Respiratory Anatomy

37. Pulmonary Ventilation

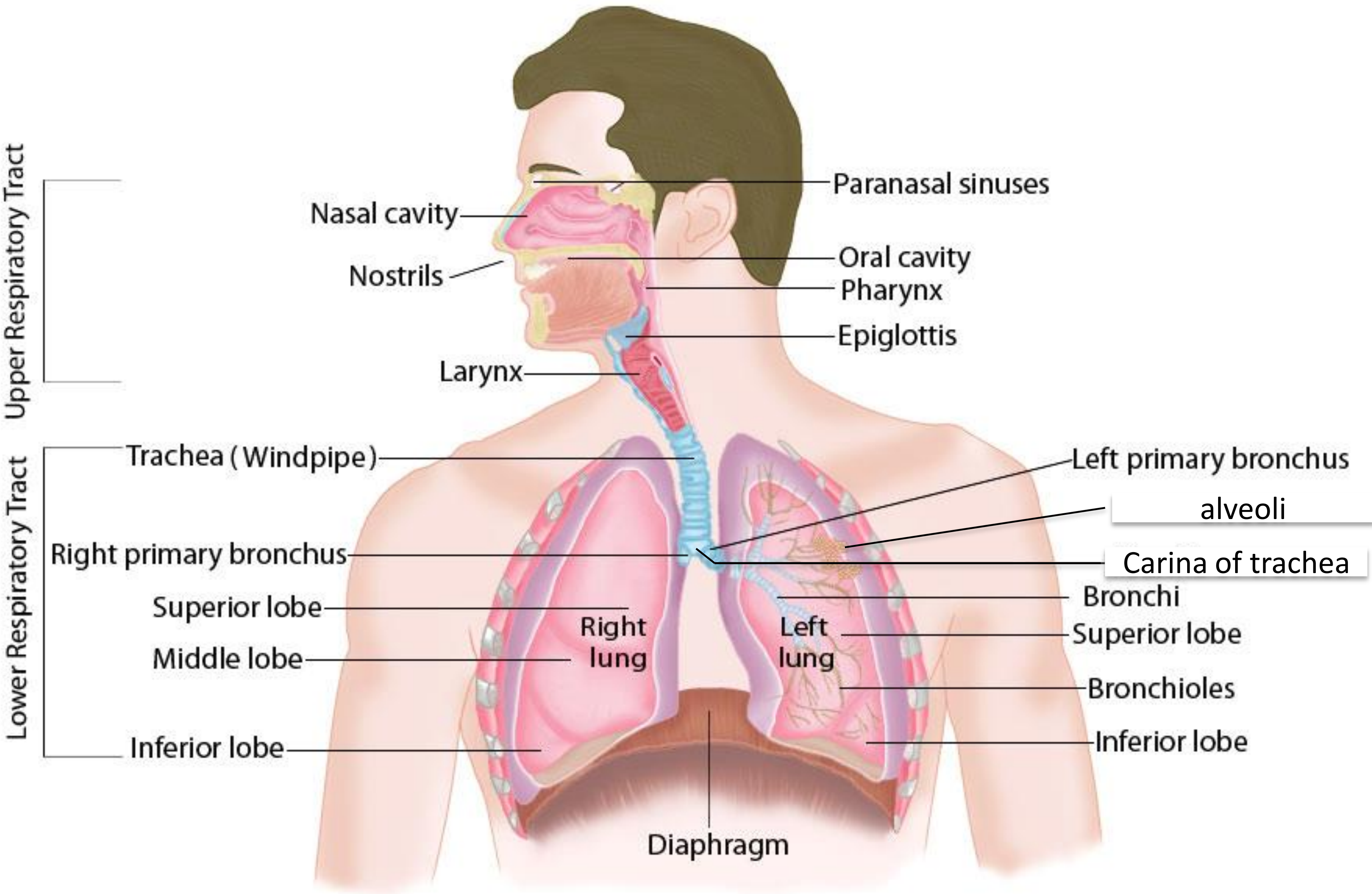
Gas Exchange

Gas Transport

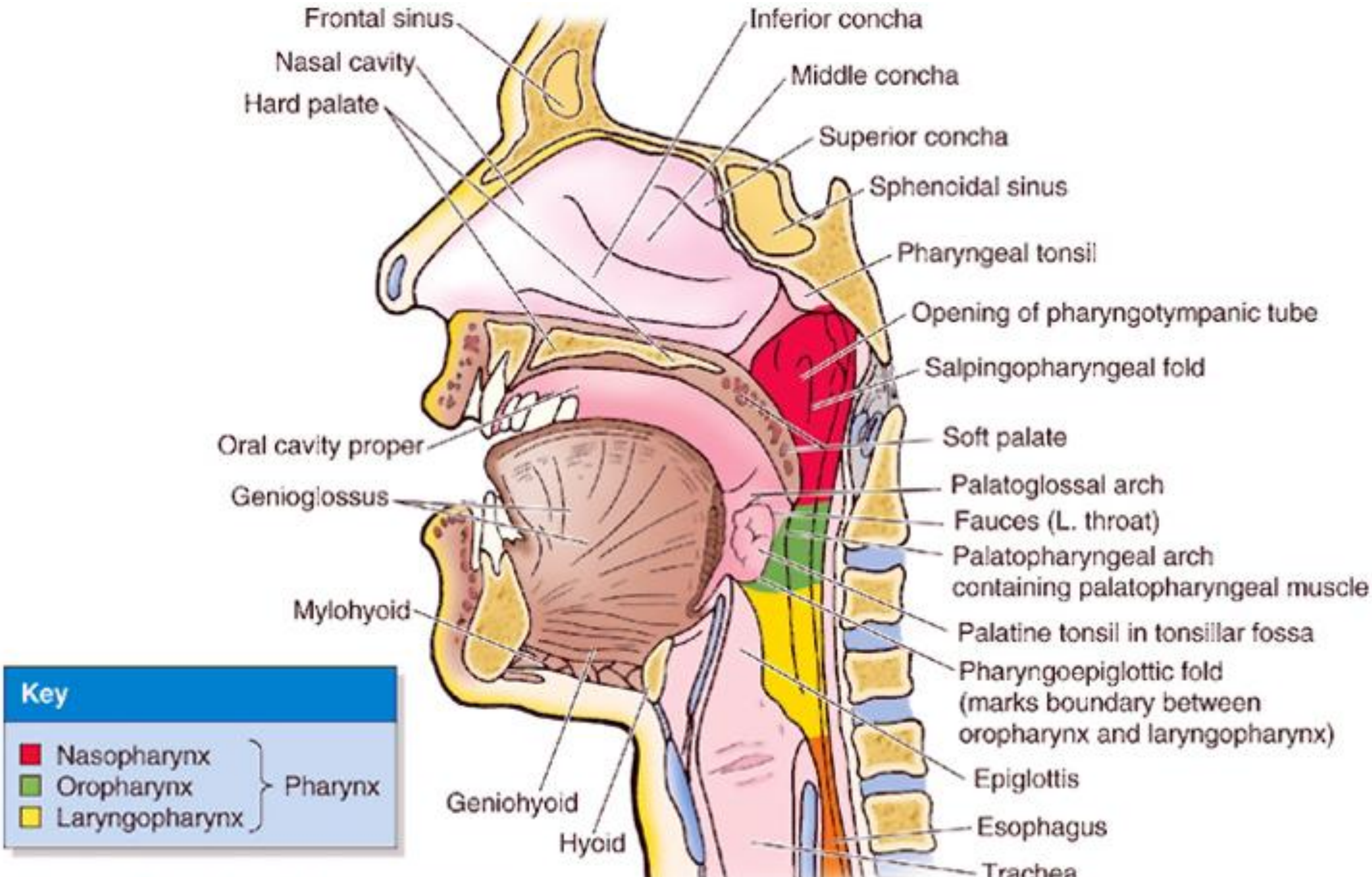
- Respiratory system is responsible for inhaling oxygen and carrying out the exchange of oxygen and carbon dioxide in the human body
- It has specific respiratory organs, blood vessels and muscles.
- Main functions of the respiratory system:

✓ Providing oxygen and removing carbondioxide for metabolism in tissues
✓ Protecting respiratory surfaces from dehydration, temperature changes
✓ Defending the respiratory system and other tissues from invasion by pathogenic microorganisms
✓ Producing sounds involved in speaking, singing, or nonverbal communication
✓ Assisting in the regulation of blood volume, blood pressure, and the control of body fluid pH

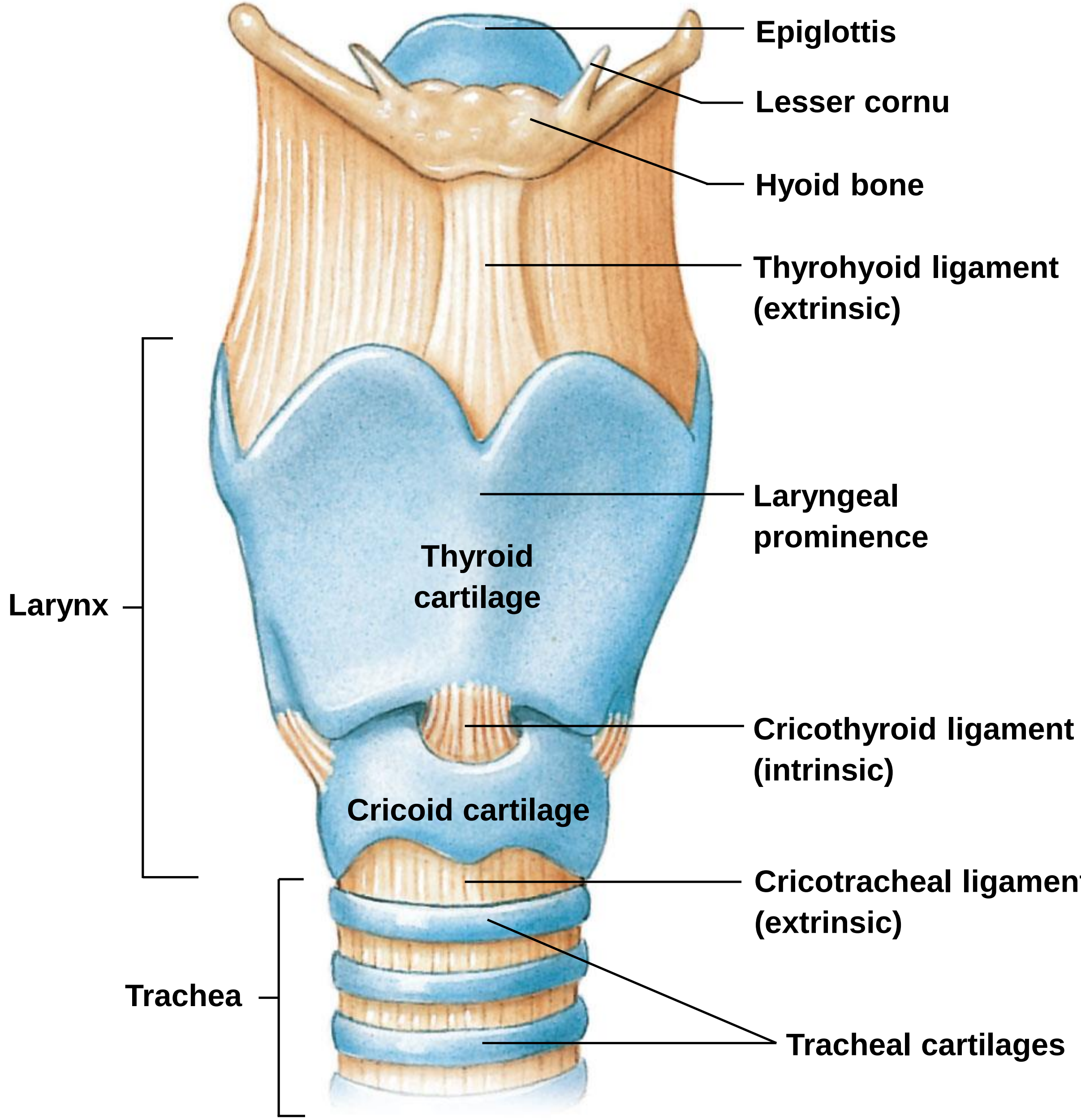
Airway Anatomy



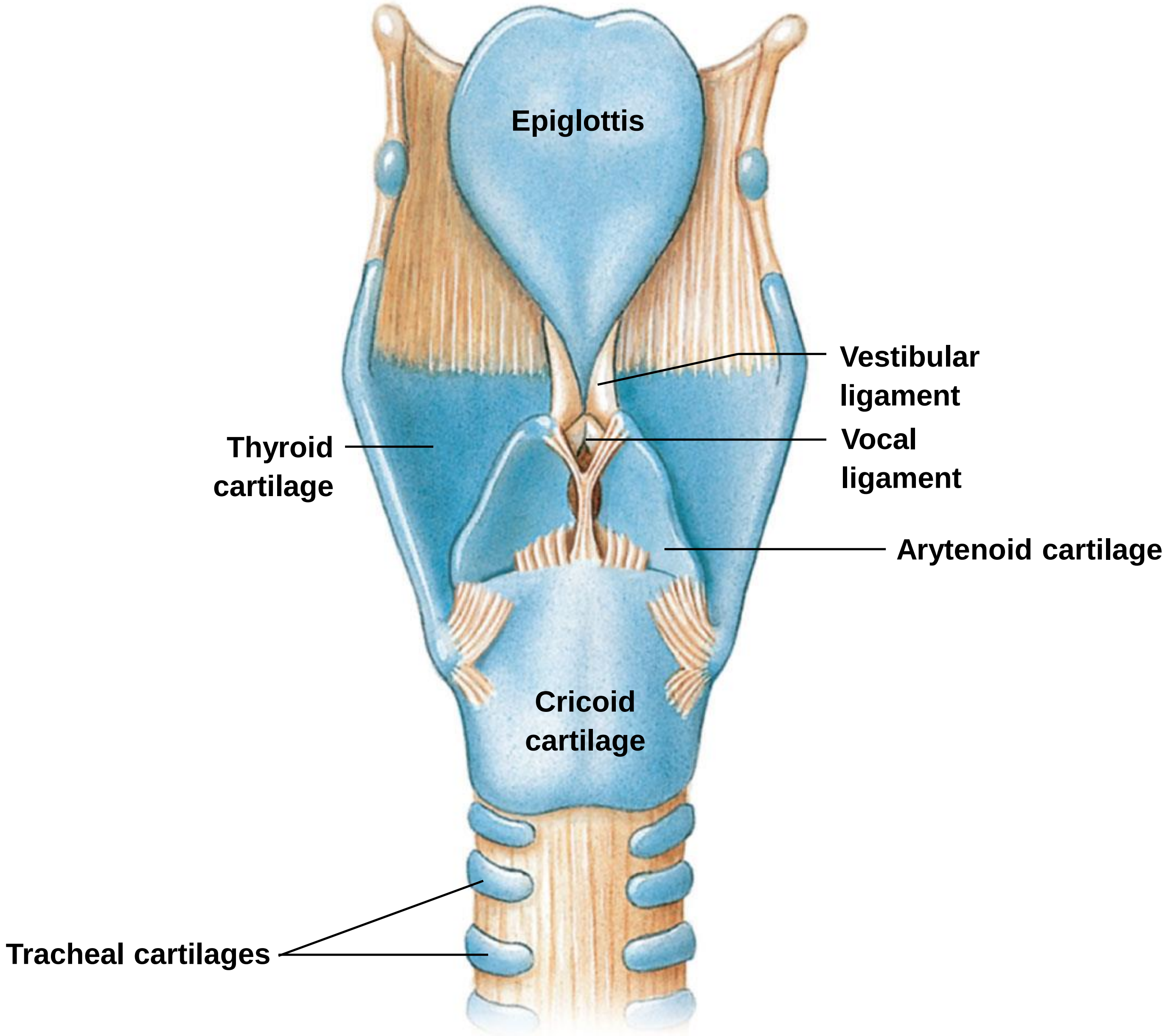
- **anatomy of upper respiratory system**



