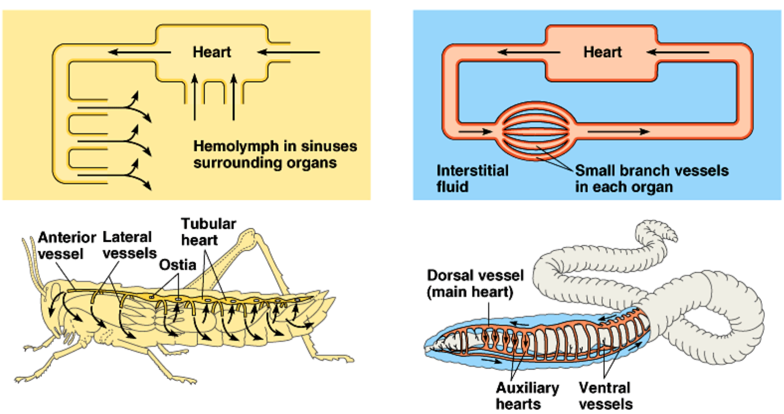
Design of Circulatory Systems

1. Open
   "Heart" (muscular tube) pumps blood through tubes that empty into general pool

2. Closed
   Heart pumps blood through a closed system of tubes.

1

Figure 42.2 Open and closed circulatory systems



(a) Open circulatory system

(b) Closed circulatory system

2

Hearts of Vertebrates (with backbones)

Fish
2-chamber heart, single circulation

Amphibian
3-chamber heart, semi-separate systemic and pulmocutaneous (lung/skin) circulation

Mammal
4-chamber heart, separate systemic and pulmonary (lung) circulation

3

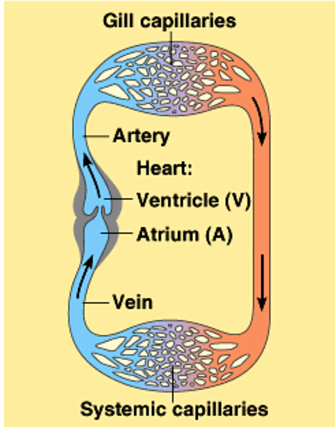
Atrium (entry way)
receives incoming blood, passes it to ventricle

Ventricle (chamber)
more muscular pump sending blood to rest of circulation.

Arteries (arterial blood)
vessels carrying blood from heart towards the capillaries. Thick muscular walls to keep pressure up. High in oxygen (except for pulmonary arteries).

Veins (venous blood)
vessels carrying blood from capillaries back to heart. Very thin flabby walls with low pressure, but have one-way valves to prevent blood from backing up. Low in oxygen (except for pulmonary veins).

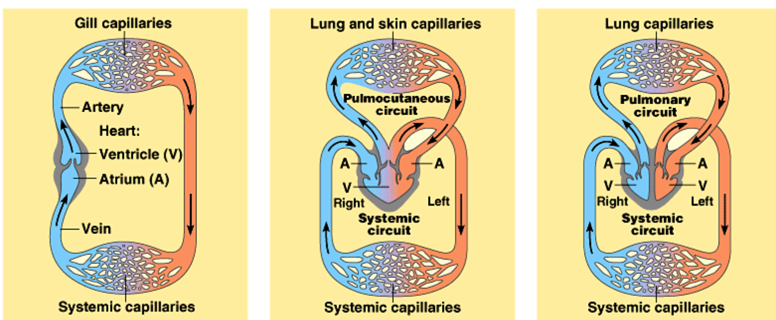
Capillaries
very small vessels (one blood cell wide) that perfuse all the tissues.



(a) Fish

4

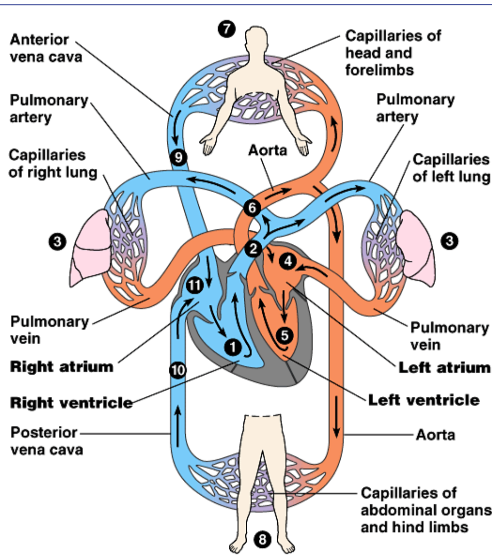
Figure 42.3 Generalized circulatory schemes of vertebrates



(a) Fish (b) Amphibian (c) Mammal

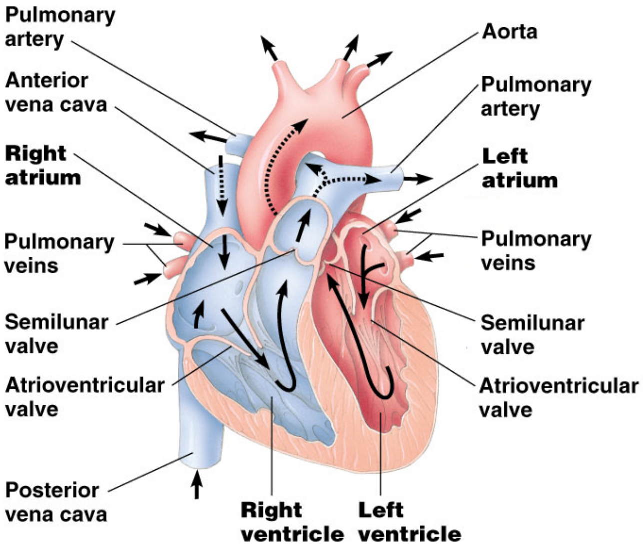
5

Figure 42.4 The mammalian cardiovascular system: an overview



6

Figure 42.5 The mammalian heart: a closer look



The Cardiac Cycle

Diastole
chambers are relaxed, blood can flow in

Atrial Systole
atria contract, pushing blood into ventricles

Ventricular Systole
ventricles contract with high pressure, pushing blood into the lungs and systemic circulation

