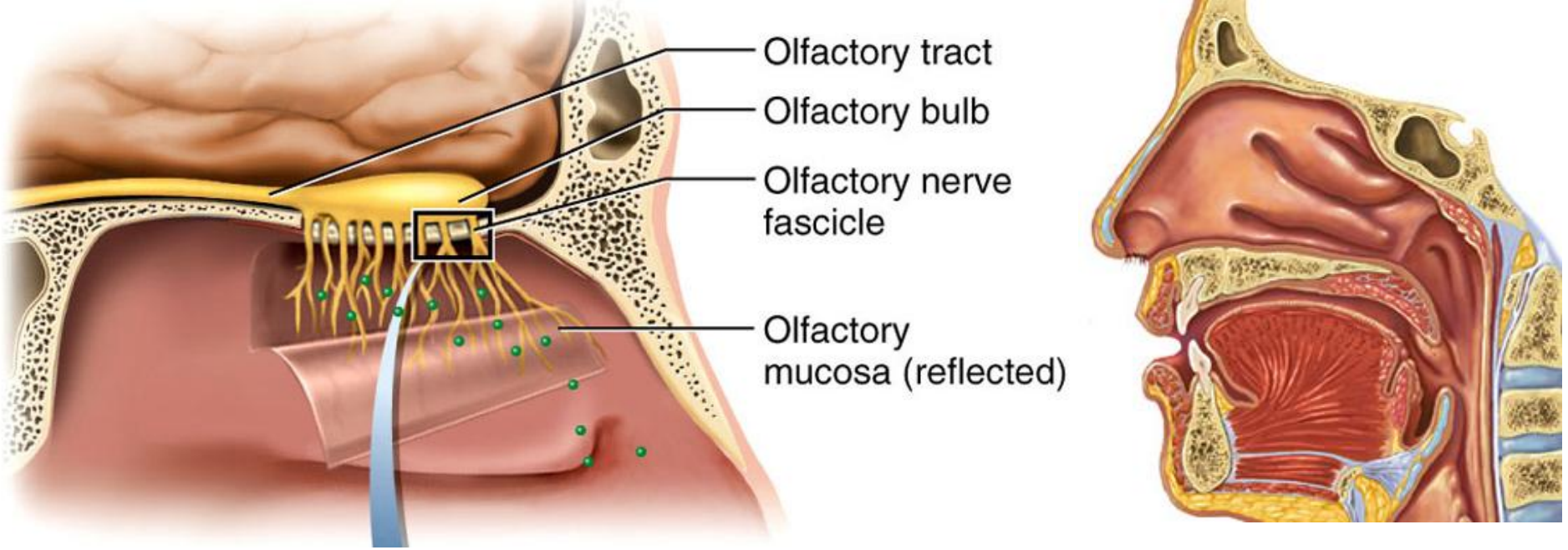



1
2
3
4
5
6
7
8
9
10
11
12
superior nasal concha
middle nasal concha
33
inferior nasal concha
16
17
18

Nasal Cavity Mucosa

- Ciliated Pseudostratified Epithelium with Goblet Cells
  - moves debris-laden mucus into pharynx to be swallowed
  - Spontaneous Epistaxis (nosebleed) can occur if this epithelium dries out or in rare cases it can be a sign of hypertension.



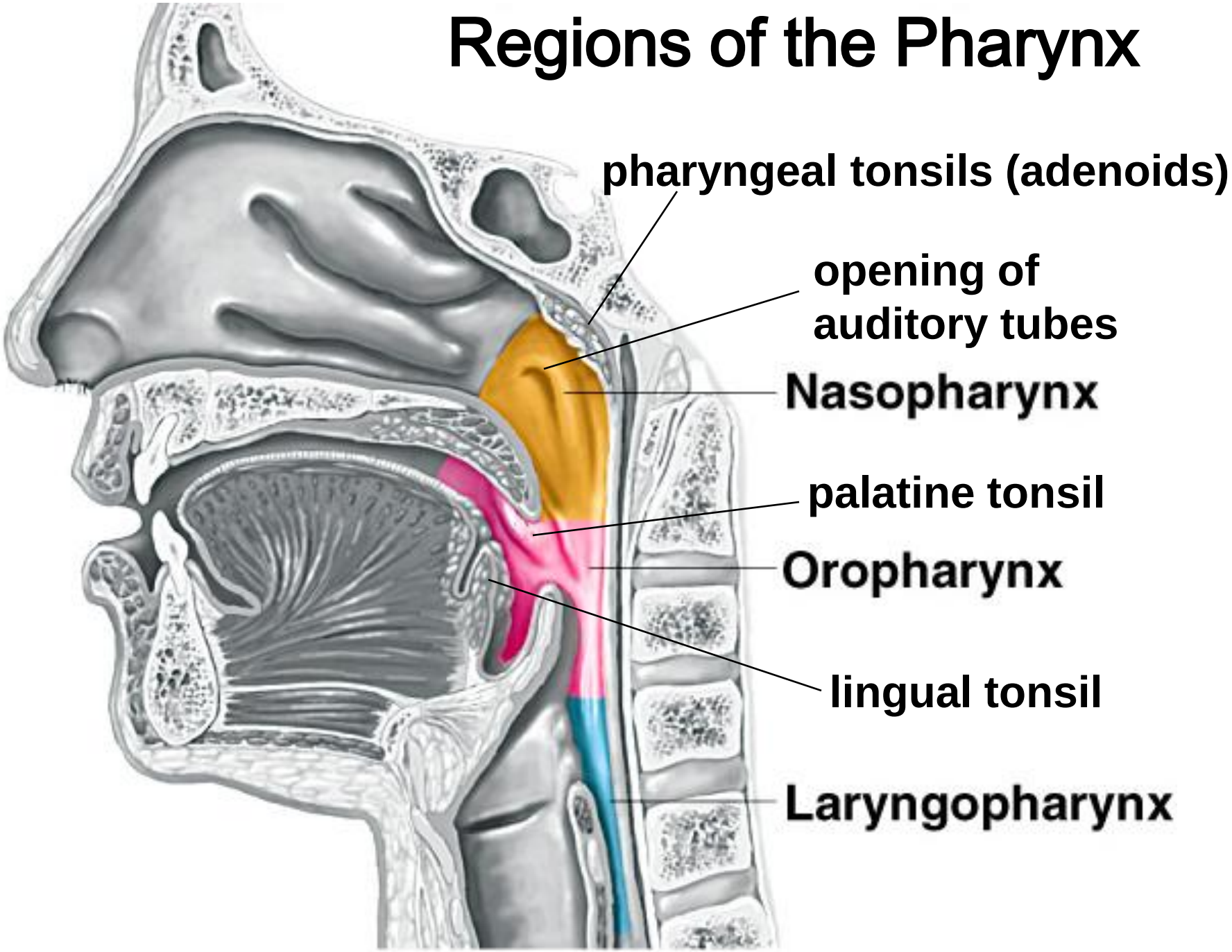


- Olfactory receptor neurons extend dendrites into the nasal mucus and extend axons up through the holes in the cribriform plate of ethmoid bone where they synapse with olfactory bulb neurons of Cranial Nerve I.
- Olfactory receptor neurons are the only neurons in the body directly exposed to the external environment.
- Unlike other neurons, the olfactory receptor neurons are replaced about every 60 days from basal cells that continually divide and differentiate into new olfactory receptor neurons.

Pharynx (FAIR-inks)

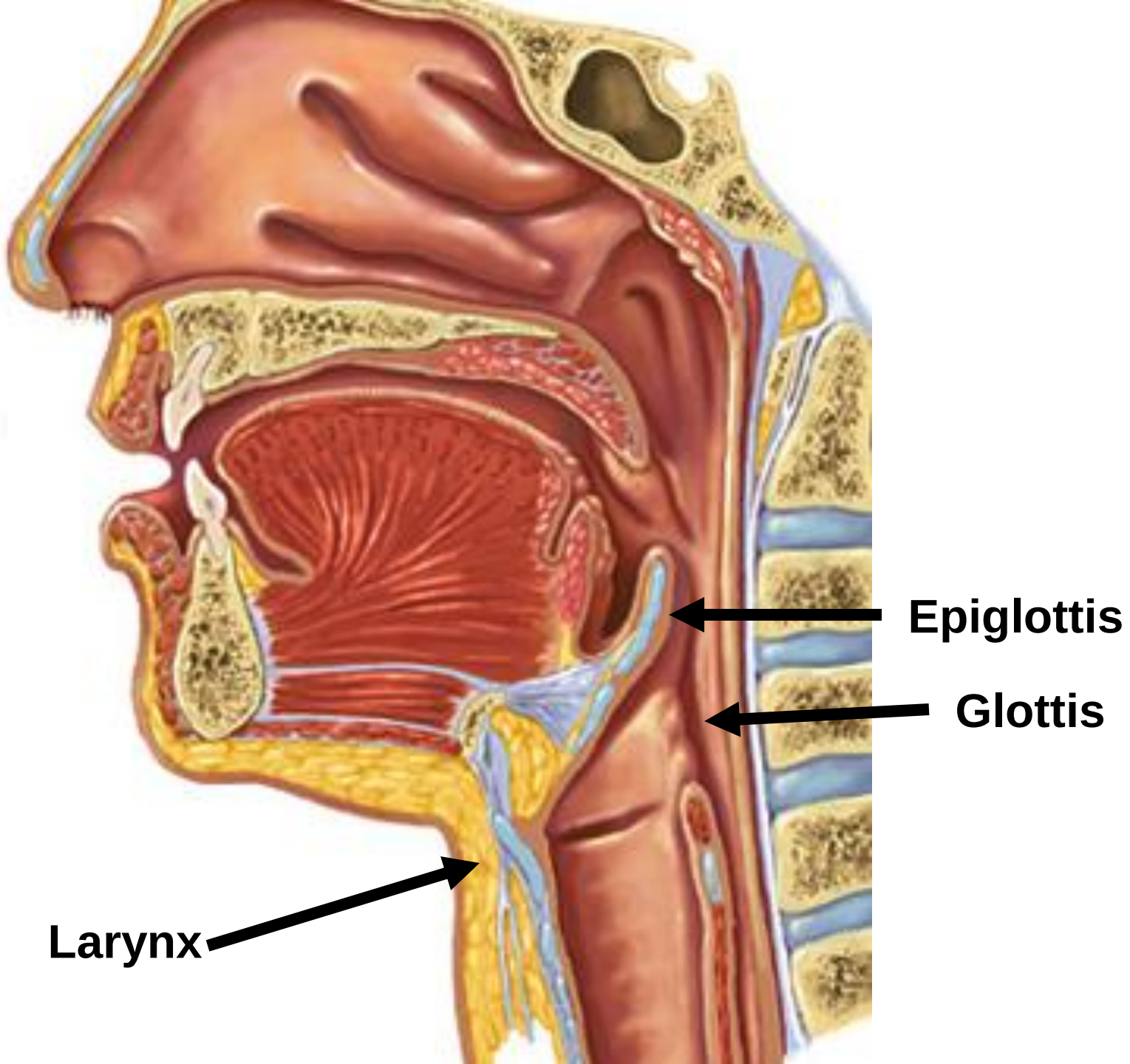
- Nasopharynx *(ciliated pseudostratified epithelium)*
  - contains the openings of the auditory tubes (Eustachian tubes) that equalize pressure between the atmosphere and the middle ear
  - contains pharyngeal tonsils (adenoids)
- Oropharynx *(stratified squamous epithelium)*
  - space between soft palate and root of tongue
  - contains palatine tonsils and lingual tonsil
- Laryngopharynx *(stratified squamous epithelium)*
  - posterior to larynx

Regions of the Pharynx

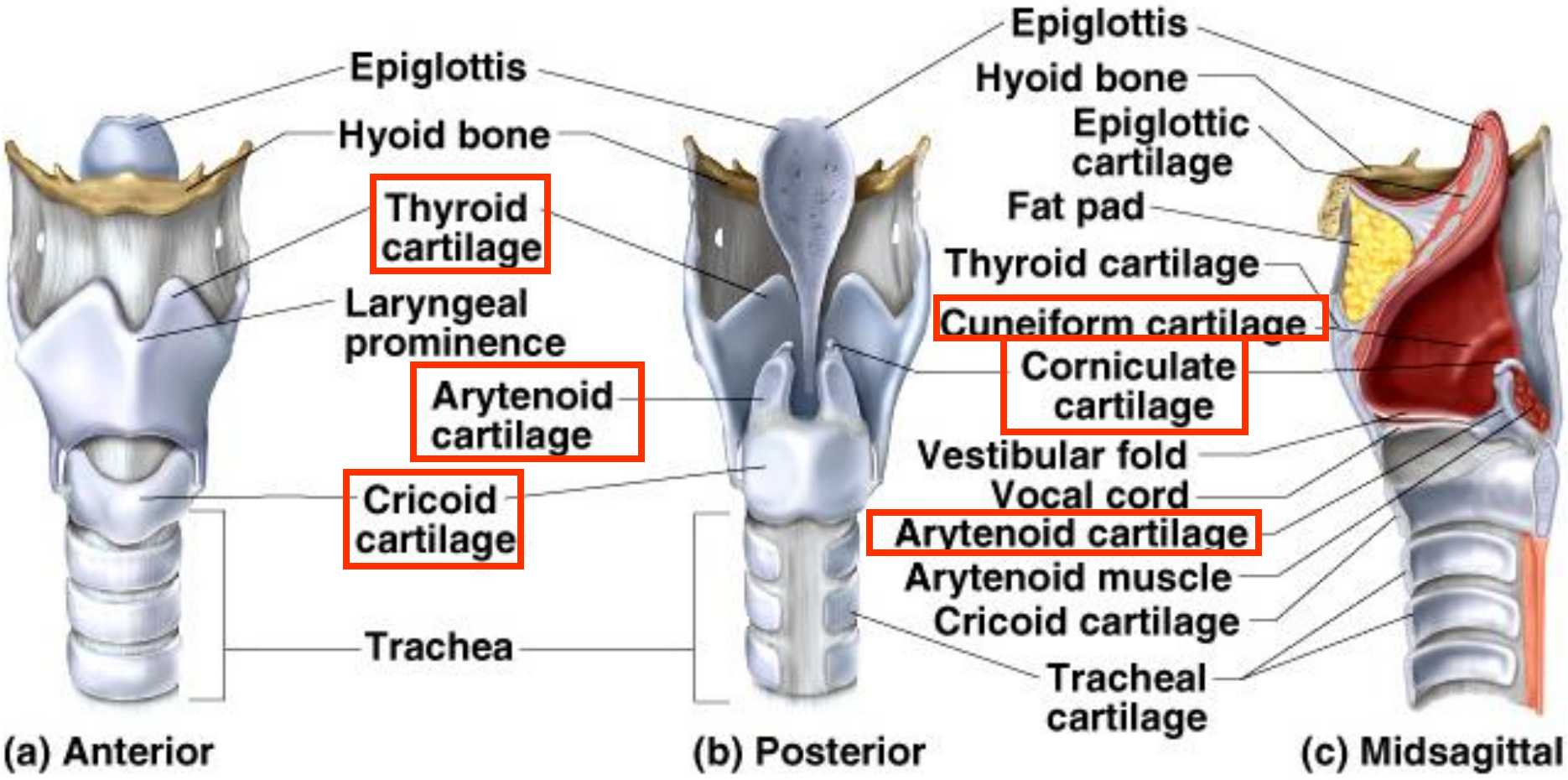


Larynx (LAIR-inks)

