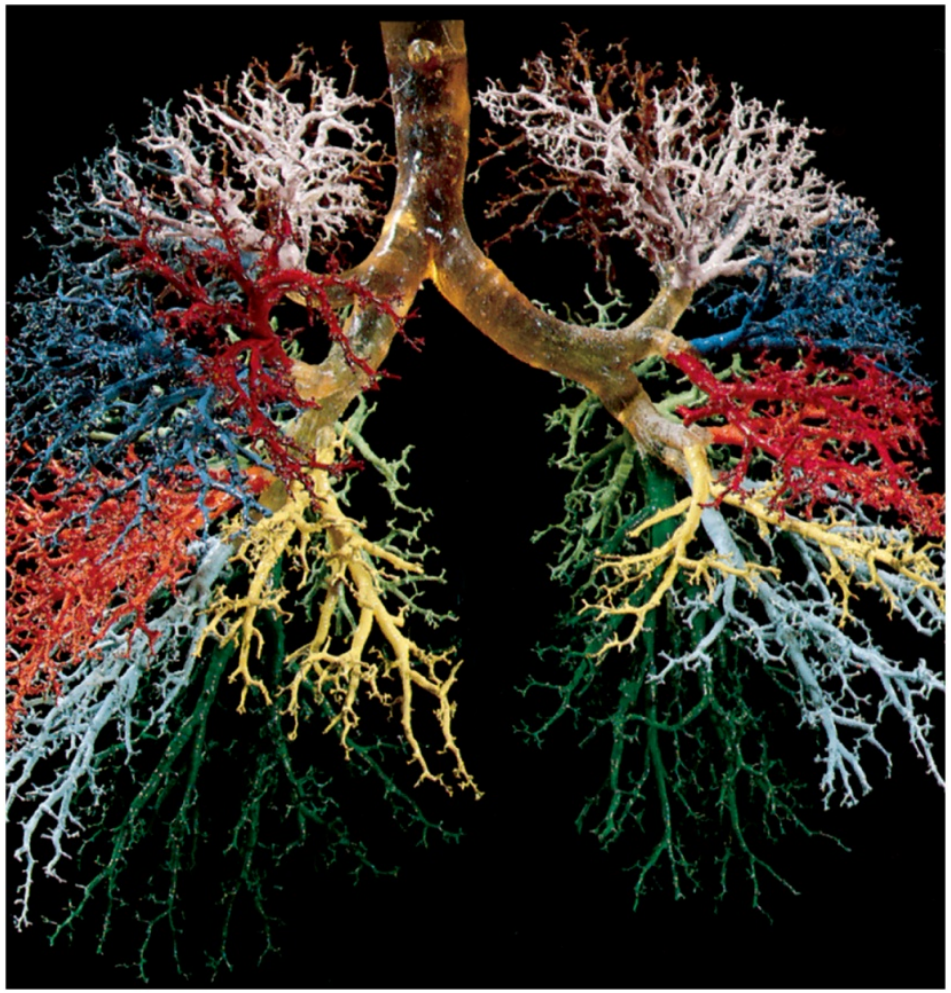
Chapter 23

An Introduction to the Respiratory System



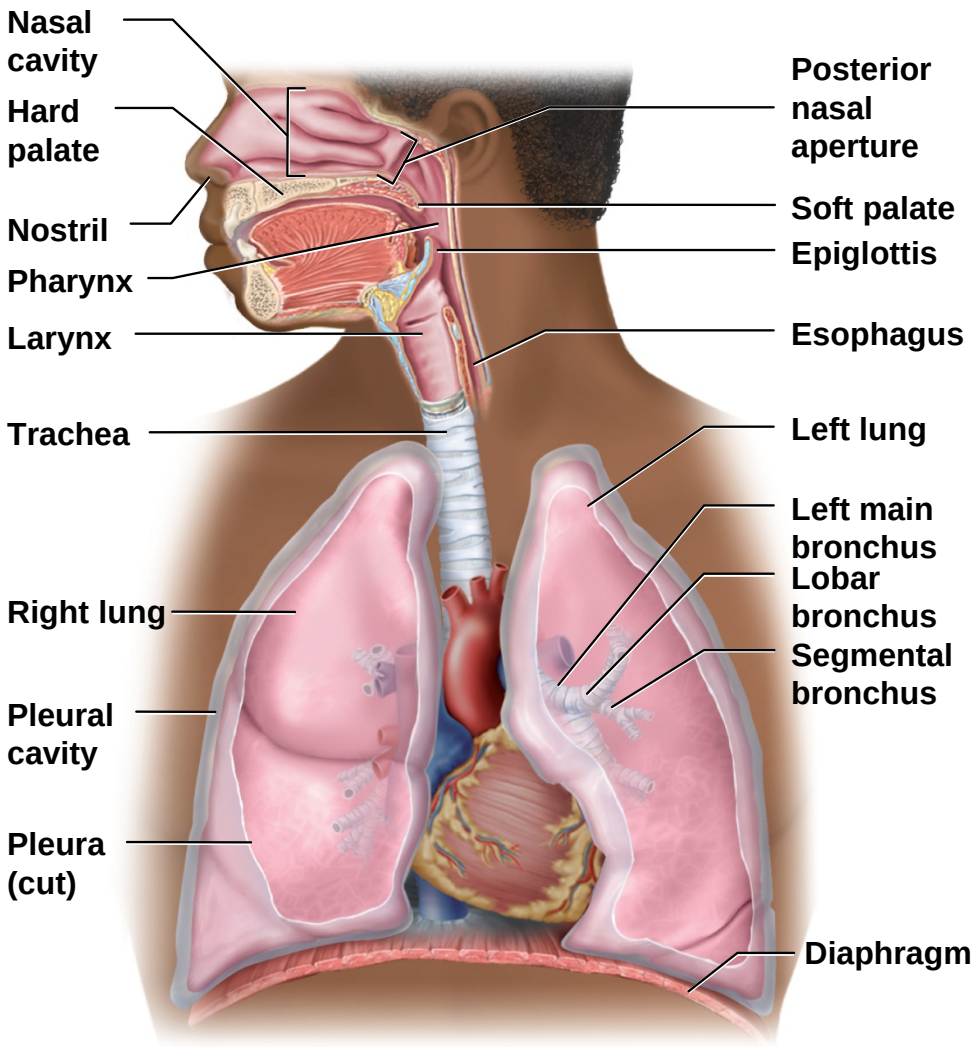
Breathing

- Cellular work requires ATP (molecular money!)
  - ATP synthesis requires oxygen and produces carbon dioxide
  - Carbon dioxide drives the need to breathe // to take in oxygen and eliminate carbon dioxide
- The respiratory system consists of a system of tubes that delivers air to the lung
  - oxygen diffuses into the blood
  - carbon dioxide diffuses out of the blood
  - gasses cross through the “respiratory membrane”

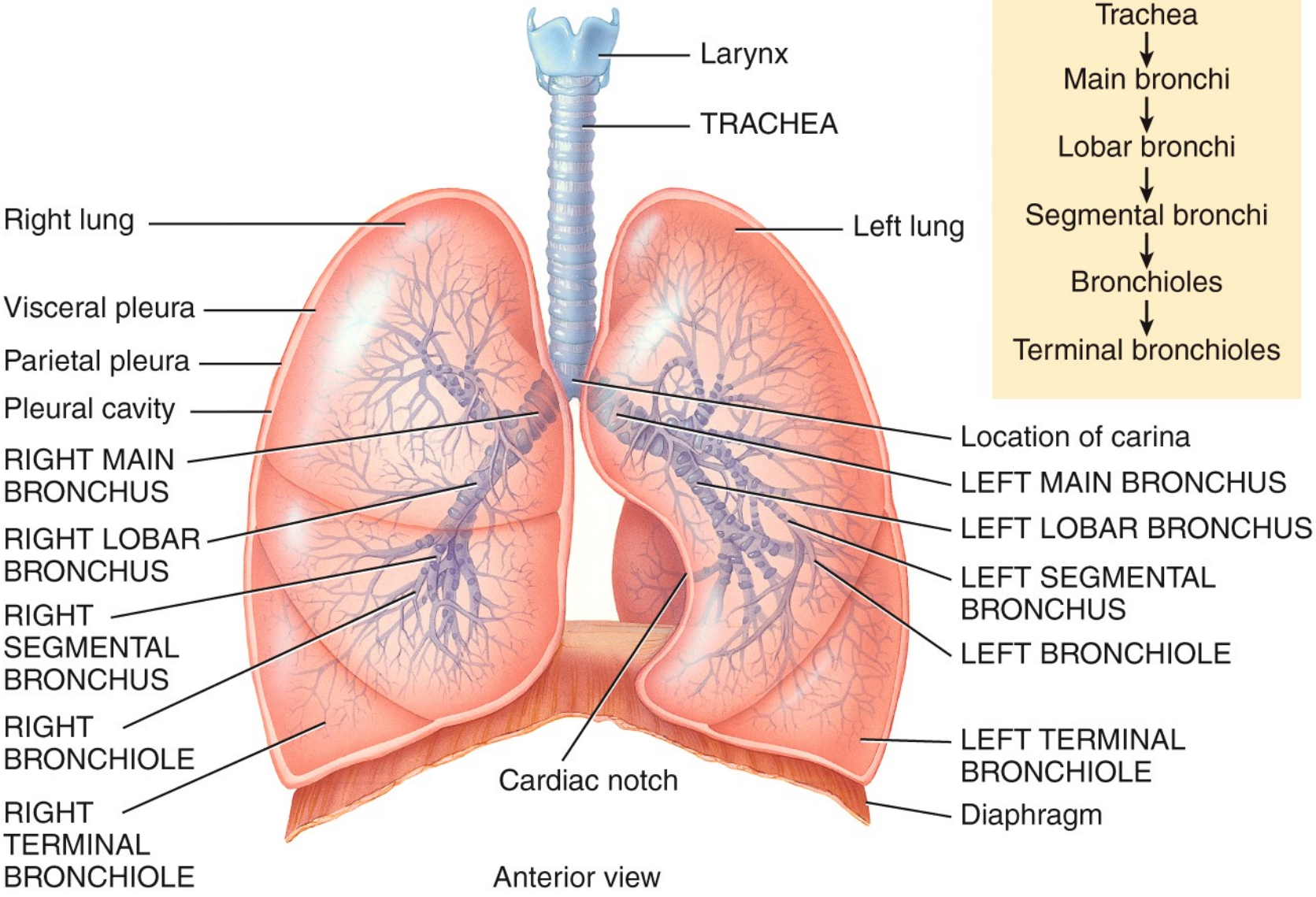
Functions of Respiratory System

- O_2 and CO_2 exchange
- speech and other vocalizations
- sense of smell
- affects pH of body fluids by eliminating CO_2
- affects blood pressure by conversion of vasoconstrictor, angiotensin I to angiotensin II
- breathing creates pressure gradients between thorax and abdomen that promote the flow of lymph and venous blood
- breath-holding helps expel abdominal contents during urination, defecation, and childbirth (Valsalva maneuver)

Organs of Respiratory System



- nose, pharynx, larynx, trachea, bronchi, lungs



BRANCHING OF BRONCHIAL TREE

Trachea
↓
Main bronchi
↓
Lobar bronchi
↓
Segmental bronchi
↓
Bronchioles
↓
Terminal bronchioles

Breathing

- respiratory and cardiovascular systems work together to deliver oxygen to the tissues and remove carbon dioxide
  - considered jointly as cardiopulmonary system
  - disorders of lungs directly effect the heart and vise versa
- respiratory system and the urinary system collaborate to regulate the body's acid base balance

Principal Organs of Respiratory System

- incoming air stops in the alveoli of the lungs
    - millions of thin-walled, microscopic air sacs
    - exchanges gases with the bloodstream through the alveolar wall, and then flows back out
- conducting division of the respiratory system
    - those passages that serve only for airflow
    - no gas exchange
    - nostrils through major bronchioles
- respiratory division of the respiratory system
    - consists of alveoli and other gas exchange regions

Principal Organs of Respiratory System

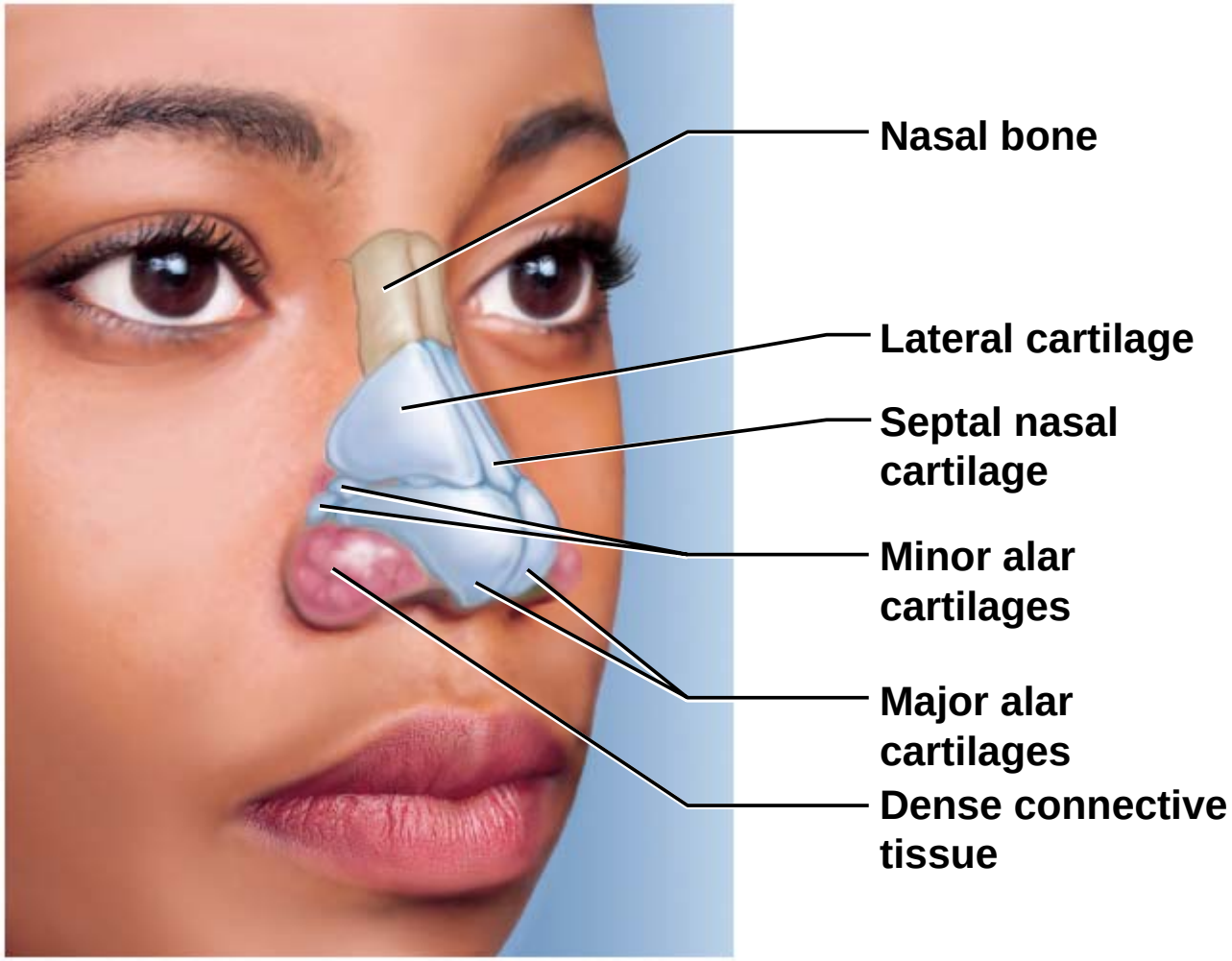
- upper respiratory tract
  - in head and neck
  - nose through laryngopharynx

