



ANP 1105 Final Exam-AID

'RAISING MARKS, RAISING MONEY, RAISING ROOFS'
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Agenda

1. Introduction
2. Blood Vessels and Hemodynamics
3. Lymphatic System
4. Respiratory System
5. How to prepare for your exam
6. Questions



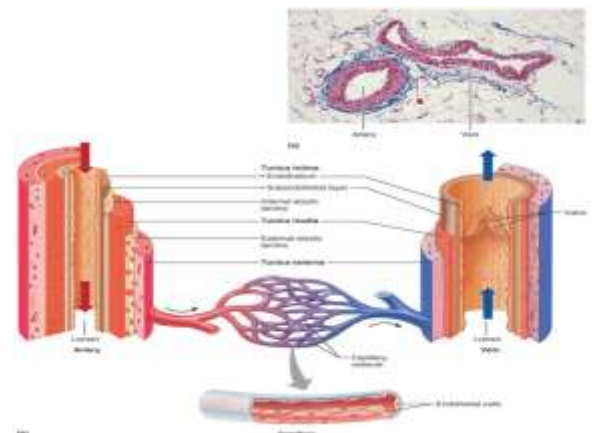

Blood Vessels and Hemodynamics

The Basics

Arteries	Capillaries	Veins
-carry blood <u>away</u> from the heart Arteriole : a small artery	-directly serve cellular needs	-carry blood <u>toward</u> the heart Venule : a small vein

arteries->arterioles->capillaries->venules
->veins


<http://www.youtube.com/watch?v=LqhvmUEdQYY>

Blood Vessels and Hemodynamics

Lumen: central blood-containing space

Tunica Intima	Tunica Media	Tunica Externa
Endothelium -simple squamous epithelium -a continuation of the endocardial lining of the heart Subendothelial layer -in vessels larger than 1mm in diameter -supports endothelium -consists of basement membrane and loose CT	-circularly arranged smooth muscle cells and sheets of elastin -the bulkiest layer in the arteries -responsible for vasodilation and vasoconstriction -plays an important role in regulation of blood flow and blood pressure	-composed of loosely woven collagen fibers -protect and reinforce vessel -anchor vessel to surrounding structures -infiltrated with nerve fibers, lymphatic vessels In larger veins -infiltrated with network of elastin fibers -contain vasa vasorum -> tiny blood vessels that nourish the external tissues of blood vessel wall



Blood Vessels and Hemodynamics

Elastic (Conducting) Arteries	Muscular (Distributing) Arteries
- largest diameter (2.5-1 cm) -near the heart-> aorta and its major branches -Thick-walled -large lumens make them low-resistance pathways that conduct blood from the heart to the medium-sized arteries -Contain more elastin than any other vessel type -Elastin contained in all three tunics but most found in tunica media -Contain substantial amounts of smooth muscle but are relatively inactive in vasoconstriction -Act as pressure reservoirs, expanding and recoiling as blood is ejected from the heart. -Maintain continuous blood flows (protects other vessels from high pressure)	-diameter (1cm-0.3mm) -deliver blood to specific body organs -thickest tunica media of all vessels -elastic lamina on each face of the tunica media -more smooth muscle and less elastic tissue in the tunica media than elastic arteries -more active in vasodilation -less distensible

Blood Vessels and Hemodynamics

Arterioles

- Smallest of the arteries (0.3mm-10µm)
- Larger arterioles have all 3 tunics
 - tunica media is mainly smooth muscle with a few elastic fibers
- Smaller arterioles leading into the capillary beds
 - single layer of smooth muscle cells spiraling around the endothelial lining
- Blood flow to capillaries is determined by arteriole diameter
 - arterioles dilate= blood flows to capillary bed
 - arterioles constrict= capillary bed bypassed

Blood Vessels and Hemodynamics

Capillaries

- Smallest blood vessels
- Walls consist only of thin tunica intima (think function)
- Made of endothelial cells and pericytes
 - Pericytes: smooth muscle-like cells that stabilize the capillary wall
- Average length 1mm
- Average lumen diameter 8-10µm
 - just enough to for red blood cells to pass through
- Do not function independently. Form networks called capillary beds.
- Allow exchange of materials between blood and interstitial fluid

	Continuous	Fenestrated	Sinusoidal
Where?	-skin -muscles	-small intestine -endocrine organs -kidneys -found wherever active capillary absorption or filtrate formation occurs	ONLY -liver -bone marrow -lymphoid tissue -some endocrine organs
What?	- most common -endothelial cells provide uninterrupted lining -adjacent cells joint by <u>tight junctions</u> -junctions usually incomplete, leave gaps called <u>intercellular clefts</u> which leave enough room for passage of fluids and small solutes -Endothelial cell cytoplasm contains pinocytotic vesicles to ferry fluid across capillary wall -Brain capillaries tight junctions complete= blood brain barrier	-similar to continuous but some of the endothelial cells are riddled with oval pores, or <u>fenestrations</u> -fenestrations usually covered by a delicate membrane (basal lamina material) -much more permeable to fluids and small solutes	-highly modified, leaky capillaries -have large, irregularly shaped lumens -usually fenestrated -endothelial lining has fewer tight junctions and larger intercellular clefts than ordinary capillaries -allow large molecules and blood cells to pass through -liver: endothelium is discontinuous and large macrophages called <u>Kupffer cells</u> , which remove and destroy any contained bacteria form part of lining -other organs: phagocytes located outside capillary stick cytoplasmic extensions through the intercellular clefts into the lumen to get at their "prey" -Blood flows slowly through these capillaries, allowing time for it to be modified

Blood Vessels and Hemodynamics

Continuous

Fenestrated

Sinusoidal

Blood Vessels and Hemodynamics

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Blood Vessels and Hemodynamics

Microcirculation

-The flow of blood from an arteriole to a venule (through a capillary bed)

Vascular shunt

-short vessel that directly connects the arteriole and venule at opposite ends of the bed (metarteriole-thoroughfare channel)

<h4>Terminal arteriole</h4> <p>-feeds the capillary bed, leads into metarteriole.</p> <h4>Metarteriole</h4> <p>-vessel structurally intermediate between arteriole and capillary</p> <h4>Precapillary sphincter</h4> <p>-cuff of smooth muscle fiber, surrounds the root of each true capillary at the metarteriole and acts as a valve to regulate blood flow into the capillary</p>	<h4>Thoroughfare channel</h4> <p>-intermediate between capillary and a venule</p> <h4>Postcapillary venule</h4> <p>-drains the capillary bed</p>
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Blood Vessels and Hemodynamics

Venules

- formed when capillaries unite
- smallest venules=postcapillary venules
- postcapillary venules
 - consist entirely of endothelium around which a few pericytes congregate
 - extremely porous, fluid and WBCs move easily from the bloodstream through their walls
- larger venules one or two layers of smooth muscle cells (a scanty tunica media) and thin externa.



Blood Vessels and Hemodynamics

Veins

- have 3 tunics
- walls thinner
- lumens larger
- little smooth muscle or elastin in tunica media (which tends to be thin)
- tunica externa is the heaviest wall layer
 - collagen
 - elastic networks
 - larger veins have smooth muscle
- blood pressure is low
- 65% of blood is found in veins



Blood Vessels and Hemodynamics

Two structural adaptations of veins that promote blood return:

1) Large-diameter lumens

- offer very little resistance

2) Venous valves

- prevent the blood from flowing backward
- formed from fold of the tunica intima
- resemble semilunar valves of heart
- most abundant in veins of the limbs
- absent in veins of ventral body cavity



Blood Vessels and Hemodynamics

Respiratory System and Venous Return

- Pressure changes occurring in the ventral body cavity during breathing create the respiratory pump that moves blood up towards the heart. At the same time, the pressure in the chest decreases, allowing thoracic veins to expand and speeding blood entry into the right atrium

Muscular Pump and Venous Return

- As the skeletal muscles surrounding the deep veins contract and relax, they "milk" blood toward the heart, and once blood passes each successive valve, it cannot flow back.



Blood Vessels and Hemodynamics

Blood Flow

- volume of blood flowing through a vessel, an organ, or the entire circulation in a given period (ml/min).
- in entire vascular system, blood flow is equivalent to cardiac output (CO)
- under resting conditions, relatively constant
- blood flow through individual body organs may vary widely and is intimately related to their immediate needs.

$$\text{Flow} = (\text{Pressure \#1} - \text{Pressure \#2}) / \text{Resistance}$$

$$\text{Flow} = \text{Change in pressure} / \text{Resistance}$$

Flows occurs in response to a pressure gradient.

No gradient, no flow!



Blood Vessels and Hemodynamics

Blood Pressure

- the force per unit area exerted on a vessel wall by the contained blood, is expressed in millimeters of mercury (mm Hg).
- Unless stated otherwise, the term blood pressure means systemic arterial blood pressure in the largest arteries near the heart.
- It is the pressure gradient—the differences in blood pressure within the vascular system—that provides the driving force that keeps blood moving, always from an area of higher pressure to an area of lower pressure, through the body.



Blood Vessels and Hemodynamics

Resistance

- Measures total of frictional forces that impede flow
- flow and resistance are inversely relate
 - Increase in resistance=decrease in flow
 - Decrease in resistance= increase in flow
- The major determinant of blood flow
 - change in blood vessel radius increases resistance to the 4th power

Peripheral Resistance

- Most friction is encountered in the peripheral (systemic) circulation



Blood Vessels and Hemodynamics

Resistance influenced by:

1) Blood viscosity

- thickness of blood
- due to formed elements, plasma proteins
- normally unchanging in a healthy person

2) Total blood vessel length

- more length=more resistance
- normally unchanging in healthy person

3) Blood vessel diameter

- can be regulated
- fluid not touching walls moves faster
- fluctuates frequently
- large arteries do not change very much. Arterioles play a more significant role in resistance.



