

Chapter 23

BIOLOGY 2402
Anatomy and Physiology Lecture

CHAPTER 23

THE RESPIRATORY SYSTEM

THE RESPIRATORY SYSTEM

(Cells need a continuous supply of Oxygen (O₂) for various metabolic reaction that release energy from nutrient molecules; and release quantities of Carbon dioxide (CO₂).)

(Since an excessive amount of carbon dioxide produces acid conditions that are poisonous to cells, the excess gas must be eliminated quickly and efficiently.)

Cardiovascular and Respiratory System are two systems that supply Oxygen and eliminate Carbon dioxide.

- (1) **Respiratory System** provides for gas exchange, intake of Oxygen and elimination of Carbon dioxide.
- (2) **Cardiovascular System** transports the gases in the blood between the lungs and body cells.

Both participate equally in respiration.

Failure of either system has the same effect on the body: disruption of homeostasis and rapid death of cells from oxygen starvation and build-up of waste products.

Respiration Is the overall exchange of gases between the atmosphere, blood, and cells.

- Includes:
1. Ventilation, the movement of air into and out of the lungs;
 2. Gas exchange between the air in the lungs and the blood, sometimes called external respiration;
 3. Transport of oxygen and carbon dioxide in the blood; and
 4. Gas exchange between the blood and the tissues, sometimes called internal respiration.

Chapter 23

Three Basic Steps in Respiration:

1. **Pulmonary Ventilation** (Breathing) - is the inspiration (inflow) and expiration (outflow) of air between the atmosphere and the lungs.
2. **External Respiration** - is the exchange of gases between the air spaces of the lungs and blood in pulmonary capillaries. Blood gains O₂ and loses CO₂.
3. **Internal Respiration** - is the exchange of gases between blood in system capillaries and tissue cells. Blood loses O₂ and gains CO₂.

PATHWAY OF AIR FROM THE NOSE TO THE CAPILLARIES OF THE LUNGS

NOSE

NASAL CAVITIES AND PARANASAL SINUSES

Tonsils

PHARYNX (throat) Upper Respiratory

TRACHEA

BRONCHI

BRONCHIOLES

ALVEOLI

LUNG CAPILLARIES
BLOOD STREAM

Chapter 23

FUNCTIONS OF THE RESPIRATORY SYSTEM

1. Gas Exchange
2. Regulation of Blood pH
3. Voice production
4. Olfaction
5. Protection

ANATOMY AND HISTOLOGY OF THE RESPIRATORY SYSTEM

Respiratory System consists of the nose, pharynx (throat), Larynx (voice box), trachea (windpipe) bronchi, and lungs.

- (a). **Upper Respiratory System** - refers to the nose, pharynx (throat), and associated structure
- (b). **Lower Respiratory System** - refers to the larynx (voice box), trachea (windpipe), bronchi, and lungs.

Nose

Has an external and an internal portion inside the skull.

External portion is made of cartilage (framework of bone and hyaline cartilage covered with muscle and skin) and skin and is lined with mucous membrane.

External Nares (Nostrils) - Openings to the exterior (Two openings called external nares (nostrils).)

-Internal portion is a large cavity in the skull that lies inferior to the cranium and superior to the mouth.

*Anteriorly, the internal nose merges with the external nose.

Chapter 23

*Posteriorly it communicates with the throat (pharynx) through the openings called the **Internal Nares (choanae)**.

Nasal cavity - an opening through both external and internal nose.

Nasal Septum - divides nasal cavity into right and left sides by a vertical partition.

Vestibule - the anterior portion of the cavity.

Functions (Physiology) of the Interior Structures

1. Incoming air is warmed, moistened, and filtered.
2. Olfactory stimuli are received; and
3. Large, hollow resonating chambers are provided for speech sounds.
(Large, hollow resonating chambers modify speech sounds)

Otorhinolaryngology - the branch of medicine that deals with the diagnosis and treatment of diseases of the ear, nose, and throat.
(oto= ear rhino=nose larynx=throat)

Rhinoplasty - commonly called a "nose job", is a surgical procedure in which the structure of the external nose is altered.

PHARYNX (THROAT)

Somewhat funnel-shaped tube about 13 cm (5 in.) long.

Starts at the internal nares and extends to the level of the cricoid cartilage.

Serve as a passageway for air and food and to provide a resonating chamber for speech sounds. **Three Subdivisions of Pharynx:**

- 1) **Nasopharynx** - the uppermost portion of the pharynx; (lies posterior to the internal nasal cavity and extends to the plane of the soft

Chapter 23

palate).

Has four openings in its wall.

- a. Two internal nares - receives air from nasal cavity.
- b. Two openings that lead into the Auditory (Eustachian) tubes.

*(The nasopharynx exchanges small amounts of air with the auditory (Eustachian) tubes so that the air pressure inside the middle ear equals the pressure of the atmospheric air flowing through the nose and pharynx).

2. **Oropharynx** - the middle portion of the pharynx; (lies posterior to the oral cavity and extends from the soft palate inferiorly to the level of the hyoid bone.)

-Has only one opening:

Fauces - opening from the mouth

*Functions in both respiration and digestion, since it is a common passageway for air, food, and drink.

3. **Laryngopharynx** - the lowest portion of the pharynx. (extends downward from hyoid bone and becomes continuous with the esophagus (food tube) posteriorly and the larynx (voice box) anteriorly.

- A respiratory and digestive pathway.