- lower respiratory tract
  - organs of the thorax
  - larynx through alveoli

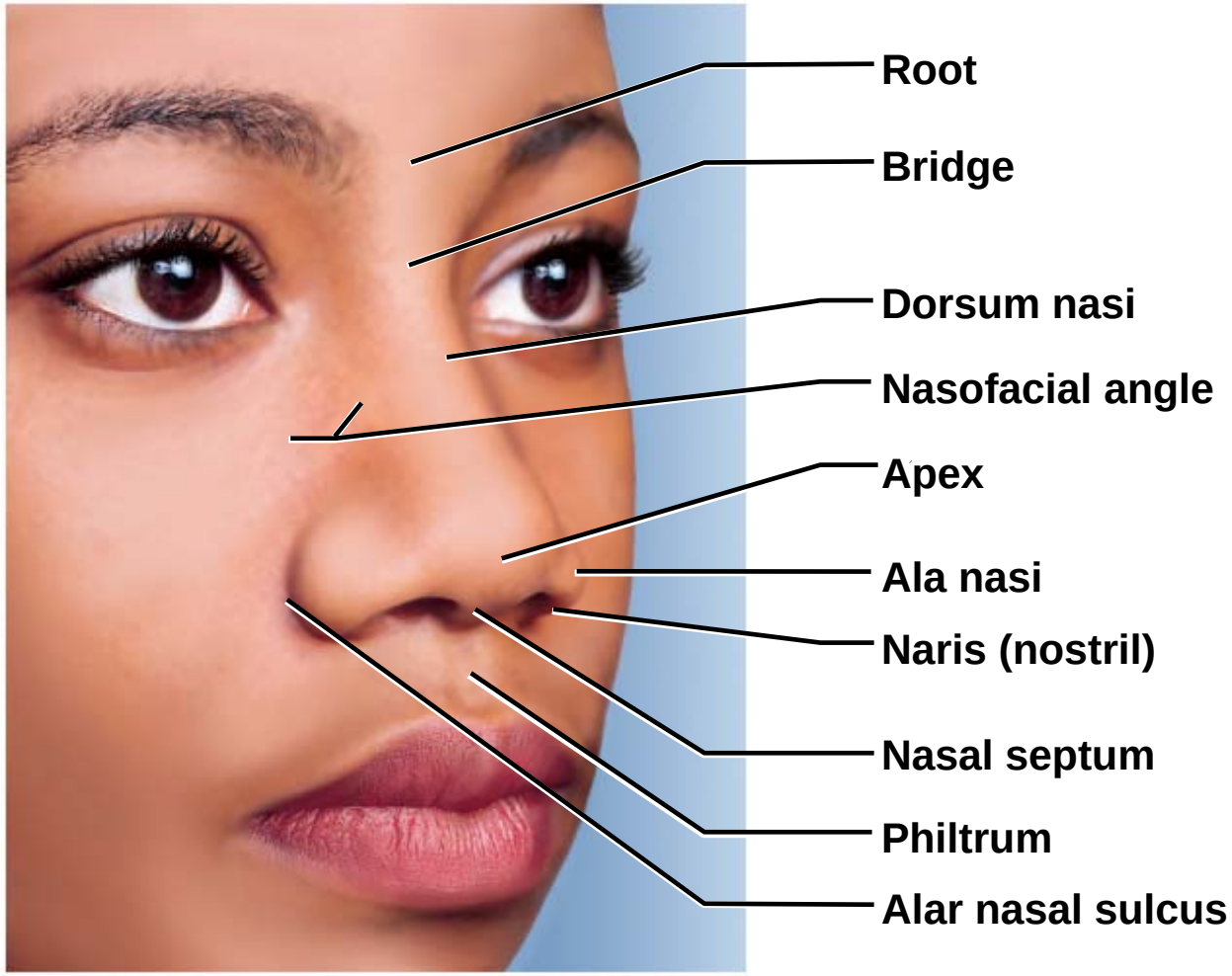
The Nose

- functions of the nose // warms, cleanses, and humidifies inhaled air
  - detects odors in the airstream
  - serves as a resonating chamber that amplifies the voice
- nose extends from nostrils (nares), to a pair of posterior openings called the posterior nasal apertures (choanae)
- facial part is shaped by bone and hyaline cartilage
  - superior half nasal bones and maxillae
  - inferior half lateral and alar cartilages
  - ala nasi – flared portion at the lower end of nose shaped by alar cartilages and dense connective tissue

Anatomy of Nasal Region



Anatomy of Nasal Region



Nasal Cavity

- vestibule – beginning of nasal cavity – small dilated chamber just inside nostrils
  - lined with stratified squamous epithelium
  - vibrissae – stiff guard hairs that block insects and debris from entering nose
- posteriorly the nasal cavity expands into a larger chamber with not much open space.

Nasal Cavity

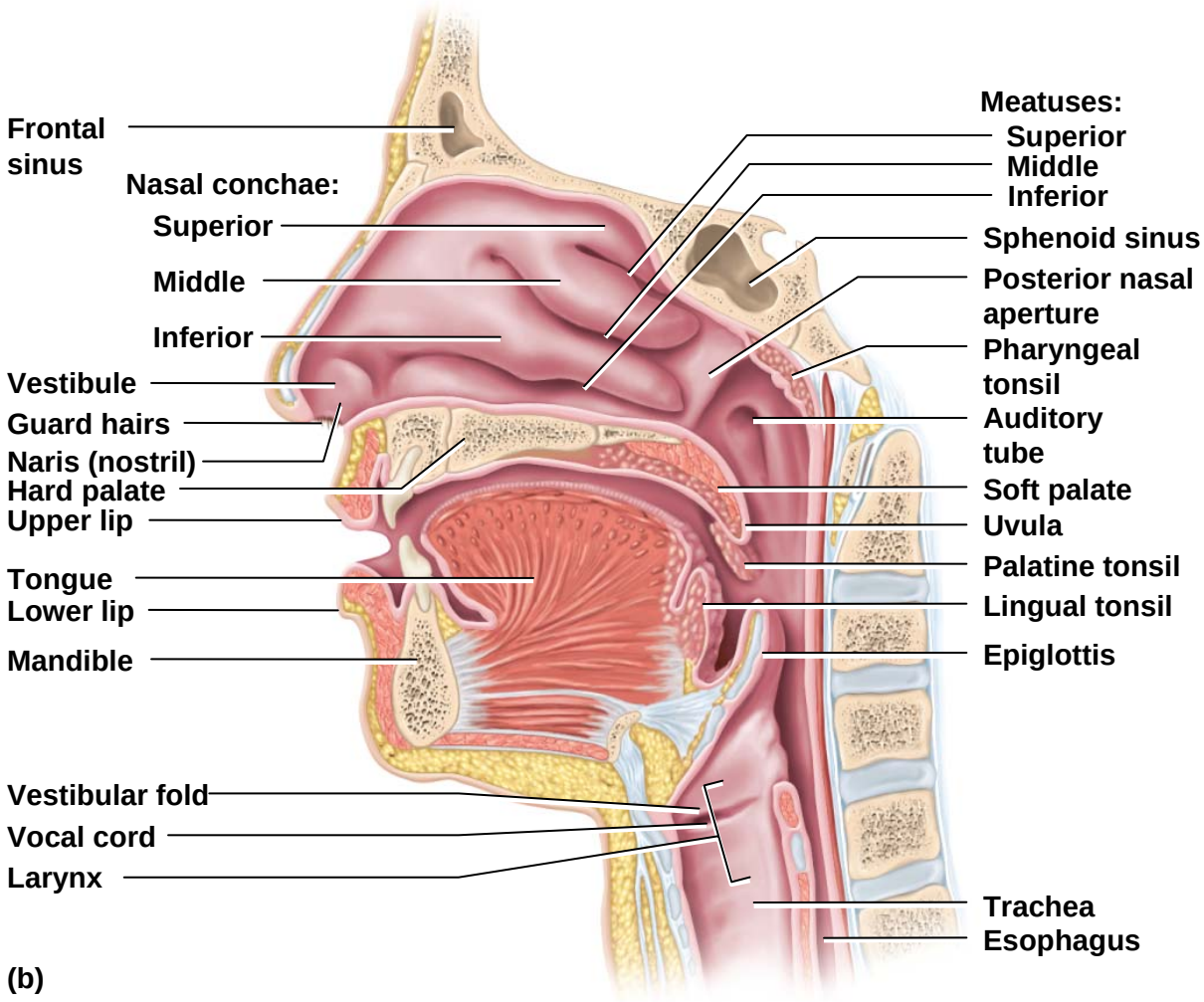
- **nasal conchae**
  - nasal cavity occupied by three folds of tissue /// **superior, middle, and inferior nasal conchae** (turbinates)
    - project from lateral walls toward septum
    - **meatus** – narrow air passage beneath each concha
    - narrowness and turbulence insure that most air contacts mucous membranes
    - cleans, warms, and moistens the air

Nasal Cavity

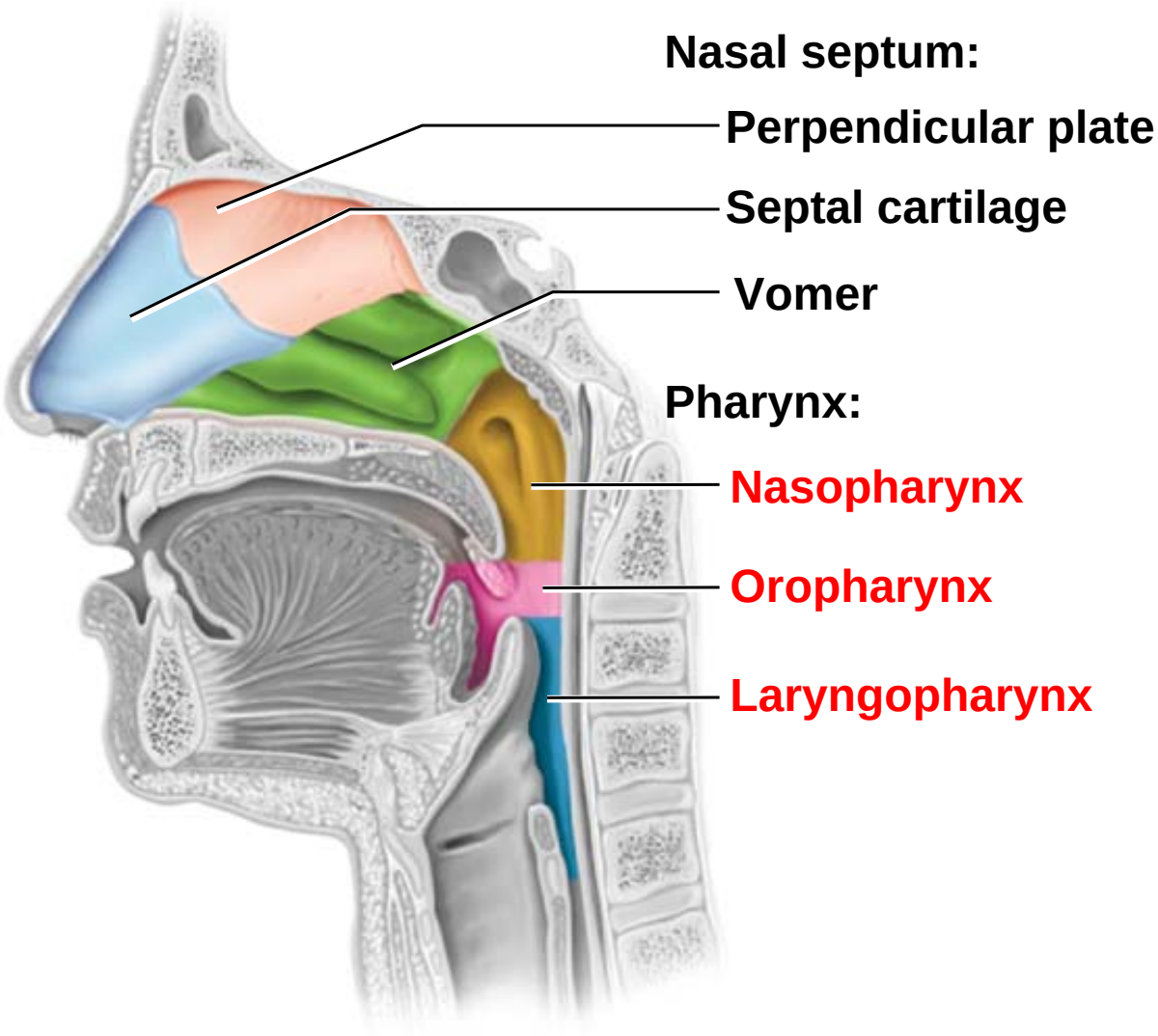
- respiratory epithelium lines rest of nasal cavity except vestibule
  - ciliated pseudostratified columnar epithelium with goblet cells // cilia are motile
  - goblet cells secrete mucus and cilia propel the mucous posteriorly toward pharynx /// swallow into digestive tract
- olfactory epithelium // detect odors
  - covers a small area of the roof of the nasal fossa and adjacent parts of the septum and superior concha
  - ciliated pseudostratified columnar epithelium with goblet cells
  - immobile cilia to bind odorant molecules

Upper Respiratory Tract

(respiratory organs in the head and neck / stop at entrance to larynx)



Regions of Pharynx



Pharynx = a muscular funnel extending about 13 cm (5 in.) from the choanae to the larynx

- pharynx (throat) –three regions of pharynx
  - nasopharynx
    - posterior to nasal apertures and above soft palate
    - receives auditory tubes and contains pharyngeal tonsil
    - 90° downward turn traps large particles (>10μm)
  - oropharynx
    - space between soft palate and epiglottis
    - contains palatine tonsils
  - laryngopharynx
    - epiglottis to cricoid cartilage
    - esophagus begins at that point

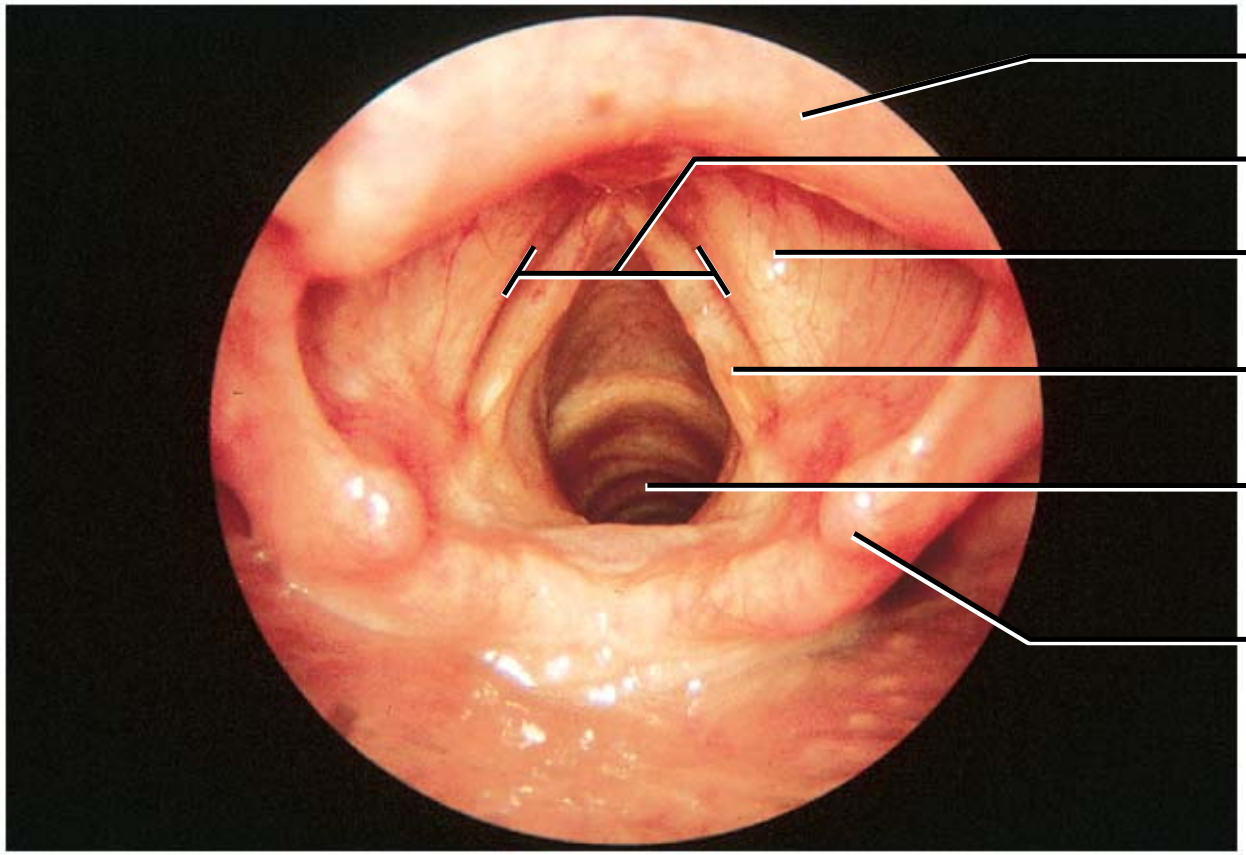
Pharynx

- **nasopharynx**
  - passes only air and is lined by **pseudostratified columnar epithelium**
- **oropharynx** and **laryngopharynx**
  - pass air, food, and drink and are lined by **stratified squamous epithelium**