Blood Vessels and Hemodynamics

Systolic arterial pressure

- pressure exerted by blood on the blood vessel walls during ventricular contractions

Diastolic arterial pressure

- Arterial blood pressure reached when the ventricles are relaxing

Pulse Pressure

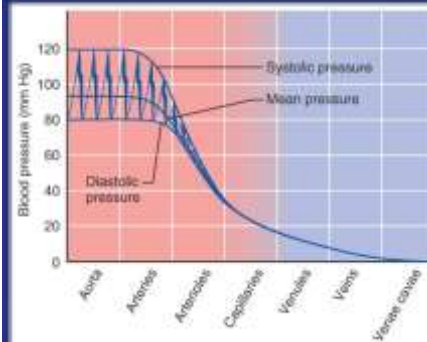
- systolic bp- diastolic bp (difference between)
- indicates vigor of contraction of ventricle
- provides info on elasticity of aorta and major arteries

Mean Arterial Pressure

- diastolic pressure+ 1/3 pulse pressure
- important pressure parameter because MAP is the pressure that propels blood to tissues throughout the cardiac cycle
- NOT mean of systolic and diastolic pressures because DIASTOLE IS LONGER THAN SYSTOLE



Blood Vessels and Hemodynamics



The steepest drop in BP occurs in the arterioles, which offer the greatest resistance to blood flow



Blood Vessels and Hemodynamics

Elastic arteries and blood flow

- during systole, elastic arteries stretch to avoid damaging smaller vessels with high pressure.
- during diastole, elastic arteries recoil to ensure that a pressure gradient is maintained so that blood will flow.
 - In order for blood to flow, the pressure in the elastic arteries has to remain higher than in subsequent vessels.



Blood Vessels and Hemodynamics

Capillary Blood Pressure

- 35 mm Hg at the beginning of the capillary bed
- 15 mm Hg at the end of the capillary bed

Low pressure important because:

- Capillaries are fragile and high pressure would rupture them
- Most capillaries are extremely permeable and thus even the low capillary pressure forces solute-containing fluids (filtrate) out of the bloodstream into the interstitial space.



Blood Vessels and Hemodynamics



Blood Vessels and Hemodynamics

Pulse

- Rhythmic expansion and recoil of arteries resulting from heart contraction; can be felt outside the body

Measuring Pulse

- You can feel a pulse in any artery that lies close to the body surface by compressing the artery against firm tissue



Blood Vessels and Hemodynamics

Measuring Blood Pressure

- Systemic arterial blood pressure is often measured indirectly in the brachial artery of the arm by the auscultatory method.
- The blood pressure cuff (sphygmomanometer) is wrapped snugly around the arm just superior to the elbow and inflated until the cuff pressure exceeds systolic pressure
- Blood flow into the arms is stopped and a brachial pulse cannot be felt or heard
- As the cuff pressure is gradually reduced, the examiner listens (auscultates) with a stethoscope for sounds in the brachial artery
- The pressure read when the first soft tapping sounds are heard is systolic pressure



Blood Vessels and Hemodynamics

Measuring Blood Pressure (cont'd)

- As the cuff pressure is reduced further, these sounds, called the sounds of Korotkoff, become louder and more distinct
- When the artery is no longer constricted and blood flows freely, the sounds can no longer be heard.
- The pressure at which the sounds first disappear is the diastolic pressure.

For healthy adults at rest:

systolic pressure 110-140 mm Hg

diastolic pressure 70-80 mm Hg



Blood Vessels and Hemodynamics

Hypotension

- Low blood pressure
- Systolic pressure below 100 mm Hg

Hypertension

- High blood pressure
- Can be transient (ex. During fever, physical exertion or emotional upset) or persistent
- Sustained arterial pressure of 140/90 or higher



Blood Vessels and Hemodynamics

Vasomotor Control of Blood Pressure

- The neural center that oversees changes in the diameter of blood vessels is the vasomotor center, a cluster of neurons in the medulla.
- Vasomotor center transmits impulses at a fairly steady rate along sympathetic efferents called vasomotor fibers, which exit from T1 through L2 levels of the spinal cord and run to innervate the smooth muscle of blood vessels, mainly arterioles.
- As a result, the arterioles are almost always in a state of moderate constriction, called vasomotor tone
- Any increase in sympathetic activity produces generalized vasoconstriction and rise in blood pressure.



Blood Vessels and Hemodynamics

Vasomotor Control of Blood Pressure (Cont'd)

- Most vasomotor fibers release norepinephrine, a potent vasoconstrictor
- In skeletal muscle, some vasomotor fibers release acetylcholine, causing vasodilation.
 - While these vasodilator fibers do influence local blood flow, they are not important in systemic blood pressure regulation

Vasomotor activity is modified by inputs from:

1. Baroreceptors
2. Chemoreceptors
3. Higher brain centers



Blood Vessels and Hemodynamics

Baroreceptors

- Neural receptors located in the carotid sinuses, aortic arch, and in the walls of nearly every large artery of the neck and thorax
- When arterial blood pressure rises, baroreceptors are stretched
- When stretched, baroreceptors send a rapid stream of impulses to the vasomotor center.
- This input inhibits the vasomotor center, resulting in:
 - vasodilation of arterioles and veins
 - decline in blood pressure
 - venodilation shifts blood to the venous reservoirs, causing a decline in both venous return and cardiac output



Blood Vessels and Hemodynamics

Baroreceptors (Cont'd)

- Afferent impulses from the baroreceptors also reach cardiac centers, where they stimulate parasympathetic activity and inhibit the cardioacceleratory center:
 - reduced heart rate
 - reduced contractile force
- Decline in MAP initiates reflex vasoconstriction and increases cardiac output, causing blood pressure to rise
- Peripheral resistance and cardiac output are regulated in tandem so that changes in BP are minimized
- Baroreceptors protect circulation against acute changes in BP (ex. Getting up out of a chair)



Blood Vessels and Hemodynamics

Chemoreceptor-Initiated Reflexes

When oxygen content or pH of the blood drops sharply or carbon dioxide levels rise, chemoreceptors in the aortic arch and large arteries of the neck transmit impulses to

the cardioacceleratory center which:

- increases cardiac output

the vasomotor center which:

- causes reflex vasoconstriction

= Rise in blood pressure that speeds the return of blood to the heart and lungs



Blood Vessels and Hemodynamics

Influence of Higher Brain Centers

- reflexes that regulate BP are integrated in the medulla of the brain stem
- cerebral cortex and hypothalamus are not involved in routine controls of BP but can modify arterial pressure via relays to medullary centers.
- Ex. Fight or flight response mediated by hypothalamus
- Ex. Hypothalamic regulation of the redistribution of blood flow and other cardiovascular responses that occur during exercises and changes in body temperature.



Blood Vessels and Hemodynamics

Renal Regulation of Blood Pressure

- long term control
- alters blood volume (vs. peripheral resistance in short-term control)
- blood volume usually close to 5 L
- blood volume major determinant of cardiac output
- increase blood volume, increase BP
- increases in blood volume that cause a rise in blood pressure also stimulate the kidneys to eliminate water, which reduced blood volume and BP.
- falling blood volume triggers renal mechanisms that increase blood volume and BP
- kidneys act both directly and indirectly



Blood Vessels and Hemodynamics

Direct Renal Mechanism

- Alters blood volume independently of any hormones
- When either blood volume or blood pressure rises, the rate at which fluid filters from the bloodstream into the kidney tubules is speeded up
- In such situations, the kidney cannot process the filtrate rapidly enough, and more of it leave the body in urine
- As a result, blood volume and blood pressure fall.
- When blood pressure or blood volume is low, water is conserved and returned to the bloodstream and blood pressure rises



Blood Vessels and Hemodynamics

Indirect Renal Mechanism

Renin-angiotensin mechanism

- When arterial BP declines, kidneys release the enzymatic hormone renin into the blood
- Renin triggers a series of reactions that produce angiotensin II
- Angiotensin II is a potent vasoconstrictor, increasing BP by increasing peripheral resistance
- Angiotensin II also stimulates the adrenal cortex to secrete aldosterone
- Aldosterone is a hormone that enhances renal reabsorption of sodium (water follows sodium into bloodstream)
- Angiotensin II promotes the release of ADH from the posterior pituitary
- ADH promotes more water reabsorption

Blood volume and blood pressure rise



Blood Vessels and Hemodynamics

Autoregulation

- Is the automatic adjustment of blood flow to each tissue in proportion to the tissue's requirements at any instant.
- The process is regulated by local conditions and is largely independent of systemic factors.
- Changes in blood flow through individual organs are controlled intrinsically by modifying the diameter of local arterioles feeding the capillaries
- What is happening in the arterioles feeding the capillary beds of a given organ has little effect on pressure in the muscular artery feeding the organ
- Intrinsic control mechanisms may be classed as metabolic or myogenic



Blood Vessels and Hemodynamics

Metabolic Controls

- In most tissues, declining levels of oxygen and nutrients are the strongest stimuli for autoregulation
- Other substances released by metabolically active tissues (ex. K⁺, H⁺, adenosine, lactic acid, and prostaglandins) also serve as autoregulation stimuli
- Many of these substances act directly to relax vascular smooth muscle, but some may act by causing the release of nitric oxide (NO), a powerful vasodilator.
- Nitric oxide is quickly destroyed and effects are brief
- NO plays the major role in vasodilation
- The endothelium also releases potent vasoconstrictors, including a family of peptides called endothelins, which are among the most potent vasoconstrictors known



Blood Vessels and Hemodynamics

Metabolic Controls (Cont'd)

- Inflammatory chemicals (ex. Histamine, kinins, prostaglandins) released in injury, infection or allergic reactions also cause vasodilation.
- The net result of metabolically controlled autoregulation is immediate vasodilation of the arterioles serving the capillary beds of the "needy" tissues, and therefore a temporary increase in blood flow to the area. This is accompanied by relaxation of the pre-capillary sphincters, which allows blood to surge through the true capillaries and become available to tissue cells.