- Glottis is the superior opening of larynx
- Epiglottis
  - flap of tissue that guards glottis, directs food and liquid into the esophagus
  - core of elastic cartilage makes it very flexible
- Laryngeal Cartilages are composed of hyaline cartilage
  - Thyroid Cartilage - largest, has laryngeal prominence
  - Cricoid Cartilage – ring between thyroid cartilage and the trachea
  - Cartilages associated with vocal cords:
    - Arytenoid cartilages (2)
    - Corniculate cartilages (2)
    - Cuneiform cartilages (2)
- Shape and size of the larynx affects tone of voice


Epiglottis
Glottis
Larynx

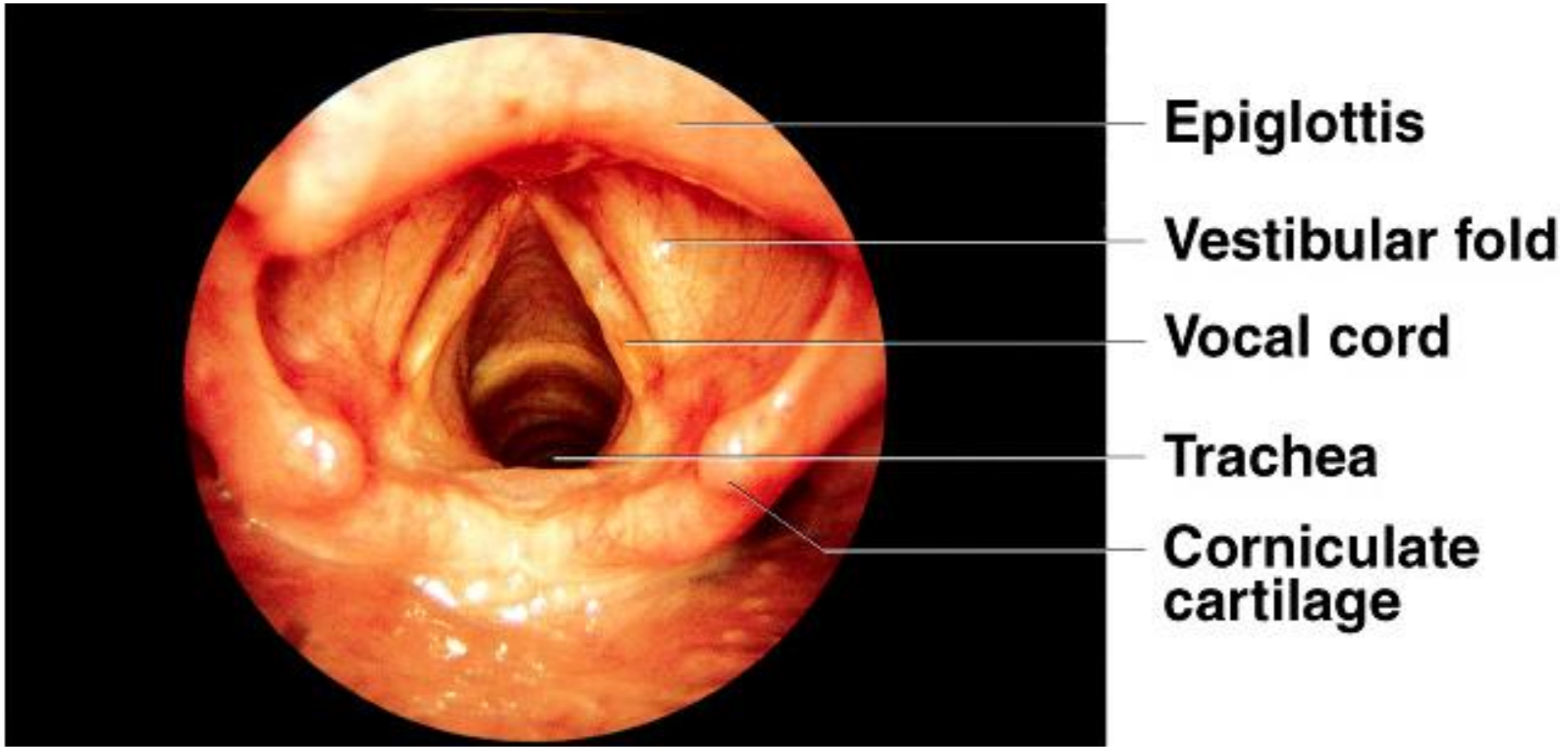
Cartilages of the Larynx



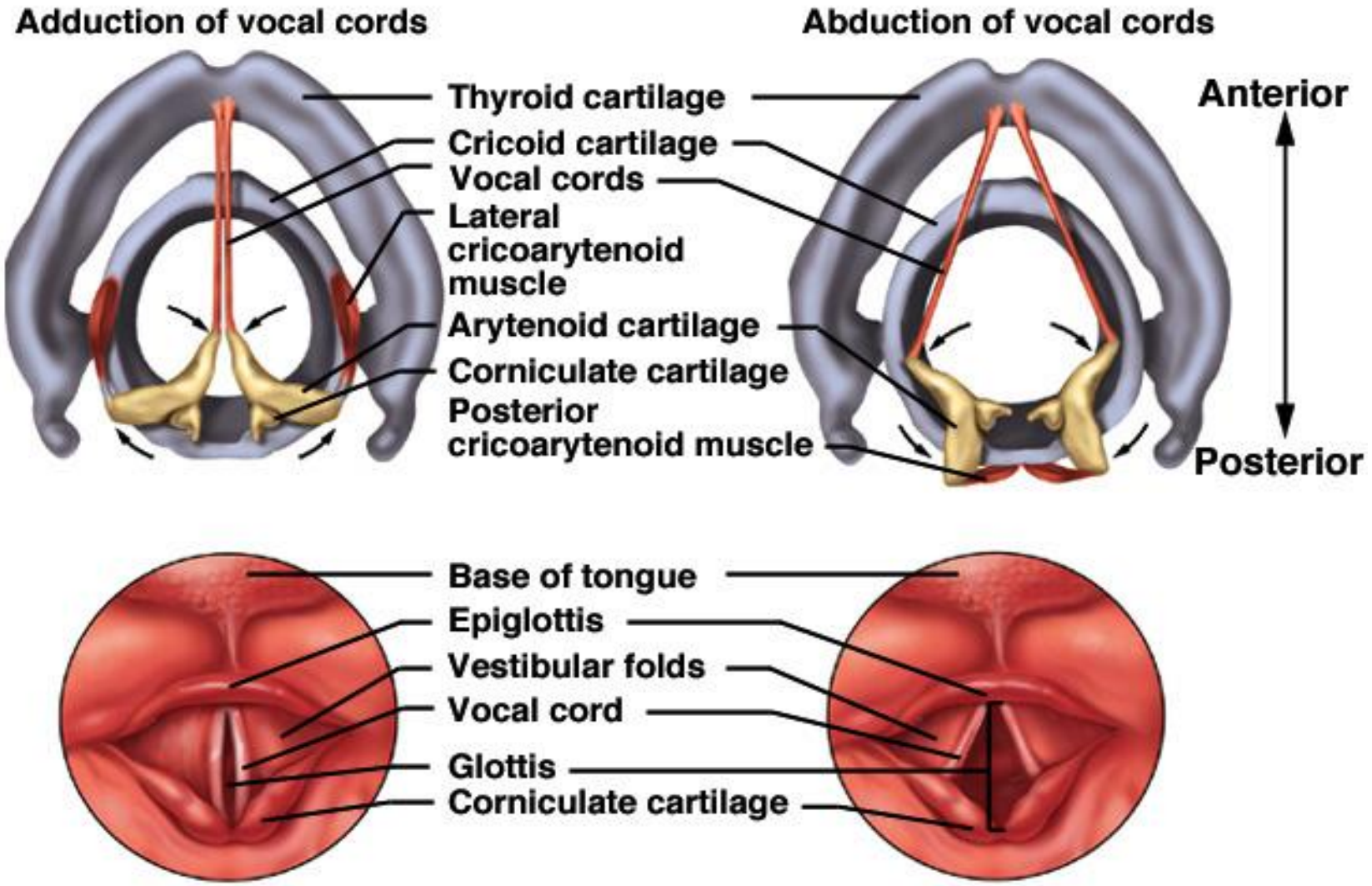
Vocal Cords

- False Vocal Cords (Vestibular Folds) are superior to the vocal cords and normally close the glottis during swallowing.
- Vocal Cords: cords of connective tissue under the laryngeal mucosa that run from the tips of the arytenoid cartilages to the thyroid cartilage.
  - Air moving past the vocal cords causes them to vibrate and produce sound
  - Velocity of the air and tension on the cords varies the pitch
- Intrinsic muscles - rotate cartilages that tighten vocal cords for high pitch sound or loosens vocal cords for low pitch sound
- Extrinsic muscles - connect larynx to hyoid bone, elevate larynx during swallowing

Laryngoscopic View of Larynx



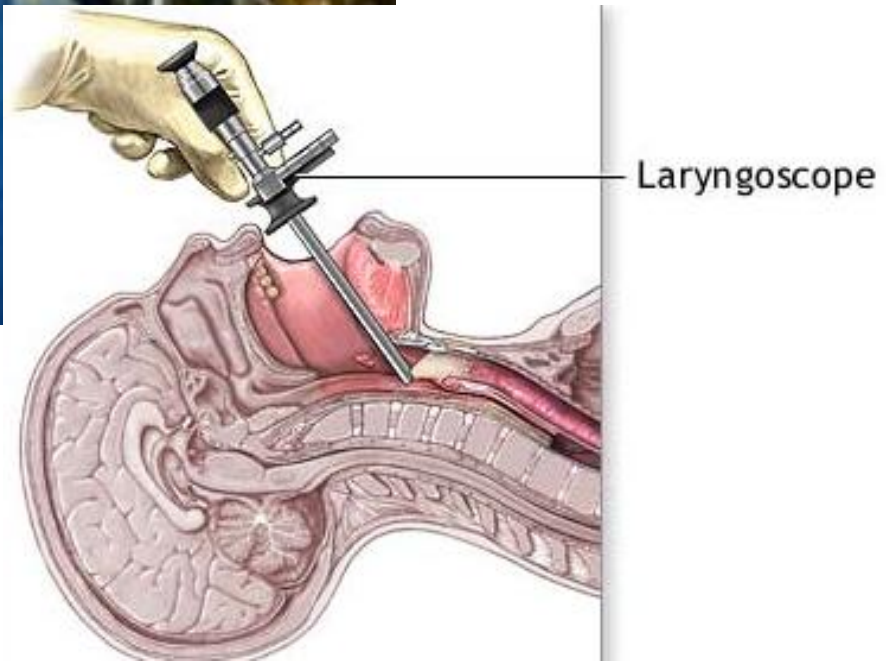
Action of Vocal Cords



Adduction stretches vocal cords and produces high pitch sound

Abduction moves vocal cords apart and produces a lower pitch

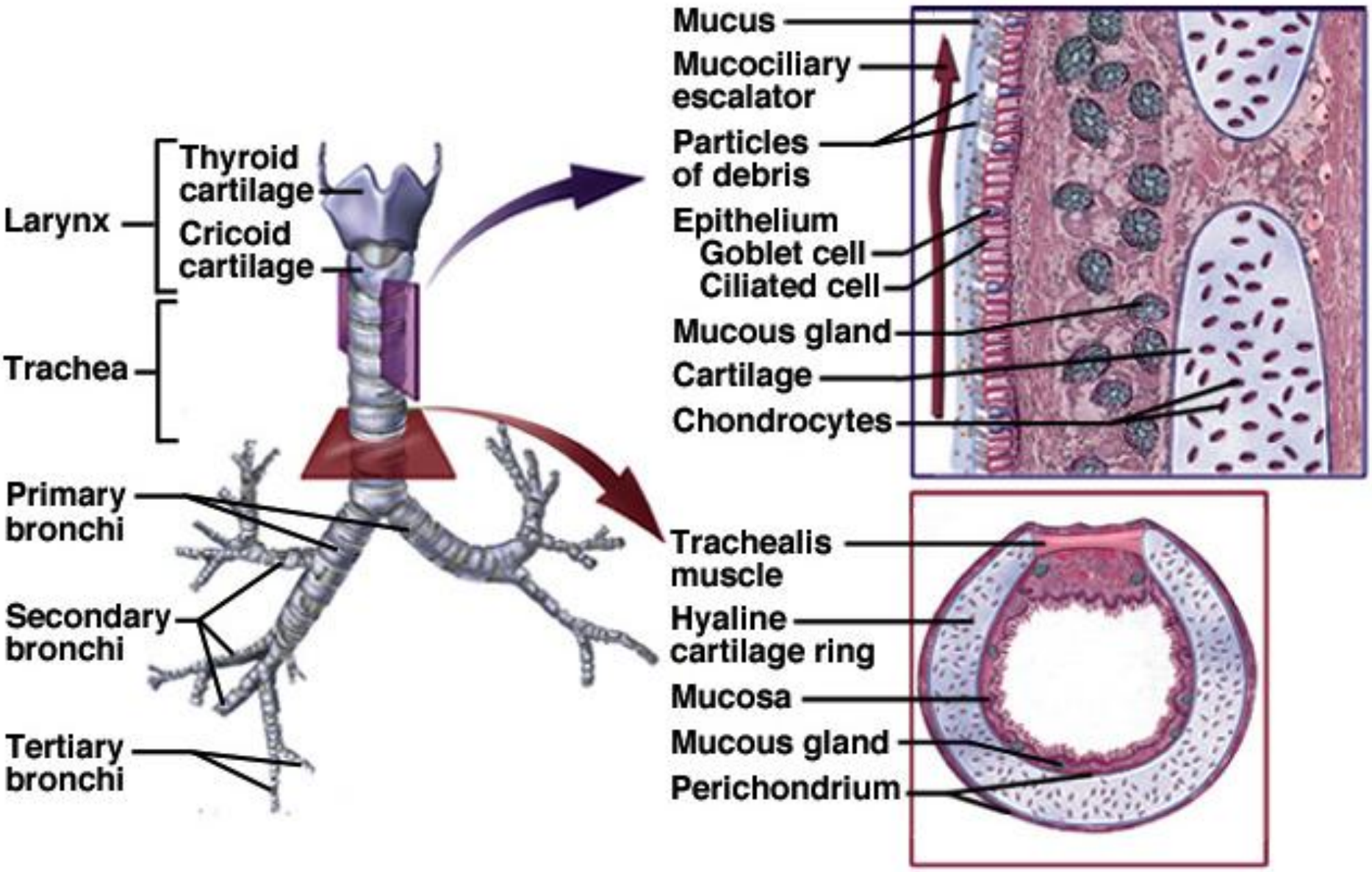
Laryngeal Video Recordings



http://www.youtube.com/watch?v=MKqCFa6bE-Q&feature=bf_prev&list=PL38D4C3E68F501A1F&lf=results_main