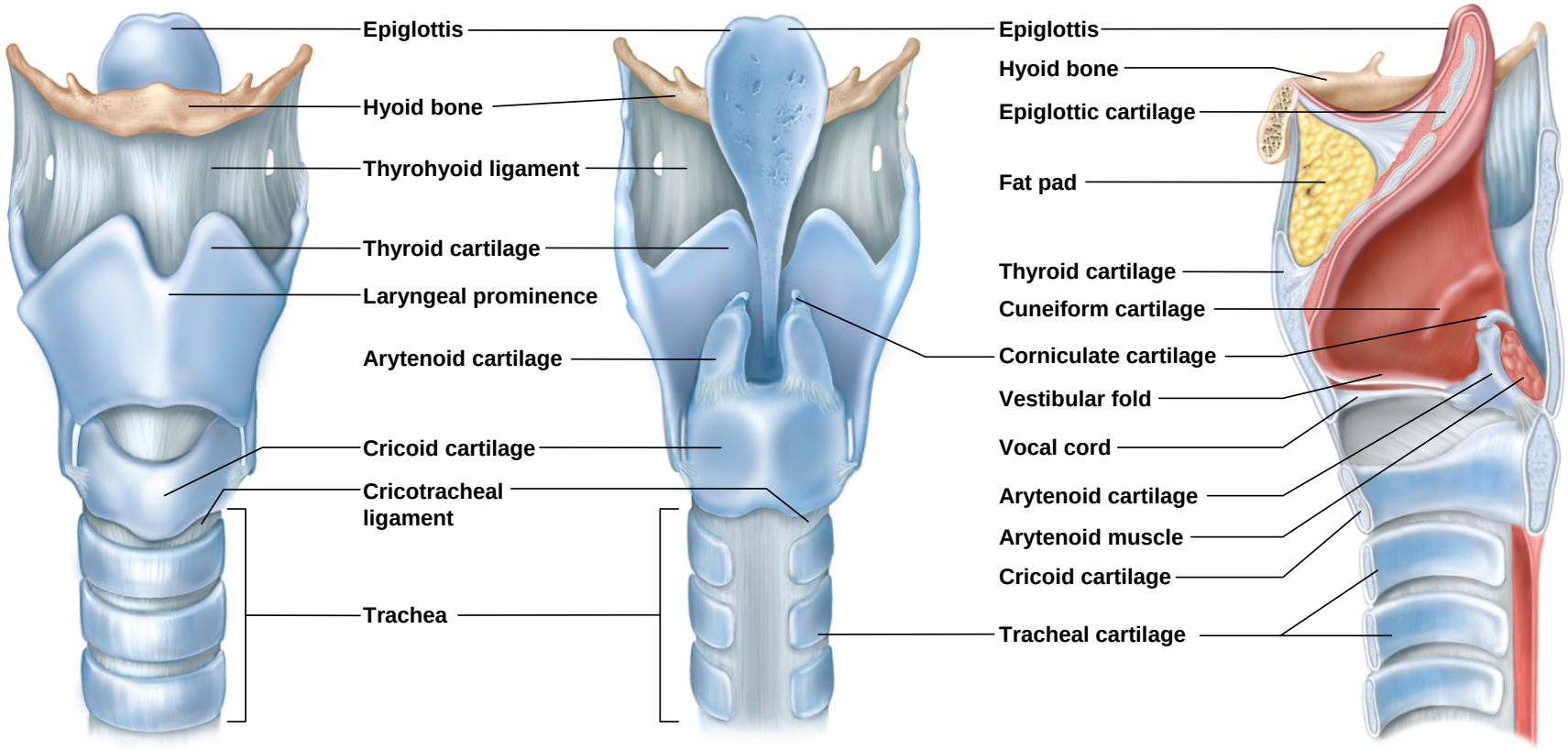
Larynx

- larynx (voice box) – cartilaginous chamber about 4 cm (1.5 in.)
- primary function is to keep food and drink out of the airway
- has evolved to additional role – phonation – production of sound
- epiglottis – flap of tissue that guards the superior opening of the larynx
  - at rest, stands almost vertically
  - during swallowing, extrinsic muscles of larynx pull larynx upward
  - tongue pushes epiglottis down to meet it
  - closes airway and directs food to the esophagus behind it
  - vestibular folds of the larynx play greater role in keeping food and drink out of the airway

Endoscopic View of the Larynx



Views of Larynx



(a) Anterior (b) Posterior (c) Median

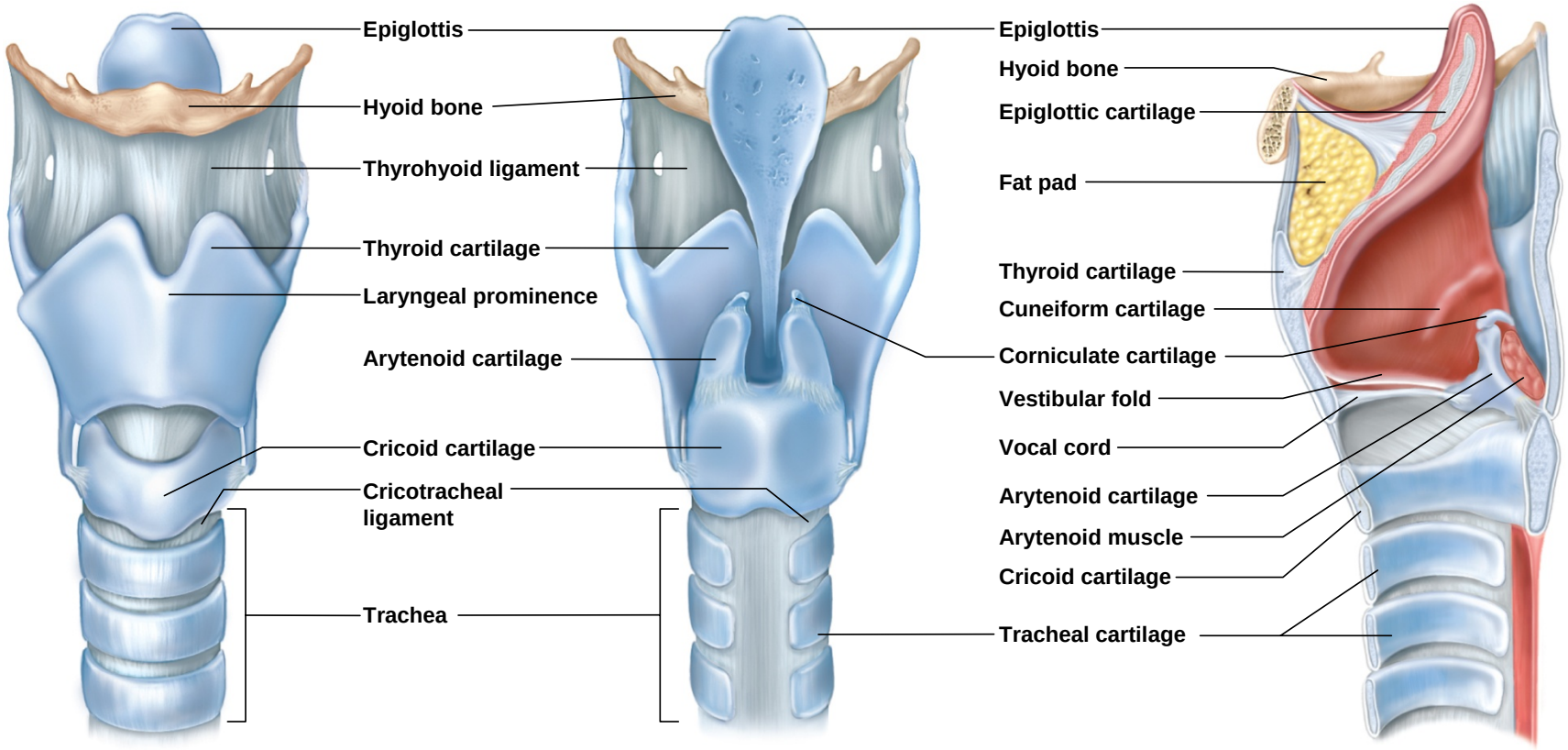
Larynx (1 of 2)

- nine cartilages that make up framework of larynx
- first three are solitary and relatively large
  - epiglottic cartilage – spoon-shaped supportive plate in epiglottis most superior one
  - thyroid cartilage – largest, laryngeal prominence (Adam's apple) shield-shaped
    - testosterone stimulated growth, larger in males
  - cricoid cartilage - connects larynx to trachea, ringlike

Larynx (2 of 2)

- three smaller, paired cartilages
  - **arytenoid cartilages** (2) - posterior to thyroid cartilage
  - **corniculate cartilages** (2) - attached to arytenoid cartilages like a pair of little horns
  - **cuneiform cartilages** (2) - support soft tissue between arytenoids and epiglottis

Views of Larynx



(a) Anterior (b) Posterior (c) Median

Walls of the Larynx (1 of 3)

- walls of larynx are quite muscular
  - deep **intrinsic muscles** operate the vocal cords
  - superior **extrinsic muscles** connect the larynx to hyoid bone
    - elevate the larynx during swallowing
    - infrahyoid group

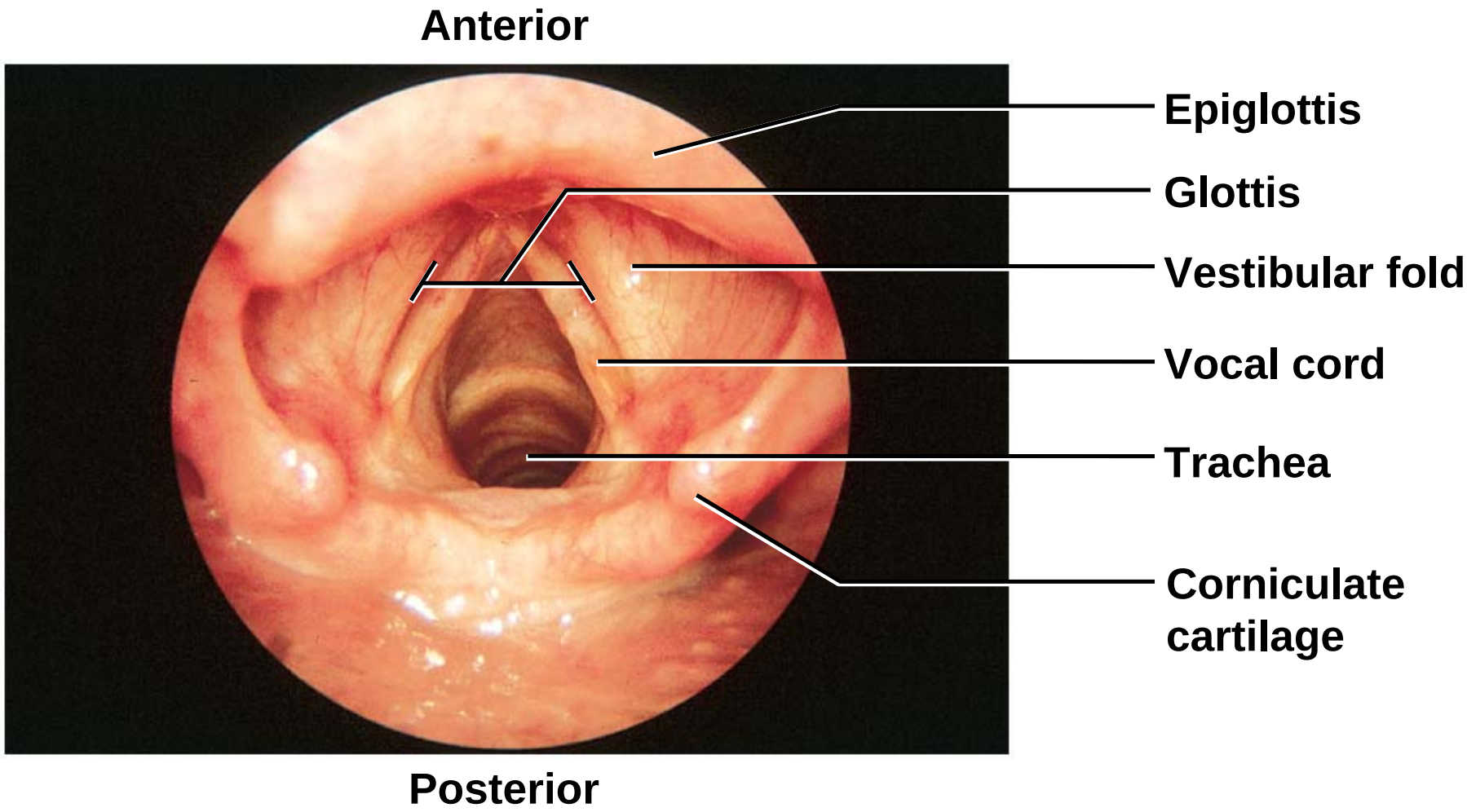
Walls of the Larynx (2 of 3)

- interior wall has **two folds** on each side that extend from thyroid cartilage in front to arytenoid cartilages in the back
  - superior **vestibular folds**
    - play no role in speech
    - close the larynx during swallowing

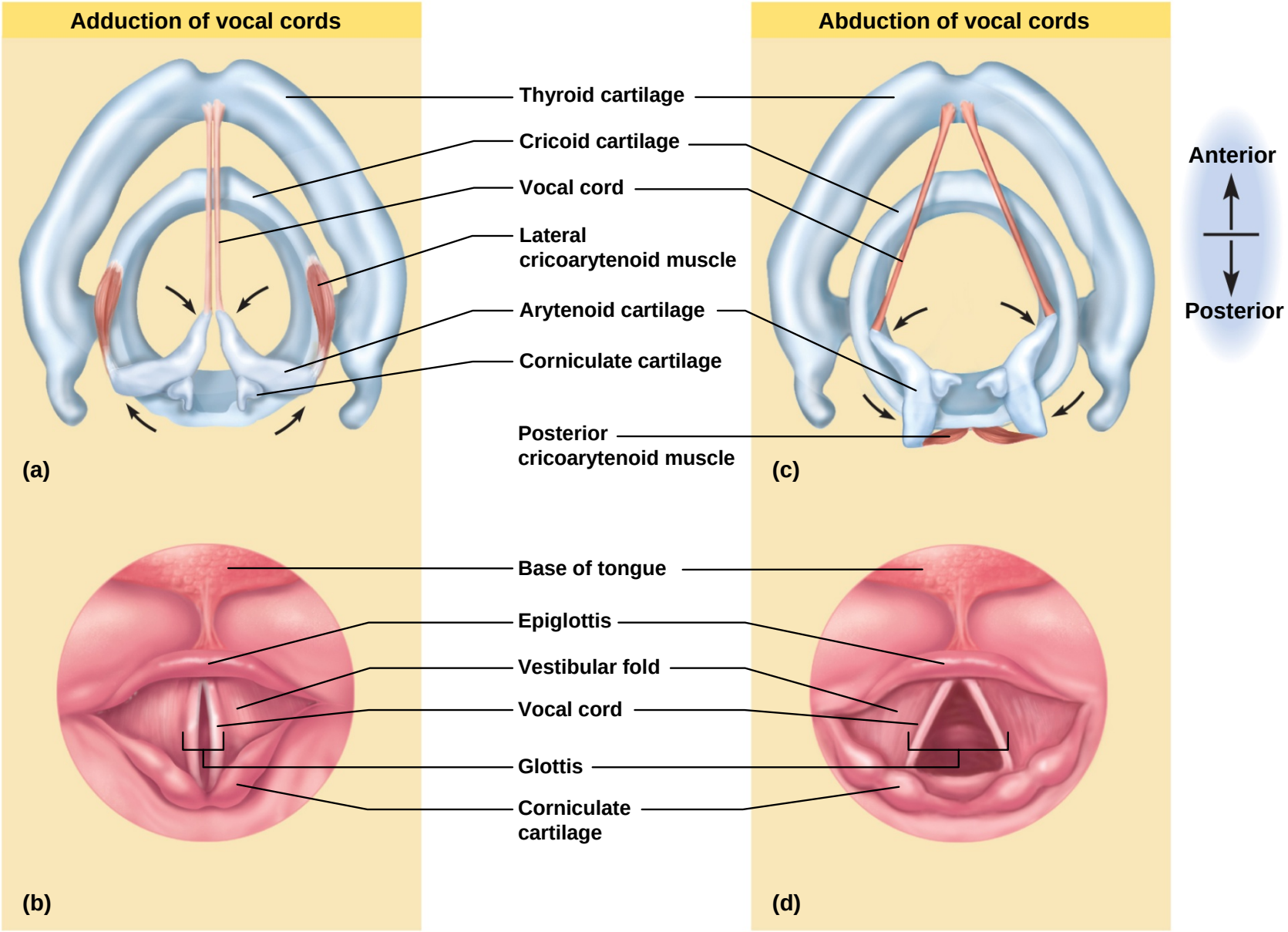
Walls of the Larynx (3 of 3)