Medial view of right half of viscerocranium

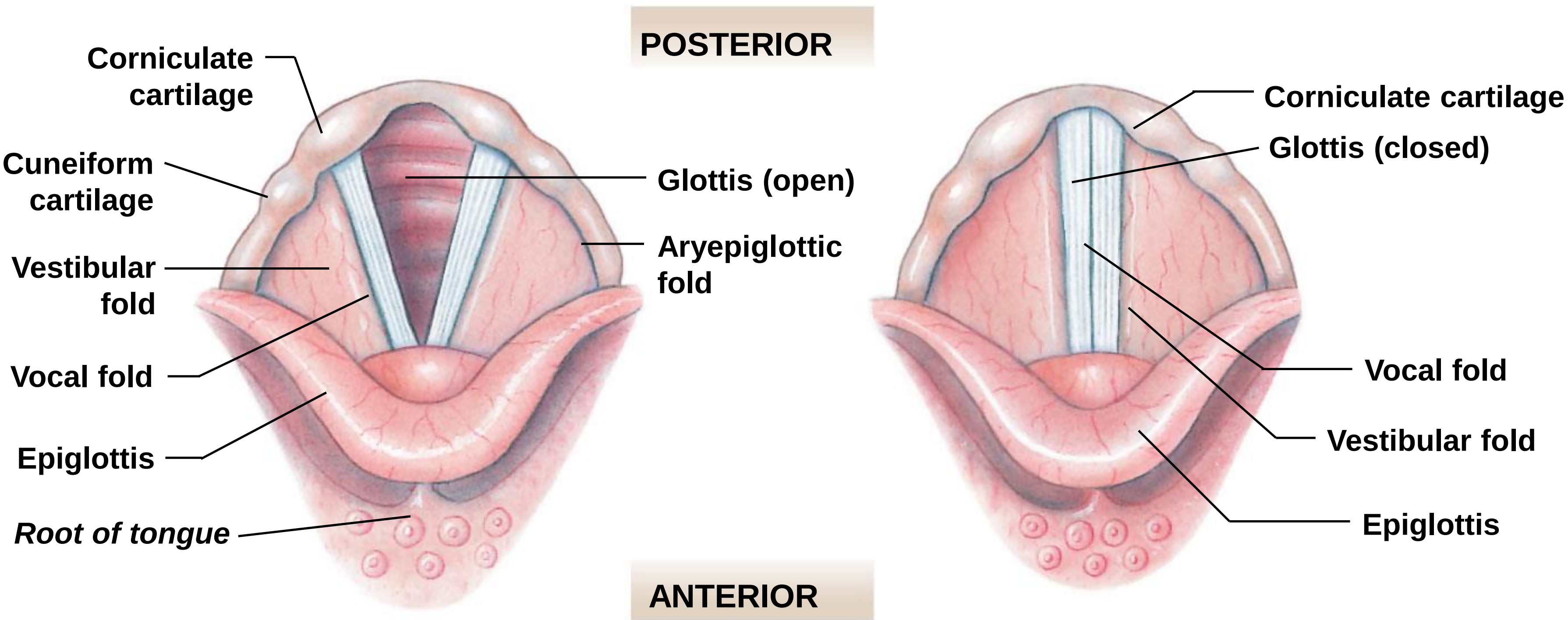


Anterior view of the intact larynx



Posterior view of the intact larynx

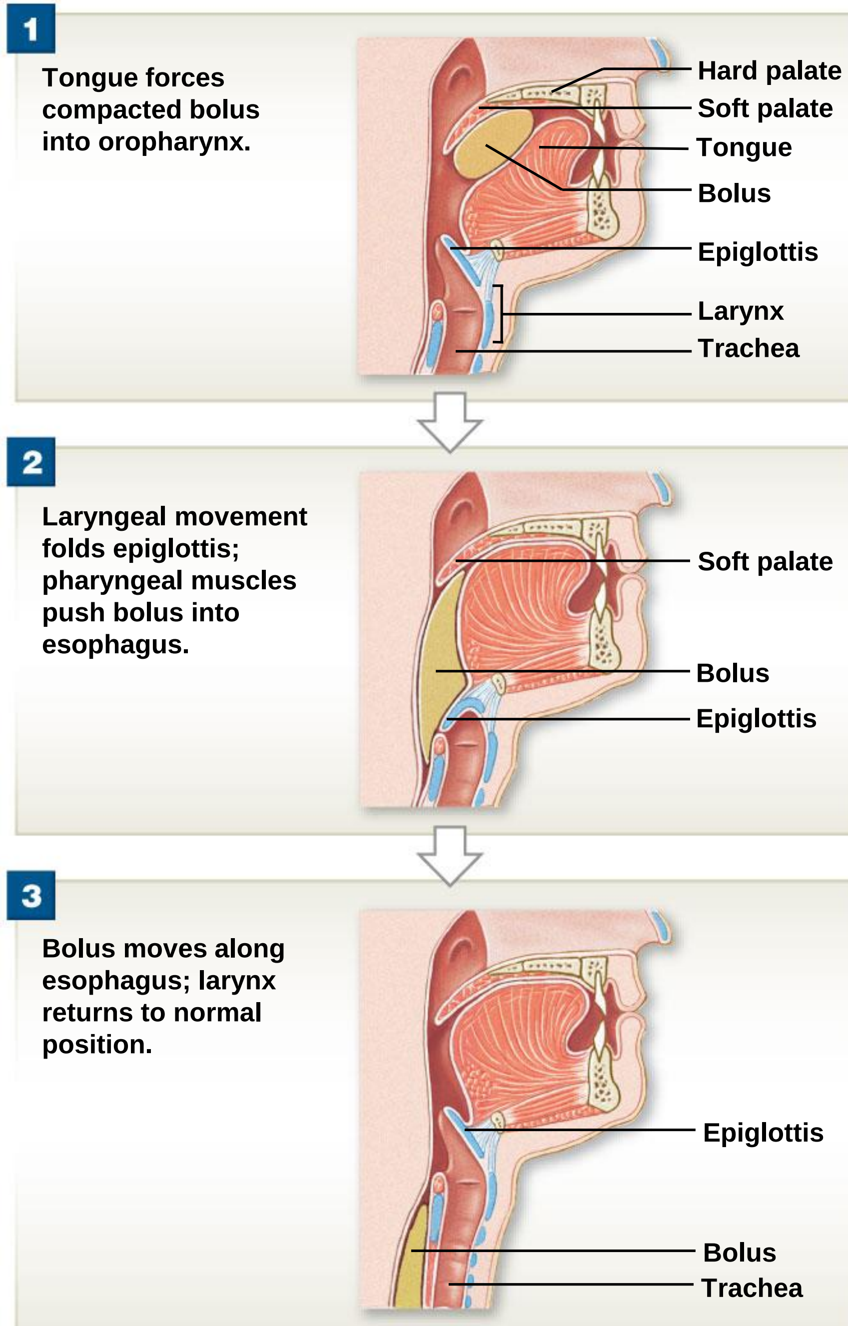
The Vocal Cords



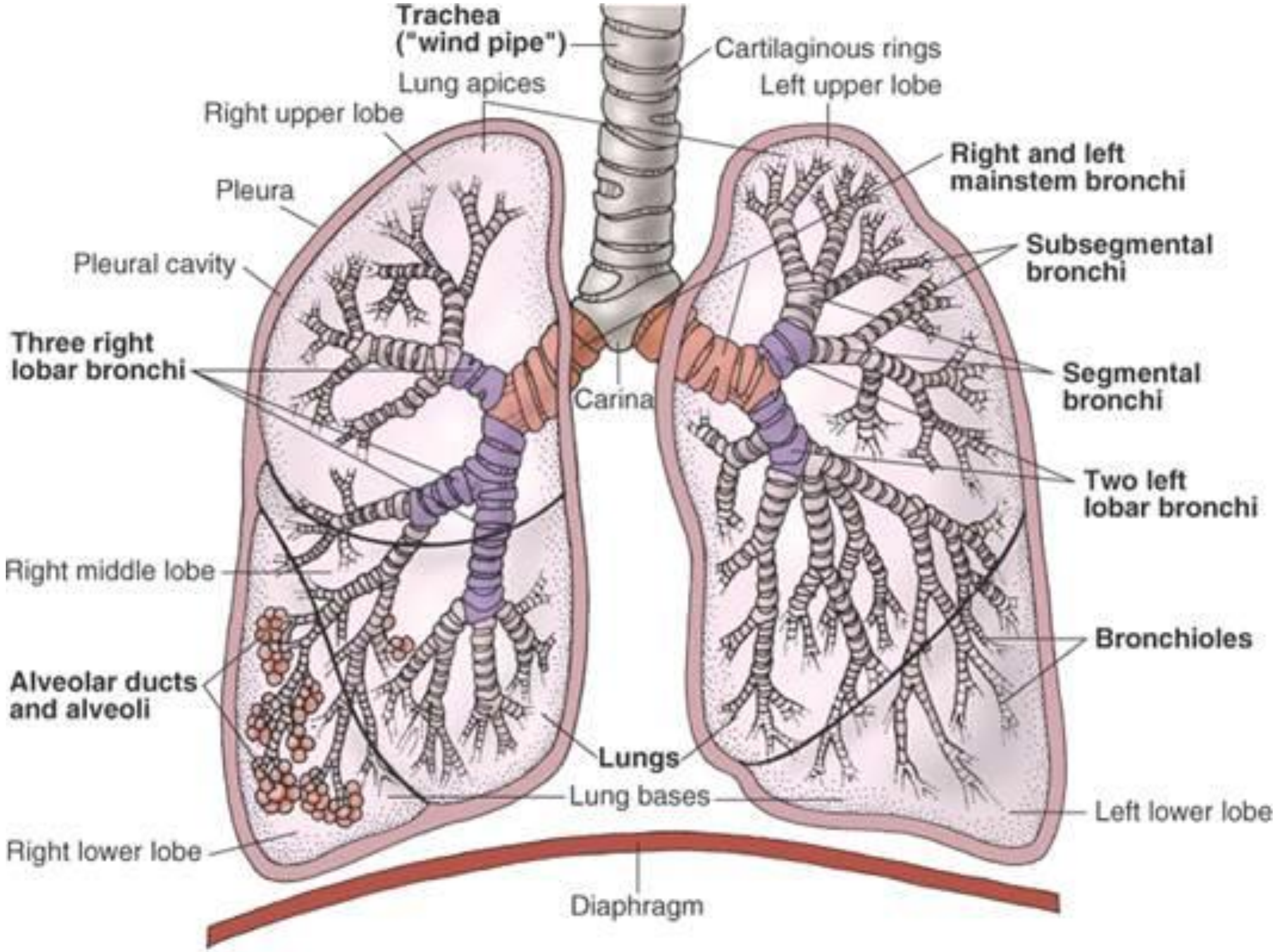
Glottis in the open position

Glottis in the closed position

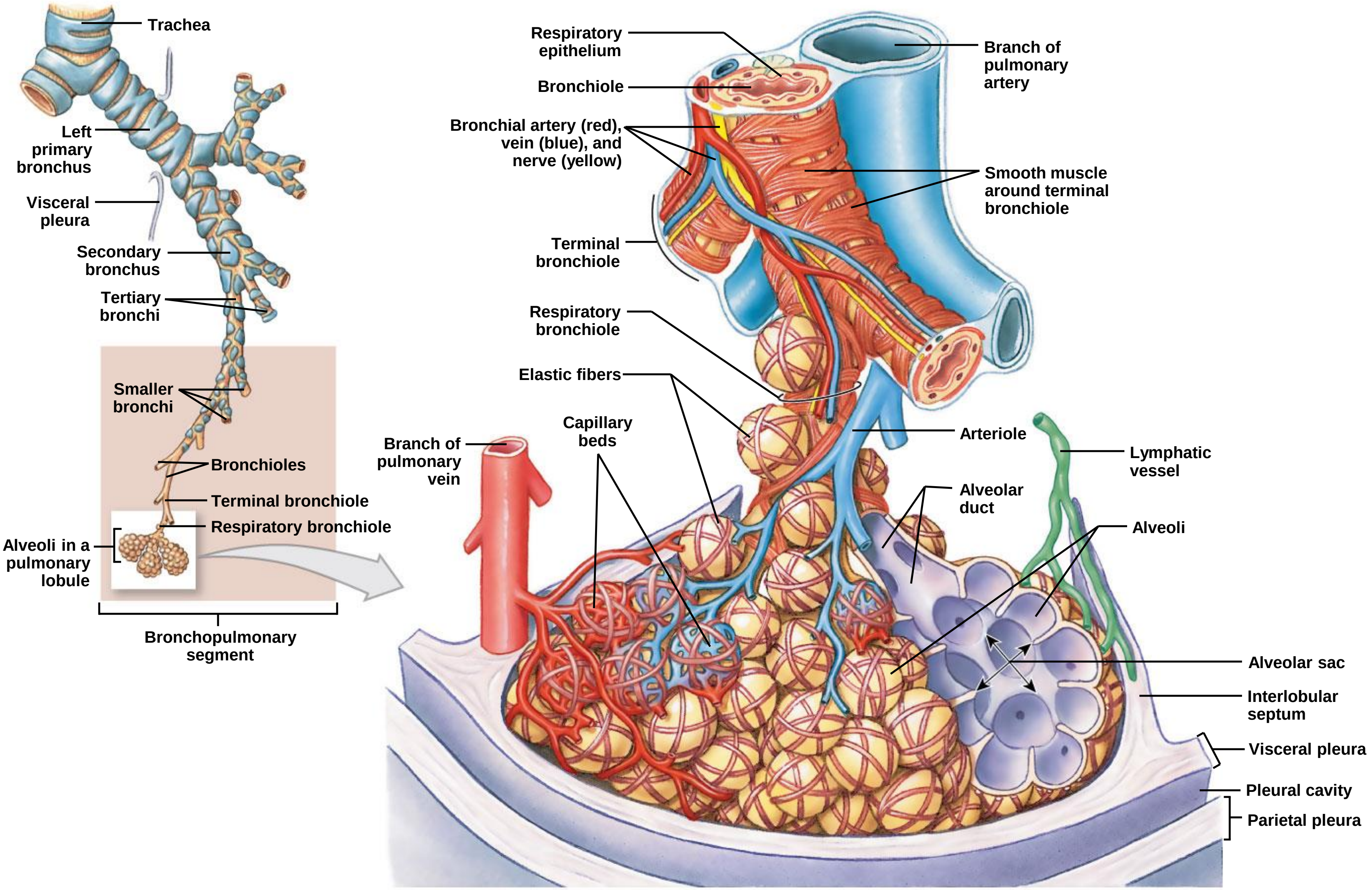
Movements of the Larynx during Swallowing



- **anatomy of lower respiratory system**



Bronchi and Bronchioles

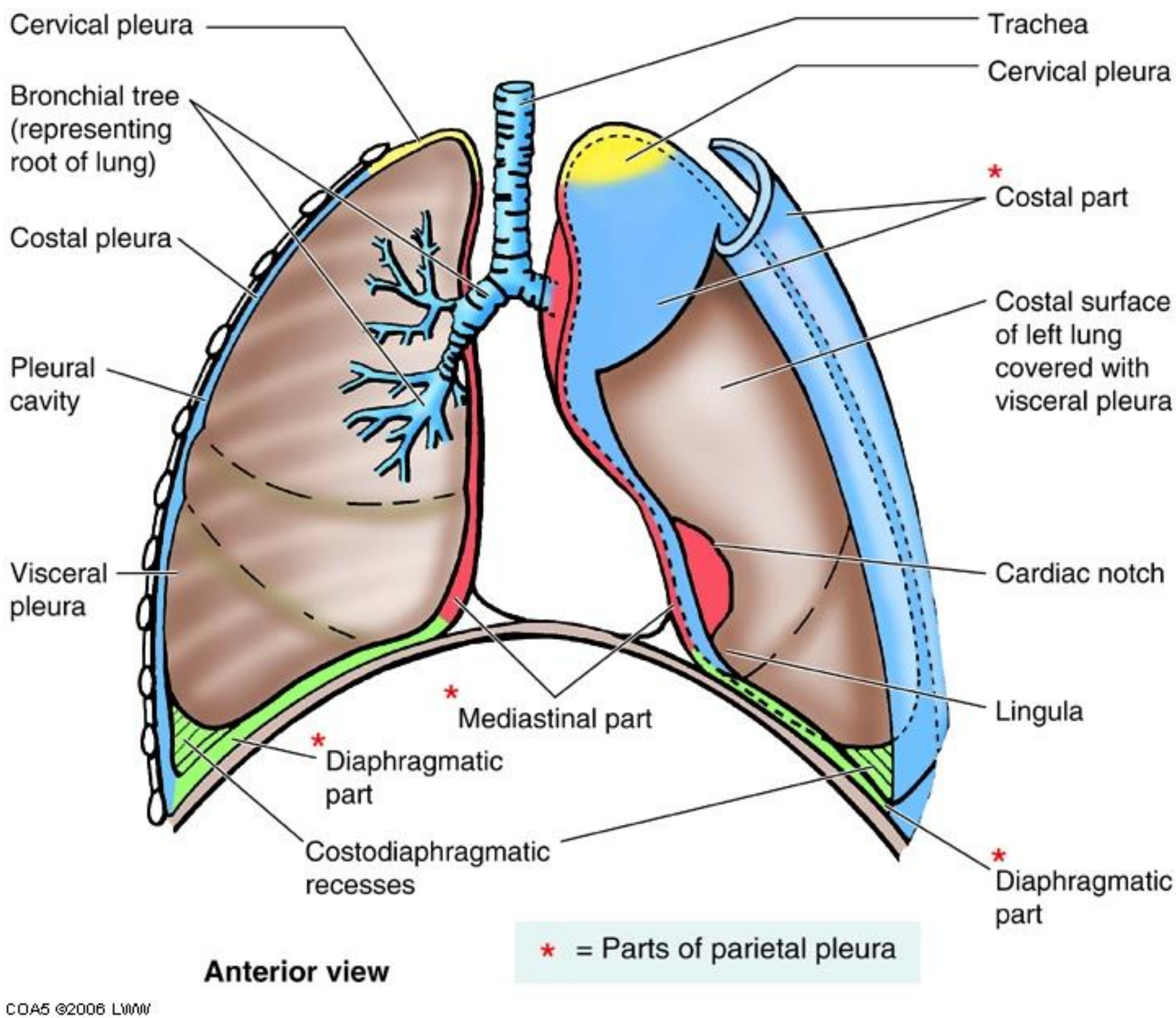


a The structure of one portion of a single pulmonary lobule

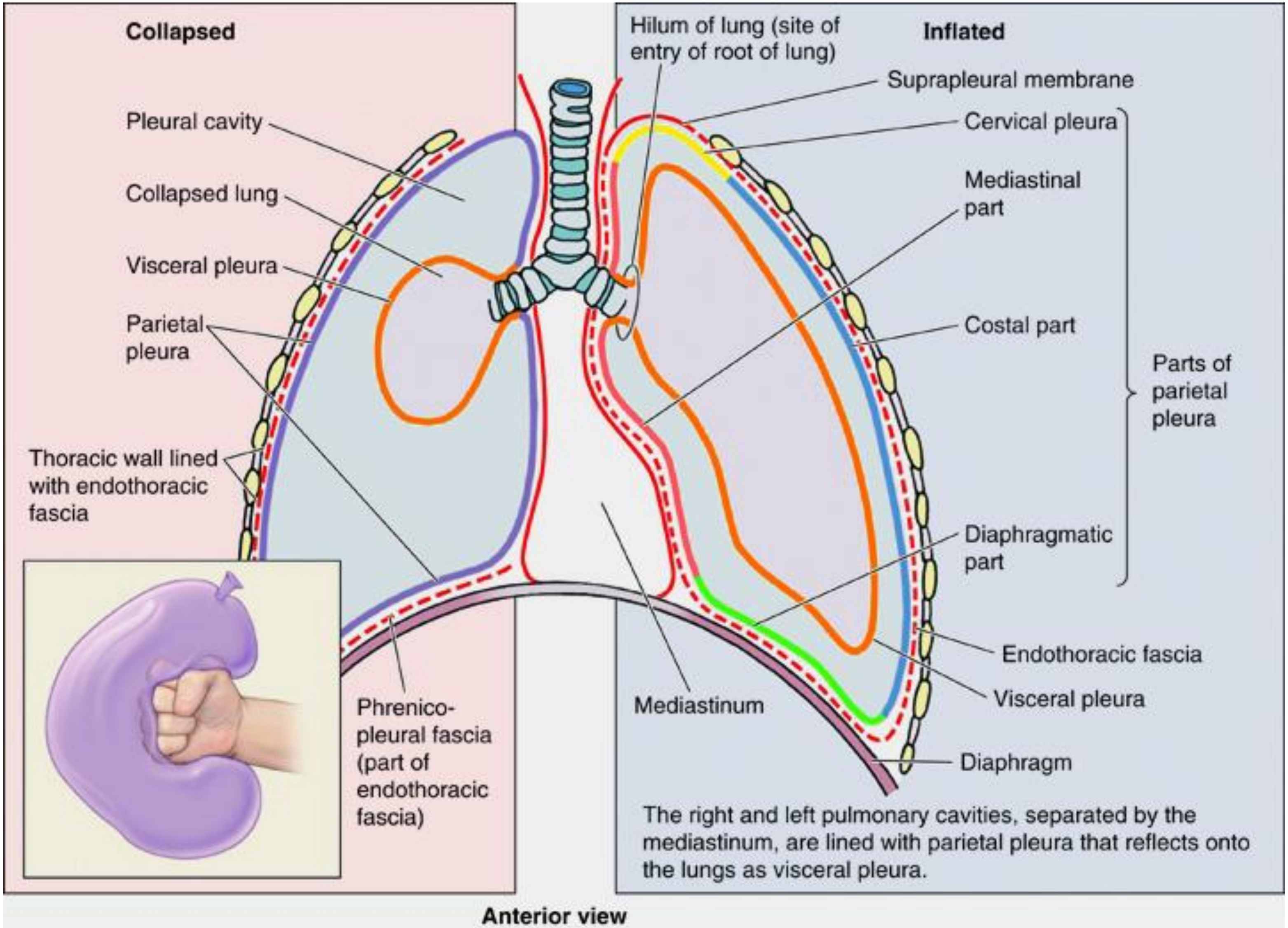
Table 22.1 Principal Organs of the Respiratory System