Blood Vessels and Hemodynamics

Myogenic Controls

- Vascular smooth muscle responds directly to passive stretch (increased intravascular pressure) with increased tone, which resists the stretch and causes vasoconstriction
- Reduced stretch promotes vasodilation and increases blood flow into the tissue
- The myogenic mechanism keeps tissue perfusion fairly constant despite most variations in systemic pressure



Blood Vessels and Hemodynamics

Capillary Blood Flow

- Capillaries-> major point of communication between interstitial fluid and blood
- Most cells in the body within 0.02mm of a capillary
- Capillary walls only 1 cell thick-> mix of diffusional, osmotic and hydrostatic forces.

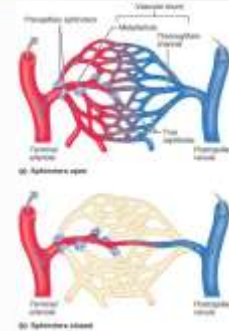
Precapillary sphincter: cuff of smooth muscle at beginning of capillary; capillary walls themselves have no smooth muscle

Vasomotion: Contraction and relaxation of precapillary sphincter-> sporadic flow through capillary

What is an **arteriovenous shunt**?



Blood Vessels and Hemodynamics



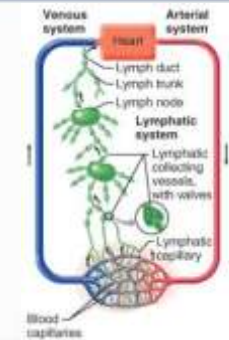
Blood Vessels and Hemodynamics

Capillary exchange mechanisms

1. **Vesicle transport**
 - For relatively large, lipid-insoluble molecules
 - Shuttling via endocytosis, then exocytosis
 - Also antibody molecules from maternal to fetal circulation
2. **Diffusion**
 - Primary mechanism for dissolved solutes and gases
 - Follow gradients
 - Heat moves via convection down a thermal gradient
 - Water-filled pores (Na^+ , K^+ , Cl^- , glucose) or through bilayer (O_2 , CO_2 , urea)
3. **Bulk Flow**
 - Hydrostatic pressure
 - Colloid osmotic pressure
 - Net filtration pressure



Lymphatic System



Lymphatic System

Two Parts:

- 1) **Lymphatic vessels**
 - transport back to the blood any fluids that have escaped from the blood vascular system
 - up to 3 L of "leaked" fluid plus plasma proteins returned to circulatory system
 - 2) **Lymphoid tissues and organs**
 - house phagocytic cells and lymphocytes, which play essential roles in the body's defense mechanisms
- *Once interstitial fluid enters the lymphatics, it is called LYMPH***



Lymphatic System

Lymphatic Vessels

- one way system of flow toward heart
- ```

Tissue
 ↓
Lymphatic capillaries
 ↓
lymphatic collecting vessels
 ↓
lymphatic trunks
 ↓
lymphatic duct
 ↓
Return to venous circulation

```





## Lymphatic System

### Lymphatic Vessels

#### Functions

1. Return excess tissue fluid to the bloodstream
2. Return leaked proteins to the blood
3. Carry absorbed fat from the intestine to the blood (through lacteals)



## Lymphatic System

### Lymphatic capillaries

- weave between tissue cells and blood capillaries in the loose CT
- are widespread
- absent from bones, teeth, bone marrow and CNS (drains into CSF)
- VERY permeable



## Lymphatic System

### Lymphatic capillaries (cont'd)

2 Structural modifications to allow permeability:

1. Flaplike minivalves
  - endothelial cells of walls not tightly joined
  - edge of adjacent cells overlap each other loosely
1. Collagen filaments anchoring endothelial cells to surrounding structures
  - Increase in interstitial fluid opens the minivalves rather than collapse capillary

↑ Interstitial fluid= Open minivalves,  
↓ Interstitial fluid= Closed minivalves



## Lymphatic System

Fluid pressure in interstitial space

Pressure in the lymphatic capillary  
=Minivalves **OPEN**

Fluid pressure in interstitial space

Pressure in the lymphatic capillary  
=Minivalves **CLOSED**

**\*\*THINK ABOUT PRESSURE GRADIENTS\*\***



## Lymphatic System

### Lymphatic capillaries (con't)

- Proteins in the interstitial space are unable to enter blood capillaries, but can enter lymphatic capillaries
- When tissues are inflamed, lymphatic capillaries develop openings that permit the uptake of even larger particles such as cell debris, pathogens, and cancer cells
- Pathogenic agents and cancer cells encounter cells of the immune system when they enter lymph nodes



## Lymphatic System

### Lacteals

- Highly specialized lymphatic capillaries
- Present in the fingerlike villi of intestinal mucosa
- Lacteals play a major role in absorbing digested fats from intestine
- Lymph from digestive viscera is milky white due to fat content and is called CHYLE



## Lymphatic System

### Lymphatic collecting vessels

- Have the same three tunics as veins, but the collecting vessels are thinner-walled, have more internal valves, and anastomose more.
- Lymphatics in the skin travel along with superficial veins, while the deep lymphatic vessels of the trunk and digestive viscera travel with the deep arteries



## Lymphatic System

### Lymphatic trunks

- Formed by the union of the largest collecting vessels, and drain fairly large areas of the body
- Major trunks, named mostly for the regions from which they collect lymph are:
  - (paired) lumbar, bronchomediastinal, subclavian, and jugular trunks
  - (single) intestinal trunk

Lymph is eventually delivered to one of two large **ducts** in the thoracic region.



## Lymphatic System

### Lymphatic ducts

- Right lymphatic duct drains lymph from
  - right upper arm
  - right side of the head
  - right side of the thorax
- The much larger thoracic duct drains lymph from the rest of the body
  - It arises anterior to the first two lumbar vertebrae as an enlarged sac, the **cisterna chyli**.

\*\*\*Each terminal duct empties its lymph into the venous circulation at the junction of the internal jugular vein and subclavian vein on its own side of the body\*\*\*



## Lymphatic System

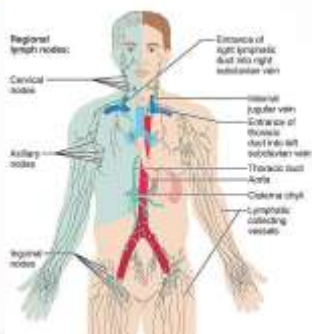
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## Lymphatic System



## Lymphatic System

### Lymph Transport

- The lymphatic system lacks an organ that acts as a pump
- Under normal conditions, lymphatic vessels are low-pressure conduits
- The same mechanisms that promote venous return in blood vessels act here as well- the milking action of active skeletal muscles, pressure changes in the thorax during breathing, and valves to prevent backflow.
- Lymphatics are usually bundled together in CT sheaths along with blood vessels, and pulsations of nearby arteries promote flow
- Smooth muscle in the walls of the lymphatic trunks and thoracic duct contracts rhythmically, helping to pump the lymph along



## Lymphatic System

### Lymphoid Cells

- Lymphocytes
  - Arise in the red bone marrow
  - Mature into T cells (T lymphocytes) or B cells (B lymphocytes)
  - Protect the body against antigens
  - Activated T cells manage the immune response, some of them directly attack and destroy infected cells
  - B cells protect the body by producing plasma cells, daughter cells that secrete antibodies into the blood or other bodily fluid. Antibodies immobilize antigens until they can be destroyed by phagocytes or other means.



## Lymphatic System

### Lymphoid Cells

- Macrophages
  - Play a crucial role in body protection and in the immune response by phagocytizing foreign substances and activating T cells.
- Dendritic cells
  - Capture antigens and bring them back to the lymph nodes
- Reticular cells
  - Fibroblast-like cells that produce the reticular fiber **stroma** which is the network that supports the other cells types in the lymphoid organs



## Lymphatic System

### Lymphoid Tissue

1. Houses and provides proliferation site for lymphocytes
  2. Furnishes an ideal surveillance vantage point for lymphocytes and macrophages
- Largely composed of loose CT called reticular connective tissue, which dominates all lymphoid organs EXCEPT THYMUS
  - Macrophages live on the fibers of the reticular network
  - In the spaces of the network are huge numbers of lymphocytes
  - Lymphocytes reside temporarily in the lymphoid tissue and then leave to patrol the body again.



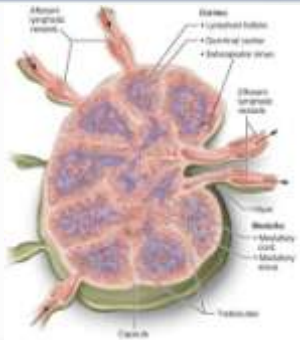
## Lymphatic System

### Lymph Nodes

1. Act as lymph filters. Macrophages in the nodes remove and destroy microorganisms and other debris that enter the lymph, preventing its return to the blood.
  2. Help activate the immune system. Lymphocytes, also strategically located in the lymph nodes, monitor the lymphatic stream for the presence of antigens and mount and attack against them.
- Large clusters where the lymphatic collecting vessels converge to form trunks:
    - inguinal, axillary and cervical regions



## Lymphatic System



## Lymphatic System

### Lymph Nodes

- Bean shaped and less than 2.5 cm in length
- Each node surrounded by dense fibrous capsule
- Trabeculae (CT strands extending inward from capsule) divide the node into compartments
- Two different regions CORTEX and MEDULLA

## Lymphatic System

| Cortex                                                                                                                                                                                                                                                                                                                     | Medulla                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>-Superficial part contains densely packed follicles, many with germinal centers heavy with dividing B cells.</li> <li>-Dendritic cells nearly encapsulate the follicles and abut the deeper part of the cortex</li> <li>-Deeper part primarily houses T cells in transit</li> </ul> | <ul style="list-style-type: none"> <li>-Medullary cords (inward extensions from cortical lymphoid tissue) contain T cells and B cells plus plasma cells</li> <li>-Throughout the node are lymph sinuses, large lymph capillaries spanned by cross-crossing reticular fibers. Numerous macrophages reside on these reticular fibers and phagocytize foreign matter in the lymph as it flows through the sinuses. Additionally, some of the lymph-borne antigens in the percolating lymph leak into the surrounding lymphoid tissue, where they activate lymphocytes to mount an immune response.</li> </ul> |

## Lymphatic System

## Lymphatic System

### Other Lymphoid Organs

1. Spleen
2. Thymus
3. Tonsils
4. Peyer's patches
5. Appendix

- EXCEPT FOR THE THYMUS, the common feature of these organs is their tissue makeup: all are composed of reticular connective tissue.
- These organs have efferent lymphatics draining them, but lack afferent lymphatics.