- inferior **vocal cords**
  - produce sound when air passes between them
  - contain vocal ligaments
  - covered with stratifies squamous epithelium
    - best suited to endure vibration and contact between the cords
  - **glottis** – the vocal cords and the opening between them

Endoscopic View of the Larynx



Action of Vocal Cords



Action of Vocal Cords

- intrinsic muscles control the vocal cords
  - pull on the corniculate and arytenoid cartilages
  - causing the cartilages to pivot
  - abduct or adduct vocal cords, depending on direction of rotation
  - air forced between adducted vocal cords // vibrates them
  - producing high pitched sound when cords are taut
  - produce lower-pitched sound when cords are more slack
  - adult male vocal cords are:
    - usually longer and thicker
    - vibrate more slowly
    - produce lower pitched sound
  - loudness – determined by the force of air passing between the vocal cords
  - vocal cords produce **crude sounds** <u>that are formed into words by actions of pharynx, oral cavity, tongue, and lips</u>

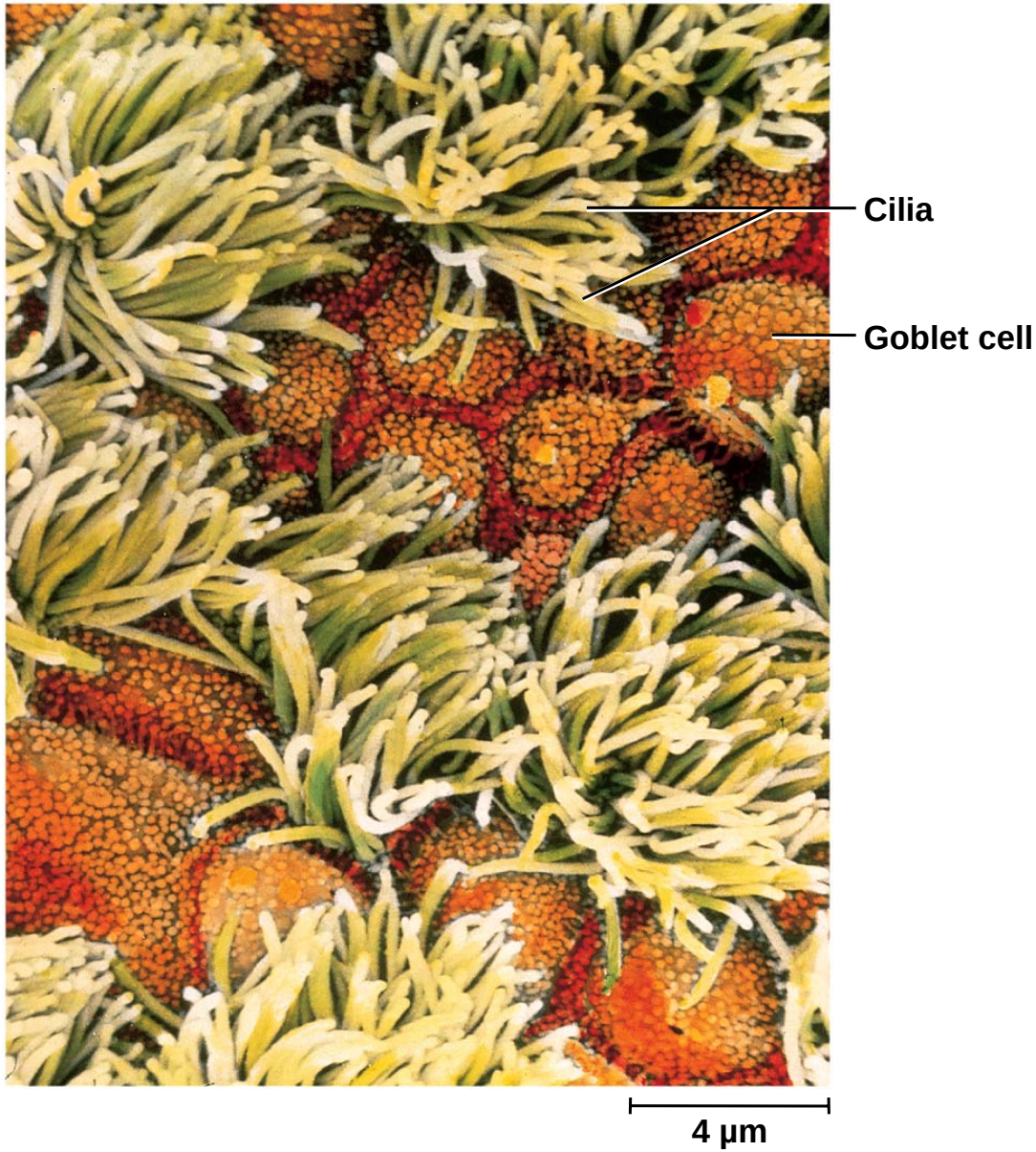
Trachea (1 of 2)

- **trachea** (windpipe) – a rigid tube about 12 cm (4.5 in.) long and 2.5 cm (1 in.) in diameter
  - found anterior to esophagus
  - supported by 16 to 20 **C-shaped** rings of **hyaline cartilage**
  - reinforces the trachea and keeps it from collapsing when you inhale
  - opening in rings faces posteriorly towards esophagus
  - **trachealis muscle** spans opening in rings
    - gap in C allows room for the esophagus to expand as swallowed food passes by
    - contracts or relaxes to adjust air flow

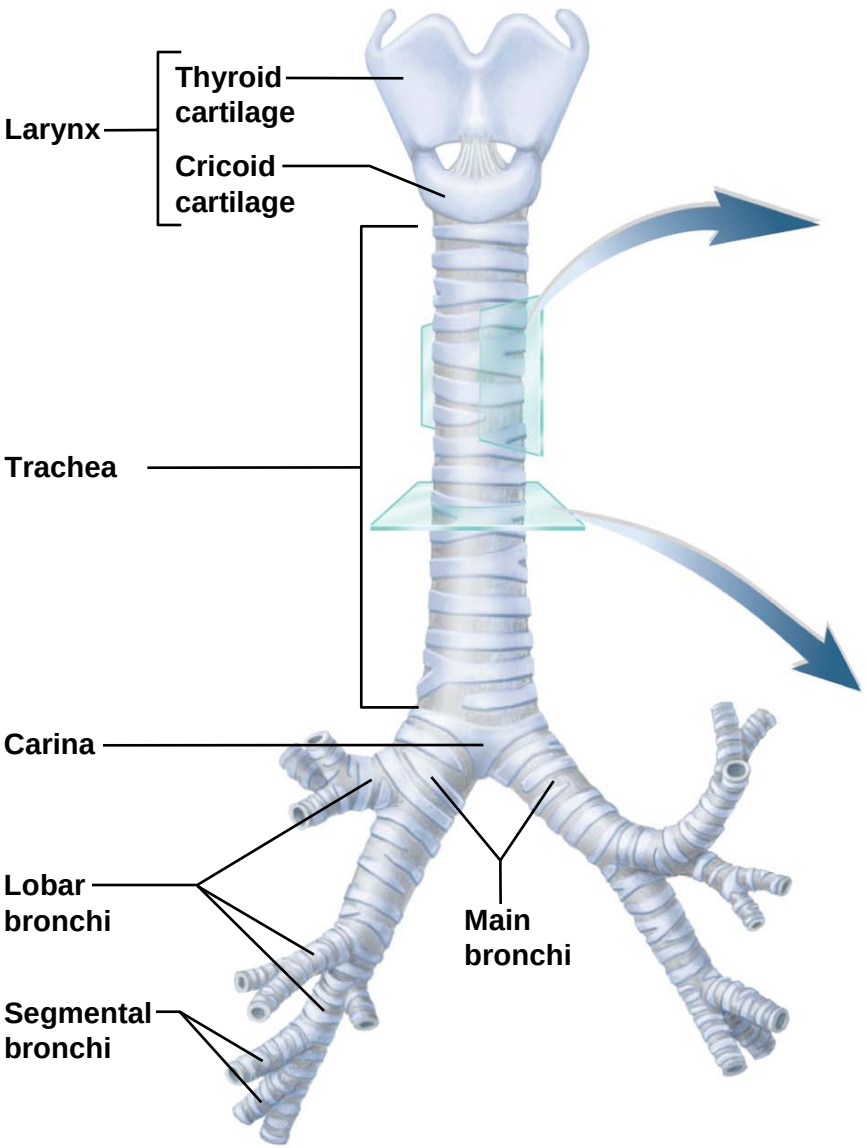
Trachea (2 of 2)

- inner lining of trachea is a ciliated pseudostratified columnar epithelium
  - composed mainly of mucus-secreting cells, ciliated cells, and stem cells
  - mucociliary escalator – mechanism for debris removal
    - mucus traps inhaled particles
    - upward beating cilia drives mucus toward pharynx where it is swallowed
- right and left main bronchi
  - trachea forks at level of sternal angle /// carina – internal medial ridge in the lowermost tracheal cartilage
    - directs the airflow to the right and left

Tracheal Epithelium



Lower Respiratory Tract



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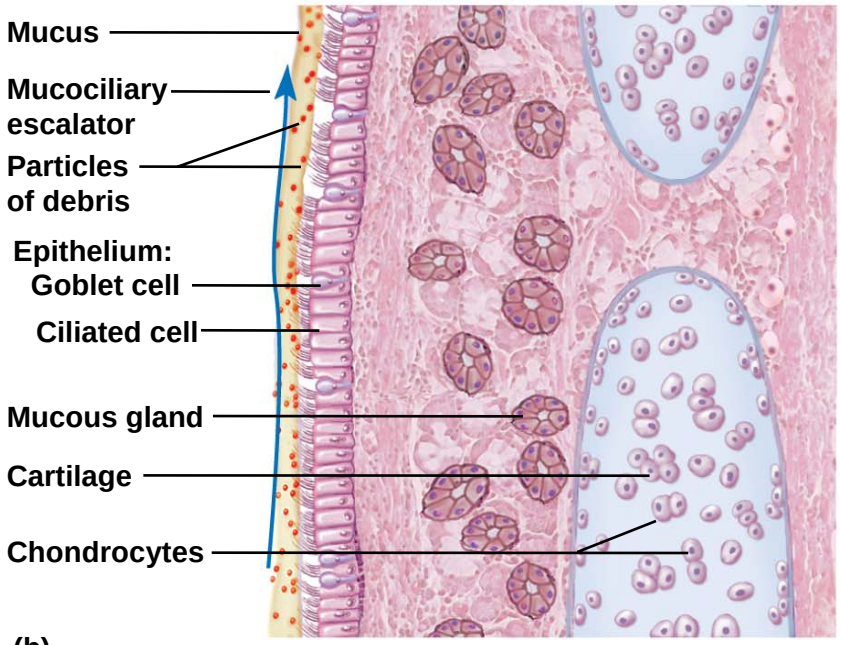

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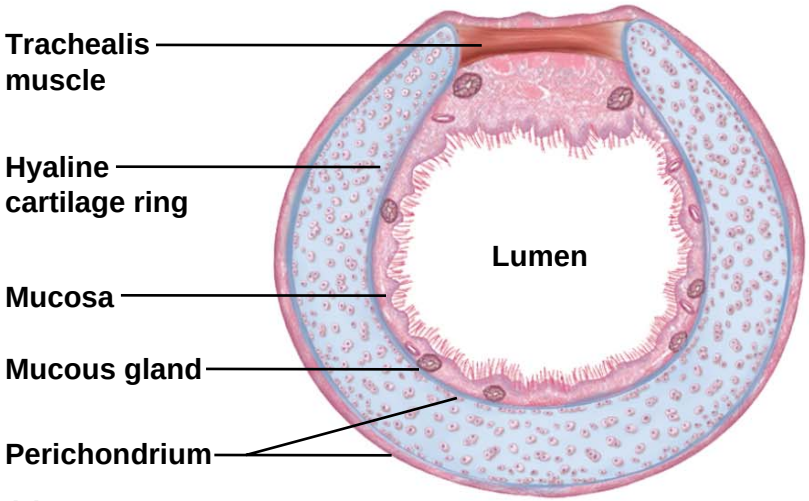
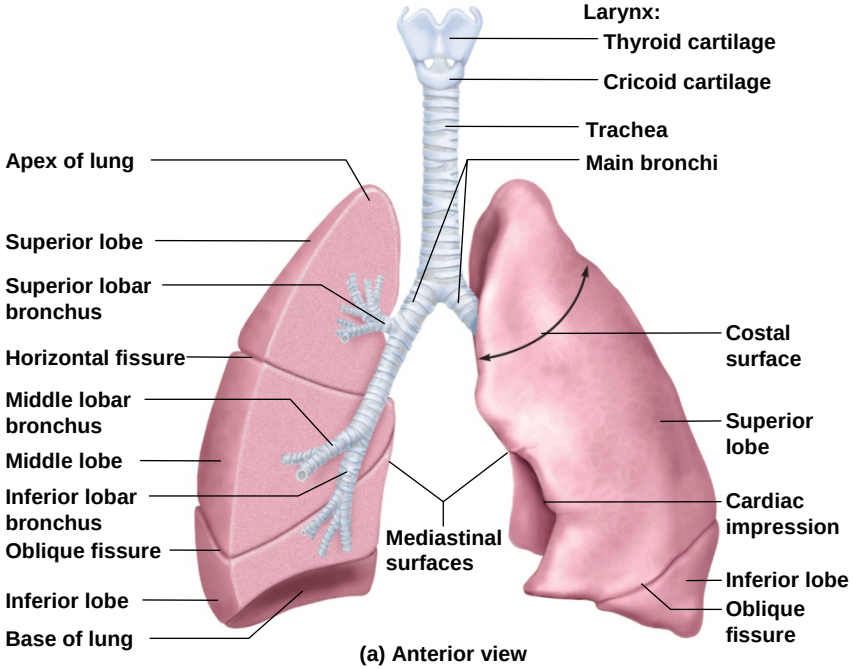
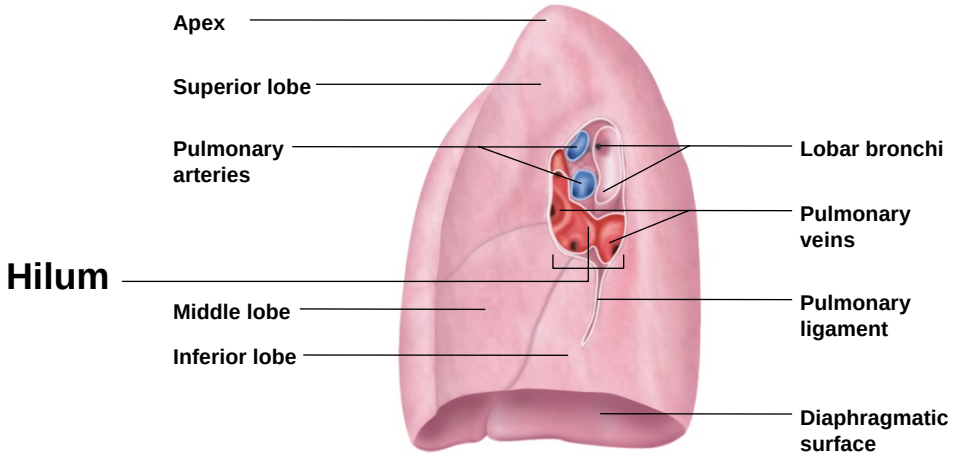


