Topic 6. Organ Systems – Part I

TOPICS

- Standard Man
- Tissues and Organ Systems
- Digestive System
- Cardiovascular System
- Lymph System
- Renal System
- Endocrine System

Standard Man

This table shows the approximate values of certain biophysical parameters in male subjects.

Quantity	Approx. value
Basal metabolic rate	70 kcal/hour
Breathing rate	15 /min
Blood pressure	120/80 mmHg
Blood volume	5.2 l
Carbon dioxide production	208 ml/min
Cardiac output	5 l/min
Core temperature	37.0 deg C
Dead space	0.15 l
Fat mass	10 kg
Heart rate	70 beats/min
Heat capacity	0.86 kcal/kg/deg C
Height	1.72 m
Mass	70 kg
Muscle mass	30 kg
Oxygen consumption	260 ml/min
Skin temperature	34.0 deg
Surface area	1.85 sq m
Tidal volume	0.5 l
Total lung capacity	6 l
Vital capacity	4.8 l

http://www.kevinboone.com/PF_biodat_stdman.html

MMD also gives standard man parameters taken from Cooney in Table 9.1.
Derived from International Commission on Radiological Protection, ICRP

Body Composition

Elemental Composition of Human Body (reductionism)

Major Elements	Symbol	Percentage (by weight)
Oxygen	O	65.0
Carbon	C	18.5
Hydrogen	H	9.5
Nitrogen	N	3.3
Calcium	Ca	1.5
Phosphorus	P	1.0
Potassium	K	0.4
Sulfur	S	0.3
Sodium	Na	0.2
Chlorine	Cl	0.2
Magnesium	Mg	0.1

Trace Elements together less than 0.1%	boron (B), chromium (Cr), cobalt (Co), copper (Cu), Fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin(Sn), vanadium(V), & zinc(Zn).

http://fig.cox.miami.edu/~cmallery/150/life/elements.htm

Element	Mass of element in a 70-kg person	Volume of purified element	Element would comprise a cube this long on a side:
oxygen	43 kg	37 L	33.5 cm
carbon	16 kg	7.08 L	19.2 cm
hydrogen	7 kg	98.6 L	46.2 cm
nitrogen	1.8 kg	2.05 L	12.7 cm
calcium	1.0 kg	645 mL	8.64 cm
phosphorus	780 g	429 mL	7.54 cm
potassium	140 g	162 mL	5.46 cm
sulfur	140 g	67.6 mL	4.07 cm
sodium	100 g	103 mL	4.69 cm
chlorine	95 g	63 mL	3.98 cm
magnesium	19 g	10.9 mL	2.22 cm
iron	4.2 g	0.53 mL	8.1 mm
fluorine	2.6 g	1.72 mL	1.20 cm
zinc	2.3 g	0.32 mL	6.9 mm
silicon	1.0 g	0.43 mL	7.5 mm
rubidium	0.68 g	0.44 mL	7.6 mm
strontium	0.32 g	0.13 mL	5.0 mm
bromine	0.26 g	64.2 µL	4.0 mm
lead	0.12 g	10.6 µL	2.2 mm
copper	72 mg	8.04 µL	2.0 mm
aluminum	60 mg	22 µL	2.8 mm
cadmium	50 mg	5.78 µL	1.8 mm
cerium	40 mg	4.85 µL	1.7 mm
barium	22 mg	6.12 µL	1.8 mm
iodine	20 mg	4.06 µL	1.6 mm
tin	20 mg	3.48 µL	1.5 mm
titanium	20 mg	4.41 µL	1.6 mm
boron	18 mg	7.69 µL	2.0 mm
nickel	15 mg	1.69 µL	1.2 mm
selenium	15 mg	3.13 µL	1.5 mm

chromium	14 mg	1.95 µL	1.3 mm
manganese	12 mg	1.61 µL	1.2 mm
arsenic	7 mg	1.21 µL	1.1 mm
lithium	7 mg	13.1 µL	2.4 mm
cesium	6 mg	3.2 µL	1.5 mm
mercury	6 mg	0.44 µL	0.8 mm
germanium	5 mg	0.94 µL	1.0 mm
molybdenum	5 mg	0.49 µL	0.8 mm
cobalt	3 mg	0.34 µL	0.7 mm
antimony	2 mg	0.30 µL	0.7 mm
silver	2 mg	0.19 µL	0.6 mm
niobium	1.5 mg	0.18 µL	0.6 mm
zirconium	1 mg	0.15 µL	0.54 mm
lanthanium	0.8 mg	0.13 µL	0.51 mm
gallium	0.7 mg	0.12 µL	0.49 mm
tellurium	0.7 mg	0.11 µL	0.48 mm
yttrium	0.6 mg	0.13 µL	0.51 mm
bismuth	0.5 mg	51 nL	0.37 mm
thallium	0.5 mg	42 nL	0.35 mm
indium	0.4 mg	55 nL	0.38 mm
gold	0.2 mg	10 nL	0.22 mm
scandium	0.2 mg	67 nL	0.41 mm
tantalum	0.2 mg	12 nL	0.23 mm
vanadium	0.11 mg	18 nL	0.26 mm
thorium	0.1 mg	8.5 nL	0.20 mm
uranium	0.1 mg	5.3 nL	0.17 mm
samarium	50 µg	6.7 nL	0.19 mm
beryllium	36 µg	20 nL	0.27 mm
tungsten	20 µg	1.0 nL	0.10 mm