## Lymphatic System

### Spleen

Largest lymphoid organ

Located in the left side of the abdominal cavity just beneath the diaphragm

1. Provides site for lymphocyte proliferation and immune surveillance and response.
2. Blood-cleansing functions
  - Extracts aged and defective blood cells and platelets from the blood
  - Its macrophages remove debris and foreign matter from blood flowing through its sinuses

## Lymphatic System

### Spleen

3. Stores some of the breakdown products of red blood cells for later reuse (salvages iron for making hemoglobin) and releases others to the blood for processing by the liver
4. It is a site of erythrocyte production in the fetus (capability that normally ceases after birth)
5. It stores blood platelets

White pulp-> immunity

Red pulp-> disposal of worn-out RBCs and blood born pathogens

## Lymphatic System

### Thymus

- Important functions primarily during early years
- Prominent in newborns, continues to increase in size during the first year, when it is highly active. After puberty, it starts to atrophy
- Found in the inferior neck and extends into the superior thorax
- By secreting thymopoietin and thymosins, the thymus causes T lymphocytes to become immunocompetent
- NO B Cells
- Functions only in T lymphocyte maturation, ONLY LYMPHOID ORGAN THAT DOES NOT DIRECTLY FIGHT ANTIGENS



## Lymphatic System

### Thymus

- Blood-thymus barrier keeps bloodborne antigens from leaking into the cortical regions to prevent premature activation by immature lymphocytes.
- The stroma of the thymus consists of epithelial cells rather than reticular fibers.
- Epithelial cells secrete hormones to stimulate lymphocytes to become immunocompetent



## Lymphatic System

### Tonsils

Simplest lymphoid organs

Form a ring of lymphatic tissue around the entrance to the pharynx (throat)

#### 1) Palatine tonsils (paired)

- located on either side at the posterior end of the oral cavity.
- largest of the tonsils and the ones most often infected

#### 2) Lingual tonsil

- lumpy collection of lymphoid follicles at the base of the tongue

#### 3) Pharyngeal tonsil (referred to as the adenoids if enlarged)

#### 4) Tubal tonsils



## Lymphatic System

### Tonsils

- 3) Pharyngeal tonsil (referred to as the adenoids if enlarged)
  - In the posterior wall of the nasopharynx
- 4) Tubal tonsils
  - tiny
  - surround the openings of the auditory tubes into the pharynx
- Tonsils gather and remove many of the pathogens entering the pharynx in food or inhaled air.
- Not fully encapsulated



## Lymphatic System

### Peyer's patches

- Large, isolated clusters of lymphoid follicles, structurally similar to the tonsils, located in the wall of the distal portion of the small intestine (ileum).

### Appendix

- Lymphoid follicle also heavily concentrated in the wall of appendix, a tubular offshoot of the first part of the large intestine.

### Both

- Are in an ideal position to destroy bacteria and generate many memory lymphocytes for long-term immunity.



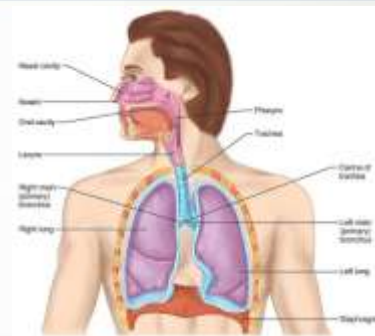
## Lymphatic System

### Mucosa-associated lymphatic tissue (MALT)

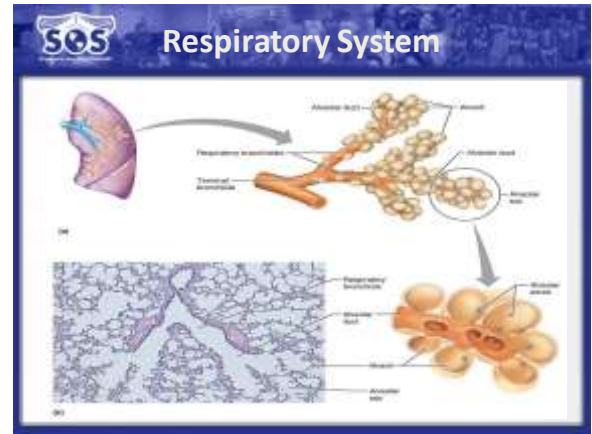
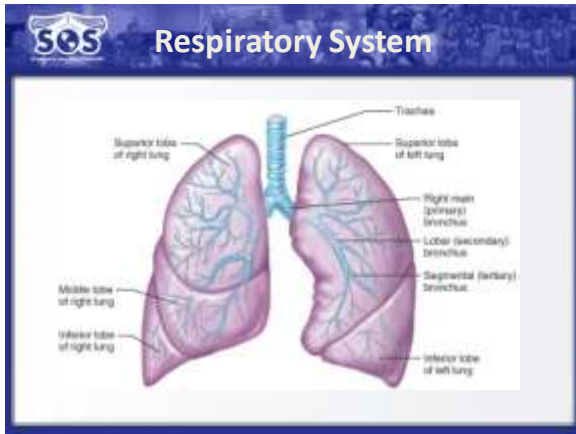
1. Peyer's patches
  2. Appendix
  3. Tonsils
  4. Nodules in walls of bronchi
  5. Areas of GI tract
  6. Areas of genitourinary system
- Collection of small lymphoid tissue protecting passages that are open to the exterior from the never-ending onslaughts of foreign matter entering them.



## Respiratory System







**Respiratory System**

**Function**

- Supplies the body with oxygen
- Disposes of carbon dioxide
- Involved with sense of smell\*
- Involved with speech generation\*

\*because respiratory system moves air

**Respiratory System**

**4 processes of Respiration**

1. Pulmonary Ventilation
2. External respiration
3. Transport of respiratory gases
4. Internal respiration

**Note:** Only the first two processes are carried out by the respiratory system. The other two are the domain of the circulatory system. These two systems are closely coupled .

**Respiratory System**

**Divided into:**

1. **Conducting Zone**
  - Nose and nasal cavity
  - Pharynx, larynx, trachea
  - Bronchi and smaller branches
2. **Respiratory Zone**
  - Respiratory bronchioles
  - Alveolar ducts
  - Alveoli

**Respiratory System**

**Conducting Zone**

- Provide conduits for air to reach sites of gas exchange
- Cleanses incoming air
- Humidifies incoming air
- Warms incoming air

**Respiratory Zone**


- Actual site of gas exchange

## Respiratory System

### Functions of the Nose

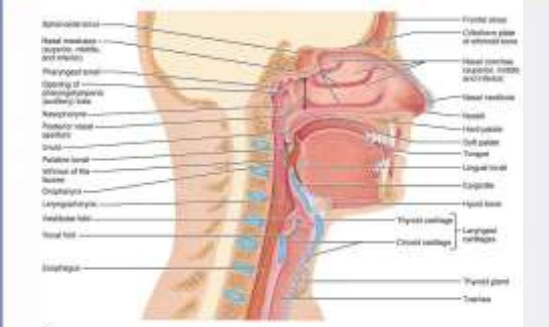
1. Provides an airway for respiration
2. Moistens and warms entering air
3. Filters and cleans inspired air
4. Serves as a resonating chamber for speech
5. Houses the olfactory (smell) receptors

## Respiratory System



(a) Skin covering the nose's dorsal and lateral aspects is thin and contains many sebaceous glands

## Respiratory System



## Respiratory System

- Structures of the nose divided into external nose and the internal nasal cavity
- Air enters the **NASAL CAVITY** via **EXTERNAL NARES (NOSTRILS)** – divided by midline **NASAL SEPTUM** (cartilage-> bone). Air goes via **INTERNAL NARES** to **NASOPHARYNX**
- **ROOF** of **NASAL CAVITY** formed by **ETHMOID** and **SPHENOID** bones of skull
- **FLOOR** of **NASAL CAVITY** formed by **PALATE** (anterior= hard, posterior = soft)

## Respiratory System

- **VIBRISSAE**-> Hairs that filter coarse particles from air
- Nasal cavity lined by **OLFACTORY MUCOSA** and **RESPIRATORY MUCOSA**
- **OLFACTORY MUCOSA**-> line the superior region of the nasal cavity, contain smell receptors
- **RESPIRATORY MUCOSA**-> pseudo stratified ciliated columnar epithelium, containing scattered **GOBLET CELLS**, that rest on a lamina propria richly supplied with **MUCOUS** and **SEROUS GLANDS** (secrete a watery fluid containing enzymes).

## Respiratory System

- Everyday, these glands secrete ~1 quart of mucus containing **LYZOSYME** (antibacterial enzyme). Sticky mucus traps inspired dust, bacteria, and other debris, while lysozyme attacks and destroys bacteria chemically.
- Epithelial cells of the respiratory mucosa also secrete **DEFENSINS**, natural antibiotics that help get rid of invading microbes.
- This high water content of the mucus film acts to humidify the inhaled air.