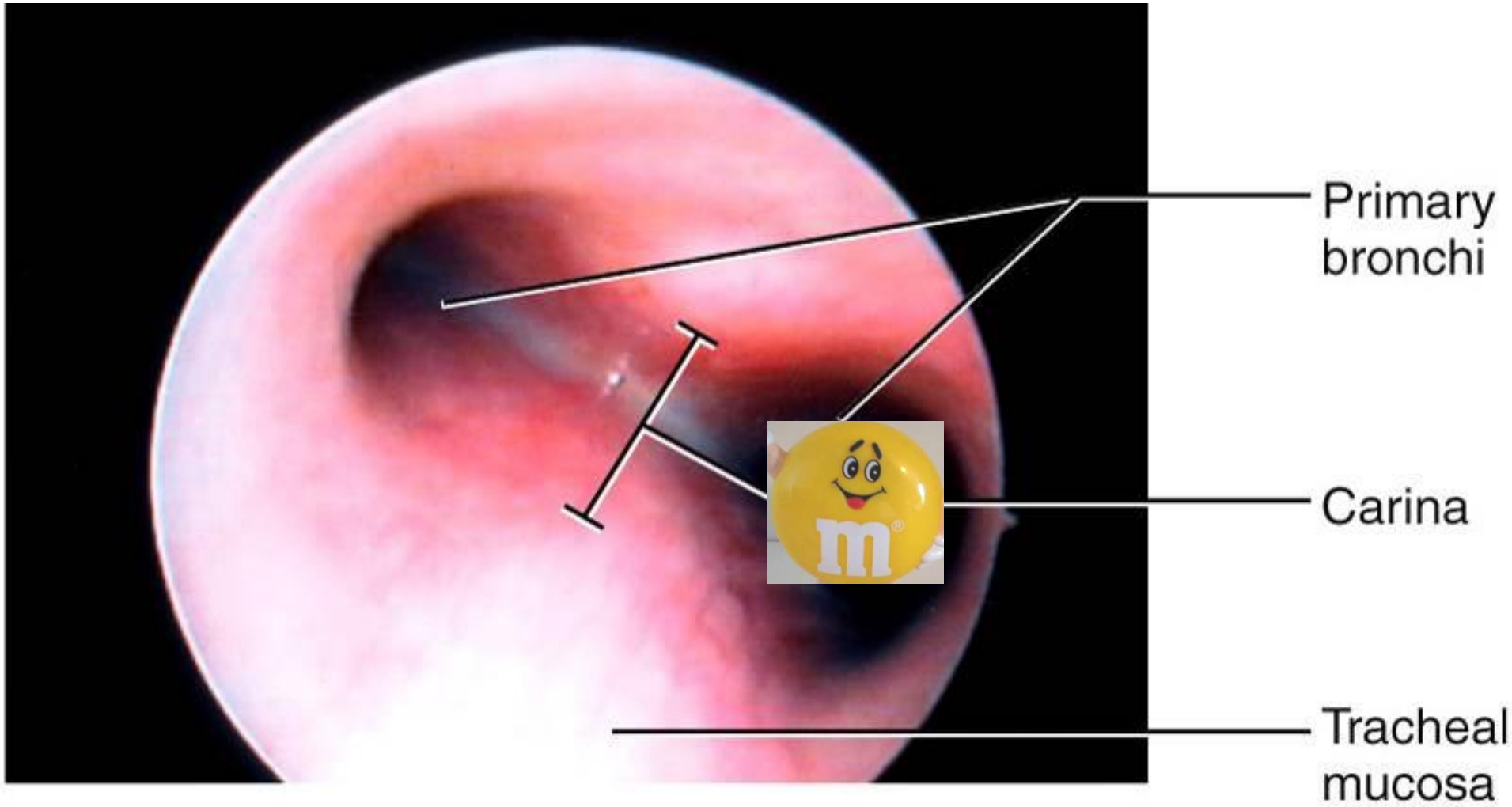
http://www.voicedoctor.net/media/video/index.html

Lower Respiratory Tract (trachea and lungs)

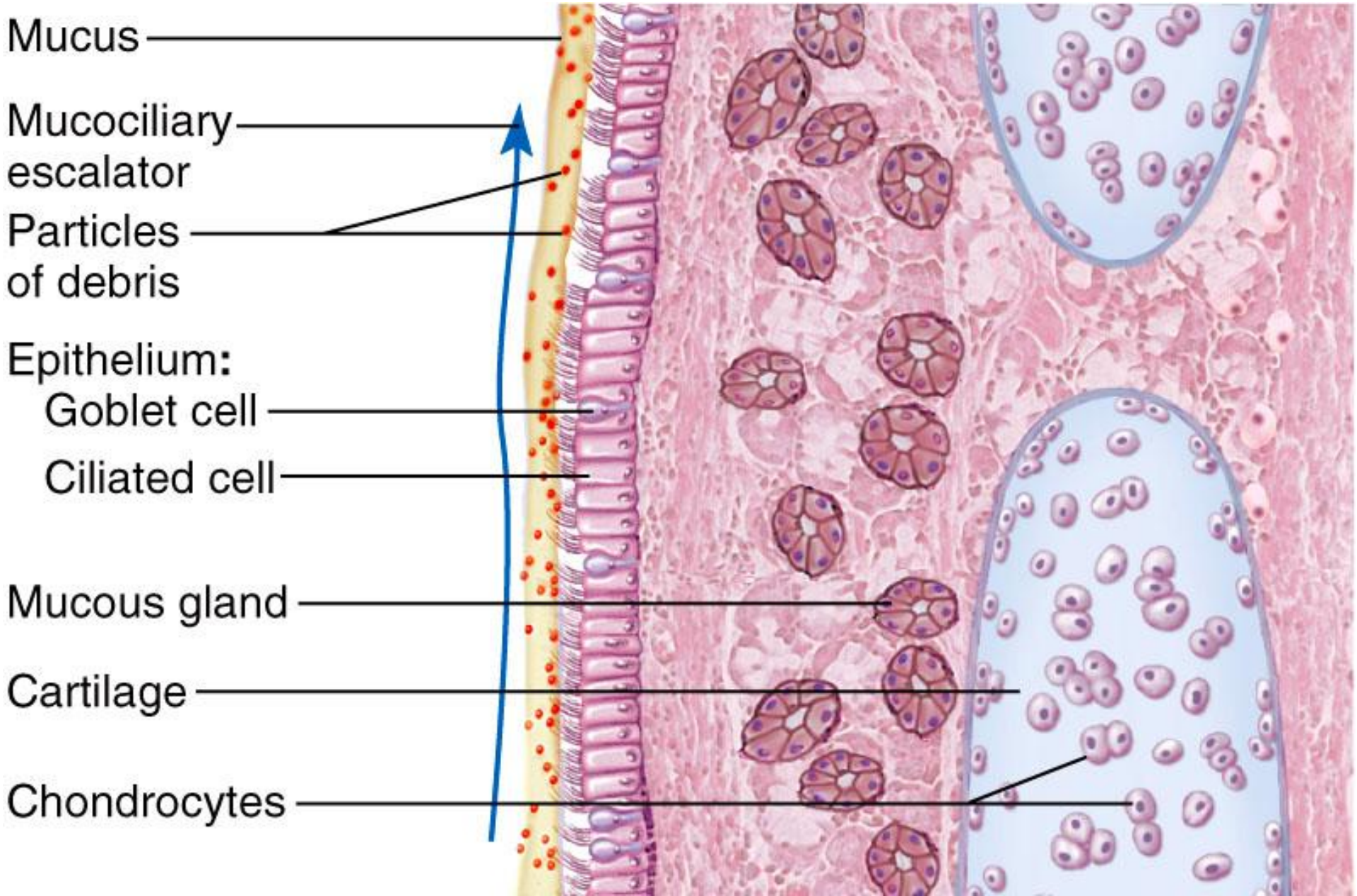


Trachea

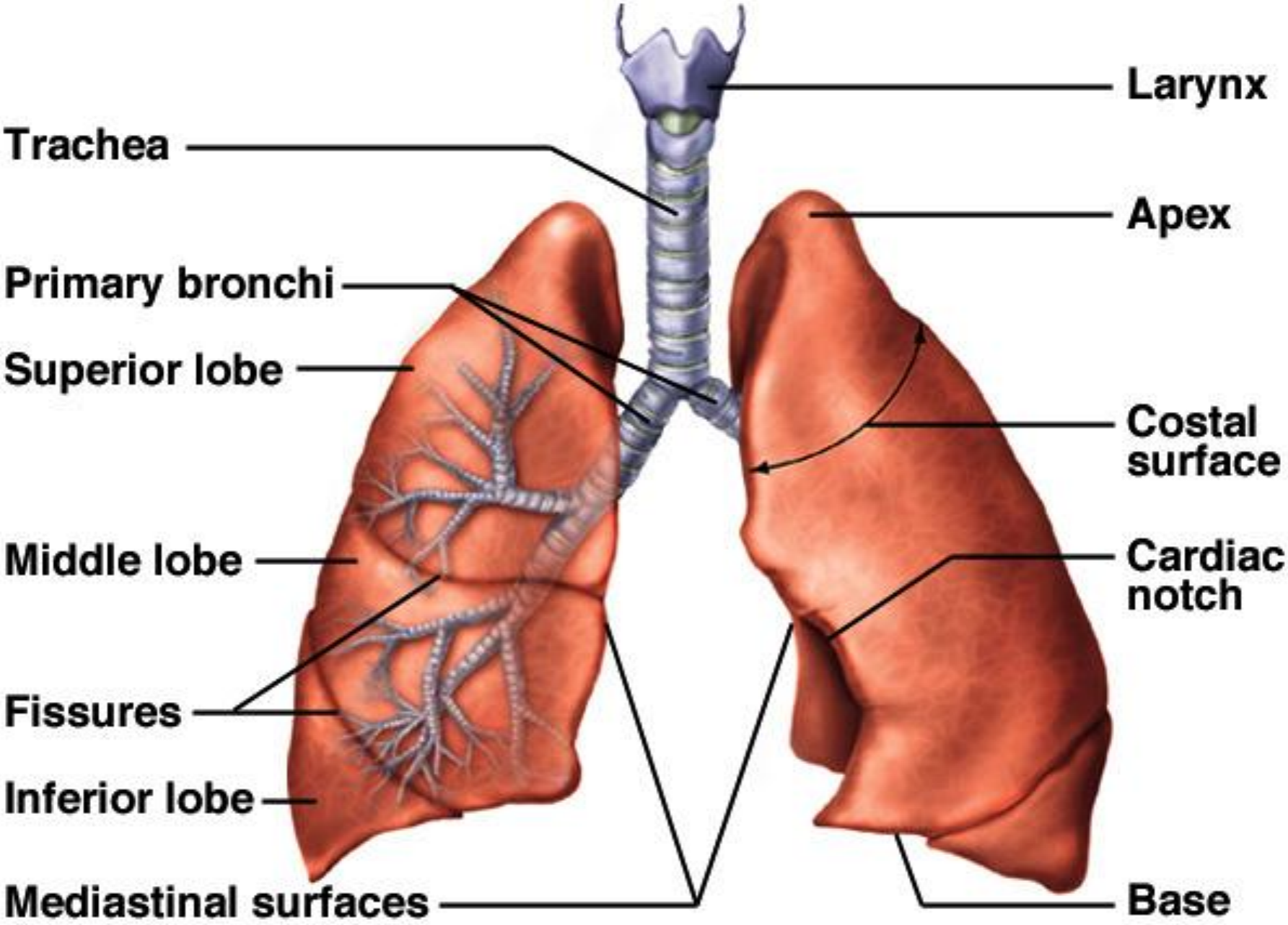
- Semi-rigid tube 4.5” long and 2.5” in diameter, anterior to esophagus is supported by C-shaped cartilaginous rings
  - Opening in rings faces posterior towards esophagus
  - **Trachealis Muscle** spans opening in rings, adjusts airflow by relaxing while breathing or contracting when coughing
- Bifurcates into right and left Primary Bronchi
  - **Carina** is the extremely sensitive, bifurcated terminal segment of the trachea
  - Sensory epithelia ends below the carina
  - Right primary bronchus is more likely to contain aspirated objects because it is wider and more vertical
- Larynx and trachea are lined with ciliated pseudostratified epithelium
  - epithelium has many goblet cells
  - lamina propria contains many mucous glands
  - functions as mucociliary escalator that sweeps mucus **up** to pharynx


Primary bronchi
Carina
Tracheal mucosa

Mucociliary Escalator



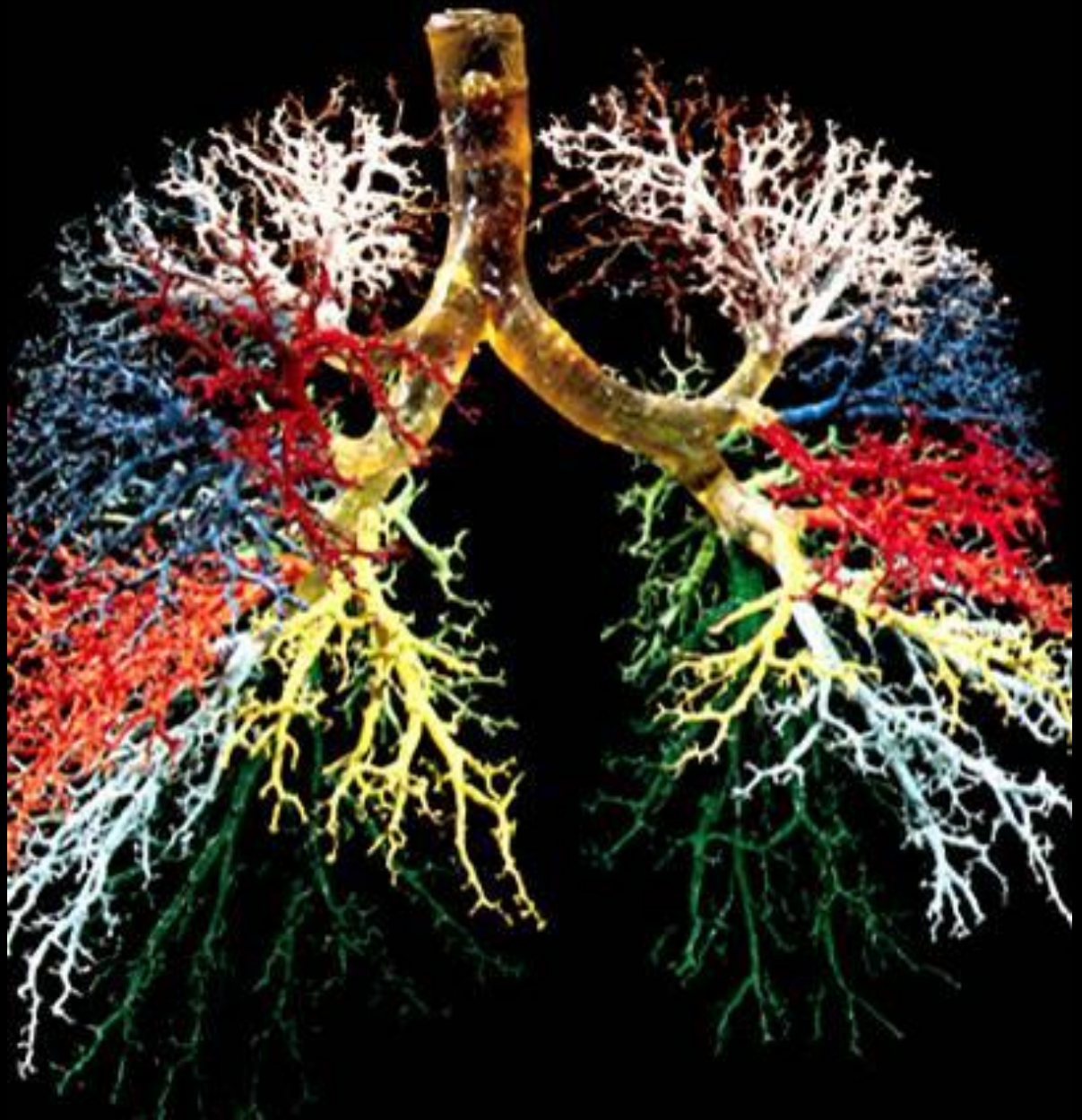
Lungs and Bronchial Tree



Bronchial Tree

- Primary Bronchi
  - two branches of the trachea
  - one goes to each lung
  - supported with rings of cartilage
- Secondary Bronchi
  - one secondary bronchus for each lobe of a lung
    - right lung has 3 lobes
    - left lung has 2 lobes
  - supported with overlapping plates of cartilage
- Tertiary Bronchi supply bronchopulmonary segments
    - 10 in right lung
    - 8 in left lung
  - supported by fewer plates of cartilage
- Bronchioles
  - surrounded by smooth muscle and no supporting cartilage
  - divide into 50-80 terminal bronchioles