Diastolic pressure (bottom number)
arterial pressure when ventricle is relaxed

Systolic pressure (top number)
arterial pressure when ventricle contracts and pumps

Figure 42.6 The cardiac cycle

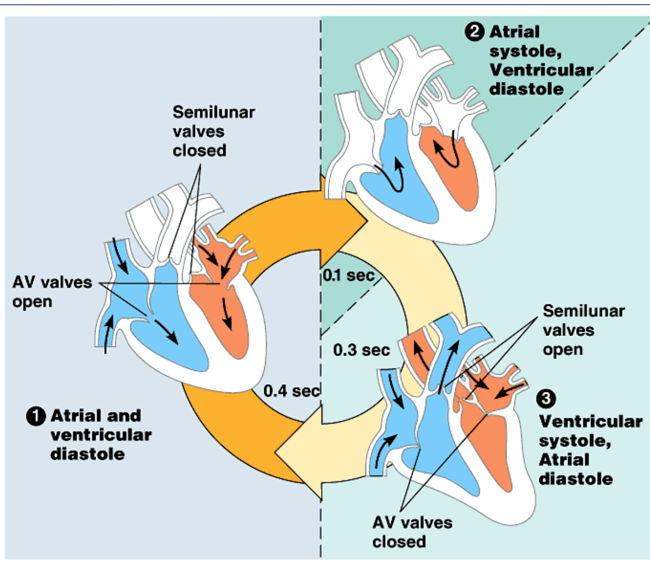
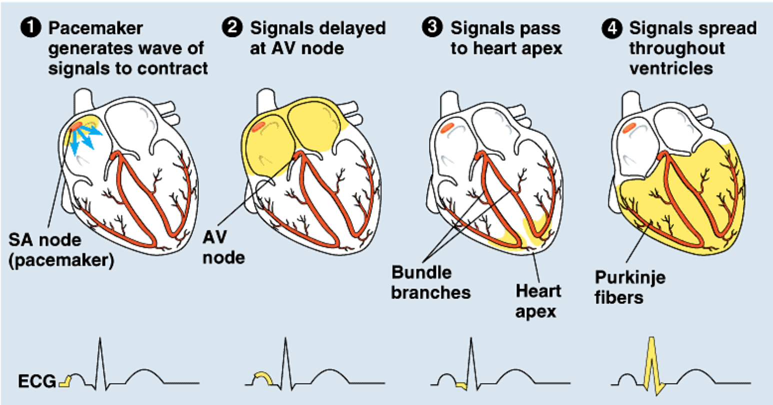


Figure 42.7 The control of heart rhythm



10

Events of the Cardiac Cycle

Electrical	Atria	AV valves	Ventricles	Semi-Lunar valves	Blood Flow
between beats	diastole	open	diastole	closed	into atria
SA node fires, spreads to AV node	systole	open	diastole	closed	into ventricles
spreads to Apex	systole	open	diastole	closed	
spreads thru Purkinje fibers	diastole	closed	systole	open	into lungs, systemic circ.

diastole = relaxed, systole = contracting.

11

Atrium
receives incoming blood, passes it to ventricle

Ventricle
more muscular pump sending blood to rest of circulation.

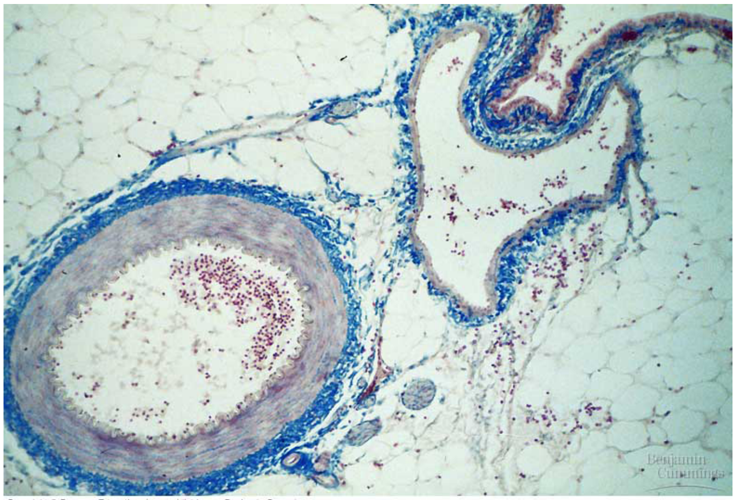
Arteries (arterial blood)
vessels carrying blood from heart towards the capillaries. Thick muscular walls to keep pressure up. High in oxygen (except for pulmonary arteries).

Veins (venous blood)
vessels carrying blood from capillaries back to heart. Very thin flabby walls with low pressure, but have one-way valves to prevent blood from backing up. Low in oxygen (except for pulmonary veins).

Capillaries
very small vessels (one blood cell wide) that perfuse all the tissues.