STRUCTURE	DESCRIPTION, GENERAL AND DISTINCTIVE FEATURES	FUNCTION
Nose (external nose and nasal cavity)	Jutting external portion is supported by bone and cartilage. Internal nasal cavity is divided by midline nasal septum and lined with mucosa.	Produces mucus; filters, warms, and moistens incoming air; resonance chamber for speech
	Roof of nasal cavity contains olfactory epithelium.	Receptors for sense of smell
Paranasal sinuses	Mucosa-lined, air-filled cavities in cranial bones surrounding nasal cavity.	Same as for nasal cavity except no receptors for smell; also lighten skull
Pharynx	Passageway connecting nasal cavity to larynx and oral cavity to esophagus. Three subdivisions: nasopharynx, oropharynx, and laryngopharynx.	Passageway for air and food
	Houses tonsils (lymphoid tissue masses involved in protection against pathogens).	Facilitates exposure of immune system to inhaled antigens
Larynx	Connects pharynx to trachea. Has framework of cartilage and dense connective tissue. Opening (glottis) can be closed by epiglottis or vocal folds.	Air passageway; prevents food from entering lower respiratory tract
	Houses vocal folds (true vocal cords).	Voice production
Trachea	Flexible tube running from larynx and dividing inferiorly into two main bronchi. Walls contain C-shaped cartilages that are incomplete posteriorly where connected by trachealis.	Air passageway; cleans, warms, and moistens incoming air
Bronchial tree	Consists of right and left main bronchi, which subdivide within the lungs to form lobar and segmental bronchi and bronchioles. Bronchiolar walls lack cartilage but contain complete layer of smooth muscle. Constriction of this muscle impedes expiration.	Air passageways connecting trachea with alveoli; cleans, warms, and moistens incoming air
Alveoli	Microscopic chambers at termini of bronchial tree. Walls of simple squamous epithelium overlie thin basement membrane. External surfaces are intimately associated with pulmonary capillaries.	Main sites of gas exchange
	Special alveolar cells produce surfactant.	Reduces surface tension; helps prevent lung collapse
Lungs	Paired composite organs that flank mediastinum in thorax. Composed primarily of alveoli and respiratory passageways. Stroma is fibrous elastic connective tissue, allowing lungs to recoil passively during expiration.	House respiratory passages smaller than the main bronchi
Pleurae	Serous membranes. Parietal pleura lines thoracic cavity; visceral pleura covers external lung surfaces.	Produce lubricating fluid and compartmentalize lungs

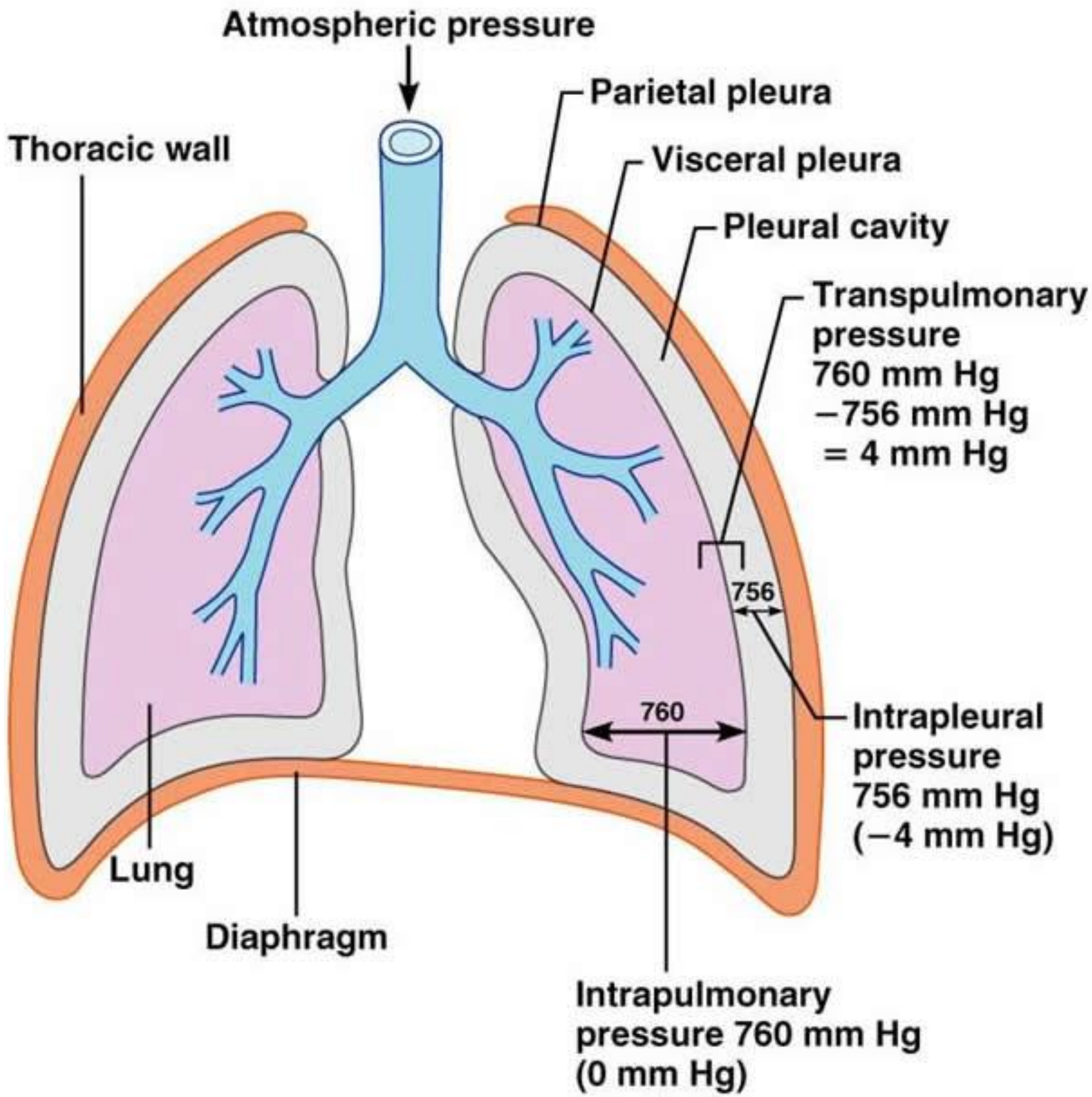
➢ **pleura**



Cervical pleura
Bronchial tree
(representing
root of lung)
Costal pleura
Pleural
cavity
Visceral
pleura
Trachea
Cervical pleura
* Costal part
Costal surface
of left lung
covered with
visceral pleura
Cardiac notch
Lingula
* Mediastinal part
* Diaphragmatic
part
Costodiaphragmatic
recesses
* Diaphragmatic
part
* = Parts of parietal pleura
Anterior view
COA5 ©2006 LWW


Collapsed
Inflated
Hilum of lung (site of entry of root of lung)
Suprapleural membrane
Cervical pleura
Pleural cavity
Collapsed lung
Mediastinal part
Visceral pleura
Parietal pleura
Costal part
Parts of parietal pleura
Thoracic wall lined with endothoracic fascia
Diaphragmatic part
Endothoracic fascia
Phrenico-pleural fascia (part of endothoracic fascia)
Mediastinum
Visceral pleura
Diaphragm
The right and left pulmonary cavities, separated by the mediastinum, are lined with parietal pleura that reflects onto the lungs as visceral pleura.
Anterior view

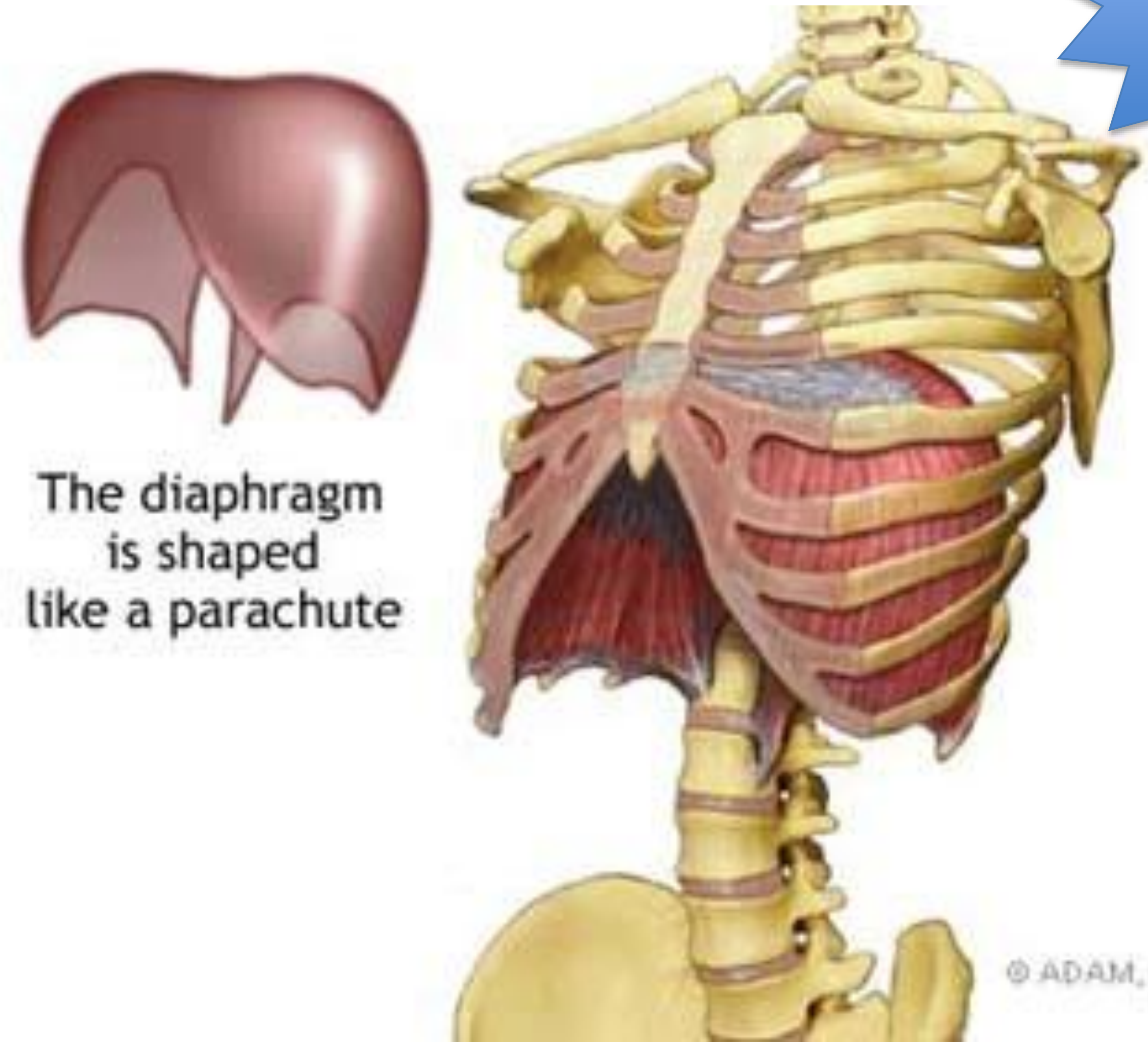
- **Intrapleural pressure** is the pressure in the pleural cavity. It also rises and falls during respiration, but is always about 4 mm Hg less than **intrapulmonary pressure**.



➢ Diaphragm

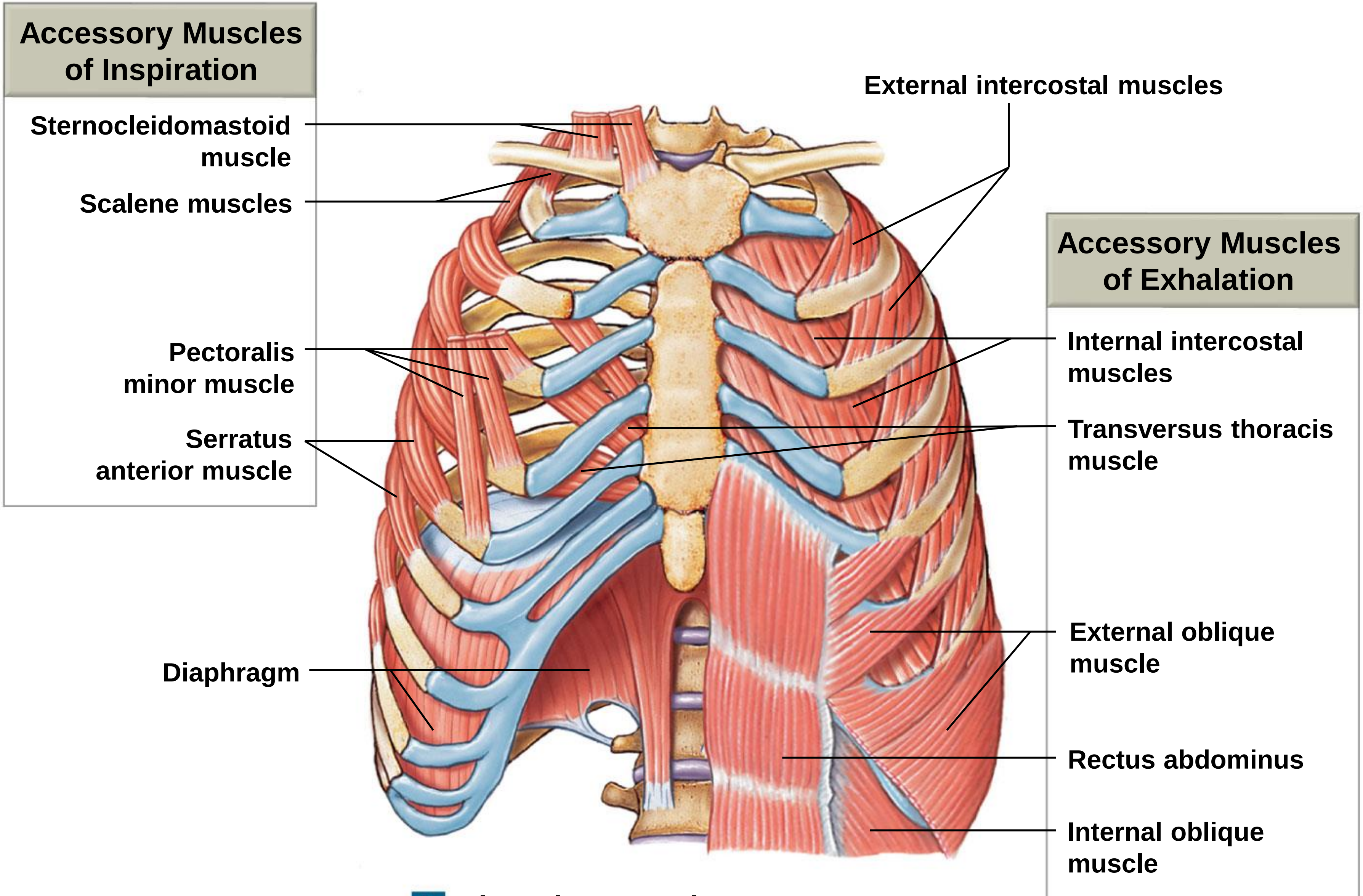
- acts as a separating sheath between the chest cavity and the abdominal cavity.
- composed of both muscle and tendon

