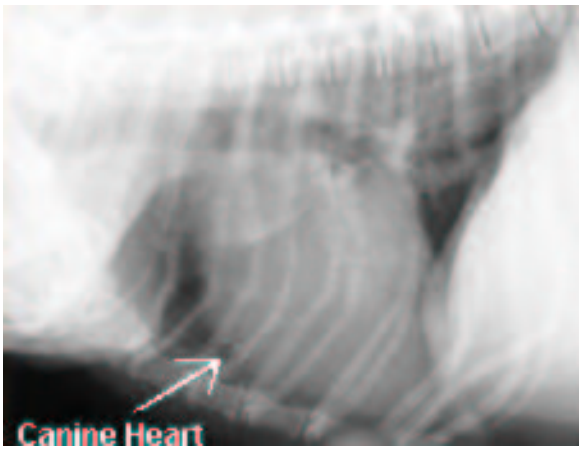
Cardiovascular System
ANS 215
Physiology and Anatomy of Domesticated Animals

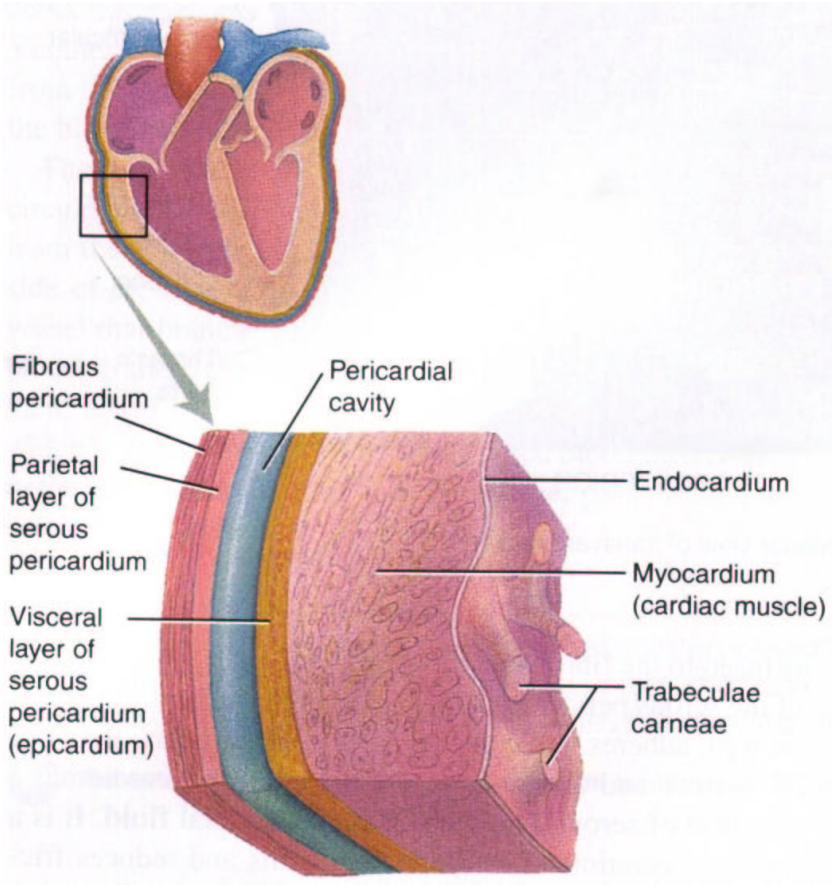
I. Structure and Function

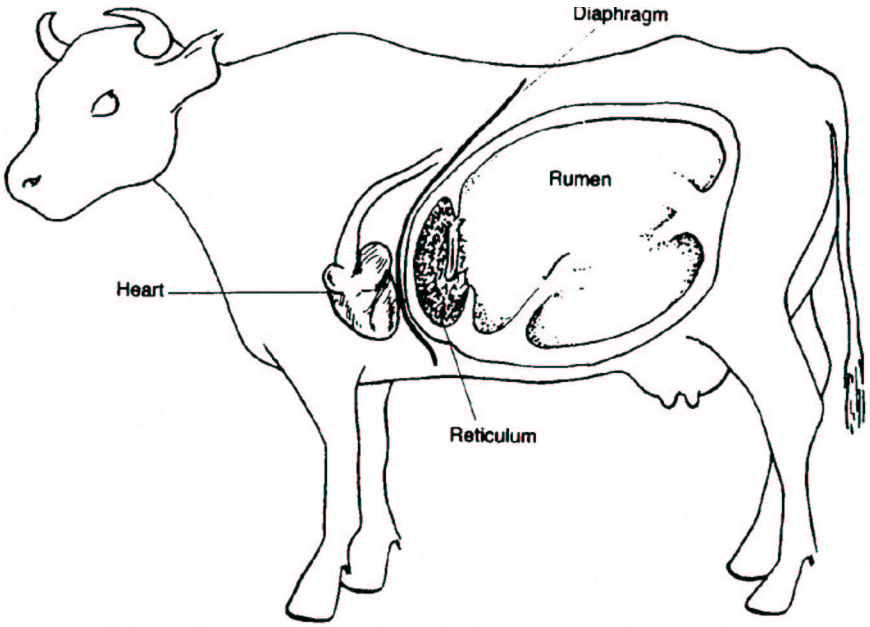
A. Heart is a cone-shaped, hollow, muscular structure located in the thorax.



B. Larger arteries and veins are continuous with the heart as its base.
   1. Base is directed upward (dorsal) and forward (cranial).
   2. Opposite end of the cone is known as the apex

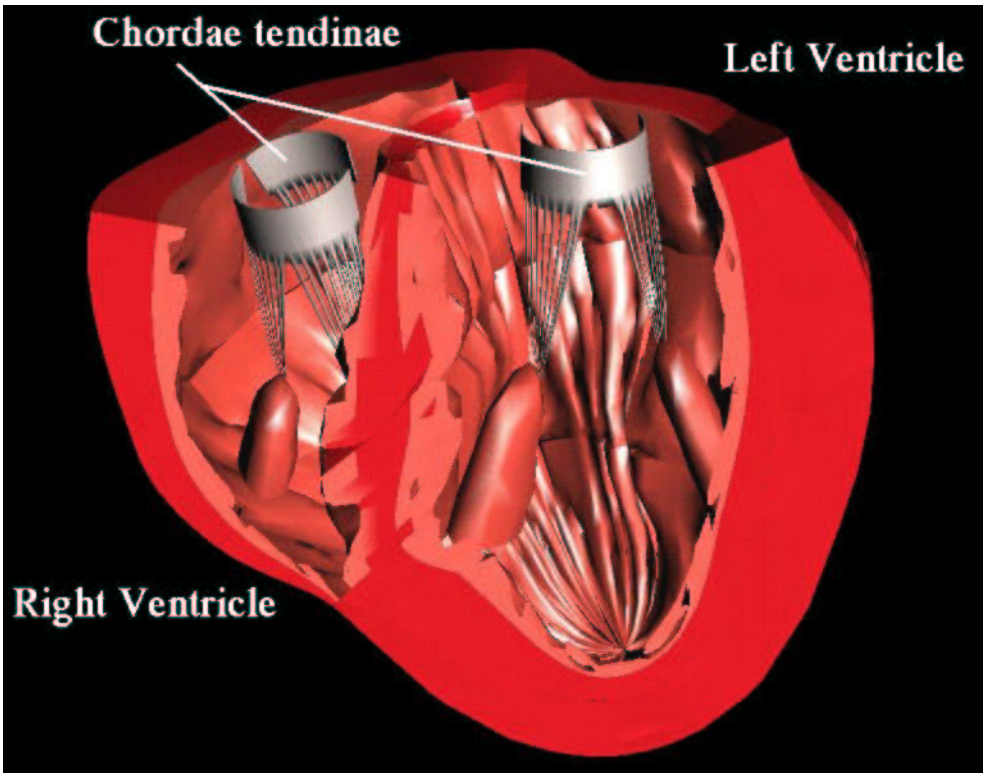
C. Membrane around the heart is known as the pericardium
   1. Membrane next to hear fuses with the heart muscle and is called the visceral pericardium or epicardium
   2. outer membrane is parietal pericardium
   3. apex is free
   4. Inflammation of the pericardium is called pericarditis.
      a. increase in fluid in pericardium
      b. traumatic pericarditis (hardware) disease in cattle



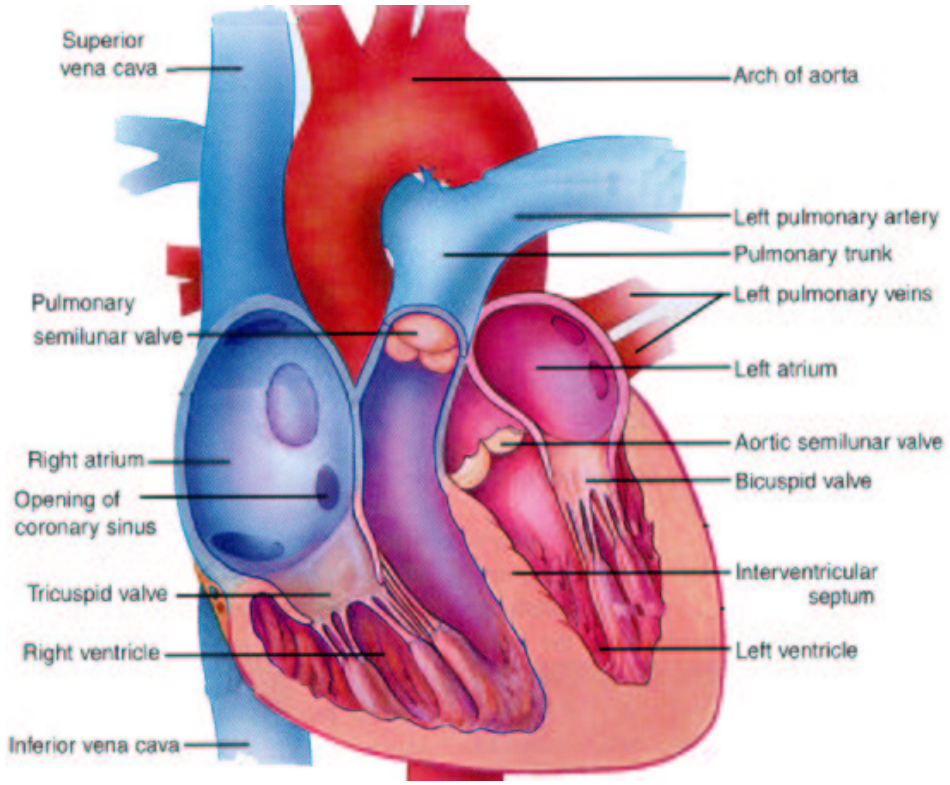


Left view of bovine thorax and abdomen showing location of the heart relative to the stomach. Foreign objects (nails, wire), sometimes ingested by cattle, accumulate in the reticulum (one of the bovine forestomachs). Contraction of the reticulum can force pointed objects through the reticulum wall and the diaphragm, causing final penetration of the pericardium and subsequent inflammation (pericarditis).