Bronchial Tree and Bronchopulmonary Segments

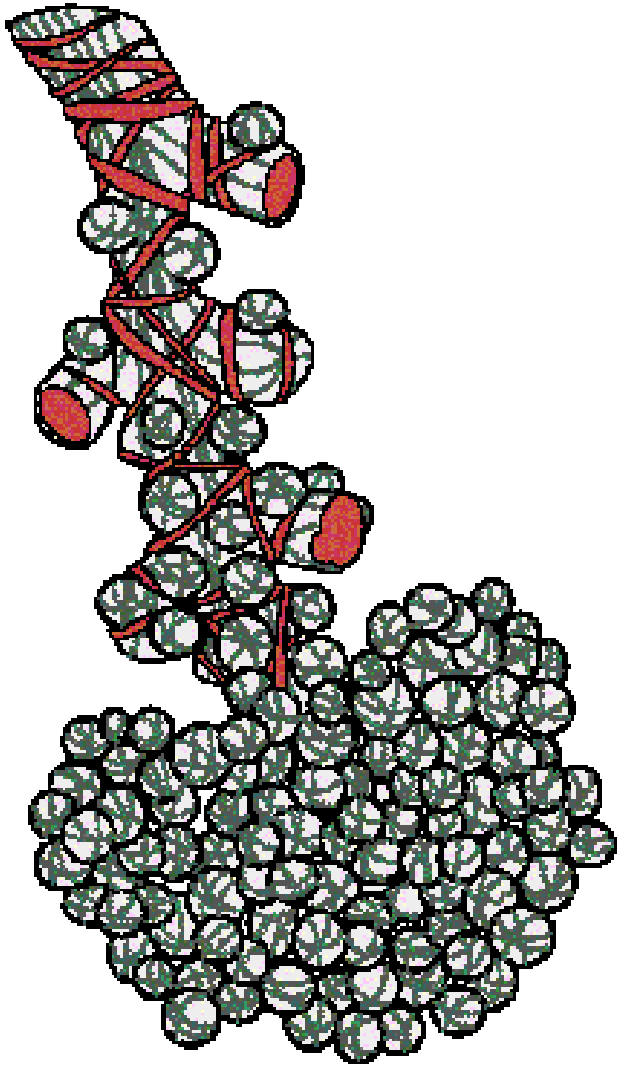


Normal Lateral Bronchography

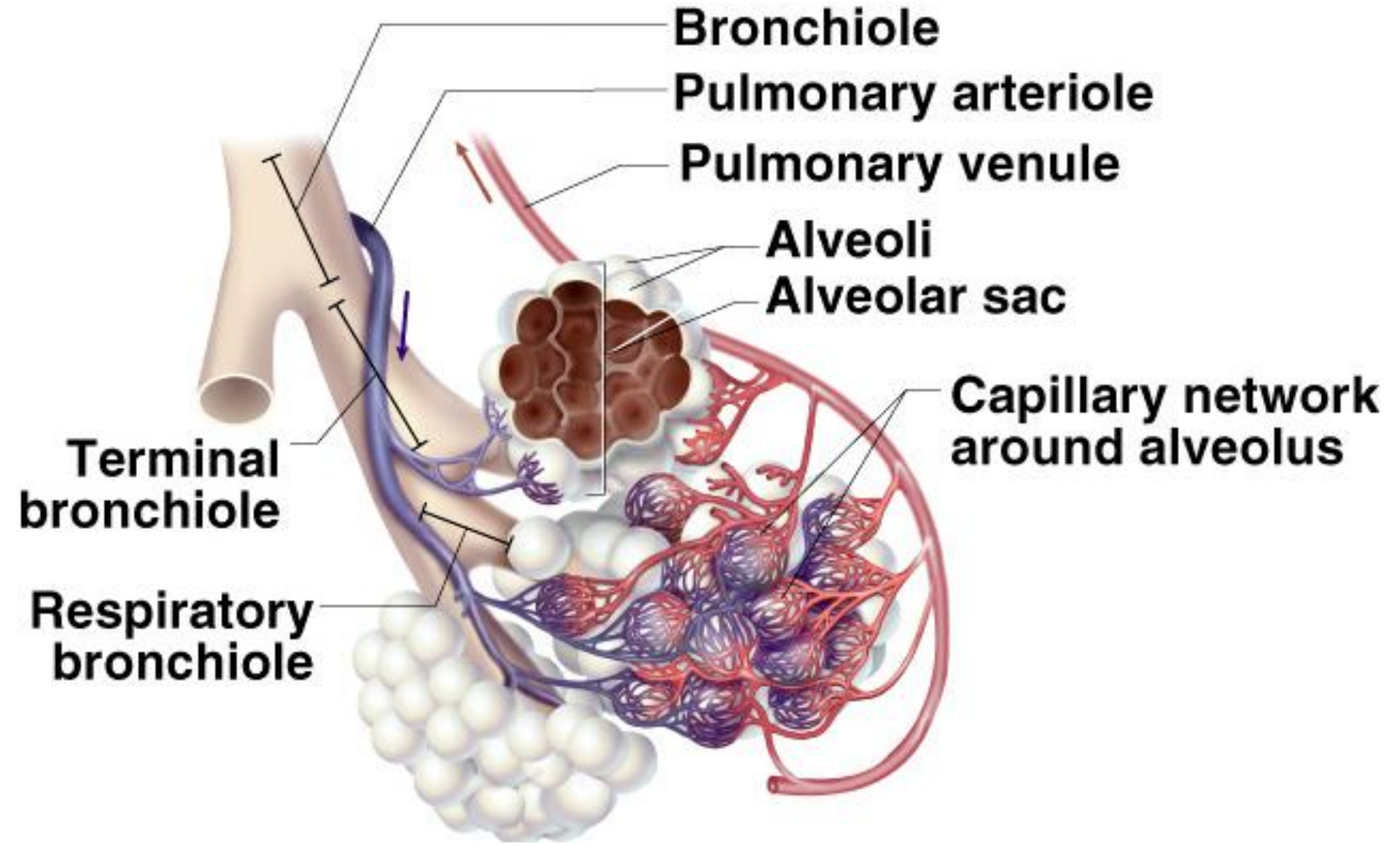
Bronchopulmonary Segments

Bronchial Tree (- continued)

- Terminal Bronchioles
  - last bronchial segment without any alveoli
  - have some smooth muscle
  - divide into respiratory bronchioles
- Respiratory Bronchioles
  - bronchioles with a few alveoli
  - alveoli are pockets of thin respiratory tissue
- Alveolar Ducts – short tubes with walls composed of alveoli
- Alveolar Sacs – clusters of alveoli



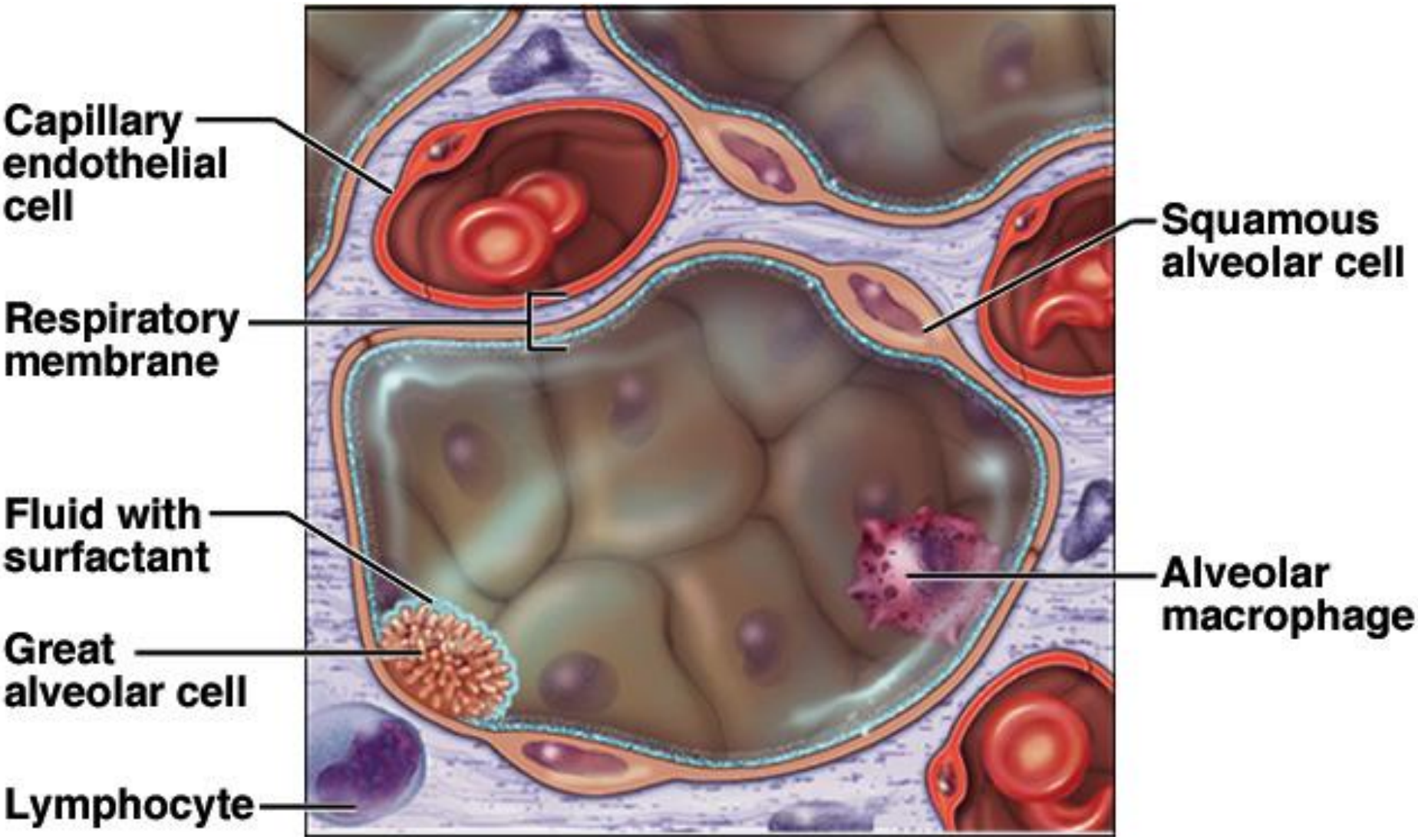
Alveolar Blood Supply

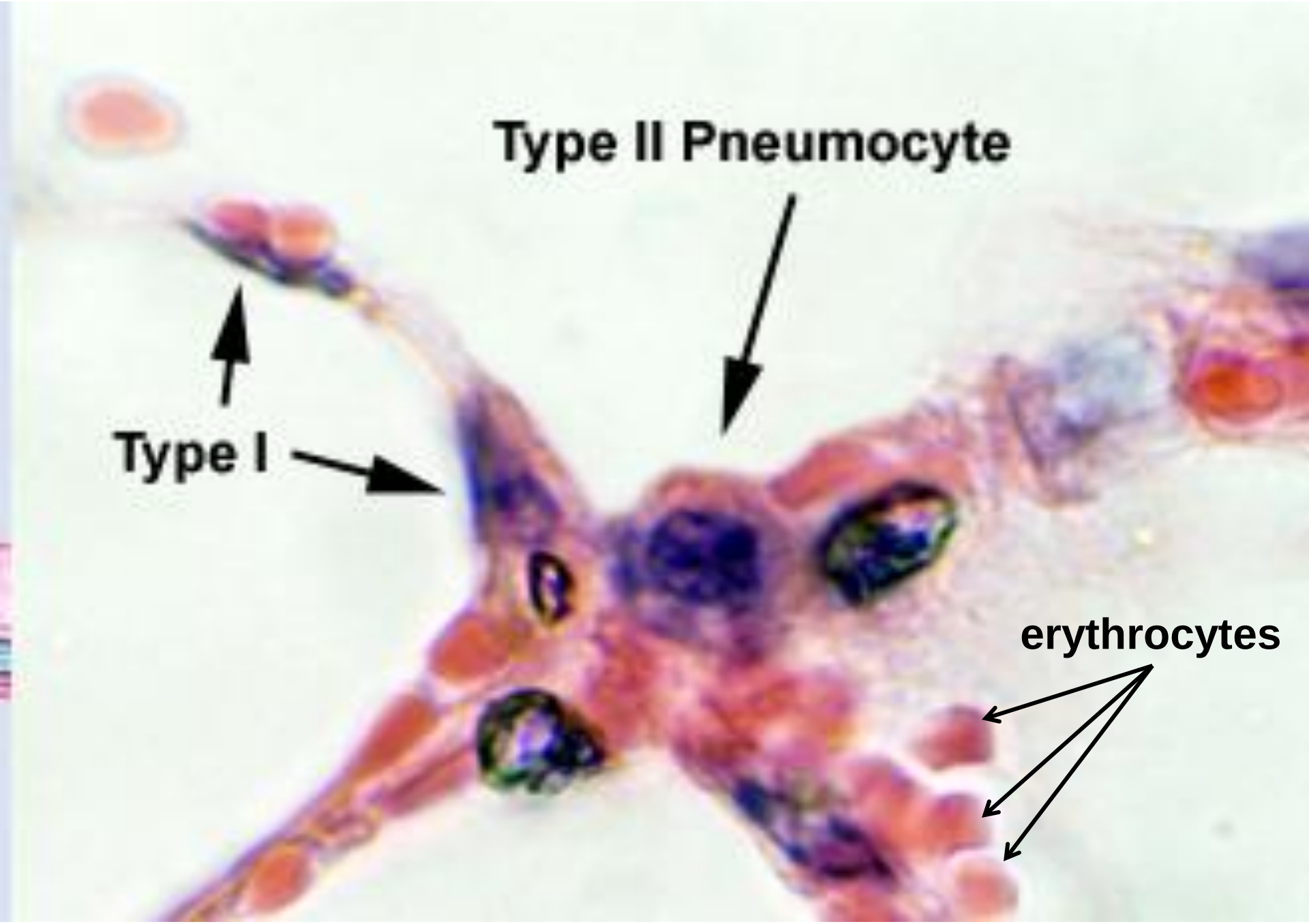


Cells of the Alveoli

- Type I Pneumocytes (squamous alveolar cells)
  - epithelial cells that line the alveoli
- Type II Pneumocytes (great alveolar cells)
  - Secrete pulmonary surfactant (detergent-like lipoprotein)
- Alveolar Macrophages
  - Outnumber all other cell types in the lung
  - 50 million a day move out of the lungs into the mucociliary escalator to be swallowed