LARYNX (VOICE BOX)

- A short passageway that connects the pharynx and the trachea.

Contains:

- Thyroid cartilage (Adam's Apple)
- **Epiglottis** - prevents food from entering the larynx
- **Cricoid cartilage** - connects larynx and trachea
- **Paired arytenoid**, corniculate, and cuneiform cartilages

Chapter 23

* **Laryngitis** is an inflammation of the larynx that is most often caused by a respiratory infection or irritants such as cigarette smoke.

Causes hoarseness or loss of voice

TRACHEA (WINDPIPE)

Extends from the larynx to the primary bronchi.

Located anterior to the esophagus.

It divides into right and left primary bronchi.

Histology: Layers of Trachea from deep to superficial

- (1) Mucosa
- (2) Submucosa
- (3) Hyaline cartilage
- (4) Adventitia, composed of areolar connective tissue

Mucosa consists of:

- (a) Epithelium (pseudostratified ciliated columnar epithelium)

Functions: Secretion and movement of mucus by ciliary action.

Consists of: (1) **Ciliated columnar cells**, (2) **Globular cells** that reach the luminal surface; and (3) **Basal cells** that do not reach luminal surface.

Epithelium provides the same protection against dust as the membrane lining the nasal cavity and larynx.

- (b) Lamina propria (contains elastic and reticular fibers)

Submucosa consists of consists of areolar connective tissue and

Chapter 23

contains seromucous glands and their ducts.

Hyaline cartilage 16-20 incomplete rings of hyaline cartilage look like letter Cs and are arranged horizontally and stacked one on top of another.

May be felt through the skin inferior to the larynx.

The open part of the C-shaped cartilage ring faces the esophagus, and accommodates slight expansion of the esophagus into the trachea during swallowing.

Adventitia consists of areolar connective tissue which joins the trachea to surrounding tissues.

Tracheostomy and **intubation** are two methods of bypassing obstructions from the respiratory passageway.

BRONCHI

Trachea, at the superior border of the fifth thoracic vertebra, divides into:

- (a) Right primary bronchus, and
- (b) Left primary bronchus

Bronchial tree consists of the trachea , primary bronchi, secondary bronchi, tertiary bronchi, bronchioles, and terminal bronchioles.

Larynx

Trachea

Terminates in chest

Left Primary Bronchus

Right Primary Bronchus

Entering the lungs

Left Secondary (Lobar) Bronchus

Right Secondary (Lobar) Bronchus

Chapter 23

Left & Right Tertiary (Segmental) Bronchus

Left & Right Bronchiole

Left & Right Terminal Bronchiole

(The right primary bronchus is more vertical, shorter, and wider than the left. As a result, foreign objects in the air passageways are more likely to enter and lodge in the right primary bronchi than the left.)

Several structural changes result as the branches become more extensive in the bronchial tree:

- (1) Epithelium gradually changes from pseudostratified ciliated columnar epithelium in the bronchi to nonciliated simple cuboidal epithelium in the terminal bronchioles.

Simple cuboidal epithelium functions are secretion and absorption.

- (2) Incomplete rings of cartilage in primary bronchi are gradually replaced by plates of cartilage that finally disappear in the distal bronchioles.
- (3) As the cartilage decreases, the amount of smooth muscle increases.

Smooth muscle encircles the lumen in spiral bands and its contraction is affected by both the autonomic nervous system (ANS) and various chemicals.

During exercise, activity in the sympathetic division of the ANS increases and the adrenal medulla releases the hormones **epinephrine** and **norepinephrine**.

Both changes relax smooth muscle in the bronchioles, thus dilating the airways. Improves lung ventilation as

Chapter 23

more air reaches the alveoli.

Parasympathetic division of the ANS and mediators of allergic reactions, such as **histamine**, cause constriction of distal bronchioles.

During an **asthma attack** the smooth muscle of bronchioles contract, reducing the diameter of the airways.

Because there is no supporting cartilage, the muscle spasms can even close off the airways, a life-threatening situation.

Epinephrine, administered as an inhaled mist (nebulization), often is used to relax the smooth muscle and open the airways.

Bronchography - is a technique for examining the bronchial tree. (An intratracheal catheter is passed into the mouth or nose, through the glottis, and into the trachea.)

LUNGS

Are cone-shaped organs lying in the thoracic cavity. Separated from each other by the heart and other structures in the mediastinum.

Pleural membrane enclose and protect each lung.

- Parietal Pleura - is the outer layer.
- Visceral Pleura is the inner layer.

Right Lung is thicker and broader than the left lung. It is also somewhat shorter than the left because the diaphragm is higher on the right side to accommodate the liver that lies below it.

Chapter 23

- **Pleural cavity** contains a lubricating fluid secreted by the membranes, which prevents friction between the membranes and allows them to move easily on one another during breathing.

Gross Anatomy of Lungs

Lobes and Fissures

Right lung has three lobes separated by two fissures (oblique and horizontal fissures)

- a. superior lobe
- b. middle lobe
- c. inferior lobe

Left lung has two lobes separated by one fissure (oblique fissure) and a depression, the cardiac notch.

- a. superior lobe
- b. inferior lobe

*Each lobe receives its own secondary (lobar) bronchus.