12

Vein with thin floppy wall



Artery with thick, muscular elastic wall

13

Figure 42.8 The structure of blood vessels

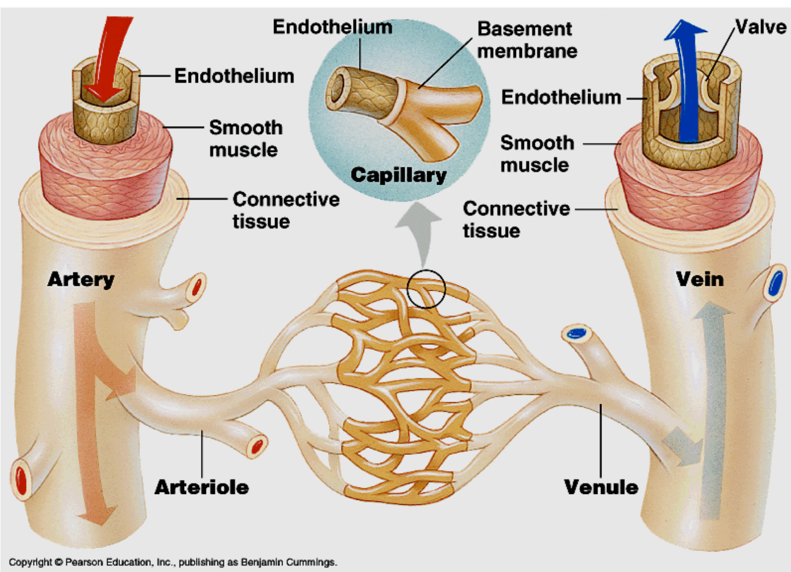


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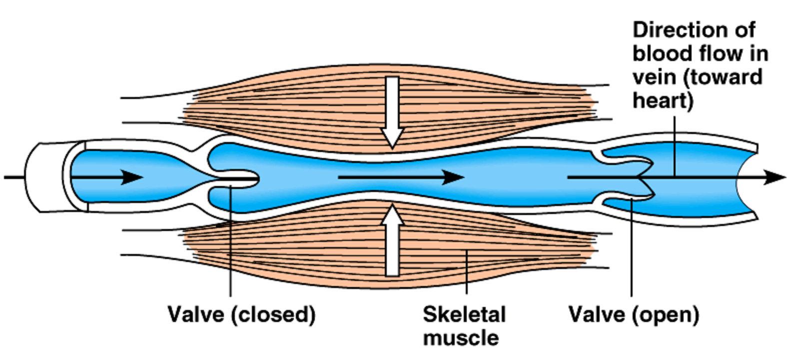
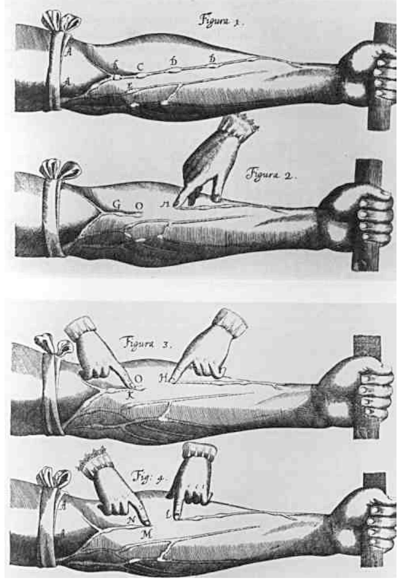
Figure 42.9 Blood flow in veins



15



Features of Capillaries

Capillaries are a way to increase surface area of circulation exposed to the tissues.

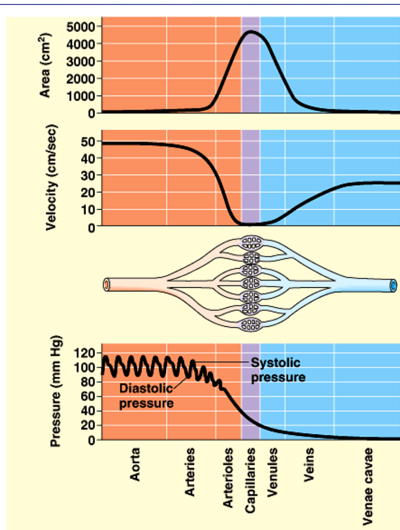
High Arterial pressure forces fluid out of capillaries at arterial end, but lower pressure pulls fluid into capillaries as they leave the tissue at venous end.

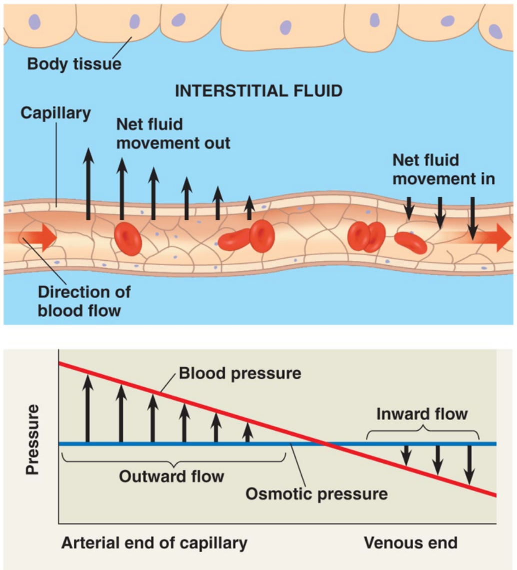
Walls are fenestrated (window-like holes) thus leaky; gases, nutrients etc. readily exchanged.

Except for capillaries in the brain, which have specialized endothelium cells that block most chemicals from entering, unless they are transported (e.g. glucose, amino acid transporters) or hydrophobic (steroids, drugs).

Blood flow into the tissues is controlled by hormones and nerves via sphincters at the arterioles feeding the capillary beds.

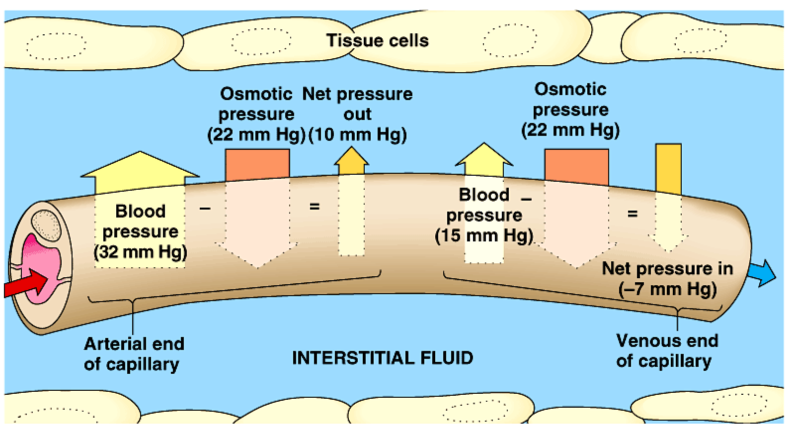
Figure 42.10 The interrelationship of blood flow velocity, cross-sectional area of blood vessels, and blood pressure