Structure of an Alveolus





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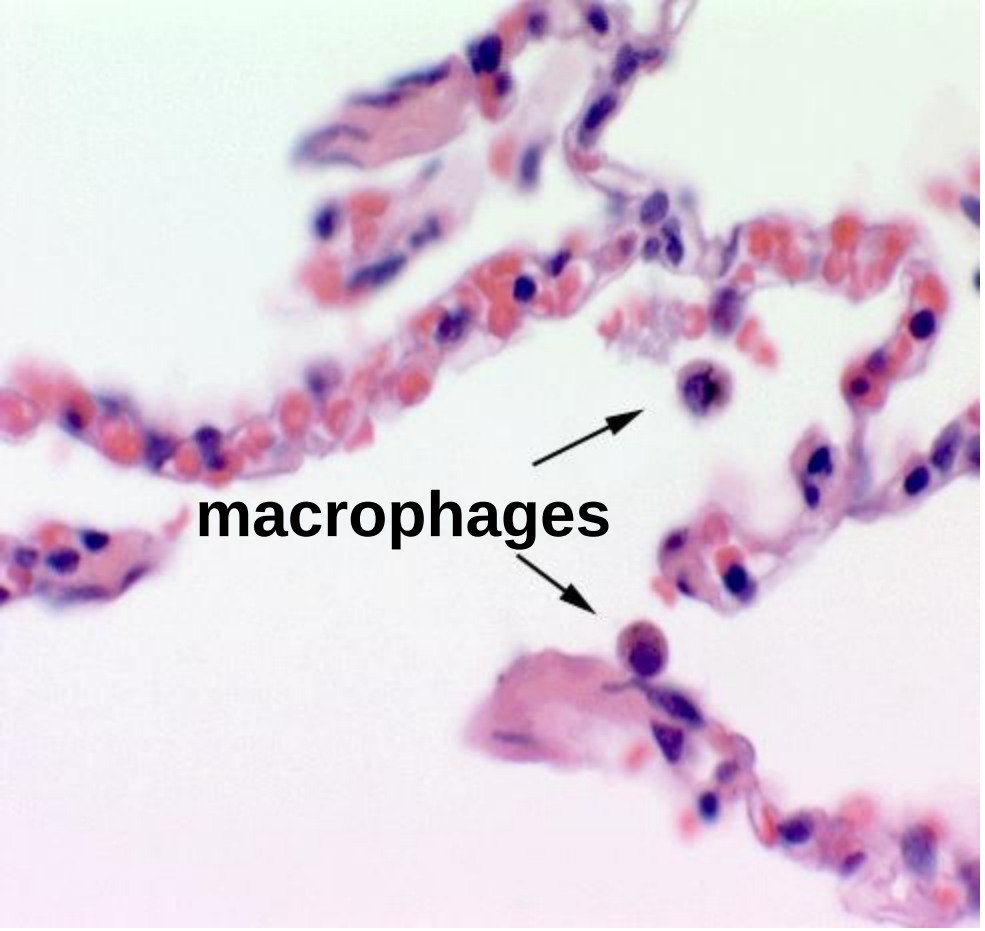
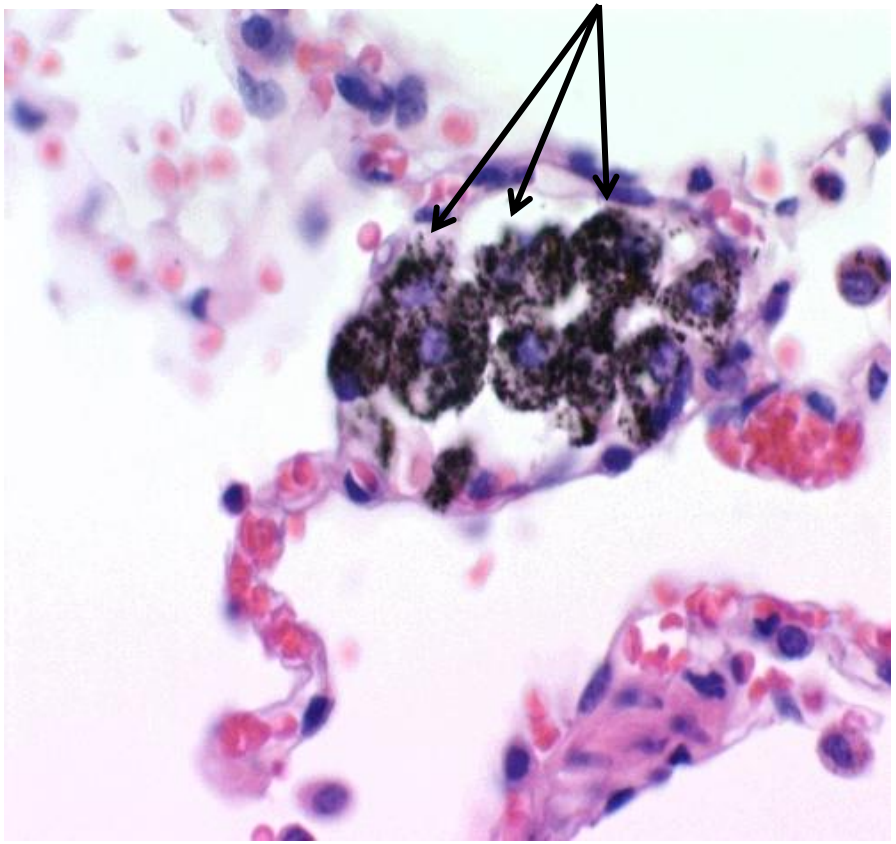
Alveolar Surface Tension

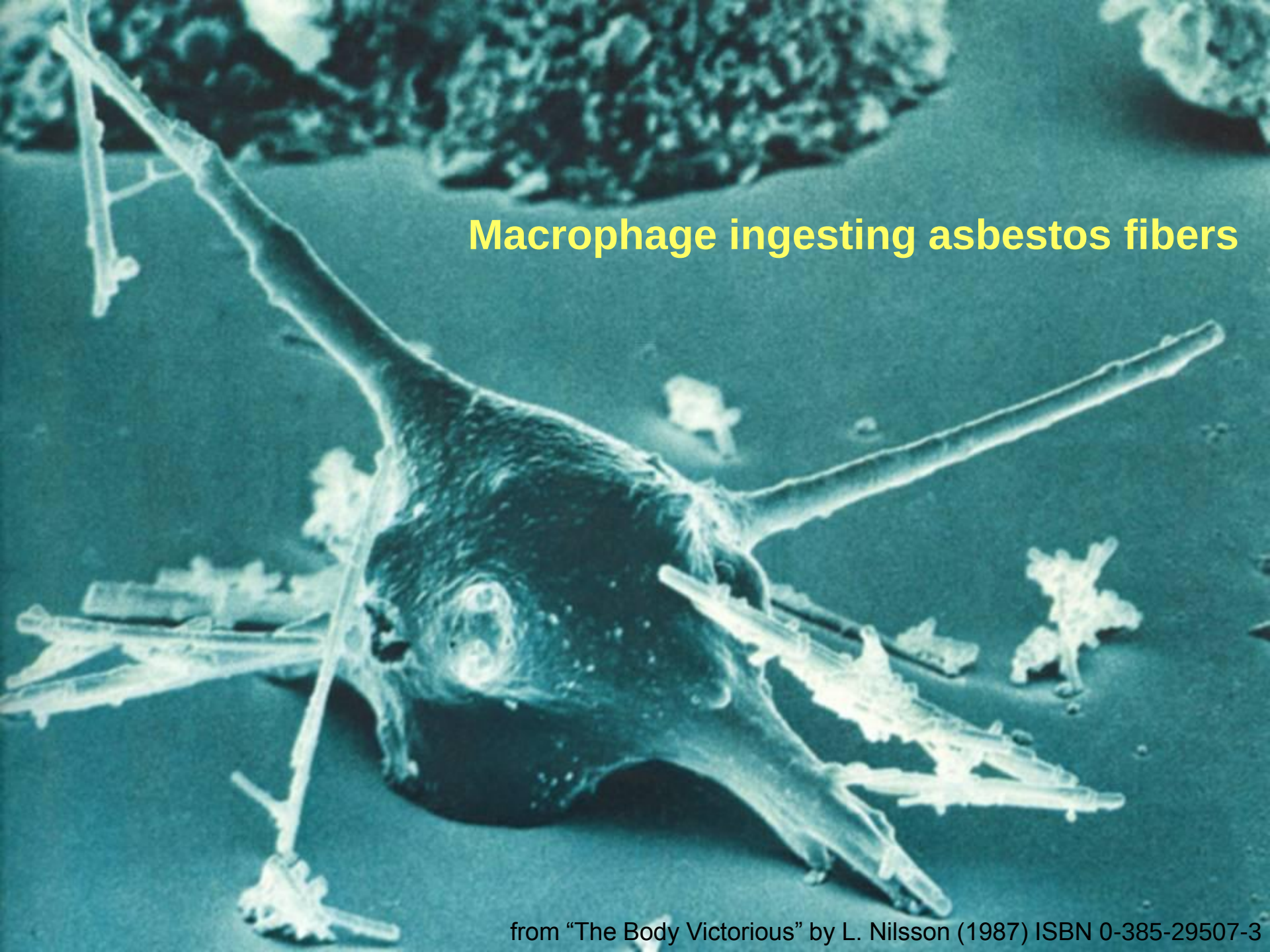
- A thin film of water is necessary for gas exchange
  - O_2 and CO_2 must dissolve in water to be absorbed
  - Water creates a strong surface tension that can easily collapse alveoli and distal bronchioles
- Pulmonary Surfactant
  - Produced by Type II Pneumocytes (great alveolar cells)
  - A protein and lipid mixture that disrupts hydrogen bonds of water, ↓ surface tension
  - Develops late in fetal development – must be administered to premature infants to prevent respiratory distress syndrome

Alveolar Macrophages



Macrophages that have ingested carbon particles





from “The Body Victorious” by L. Nilsson (1987) ISBN 0-385-29507-3

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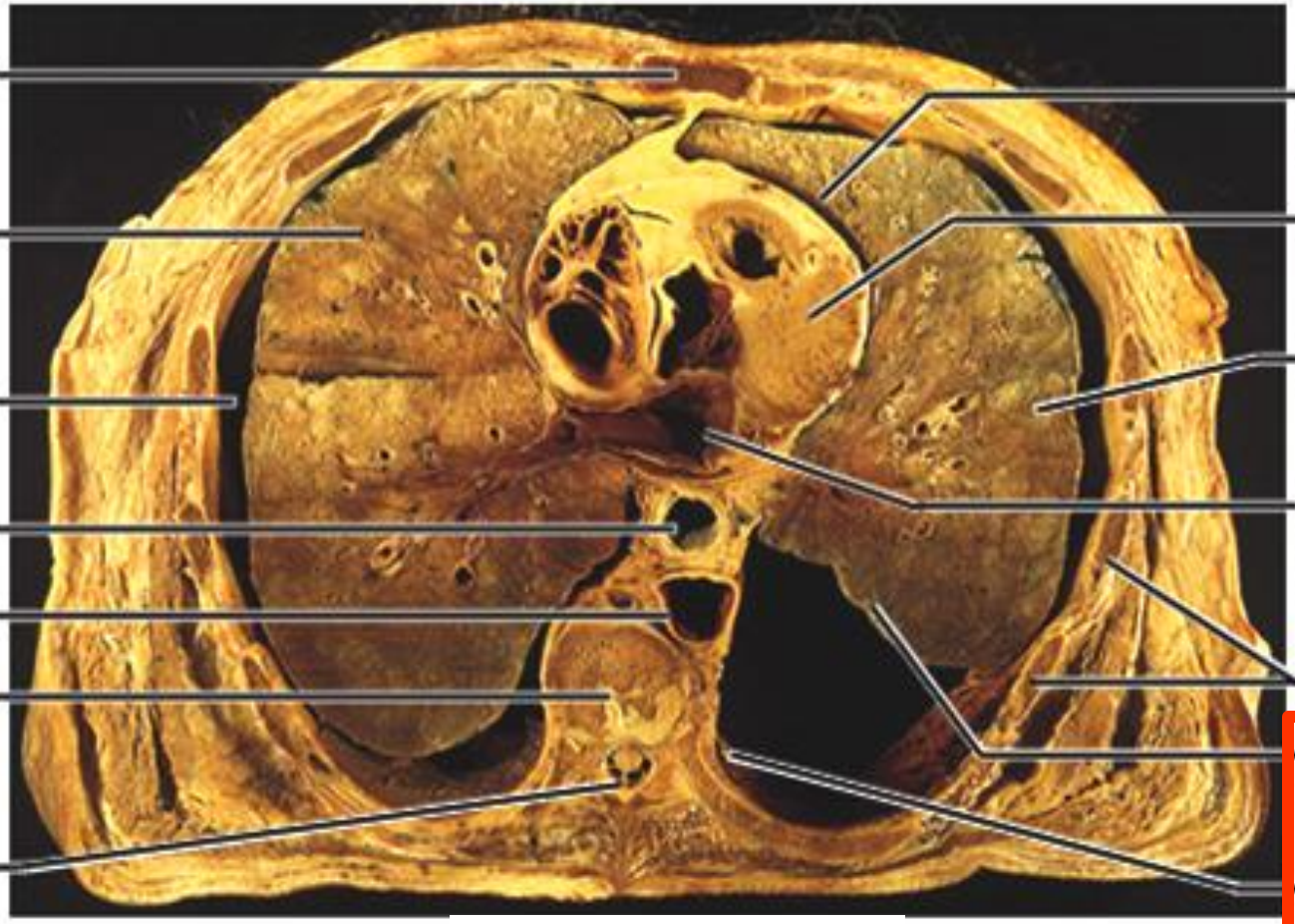
Pleurae and Pleural Fluid

- Visceral Pleura – membrane attached to surface of lung tissue
- Parietal Pleura – membrane attached to the inner thoracic wall
- Pleural Cavity contains a thin film of Pleural Fluid
- Functions of Pleurae and Pleural Fluid:
  - reduces friction
  - membranes separate areas of low pressure and high pressure
    - lower pressure in pleural cavity is necessary to inflate the lungs
  - membranes compartmentalize each lung
    - prevents spread of infection