(Thus, the right Primary Bronchus gives rise to three secondary (lobar) bronchi--

- a. Superior secondary (lobar) bronchus
- b. Middle secondary (lobar) bronchus
- c. Inferior secondary (lobar) bronchus

The left primary bronchus gives rise to two secondary (lobar) bronchi

- a. Superior secondary (lobar) bronchus
- b. Inferior secondary (lobar) bronchus

Chapter 23

(Within the substance of the lung, the secondary bronchi give rise to the tertiary (segmental bronchi)).

Bronchopulmonary Segment - the segment of lung tissue that each tertiary (segmental) bronchus supply.

Lobules

Each bronchopulmonary segment of the lungs is broken up into many small compartments called lobules.

Each Lobules is wrapped in elastic connective tissue and contains:

- lymphatic vessel
- arteriole pulmonary
- venule pulmonary
- branch from a

Terminal Bronchiole

subdivides into

Respiratory Bronchioles

subdivides into

Alveolar Ducts (atria)

Found around the circumference of Alveolar ducts

Alveoli and Alveolar Sacs

(Two or more Alveoli that share a common opening)

Alveolar-Capillary (Respiratory) Membrane

Exchange of respiratory gases (O₂ and CO₂) between the lungs and blood takes place by diffusion across alveolar and capillary walls.

Chapter 23

Blood Supply to the Lung

*There is a double blood supply to the lungs.

- (1) Deoxygenated blood passes through the pulmonary trunk, which divides into a left pulmonary artery that enters the left lung and a right pulmonary artery that enters the right lung.

Oxygenated blood is returned by way of the pulmonary veins, typically two in number on each side- the right and left superior and inferior pulmonary veins. All four veins drain into the left atrium.

- (2) Oxygenated blood is delivered to the lungs by Bronchial arteries, which branch from the aorta.

PULMONARY VENTILATION (BREATHING)

Pulmonary ventilation (breathing) is the process by which gases are exchanged between the atmosphere and lung alveoli.

(The bulk flow of air between the atmosphere and lungs occurs for the same reason that blood flows through the body: a pressure gradient exists.):

*(Air moves into the lungs when the pressure inside the lungs is less than the air pressure in the atmosphere.)

*(Air moves out of the lungs when the pressure inside the lungs is greater than the pressure in the atmosphere.)

Chapter 23

Inspiration (Inhalation)

Inspiration (inhalation) is breathing in.

-(Just before each inspiration, the air pressure inside the lungs equals the pressure of the atmosphere, which is about **760 mm. Hg, or 1 atmosphere (atm)**, at sea level.)

For inspiration to occur, the lungs must expand.

(For air to flow into the lungs, the pressure inside the lungs must become lower than the pressure in the atmosphere-)

This condition is achieved by increasing the volume (size) of the lungs.

This increases lung volume and thus decrease the pressure in the lungs below atmospheric pressure.

Boyle's Law - the volume of a gas varies inversely with the pressure. (assuming that temperature is constant).

Illustrates how lungs function:

The pressure of gas in a closed container is inversely proportional to the volume of the container.

(If the size of a closed container is increased, the pressure of the air inside the container decreases. If the size of the container is decreased, than the pressure inside it increases).

Position of Diaphragm In Inspiration

- *Diaphragm contracts/descends
- areas of thoracic cavity enlarges
- lungs increase
- pressure drops
- air goes in

Chapter 23

- Diaphragm contracts and descends with each inhalation (inspiration).
- Downward movement of the diaphragm enlarges the area in the thoracic cavity and reduces the internal air pressure, so that air flows into the lungs to equalize the pressure.

Intrapleural (Intrathoracic) pressure - Pressure between the two pleural layers during normal breathing. Always subatmospheric (lower than atmospheric pressure).

Just before inspiration, it is about 4 mm Hg less than the atmospheric pressure, or 756 mm Hg if the atmospheric pressure is 760 mm Hg.

Alveolar (Interpulmonic) Pressure - Pressure inside the lungs when the volume of the lungs increases - (Pressure drops from 760 to 758 mm Hg).

Expiration (exhalation)

Expiration (exhalation) is breathing out.

Also achieved by pressure gradient - in reverse of inspiration.

The pressure in the lung is greater than the pressure of the atmosphere.

Normal expiration during quiet breathing is a **passive process** (no muscular contractions are involved).

It results from **elastic recoil** of the chest wall and lungs: they have a natural tendency to spring back after they have been stretched.

Two inward directed forces that contribute to elastic recoil:

1. The recoil of elastic fibers that were stretched during inspiration
2. The inward pull of surface tension due to the film of alveolar fluid

Expiration starts when the inspiration muscles relax.

Chapter 23

Expiration (a) Epithelium (pseudostratified ciliated columnar epithelium) changes from passive to active during labored breathing and when air movement out of the lung is impeded.

Forced Expiration employs contraction of the internal intercostals and abdominal muscles.

Position of Diaphragm in Expiration

- Diaphragm relaxes/Elevates air
- Areas of the thoracic cavity decreases
- Lungs decrease
- Pressure increases
- Air goes out

-Diaphragm relaxes and elevates, making the area in the thoracic cavity smaller, and thus increasing the air pressure in the thorax.
 - Air then is expelled out of the lungs to equalize the pressure - called exhalation (expiration).

Breathing Patterns

Eupnea - applied to normal quiet breathing.

- Involves shallow, deep, or combined shallow and deep breathing.

Apnea - Refers to a temporary cessation of breathing.

Dyspnea - Refers painful or labored breathing.

Tachypnea - Refers to rapid breathing.

Costal Breathing - shallow (chest) breathing.