(c)

Lungs - Surface Anatomy

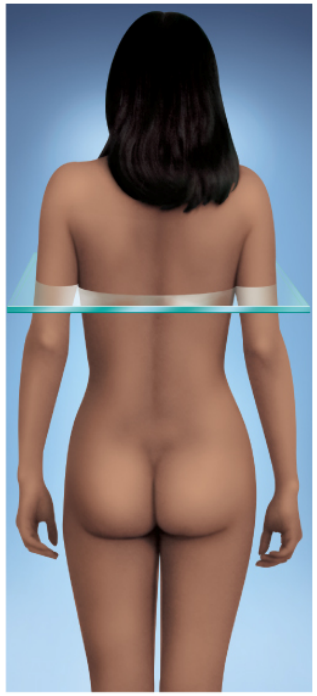


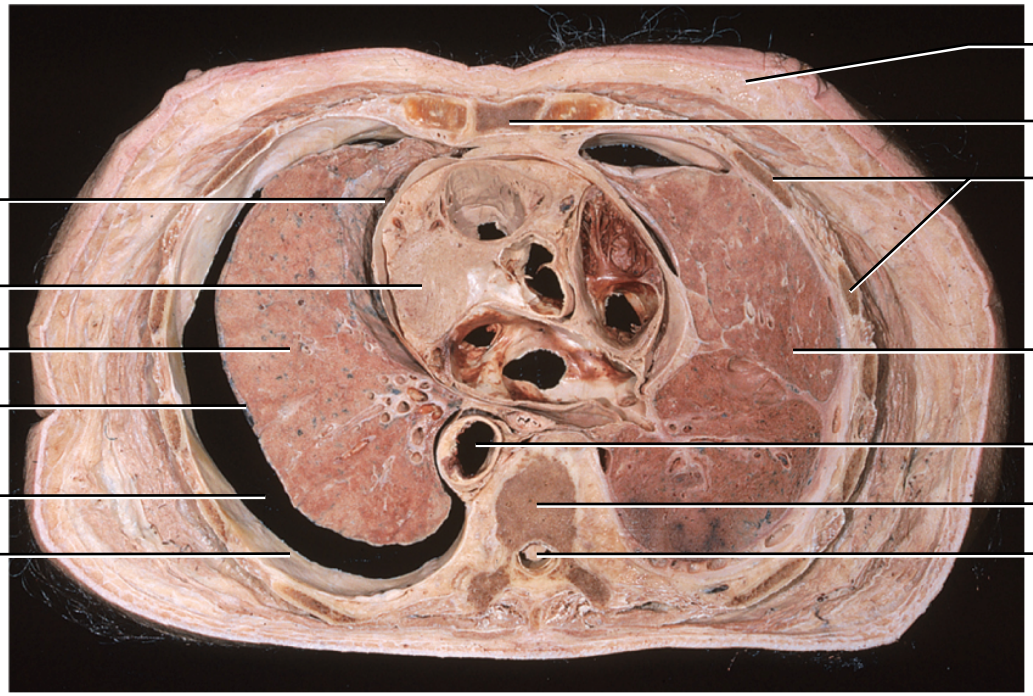
(a) Anterior view



(b) Mediastinal surface, right lung

Thorax - Cross Section





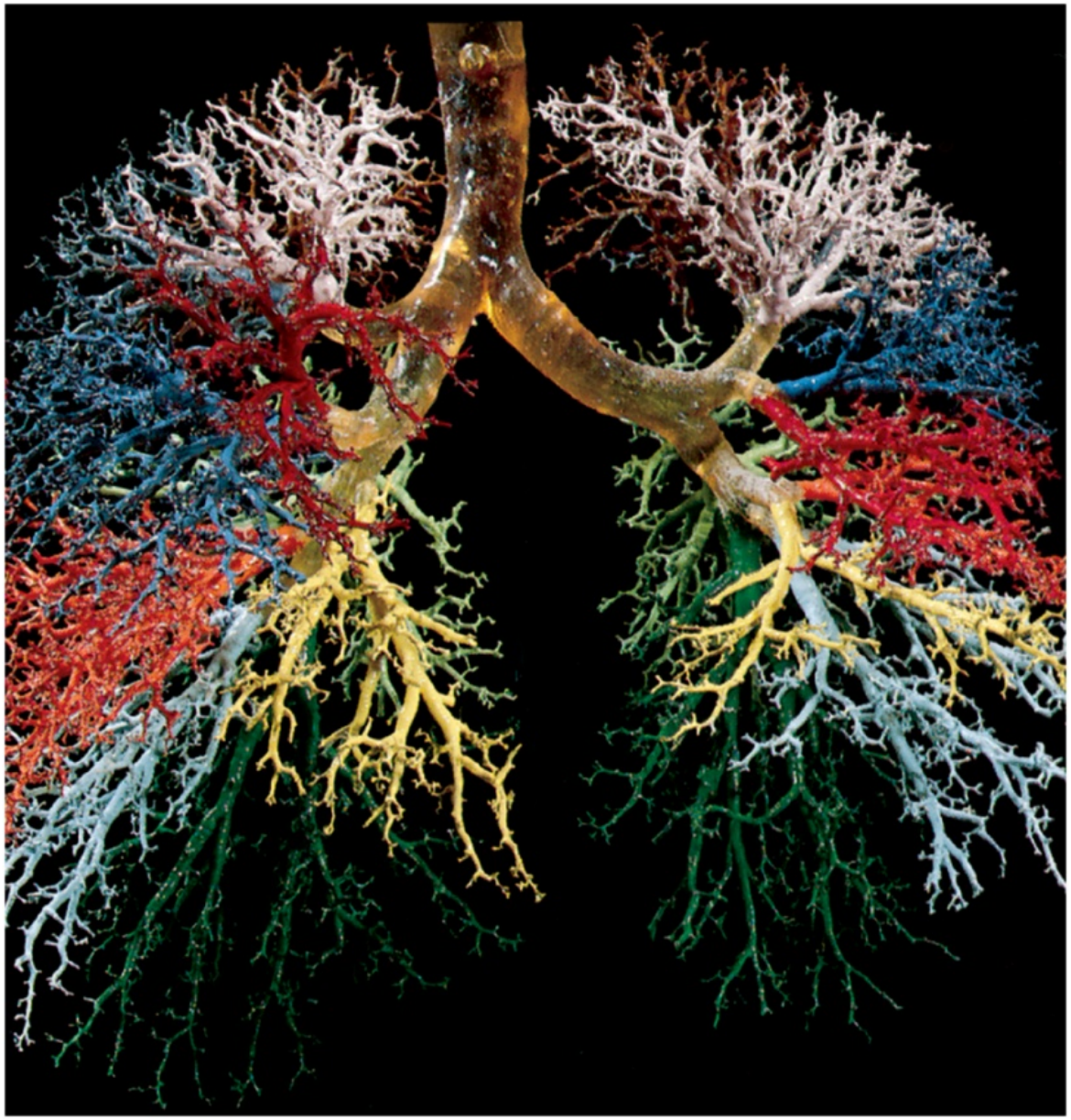
Lungs

- conical organ with a broad, concave base, resting on the diaphragm, and a blunt peak called the apex projecting slightly above the clavicle
  - costal surface – pressed against the ribcage
  - mediastinal surface – faces medially toward the heart
    - hilum – slit through which the lung receives the main bronchus, blood vessels, lymphatics and nerves
    - these structures constitute the root of the lung

Lungs

- crowded by adjacent organs, neither fill the entire ribcage, nor are they symmetrical.
  - right lung
    - shorter than left because the liver rises higher on the right
    - has three lobes – superior, middle, and inferior separated by horizontal and oblique fissure
  - left lung
    - taller and narrower because the heart tilts toward the left and occupies more space on this side of mediastinum
    - has indentation – cardiac impression
    - has two lobes – superior and inferior separated by a single oblique fissure

Bronchial Tree (Main / Lobar / Segmental)



Bronchial Tree (Main / Lobar / Segmental)

- bronchial tree – a branching system of air tubes in each lung
  - from one main bronchus extends 65,000 terminal bronchioles

- main (primary) bronchi – supported by c-shaped hyaline cartilage rings
  - rt. main bronchus is a 2-3 cm branch arising from fork of trachea
    - right bronchus slightly wider and more vertical than left
    - aspirated (inhaled) foreign objects lodge right bronchus more often the left
  - lt. main bronchus is about 5 cm long /// slightly narrower and more horizontal than the right

Bronchial Tree (Main / Lobar / Segmental)

- lobar (secondary) bronchi – supported by crescent shaped cartilage plates
  - three rt. lobar bronchi – superior, middle, and inferior
    - one to each lobe of the right lung
  - two lt. lobar bronchi - superior and inferior
    - one to each lobe of the left lung
- segmental (tertiary) bronchi - supported by crescent shaped cartilage plates
  - 10 on right, and 8 on left
  - bronchopulmonary segment –functionally independent unit of the lung tissue

Bronchial Tree (Main / Lobar / Segmental)

- all bronchi are lined with ciliated pseudostratified columnar epithelium
  - lamina propria has an abundance of mucous glands and lymphocyte nodules (bronchus-associated lymphoid tissue, BALT)
  - all divisions of bronchial tree have a large amount of elastic connective tissue /// contributes to the recoil that expels air from lungs
  - mucosa also has a well-developed layer of smooth muscle /// muscularis mucosae which contracts or relaxes to constrict or dilate the airway, regulating air flow

The Distal Bronchiole Tree

(Bronchioles / Terminal Bronchioles / Respiratory Bronchioles)

- **Bronchioles**
  - **<u>lack cartilage</u>**
  - 1 mm or less in diameter
  - **pulmonary lobule -** portion of lung ventilated by one bronchiole
  - have ciliated cuboidal epithelium
  - mucus glands
  - well developed layer of smooth muscle

The Distal Bronchiole Tree

(Bronchioles / Terminal Bronchioles / Respiratory Bronchioles)

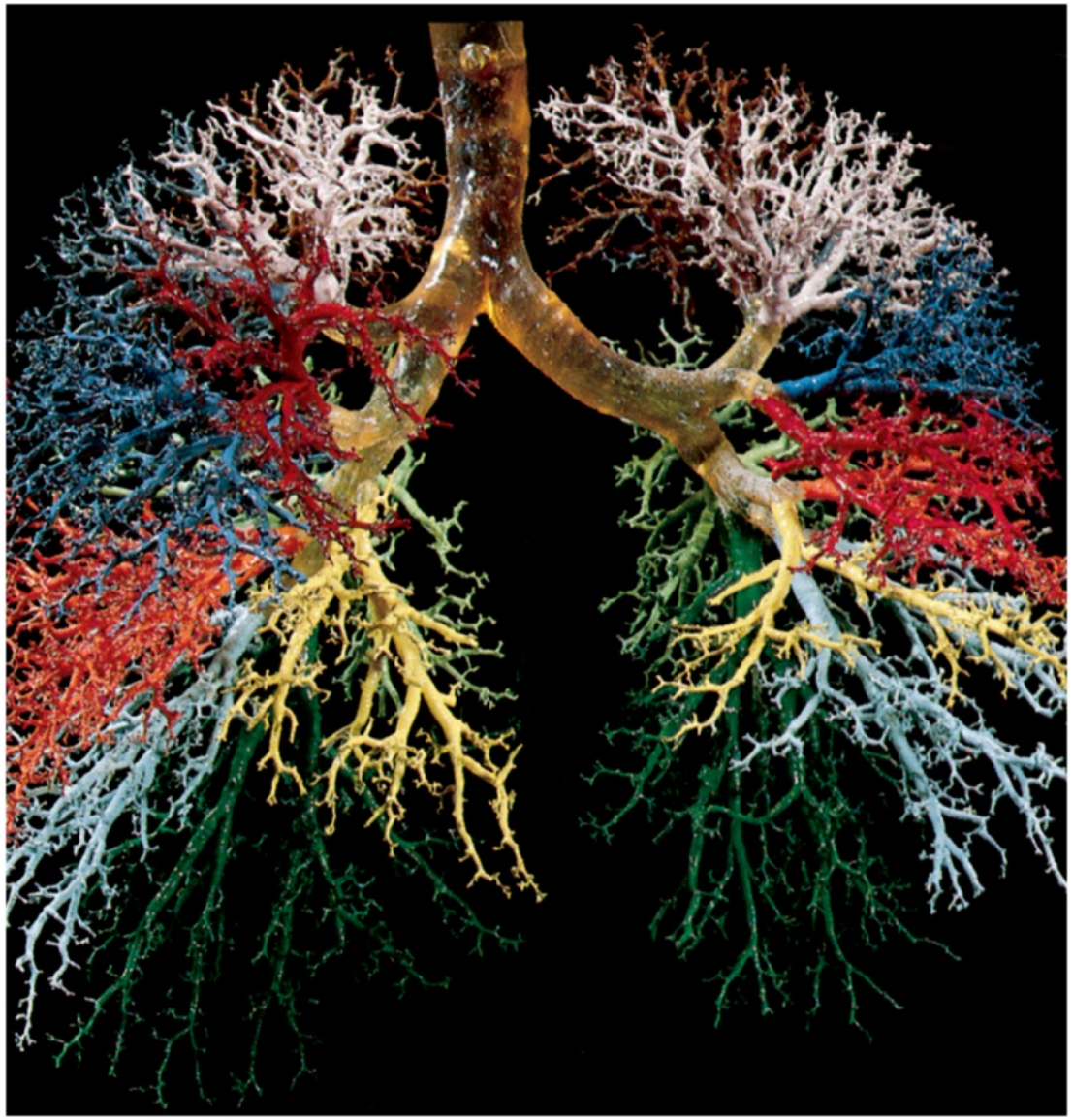
- **Terminal bronchioles**
  - divides into 50 - 80 branches
  - final branches of conducting division
  - measure 0.5 mm or less in diameter
  - have **no mucous glands** or goblet cells
  - **have cilia** // move mucus draining into them from bronchioles towards larynx by mucociliary escalator (last segment with cilia)
  - each terminal bronchiole gives off two or more smaller respiratory bronchioles

The Distal Bronchiole Tree

(Bronchioles / Terminal Bronchioles / Respiratory Bronchioles)

- **Respiratory bronchioles**
  - **no cilia and no mucous glands**
  - have alveoli budding from their walls
  - considered the **beginning of the respiratory division** since alveoli participate in gas exchange
  - divide into 2-10 **alveolar ducts**
  - end in **alveolar sacs** – grape-like clusters of alveoli arrayed around a central space called the **atrium**