http://web2.iadfw.net/uthman/elements_of_body.html

b o d y   c o m p o s i t i o n

m o r e   i m p o r t a n t   t h a n   w e i g h t

Many people are under the impression that they can gauge obesity by using weight as a measure. This misconception is assumed true when using Body Mass Index charts, that take into consideration, only a person's height and weight. Obesity is better defined as carrying excessive bodyfat for a given weight. Muscle, bone, and water, all have a higher density (Db) than fat. We must therefor concern ourselves with an individual's body composition, in order to estimate how much of it is bodyfat (BF). It is possible for a client gain weight (BW), and lose fat through exercise. If using weight as a measure of progress for this person, they would be seen to be failing in their training goals. In order to quantify change in %BF, we need to identify accurate ways to measure it.

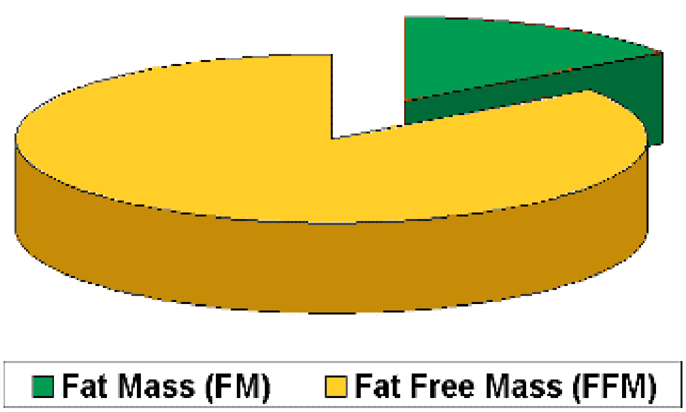
$$\%BF = (FM/BW) \times 100$$

In 1992 a well respected body composition reseacher, Dr Timothy G. Lohman created these widely accepted%BF standards.

Relative Fatness	♂	♀
At Risk - Too Low	0% - 5%	0% - 8%
Below Average	6% - 14 %	9% - 22%
Average	15%	23%
Above Average	16% - 24%	24% - 31%
At Risk - Too High	25% +	32% +

How to best estimate %BF for individuals has been conjectural for many years.

c o m p o n e n t   m o d e l s



w h o l e   b o d y   2   c o m p o n e n t   m o d e l

In 1963 Brozek et al. dissected 3 white male cadavers recording their Db & % of FM (fat) and FFM (water protein & minerals). Dividing the body into these 2 components has been the foundation of (Db) and (BF) prediction equations for many years.

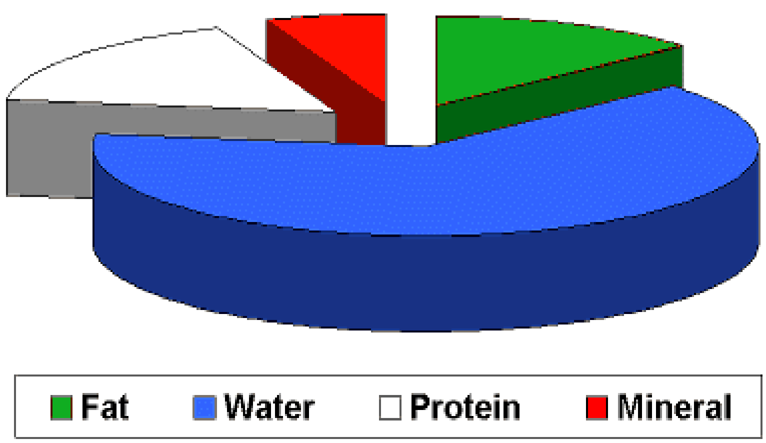
Component	Density (gm/cc)	Proportion (%)
1 - Fat Mass	**0.9007**	**15.3**
2 - Fat Free Mass	**1.1000**	**84.7**
2a - FFM (Water)	*0.9937*	*73.8*
2b - FFM (Protein)	*1.3400*	*19.4*
2c - FFM (Minerals)	*3.038*	*6.8*

Using the above proportions and relative densities, scientists have formulated prediction equations to convert a persons Db (obtained through under water weighing (UWW) otherwise known as Hydrodensitometry) to %BF. The two most commonly used are