D. Myocardium
    1. Muscular part of the heart which forms the walls for the chambers
    2. Heart chambers (4) divided into left and right side of the heart
        a. Each side has an atrium and ventricle.
        b. Each atrium has an extension known as the auricle.
        c. Atria receive blood from veins and ventricles receive blood from atria.

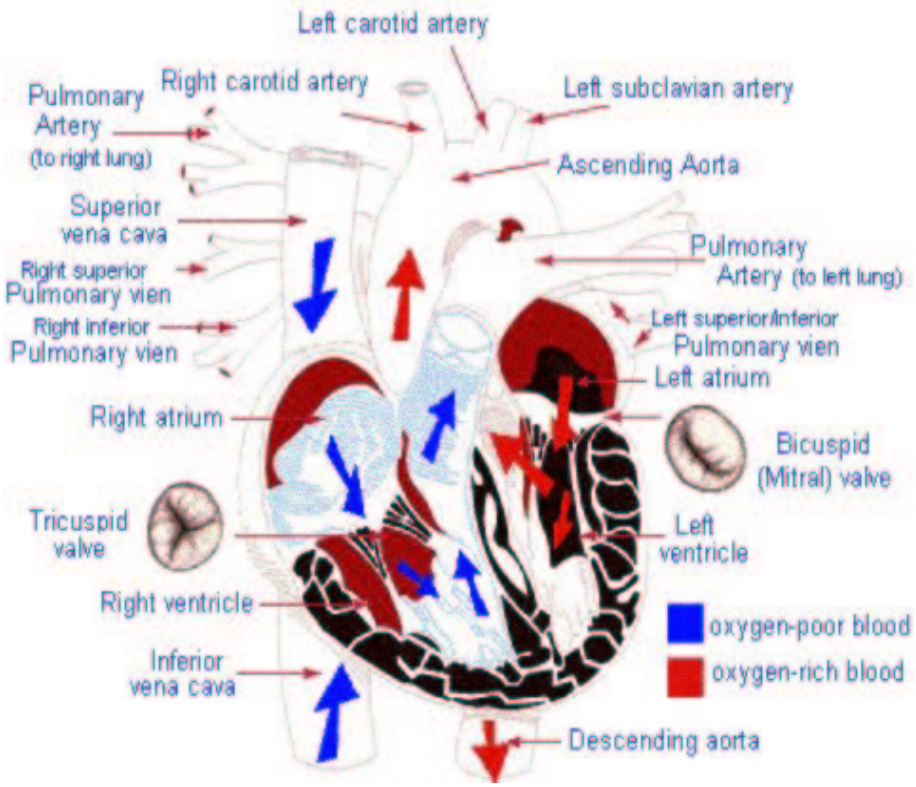


Computer image of a cross sectional view of the heart at the ventricular level showing the chordae tendinae and the relative thickness of the myocardium.



A sagittal section of the heart. The right and left chambers are shown with separation of the atria and ventricles by atrioventricular valves. The auricles (not pictured here) are extensions of the atria. The aorta is seen to be arising from the left ventricle. The pulmonary trunk arises from the right ventricle and divides into right and left pulmonary arteries just beyond the pulmonary semilunar valve. The cranial/superior vena cava and caudal/inferior vena cava deliver venous (unoxygenated) blood into the right atrium. (Note: recall that super/inferior would be used in reference to bipeds while cranial/caudal would be used for quadrupeds)

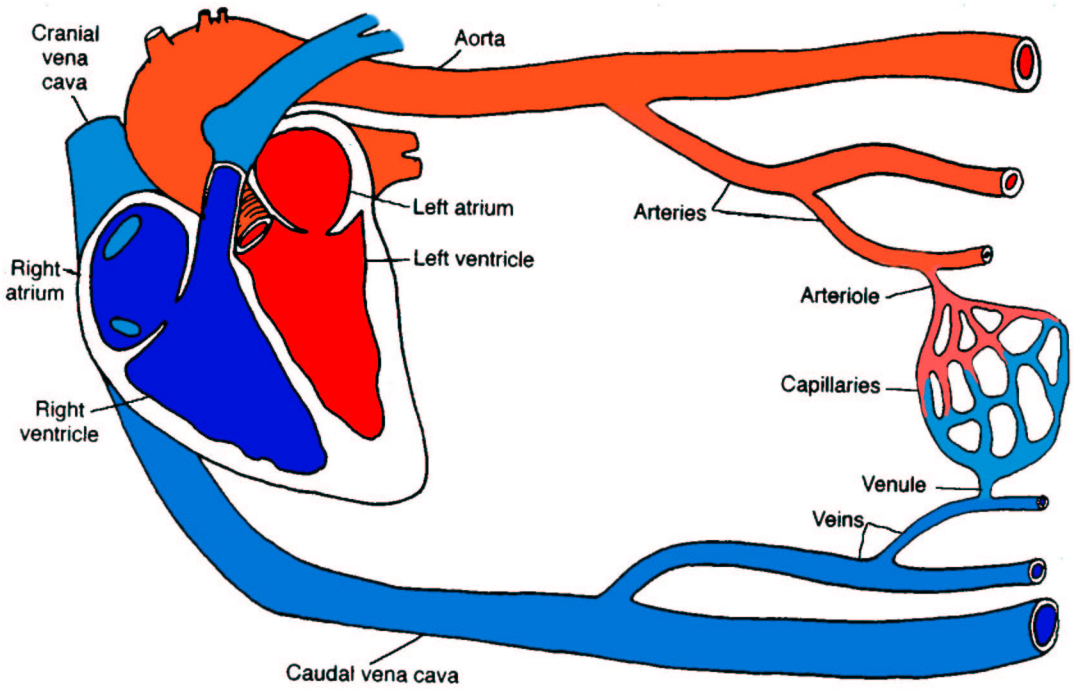
E. Heart valves
   1. Valves located between the atria and ventricles are known as the atrioventricular (AV) valves.
      a. valve on right side has 3 cusps (tricuspid)
      b. valve on left side has 2 cusps (bicuspid)
   2. AV valves prevent backflow of blood into atria when ventricle contracts
      a. eversion of valves into atrium is prevented by chords (chordae tendinea) attached to free margin of cusps and to small muscles (papillary muscles) at heart wall
   3. Semilunar valves prevent backflow of blood into ventricles flowing contraction.
      a. each have 3 cusps
      b. valve on right side is pulmonary semilunar
      c. valve on left side is aortic semilunar



F. Blood flow through the heart

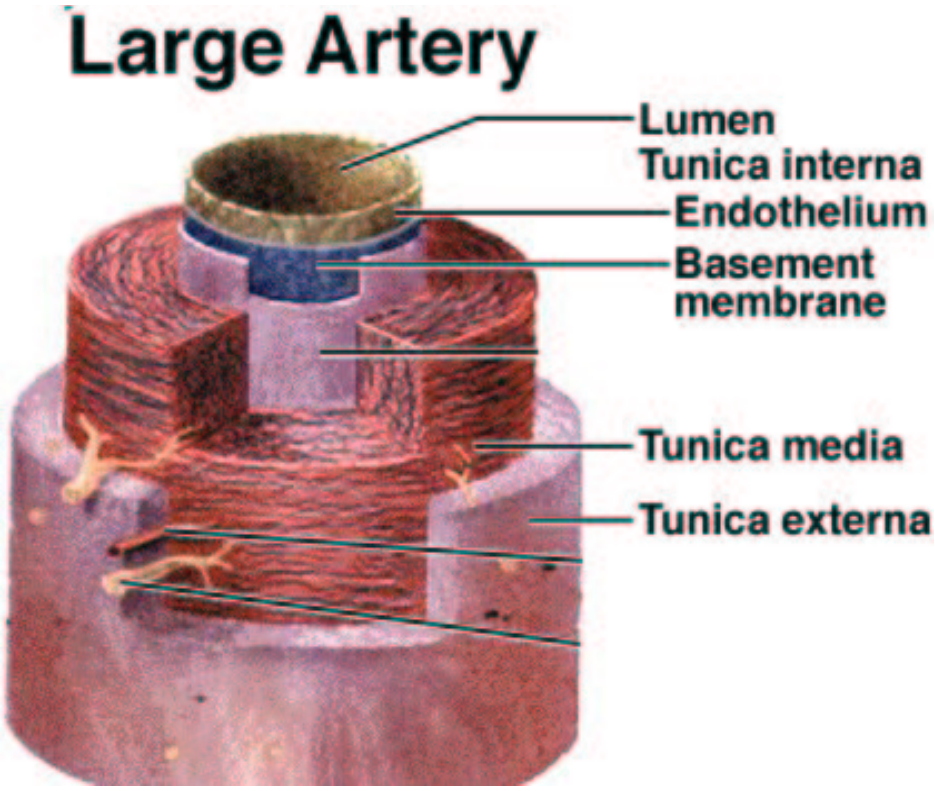
1. Blood that circulates to the tissues returns to the heart by the cranial vena cava (forward parts of body) and caudal vena cava (blood from rear parts of body).
2. Venous blood enters the right atrium during the atrial relaxation phase of the cardiac cycle and is then directed through the tricuspid valve to the right ventricle.
3. Ventricles then contract and the blood is pumped through the pulmonary semilunar valves to pulmonary arteries and the lungs.
4. After circulation through the lungs, the blood enters the left atrium via the pulmonary veins.
5. Blood (now oxygenated) is directed to the left ventricle where it is pumped throughout the body through the aorta.