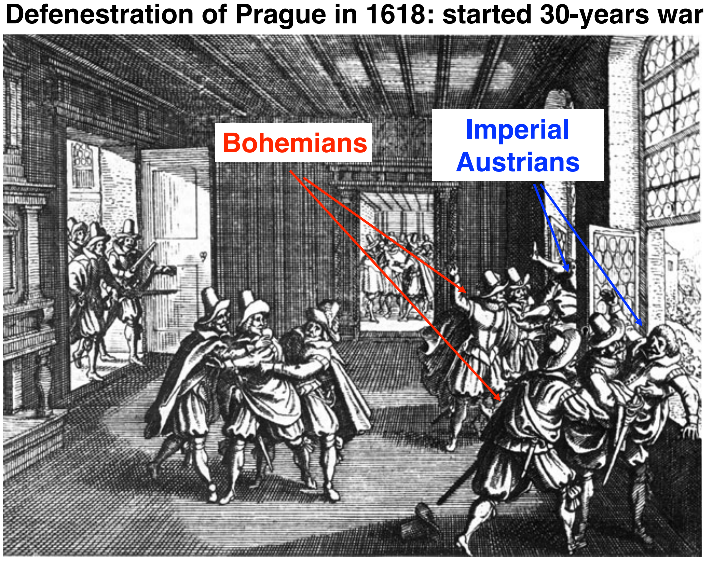
19

Figure 42.13 The movement of fluid between capillaries and the interstitial fluid



20

Defenestration of Prague in 1618: started 30-years war



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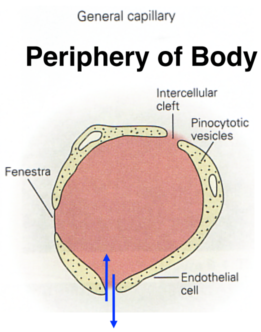
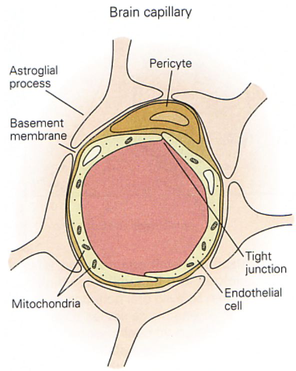
Blood Brain Barrier

Periphery of Body



Fenestrated Capillaries



Brain

Only transported or hydrophobic molecules can cross

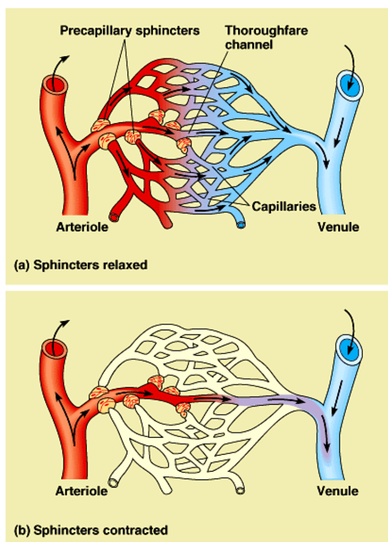
22

Figure 42.12 Blood flow in capillary beds

leg muscles

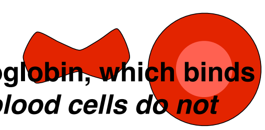
Adrenalin

GI tract



23

Composition of Blood (see Figure 42.14)



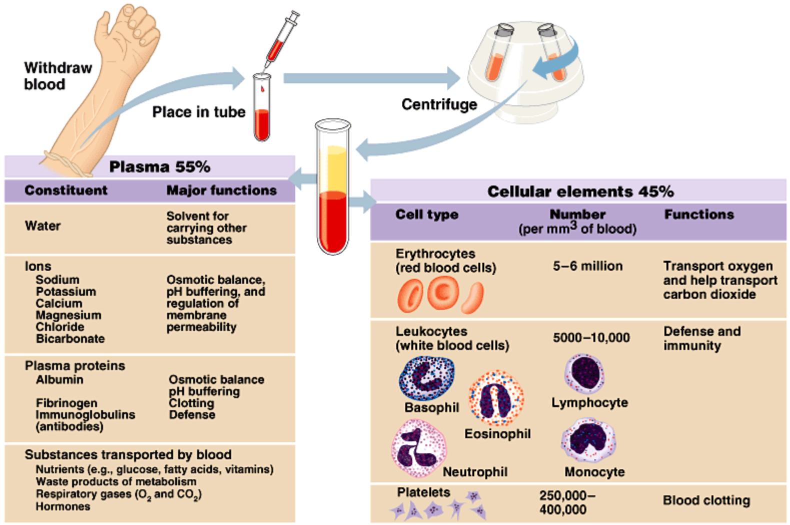
Red Blood Cells
Biconcave discoids. Contain hemoglobin, which binds O_2 and helps transport CO_2. ***Red blood cells do not have nuclei or mitochondria, so no DNA!***

White Blood Cells
Immune system cells. Source of DNA for PCR fingerprinting studies using blood.

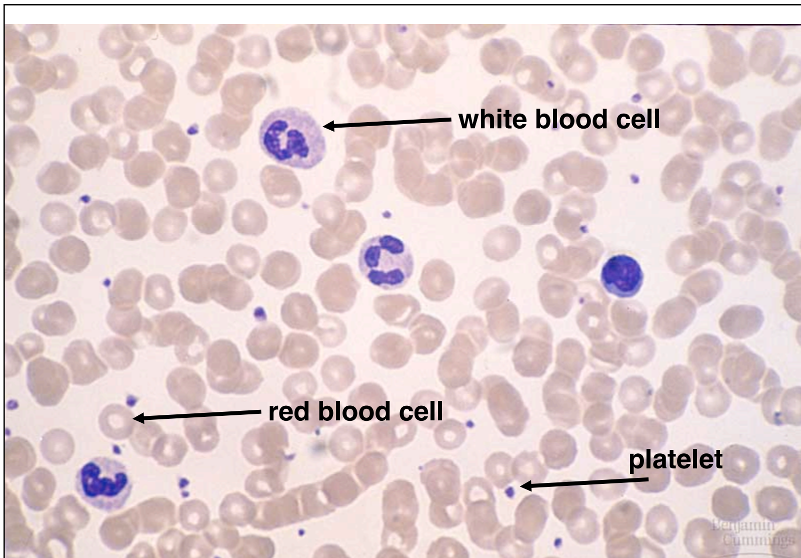
Platelets
Very small fragments of cells which help in blood clotting.

All derived from bone marrow stem cells.