%BF = [(4.95 / Db) - 4.90] x 100 (Siri 1961)

%BF = [(4.57 / Db) - 4.142] x 100 (Brozek 1963)

These equations however accurate for the assumed values in the above table, need to be adapted for populations with different FFM proportions and relative densities. White males between 19 - 55 years old do correlate reasonably well.



multi-component chemical model

Recent advances in technology have enabled us to use multicomponent models for more accurate measurements of theFFM components. Dual X-ray Absorptiometry (DXA) can measures mineral mass; Isotopic Dilution for water measurements; & Neutron Aactivation Analysis is used to record protein mass. When performed on large sample groups for specific populations, information derived from these methods is used to develop multi component equations, which in turn provide a more accurate estimate of an individual's Db and %BF. NB:- Equations should be selected carefully with consideration given to race, gender and age.

references

Anthropometrica - (Olds & Norton) UNSW press. ISBN 0-86840-223-0

Applied Body Composition Assessment - (Heyward & Stolarczyk) Human Kinetics. ISBN 0-87322-653-4

Human Body Composition - (Roche, Heymsfield & Lohman) Human Kinetics. ISBN 0-87322-638-0

www.ifpa-fitness.com

Tissue and Organ Systems

http://www.rhodes.edu/biology/glindquester/viruses/mechanisms.html#Organs

Tissues

Tissues are sets of cells which function in a related, coordinated manner. There are 4 types.
1. **Epithelial** - columnar, cuboidal or flat cells that form layers over the surfaces of the body and internal organs - functions in protection, absorption and secretion
2. **Connective** - widely dispersed in body, found under epithelial layers, in body spaces, in organs - variety of cell shapes, sizes and forms, function in connection, protection, insulation, support, internal transportation
3. **Muscle** - elongated cells have the ability to contract, tissue consists of bundles or layers of such cells, three types - skeletal, cardiac (heart), and smooth (lining blood vessels and digestive tract)
4. **Nervous** - cells with long extensions that contact other nervous cells (neurons) have the ability to conduct electrical signals for internal communication, tissue consists of many such interconnected cells in a functional communication network

Organs and Systems

As mentioned above, the organs are composed of functional combinations of tissues and systems are composed of functionally interrelated organs which serve the needs of the body. The list below cites each major organ system including a list of the organs within each system and a brief description of the system's function.

Integumentary system
- skin and its "appendages" - i.e. hair, nails, sense receptors, sweat glands, oil glands, etc.
- consists of epithelial cells overlying a network of connective tissue cells and proteins
-functions in protection, sensation, heat exchange

Skeletal system
- bones and their connections (ligaments)
- mainly connective tissue
- functions in support and movement

Muscular system
- the skeletal muscles and their connections (tendons)
- skeletal muscle tissue with connective tissue (tendons)
- functions in support and movement

Nervous system
- brain, spinal cord and peripheral nerves
- nervous and connective tissue
- functions in regulation and coordination of body functions Endocrine system
- includes a variety of "endocrine"glands - glands which secrete hormones (chemical signals) directly into the blood stream. The hormones are received by certain target cells with specific protein receptors and the cells respond in an appropriate way
- glands include pituitary, thyroid, adrenal, pancreas, ovaries and testes
- epithelial and connective tissues, mainly
- functions in regulation and coordination of body functions

Circulatory system
- heart and blood vessels
- cardiac and smooth muscle, epithelial and connective tissues
- functions to transport food, waste, oxygen, carbon dioxide and many other materials to all parts of the body, has an important role in immunity

Lymphatic system
- lymph nodes and vessels, thymus, spleen, tonsils
- epithelial and connective tissues
- functions to collect extracellular fluid (fluid outside of cells or the circulatory system) in the body, filter it and return it to the circulatory system
- also functions in immunity