Diaphragmatic Breathing - deep (abdominal) breathing.

Chapter 23

Alveolar Surface Tension

Surface tension is the force exerted by a thin layer of alveolar fluid next to air in the alveoli.

(Surface tension arises at all air-water junctions because the polar water molecules are more strongly attracted to each other than they are to gas molecules in the air).

During breathing, surface tension must be overcome to expand the lungs during each inspiration.

(The surface tension of alveolar fluid is not as great as that of pure water due to the presence of a detergent-like substance called **surfactant**.)

Compliance

Compliance refers to the ease with which the lungs and thoracic wall can be expanded.

When a small increase in alveolar pressure produces a large increase in lung volume, compliance is high.

High compliance means that the lungs and thoracic wall expand easily; lower compliance means that they resist expansion.

In the lungs, compliance is related to two principal factors:

- (1) Elasticity, and
- (2) Surface tension

The lungs normally have high compliance and expand easily because elastic fibers in lung tissue are easily stretched and surfactant in alveolar fluid reduces surface tension.

Compliance decreases in conditions that:

- (1) Scar lung tissue, for example, tuberculosis

Chapter 23

- (2) Cause it to become filled with fluid (pulmonary edema)
- (3) Produce a deficiency in surfactant, or
- (4) Impede lung expansion in any way, for example, paralysis of the intercostal muscles.

Emphysema increases compliance.

Airway Resistance

As is true for blood flow through blood vessels, the flow of air through the airways depends on both the **pressure difference** and the **resistance**:

Airflow equals the pressure difference between the alveoli and the atmosphere divided by the resistance.

The walls of the airways, especially the bronchi and bronchioles, offer some resistance to the normal flow of air into the lungs.

During inhalation, the increase in size of the thoracic cavity decreases resistance to airflow by increasing the diameter of bronchi and bronchioles. Resistance increases, however, during exhalation because the airways narrow somewhat

Any condition that narrow or obstructs the airways increases resistance, and more pressure is required to force air through.

During forced expiration, as in coughing or playing a wind instrument, intrapleural pressure may increase.

People with chronic obstructive pulmonary diseases (COPD), such as bronchial asthma and emphysema, have some degree of obstruction or collapse of airways, which increases resistance.

Modified Respiratory Movement

Respiration also provides humans with methods for expressing emotions

Chapter 23

such as laughing, sighing, and sobbing.

Respiratory air can be used to expel foreign matter from the lower air passages through actions such as sneezing and coughing.

Respiratory movements are also modified and controlled during talking and singing.

MODIFIED RESPIRATORY MOVEMENTS

(1) Respiration for expressing emotions:

Laughing
Yawning
Sighing
Sobbing
Crying
Hiccups

(2) Respiration to expel foreign matter from the upper air passages:

Sneezing
Coughing

*All modified respiratory movements are reflexes, but some of them also can be initiated voluntarily.

***Atelectasis** - a collapsed lung or portion of a lung.

(Maintenance of a low intrapleural pressure is vital to the functioning of the lungs.)

*The walls of the respiratory passageways offer some resistance to breathing.

Chapter 23

LUNG VOLUMES AND CAPACITIES

Respiration (ventilation) means one inspiration plus one expiration.

(1 inspiration + 1 expiration = Respiration)

*Healthy adult averages about **12 respirations/mm** while at rest. (Normal breathing rate.) Moves about **6 liters** of air into and out of the lungs while at rest.

- (a) **Spirometer or Respirometer** - apparatus commonly used to measure the amount of air exchanged during breathing and the rate of ventilation.

Inspiration is recorded as an upward deflection; Expiration as downward deflection.

Spirogram - the record.

About **500 ml** of air moves in and then out of the airways with each inspiration and expiration during normal quiet breathing.

- (b) **Tidal Volume (V_T)** - Volume of one breath.

In an average adult, about 70% (350 ml) of the tidal volume actually reaches respiratory bronchioles, alveolar ducts, alveolar sacs, and alveoli (respiratory portion of the respiratory system) and participates in respiration.

The other 30% (150 ml) remains in air spaces of the nose, pharynx, larynx, trachea, bronchi, bronchioles, and terminal bronchioles (conducting portion of the respiratory system).

These areas are known as the **anatomic dead space (V_D)**.

Any easy rule of thumb is that the volume of your anatomic dead space in milliliters is about the same as your weight in pound.

Chapter 23

- (c) **Minute Volume of Respiration (MVR)** or **Minute ventilation** - Is the total volume of air taken in during one minute.

$$\begin{aligned} & \text{Tidal Volume} \times \text{Normal Breathing rate/min} \\ & (500 \text{ ml}) \times (12 \text{ respiratory/min}) = \underline{\underline{6000 \text{ ml/min}}} \end{aligned}$$

- (d) **Alveolar Ventilation Rate (AVR)** is the volume of air per minute that reaches the alveoli.

$$\begin{aligned} \text{AVR} &= 350 \text{ ml} \times 12 \text{ respirations/min} \\ &= \underline{\underline{4200 \text{ ml/min}}} \end{aligned}$$

(Several other lung volumes result when one engages in strenuous breathing. In general, these volumes are larger in males, taller persons, and younger adults and smaller in females, shorter persons, and the elderly).

- (e) **Inspiratory Reserve Volume** - Is the additional inhaled air, about 3100 ml above tidal volume of 500 ml, for a total of **3600 ml**.

Can be achieved by taking a very deep breath.