Watch video #19,20,21



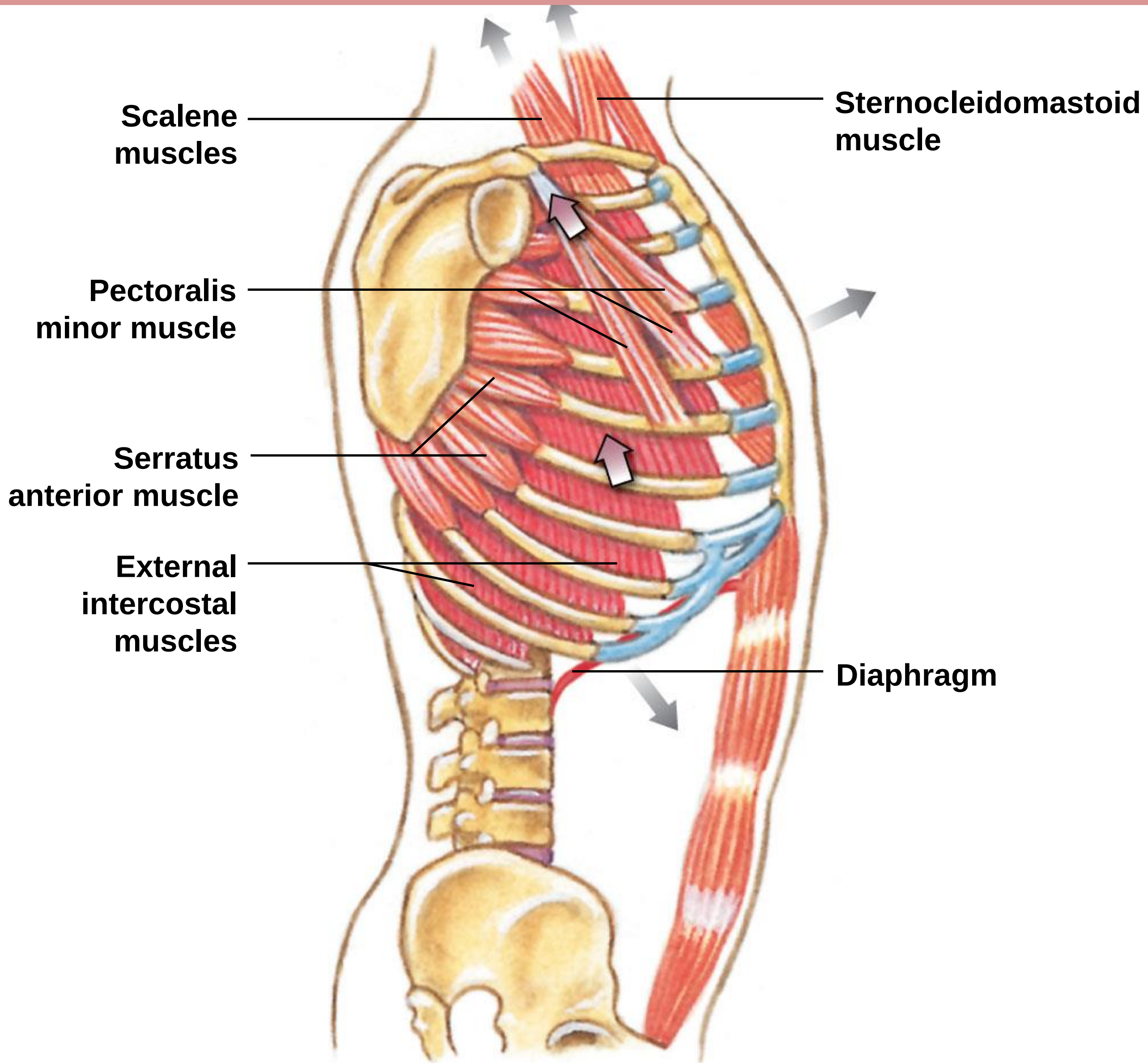
Respiratory Muscles

- Inspiratory muscles
    - Diaphragm
    - External intercostal muscles
- Expiratory muscles
    - Usually not needed due to elastic recoil of lungs and thoracic cavity
- Accessory respiratory muscles
    - Inspiration
        - Sternocleidomastoid, serratus anterior, pectoralis minor, and scalene muscles
    - Expiration
        - Transversus thoracis, oblique, and rectus abdominis muscles
        - Internal intercostal muscles

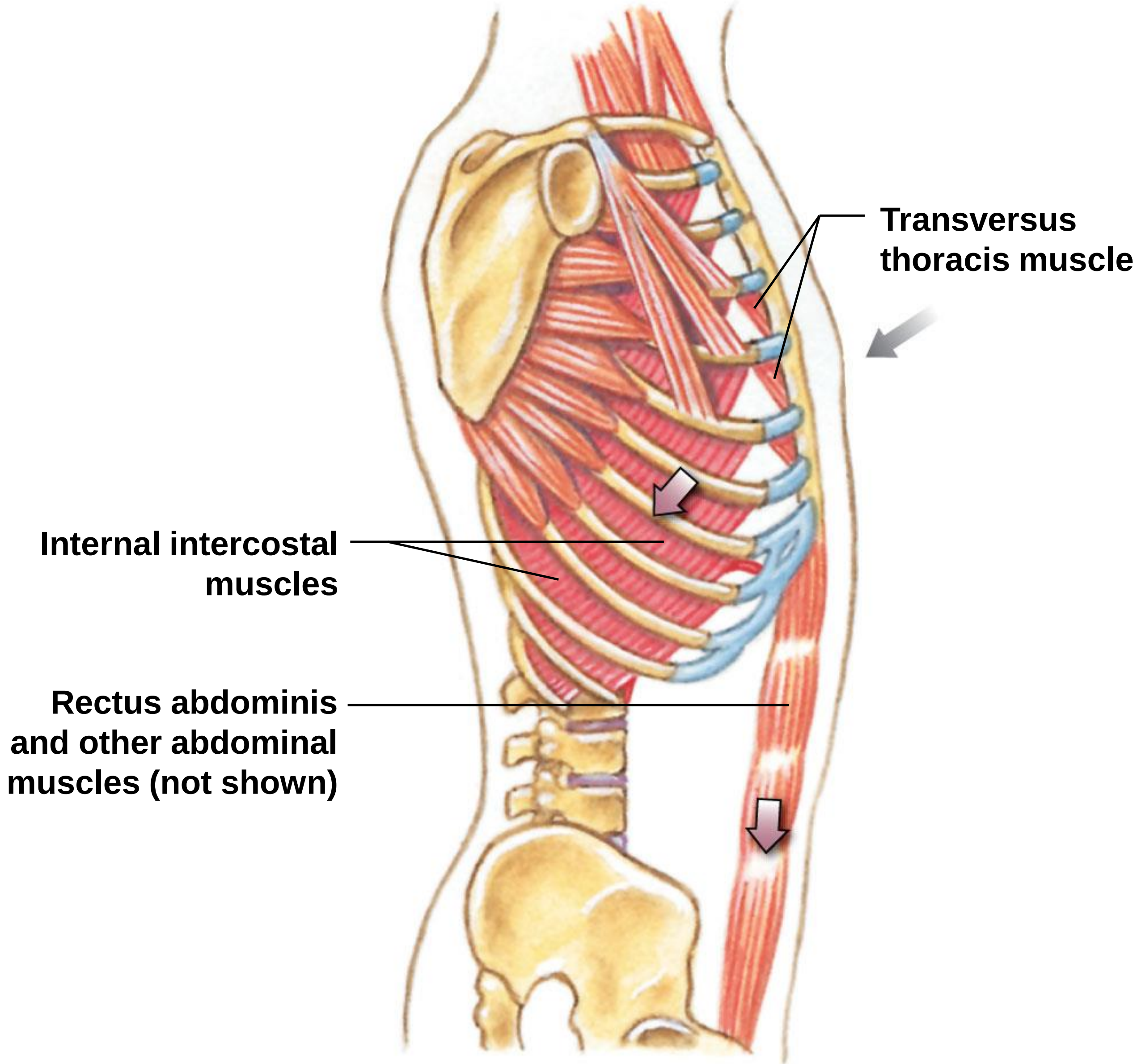


b The primary and accessory muscles of respiration

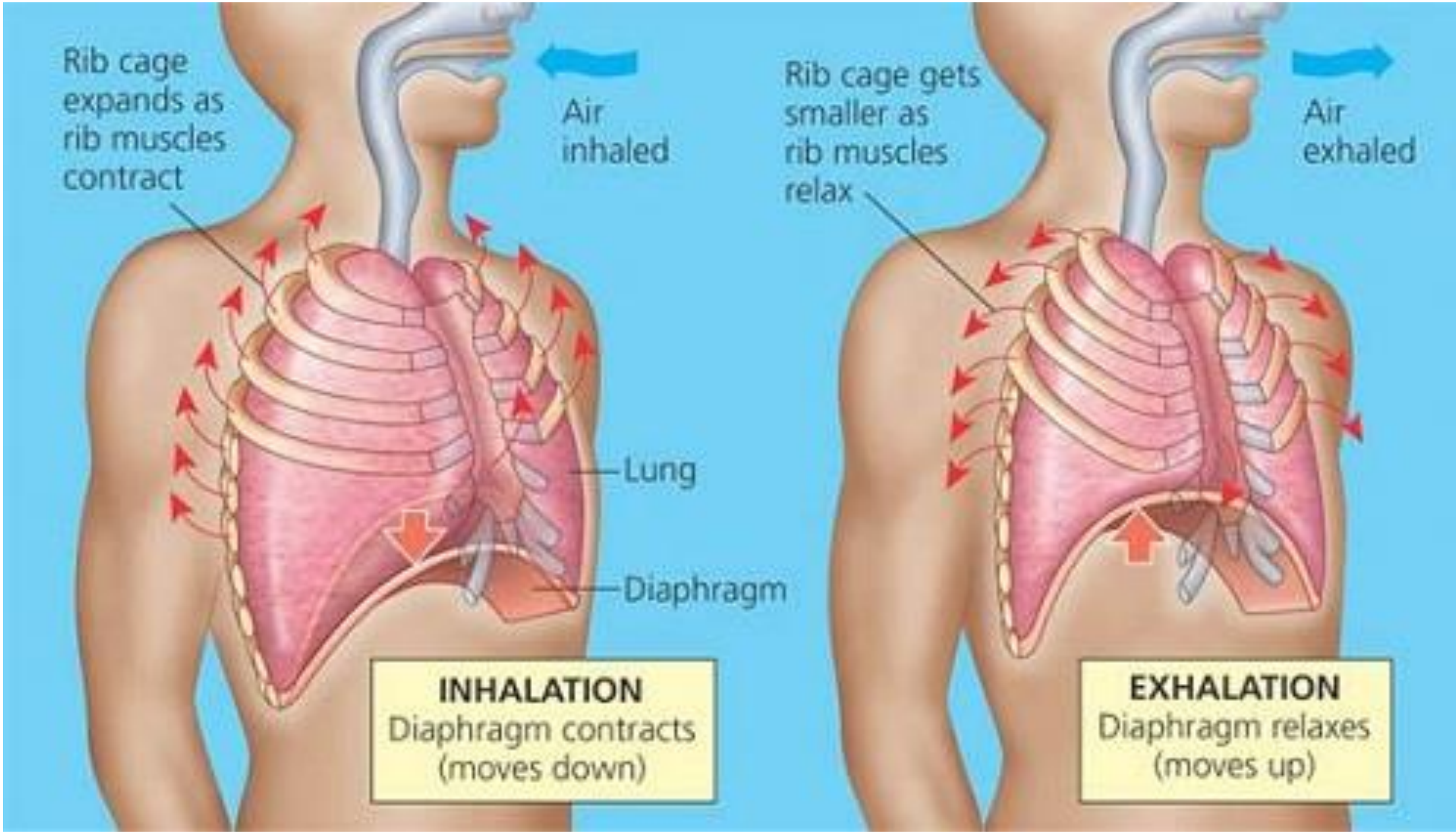
Mechanics of Respiration



Inhalation, showing the primary and accessory respiratory muscles that elevate the ribs and flatten the diaphragm.



Exhalation, showing the primary and accessory respiratory muscles that depress the ribs and elevate the diaphragm.


Rib cage
expands as
rib muscles
contract
Air
inhaled
Lung
Diaphragm
INHALATION
Diaphragm contracts
(moves down)
Rib cage gets
smaller as
rib muscles
relax
Air
exhaled
EXHALATION
Diaphragm relaxes
(moves up)

Mechanics of Respiration- (cont.)

➢ MVPA Process

M **M**uscle & Movement	**V** **V**olume	**P** **P**ressure (relative to atmosphere)	A **A**ir flow (H to L)

Mechanics of Respiration- (cont.)

➢ Inspiration at REST

- **Diaphragm muscle**

contracts-flattens, lowering dome when contracted

- **External intercostal Muscles**

contract to move ribs up & out

When thorax expands.

So do parietal and visceral pleurae.

Lung Volume increases

Alveolar Pressure drops

(lower than the atmospheric pressure)

Air moves IN

From atmosphere to alveoli

Inspiration at REST → active

Mechanics of Respiration- (cont.)

➢ Expiration at REST

- **Respiratory muscles relax**

When thorax returns to resting volume.

Lung Volume decreases

Alveolar Pressure increases

(higher than atmospheric pressure)

Air moves OUT

From alveoli to atmosphere

Inspiration at REST → passive

Mechanics of Respiration- (cont.)

Inspiration During Exercise

- **Accessory muscles** help deeper breating and increase TV
- **External intercostal muscles & diaphragm** contract

Larger Volume
Increase in lungs

Larger ressure reduction
(relative to atmosphere)

More Air flows (sucked faster) into lungs

Inspiration at EXERCISE → active

Mechanics of Respiration- (cont.)

Expiration During Exercise

- **Accessory muscles makes expiratin FORCED**
- **External intercostal muscles & diaphragm** relax
- **Internal intercostal contract** to force ribs to normal position

Volume is forcibly reduced.

Pressure quickly increase (relative to atmosphere)