Thorax - Cross Section



Pressure and Flow

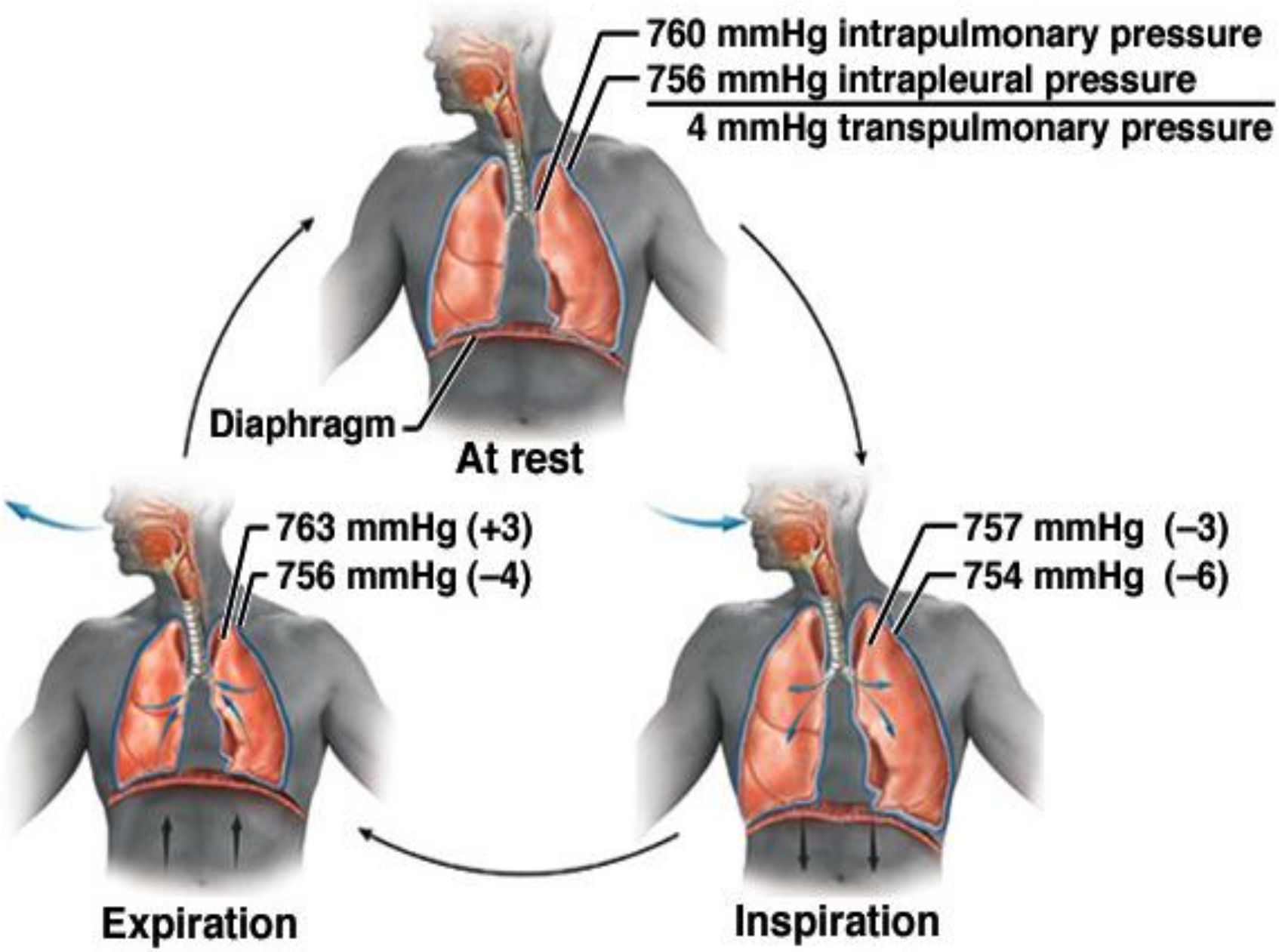
- Atmospheric pressure drives respiration
  - **1 atmosphere (atm) = 760 mmHg = 14.7 psi** at sea level
  - Atmospheric pressure decreases as elevation increases
  - Every 33’ below water is equal to 1 atm
    - A diver 66’ below the surface would be under 3 atmospheres of pressure
- Intrapulmonary pressure and lung volume
  - **Boyle’s Law** states that pressure is inversely proportional to volume
    - for a given amount of gas, as volume ↑, pressure ↓
    - and as pressure ↑, volume ↓
- Pressure gradients
  - difference between atmospheric and intrapulmonary pressure
  - created by changes in volume of thoracic cavity

http://www.smm.org/heart/lungs/breathing.htm

http://www.smm.org/heart/lungs/breathing.htm

http://solutions.3m.com/wps/portal/3M/en_US/Littmann/stethoscope/education/lung_sounds/

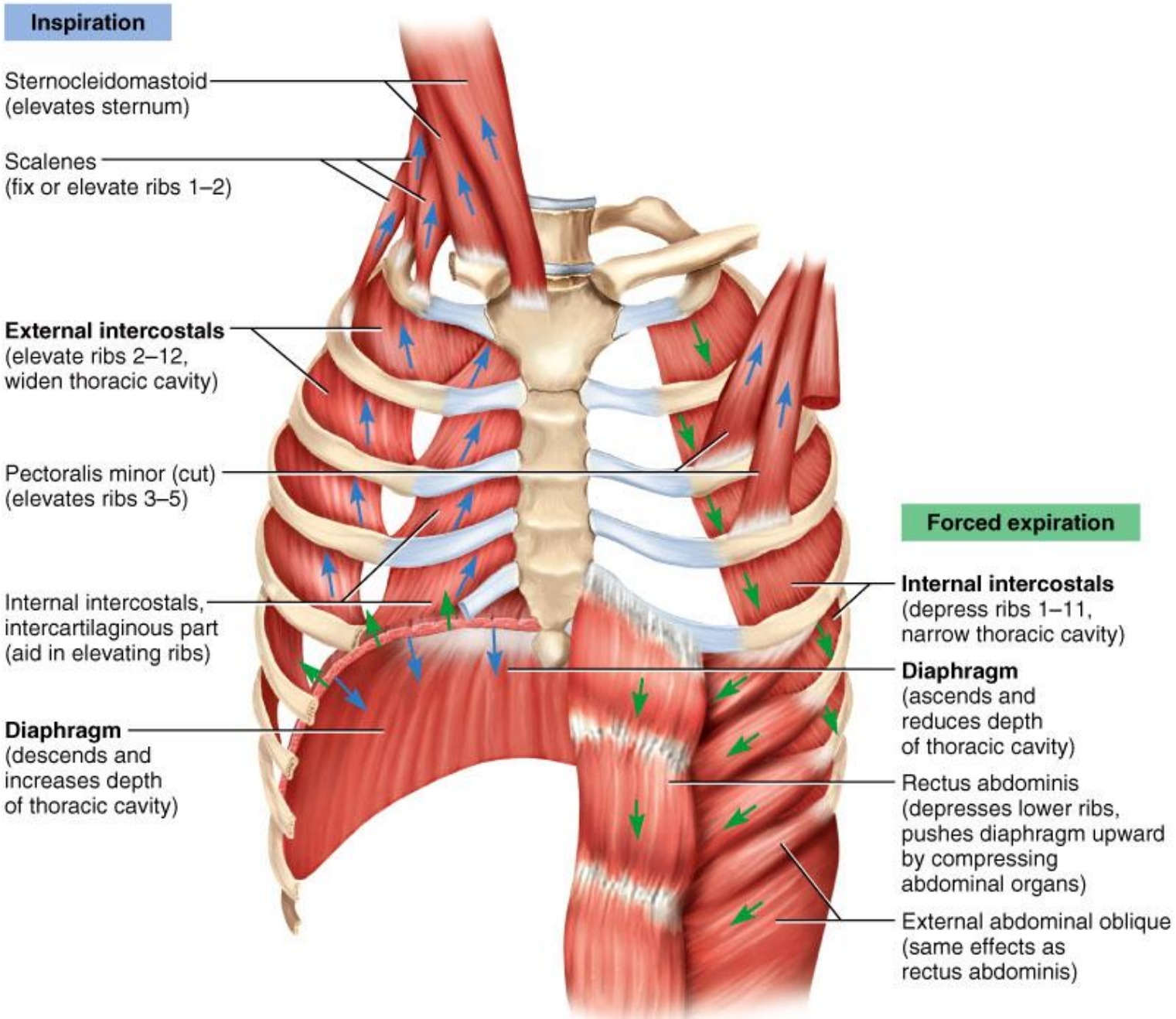
Respiratory Pressure & Lung Ventilation



Muscles Involved in Inspiration

- Diaphragm (dome shaped)
  - contraction flattens diaphragm and increases volume of thorax
- Scalenes
  - fix first pair of ribs
- External intercostals
  - elevate 2 - 12 pairs
- Pectoralis minor, sternocleidomastoid and erector spinae muscles
  - used in deep inspiration to expand thorax

Muscles Involved in Inspiration



Passive Expiration

- During quiet breathing, expiration is achieved by elastic recoil of lungs and thoracic cage
- As volume of thoracic cavity ↓, intrapulmonary pressure ↑ and air is expelled

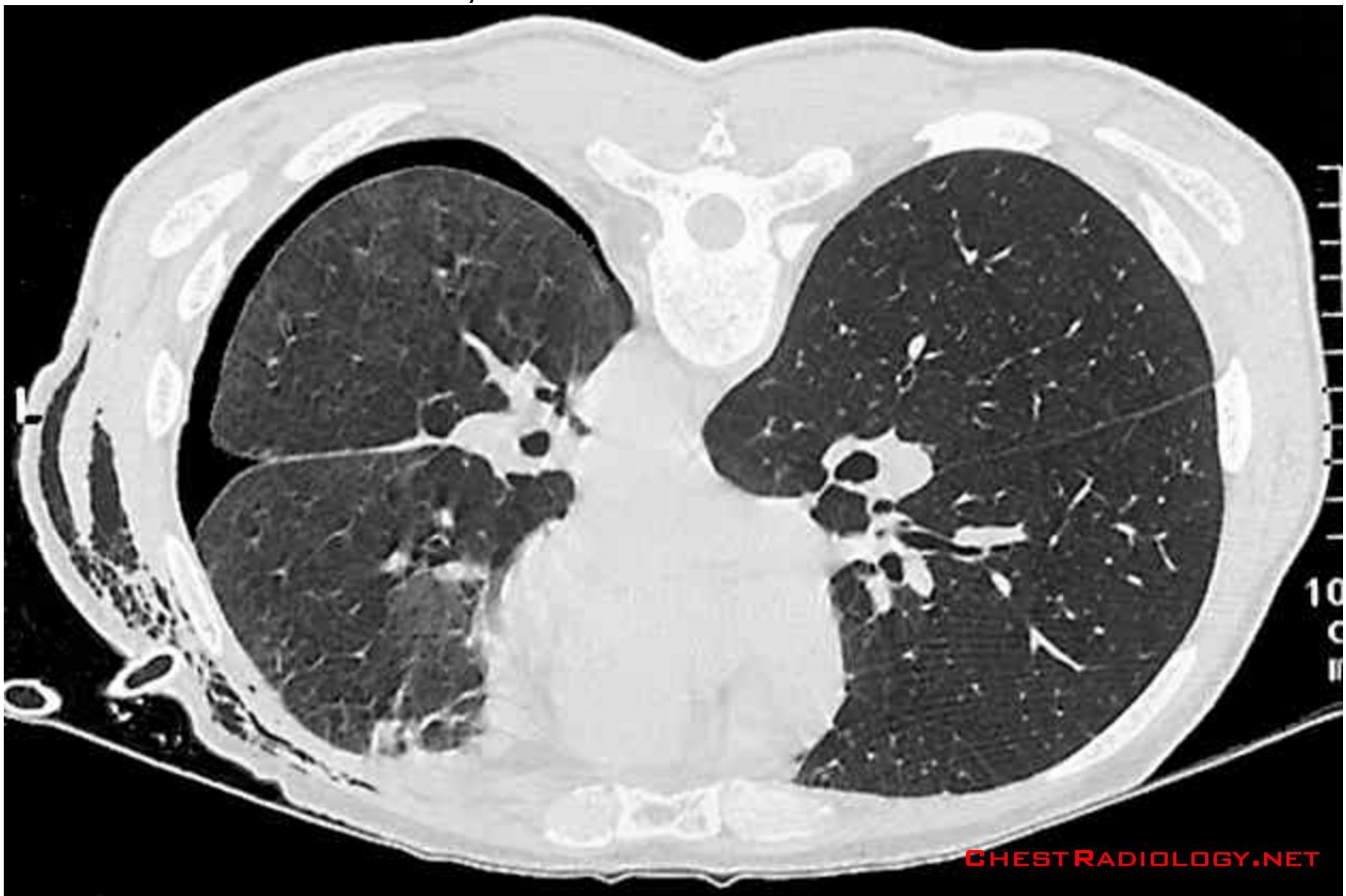
Forced Expiration

- Internal intercostal muscles
  - depress the ribs
- Abdominal muscles
  - Contraction of abdomen ↑ intra-abdominal pressure and forces diaphragm upward which ↑ pressure in thoracic cavity

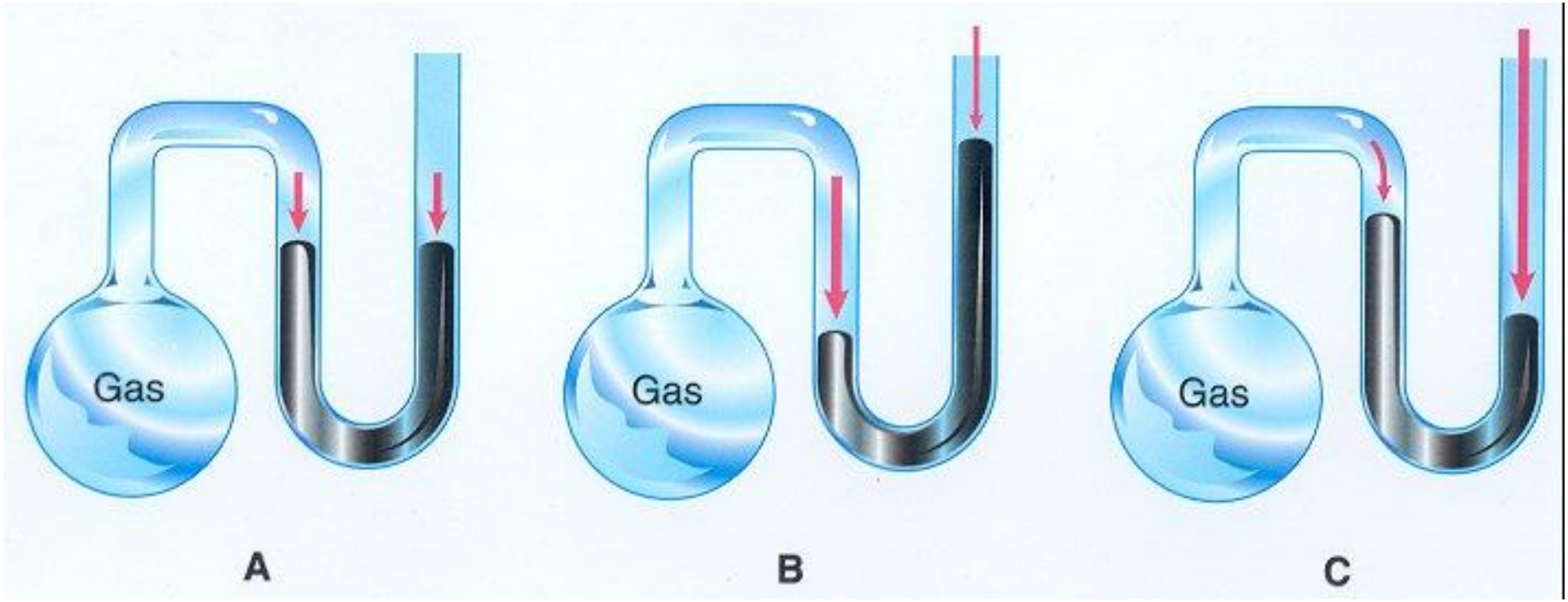
Pneumothorax

- Presence of air in pleural cavity
  - loss of negative intrapleural pressure allows lungs to recoil and collapse
- Collapse of lung can be corrected by inserting a tube into the intrapleural space and applying suction

The pleura is usually not seen in CT. It may be recognized as a dense line when, with a pneumothorax, the lung retracts from the thoracic wall, as seen in this case.