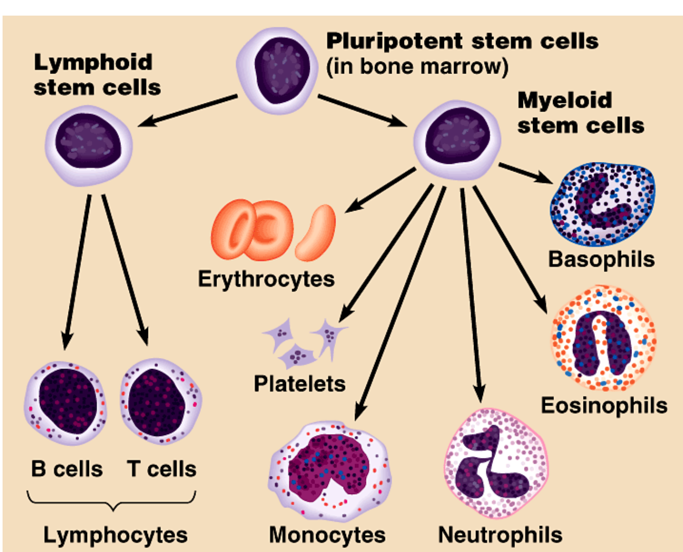
24


Withdraw blood
Place in tube
Centrifuge
Plasma 55%
Constituent
Major functions
Water
Solvent for carrying other substances
Ions
Sodium
Potassium
Calcium
Magnesium
Chloride
Bicarbonate
Osmotic balance, pH buffering, and regulation of membrane permeability
Plasma proteins
Albumin
Fibrinogen
Immunoglobulins (antibodies)
Osmotic balance
pH buffering
Clotting
Defense
Substances transported by blood
Nutrients (e.g., glucose, fatty acids, vitamins)
Waste products of metabolism
Respiratory gases (O_2 and CO_2)
Hormones
Cellular elements 45%
Cell type
Number (per mm^3 of blood)
Functions
Erythrocytes (red blood cells)
5–6 million
Transport oxygen and help transport carbon dioxide
Leukocytes (white blood cells)
5000–10,000
Defense and immunity
Basophil
Eosinophil
Lymphocyte
Neutrophil
Monocyte
Platelets
250,000–400,000
Blood clotting

25


white blood cell
red blood cell
platelet

26


Pluripotent stem cells (in bone marrow)
Lymphoid stem cells
Myeloid stem cells
Basophils
Erythrocytes
Eosinophils
Platelets
B cells
T cells
Lymphocytes
Monocytes
Neutrophils

27

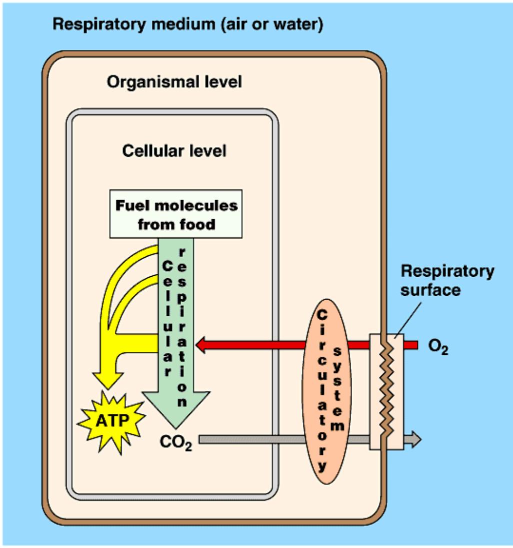


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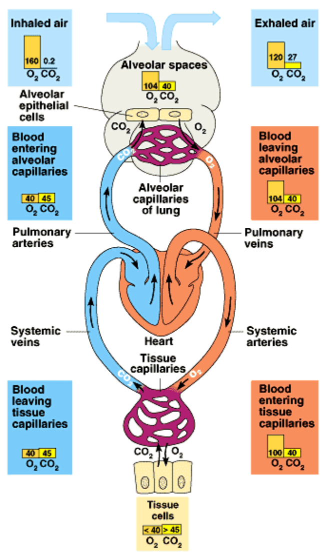
Figure 42.27 Loading and unloading of respiratory gases



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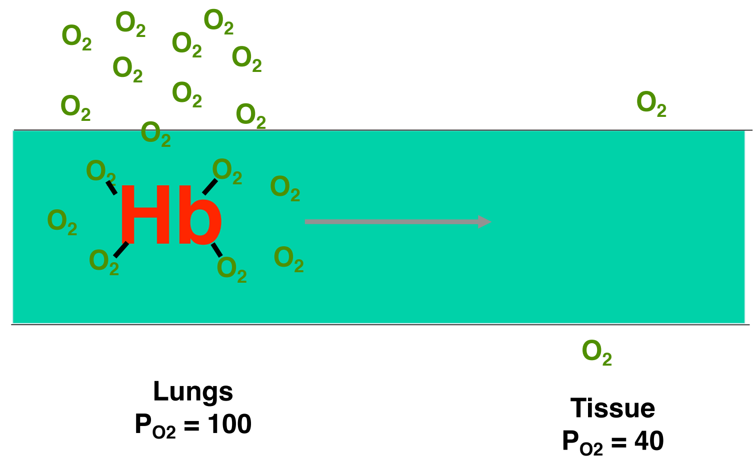
Respiratory Pigments

Hemocyanin
Copper-based O2 binding protein in arthropods and mollusks, so bluish blood.

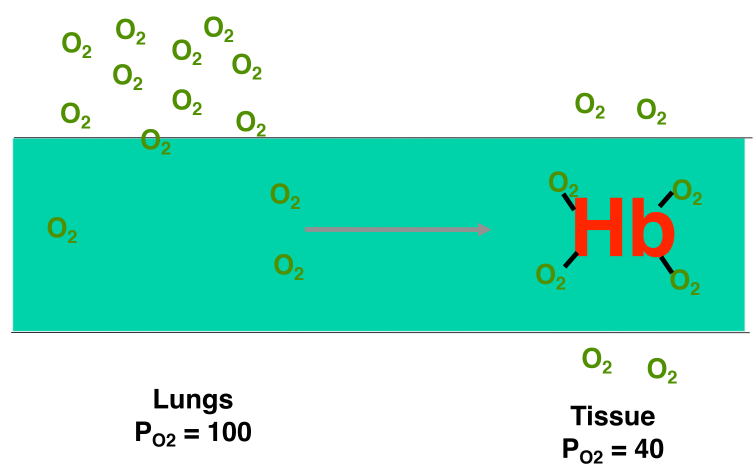
Hemoglobin
Iron-based O2 binding protein in vertebrates, so reddish blood.