## Respiratory System

- Ciliated cells of the respiratory mucosa create a gentle current that moves the sheet of contaminated mucus posteriorly toward the throat, where is swallowed and digested by stomach juices.
- Nasal mucosa richly supplied with sensory nerve endings, contact with irritating particles triggers sneeze reflex to expel irritants.
- Rich plexus of capillaries and thin-walled veins underlie nasal epithelium and warm incoming air as it flows across the mucosal surface (think about why this might cause nose bleeds)



## Respiratory System

- Protuding medially from each lateral wall of the nasal cavity are three scroll-like mucosa-covered projections: the **SUPERIOR**, **MIDDLE**, and **INFERIOR NASAL CONCHAE**. The groove inferior to each **CONCHA** is a **NASAL MEATUS**. The curved **CONCHAE** greatly increase the mucosal surface areas exposed to the air and enhance air turbulence in the cavity. The gases in inhaled air swirl through the twists and turns, but heavier, nongaseous particles tend to be deflected onto the mucus-coated surfaces, where they become trapped.

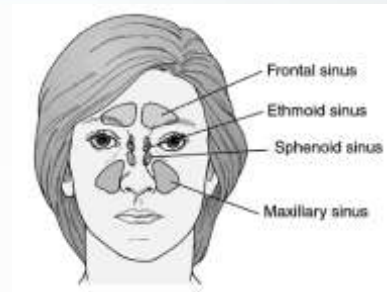


## Respiratory System

- The **CONCHAE** and **NASAL MUCOSA** also act during exhalation to reclaim heat and moisture.
- The **NASAL CAVITY** is surrounded by a ring of **PARANASAL SINUSES** located in the **FRONTAL**, **SPHENOID**, **ETHMOID**, and **MAXILLARY BONES**.
  - The sinuses lighten the skull, and warm and moisten the air.
  - The mucus they produce ultimately flows into the nasal cavity.
  - Nose blowing helps drain the sinuses.



## Respiratory System



## Respiratory System

### Pharynx

- Connects the nasal cavity and mouth superiorly to the larynx and esophagus inferiorly.
- Extends from the base of the skull to the level of the 6<sup>th</sup> cervical vertebra.
- Divided into nasopharynx, oropharynx and laryngopharynx.



## Respiratory System

### Nasopharynx

- Posterior to the nasal cavity, inferior to the sphenoid bone, and superior to the level of the soft palate
- Because it lies above the point where food enters the body, it serves only as an air passageway.
- During swallowing, the soft palate and its pendulous uvula move superiorly, and action that closes off the nasopharynx and prevents food from entering the nasal cavity (What happens when we giggle?)
- Continuous with nasal cavity through posterior nasal apertures, and its pseudostratified ciliated epithelium takes over the job of propelling mucus where the nasal mucosa leaves off.
- High on its posterior wall is the pharyngeal tonsil (adenoids), which traps and destroys pathogens entering the nasopharynx in air.



## Respiratory System

### Nasopharynx (cont'd)

- The **PHARYNGOTYMPANIC (AUDITORY) TUBES**, which drain the **MIDDLE EAR CAVITIES** and allow the middle air pressure to equalize with atmospheric pressure, open into the lateral walls of the the nasopharynx. A ridge of **PHARYNGEAL MUCOSA**, referred to as **TUBAL TONSIL**, arched over each of these openings. Because of their strategic location, the **TUBAL TONSILS** help protect the middle ear against infections likely to spread from the nasopharynx. The **PHARYNGEAL TONSIL**, superoposterior and medial to the tubal tonsil, also plays this protective role



## Respiratory System

### Oropharynx

- Lies posterior to the oral cavity and is continuous with it through an archway called the isthmus of the fauces.
- Both swallowed food and inhaled air pass through it.
- As the nasopharynx blends into the oropharynx, the epithelium changes from pseudostratified columnar to more protective stratified **squamous epithelium**. This structural adaptation accommodates the increased friction and greater chemical trauma accompanying food passage.
- Two kinds of tonsils lie embedded in the oropharyngeal mucosa. The paired **PALATINE TONSILS** lie in the lateral walls of the fauces. The **LINGUAL TONSIL** covers the base of the tongue.



## Respiratory System

### Laryngopharynx

- Serves as a passageway for food and air
- Line with stratified squamous epithelium
- Lies directly posterior to the upright epiglottis and extends to the larynx, where the respiratory and digestive pathways diverge.
- Air enters the larynx anteriorly
- The laryngopharynx is continuous with the esophagus posterior to the larynx.
- During swallowing, food has the right of way and air passage temporarily stops.



## Respiratory System

### Larynx "voice box"

- 4-6<sup>th</sup> cervical vertebrae
- Attached to hyoid bone (above); continuous with trachea (below)
- 3 Functions
  - open, 2 directional airway
  - switching: food vs. air
  - voice production (houses vocal cords)



## Respiratory System

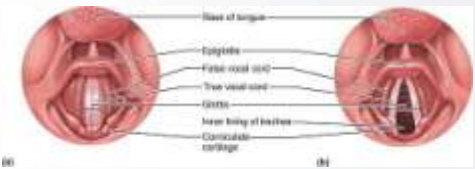


## Respiratory System

- Framework of the larynx made of nine cartilages.
- Except for the epiglottis, all laryngeal cartilages are hyaline cartilages.
- Thyroid cartilage
  - Large, shield-shaped cartilage in front. Larger in males because male sex hormones stimulate its growth during puberty.
- Arytenoid cartilages (2)
  - Lateral, pyramid-shaped, anchor vocal cords
- 9<sup>th</sup> cartilage is epiglottis
  - Elastic cartilage, anchored to anterior rim of thyroid cartilage & extends to base of the tongue
  - Called the "guardian of the airway"

## Respiratory System

- True vocal cords
  - White (avascular); vibrate in response to air movement from lungs
    - Glottis= opening between the vocal cords
- False vocal cords
  - Above true vocal cords



The diagrams show two cross-sections of the larynx. The left diagram (a) shows the larynx in a relaxed state with the glottis open. The right diagram (b) shows the larynx in a contracted state with the glottis closed. Labels include: Base of tongue, Epiglottis, False vocal cord, True vocal cord, Glottis, Horns of hyaline cartilage, and Corniculate cartilage.

## Respiratory System

- The superior portion of the larynx, an area subject to food contact, is lined by stratified squamous epithelium.
- Below the vocal folds, the epithelium is a pseudostratified ciliated columnar tupe that acts as a dust filter. The power stroke of its cilia is directed upward toward the pharynx so that mucus is continually moved away from the lungs.

## Respiratory System

### Voice Production

- Speech= intermittent release of expired air +opening and closing of glottis
- Length of vocal cords & size of glottis altered by action of laryngeal muscles that move arytenoid cartilages.
- As the length and tension of the cords change, the pitch of the sounds varies. The tenser the cords, the faster they vibrate and the higher the pitch. The glottis is wide when we produce deep tones and narrows to a slit for high-pitched sounds
- As a boy's larynx enlarges during puberty, his true vocal cords become longer and thicker.

## Respiratory System

### Voice Production (cont'd)

Loudness of voice-> force of air across vocal cords

Laryngitis-> inflammation of vocal cords

### Sphincter Function

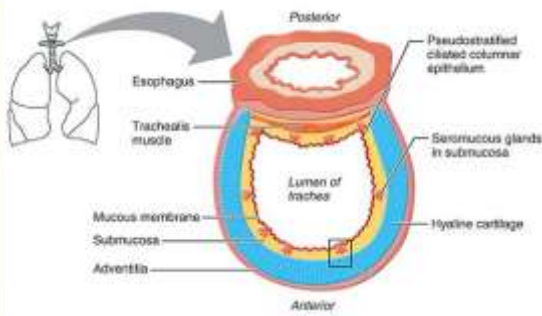
1. Epiglottis closes respiratory tract during swallowing
2. Valsalva's manoeuver: glottis closed & abdominal muscles contract to increase intra-abdominal pressure when defecating, forcibly emptying bladder, lifting heavy load.

## Respiratory System

### Trachea

- Also called "wind pipe"
- Descends from the larynx through the neck and into the mediastinum. Ends into the two main bronchi at midthorax.
- Very flexible and mobile
- Tracheal wall consists of the mucosa, submucosa, and adventitia.

## Respiratory System



The diagram shows a cross-section of the trachea. Labels include: Posterior, Pseudostratified ciliated columnar epithelium, Semimucous glands in submucosa, Hyaline cartilage, Anterior, Adventitia, Submucosa, Mucous membrane, Lumen of trachea, Trachealis muscle, and Esophagus. An inset shows the trachea in the context of the lungs.





## Respiratory System

- The mucosa has the same goblet cell-containing pseudostratified epithelium that occurs throughout most of the respiratory tract. Its cilia continually propel debris-laden mucus toward the pharynx. This epithelium rests on a fairly thick lamina propria that has a rich supply of elastic fibers.
- The submucosa is a connective tissue layer deep to the mucosa and contains seromucous glands that help produce mucus sheets within the trachea.
- The outermost adventitia layer is a connective tissue layer reinforced internally by 16-20 C-shaped rings of hyaline cartilage.
- Because of its elastic elements, the trachea is flexible enough to stretch and move inferiorly during inspiration and recoil during expiration, but the cartilage keep the airway patent (prevent from collapsing) despite pressure changes.



## Respiratory System

### The Bronchial Tree

- The bronchial tree is the site where conducting zone structures give way to respiratory zone structures.
- Trachea-> right and left main (primary bronchi)
  - Right main bronchus is wider, shorter, and more vertical than the left and is the more common side or an inhaled foreign object to become lodged
  - By the time incoming air reaches the bronchi, it is warm, cleansed of most impurities, and saturated with water vapor.