Measuring Air Pressure with a Mercury Manometer



A) equal pressure

B) low atmospheric pressure

C) high atmospheric pressure

Composition of Air

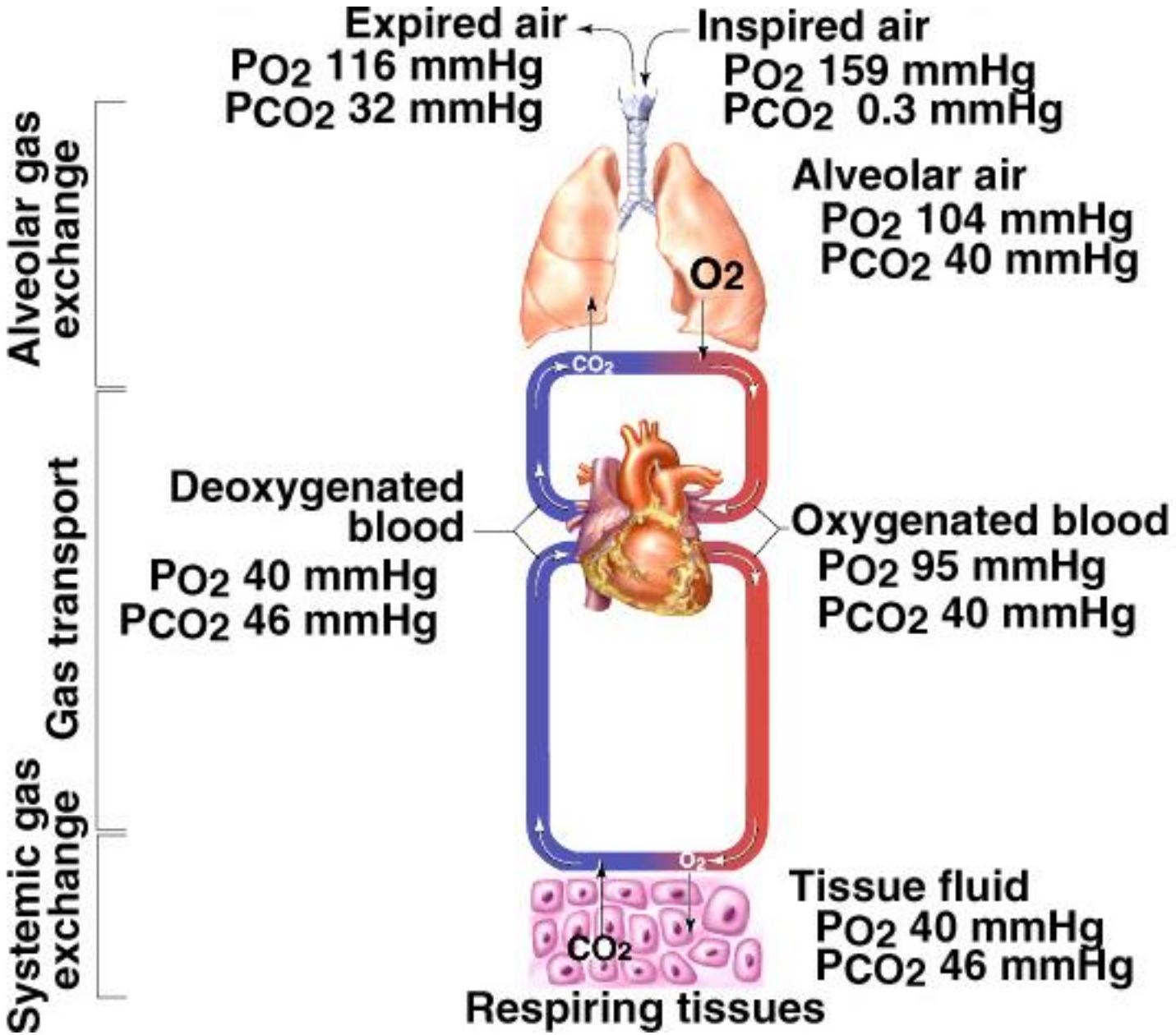
- Air is a mixture of gases, and each gas contributes its partial pressure (at sea level 1 atm of pressure = 760 mmHg)
  - nitrogen constitutes 78.6% of the atmosphere, therefore P_{N_2} = 78.6% x 760 mmHg = 597.0 mmHg
  - P_{O_2} = 20.8% x 760mmHg = 159.0 mmHg
  - P_{H_2O} = 0.50% x 760 mmHg = 3.7 mmHg
  - P_{CO_2} = 0.04% x 760 mmHg = 0.3 mmHg
  - ATM = 597 + 159 + 3.7 + 0.3 = 760
  - All other gasses contribute an insignificant amount to the total partial pressure
- Partial pressures determine rate of diffusion of gas between blood and alveolus.
- Alveolar air
  - 100% humid, gases dissolve in water and diffuse into blood
  - contains: P_{N_2} = 569, P_{O_2} = 104, P_{H_2O} = 47, P_{CO_2} = 40 mmHg

Air-Water Interface

- Gases diffuse down their concentration gradients from high concentration to low concentration
- **Henry's Law**: amount of gas that dissolves in water is determined by its **solubility in water** and its **partial pressure.**

gas	solubility in water (g/kg water)
Nitrogen	0.03
Oxygen	0.07
Carbon Dioxide	3.40

Concentration Gradients of Gases



Control of Ventilation

- Neural pathways
  - Conscious: Voluntary motor cortex of frontal lobe of cerebrum sends impulses down to respiratory neurons in spinal cord to respiratory muscles
  - Unconscious: Neurons in medulla oblongata and pons of brain stem control unconscious breathing
- Limitations on voluntary control
  - Holding breath can lead to loss of consciousness, but breathing will involuntarily resume.

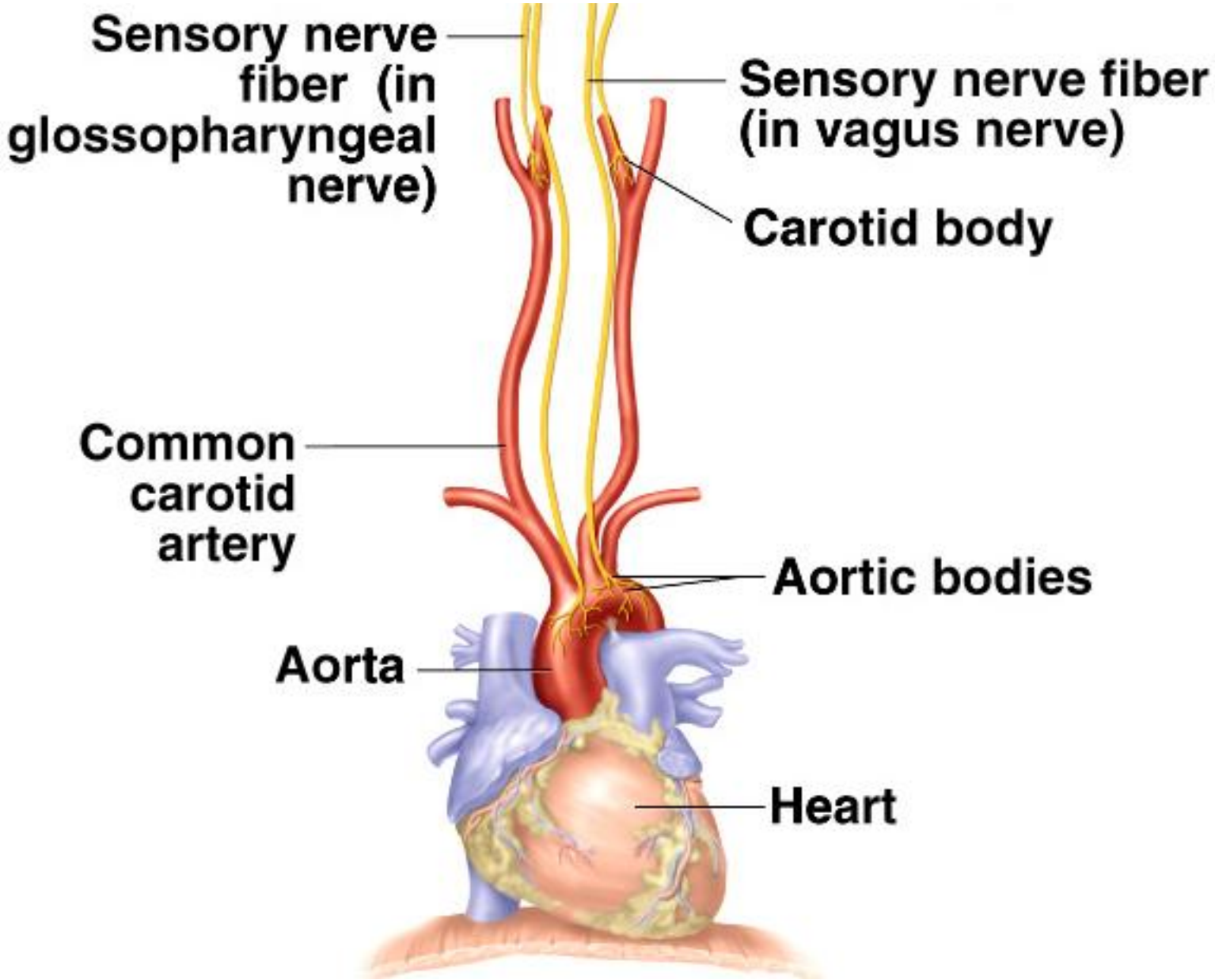
Chemoreceptors and Respiratory Rhythm

- Chemoreceptors monitor body fluids
- Peripheral Chemoreceptors in aortic bodies and carotid bodies monitor blood
- Central Chemoreceptors (medulla oblongata) monitor pH of cerebrospinal fluid (CSF)
  - CO_2 easily crosses blood-brain barrier into CSF. The CO_2 reacts with water and releases H^+ that stimulate central chemoreceptors that strongly stimulate inspiratory center
  - corrected by hyperventilation, pushes reaction to the left by "blowing off " CO_2

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow HCO_3^- + H^+$$

H_2CO_3 = carbonic acid HCO_3^- = bicarbonate ion

Peripheral Chemoreceptor Pathways



Effects of Hydrogen Ions

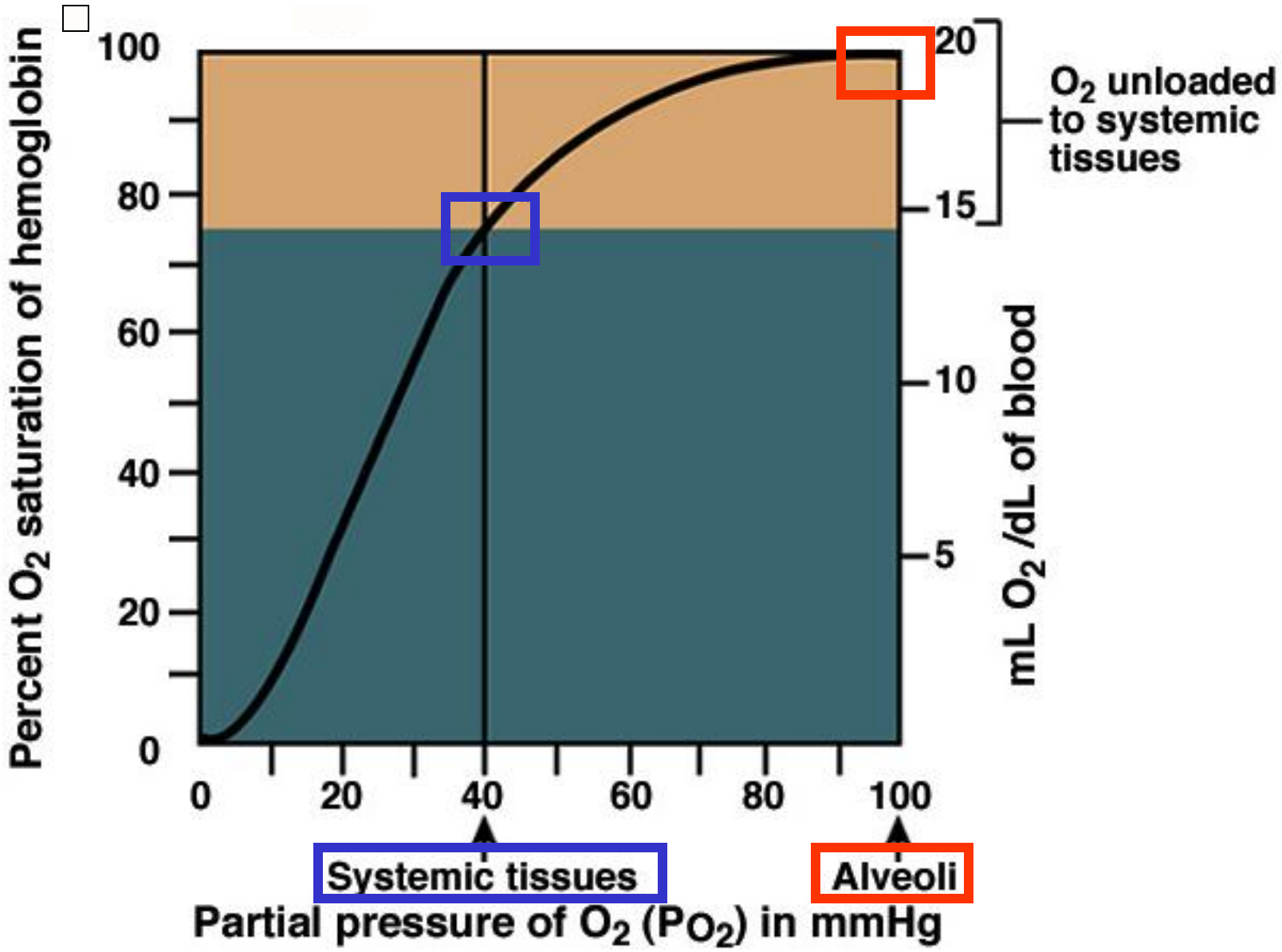
- Respiratory acidosis (pH below 7.35)
  - caused by hypercapnia (high P_{CO_2})
  - corrected by hyperventillation
- Respiratory alkalosis (pH above 7.35)
  - hypocapnia (low P_{CO_2})
  - Can be caused by hyperventillation and can be corrected by hypoventilation or breathing into a bag to increase P_{CO_2}
  - pushes reaction to the right and lowers pH to normal