Each hemoglobin molecule binds four O_2 molecules; red blood cell has 250 millon hemoglobin molecules, so 1 billion O_2 molecules per cell.

30



31



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Dissociation Curve for Hemoglobin

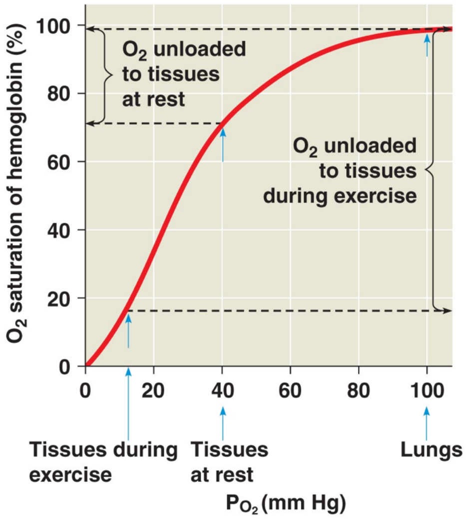
How to pick and deliver O_2 at the right places? Use chemistry of hemoglobin in response to O_2 and CO_2

A. **Hemoglobin binds O_2 very well when the O_2 concentration is high (e.g. lung)**

Hemoglobin releases O_2 well when the O_2 concentration is low (i.e. tissues)

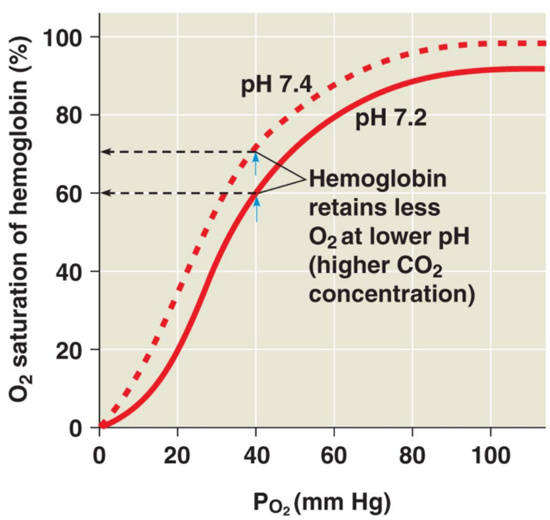
B. **Bohr Shift:**
Hemoglobin releases O_2 even better when pH is low (i.e. high CO_2 -> high carbonic acid -> low pH)

33



(a) P_{O_2} and hemoglobin dissociation at pH 7.4

34



(b) pH and hemoglobin dissociation

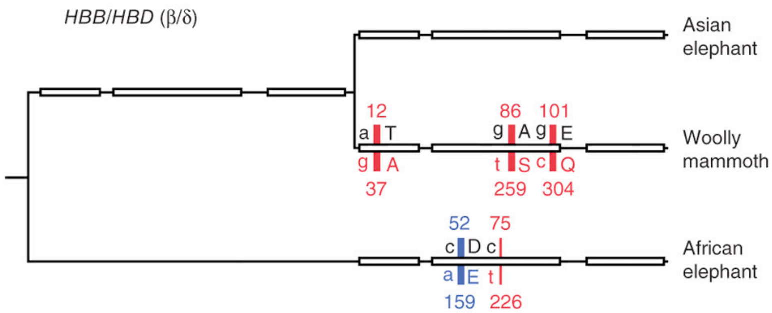
35

Mammoth Hemoglobin

http://www.pbs.org/wgbh/nova/sciencenow/0306/03-mamm-02.html

36

Mammoth Hemoglobin



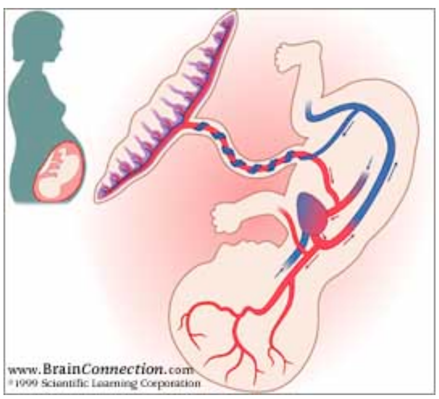
- Hemoglobin binds O_2 more strongly at low temperatures
- How to offload O_2 in extremities in artic cold?
- Hb DNA amplified from 43,000 y.o. frozen Siberian mammoth
- 3 amino acid substitutions give mammoth Hb a lower affinity for O_2 at low temperatures

Nature Genetics **42**, 536 - 540 (2010)

37

Fetal Circulation

- Placenta: Gas (and nutrient) exchange in high-surface area capillary bed
- Fetal Hemoglobin binds more O_2 in low-O_2 environment of placenta
- Shunts in fetal heart to send O_2 rich blood directly from vena cava to left side atrium (oval foramen) and to aorta (ductus arteriosus) so that lungs are bypassed