- (f) **Expiratory Reserve Volume** - If you inhale normally and then exhale as forcibly as possible, you should be able to push out 1200 ml of air in addition to the 500 ml of tidal volume. Expiratory Reserve Volume is the excess 1200 ml.

- (g) **Forced Expiratory Volume in 1 second (FEV₁)** is the volume of air that can be expelled from the lungs in 1 second with maximal effort following a maximal inhalation.

- (h) **Residual Volume** - air that remains in the lungs - about 1200 ml.

- (i) **Minimal Volume** - air remaining after residual volume has been forced out.

Chapter 23

Provides a medical and legal tool for determining whether a baby was born dead or died after birth.

*(Presence of Minimal volume can be demonstrated by placing a piece of lung in water and watching it float.)

*(Fetal lungs contain no air, and so the lung of a stillborn will not float in water.)

- (j) **Inspiratory Capacity** - the total inspiratory ability of the lungs (Tidal volume + Inspiratory Reserve volume)

$$500 \text{ ml} + 3,100 \text{ ml} = 3,600 \text{ ml}$$

- (k) **Functional Residual Capacity** - is the sum of the residual volume plus expiratory volume.

(Residual volume + Expiratory volume)

$$1,200 \text{ ml} + 1,200 \text{ ml} = 2,400 \text{ ml}$$

- (l) **Vital Capacity** - is the sum of inspiratory reserve volume, tidal volume, and expiratory reserve volume.
(Inspiratory Reserve + Tidal Volume + Expiratory Reserve Volume)

$$3,100 \text{ ml} + 500 \text{ ml} + 1,200 \text{ ml} = 4,800 \text{ ml}$$

- (m) **Total Lung Capacity** - is the sum of all volumes

(Inspiratory Reserve Volume + Tidal Volume + Expiratory Reserve Volume + Residual Volume)

$$3,100 \text{ ml} + 500 \text{ ml} + 1,200 \text{ ml} + 1,200 \text{ ml} = 6,000 \text{ ml}$$

Chapter 23

EXCHANGE OF OXYGEN AND CARBON DIOXIDE

(At birth, as soon as the lungs fill with air, oxygen diffuses from the alveoli into the blood, through the interstitial fluid, and finally into the cells. Carbon dioxide diffuses in the opposite direction - from the cells, through interstitial fluid to the blood, and to the alveolar air)

*To understand how respiratory gases are exchanged in the body, we need to know a few gas laws:

Gas Laws

The exchange of O₂ and CO₂ are purely passive - no ATP is consumed.

They depend on the behavior of gases described in **Dalton's law** and **Henry's law**.

1. **Dalton's Law** - Each gas in a mixture of gases exerts its own pressure as if all the other gases were not present.

Partial pressure (p) is the pressure of a specific gas in a mixture.

Can be calculated by adding all the partial pressures.

Atmospheric air is mixture of several gases - oxygen, carbon dioxide, nitrogen, water vapor, and several other gases in small enough quantities to be ignored.

Atmospheric pressure is the sum of the pressure of all these gases:

$$\begin{aligned} \text{Atmospheric pressure (760 mm Hg)} \\ = p_{\text{O}_2} + p_{\text{CO}_2} + p_{\text{N}_2} + p_{\text{H}_2\text{O}} \end{aligned}$$

*(We can determine the partial pressure exerted by each component in the

Chapter 23

mixture by multiplying the percentage of the gas in the mixture by the total pressure of the mixture.)

For example, to find the partial pressure of Oxygen in the atmosphere:

Oxygen = 21% of atmospheric air
 Carbon Dioxide = 0.04% of atmospheric air
 Total Pressure = 760 mm Hg

Atmospheric pO_2 = 21% X 760 mm Hg = 159.6 or 160 mm Hg

Atmospheric pCO_2 = 0.04% X 760 mm Hg 0.3040 or 0.3 mm Hg

These partial pressures are important in determining the movement of O_2 and CO_2 between the atmosphere and the lungs and blood and body cells.

*(When a mixture of gases diffuse across a permeable membrane, each gas diffuses from the area where its partial pressure is greater to the area where its partial pressure is less.)

Every gas is on its own and behaves as if the other gases in the mixture did not exist.

The partial pressure of O_2 and CO_2 in mm Hg in air, blood, and tissue cells are as follows:

| | <u>pO_2</u> | <u>pCO_2</u> |
|--------------------------------|--------------------------|---------------------------|
| Atmosphere (sea level) | 160 | 0.3 |
| Alveoli | 105 | 40 |
| Oxygenated blood | 100 | 40 |
| Tissue cells (average at rest) | 40 | 45 |
| Deoxygenated blood | 40 | 45 |

The relative amount of O_2 and CO_2 differ in inspired (atmospheric) air, alveolar air, and expired air as follows:

O_2 _____ CO_2

Chapter 23

| | | |
|--------------|-----|-------|
| Inspired air | 21% | 0.04% |
| Alveolar air | 14% | 5.2% |
| Expired air | 16% | 4.5% |

(Compared with inspired air, alveolar air has less O₂ (21% versus 14%) and more CO₂ (0.04% versus 5.2%) because gas is occurring in the alveoli).

(On the other hand, expired air contains more O₂ than alveolar air (16% versus 14%) and less CO₂ (4.5% versus 5.2%) because some of the expired air was in the anatomic dead space and did not participate in gas exchange).

(Expired air is a mixture of alveolar air and inspired air that was in the anatomic dead space).