The Bronchial Tree



Path of Air Flow

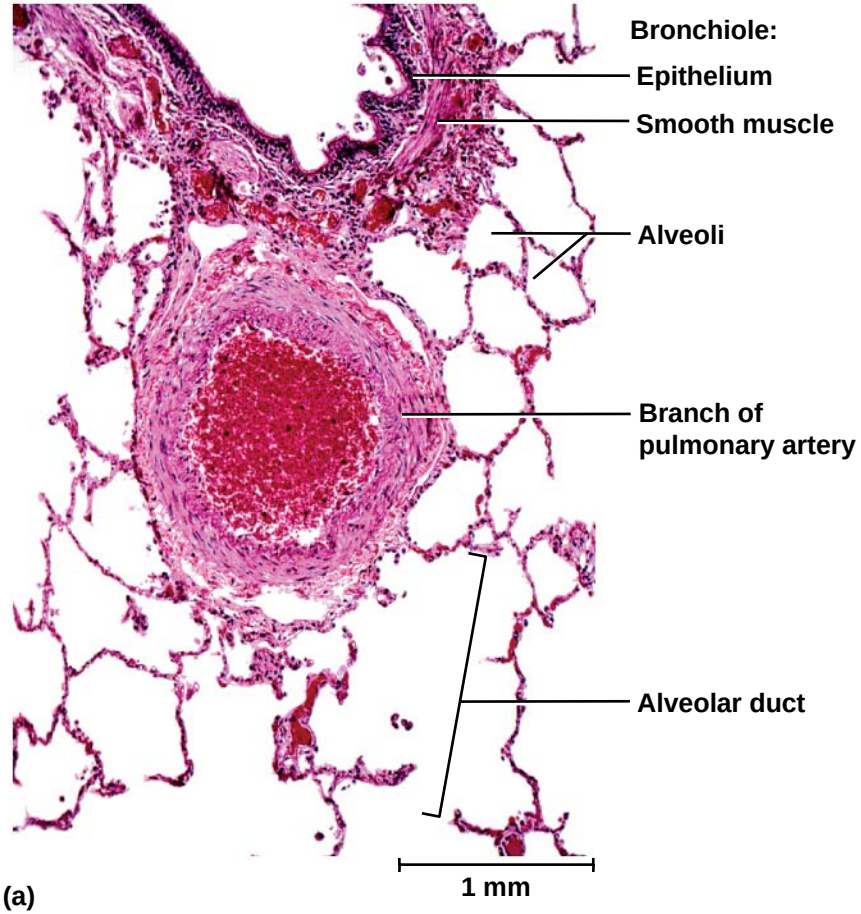
Conducting Division

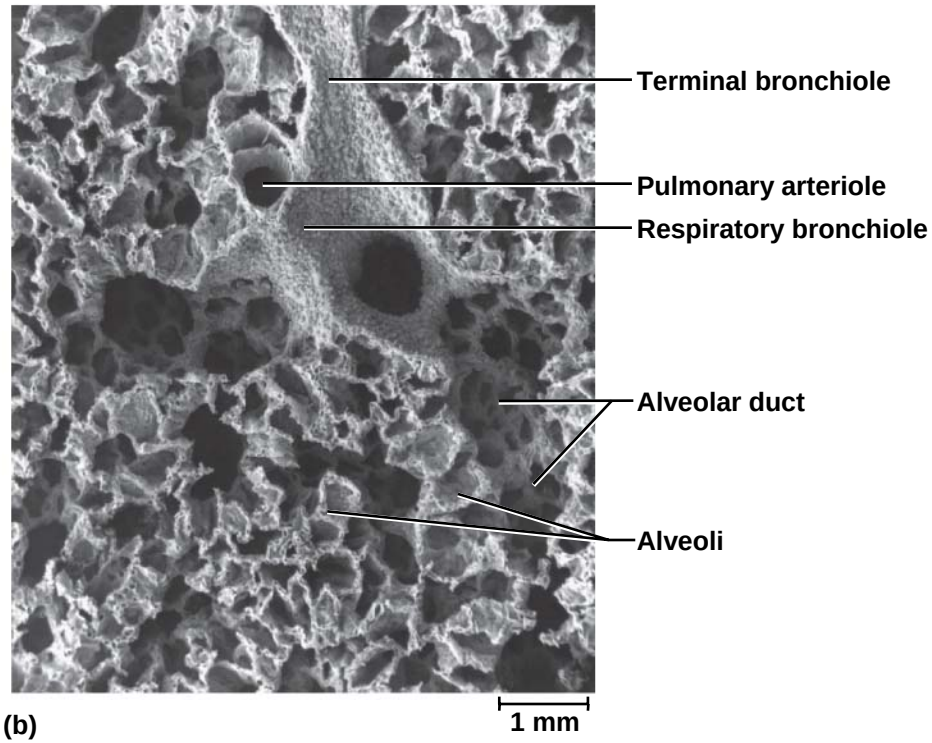
- **nasal cavity**
- **pharynx**
- **larynx**
- **trachea**
- **main bronchus**
- **lobar bronchus**
- **segmental bronchus**
- **Bronchiole**
- **Terminal bronchiole**

Respiratory Division

- **respiratory bronchiole**
- **alveolar duct**
- **atrium**
- **alveolus**

Lung Tissue


Bronchiole:
Epithelium
Smooth muscle
Alveoli
Branch of pulmonary artery
Alveolar duct
1 mm
(a)

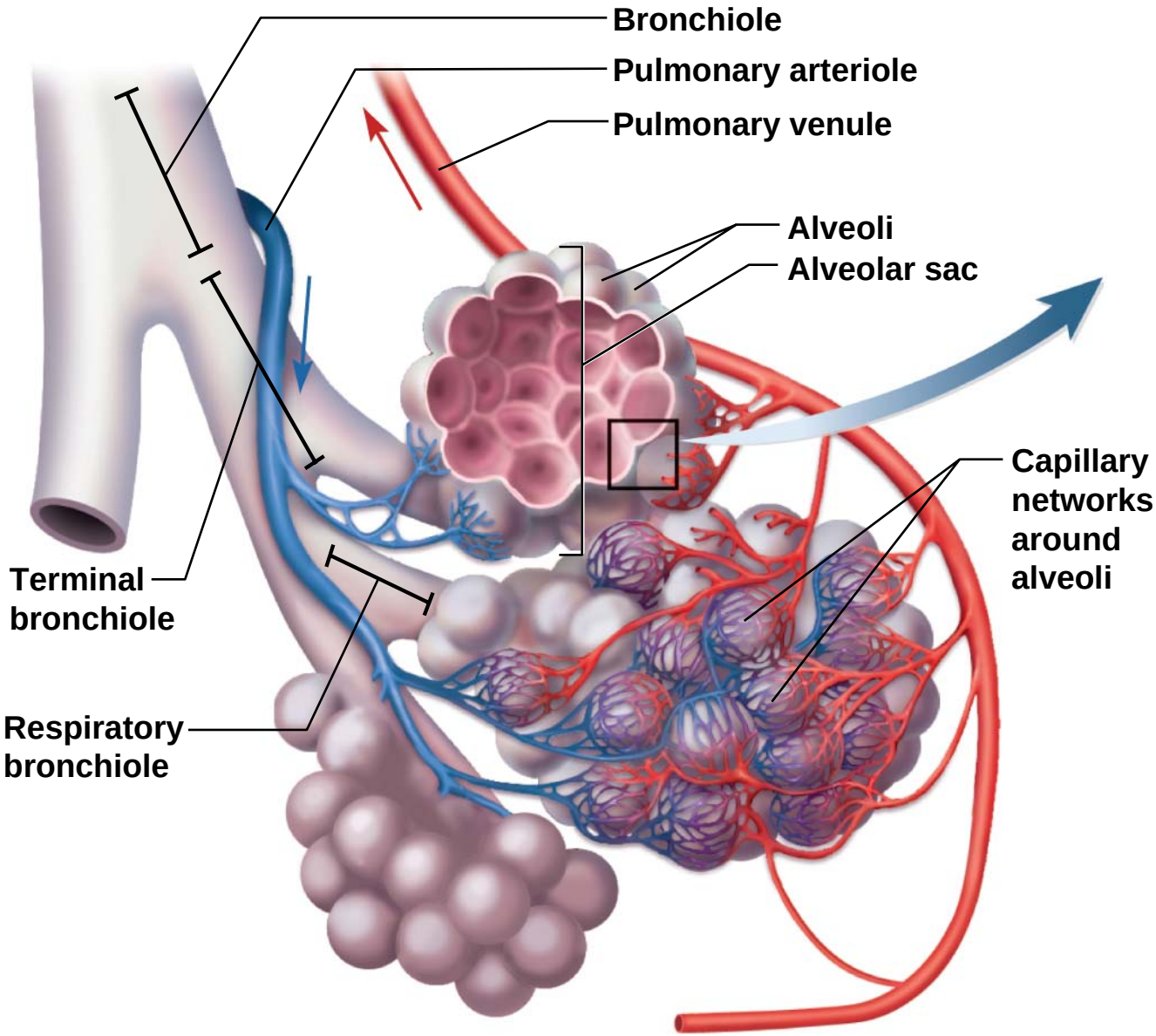

Terminal bronchiole
Pulmonary arteriole
Respiratory bronchiole
Alveolar duct
Alveoli
1 mm
(b)

Blood Vessels of Bronchial Tree

- pulmonary arteries / veins branches closely follow the bronchial tree on their way to the alveoli /// blood flow from rt. ventricle to left atria

- bronchial arteries / veins – delivers oxygen and removes waste products from bronchial tree with systemic blood /// arises from the aorta

Alveolar Blood Supply



Alveoli (1 of 3)

- 150 million alveoli in each lung
- providing about 70 m^2 of surface for gas exchange
- Three cell type of the alveolus (type I / type II / dust cells)
  - **squamous (type I) alveolar cells**
    - thin, broad cells that allow for rapid gas diffusion between alveolus and bloodstream
    - cover 95% of alveolus surface area

Alveoli (2 of 3)

- great (type II) alveolar cells
  - round to cuboidal cells that cover the remaining 5% of alveolar surface
  - repair the alveolar epithelium when the squamous (type I) cells are damaged
  - secrete pulmonary surfactant
    - a mixture of phospholipids and proteins that coats the alveoli and prevents them from collapsing when we exhale

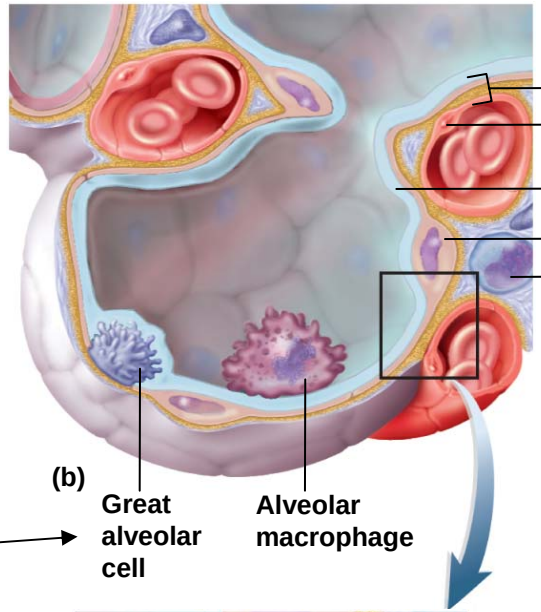
Alveoli (3 of 3)

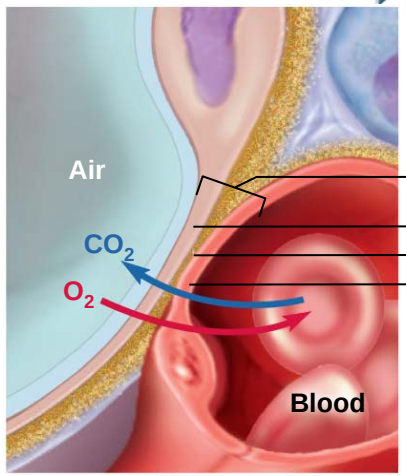
- alveolar macrophages (dust cells)
  - most numerous of all cells in the lung
  - wander the lumen and the connective tissue between alveoli
  - keep alveoli free from debris by phagocytizing dust particles
  - 100 million dust cells perish each day as they ride up the mucociliary escalator to be swallowed and digested with their load of debris

Respiratory Membrane

- each alveolus surrounded by a basket of blood capillaries supplied by the pulmonary artery
- respiratory membrane – the barrier between the alveolar air and blood
- respiratory membrane consists of
  - squamous alveolar cells
  - endothelial cells of blood capillary
  - their shared basement membrane

Alveolus and the Respiratory Membrane





Pressure and Airflow

- respiratory airflow is governed by the same principles that regulates the flow of blood: pressure, and resistance
  - the flow of a fluid is directly proportional to the pressure difference between two points
  - the flow of a fluid is inversely proportional to the resistance
  - So if we want to ventilate the lungs (move air in and out) then we need to be able to create a pressure gradient between the atmosphere and the space within the lungs and furthermore be able to reverse this pressure gradient to change the flow of air

The Physics Behind the Mechanism of Breathing

To understand pulmonary ventilation (moving air in and out of the lungs) you need to know these four “Laws of Physics”

1. Boyle’s Law – the relationship between a volume (which contains a gas and may change) and the pressure of the gas

2. Charles’ Law – the relationship between temperature and the pressure of the gas within a volume which does not change

3. Dalton’s Law – understanding that air is a mixture of gases and its pressure is proportional to the amount of the individual gasses (partial pressure concept)

4. Henry’s Law – the movement of any gas molecule from air into liquid is a condition of the partial pressure and solubility of the gas

Pulmonary Ventilation

- breathing (pulmonary ventilation) /// consists of a repetitive cycle
- respiratory cycle – one complete inspiration and expiration
  - quiet respiration – while at rest, effortless, and automatic
  - forced respiration – deep rapid breathing, such as during exercise
- flow of air in and out of lung depends on a <u>pressure difference</u> between air pressure within lungs and outside body
- breathing muscles change lung volumes and create differences in pressure relative to the atmosphere

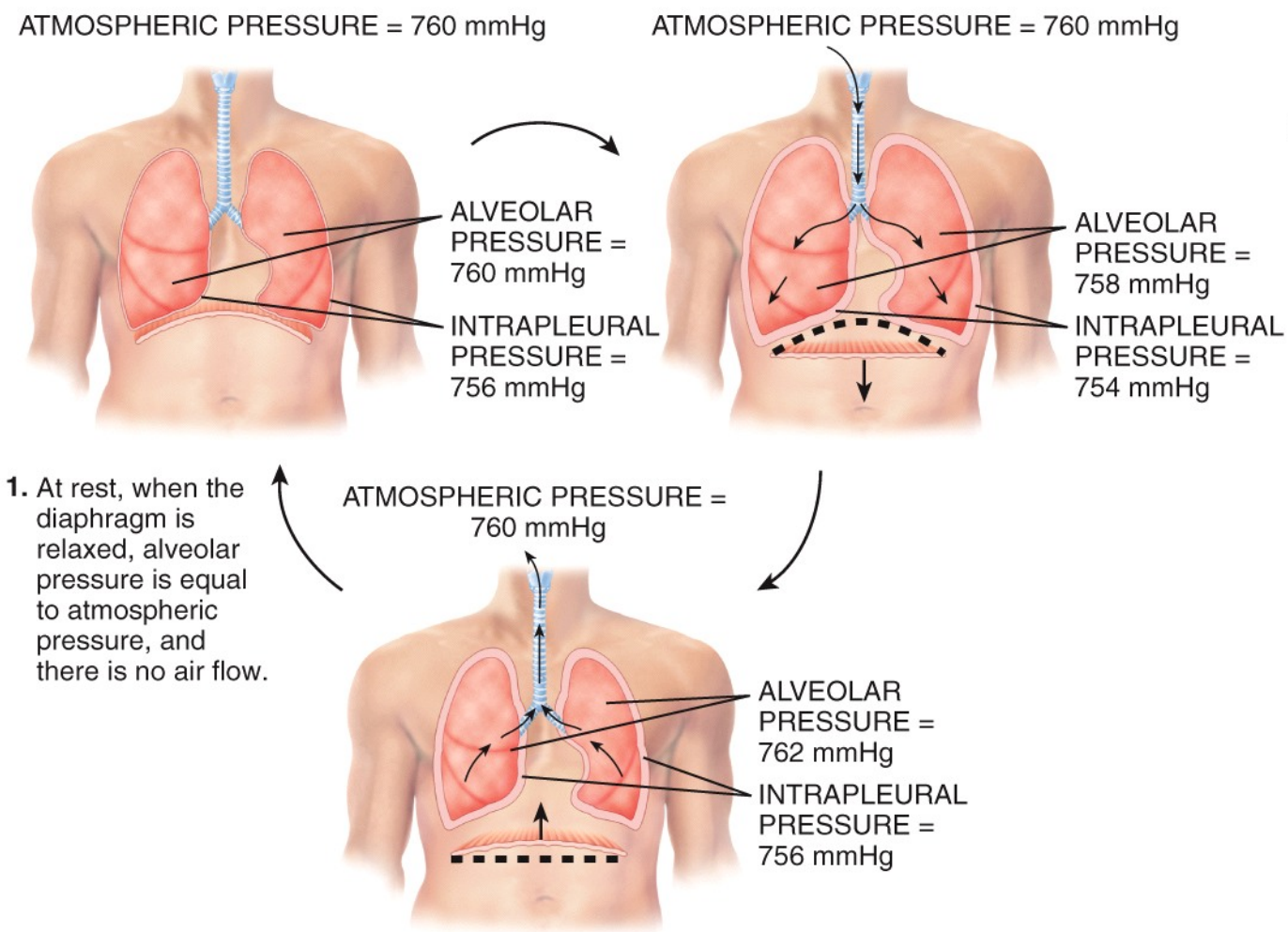
Pressure and Airflow

- Atmospheric pressure /// the weight of the air above us /// 760 mm Hg at sea level - 1 atmosphere (atm)

  - Force exerted by one square inch of “air” between the ground and all the space (earth’s atmosphere / gasses) above it!