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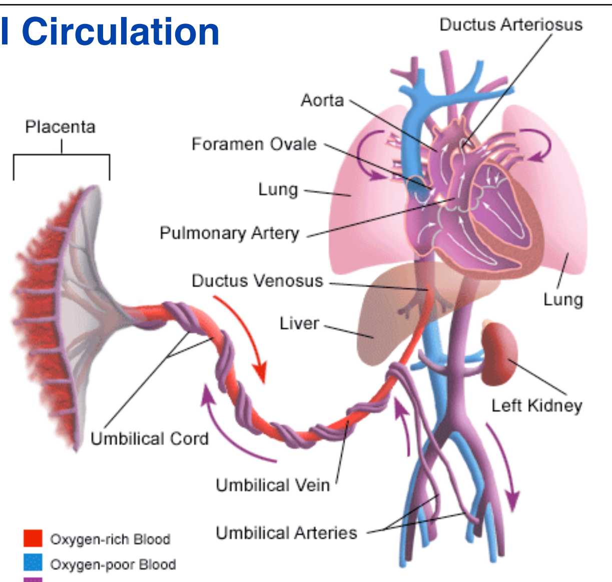
Fetal Circulation



http://www.lpch.org/DiseaseHealthInfo/HealthLibrary/hrnewborn/0181-pop.html

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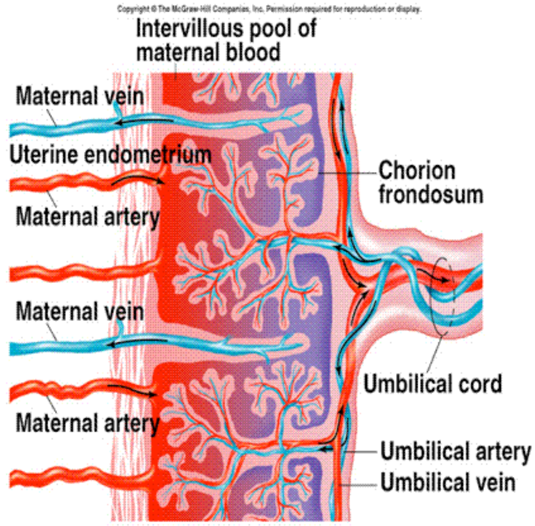
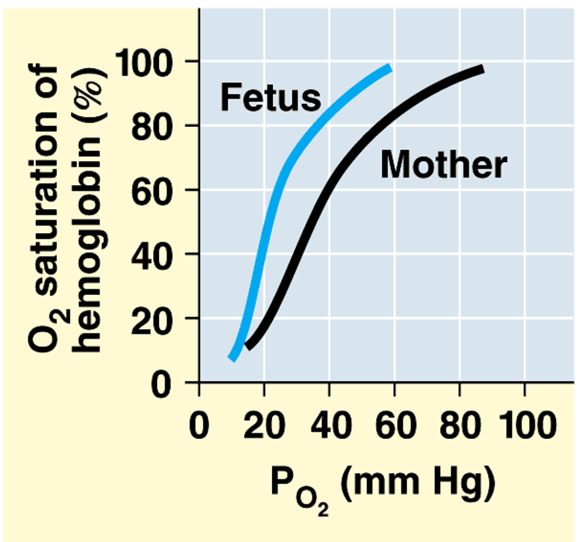
Placental Circulation



https://courses.stu.qmul.ac.uk/smd/kb/microanatomy/humandev/placenta/index.htm

Fetal Hemoglobin

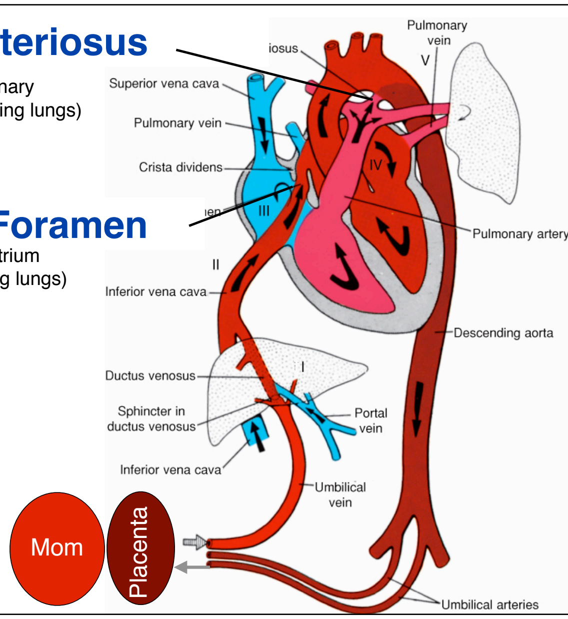


Ductus Arteriosus

Shunt connects pulmonary artery to aorta (bypassing lungs)

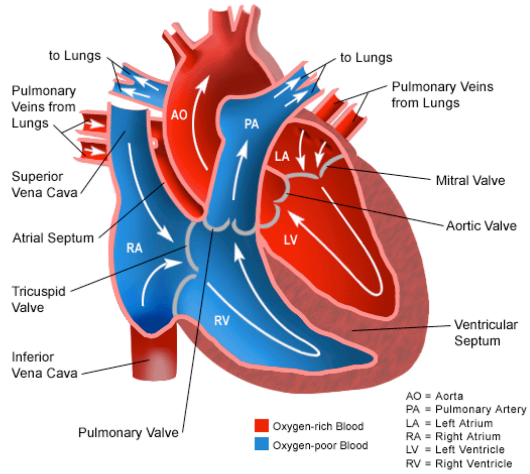
Oval Foramen

Shunt connects right atrium to left atrium (bypassing lungs)



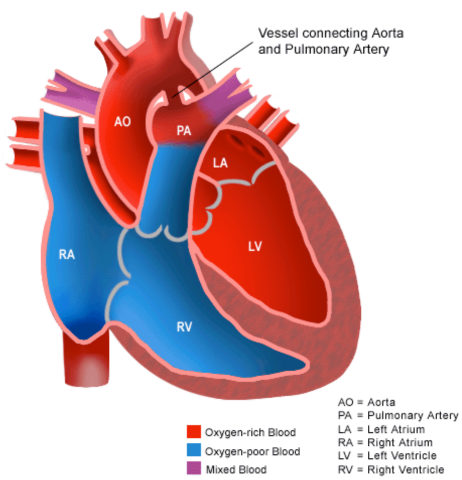
http://macomb-rspt.com/FILES/RSPT1210 /MODULE%20A/Fetal%20Circulation.jpg

Normal Heart



http://www.chop.edu/healthinfo/patent-ductus-arteriosus-pda.html

Patent Ductus Arteriosus (PDA)



http://www.chop.edu/healthinfo/patent-ductus-arteriosus-pda.html

Hemoglobin and Carbon Dioxide

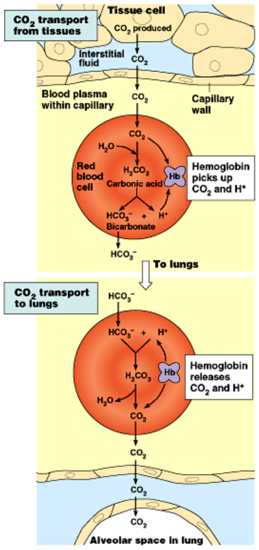
Hemoglobin also aids in the transport of CO_2:

- **7% CO_2 dissolves in plasma**
- **23% binds to hemoglobin**
- **70% dissociates into bicarbonate in plasma**

Carbon Monoxide also binds hemoglobin, but binding is irreversible (210x higher than O_2). Binding of 50-80% of hemoglobin is fatal.