(Also, expired air and alveolar air have higher water vapor content than inspired air because the moist mucosal linings humidify air as it is inhaled).

2. **Henry's Law** - the quantity of a gas that will dissolve in a liquid is proportional to the partial pressure of the gas and its solubility coefficient, when the temperature remains constant.

(You have probably noticed that a soft drink makes a hissing sound when the top of the container is removed, and bubbles rise to the surface for some time afterward).

The gas dissolved in carbonated beverages is CO₂.

(The ability of gas to stay in solution depends on its partial pressure and solubility coefficient, that is, its physical or chemical attraction for water).

| | | |
|--|---------|------|
| Solubility coefficient of carbon dioxide | = 0.57 | High |
| " " Oxygen | = 0.024 | Low |
| " " Nitrogen | = 0.012 | Low |

(The higher the partial pressure of a gas over a liquid and the solubility coefficient, the more gas will stay in solution.)

Chapter 23

(Since the soda is bottled under pressure and capped, the CO₂ remains dissolved as long as the bottle is uncapped. Once you remove the cap, the pressure is released and the gas begins to bubble out.)

***Though the air contains 79% nitrogen**, it has no known effect on bodily function since very little of it dissolves in blood plasma because of its low solubility coefficient at sea level pressure.

But can change drastically during deep-sea diving. (Below sea level)

When a **Scuba** (self-contained underwater breathing apparatus) **diver** breaths air under high pressure, the N₂ in the mixture can have serious negative effects.

*Nitrogen can then dissolve rapidly under higher pressure resulting to **Nitrogen Narcosis**. "rapture of the depths"

(If a diver comes to the surface slowly, the dissolved N₂ can be eliminated through the lungs. However, if the ascent is too rapid, N₂ comes out of solution too quickly to be eliminated by exhalation. Instead, it forms gas bubbles in the tissues, resulting in **decompression sickness** (the **bends**).

Symptoms include joint pain, especially in the arms and legs, dizziness, shortness of breath extreme fatigue, paralysis, and unconsciousness).

EXTERNAL RESPIRATION

External (pulmonary) Respiration - Is the exchange of oxygen and carbon dioxide between the alveoli of the lungs and pulmonary blood capillaries.

Results in the conversion of **deoxygenated blood** to **oxygenated blood**.

(Check partial pressure in drawing to determine direction of flow for each gas).

Chapter 23

The Rate of External Respiration depends on the following Factors:

1. Partial pressure differences of the gases.
2. Surface area for gas exchange
3. Diffusion distance
4. Solubility and molecular weight of the gases.

INTERNAL RESPIRATION

Internal (tissue) Respiration - Is the exchange of oxygen and carbon dioxide between tissue blood capillaries and tissue cells.

Results in the conversion of **oxygenated blood** into **deoxygenated blood**.

(Check partial pressure in drawing to determine direction of flow for each gas).

TRANSPORT OF OXYGEN AND CARBON DIOXIDE

(The transport of gases between the lungs and body tissue is a function of the blood. When oxygen and carbon dioxide enter the blood, certain physical and chemical changes occur that aid in gas transport and exchange).

Oxygen Transport

*Oxygen does not dissolve easily in water.

1.5% of oxygen is carried in dissolved state in watery blood plasma;

98.5% of oxygen is transported in chemical combination with hemoglobin inside red blood cells.

Chapter 23

*Each 100 ml of oxygenated blood contains about 20 ml of oxygen

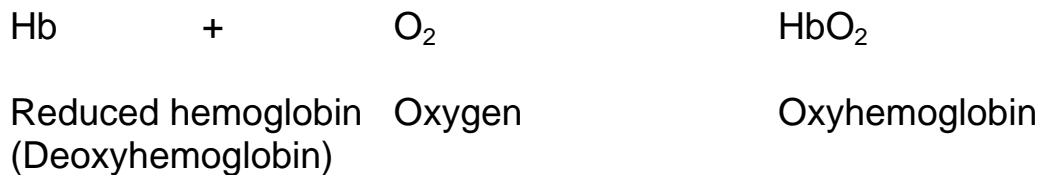
0.3 ml of oxygen dissolved in the plasma

19.7 ml of oxygen bound to hemoglobin

Hemoglobin consists of a protein portion called **globin** and an iron-containing pigment called **heme**.

Each hemoglobin molecule has four heme groups, and each heme group can combine with one molecule of oxygen

*Oxygen and hemoglobin combine in an easily reversible reaction to form **oxyhemoglobin** (HbO₂):



Factors that Promote Oxygen Binding to and Dissociation from Hemoglobin

A. Hemoglobin and Oxygen Partial Pressure

Oxygen partial pressure (p_{O₂}) is the most important factor that determines the percent saturation of hemoglobin - (how much oxygen combines with hemoglobin)

When reduced hemoglobin (deoxyhemoglobin) is completely converted to Oxyhemoglobin (HbO₂), it is **fully saturated**.

Partially saturated when hemoglobin consists of a mixture of Hb and HbO₂.

Percent saturation of Hemoglobin is the percentage of HbO₂ in total hemoglobin.

Chapter 23

When oxygen partial pressure (p_{O_2}) is high, hemoglobin binds with large amounts of oxygen and is almost fully saturated.

When oxygen partial pressure (p_{O_2}) is low, hemoglobin is only partially saturated and oxygen is released from hemoglobin.