G. Blood vessels

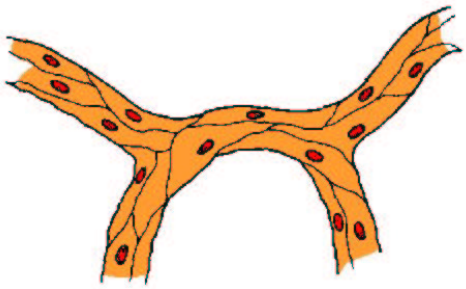


Schematic representation of the functional circulatory system. A network of arteries, arterioles, capillaries, venules, and veins exist between the aorta and cranial and caudal vena cava.

1. The inner aspect of the pericardium is described as the outer cell layer of the heart and is known as epicardium.
2. The middle layer of the heart is cardiac muscle.
3. The inner layer of the heart is endocardium, which is continuous with the endothelium of all blood vessels.
    a. inflammation of endocardium is endocarditis
    b. inflammation of heart valve is valvular endocarditis
4. Blood vessels provide for a continuous route for blood leaving the heart to return to the heart.
5. arteries, arterioles, capillaries, venules, and veins
    a. arteries more elastic
    b. small arteries have some portion of elastic tissue replaced by smooth muscle – helps to regulate blood flow to capillary beds

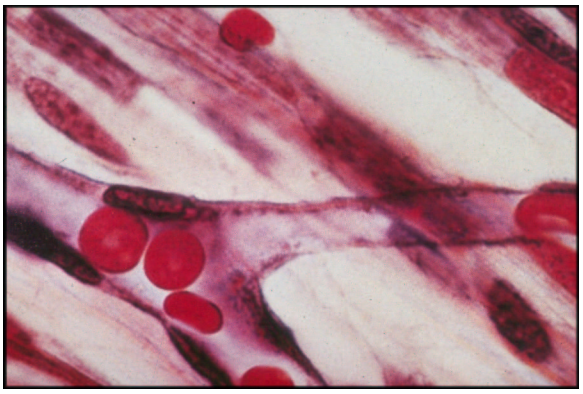


c. capillaries are merely endothelial tubes

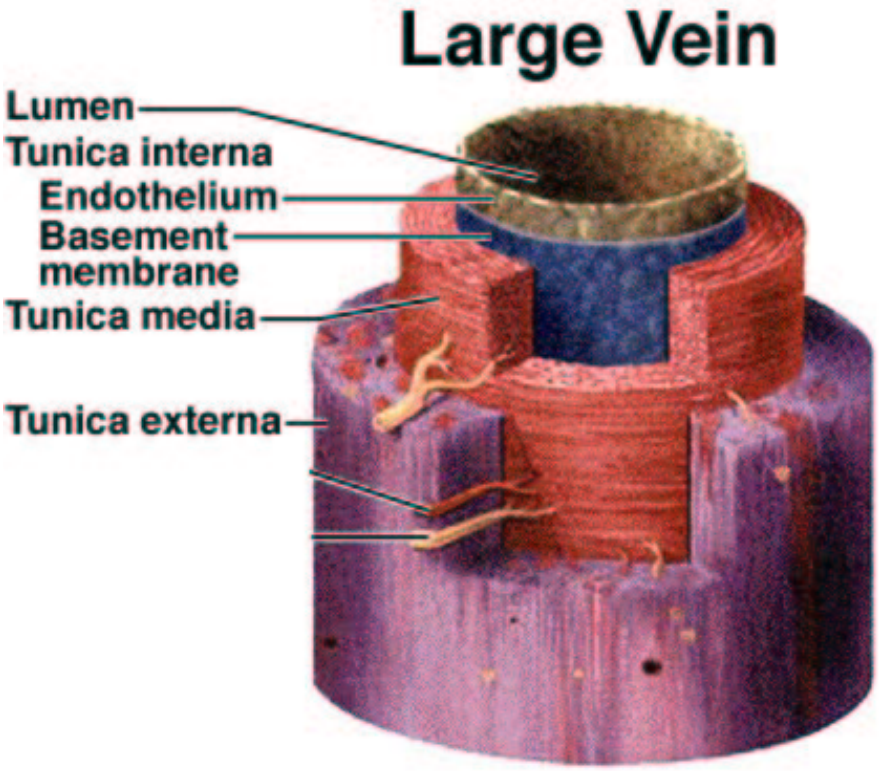


d. Where endothelial cells border each other, a thin slit (slit pore) or intracellular cleft is provided for diffusion of dissolved substances from plasma.

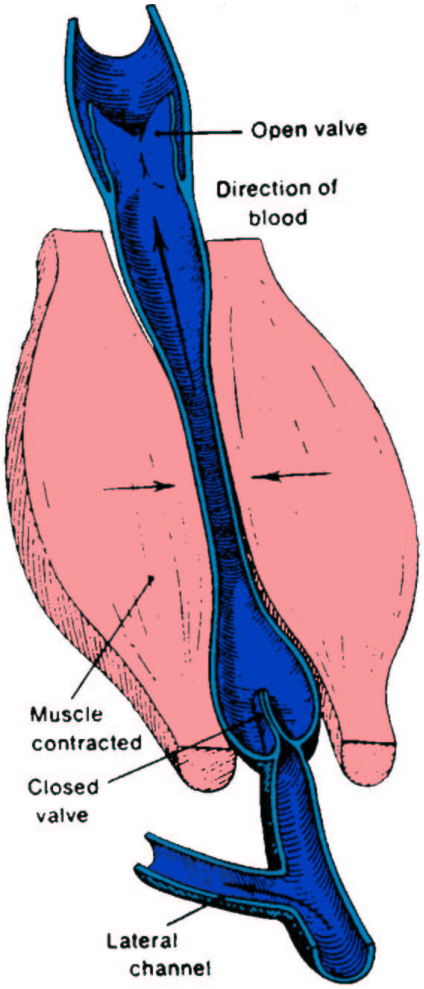
e. Pinocytotic vesicles are also present in the endothelial cells for nutrient transfer.



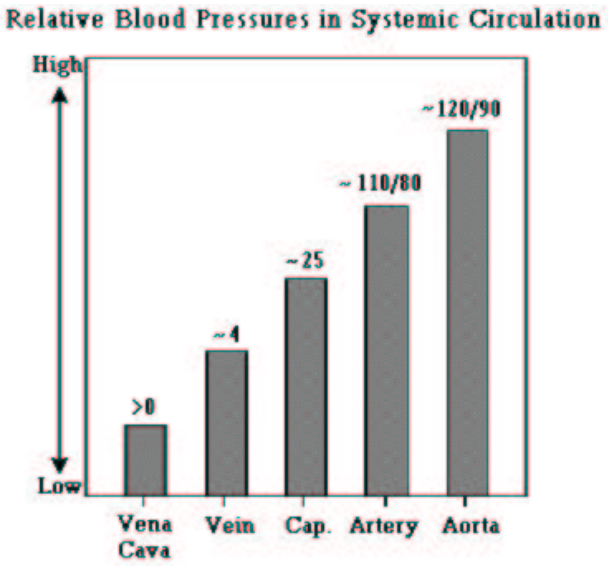
f. Veins are thin-walled tubes reinforced by connective tissue. They also contain some smooth muscle fibers.

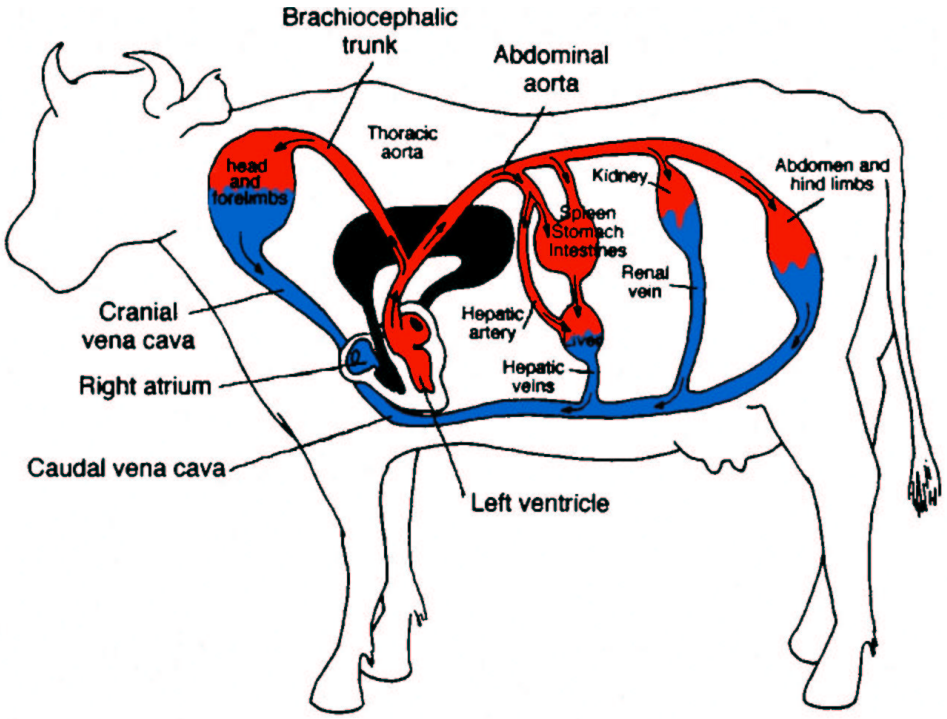


g. Valves are present in the veins at irregular intervals that are directed towards the heart – prevents backflow



Valves of a vein showing the pumping action of adjacent muscles.