## Respiratory System

### The Bronchial Tree (cont'd)

- Once inside the lungs, each main bronchus-> lobar (secondary) bronchi
  - three on right, two on left
  - each supply one lobe of lung
- Lobar (secondary) bronchi->segmental (tertiary) bronchi-> divide into smaller and smaller bronchi-> bronchioles
  - about 23 orders of branching

Bronchiole= passages smaller than 1 mm in diameter

Terminal bronchioles= less than 0.5 mm in diameter

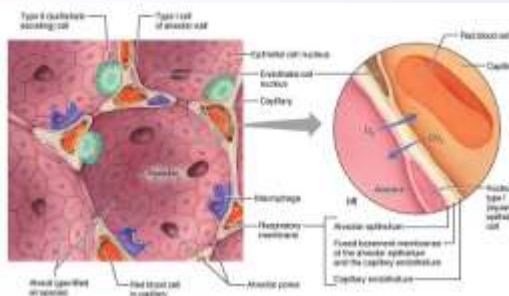


## Respiratory System

- The tissue composition of the walls of the main bronchi mimics that of the trachea, but as the conducting tubes become smaller, the following structural changes occur:
  - Support structure changes
    - Cartilage rings replaced by irregular plates. Supportive cartilage no longer present by the time the bronchioles are reached. Elastic fibers are found in the tube walls throughout the bronchial tree.
  - Epithelium type changes
    - Mucosal epithelium things as it changes from pseudostratified columnar to columnar and then cuboidal in the terminal bronchioles. Cilia are sparse, and mucus producing cells are absent in the bronchioles. Most airborne debris found at or below the level of the bronchioles is removed by macrophages in the alveoli.
  - Amount of smooth muscle increases
    - Relative amount of smooth muscle in the tube walls increases as the passageways become smaller.



## Respiratory System



## Respiratory System

### Respiratory Zone

- Terminal bronchioles branch into respiratory bronchioles
- Defined by the presence of thin-walled air sacs called alveoli.
- Respiratory bronchioles->alveolar ducts-> clusters of alveoli (alveolar sacs)->alveoli
- 300 million alveolar sacs in lung account for most of the lung volume and provide a tremendous surface area for gas exchange



## Respiratory System

### Respiratory Membrane

- Walls of alveoli composed primarily of a single layer of squamous epithelial cells (TYPE I CELLS) surrounded by flimsy basement membrane
- External surfaces of the alveoli are densely covered with a "cobweb" of pulmonary capillaries
- Respiratory membrane= alveolar and capillary walls and their fused basement membranes
  - Air-blood barrier that has gas on one side and blood flowing past on the other
  - Gas exchange by simple diffusion across the respiratory membrane (oxygen from the alveolus to the blood, and carbon dioxide from the blood to the alveolus)



## Respiratory System

- Scattered amid type I cells are cuboidal type II cells. These cells secrete a fluid containing surfactant that coats the gas-exposed alveolar surfaces
- The aveoli have 3 other important features:
  1. They are surrounded by fine elastic fibers of the same type that surround the entire bronchial tree
  2. Open alveolar pores connecting adjacent alveoli allow air pressure throughout the lung to be equalized and provide alternate air routes to any alveoli whose bronchi have collapsed due to disease.
  3. Alveolar macrophages on the internal alveolar surfaces, also called dust cells.



## Respiratory System

### Lungs

- Paired lungs occupy the entire thoracic cavity except the mediastinum
- Each lung suspended in own pleural cavity
- Costal surface= anterior, lateral & posterior lung surface in close contact with ribs

Apex->top

Base-> bottom

Hilum-> indentations through which systemic and pulmonary blood vessels leave lungs

Fissures-> oblique and horizontal, subdivide each lung into 10 bronchopulmonary segments (CT divisions with own artery and vein)



## Respiratory System

Lobule-> smallest subdivision seen with naked eye; hexagon- size of pencil eraser, served by large bronchioles.

### Lung

-Primarily air spaces, rest is elastic CT

### Blood supply and innervation

-pulmonary arteries bring blood to be oxygenated

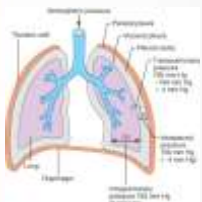
-pulmonary veins return oxygenated blood

-bronchial arteries provide systemic blood to lungs

-innervated by parasympathetic (constrict air tubules) and sympathetic (dilate air tubules) motor fibers, and visceral sensory fibers. These nerves fibers enter each lung through the pulmonary plexus.



## Respiratory System



### The Pleurae

- Form thin, double-layered (parietal & visceral) serosa.
- Pleural fluid-> serous secretion that fills pleural cavity and allows the lungs to slide easily during breathing. Surface tension keeps pleurae from separating.
- 3 chambers-> central mediastinum and 2 lateral pleural compartments (what is the significance of having two pleural compartments?)



## Respiratory System

### Intrapulmonary pressure

-pressure in the alveoli. Rises and falls with the phases of breathing, but always eventually equalizes with the atmospheric pressure

### Intrapleural pressure

-the pressure in the pleural cavity. Also fluctuates with breathing phases, but is always about 4 mm Hg less than intrapulmonary pressure (always negative relative to intrapulmonary pressure)

### Transpulmonary pressure

-difference between the intrapulmonary and intrapleural pressure. Keeps the air spaces of the lungs open and prevents the lungs from collapsing. The greater the transpulmonary pressure, the larger the lungs.



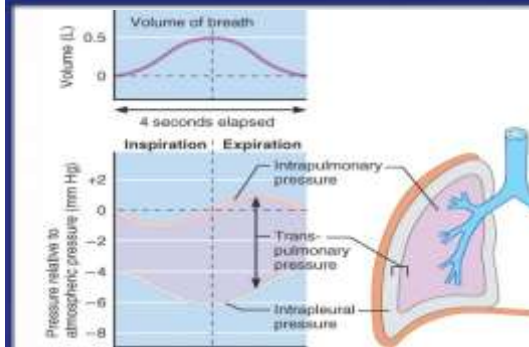
## Respiratory System

Boyle's law: At constant temperature, the pressure of a gas varies inversely with its volume. (Pressure increase=volume decrease, Pressure decrease= volume increase)

When the volume of the thoracic cavity increases, pressure in the lungs decreases and falls below atmospheric pressure. Air fills the lungs as it travels from an area of high pressure (outside of the lungs) to an area of lower pressure (inside the lungs). This will continue until the internal and external pressure are equalized.



## Respiratory System



## Respiratory System

### Quiet Inspiration

Diaphragm contracts to increase height of thoracic cavity  
Intercostals contract to lift rib cage up & pull sternum forward to increase thorax diameter

Mm changes in each direction but overall increase in volume of about 0.5 L and drop in intrapulmonary pressure of about 1 mm Hg

Air rushes in, inspiration ends when intrapulmonary pressure= atmospheric pressure

At the same time, intrapleural pressure drops to about 6 mm Hg



## Respiratory System

### Quiet Expiration

- Passive, depends more on elasticity of lungs (recoil) than on muscle contraction
- Inspiratory muscles relax-> rib cage descends and lungs recoil-> thoracic cavity & intrapulmonary volumes decrease -> alveoli compress/ intrapulmonary pressure to +1 mm Hg-> gas out



## Respiratory System

### Deep/forced inspiration

Accessory muscles (neck & chest) raise ribs more, extend back by straightening spine

### Forced Expiration

1. Contract abdominal wall muscles: increase intra-abdominal pressure
2. Depress rib cage



## Respiratory System

### 3 Factors Influencing Pulmonary Ventilation

1. Airway Resistance
2. Alveolar Surface Tension
3. Lung Compliance

## Respiratory System

**Airway Resistance**

- Recall in blood circulation  
flow = change in pressure/resistance (same in respiration)
- Flow is reduced with increased resistance
- Resistance determined mainly by diameters of conducting tubes. This is not the dominant feature of the respiratory system because as the tubes become smaller, they increase dramatically in number (total cross sectional area is huge)
- Resistance not an issue starting at the terminal bronchioles because gas flow stops and diffusion takes over.

## Respiratory System

**Alveolar Surface Tension**

- At any gas-liquid boundary, the molecules of the liquid are more strongly attracted to each other than to the gas molecules. This unequal attraction produces a state of tension at the liquid surface called surface tension

Two functions of surface tension:

- 1) Draws the liquid molecules closer together and reduces their contact with the dissimilar gas molecules
- 2) Resists any force that tends to increase the surface area of the liquid

- Water composed of highly polar molecules → high surface tension, acts to reduce the alveoli to their smallest possible size

## Respiratory System

**Alveolar Surface Tension (cont'd)**

- If the film was pure water, the alveoli would collapse between breaths.
- The alveolar film contains surfactant, a detergent-like complex of lipids and proteins that decrease the cohesiveness of the water molecules.
- Surfactant reduces surface tension and reduces the energy needed to overcome those forces to expand the lungs and discourage alveolar collapse.
- Breaths that are deeper than normal stimulate type II cells to secrete more surfactant.

## Respiratory System

**Infant respiratory distress syndrome (IRDS)**

- When too little surfactant is present, surface tension forces can collapse the alveoli. Once this happens, the alveoli must be completely reinflated during each inspiration.
- This is a problem in premature babies produce inadequate amounts of surfactant.
- Treated with positive pressure respirators that force air into the alveoli
- Spraying natural or synthetic surfactant into the respiratory passageways also helps.

## Respiratory System

**Lung Compliance**

- Lung compliance is a measure of the change in lung volume that occurs with a given change in transpulmonary pressure
- The more a lung expands for a given rise in transpulmonary pressure, the greater the compliance. (The higher the lung compliance, the easier it is to expand the lungs at any given transpulmonary pressure).
- Lung compliance determined by:
  - Distensibility of the lung tissue
  - Alveolar surface tension

## Respiratory System

**Lung Compliance (cont'd)**

- Chronic inflammation or infections that cause scar tissue development as well as decreased production of surfactant decrease lung compliance.
- Factors that decrease the compliance of the thoracic wall also decrease lung compliance.
- The lower the lung compliance, the more energy needed just to breathe.