Note that when the p_{O_2} is high, hemoglobin binds with large amount of O_2 and is almost fully saturated.

Note that when the p_{O_2} is low, hemoglobin is only partially saturated and O_2 is released from hemoglobin.

*(Therefore in pulmonary capillaries, where PO_2 is high, a lot of oxygen binds with hemoglobin, but in tissue capillaries. Where the PO_2 is lower, hemoglobin does not hold as much oxygen, and oxygen is released for diffusion into tissue cells.)

When the oxygen partial pressure (p_{O_2}) is between 60 and 100 mm Hg, hemoglobin is 90% or more saturated with O_2 .

(Thus blood picks up a nearly full load of O_2 from the lungs even when the alveolar p_{O_2} is as low as 60 mm Hg).

(This explains why people can still perform well at high altitudes or when they have certain cardiac and pulmonary diseases, even though p_{O_2} , may drop as low as 60 mm Hg).

B. Hemoglobin and Other Factors:

Partial pressure of oxygen (p_{O_2}) is the most important factor that determines the percent O_2 saturation of hemoglobin.

Several other factors that influence the **tightness** or **affinity** of hemoglobin for oxygen, the strength of the hemoglobin-oxygen bonding.

(Each of the listed factors makes sense if you keep in mind that metabolically active tissue cells need O_2 and produce **acids**, **CO_2** , and **heat**).

Chapter 23

1. **Acidity (pH)**

As **acidity increases** (pH decreases), the affinity of hemoglobin for O₂ dissociates more readily from hemoglobin.

Bohr effect is the shift of the oxygen-hemoglobin dissociation to the right as a result of the change in pH.

Left = Higher affinity
 Middle = Normal
 Right = Lower affinity

(The explanation for the Bohr effect is that hydrogen ions (H⁺) bind to certain amino acids in the hemoglobin, slightly alters its structure, and thereby decrease its oxygen-carrying capacity). Just like Allosteric effect on enzymes.

Elevated pH (decreased acidity) increases the affinity of hemoglobin for O₂ and shifts the curve to the left.

2. **Partial Pressure of Carbon Dioxide**

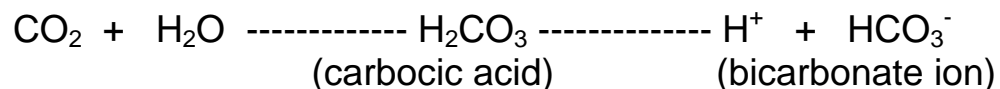
Carbon dioxide can also bind to hemoglobin.

Has the same effect as H⁺ (low pH or high acidity).

Shifting the saturation curve to the right.

As partial pressure of carbon dioxide (pCO₂) rises, hemoglobin releases O₂ more readily.

pCO₂ and pH are related factors because low blood pH (acidity) results from high CO₂.



Chapter 23

(The carbonic acid thus formed in red blood cells dissociates into hydrogen ion and bicarbonate ions (HCO_3^-))

As the H^+ concentration increases, pH decreases.

(Thus an increased pCO_2 produces a more acidic environment, which helps release O_2 from hemoglobin.)

During exercise, lactic acid, a by-product of anaerobic metabolism within muscles, also decreases the blood pH.

Decreased pCO_2 (and elevated pH) shifts the saturation curve to the left.

3. **Temperature**

As temperature increases, so does the amount of oxygen released from hemoglobin, within limits.

Heat is a by-product of the metabolic reactions of all cells. Metabolically active cells require more O_2 and liberate more acids and heat.

The acids and heat, in turn, promote release of O_2 from oxyhemoglobin.

Fever produces a similar result.

During hypothermia (lowered body temperature) cellular metabolism slows, the need for O_2 is less. More O_2 remains bound to hemoglobin.

A shift to the left in the saturation curve.

4. **BPG (2,3- Bisphosphoglycerate)**

A substance found in red blood cells, previously called diphosphoglycerate (DPG).

Chapter 23

Decreases the affinity of hemoglobin for oxygen and thus helps release oxygen from hemoglobin.

BPG is formed in red blood cells when they break down glucose for energy in a process called glycolysis.

Hemoglobin binds O_2 less tightly when it combines with BPG. The greater the level of BPG, the more O_2 is released from hemoglobin.

Certain hormones such as **thyroxin**, **human growth hormone**, **epinephrine**, **norepinephrine**, and **testosterone**, increase the formation of BPG.

Fetal Hemoglobin:

Fetal hemoglobin (Hb-F) differs from adult hemoglobin (Hb-A) in structure and in its affinity for oxygen.

Fetal hemoglobin (Hb-F) has a higher affinity for oxygen because it binds BPG less strongly.

When partial pressure of oxygen (pO_2) is low, Hb-F can carry up to 30% more O_2 than maternal Hb-A.

As the maternal blood enters the placenta, O_2 is readily transferred to fetal blood

(This is very important since the O_2 saturation in maternal blood in the placenta is quite low and the fetus might suffer hypoxia were it not for the greater affinity of fetal hemoglobin for O_2 .)

Hypoxia

Hypoxia is a deficiency of oxygen at the tissue level.

Classifications of Hypoxia:

1. **Hypoxic hypoxia** - caused by a low pO_2 in arterial blood.

Chapter 23

May be the result of high altitude, obstructions in air passageways, or fluid in the lungs.