Victims of CO poisoning are cherry red, because of carboxyhemoglobin color.

Figure 42.29 Carbon dioxide transport in the blood



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Compartments of the Body

The body can be divided up into conceptual “compartments” that are separated by physical barriers (e.g. linings of blood vessels, lining of lungs, lining of GI tract)

Circulatory system transports O2 and water-soluble chemicals between compartments (e.g. from lungs to tissues, or from gut to tissues)

Other compounds may take different routes (e.g. fats travel from gut to tissues and fat depots through lymphatic vessels).

Different compartments have different permeabilities, so a compound or drug may be distributed unevenly through the body.

Two compartments have very tight barriers that block all chemicals except very small molecles (O_2, H_20) or hydrophobic compounds (steroids, many drugs): the brain and the placenta.

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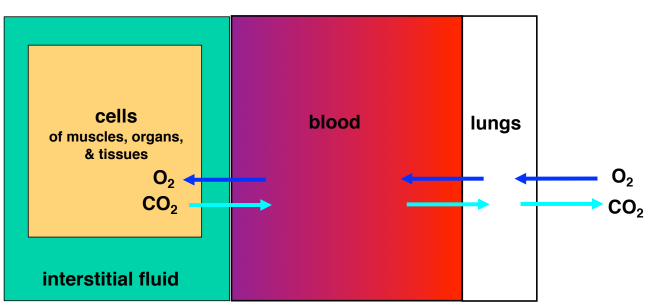
Movement between “Compartments”



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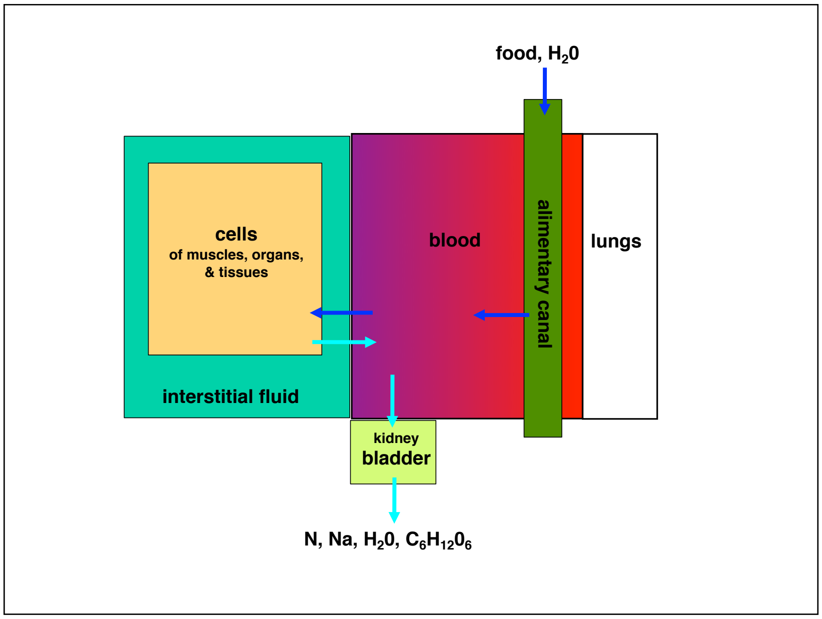
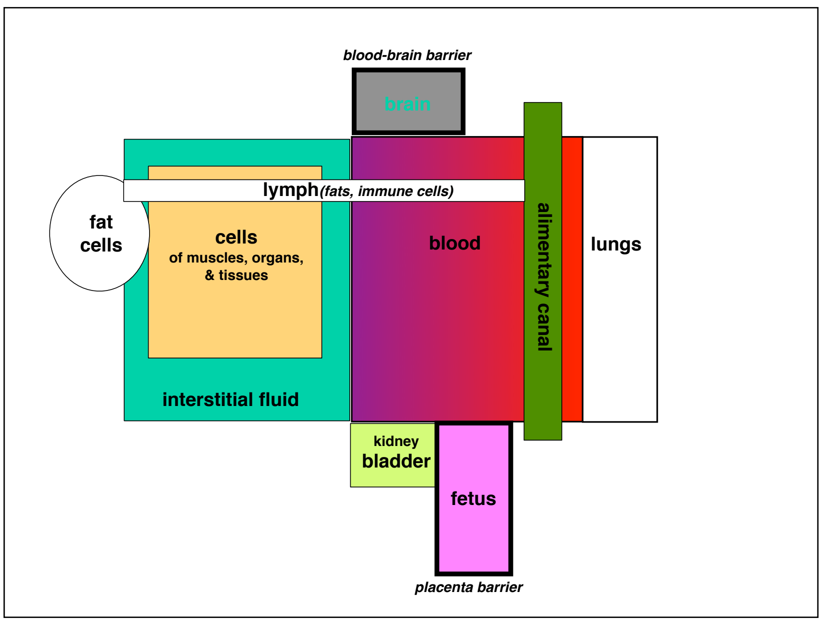

food, H_20
cells
of muscles, organs,
& tissues
blood
alimentary canal
lungs
interstitial fluid
kidney
bladder
N, Na, H_20, $C_6H_{12}0_6$

49


blood-brain barrier
brain
lymph(fats, immune cells)
fat
cells
cells
of muscles, organs,
& tissues
blood
alimentary canal
lungs
interstitial fluid
kidney
bladder
fetus
placenta barrier

50