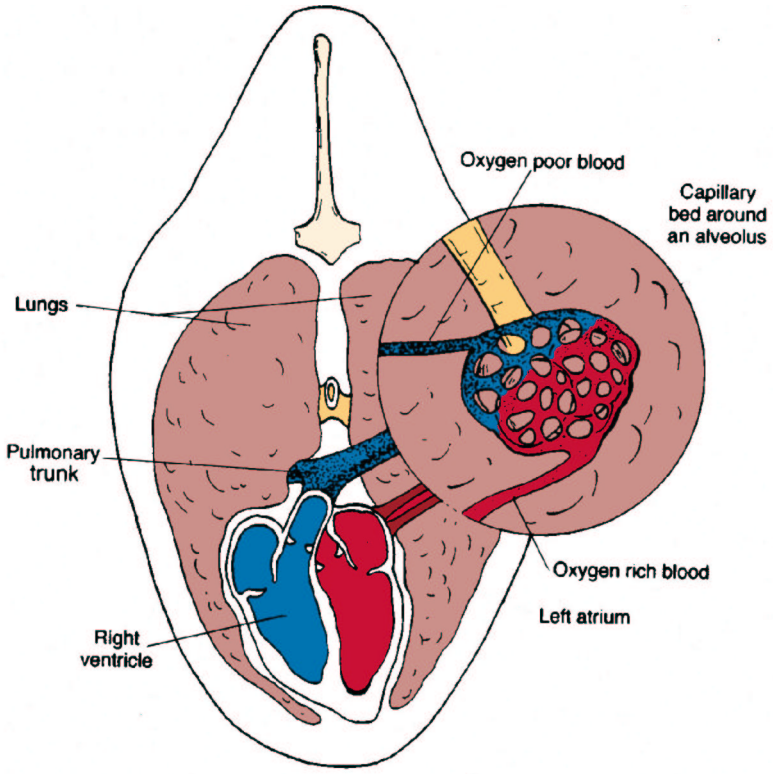


General scheme of mammalian circulation showing the pulmonary system, which serves the lungs, and the systemic system which serves the remainder of the body. The pulmonary circulation is shown in black.

II. Blood Circulatory Systems

A. Pulmonary

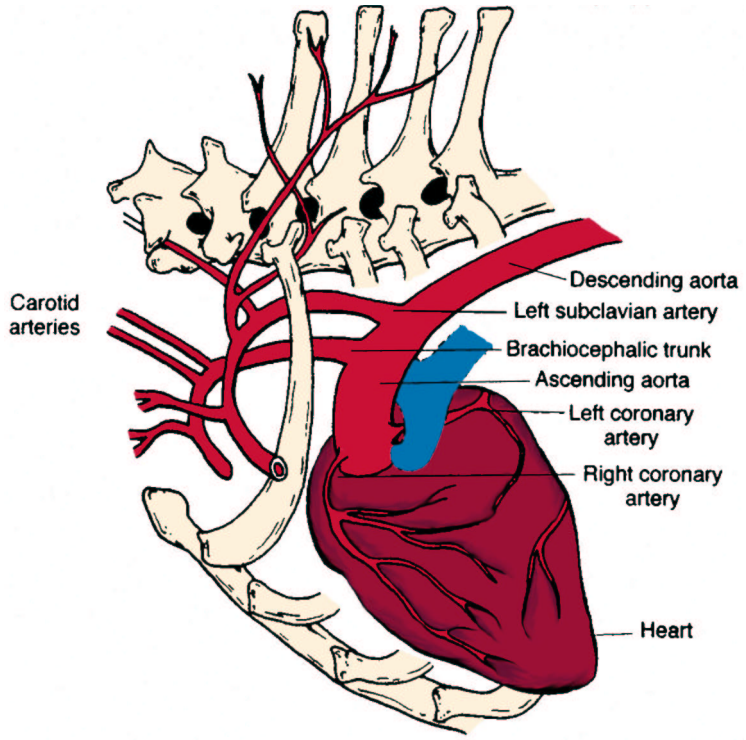
1. circulates blood through the lungs
2. Pressure for this system originates in the right ventricle.
3. Capillaries for this system lien in pulmonary alveoli



Schematic representation of the lungs and the pulmonary circulation. The circled inset represents a functional unit of the lung, the alveolus. Mixed venous blood leaves the right ventricle through the pulmonary trunk and is oxygenated at the level of the alveoli. Oxygenated blood returns to the left atrium through the pulmonary veins.

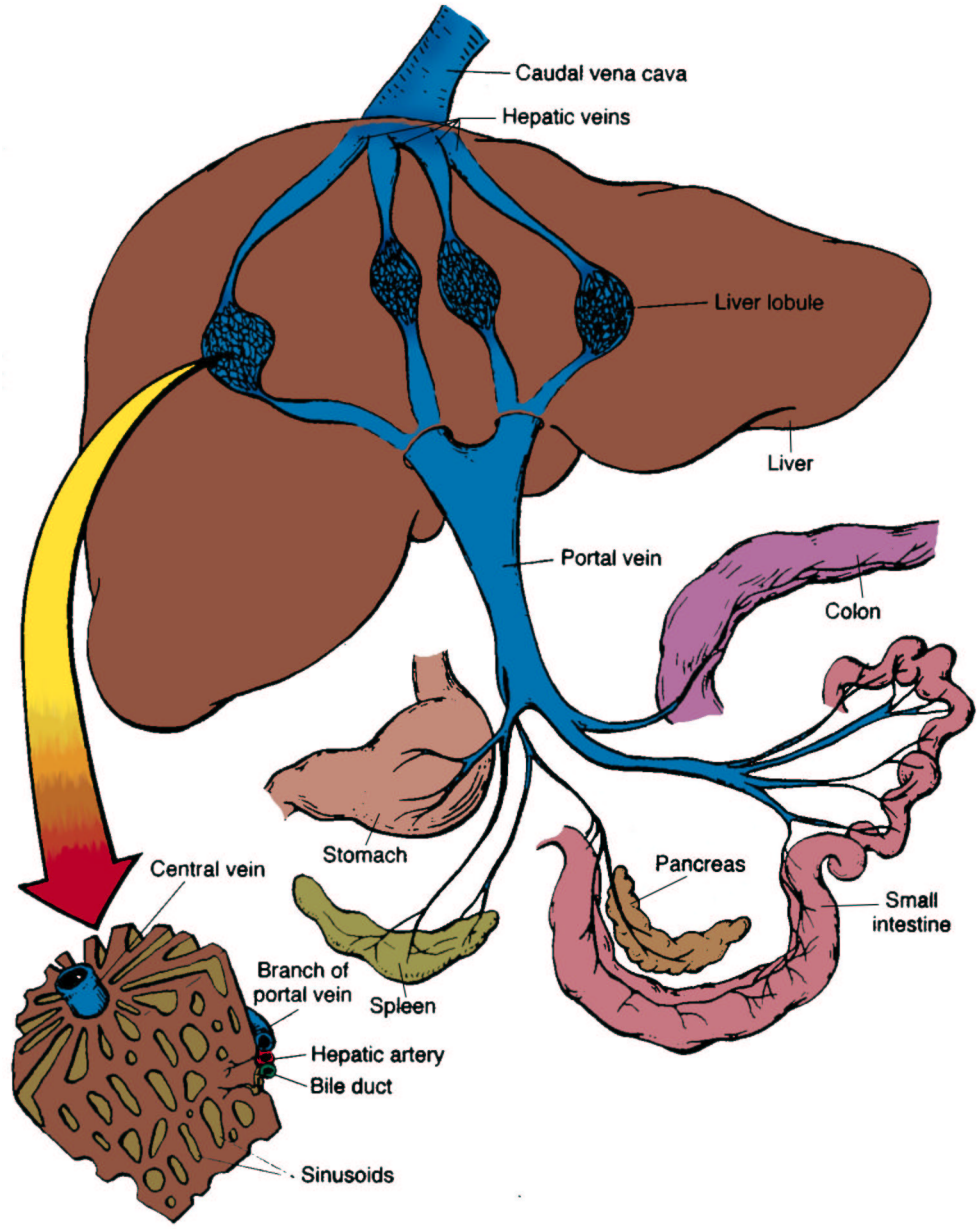
B. Systemic circulation

1. carries blood that has returned from the lungs
2. Pressure for this system originates in the left ventricle.
3. Blood traversing this system leaves the left ventricle through the aorta and is returned to the right atrium via the vena cava.
    a. first branches of the aorta supply the heart through coronary arteries



Cranial aspects of the systemic circulation. The first branches of the aorta supply the heart muscles through the coronary arteries. The descending aorta is comprised of the thoracic and abdominal aorta. The main arteries to the forelimbs arise from the left subclavian artery on the left side and from the brachiocephalic trunk on the right side. The carotid arteries ascend to the head.