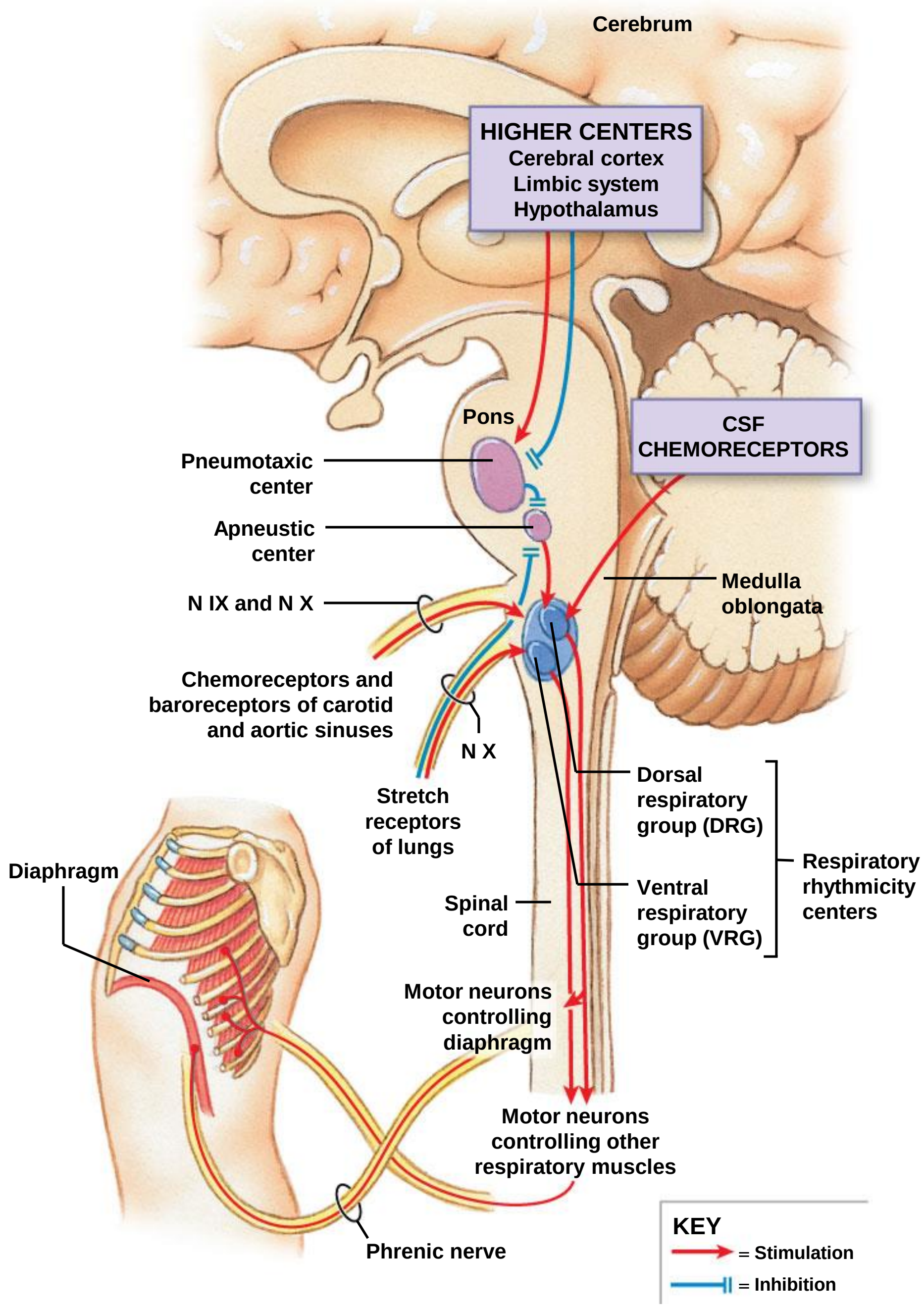
More Air is forced ut faster

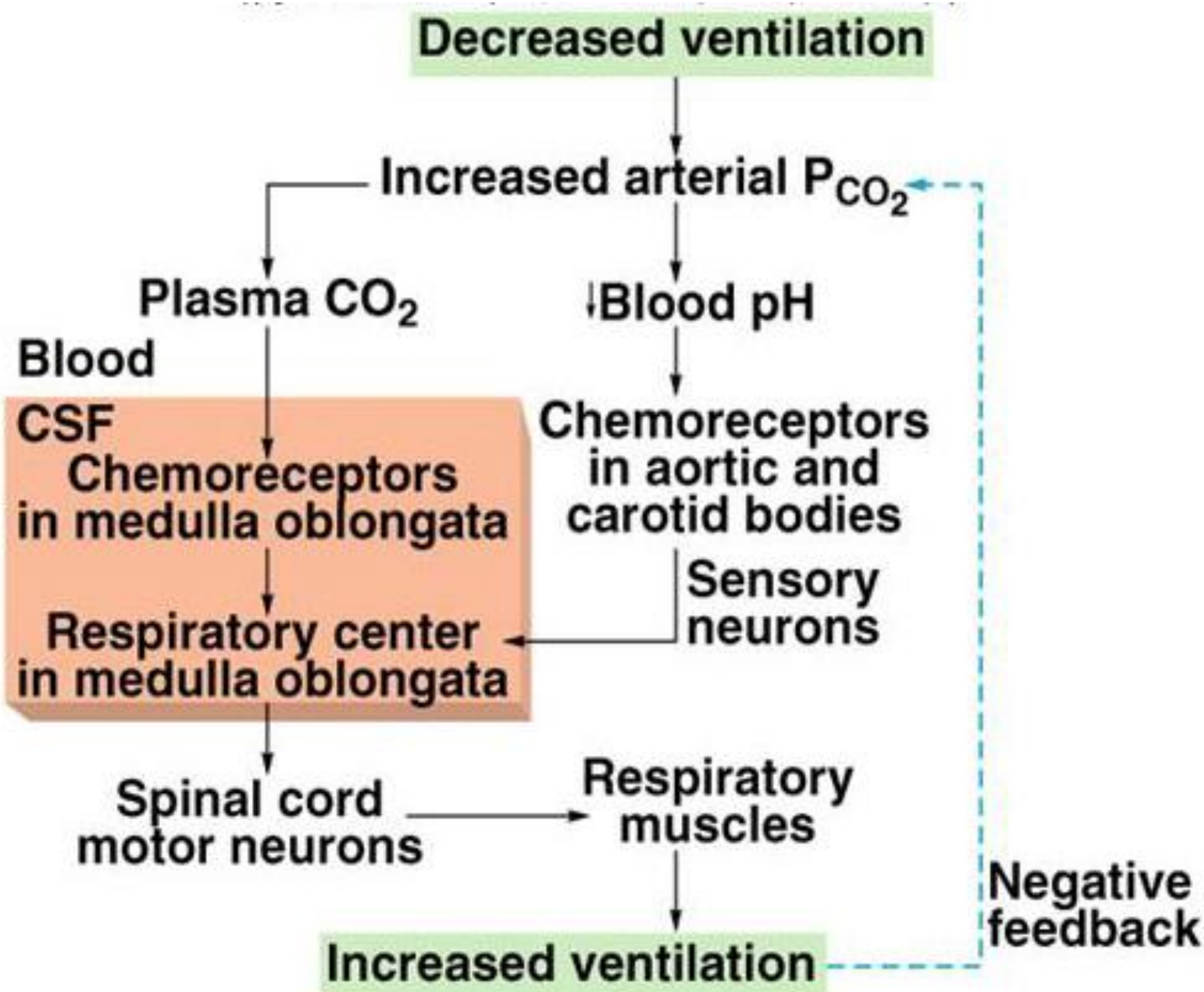
Inspiration at EXERCISE → active

Mechanics of Respiration- (cont.)

SUMMARY	REST		DURING EXERCISE	
	INSPIRATION	EXPIRATION	INSPIRATION	EXPIRATION
(M) Muscles	External intercostal muscles & diaphragm CONTRACT (Active)	External intercostal muscles & diaphragm RELAX (Passive)	External intercostals & diaphragm CONTRACT (Active) Sternocleidomastoid, Scalenes and Pectoralis minor contract to exaggerate action (Active)	External IC and diaphragm relax (Passive) Internal intercostals & diaphragm CONTRACT to force ribs to normal position Rectus abdominus and Lat Dorsi contract to exaggerate action (Active)
(M) Movement	Rib cage pulled up and out and diaphragm flattens	D – dome-shaped and ribs in and down	Greater expansion of thoracic cavity	More forceful reduction in cavity
(V) Volume	INCREASES	DECREASES	Greater and faster Increase in volume	Greater and faster decrease in volume
(P) Pressure	LOW (in comparison to atmospheric air outside body)	HIGH	VV LOW	VV HIGH
(A) Air movement	AIR SUCKED IN – HIGH TO LOW PRESSURE	AIR MOVES OUT – HIGH TO LOW PRESSURE	MORE AIR FORCED IN – high to low	MORE AIR FORCED OUT – HIGH TO LOW PRESSURE

- **Respiratory Centers and Reflex Controls**

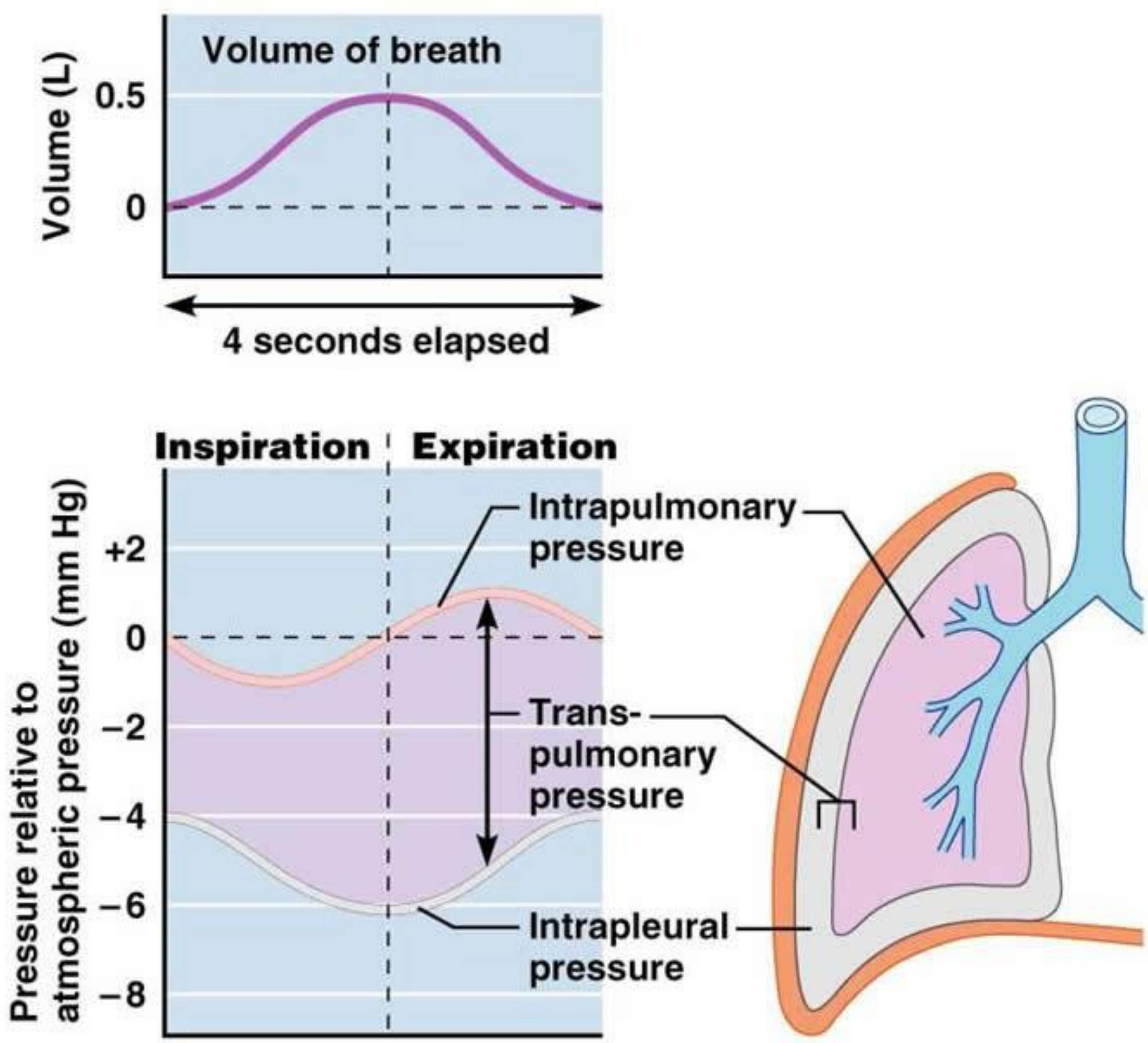




Decreased ventilation
Increased arterial P_{CO_2}
Plasma CO_2
↓Blood pH
Blood
CSF
Chemoreceptors in medulla oblongata
Chemoreceptors in aortic and carotid bodies
Sensory neurons
Respiratory center in medulla oblongata
Spinal cord motor neurons
Respiratory muscles
Negative feedback
Increased ventilation

Mechanics of Respiration- (cont.)

- Pressure and Volume Changes During Breathing



Pulmonary Volumes and Capacities

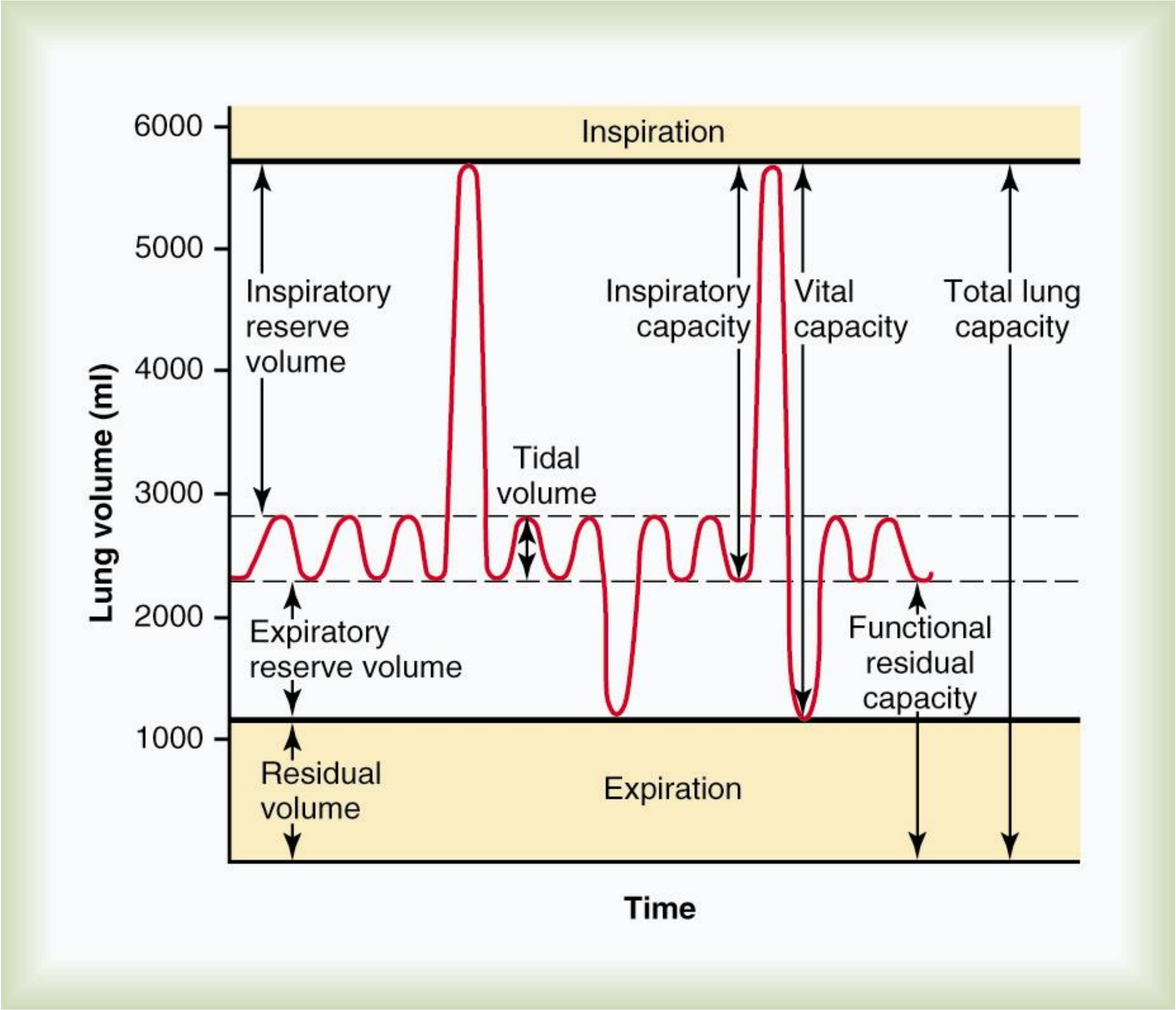
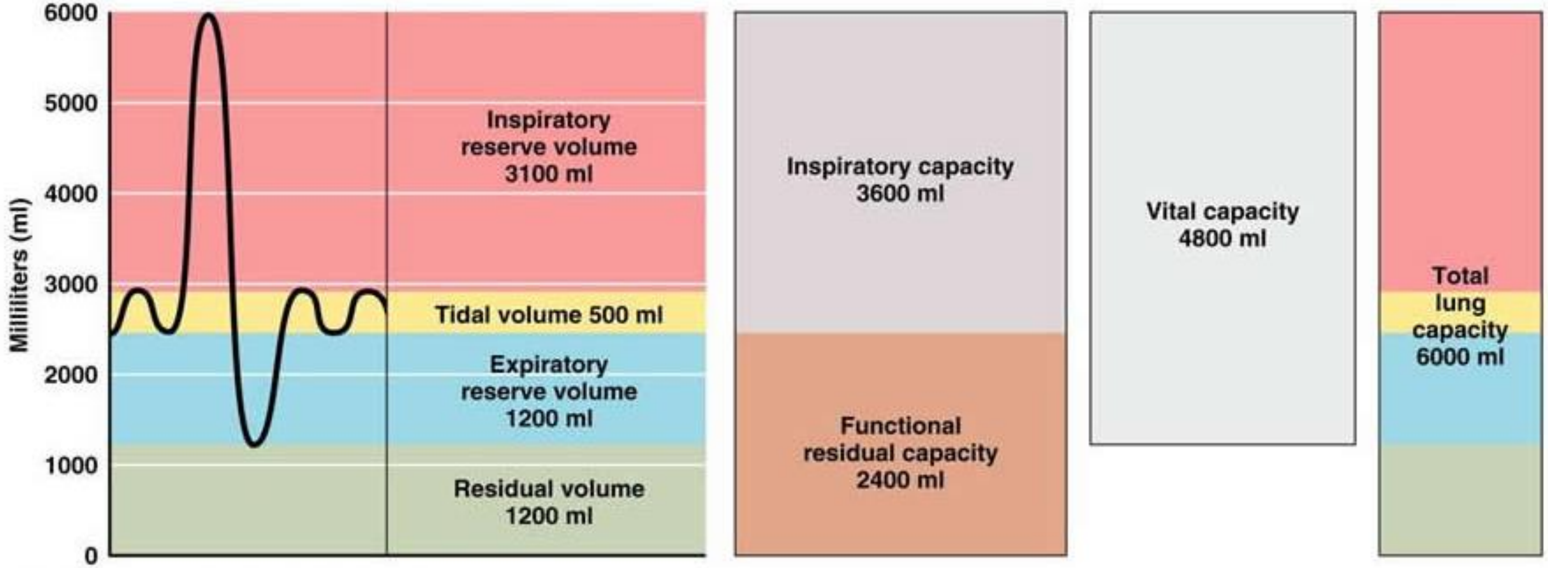


Figure 37-6; Diagram showing respiratory excursions during normal breathing and during maximal inspiration and maximal expiration.