## Respiratory System

### Respiratory Volumes

**Tidal Volume (TV)**  
-During normal quiet breathing, about 500 mL of air moves into and then out of the lungs with each breath.

**Inspiratory Reserve Volume (IRV)**  
-Amount of air that can be inspired forcibly beyond the tidal volume (2100 to 3200 mL)

**Expiratory Reserve Volume (ERV)**  
-Amount of air (1000-1200 mL) that can be evacuated from the lungs after a tidal expiration

**Residual Volume (RV)**  
-Even after the most strenuous expiration, about 1200 mL of air remains in the lungs, which helps to keep the aveoli patent.

## Respiratory System

### Respiratory capacities

**Inspiratory capacity (IC)**  
-The total amount of air that can be inspired after a tidal expiration (sum of TV and IRV).

**Functional residual capacity (FRC)**  
-Combined RV and ERV and represents the amount of air remaining in the lungs after tidal expiration.

**Vital capacity (VC)**  
-Total amount of exchangeable air. Sum of TV, IRV, and ERV. In healthy young males, VC is approx. 4800 mL.

**Total lung capacity (TLC)**  
-Sum of all lung volume and is normally around 6000 mL.

## Respiratory System

### Dead Space

- Some of the inspired air fills the conducting respiratory passages and never contributes to gas exchange in the alveoli. The volume of these conducting zone conduits, which make up the anatomical dead space, typically amounts to about 150 mL.
- If some alveoli cease to act in gas exchange, the alveolar dead space is added to the anatomical dead space, and the sum of the non useful volumes is referred to as total dead space.

## Respiratory System

### Alveolar Ventilation Rate (AVR)

$AVR \text{ (mL/min)} = \text{frequency (breaths/minute)} \times (TV - \text{dead space}) \text{ (mL/breath)}$

- AVR is a better index of effective ventilation because it takes into the account the volume of air wasted in the dead space.
- Because anatomical dead space is constant in particular individual, increasing the volume of each inspiration enhances AVR and gas exchange more than raising respiratory rate.
- AVR drops dramatically during rapid shallow breathing because most of the inspired air never reaches the exchange sites.

## Respiratory System

### Nonrespiratory Air (Gas) Movements

| MOVEMENT | MECHANISM AND RESULT                                                                                                                                                                                                                                              |
|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Cough    | Taking a deep breath, closing glottis, and forcing air superiorly from lungs against glottis; glottis opens suddenly and a blast of air rushes upward; can dislodge foreign particles or mucus from lower respiratory tract and propel such substances superiorly |
| Sneeze   | Similar to a cough, except that expelled air is directed through nasal cavities as well as through oral cavity; depressed uvula rises an upward through nasal cavity; moves clean upper respiratory passages                                                      |
| Crying   | Inspiration followed by release of air in a number of short expirations; primarily an emotionally induced mechanism                                                                                                                                               |
| Laughing | Essentially same as crying in terms of air movements produced; also an emotionally induced response                                                                                                                                                               |
| Hiccups  | Sudden inspirations resulting from spasms of diaphragm; believed to be initiated by irritation of diaphragm or phrenic nerves, which serve diaphragm; sound occurs when inspired air hits vocal folds of closing glottis                                          |
| Yawn     | Very deep inspiration, taken with jaws wide open; not believed to be triggered by levels of oxygen or carbon dioxide in blood; ventilates all alveoli (not the case in normal quiet breathing)                                                                    |

## Respiratory System

### Dalton's Law of Partial Pressures

- The total pressure exerted by a mixture of gases is the sum of the pressures exerted by independently by each gas in the mixture. Further, the pressure exerted by each gas- its partial pressure- is directly proportional to the percentage of that gas in the gas mixture



## Respiratory System

**TABLE 22.4**  
Comparison of Gas Partial Pressures and Approximate Percentages in the Atmosphere and in the Alveoli

| Gas    | ATMOSPHERE (sea level) |                          | ALVEOLI                |                          |
|--------|------------------------|--------------------------|------------------------|--------------------------|
|        | APPROXIMATE PERCENTAGE | PARTIAL PRESSURE (mm Hg) | APPROXIMATE PERCENTAGE | PARTIAL PRESSURE (mm Hg) |
| $N_2$  | 78.1                   | 597                      | 74.9                   | 560                      |
| $O_2$  | 20.9                   | 159                      | 14.7                   | 109                      |
| $CO_2$ | 0.04                   | 0.3                      | 5.7                    | 40                       |
| $H_2O$ | 0.46                   | 3.7                      | 6.2                    | 47                       |
|        | 100.0%                 | 760                      | 100.0%                 | 760                      |

Alveoli contain more carbon dioxide and water vapor and less oxygen than atmosphere. Why the difference?

1. Gas exchanges occurring in the lungs.
2. Humidification of air by conducting passageways.
3. Mixing of alveolar gas that occurs with each breath.

**\*\*Alveolar partial pressure of carbon dioxide and oxygen are easily changed by increasing breathing depth and rate. \*\***

## Respiratory System

### Henry's Law

- When a mixture of gases is in contact with a liquid, each gas will dissolve in the liquid in proportion to its partial pressure.
- The greater the concentration of a particular gas in the gas phase, the more and the faster that gas will go into solution in the liquid.
- At equilibrium, the gas partial pressures in the two phases are the same. If, however, the partial pressure of one of the gases later become greater in the liquid than in the adjacent gas phase, some of the dissolved gas molecules will reenter the gaseous phase.
- The direction and amount of movement of each gas is determined by its partial pressure in the two phases.
- How much of a gas will dissolve in a liquid at any given partial pressure also depends on the solubility of the gas in the liquid and on the temperature of the liquid. Carbon dioxide is 20x more soluble than oxygen and nitrogen gas is half as soluble as oxygen.

## Respiratory System

### 3 Factors that influence the movement of oxygen and carbon dioxide across the respiratory membrane (external respiration):

1. Partial pressure gradients and gas solubilities
2. Matching of alveolar ventilation and pulmonary blood perfusion (ventilation/perfusion coupling)
3. Structural characteristics of respiratory membrane

## Respiratory System

### Partial pressure gradients and gas solubilities

- Because the  $P_{O_2}$  of venous blood in the pulmonary arteries is only 40 mm Hg, as opposed to  $P_{O_2}$  of 104 mm Hg in the alveoli, a steep oxygen partial pressure gradient exists and oxygen diffuses rapidly across the respiratory membrane.
- Carbon dioxide diffuses just as rapidly at a lower pressure gradient because it is more soluble.

## Respiratory System

The diagram illustrates the flow of air and blood through the respiratory and circulatory systems. Key partial pressures are labeled:

- Inhaled air:**  $P_{O_2}$  160 mm Hg,  $P_{CO_2}$  0 mm Hg
- Expired air:**  $P_{O_2}$  120 mm Hg,  $P_{CO_2}$  40 mm Hg
- Alveolar air:**  $P_{O_2}$  104 mm Hg,  $P_{CO_2}$  40 mm Hg
- Deoxygenated blood (pulmonary arteries):**  $P_{O_2}$  40 mm Hg,  $P_{CO_2}$  45 mm Hg
- Oxygenated blood (pulmonary veins):**  $P_{O_2}$  100 mm Hg,  $P_{CO_2}$  40 mm Hg
- Systemic arteries:**  $P_{O_2}$  95 mm Hg,  $P_{CO_2}$  40 mm Hg
- Systemic veins:**  $P_{O_2}$  40 mm Hg,  $P_{CO_2}$  45 mm Hg

## Respiratory System

The diagram shows four scenarios of ventilation-perfusion coupling in the lungs:

- Reduced alveolar ventilation, excessive perfusion:** Leads to decreased  $P_{O_2}$  and increased  $P_{CO_2}$  in the alveoli.
- Pulmonary arteries serving these alveoli constricted:** Reduces blood flow to the alveoli, improving the  $P_{O_2}$  and  $P_{CO_2}$  gradient.
- Enhanced alveolar ventilation, inadequate perfusion:** Leads to increased  $P_{O_2}$  and decreased  $P_{CO_2}$  in the alveoli.
- Pulmonary arteries serving these alveoli dilated:** Increases blood flow to the alveoli, improving the  $P_{O_2}$  and  $P_{CO_2}$  gradient.



## Respiratory System

### Ventilation/perfusion coupling

- For gas exchange to be efficient, there must be a close match between ventilation and perfusion.
- Local autoregulatory mechanisms continuously respond to alveolar conditions.
- In alveoli where ventilation is inadequate,  $P_{O_2}$  is low. As a result, terminal arterioles constrict, and blood is redirected to respiratory areas where  $P_{O_2}$  is higher and oxygen pickup may be more efficient.
- In alveoli where ventilation is maximal, pulmonary arterioles dilate, increasing blood flow into the associated pulmonary capillaries.



## Respiratory System

### Ventilation/perfusion coupling

- While changes in alveolar  $P_{O_2}$  affect the diameter of pulmonary blood vessels, changes in alveolar  $P_{CO_2}$  causes changes in the diameters of the bronchioles. Passageways servicing areas where alveolar  $CO_2$  levels are high dilate, allowing  $CO_2$  to be eliminated from the body more rapidly



## Respiratory System

### Structural characteristics of respiratory membrane

- In healthy lungs, the respiratory membrane is only 0.5 to 1  $\mu m$  thick, and gas exchange is usually very efficient.
- Surface area is huge!



## Respiratory System

### Internal Respiration

- Same mechanism as external respiration -> partial pressure gradients
- See diagram of partial pressures.