2. **Anemic hypoxia** - too little functioning hemoglobin in the blood. Hemorrhage, anemia, or failure of hemoglobin to carry its normal complement of oxygen, as in carbon monoxide poisoning.
3. **Stagnant (ischemic) hypoxia** - results from the inability of blood to carry oxygen to tissue fast enough to sustain their needs.
- caused by heart failure or circulatory shock.
4. **Histotoxic hypoxia** - the blood delivers adequate oxygen to tissues, but the tissue are unable to use it properly because of action of a toxic agent.

Cyanide poisoning, in which cyanide blocks the metabolic machinery of cells related to oxygen utilization.

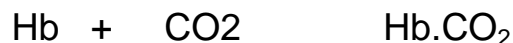
Carbon Dioxide Transport

Under normal resting conditions:

Each 100 ml of deoxygenated blood contains about 55 ml of CO₂.

Carried by the blood in three main forms:

1. **Dissolved CO₂** - the smallest percentage, about 7%, is dissolved in plasma. Upon reaching the lungs, it diffuses into the alveoli.
2. **Carbaminohemoglobin** - about 23% combines with the globin portion of hemoglobin to form carbaminohemoglobin (Hb.CO₂).



The formation of carbaminohemoglobin is greatly influenced by partial pressure of carbon dioxide (pCO₂).

In tissue capillaries partial pressure of carbon dioxide (pCO₂) is relatively high.

Chapter 23

Promotes formation of carbaminohemoglobin.

In pulmonary capillaries partial pressure of carbon dioxide (p_{CO_2}) is relatively low ; CO_2 rapidly splits apart from globin and enters the alveoli by diffusion.

3. **Bicarbonate ions** - About 70% of CO_2 is transported in plasma as bicarbonate ions.



As carbon dioxide diffuses into tissue capillaries and enters the red blood cells. It reacts with water, in the presence of the enzyme carbonic anhydrase (CA), to form carbonic acid.

Chloride ions (Cl^-) diffuse dfrom plasma into the RBCs. This exchange of negative ions maintain the electrical balance between plasma and RBC.

This is known as the **Chlorine shift**.

Summary of Gas Exchange and Transport in Lungs and Tissues

*Summary of the nervous control of Respiration.

*Summary of stimuli that affect ventilation rate and depth.

1) Disorders: Homeostatic Imbalance

*Medical Terminology

Chapter 23

CONTROL OF RESPIRATION

A. Nervous Control:

1. The respiratory center consists of a medullary rhythmicity area (inspiratory and expiratory area), pneumotoxic area, and apneustic area.
2. The inspiratory area has an intrinsic excitability that sets the basic rhythm of respiration.
3. The pneumotoxic and apneustic areas coordinate the transition between inspiration and expiration.

B. Regulation of Respiratory Center Activity

1. Respiration may be modified by a number of factors, both in the brain and outside.
2. Among the modifying factors are cortical influences, the inflation reflex, chemical stimuli, such as O₂ and CO₂ (actually H⁺) levels, blood pressure, temperature, pain, and irritation to the respiratory mucosa.

AGING AND THE RESPIRATORY SYSTEM

1. Aging results in decreased vital capacity, decreased blood level of oxygen, and diminished alveolar macrophage activity.
2. Elderly people are more susceptible to pneumonia, emphysema, bronchitis, and other pulmonary disorders.

Chapter 23

DEVELOPMENTAL ANATOMY OF THE RESPIRATORY SYSTEM

1. The respiratory system begins as an outgrowth of endoderm called the Laryngotracheal bud.
2. Smooth muscle, cartilage, and connective tissue of the bronchial tubes and pleural sacs develop from mesoderm.

DISORDERS: HOMEOSTATIC IMBALANCES

1. Bronchogenic Carcinoma - bronchial epithelial cells are replaced by cancer cells after constant irritation has disrupted the normal growth, division, and function of the epithelial cells.
2. Bronchial Asthma - characterized by spasms of smooth muscle in bronchial tubes that result in partial closure of air passageways; inflammation; inflated alveoli; and excess mucus production.
3. Bronchitis - an inflammation of the bronchial tubes.
4. Emphysema - characterized by deterioration of alveoli, leading to loss of their elasticity. Symptoms are reduced expiratory volume, inflated lungs at the end of expiration, and enlarged chest.
5. Pneumonia - an acute inflammation or infection of alveoli.
6. Tuberculosis (TB) - an inflammation of pleural and lungs produced by the organism myobacterium tuberculosis.
7. Respiratory Distress Syndrome (RDS) of the New Born - an infant disorder in which surfactant is lacking and alveolar ducts and alveoli have a glassy appearance.
8. Respiratory failure - means the respiratory system cannot supply sufficient oxygen or eliminate sufficient carbon dioxide.

Chapter 23

9. Sudden Infant Death Syndrome (SIDS) - has recently been linked to laryngospasm, possibly triggered by a viral infection of the upper respiratory tract.
10. Coryza (Common cold) - is caused by viruses and is usually not accompanied by a fever, whereas influenza ((flu)) is usually accompanied by a fever greater than 101°F.
11. Pulmonary Embolism - refers to a blood clot or other foreign substances in a pulmonary arterial vessel that obstructs blood flow to lung tissue.
12. Pulmonary Edema - is an accumulation of interstitial fluid in interstitial spaces and alveoli of the lungs.
13. Smoke inhalation injury has three sequential components:
 - a. Inhibition of oxygen delivery and utilization;
 - b. Upper airway injury from heat; and
 - c. Lung damage from acids and aldehydes in smoke.