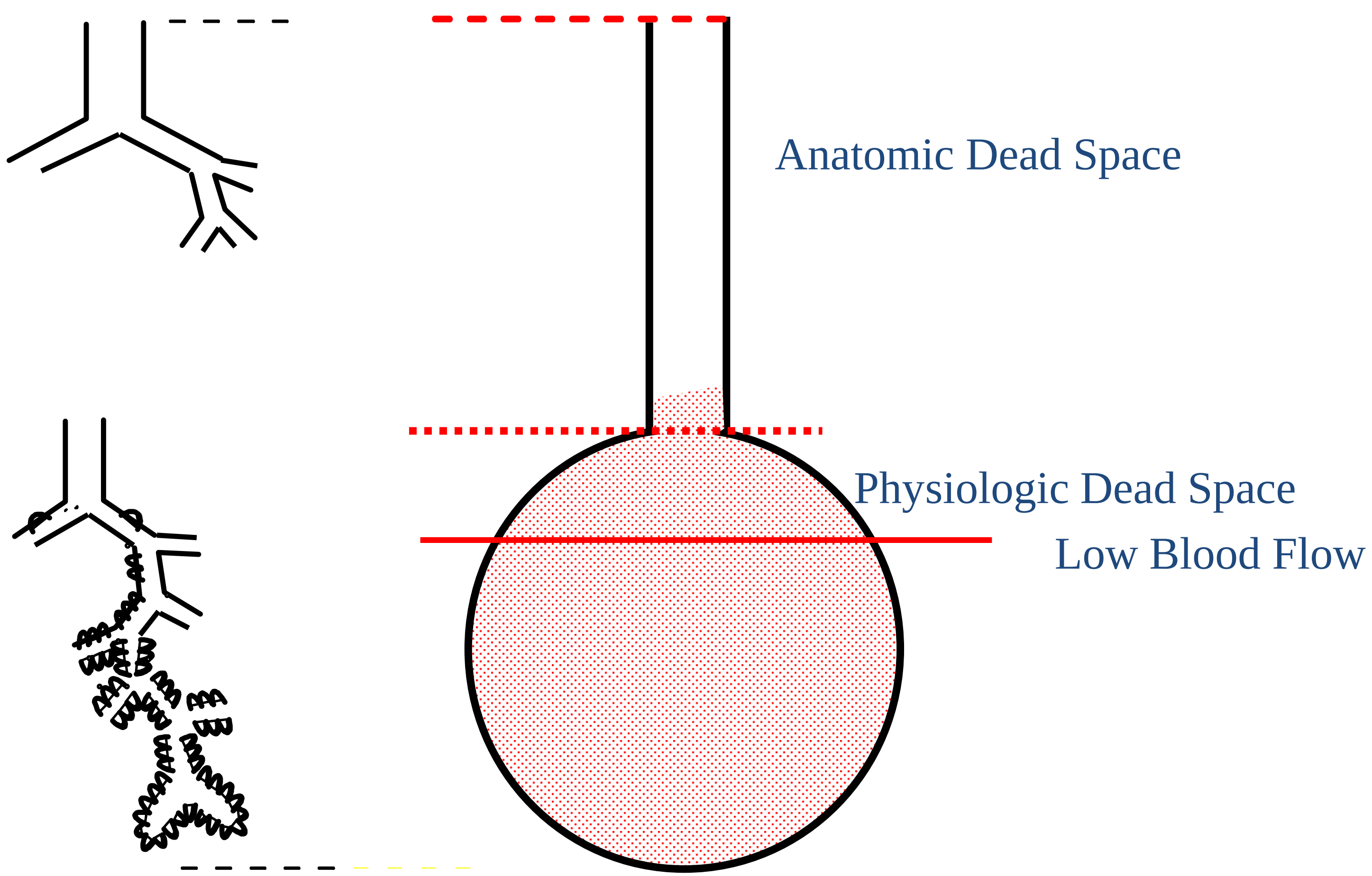
(a) Spirographic record for a male

	Measurement	Adult male average value	Adult female average value	Description
Respiratory volumes	Tidal volume (TV)	500 ml	500 ml	Amount of air inhaled or exhaled with each breath under resting conditions
	Inspiratory reserve volume (IRV)	3100 ml	1900 ml	Amount of air that can be forcefully inhaled after a normal tidal volume inhalation
	Expiratory reserve volume (ERV)	1200 ml	700 ml	Amount of air that can be forcefully exhaled after a normal tidal volume exhalation
	Residual volume (RV)	1200 ml	1100 ml	Amount of air remaining in the lungs after a forced exhalation
Respiratory capacities	Total lung capacity (TLC)	6000 ml	4200 ml	Maximum amount of air contained in lungs after a maximum inspiratory effort: TLC = TV + IRV + ERV + RV
	Vital capacity (VC)	4800 ml	3100 ml	Maximum amount of air that can be expired after a maximum inspiratory effort: VC = TV + IRV + ERV (should be 80% TLC)
	Inspiratory capacity (IC)	3600 ml	2400 ml	Maximum amount of air that can be inspired after a normal expiration: IC = TV + IRV
	Functional residual capacity (FRC)	2400 ml	1800 ml	Volume of air remaining in the lungs after a normal tidal volume expiration: FRC = ERV + RV

(b) Summary of respiratory volumes and capacities for males and females

Definitions of Dead Space

- Dead space is the the total volume of the conducting airways from the nose or mouth down to the level of the terminal bronchioles which does not participate in the gas exchange.
- **Anatomical dead space:** portions where there is no possibility of gas exchange
- **Physiological dead space:** portions where there is possibility of gas exchange but is just not happening



Compliance of Lungs

- The extent to which the lungs will expand for each unit increase in transpulmonary pressure is called the lung compliance.
- Compliance describes the elasticity or distensibility of the respiratory structures (alveoli, chest wall, and pulmonary parenchyma)

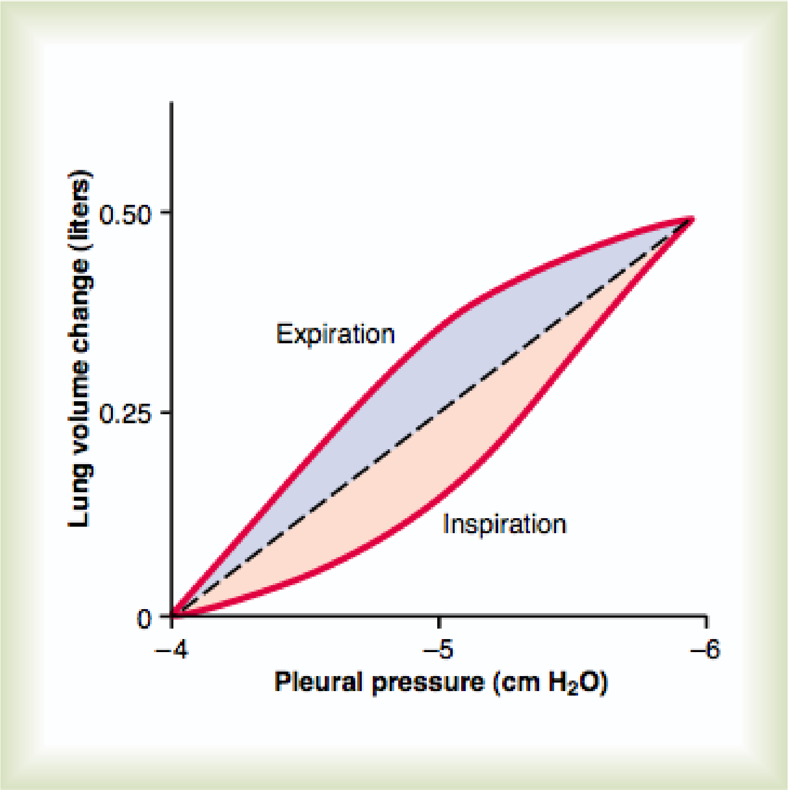


Figure 37–3

Compliance diagram in a healthy person. This diagram shows compliance of the lungs alone.

Control of Bronchiolar Diameter

- Nervous
  - Sympathetics
    - β_2 receptors dilate
  - Parasympathetics
    - Acetylcholine constrict

- Humoral
  - Histamine, acetylcholine » Constrict
  - Adrenergic (β agonists) » Relax

Airway Resistance during Forced Exhalation

- Airway resistance is the opposition to gas flow.
- Airway resistance depends on:

➢ Radii of the airways (total cross-sectional area)
➢ Lengths of the airways
➢ Flow Type: Laminar or Turbulent
➢ Density and viscosity of gas

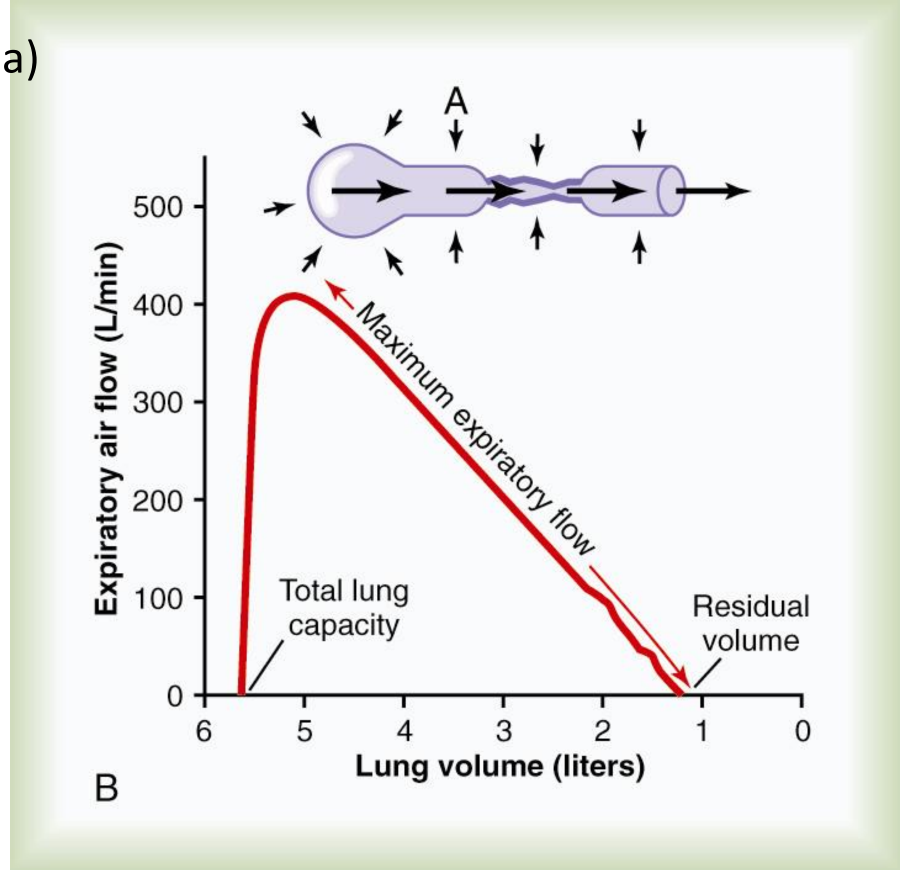


Figure 42–1; A, Collapse of the respiratory passageway during maximum expiratory effort, an effect that limits expiratory flow rate. B, Effect of lung volume on the maximum expiratory air flow, showing decreasing maximum expiratory air flow as the lung volume becomes smaller.

Determinants of Diffusion

- factors that affect the rate of gas diffusion

- Pressure Gradient
- Area (cross-sectional area of the fluid)
- Distance (the distance through which the gas must diffuse)
- Solubility (solubility of the gas in the fluid) and MW (the molecular weight of the gas)

$$\text{Rate of Diffusion} = \frac{(P_1 - P_2) * \text{Area} * \text{Solubility}}{\text{Distance} * \sqrt{\text{MW}}}$$

Changes in Alveolar Gas Composition

- *functional residual capacity* : the volume of air remaining in the lungs at the end of normal expiration

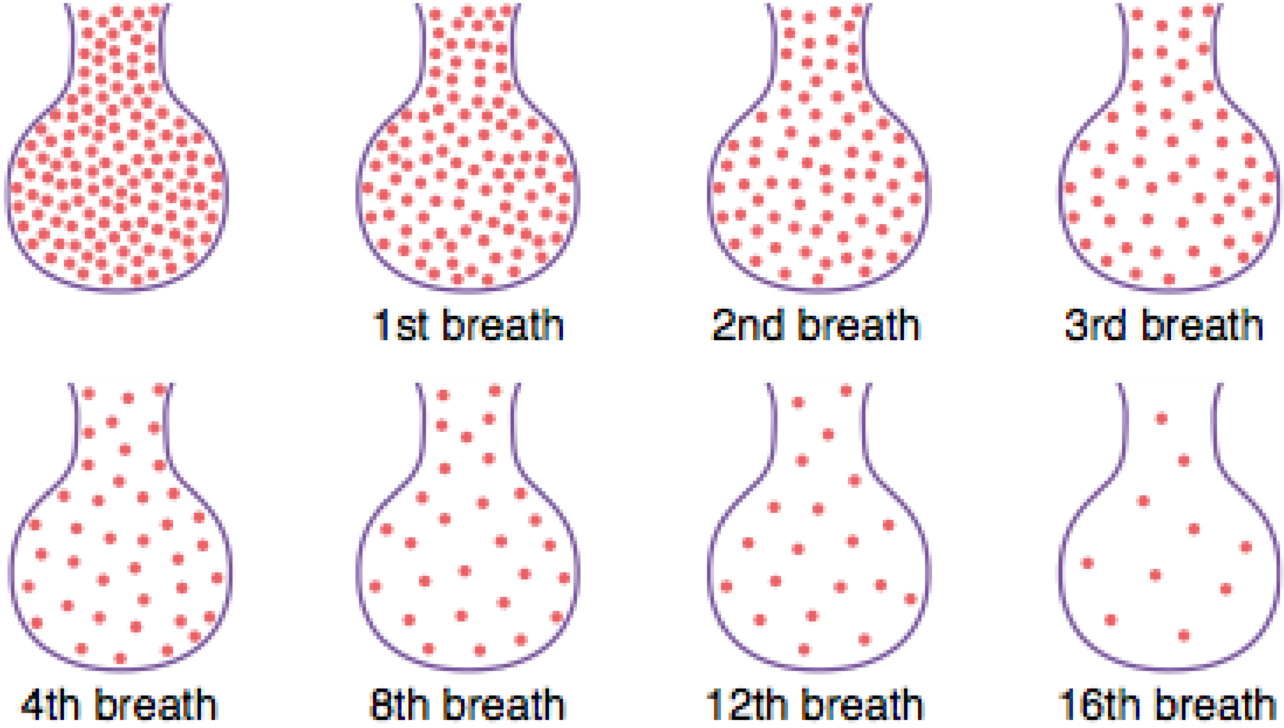


Figure 39–2

Expiration of a gas from an alveolus with successive breaths.

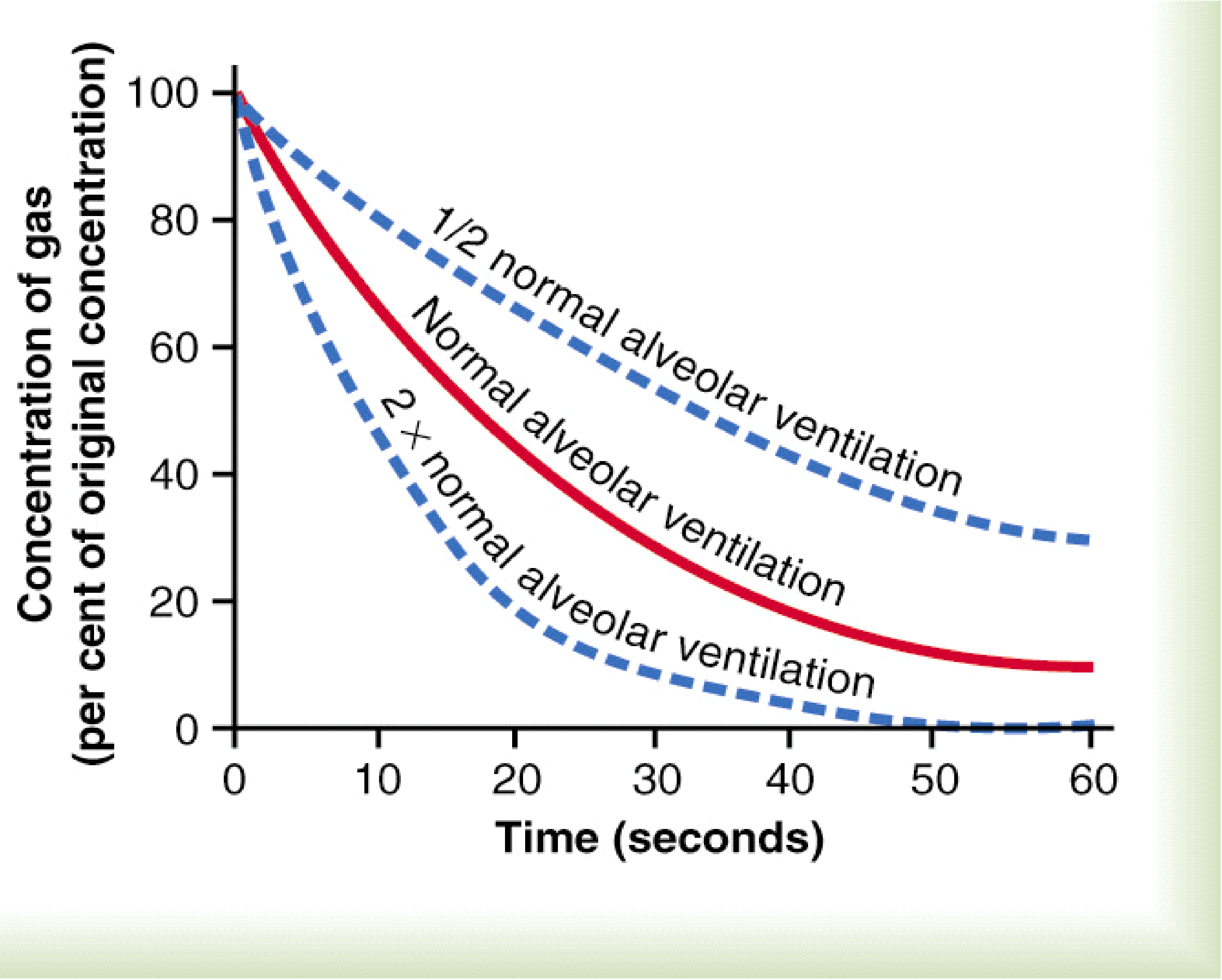


Figure 39-3; Rate of removal of excess gas from alveoli.