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow HCO_3^- + H^+$$

Oxygen Transport

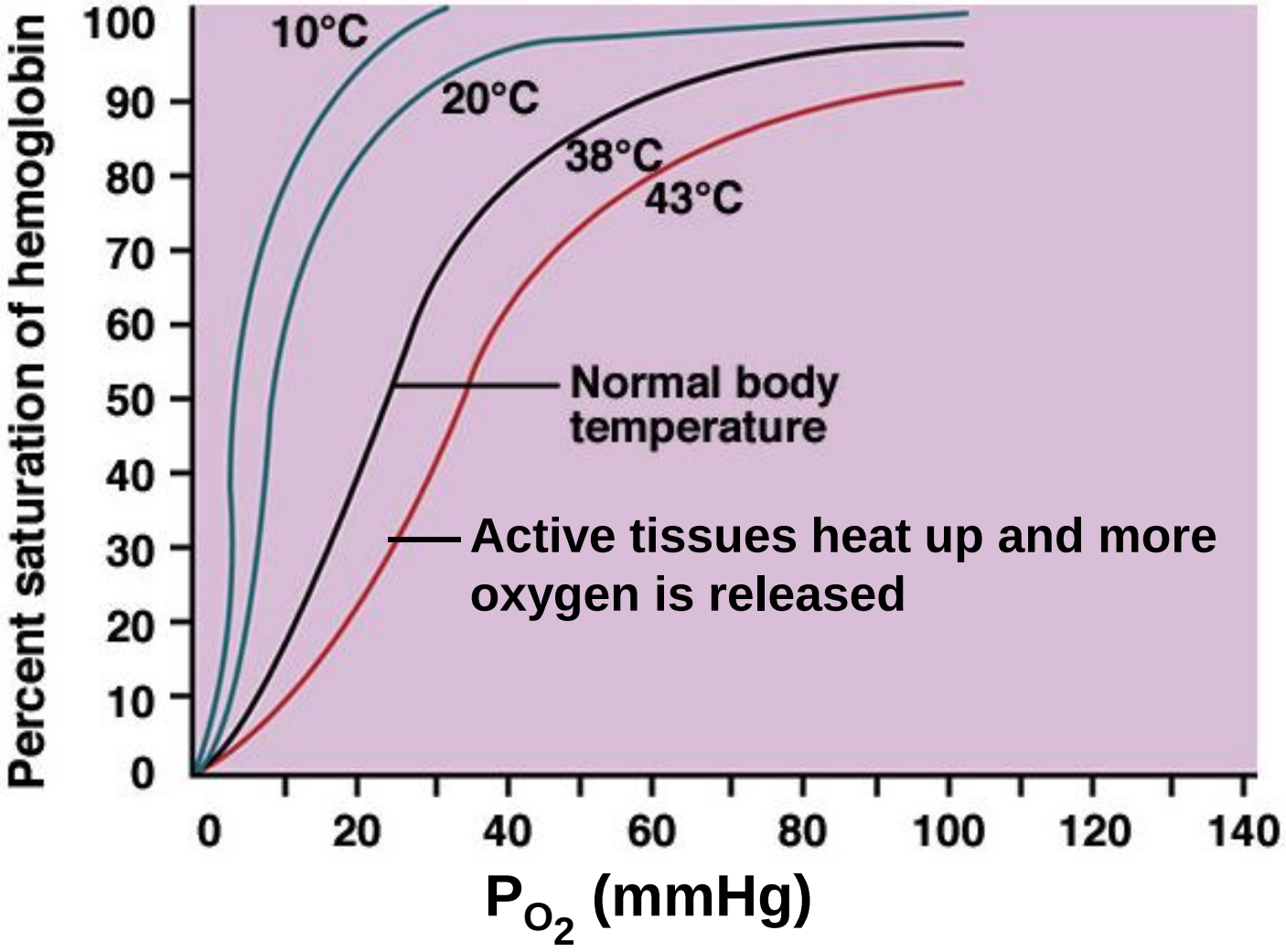
- Concentration in arterial blood
  - 20 ml/dL
  - 98.5% bound to hemoglobin, 1.5% dissolved in plasma
- Binding to hemoglobin
  - each hemoglobin molecule contains 4 heme groups
  - each heme group can bind to one O_2
  - oxyhemoglobin (HbO_2), deoxyhemoglobin (HHb)
- Oxyhemoglobin dissociation curve
  - **affinity of Hb for O_2 is high when PO_2 is high**
  - **affinity of Hb for O_2 is low when PO_2 is low**

Oxyhemoglobin Dissociation Curve



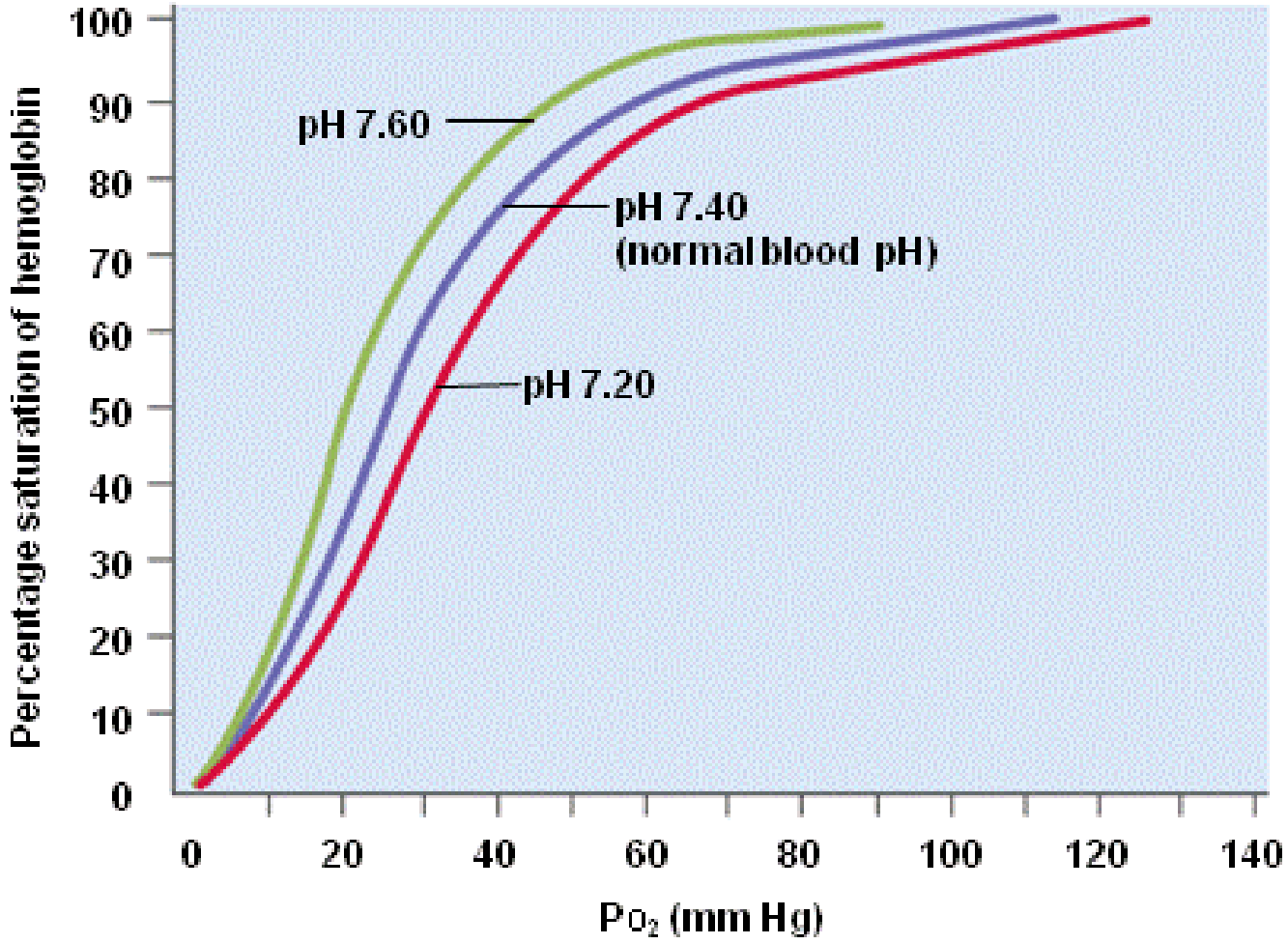
Oxygen Dissociation & Temperature

Hb has lower affinity for oxygen as temperature increases, therefore, more oxygen is released in active tissues as they heat up. This occurs in the TISSUES, not in the lungs.



Oxygen Dissociation & pH

Hb has lower affinity for oxygen as tissues become acidic, therefore, more oxygen is released in active tissues as they produce lactic acid and carbonic acid. This occurs in the TISSUES, not in the lungs.



Carbon Dioxide Transport

- 90% as **carbonic acid** and **bicarbonate**

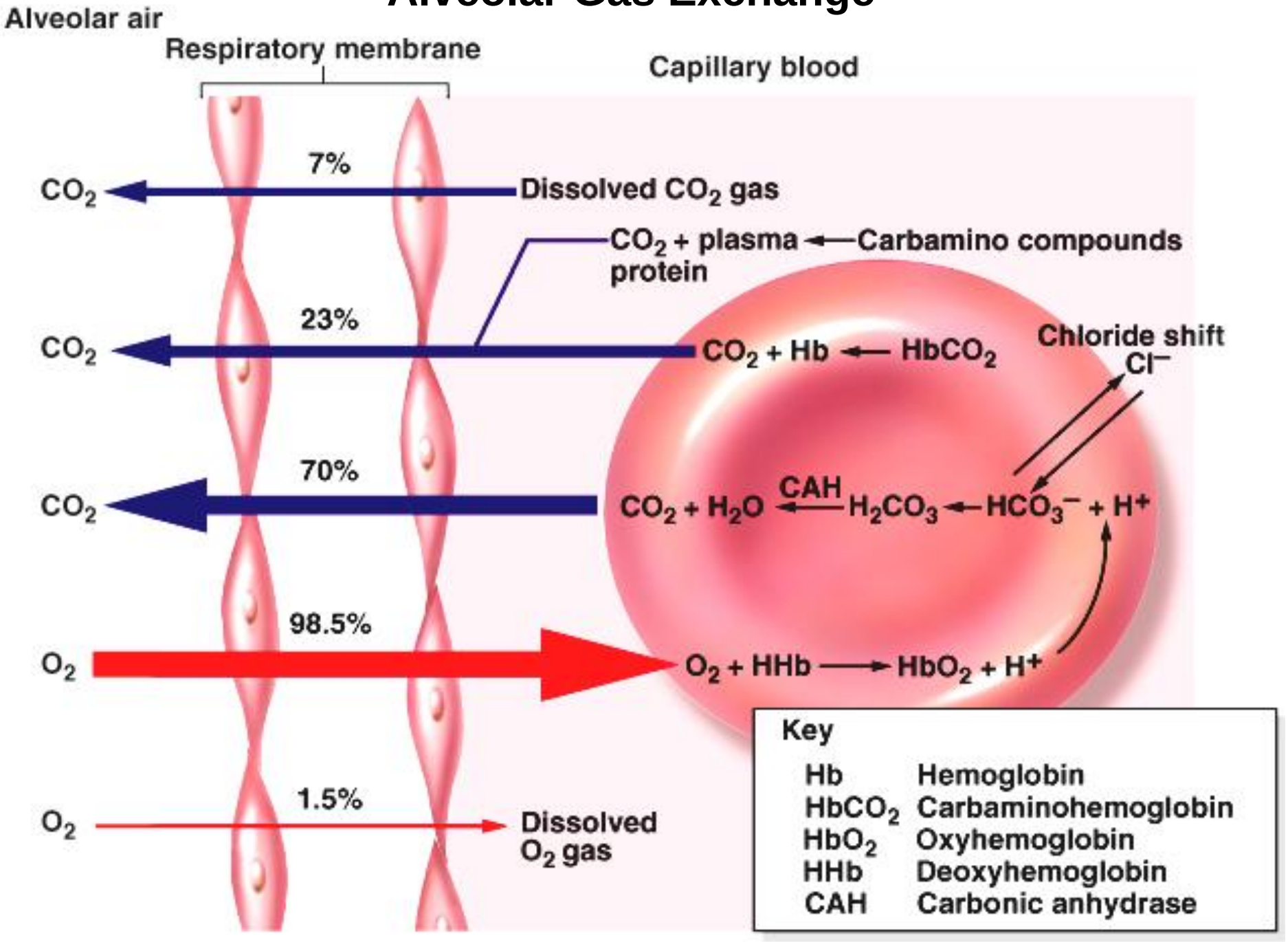
  $CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow HCO_3^- + H^+$

- 5% as **carbaminohemoglobin** ($HbCO_2$)

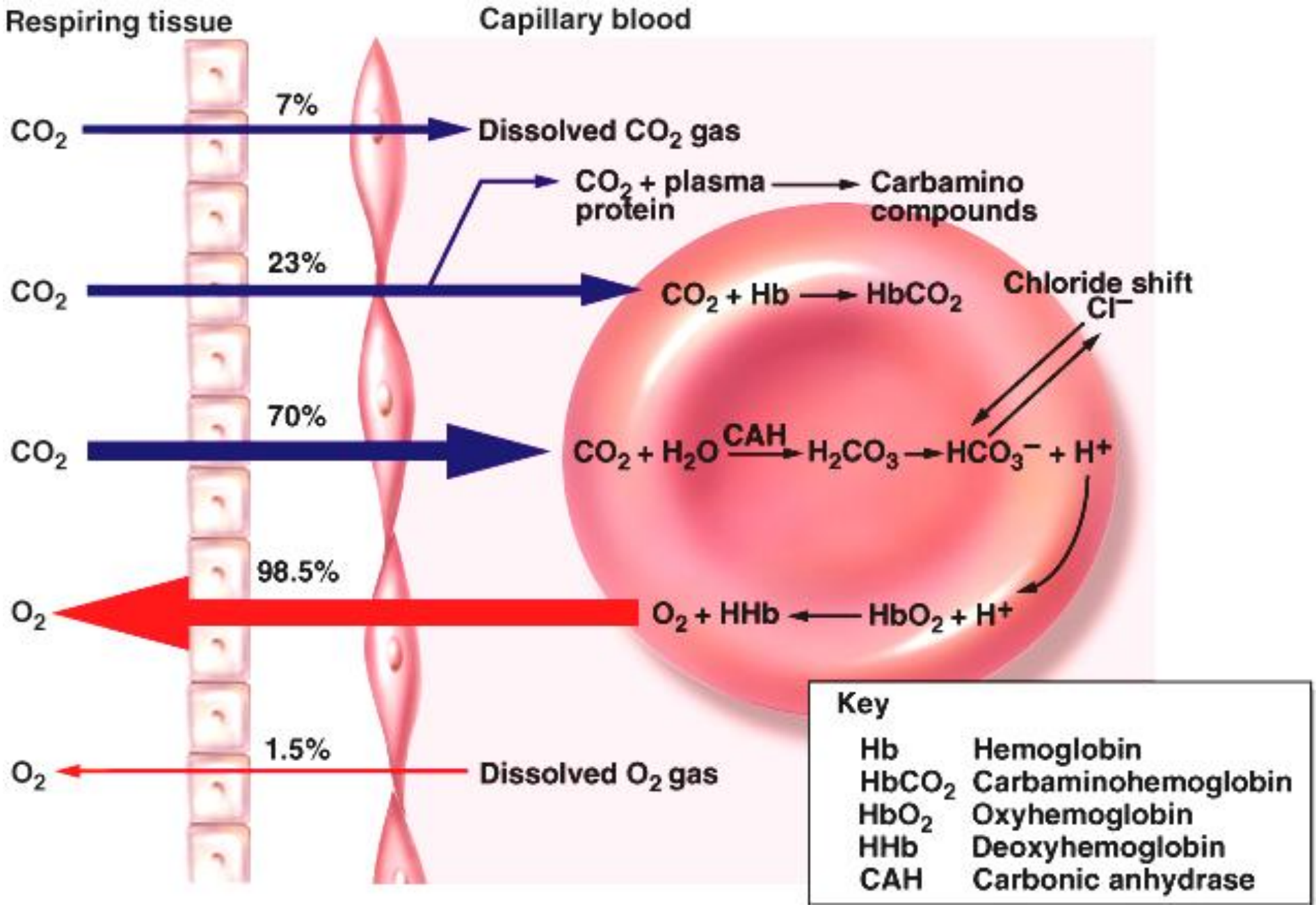
  CO_2 binds to amino groups of Hb (and plasma proteins)

- 5% as **dissolved gas** in water of plasma

Alveolar Gas Exchange



Gas Exchange in Tissues



Carbon Monoxide (CO)

- CO is a colorless, odorless gas that has a higher affinity for Hb than CO_2 or O_2 which makes it lethally toxic at a concentration of only 0.2% in the air.
- Hb is bright red when bound to CO as seen in packaged meats and in the "ruddy" complexion of smokers.
- CO is produced from incomplete combustion, as from a smoldering fire (cigarette) or a kerosene heater used in a closed room.
- CO can be removed from Hb by increasing the ppO_2 as in a hyperbaric chamber.

http://www.washingtonpost.com/wp-dyn/content/article/2007/11/13/AR2007111302016.html