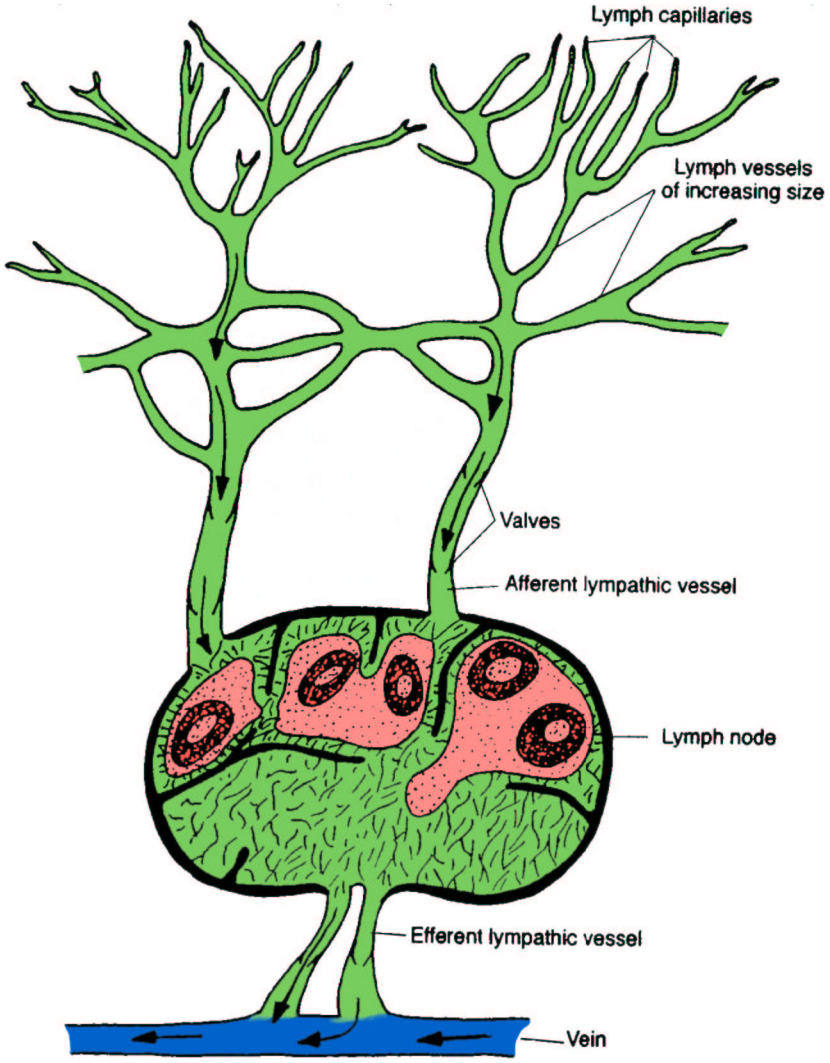
4. Within the systemic circulation, there are a few portal systems
    a. veins heading to the heart rebranch to form capillary beds which reunite to form veins
    b. Primary example is the hepatic portal system
        i. veins draining viscera all empty into the liver which reforms a capillary bed (liver sinusoids)
        ii. This portal system permits the uptake of nutrients from the digestive tract at the liver for metabolism and transport to other tissues.
        iii. also permits cleansing of blood or the removal of harmful substances (detoxification)



The mammalian hepatic portal system. Blood in the portal vein from the stomach, spleen, pancrease, and intestines goes to the liver, where it flows through the sinusoids and is reformed by the central vein of each lobule. It finally enters the caudal vena cava through the hepatic veins.

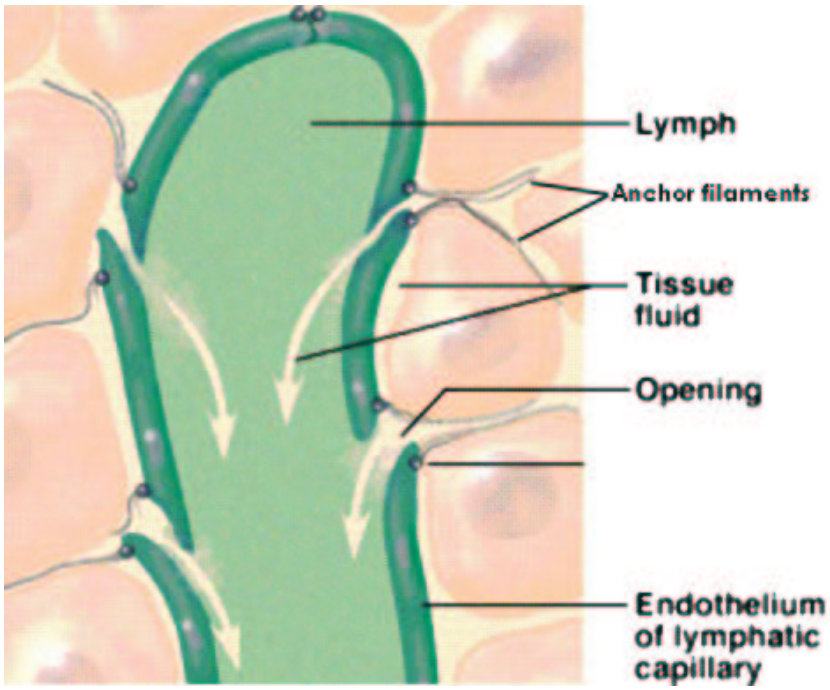
III. Lymphatic System

A. Important adjunct to the circulatory system
B. Lymphatic vessels have blind beginnings in the interstitial spaces.
C. Continuation vessels of the lymphatic system tend to parallel veins.
D. Lymph vessels join with each other and eventually form a few large lymph vessels that empty directly into large veins.



Schematic representation of lymph drainage. Interstitial fluid gains access to the blind beginnings of lymph capillaries and proceeds centrally through lymph vessels of increasing size. Lymph nodes are located along the course of lymph vessels. Lymph is returned to blood by drainage into veins.

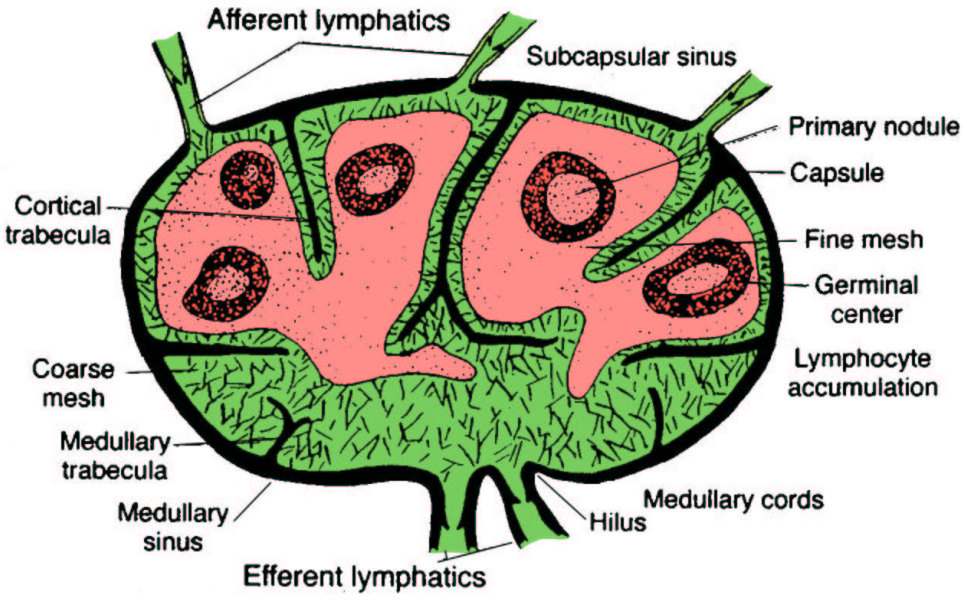
E. Fluid of lymph vessels is called lymph
    1. very close composition to interstitial fluid
    2. protein in interstitial space can only return to plasma via lymph
        a. 100% of plasma protein is turned over every 24 hours



Special structures of the lymphatic capillaries permit passage of high-molecular weight substances into the lymph. Anchoring filaments give support to portions of the endothelial cells where the capillaries begin. The unsupported portion of the endothelium allows fluid to flow into the capillary (arrows).

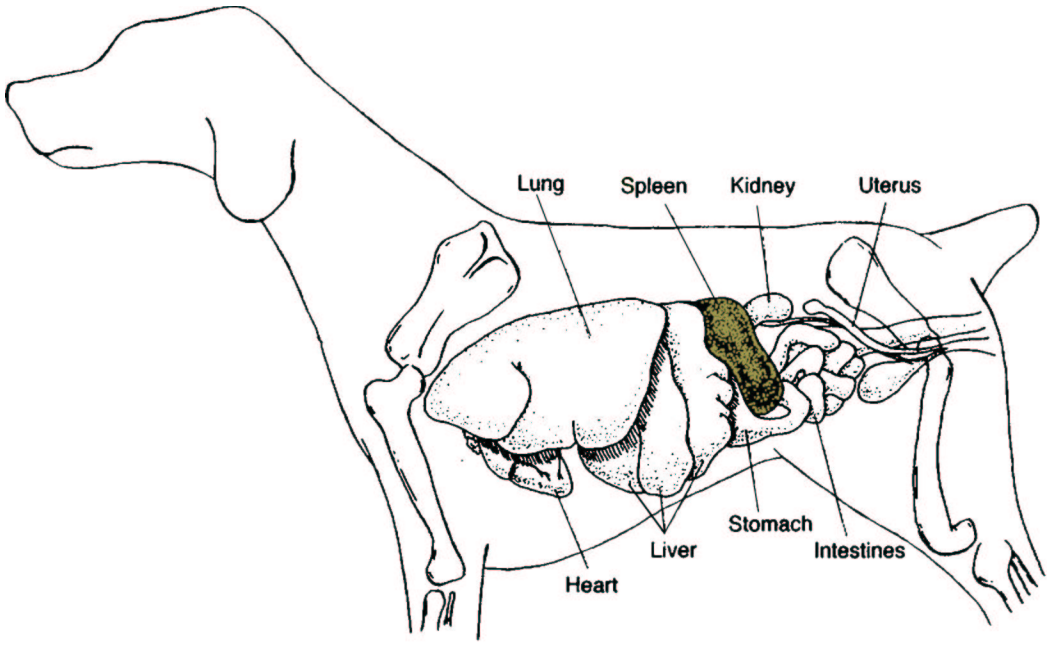
F. Blind beginnings of lymph vessels are adapted for the intake of large molecules (see above).