## Respiratory System

### Transport of oxygen in the blood

Molecular oxygen is carried in the blood in two ways:

1. Bound to hemoglobin within red blood cells
2. dissolves in plasma (oxygen poorly soluble in water so only about 1.5% of oxygen carried this way)

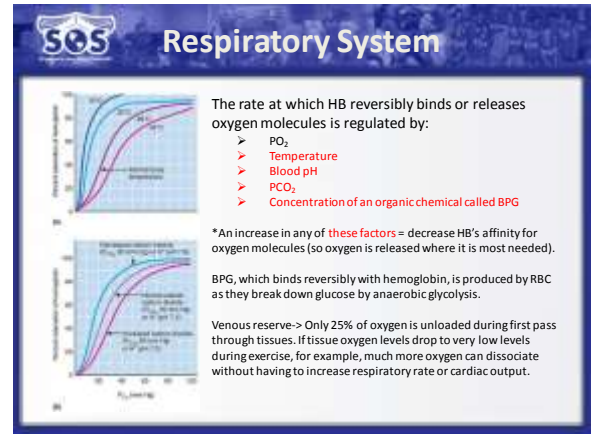
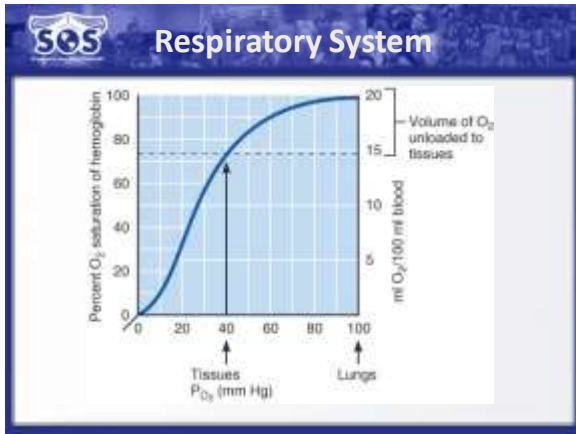
#### **Hemoglobin**

- composed of four polypeptide chains, each bound to an iron-containing heme group.
- each iron atom binds oxygen, so each hemoglobin can combine with four molecules of  $O_2$
- Oxygen loading is rapid and reversible



## Respiratory System

- Hemoglobin+oxygen= oxyhemoglobin
- Hemoglobin that has released oxygen= reduced hemoglobin or deoxyhemoglobin
- After the first  $O_2$  molecule binds to iron, the Hb molecule changes shape and becomes more about to take up the next molecules (affinity increases). Unloading works the same way.
- Partially saturated hemoglobin -> 1, 2, or 3 hemes have bound oxygen molecules
- Fully saturated hemoglobin -> all 4 hemes have bound oxygen molecules



### Respiratory System

#### Carbon dioxide transport

3 methods:

1. Dissolved in plasma (7-10 %)
2. Chemically bound to hemoglobin (~20 %)
  - Binds to the globin portion and does not compete with the oxyhemoglobin mechanism. Association/dissociation influenced by partial pressure of carbon dioxide. Deoxygenated hemoglobin combines more readily with carbon dioxide than does oxygenated hemoglobin.
3. As bicarbonate ion in plasma

### Respiratory System

#### As bicarbonate in plasma

- Most carbon dioxide molecules entering the plasma quickly enter the RBCs, where most of the reactions that prepare carbon dioxide for transport as bicarbonate ions in plasma occurs.

Carbon dioxide + water  $\rightleftharpoons$  Carbonic Acid  $\rightleftharpoons$  Hydrogen ion + Bicarbonate ion

- Although this reaction also occurs in the plasma, much faster in the RBCs because they contain an enzyme called carbonic anhydrase.
- Once generated, bicarbonate ions return to plasma.
- To counterbalance the rapid outrush of these anions from the RBCs, chloride ions move from the plasma into the RBCs. This ion exchange, called the chloride shift, occurs via facilitated diffusion through an RBC membrane protein.

### Respiratory System

#### Carbon dioxide and pH

- The bicarbonate ion that is generated by the RBC and diffuses into the plasma, acts as the alkaline reserve part of the blood's carbonic acid-bicarbonate buffer system, which is very important in resisting shifts in blood pH.
- If the hydrogen ion concentration in the blood begins to rise, excess hydrogen ions are removed by combining with bicarbonate to form carbonic acid (a weak acid)
- If hydrogen ion concentration drops below desirable levels in blood, carbonic acid dissociates, releasing hydrogen ions and lowering pH again.
- Changes in respiratory rate or depth can produce dramatic changes in blood pH by altering the amount of carbonic acid in the blood.
  - slow, shallow breathing allows carbon dioxide to accumulate in the blood. Carbonic acid levels increase and pH drops.
  - Rapid, deep breathing quickly removes carbon dioxide, reducing carbonic acid levels and increasing blood pH.

### Respiratory System

#### Neural Mechanisms and Generation of Breathing Rhythm

Involves:

- medulla
- pons



## Respiratory System

### Medullary Respiratory Centers

1. Ventral respiratory group (VRG)
  - Network of neurons that extends in the ventral brain stem from the spinal cord to the pons-medulla junction
  - Appears to be rhythm-generating and integrative center.
  - Contains groups of neurons that fire during inspiration and others that fire during expiration in a dance of mutual inhibition.
  - When its inspiratory neurons fire, a burst of impulses travels along the phrenic and intercostal nerves to excite the diaphragm and external intercostal muscles.
  - When VRG's expiratory neurons fire, the output stops, and expiration occurs passively as the inspiratory muscles relax and the lungs recoil
  - Eupnea= 12-15 breaths/min (2 sec in/3 sec out)
2. Dorsal respiratory group (DRG)



## Respiratory System

### Medullary Respiratory Centers

2. Dorsal respiratory group (DRG)
  - Located dorsally near the root of cranial nerve IX
  - Integrates input from peripheral stretch and chemoreceptors and communicates this information to the VRG.

### Pontine Respiratory Centers

- influence and modify the activity of the medullary neurons.
- Smooth out transition from inspiration to expiration.
- Pontine centers transmit impulses to the VRG of the medulla that modifies and fine tunes activities such as vocalization, sleep, and exercise.
- Receive input from higher brain center and from various sensory receptors in the periphery.



## Respiratory System

### Hypothalamic Controls

- Involuntary
- Strong emotions and pain send signals to the respiratory system, modifying respiratory rate and depth

### Cortical Controls

- We can exert conscious control over the rate and depth of our breathing (think yoga)
- During voluntary control, the cerebral motor cortex sends signals to the motor neurons that stimulate the respiratory muscles, bypassing the medullary centers.
- Our ability to voluntarily hold our breath is limited because the brainstem respiratory centers automatically reinitiate breathing when the blood concentration of carbon dioxide reaches critical levels.



## Respiratory System

### Hering Breuer Reflex

- Stretch receptors in visceral pleurae & conducting passages stimulated when lungs inflate strongly
- Send inhibitory impulses to medullary respiratory centres to terminate inspiration and allow expiration
- Lungs recoil, stretch receptors become quiet, inspiration initiated again
- Reflex thought to be protective because threshold high.



## Respiratory System

### Chemical factors influencing respiration

- Chemical fluctuations are sensed by **chemoreceptors** in the **ventrolateral medulla** (central chemoreceptors) and in the **aortic arch** and **carotid arteries** (peripheral chemoreceptors).
- Rising carbon dioxide levels are the most powerful respiratory stimulant



## Respiratory System

| PCO <sub>2</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | PO <sub>2</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Arterial pH                                                                                                                                                                                                                                                                                               |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>•Most potent</li> <li>•Most controlled</li> <li>•CO<sub>2</sub> diffuses easily from the blood to the CSF, where it forms carbonic acid.</li> <li>•When the acid dissociates, H<sup>+</sup> is liberated, leading to a reduction in pH, exciting chemoreceptors= Increases rate and depth of breathing</li> <li>•Increased ventilation self-limiting</li> <li>•When PCO<sub>2</sub> low, respiration is inhibited and becomes slow and shallow</li> </ul> | <ul style="list-style-type: none"> <li>•Chemoreceptors in carotid bodies are main oxygen sensors</li> <li>•Under normal conditions, the effect on ventilation on declining PO<sub>2</sub> is slight.</li> <li>•Makes chemoreceptors more sensitive to changes in PCO<sub>2</sub></li> <li>•Needs to decrease to at least 60 mm Hg for effect.</li> <li>•This is because of large oxygen reservoir in hemoglobin</li> <li>•Peripheral chemoreceptors stimulate respiratory centers even though central chemoreceptors are depressed</li> </ul> | <ul style="list-style-type: none"> <li>•Changes in arterial pH can change respiratory rate and rhythm even when CO<sub>2</sub> and O<sub>2</sub> levels are normal</li> <li>•The increase ventilation that occurs in response to falling pH is mediated through the peripheral chemoreceptors.</li> </ul> |



## Respiratory System

### Adjustments During Exercise

- Adjustments geared to both intensity and duration of exercise
- Working muscles consume large amounts of oxygen and produce large amounts of carbon dioxide, so ventilation can increase 10-20 fold during vigorous exercise.
- Hyperpnea (No change in  $O_2$  or  $CO_2$  levels) vs Hyperventilation (low  $P_{CO_2}$ )
- Exercise-enhanced ventilation NOT prompted by chemical factors previously described.
  - Ventilation increases abruptly as exercise begins, then gradual rise to steady state; post-exercise, decreases abruptly then gradual decline to pre-exercise levels.
  - Venous levels change but  $P_{O_2}$  &  $P_{CO_2}$  remain constant.



## Respiratory System

### Adjustments During Exercise

The abrupt increase in ventilation that occurs as exercise begins reflects interaction of three neural factors:

1. Psychological stimuli (our conscious anticipation of exercise)
2. Simultaneous cortical motor activation of skeletal muscles and respiratory centers
3. Excitatory impulses reaching respiratory centers from proprioceptors in moving muscles, tendons, and joints.



Let's talk about the exam...



Questions?



**Thank you for your support in raising roofs!**



**Good luck on your exam!**