  - Lower at higher elevations

  - The changing “pressure gradient” between atomospheric pressure and “pleura space” (intra pleura pressure) is what moves air in and out of the lungs

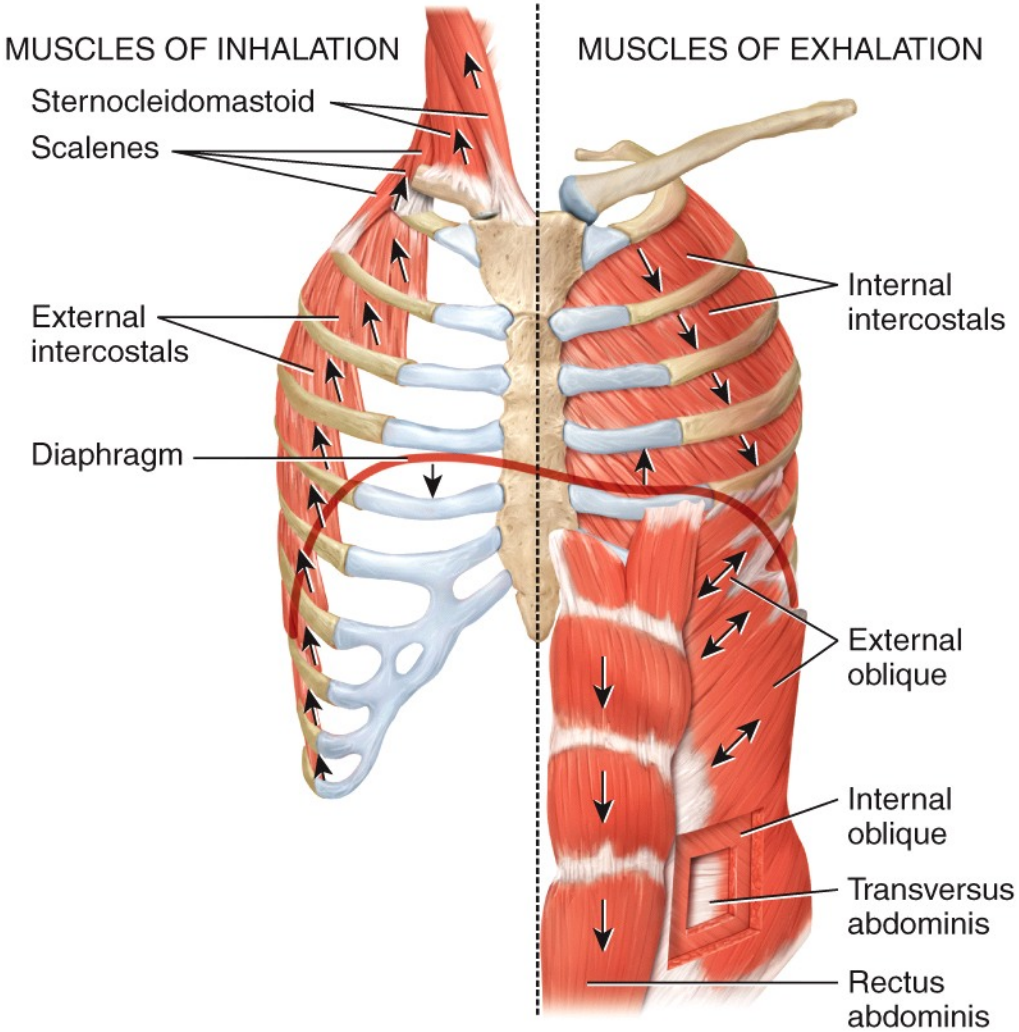


1. At rest, when the diaphragm is relaxed, alveolar pressure is equal to atmospheric pressure, and there is no air flow.

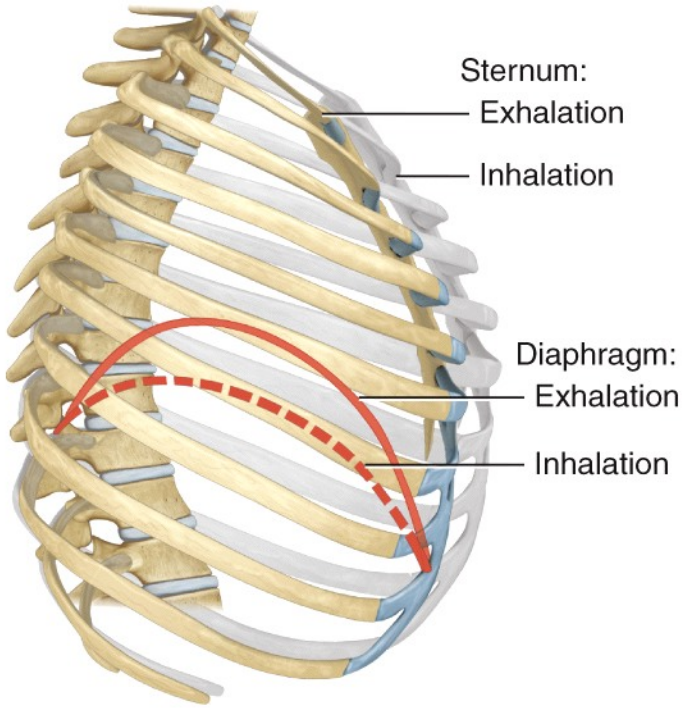
2. During inhalation, the diaphragm contracts and the external intercostals contract. The chest cavity expands, and the alveolar pressure drops below atmospheric pressure. Air flows into the lungs in response to the pressure gradient and the lung volume expands. During deep inhalation, the scalene and sternocleidomastoid muscles expand the chest further, thereby creating a greater drop in alveolar pressure.

3. During exhalation, the diaphragm relaxes and the external intercostals relax. The chest and lungs recoil, the chest cavity contracts, and the alveolar pressure increases above atmospheric pressure. Air flows out of the lungs in response to the pressure gradient, and the lung volume decreases. During forced exhalations, the internal intercostals and abdominal muscles contract, thereby reducing the size of the chest cavity further and creating a greater increase in alveolar pressure.

Respiratory Cycle



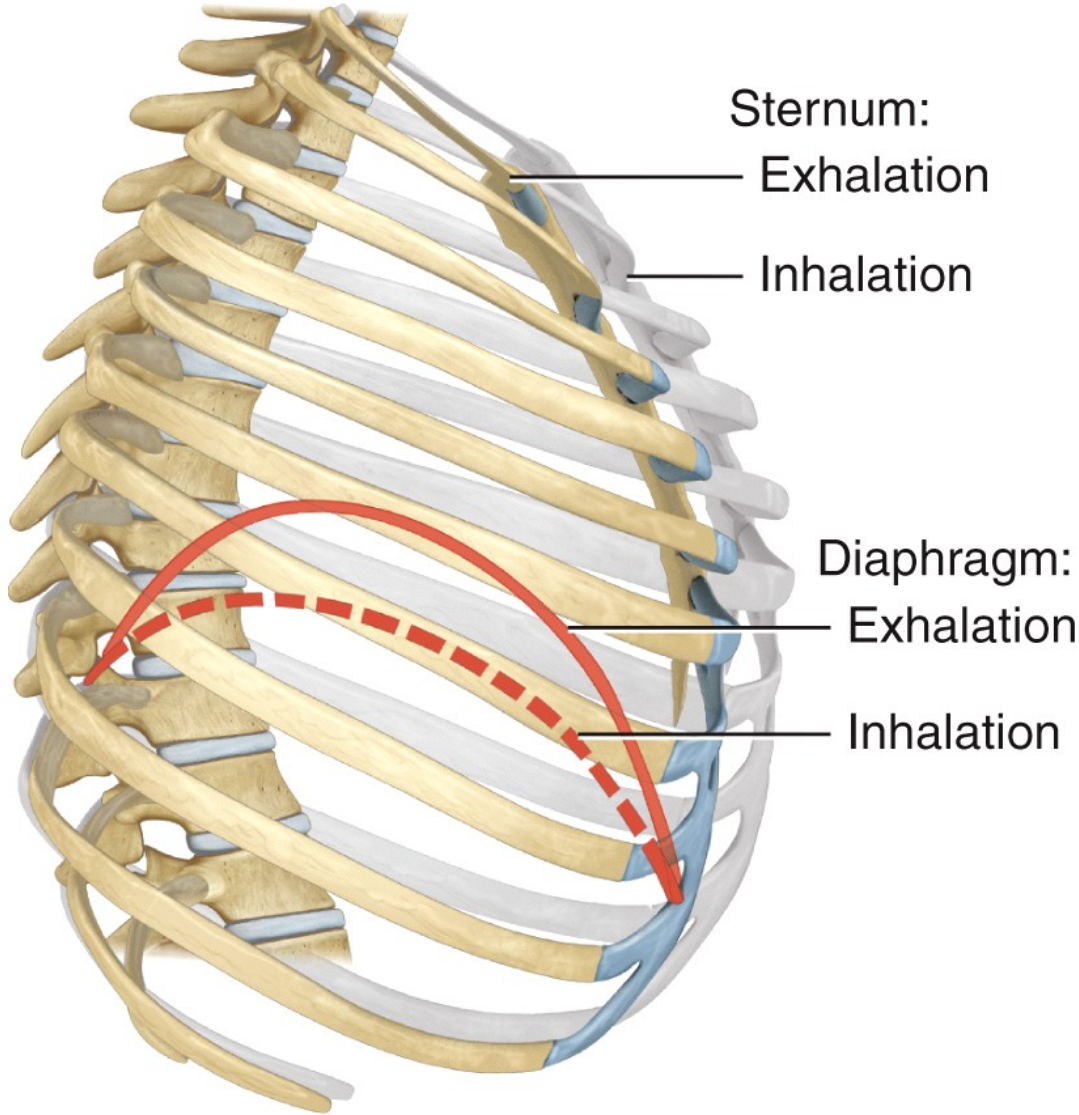
(a) Muscles of inhalation (left); muscles of exhalation (right); arrows indicate the direction of muscle contraction



(b) Changes in size of thoracic cavity during inhalation and exhalation

(c) During inhalation, the lower ribs (7–10) move upward and outward like the handle on a bucket

(c) During inhalation, the lower ribs (7–10) move upward and outward like the handle on a bucket



(b) Changes in size of thoracic cavity during inhalation and exhalation

The Pleurae and Pleural Fluid (1 of 2)

- visceral pleura – serous membrane that covers lungs
- parietal pleura – adheres to mediastinum, inner surface of the rib cage, and superior surface of the diaphragm
- pleural cavity (intra-pleural cavity) – potential space between pleurae
  - normally no room between the membranes, but contains a film of slippery pleural fluid

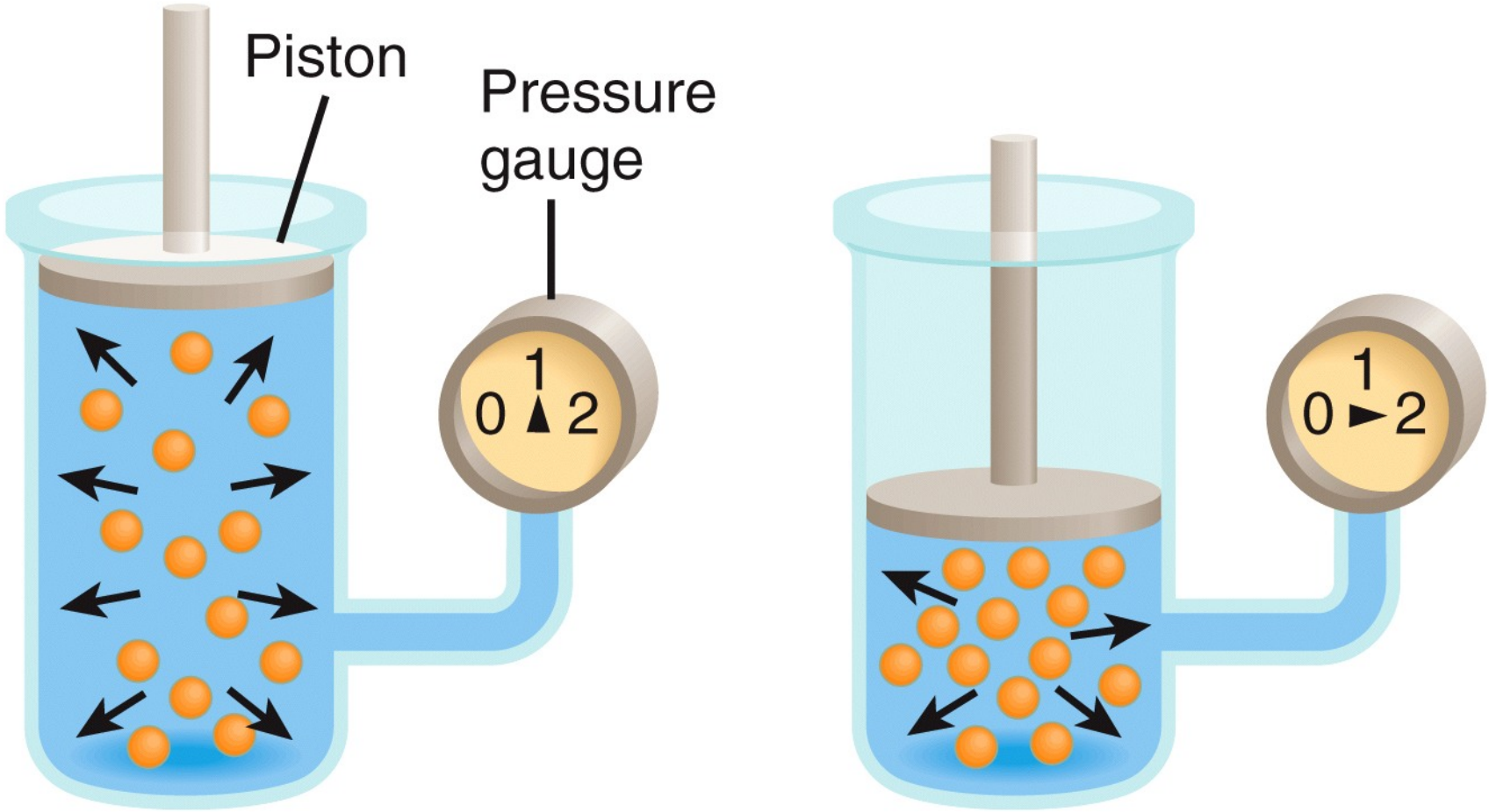
The Pleurae and Pleural Fluid (2 of 2)

- Functions of pleurae and pleural fluid
  - reduce friction
  - create pressure gradient /// lower pressure than atmospheric pressure and assists lung inflation
  - compartmentalization /// prevents spread of infection from one organ in the mediastinum to others

Physics of Inspiration & Respiration

- **Boyle's Law** – at a constant temperature, the pressure of a given quantity of gas is inversely proportional to its volume
  - if the lungs contain a quantity of a gas and the lung volume increases
    - their internal pressure (**intrapulmonary pressure**) falls
    - if the pressure falls below atmospheric pressure the air moves into the lungs
  - if the lung volume decreases
    - intrapulmonary pressure rises
    - if the pressure rises above atmospheric pressure the air moves out of the lungs

Boyle's Law



Volume = 1 liter
Pressure = 1 atm

Volume = 1/2 liter
Pressure = 2 atm

Inspiration & Boyle's Law

- the two pleural layers, their cohesive attraction to each other, and their connections to the lungs and their lining of the rib cage <u>bring about inspiration</u>
  - when the ribs swing upward and outward during inspiration, the parietal pleura follows them
  - the visceral pleura clings to it by the cohesion of water and it follows the parietal pleura
  - it stretches the alveoli within the lungs
  - the entire lung expands along the thoracic cage
  - as intrapleural volume increase
    - its internal pressure drops
    - air flows in