G. Lymph nodes are nodular structures of varying size located along the course of lymph vessels.
   1. contain clusters of germ cells that divide to form lymphocytes
   2. also contain fixed populations of macrophages
      a. attach and digest foreign substances



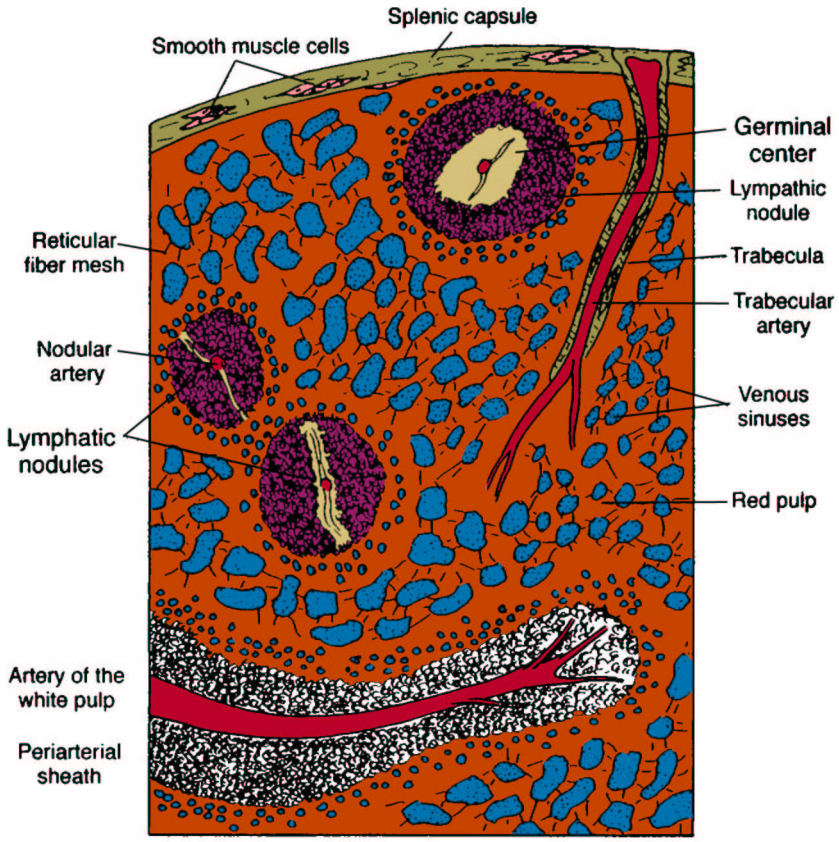
H. Spleen

1. largest lymphoid organ of the body
2. circulating fluid is blood instead of lymph
3. only organ specialized to filter blood



Projection of viscera on the left body of the female dog showing the location of the spleen relative to other body organs. Except for the dorsal tip, the dog spleen is somewhat variable in position, and its long axis can be almost longitudinal.

4. The spleen's outer covering is called the capsule.
    a. contains connective tissue and smooth muscle
    b. smooth muscle is pronounced in carnivores
5. trabeculae extend from the capsule
    a. composed of elastic fibers, collagen, and smooth muscle
    b. arteries, veins, lymph vessels, and nerves all contained within the trabeculae
6. The parenchyma of the spleen is comprised of red and white pulp and is supported by the trabeculae and blood vessels.



Schematic representation of the pig spleen. Multiple branches of the splenic artery enter the capsule and extend into the trabeculae. The lymphatic nodules and periarterial sheaths comprise the white pulp that produces lymphocytes . The red pulp is the reticular fiber mesh that acts as a filter because of its fixed macrophages. Smooth muscle cells are present in the capsule and in the trabeculae. The venous sinuses collect filtered blood and drain into venules and finally trabecular veins (not shown).

7. Most of the pulp is red because of the blood that is being filtered and contains fixed macrophages.
8. The white pulp is lymphoid tissue that is distributed throughout the spleen and which produces lymphocytes.
9. The spleen is the site of red blood cell removal, reservoir of red cells lymphocytes.

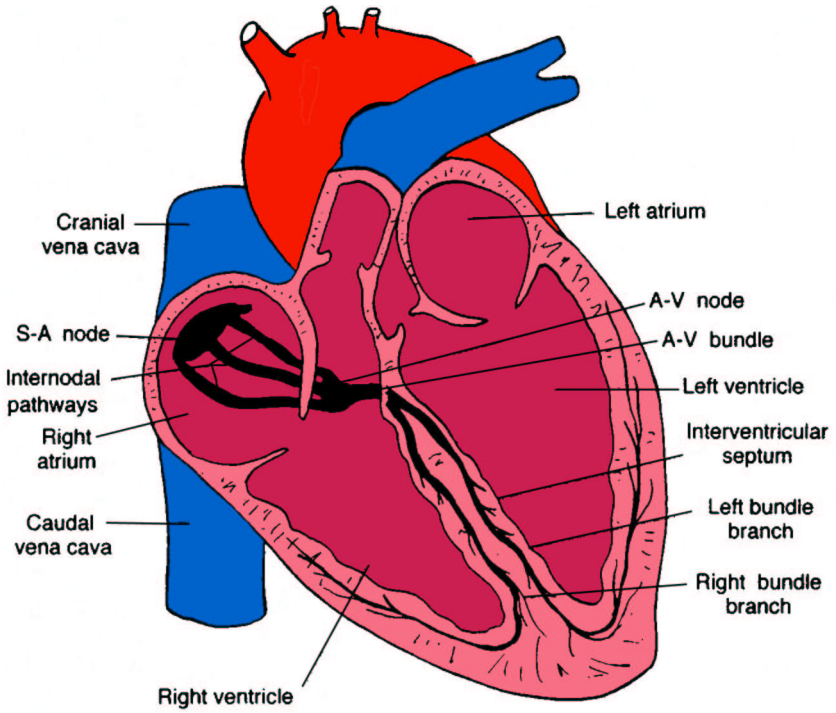
IV. Cardiac Contractility

A. Origin of the heartbeat

1. All muscles have an inherent rhythmicity of contraction.
    a. frequency of contraction is greatest in cardiac muscle
    b. Atria muscle cells have higher frequency of contraction than ventricular cells.
    c. Small area (SA node) near junction of cranial vena cava and right atrium has higher frequency of contraction than atria.
        i. This is the location of origination of cardiac contraction.
        ii. Specialized muscle fibers send out impulses, which spread throughout the musculature of the atria.

iii. serves a pacemaker function

B. Conduction of the Impulse
   1. Muscles of the atria and those of the ventricles are arranged to form an atrial and ventricular syncytium.
      a. syncytium is an arrangement of muscle fibers in which the fibers fuse to form an interconnected mass of fibers



Conduction system of the mammalian heart. Impulse originates in the SA node located near the junction of the vena cava with the right atrium. The internodal pathways conduct the impulse throughout the atria, and the left and right bundle branches of Purkinje fibers conduct the impulse throughout the ventricles. The AV node and bundle conduct the impulse from the atria to the ventricles.

B. The atrial syncytium is separated from the ventricular syncytium by a fibrous ring that surrounds the AV valves.
   1. fibrous ring acts as an insulator between the two syncytia
   2. impulse that spreads throughout the atria does not spread to ventricles
   3. permits independent contraction

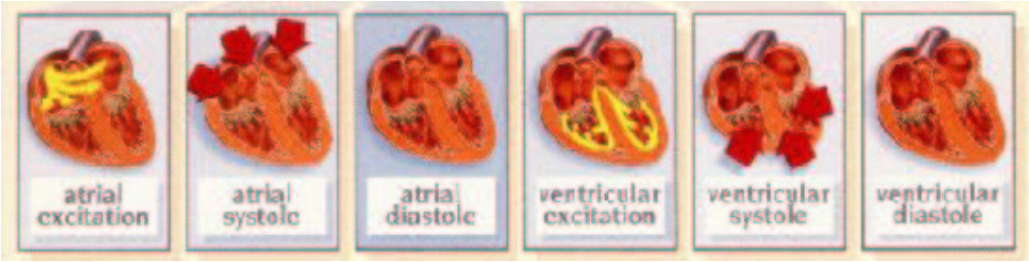
C. To facilitate conduction of the impulse from the SA node and coordinate contraction, the heart has a specialized conduction tract.
   1. Purkinje fibers join to form internodal pathways.
   2. Transmission of impulses and subsequent depolarization is facilitated by intercalated discs interposed between muscle fibers.
   3. Impulse conduction by internodal pathways is received by the AV node, which is located at a point between the atria and ventricles.
   4. The AV node is continued throughout the AV ring by the AV bundle.
   5. AV bundle fibers are smaller in diameter than other Purkinje fibers, which slows impulse down and allows emptying of atria before contraction of ventricles.
   6. conduction fibers are continued from the AV bundle in the wall dividing

it from the right and left bundle branches to supply the right and left ventricles

7. Cardiac muscle contracts more slowly than skeletal muscle and the refractory period is longer.
8. Both atria contract at the same time and both ventricles contract at the same time.
    a. contraction of muscle fibers within a syncytis is synchronized.
9. Defibrillation causes simultaneous depolarization of all cardiac muscle fibers. This permits initiation of a new cycle with impulses that begin at the SA node.

D. Cardiac Cycle

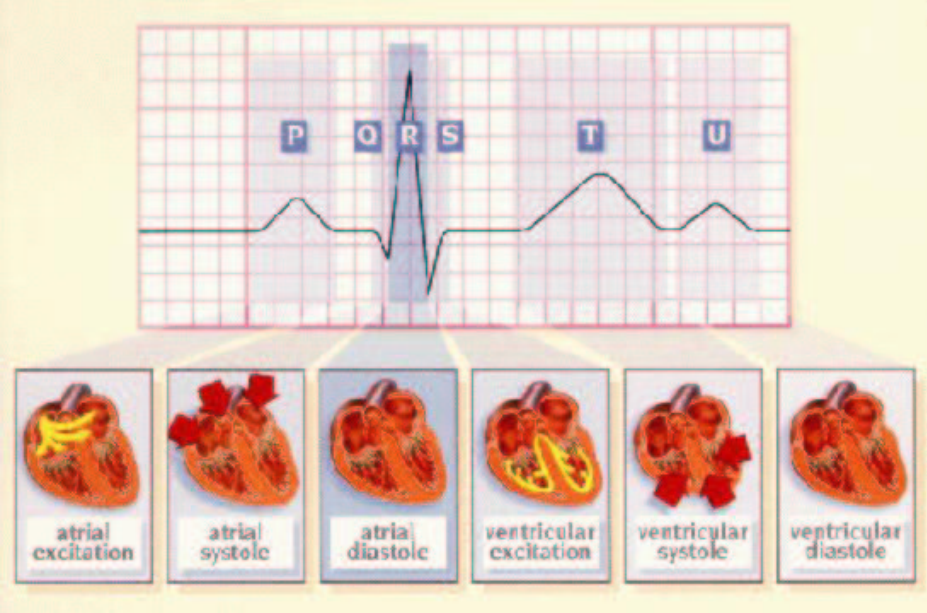
1. Refers to the sequence of events that occurs during one complete heartbeat.
2. Events are continuous and the assigned periods are arbitrary for descriptive purposes.
3. Diastole refers to relaxation of a heart chamber before and during filling of the chamber.
4. Systole refers to contraction of a heart chamber in the process of emptying.