Partial Pressure of Oxygen in Alveoli

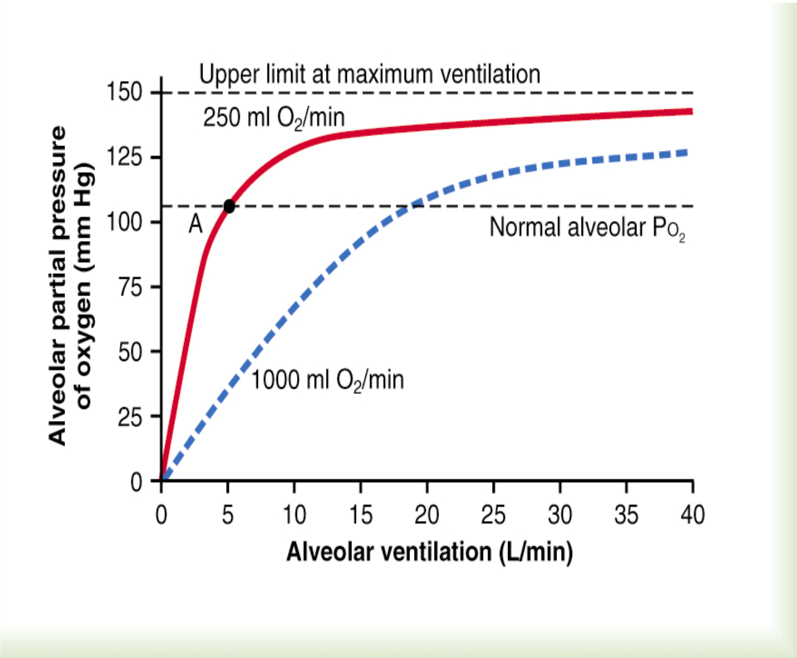


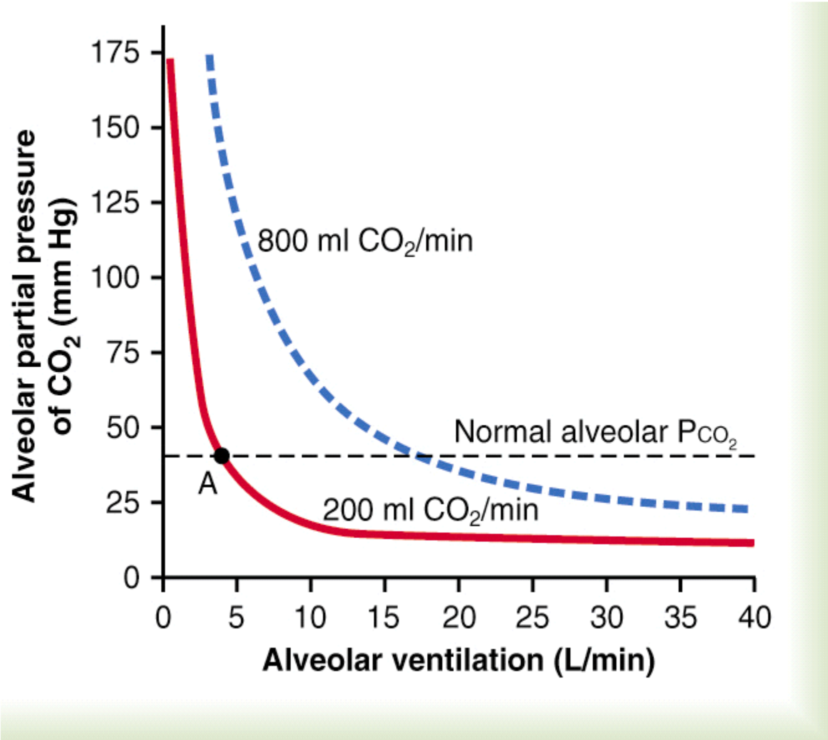
Figure 39-4: Effect of alveolar ventilation on the alveolar PO_2 at two rates of oxygen absorption from the alveoli— 250 ml/min and 1000 ml/min. Point A is the normal operating point.

- oxygen concentration in the alveoli, and its partial pressure as well, is controlled by (1) the rate of absorption of oxygen into the blood and (2) the rate of entry of new oxygen into the lungs by the ventilatory process.

- At a normal ventilatory rate of 4.2 L/min and an oxygen consumption of 250 ml/min, the normal operating point in Figure 39–4 is point A. The figure also shows that when 1000 milliliters of oxygen is being absorbed each minute, as occurs during moderate exercise, the rate of alveolar ventilation must increase fourfold to maintain the alveolar PO_2 at the normal value of 104 mm Hg.

Ventilation $\uparrow \longrightarrow PO_2 \uparrow$

Partial Pressure of CO_2 in Alveoli



- Carbon dioxide is continually being formed in the body and then carried in the blood to the alveoli; it is continually being removed from the alveoli by ventilation.
- Figure 39–5 shows the effects on the alveolar partial pressure of carbon dioxide (PCO_2) of both alveolar ventilation and two rates of carbon dioxide excretion, 200 and 800 ml/min. One curve represents a normal rate of carbon dioxide excretion of 200 ml/min. At the normal rate of alveolar ventilation of 4.2 L/min, the operating point for alveolar PCO_2 is , at point A, 40 mm Hg.

Ventilation $\uparrow$ $\rightarrow$ PCO_2 $\downarrow$

Figure 39-5; Effect of alveolar ventilation on the alveolar PCO_2 at two rates of carbon dioxide excretion from the blood—800 ml/min and 200 ml/ min. Point A is the normal operating point.

▪ Diffusion of Oxygen and Carbon dioxide

- <u>Oxygen</u>

- The PO_2 of the gaseous oxygen in the alveolus averages 104 mm Hg, whereas the PO_2 of the venous blood entering the pulmonary capillary at its arterial end averages only 40 mm Hg because a large amount of oxygen was removed from this blood as it passed through the peripheral tissues
- 230 ml/min diffusion of oxygen

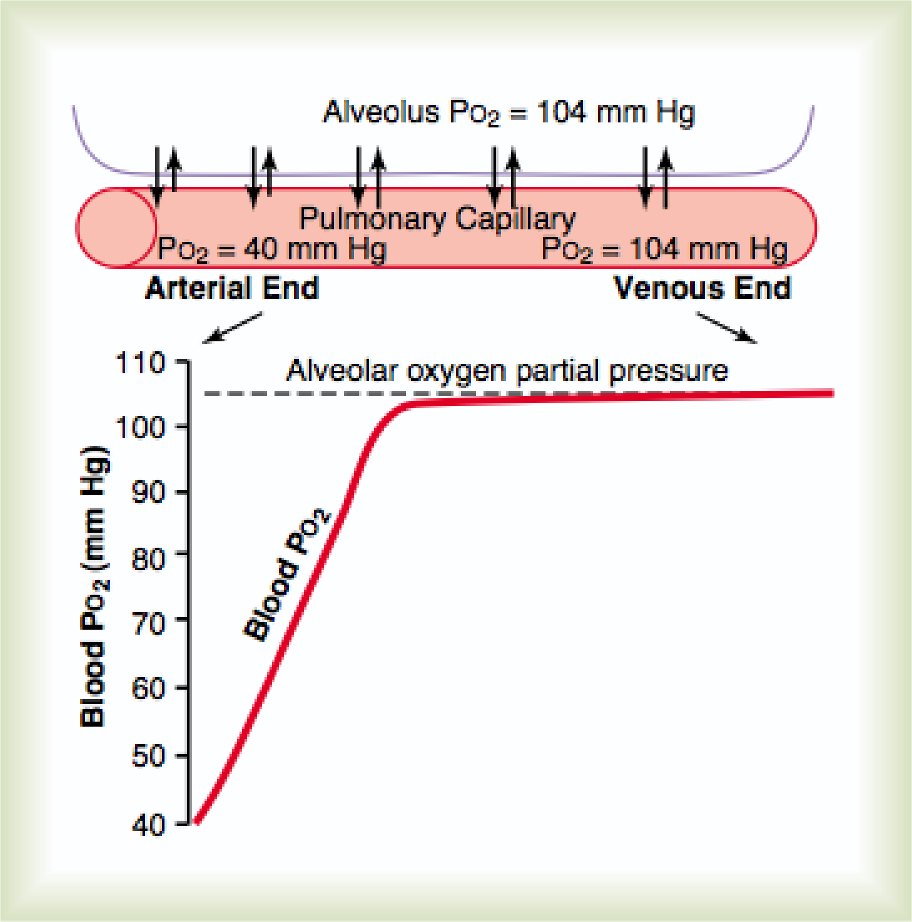


Figure 40–1

Uptake of oxygen by the pulmonary capillary blood. (The curve in this figure was constructed from data in Milhorn HT Jr, Pulley PE Jr: A theoretical study of pulmonary capillary gas exchange and venous admixture. Biophys J 8:337, 1968.)

- Carbon Dioxide

  - 200 ml/min diffusion of carbon dioxide

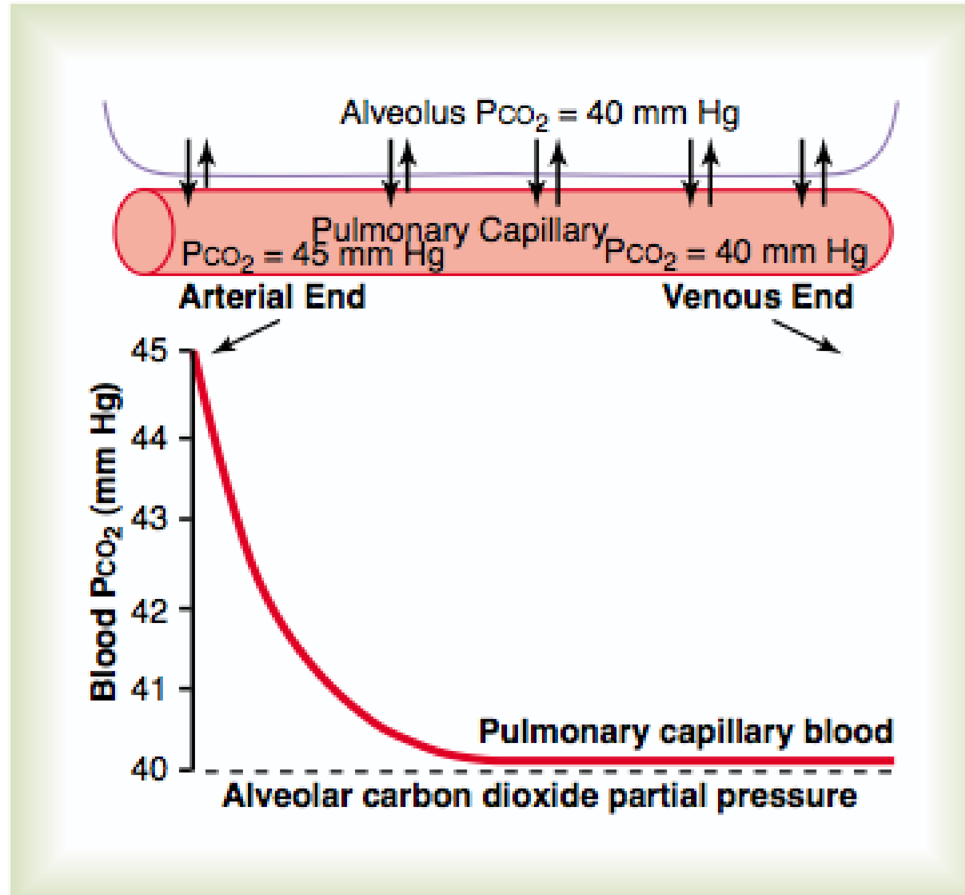
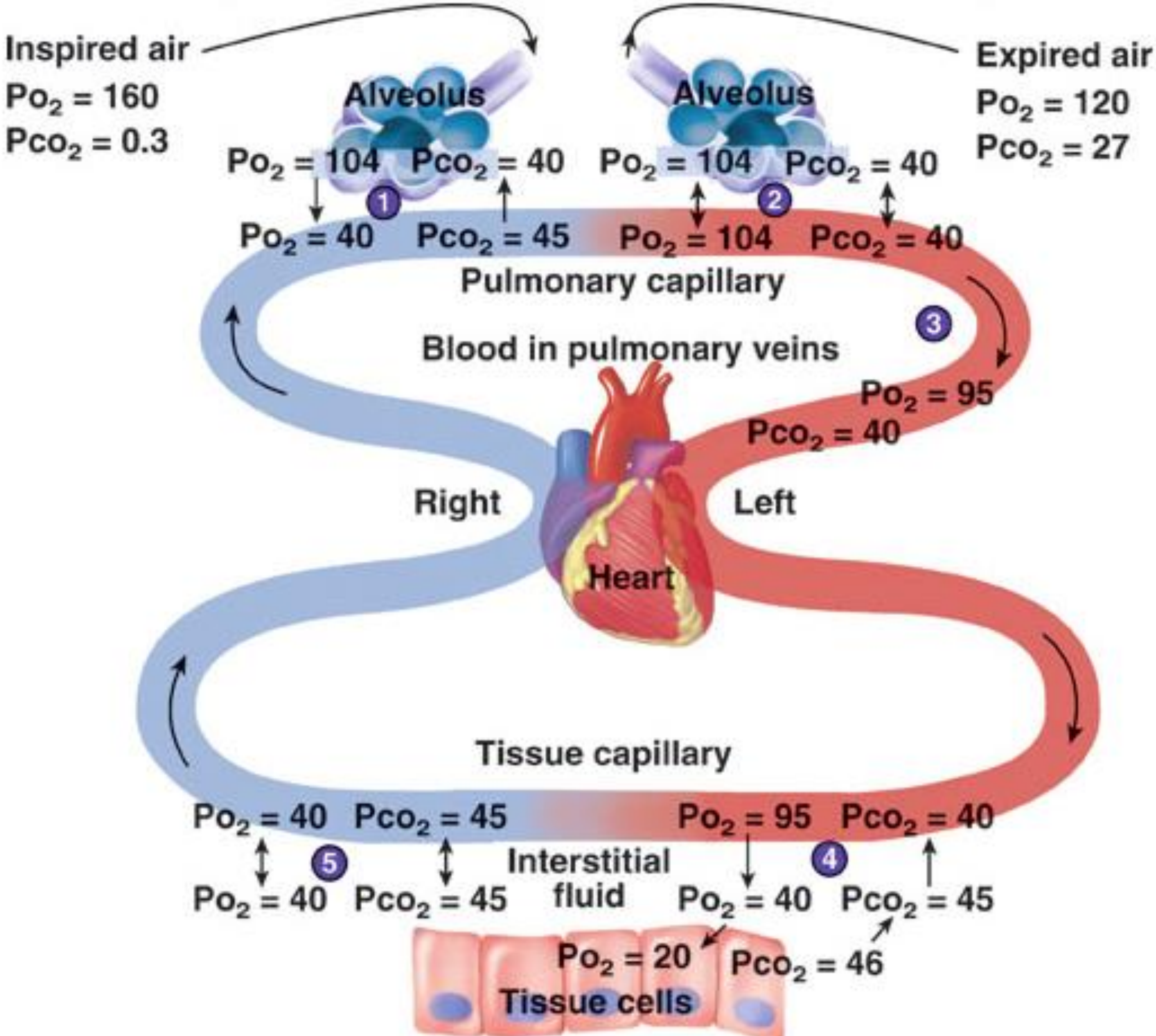


Figure 40–6

Diffusion of carbon dioxide from the pulmonary blood into the alveolus. (This curve was constructed from data in Milhorn HT Jr, Pulley PE Jr: A theoretical study of pulmonary capillary gas exchange and venous admixture. Biophys J 8:337, 1968.)



Inspired air
$P_{O_2} = 160$
$P_{CO_2} = 0.3$
Alveolus
Alveolus
Expired air
$P_{O_2} = 120$
$P_{CO_2} = 27$
$P_{O_2} = 104$
$P_{CO_2} = 40$
$P_{O_2} = 104$
$P_{CO_2} = 40$
1
2
$P_{O_2} = 40$
$P_{CO_2} = 45$
$P_{O_2} = 104$
$P_{CO_2} = 40$
Pulmonary capillary
3
Blood in pulmonary veins
$P_{O_2} = 95$
$P_{CO_2} = 40$
Right
Left
Heart
Tissue capillary
$P_{O_2} = 40$
$P_{CO_2} = 45$
$P_{O_2} = 95$
$P_{CO_2} = 40$
5
Interstitial fluid
4
$P_{O_2} = 40$
$P_{CO_2} = 45$
$P_{O_2} = 40$
$P_{CO_2} = 45$
$P_{O_2} = 20$
$P_{CO_2} = 46$
Tissue cells

Ventilation/Perfusion

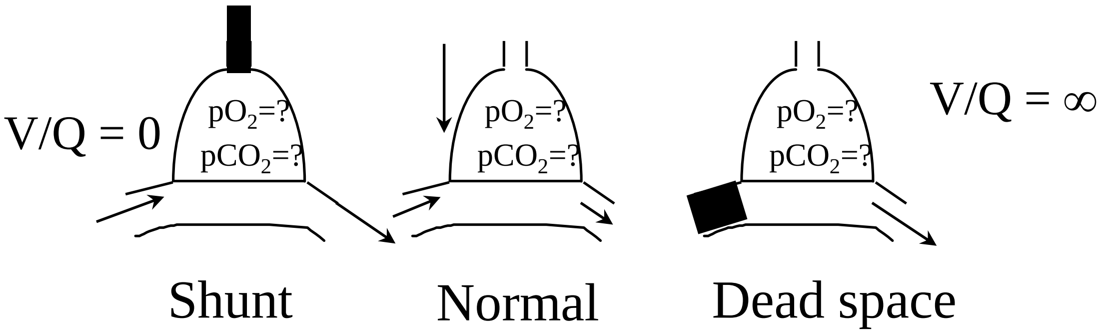
- quantitative concept has been developed to help us understand respiratory exchange when there is imbalance between alveolar ventilation and alveolar blood flow is called the ventilation-perfusion ratio.

- Defined as V/Q

- V/Q = (4 L/min)/ (5 L/min) = 0.8

Ventilation/Perfusion – (cont.)

- Whenever Va/Q is below normal, there is inadequate ventilation to provide the oxygen needed to fully oxygenate the blood flowing through the alveolar capillaries. Therefore, a certain fraction of the venous blood passing through the pulmonary capillaries does not become oxygenated. This fraction is called shunted blood.
- When ventilation of some of the alveoli is great but alveolar blood flow is low, there is far more available oxygen in the alveoli than can be transported away from the alveoli by the flowing blood. Thus, the ventilation of these alveoli is said to be wasted. The ventilation of the anatomical dead space areas of the respiratory passageways is also wasted. The sum of these two types of wasted ventilation is called the physiologic dead space.