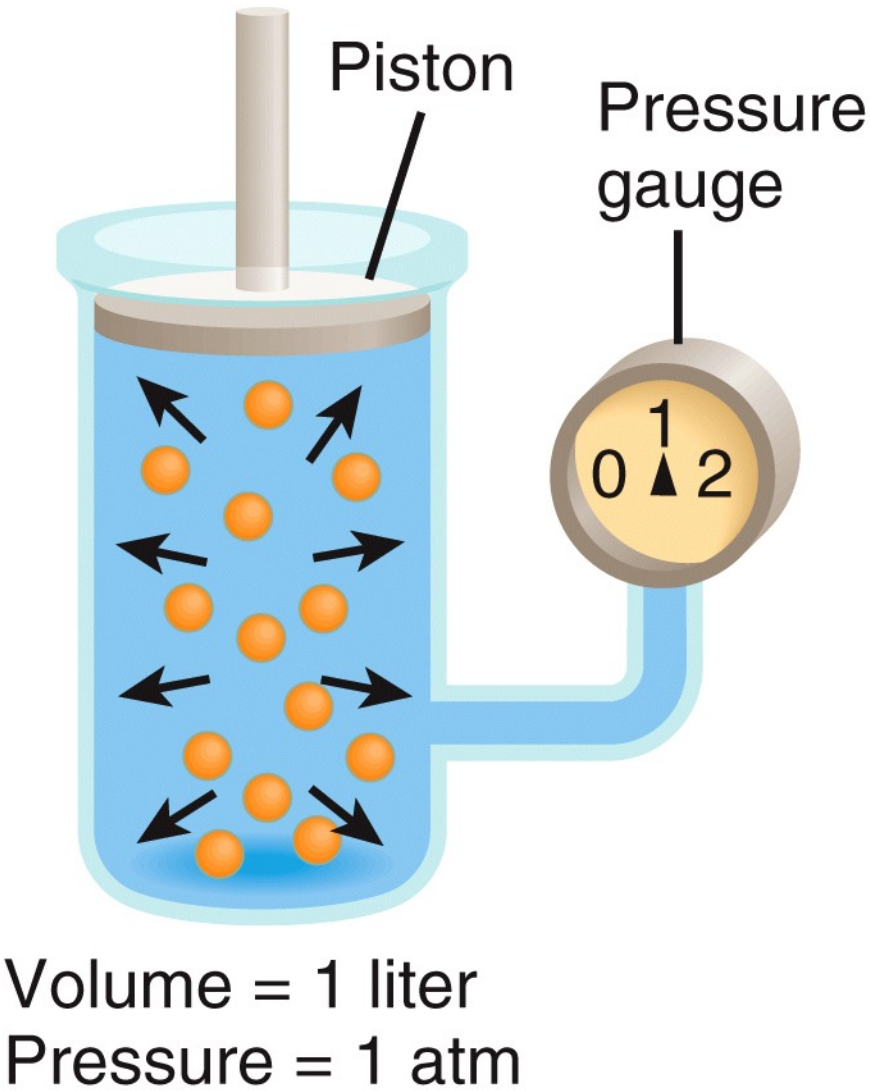
Inspiration & Boyle's Law

- intrapleural pressure – the slightly lower than atmospheric pressure that exists between the two pleural layers keeps the lungs inflated
  - This is about -4 mm Hg
  - When the diaphragm contracts // intrapleural pressure drops to -6 mm Hg // during inspiration as parietal pleura pulls away
  - Some of this pressure change transfers to the interior of the lungs // pulmonary cavity or intrapulmonary cavity (inside the alveoli)
    - intrapulmonary pressure – the pressure in the alveoli drops -3 mm Hg
    - *pressure gradient from 760 mm Hg atmosphere to 757 mm Hg in alveoli allows air to flow into the lungs*

Physics, Inspiration & Charles' Law

- **Charles' Law**
  - volume) of a gas is directly proportional to its temperature
  - on a cool day, 16°C (60°F) air will increase its temperature by 21°C (39°F) during inspiration
  - inhaled air is warmed to 37°C (99° F) by the time it reaches the alveoli
  - inhaled volume of 500 mL will expand to 536 mL as it is warmed by mucosa

Charles' Law



Here the volume is constant but the temperature increases. Since the gas molecules move faster at a higher temperature, there are more gas molecule collisions against the sides of the container which results in an increase in pressure. We did not increase the number of molecules, just the number of collisions.

When we breath in air, it is warmed by the mucosa. How does this affect our respiratory function?

Physics, Inspiration & Charles's Law

- **During quiet breathing**
  - Dimensions of the thoracic cage increase only a few millimeters in each direction
  - Only enough to increase its total volume by 500 mL.
  - 500 mL of air flows into the respiratory tract

Expiration

- Expiration during relaxed breathing
  - passive process achieved mainly by the elastic recoil of the thoracic cage
  - recoil compresses the lungs
  - volume of thoracic cavity decreases
  - raises intrapulmonary pressure to about +3 mm Hg
  - air flows down the pressure gradient and out of the lungs
- Expiration during forced breathing
  - accessory muscles raise intrapulmonary pressure as high as +30 mmHg
  - massive amounts of air moves out of the lungs

What two factors affect airflow?

- **Pressure** is one determinant of airflow
- **Resistance** is the other
  - the greater the resistance the slower the flow
  - *three factors influencing airway resistance*
    - *Diameter of bronchioles*
    - *Pulmonary compliance*
    - *Surface tension of the alveoli & distal broncholes*

Airflow

- *three factors influencing airway resistance*
  - (1) diameter of the bronchioles
    - bronchodilation – increase in the diameter of a bronchus or bronchiole
      - epinephrine and sympathetic stimulation stimulate bronchodilation /// increase air flow
    - bronchoconstriction – decrease in the diameter of a bronchus or bronchiole
      - histamine, parasympathetic nerves, cold air, and chemical irritants stimulate bronchoconstriction
      - suffocation from extreme bronchoconstriction brought about by anaphylactic shock and asthma

Airflow

- (2) pulmonary compliance
  - the ease with which the lungs can expand
  - the change in lung volume relative to a given pressure change
  - compliance reduced by degenerative lung diseases in which the lungs are stiffened by scar tissue
- (3) surface tension of the alveoli and distal bronchioles
  - surfactant – reduces surface tension of water
  - <u>infant respiratory distress syndrome</u> (IRDS) – premature babies
  - See next slide!

More About Alveolar Surface Tension

There is a thin film of water on the inner surface of the alveoli

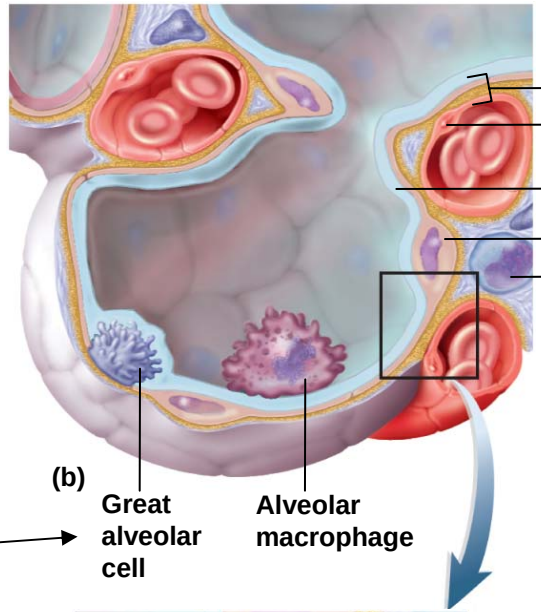
Gasses must dissolve into this layer of water before they cross the respiratory membrane /// Henry's Law

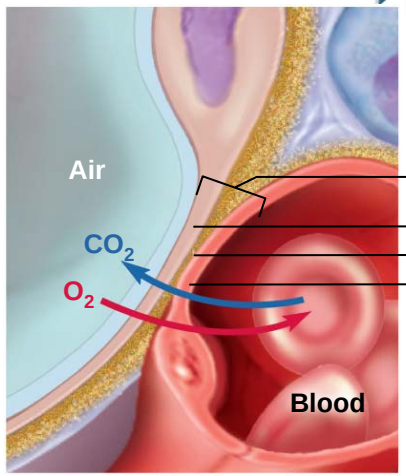
- Thin film of water creates surface tension
- Force that must be overcome to expand lung tissue
- Force that acts to collapse alveoli and distal bronchioles (along with elastic component of lung tissue)

More About Alveolar Surface Tension

- Pulmonary surfactant produced by the great alveolar cells
  - decreases surface tension by disrupting the hydrogen bonding in water
  - As lungs collapse, thickness of water within alveoli thickens, more layers of water molecules stack on top of each other to form 3D lattice of water molecules interconnected by H Bonds. Surfactant disrupts this lattice making reinflation of lungs easier!!!
- Premature infants that lack surfactant suffer from infant respiratory distress syndrome (IRDS)
  - great difficulty in breathing
  - treated with artificial surfactant until lungs can produce own

Alveolus and the Respiratory Membrane





Alveolar Ventilation and Lung Volumes

only air that enters the alveoli is available for gas exchange

not all inhaled air gets to alveoli

about 150 mL of air need to fill the conducting division of the airway

Alveolar Ventilation

- anatomic dead space
  - conducting division of airway where there is no gas exchange
  - can be altered somewhat by sympathetic and parasympathetic stimulation
- in pulmonary diseases, <u>some alveoli</u> may be unable to exchange gases because

Alveolar Ventilation

- physiologic (total) dead space
  - sum of anatomic dead space and any pathological alveolar dead space
- If a person inhales 500 mL of air /// If 150 mL stays in anatomical dead space /// then 350 mL reaches alveoli
- alveolar ventilation rate (AVR)
  - air that ventilates alveoli (350 mL) X respiratory rate (12 bpm) = 4200 mL/min
  - of all the measurements, this one is most directly relevant to the body's ability to get oxygen to the tissues and dispose of carbon dioxide

Measurements of Ventilation

- spirometer – a device that recaptures expired breath and records such variables such as rate and depth of breathing, speed of expiration, and rate of oxygen consumption (view video)

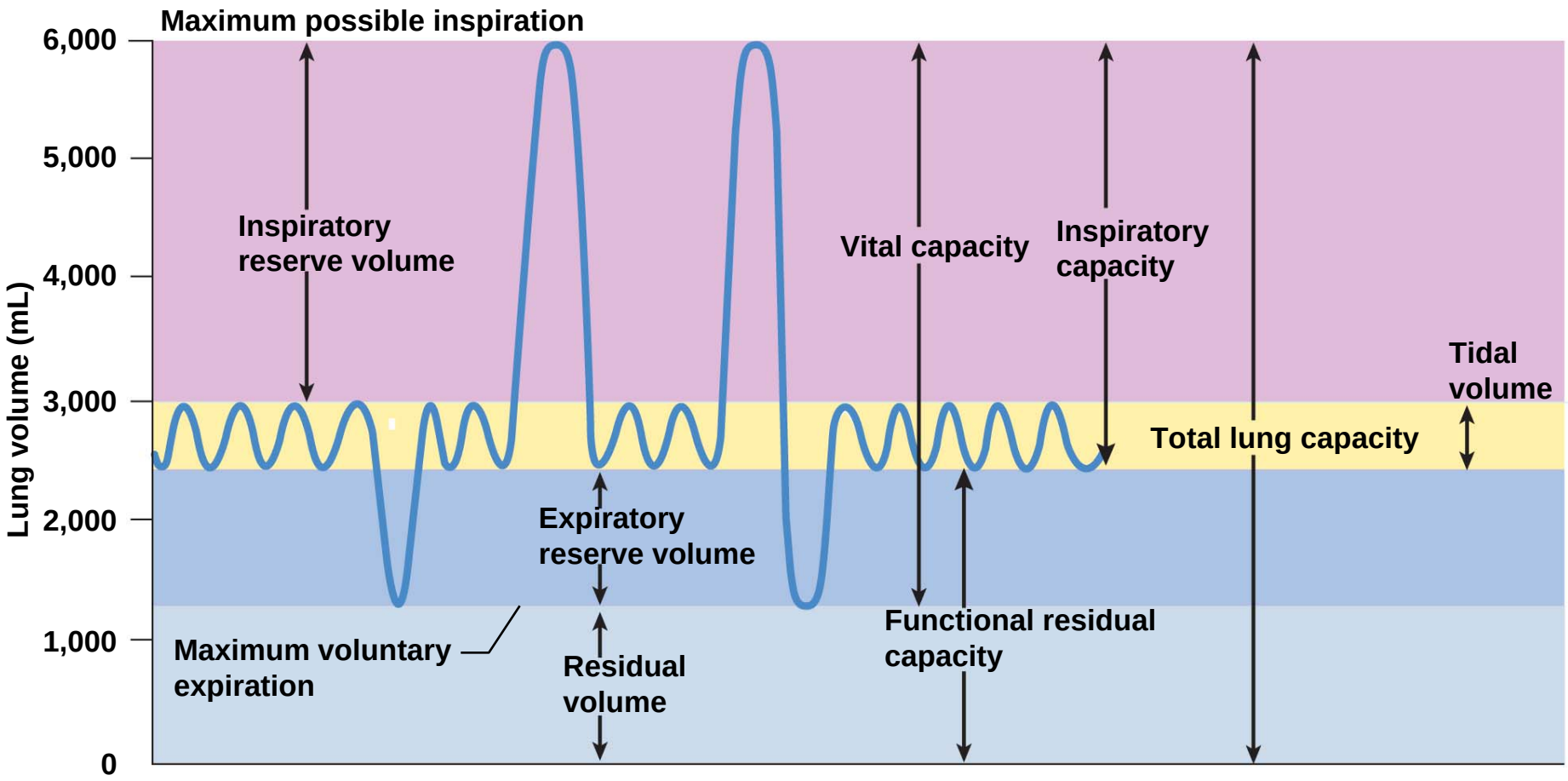
- respiratory volumes (view video)

  – tidal volume - volume of air inhaled and exhaled in one cycle during quiet breathing (500 mL)

  – inspiratory reserve volume - air in excess of tidal volume that can be inhaled with maximum effort (3000 mL)

  – expiratory reserve volume - air in excess of tidal volume that can be exhaled with maximum effort (1200 mL)

Lung Volumes and Capacities



Respiratory Capacities

- **vital capacity -** total amount of air that can be inhaled and then exhaled with maximum effort
  - VC = ERV + TV + IRV (4700 mL)
    - important measure of pulmonary health
- **inspiratory capacity -** maximum amount of air that can be inhaled after a normal tidal expiration
  - IC = TV + IRV (3500 mL)
- **functional residual capacity -** amount of air remaining in lungs after a normal tidal expiration
  - FRC = RV + ERV (2500 mL)
- **total lung capacity** – maximum amount of air the lungs can contain
  - TLC = RV + VC (6000 mL)

Respiratory Capacities

- Spirometry
  - the measurement of pulmonary function
  - aid in diagnosis and assessment of *restrictive* and *obstructive* lung disorders
- restrictive disorders
  - those that reduce pulmonary compliance
  - limit the amount to which the lungs can be inflated
  - any disease that produces pulmonary fibrosis
  - black-lung, tuberculosis

Respiratory Capacities

- **obstructive disorders**
  - those that interfere with airflow by narrowing or blocking the airway
  - make it harder to inhale or exhale a given amount of air
  - asthma, chronic bronchitis
  - emphysema combines elements of restrictive and obstructive disorders

Terminology: Variations in Respiratory Rhythm

- eupnea – relaxed quiet breathing
  - characterized by tidal volume 500 mL and the respiratory rate of 12 – 15 bpm
- apnea – temporary cessation of breathing
- dyspnea – labored, gasping breathing; shortness of breath
- hyperpnea – increased rate and depth of breathing in response to exercise, pain, or other conditions
- hyperventilation – increased pulmonary ventilation in excess of metabolic demand
- hypoventilation – reduced pulmonary ventilation
- Kussmaul respiration – deep, rapid breathing often induced by acidosis
- respiratory arrest – permanent cessation of breathing
- tachypnea – accelerated respiration rate
- bradynea – slow respiration rate