The cardiac cycle of the mammalian heart. Which valves must be open and which ones must be closed for proper function during each stage of the cycle?

E. Electrocardiogram (ECG)

1. Record of voltage changes, which occurs across the nerve and muscle membranes during waves of depolarization and repolarization.
2. Connection of the amplifier with the wires (leads) to selected body parts (usually limbs) and to a recorder proves a characteristic wave form.
    a. recording of electrical activity of the heart
    b. ECG is altered when heart muscle is damaged or ventricle walls are thickened



c. P wave is associated with depolarization of atria, after depolarization, atrial contraction occurs
d. QRS complex represents both positive (upward) and negative (downward) deflections associated with ventricular depolarization; ventricular contraction begins after depolarization of fibers
e. T wave represents ventricular repolarization

3. When viewing an electrocardiogram, it can bee seen that deflections of the waves whether positive or negative, occur from a common line known as the isoelectric line.

F. Heart Sounds

1. Listening to the heart (cardiac auscultation) permits identification of sounds that accompany contraction of heart muscle and closure of the heart valves.
   a. sounds are repeated for each cardiac cycle
   b. first sound is ventricular contraction and AV valves
   c. second sound is ventricular relaxation and closure of semilunar valves
   d. abnormal heart sounds are called murmurs and are usually associated with valve disorders

V. Heart Rate and its Control

A. Heart rate refers to the frequency of cardiac cycles.
   1. usually measured in beats per minute (bpm)

B. Generally, smaller animals have higher heart rates
   1. consequence of metabolic rate and oxygen consumption
   2. larger surface area to body mass ratio in smaller animals

Heart Rates in Adult, Resting Animals

Animal	Heart Rate (beats/minute)
Horse	32 - 44
Horse (thuroughbred)	38 - 48
Dairy cow	60 - 70
Sheep & Goat	70 - 80
Pig	60 - 80
Dog	70 - 120
Cat	110 - 130
Chicken	200 - 400
Human	60 - 90

3. physical conditioning lowers heart rate as a result of cardiac hypertrophy
4. young animals have a higher heart rate than adult animals
    a. higher metabolic rate
    b. tonic vagal inhibition is less developed in young animals

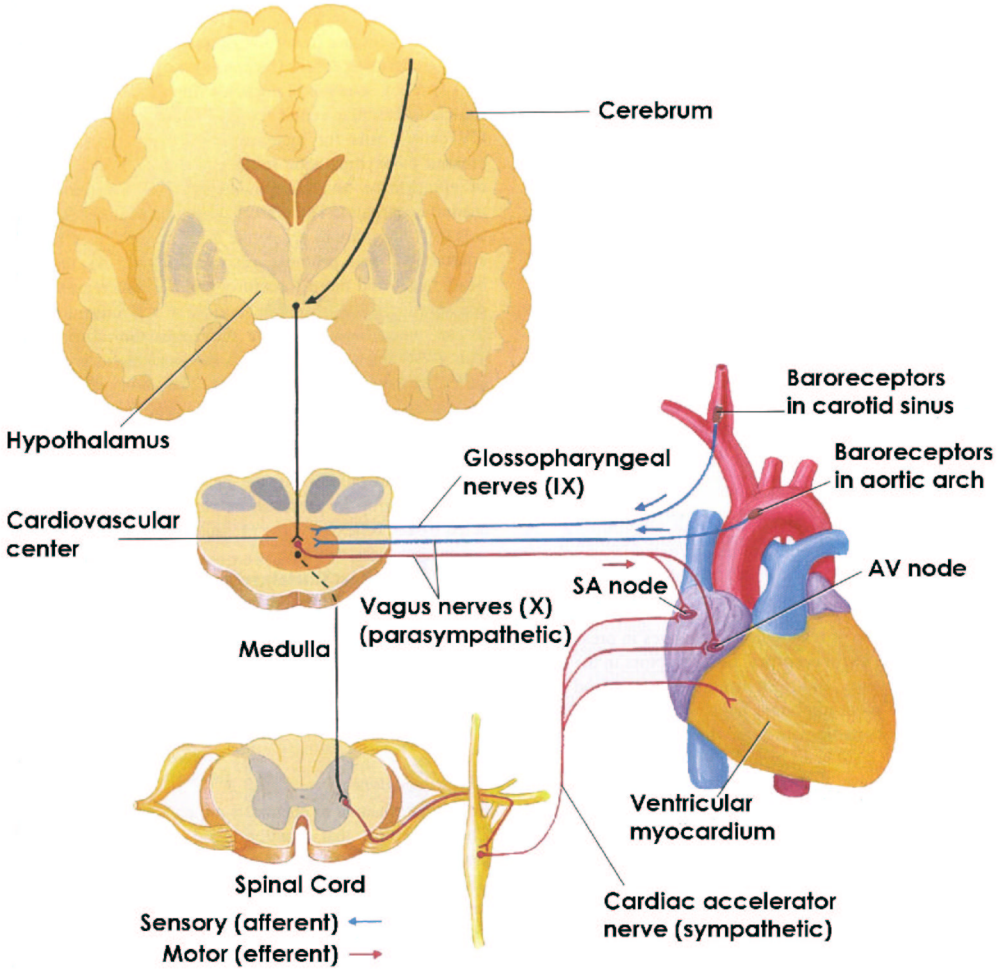
C. Autonomic nervous system regulates heart rate
1. Sympathetic innervation occurs via efferent fibers from the stellate ganglia of the sympathetic trunk.
    a. increases heart activities
2. Parasympathetic innervation is supplied by fibers from the vagus nerves.
    a. decreases heart activities
3. heart activities include rate of contraction, force of contraction, rate of impulse conduction, and amount of coronary blood flow

D. Autoregulation of the heart rate also occurs
1. Based on the volume of blood received in the atria.
2. Starling's Law of the heart
    a. The more the heart is filled during diastole, the greater the volume pumped out.

E. Reflexes
1. Several important reflexes within the cardiovascular system assist in its regulation
2. These are called baroreceptors, because they respond to blood pressure.
    a. When the artery is stretched, the receptors increase their firing rate.
    b. The impulses from the aorta are transmitted to the medulla by the vagus nerves.
    c. The impulses from the carotids are transmitted to the medulla by the glossopharyngeal nerves

d. Response to the medulla center is to decrease the blood pressure through parasympathetic stimulation of the heart and inhibition of the vasomotor center (dilating blood vessels).

3. Brainbridge Reflex
    a. receptors in right atrium stimulated by stretch to increase heart activities



VI. Blood Pressure

A. Greatest pressure develops within the aorta when the left ventricle contracts.
    1. high point of blood pressure is called systole
        a. at peak of left ventricular contraction
    2. the lowest point is called diastole
        a. occurs during left ventricular relaxation
    3. The term pulse pressure refers to the difference between the systolic and diastolic pressures.
    4. Mean pressure is the diastolic pressure and of systolic.

a. determines the average rate at which blood flows through the systemic circulation

Characteristic Blood Pressures in Adult, Resting Animals

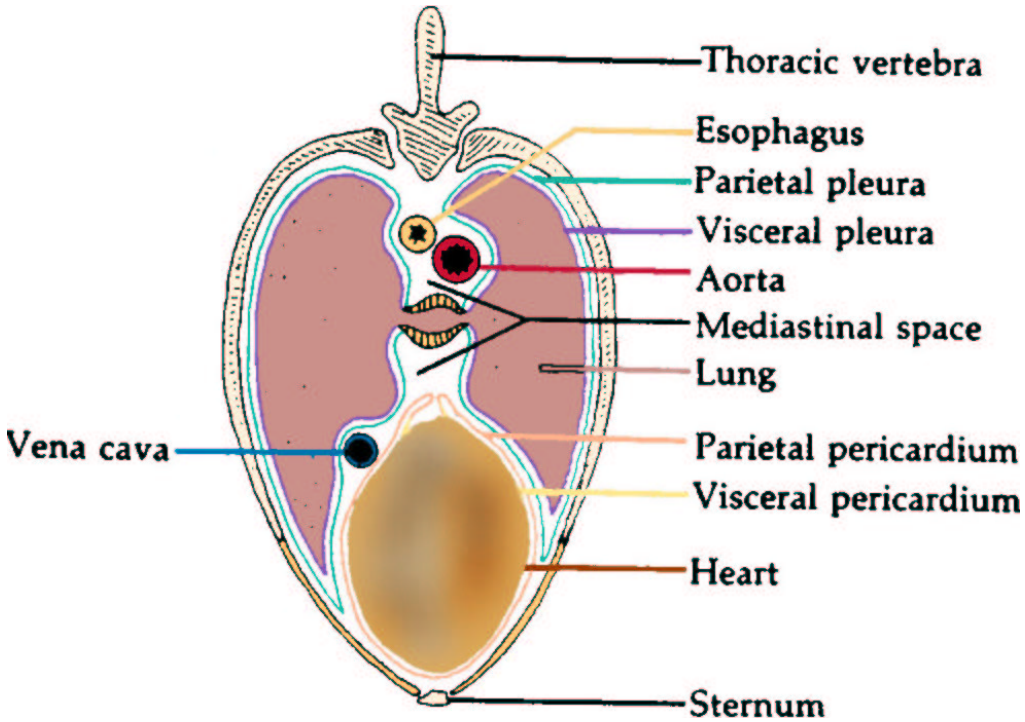
Species	Systolic/diastolic (mm Hg)	Mean (mm Hg)
Giraffe	260/160	219
Horse	130/95	115
Cow	140/95	120
Swine	140/80	110
Sheep	140/90	114
Human	120/70	100
Dog	120/70	100
Cat	140/90	110
Rabbit	120/80	100
Guinea pig	100/60	80
Rat	110/70	90
Mouse	111/80	100
Turkey	250/170	190
Chicken	175/145	160
Canary	220/150	185