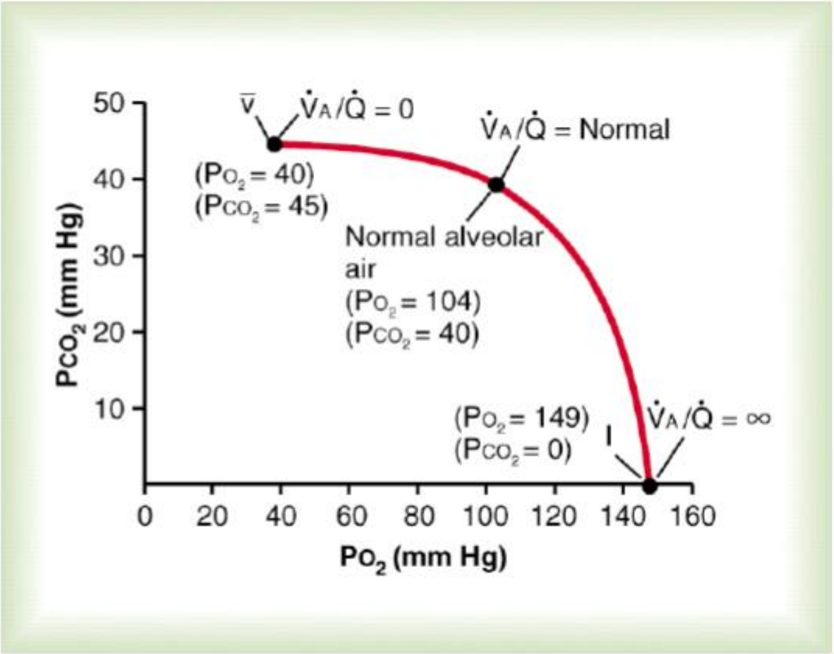


Figure 39-11; Normal PO2-PCO2, VA/Q diagram.

Ventilation/Perfusion – (cont.)

- Physiologic shunt
  - Va/Q < normal
  - low ventilation
- Physiologic dead space
  - Va/Q > normal
  - wasted ventilation
- Abnormalities
  - Upper lung Va/Q ~ 2.5
  - Lower lung Va/Q ~ .5

Uptake of Oxygen During Exercise

- Increased cardiac output
- Decreased transit time
- Increased diffusing capacity
  - Opening up of additional capillaries
  - Better ventilation/perfusion match
- Equilibration even with shorter time

Oxygen Transport

- Normally, about 97 per cent of the oxygen transported from the lungs to the tissues is carried in chemical combination with hemoglobin in the red blood cells.

- The remaining 3 per cent is transported in the dissolved state in the water of the plasma and blood cells. Thus, under normal conditions, oxygen is carried to the tissues almost entirely by hemoglobin.

- oxygen molecule combines loosely and reversibly with the heme portion of hemoglobin. When PO_2 is high, as in the pulmonary capillaries, oxygen binds with the hemoglobin, but when PO_2 is low, as in the tissue capillaries, oxygen is released from the hemoglobin. This is the basis for almost all oxygen transport from the lungs to the tissues.

▪ Hemoglobin Dissociation Curve

- from the dissociation curve that the usual oxygen saturation of systemic arterial blood averages 97 %. Conversely, in normal venous blood returning from the peripheral tissues, the PO_2 is about 40 mm Hg, and the saturation of hemoglobin averages 75 %.

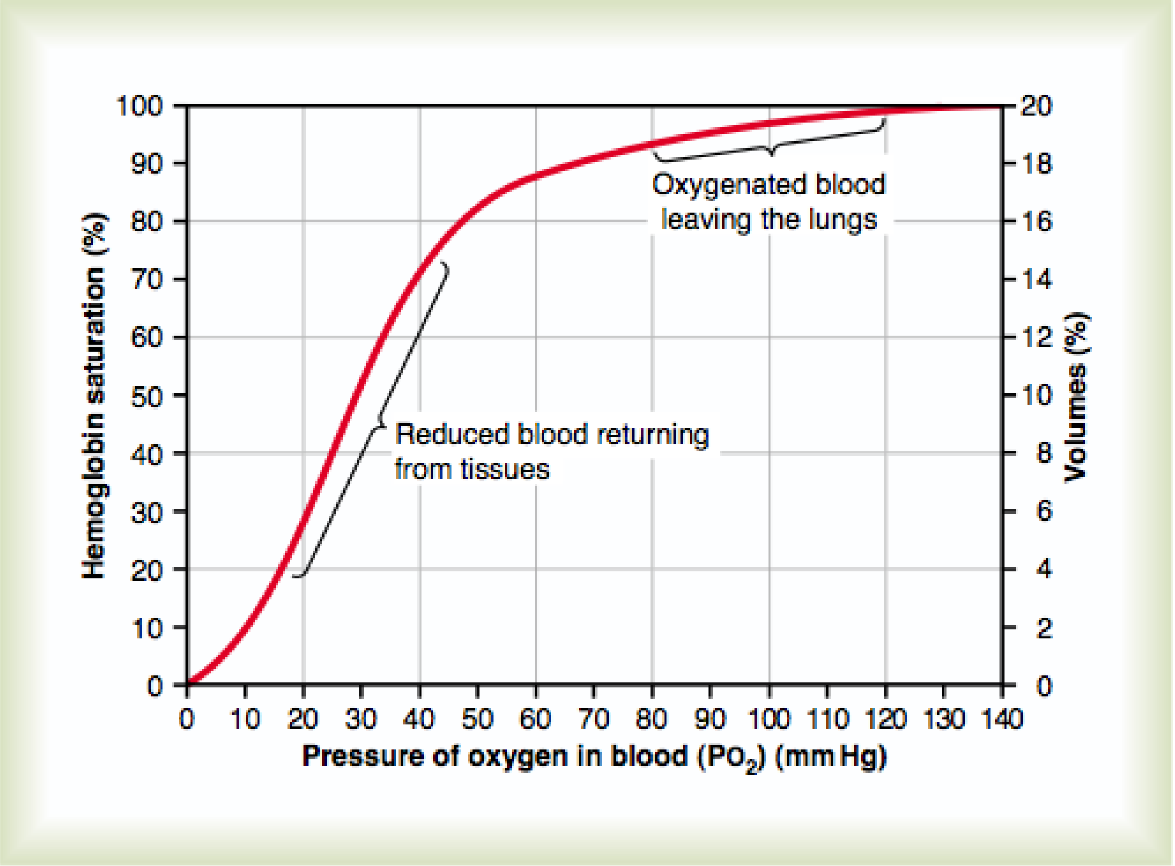
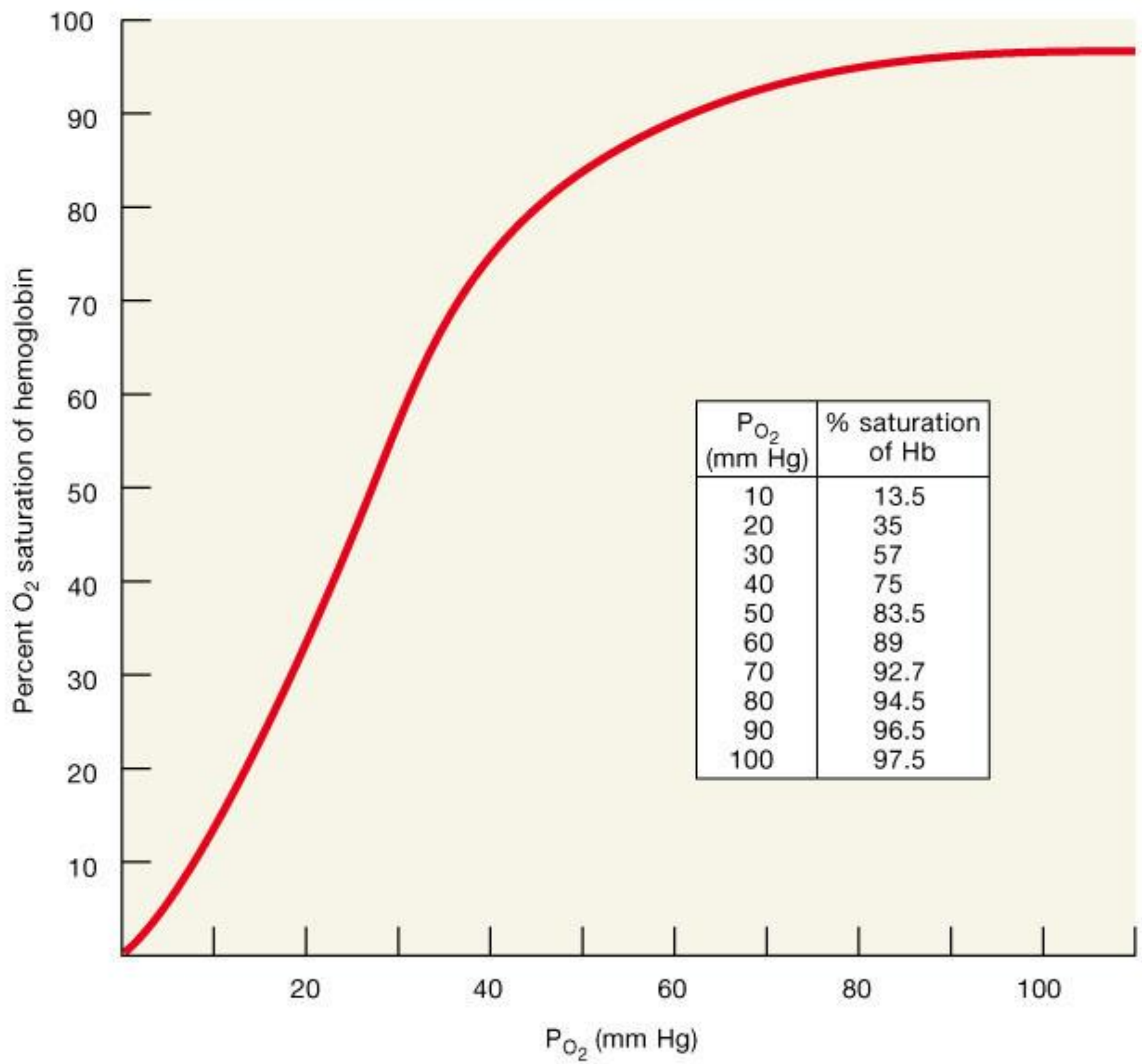


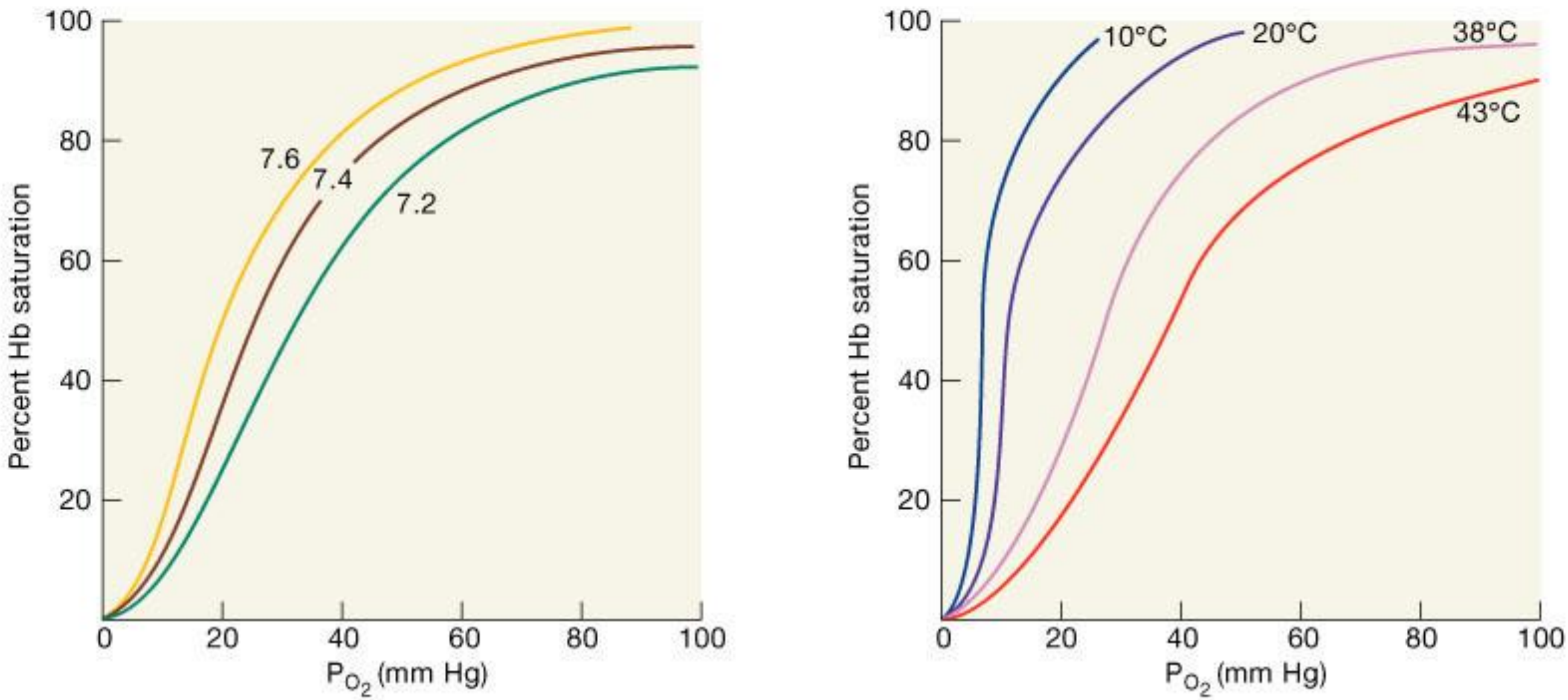
Figure 40–8
Oxygen-hemoglobin dissociation curve.

▪ The Oxygen-Hemoglobin Saturation Curve



P_{O_2} (mm Hg)	% saturation of Hb
10	13.5
20	35
30	57
40	75
50	83.5
60	89
70	92.7
80	94.5
90	96.5
100	97.5

- The Effect of pH and Temperature on Hemoglobin Saturation



(a) Effect of pH

(b) Effect of temperature

Transport of Carbon Dioxide from Tissue

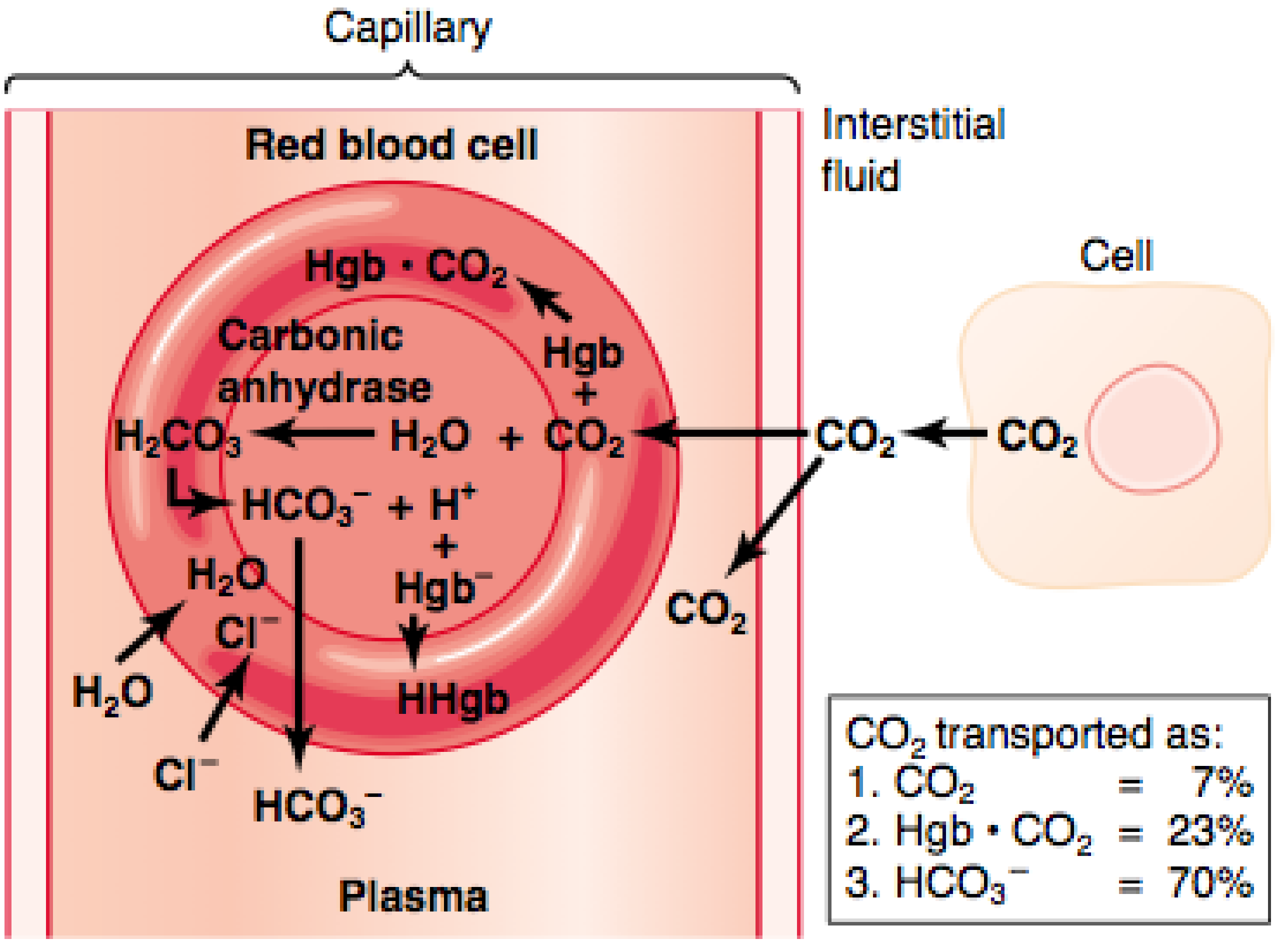


Figure 40–13

Transport of carbon dioxide in the blood.