VII. Cardiac Output

A. Defined as the amount of blood pumped by the heart in a unit period of time.
   1. usually measured in milliliters or liters per minute
   2. divided among tissues according to need
      a. accomplished by regulating arteriole constriction or relaxation, altering blood flow to vascular beds

VIII. Effect of Breathing

A. When animals inhale air (inspire) a vacuum develops in the intrapleural space that is also transferred to the mediastinal space.
B. Thin-walled structures in the mediastinal space can then expand.
   1. vena cava, lymph vessels, esophagus
   2. helpful for return of venous blood and lymph to the heart

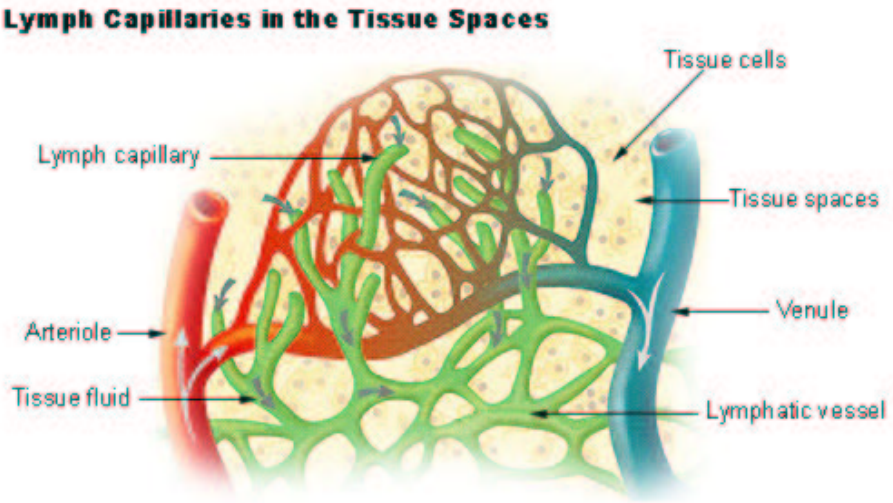


Transverse section of equine thorax at a level that shows the esophagus, caudal vena cava, aorta, and heart within the mediastinal space.

IX. Circulation Time

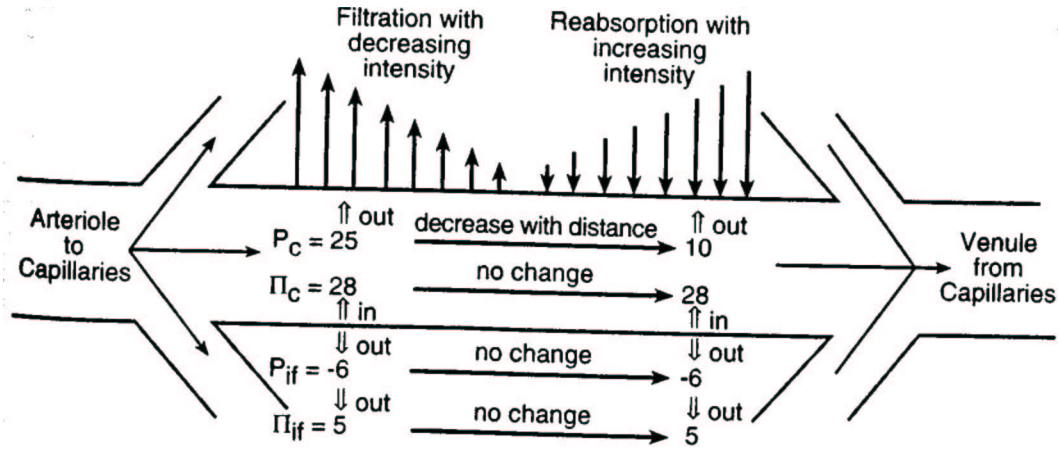
A. time required for blood to return to the right atrium after it has been pumped from the left ventricle
    1. variable, but approximately 40 – 60 seconds

X. Capillary Dynamics



A schematic representation of a capillary bed. Blood is supplied to capillaries by arterioles, and it leaves the capillaries through the venules. Tissue cells are surrounded by interstitial fluid (ISF). Water and dissolved substances from blood capillaries are interchanged with ISF and intracellular fluid by diffusion. ISF is not returned to the blood capillaries instead it is returned as lymph through lymphatic capillaries.

A. Refers to physical factors associated with the exchange of fluid between the blood and interstitial fluid at the level of the capillaries.
B. Two types:
    1. Diffusion of water and dissolved substances accounts for the greatest ‘ degree of interchange between capillaries and interstitial fluid.
    2. Bulk flow results from osmotic and hydrostatic pressure differences between plasma and interstitial fluid.
        a. Volume of bulk flow into the interstitial space from plasma is usually balanced by amount returning to the capillaries from interstitial space.
    3. Mechanisms of bulk flow
        a. capillary pressure
            i. hydrostatic pressure in capillary
        b. plasma colloidal osmotic pressure
            i. effective osmotic pressure of capillary
        c. interstitial fluid pressure
            i. hydrostatic pressure in the interstitial fluid
        d. interstitial fluid colloidal osmotic pressure
            i. effective osmotic pressure of the interstitial fluid



Physical factors associated with filtration at the arterial end and reabsorption at the venous end of a capillary. Values are in mm Hg (P_c, capillary pressure; $_c$, plasma colloidal osmotic pressure; P_{if}, interstitial fluid pressure; $_{if}$, interstitial fluid colloidal osmotic pressure). The open arrows indicate the diresction of influence of P_c, K_c, P_{if}, and $_{if}$.

4. Capillary imbalances
    a. imbalance of bulk flow due to…
        i. blockage of venous drainage
        ii. blockage of lymphatic drainage
        iii. loss of protein from capillary to interstitial space
        iv. depletion of blood protein through malnutrition
    b. leads to edema or swollen tissue due to excess fluid accumulation

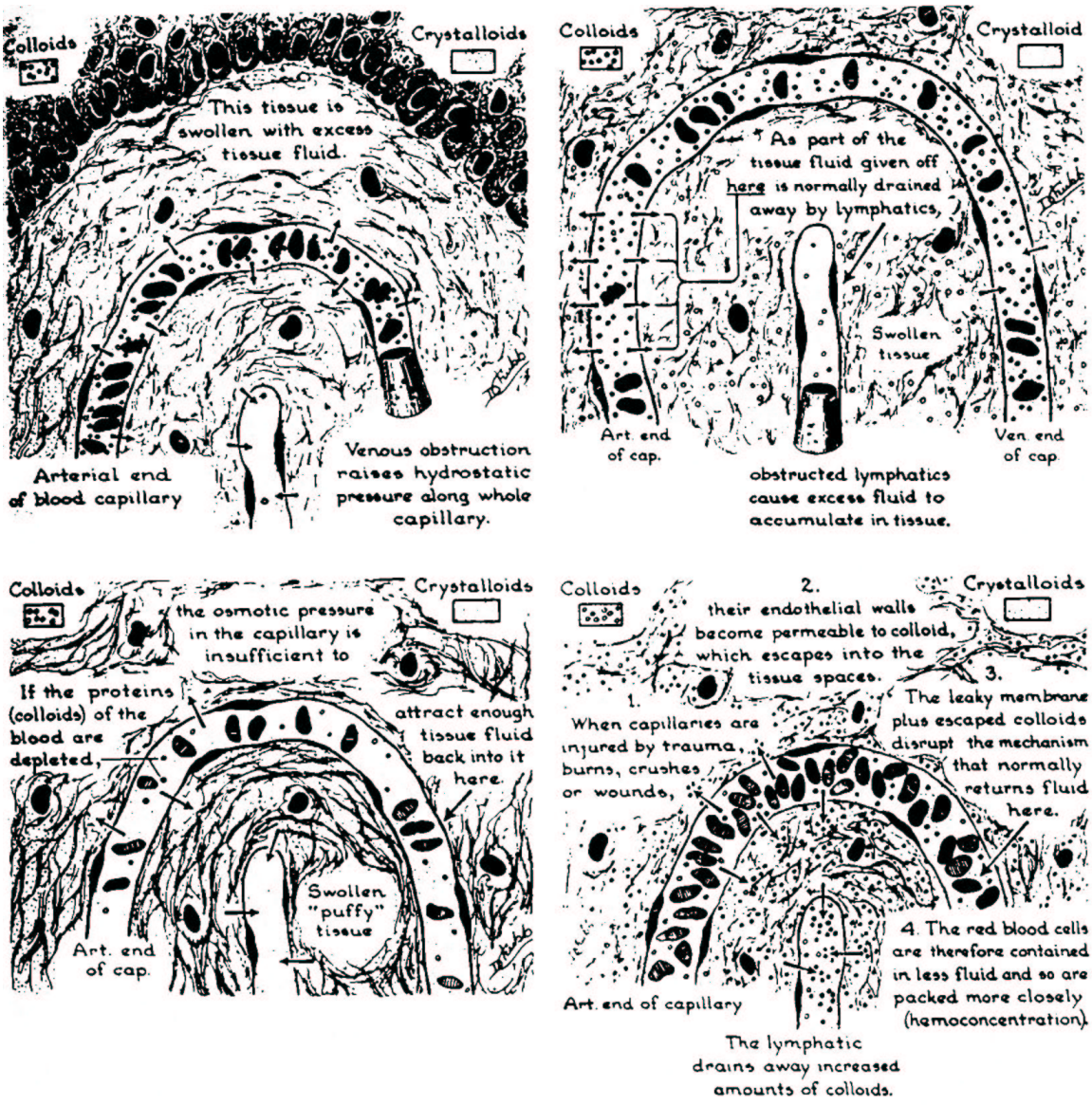


Figure 7.35. Capillary dynamic imbalances as causes for interstitial edema. From Ham AW Histology. 7th ed. Philadelphia: JB Lippincott, 1974.