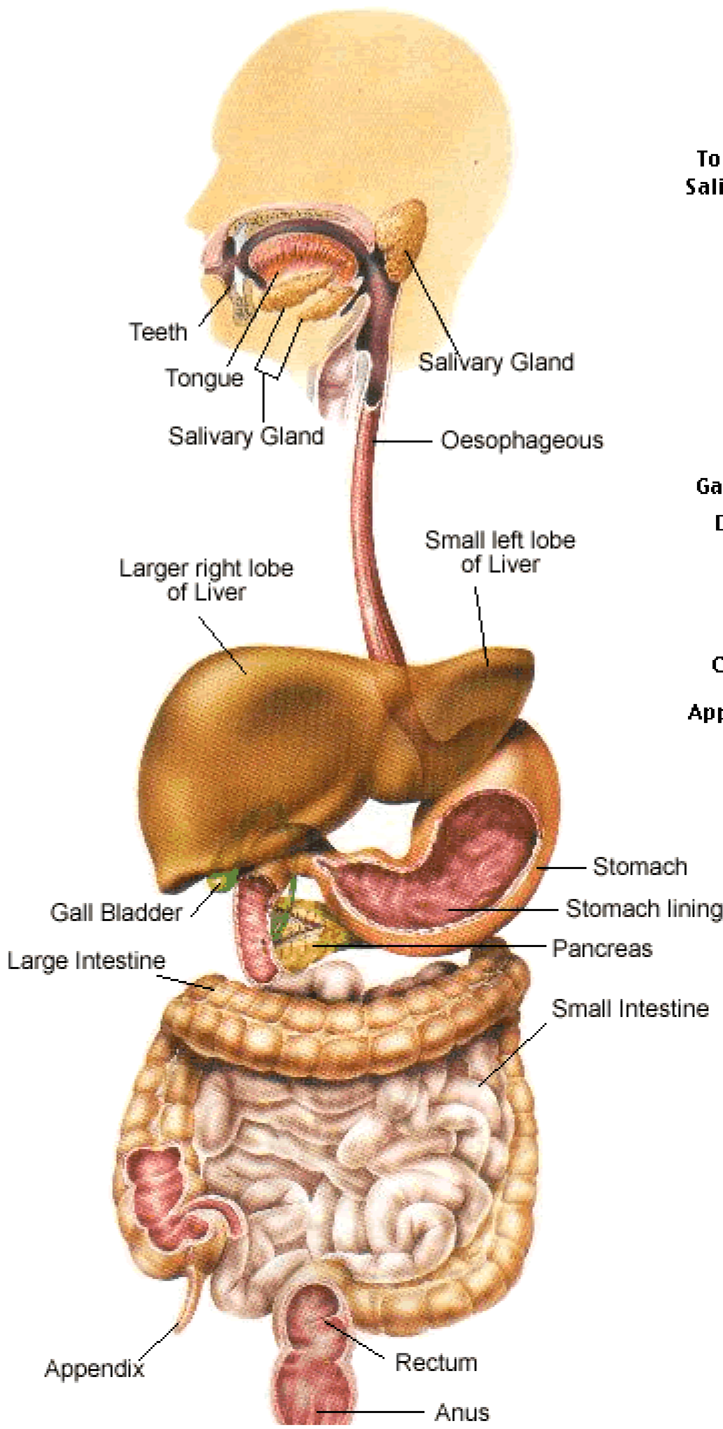
Respiratory system
- nose, sinuses, pharynx, larynx, trachea, bronchi, lungs (with bronchioles and alveoli)
- epithelial and connective tissues
- functions in gas exchange (oxygen in and carbon dioxide out)

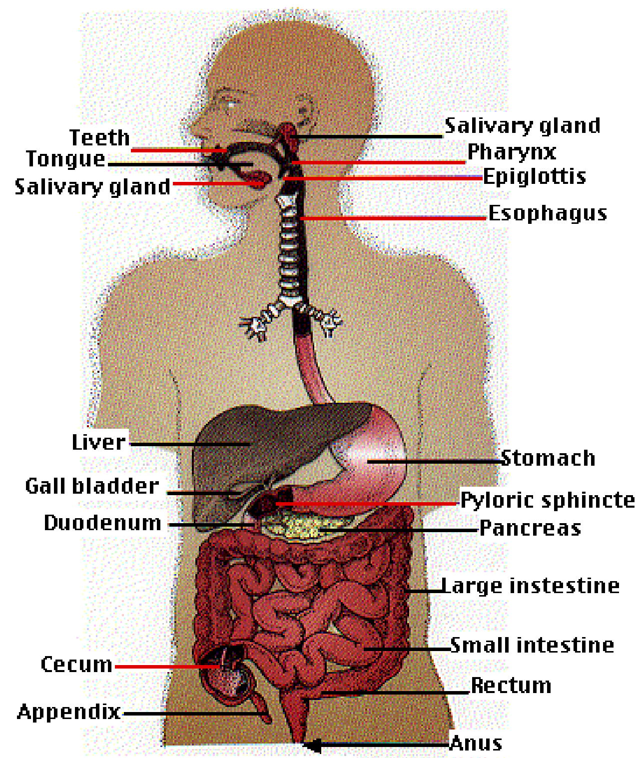
Digestive system
- mouth, pharynx, esophagus, stomach, small and large intestines, rectum, anus
- also includes teeth, tongue, salivary glands, liver, gallbladder, pancreas
- epithelial, smooth muscle and connective tissue
- functions in food acquisition and breakdown into component macromolecules (the macromolecules are later broken down further into their components directly inside cells) and elimination of solid waste

Urinary system
- kidneys, ureters, bladder, urethra
- epithelial, smooth muscle and connective tissue
- functions in collection, concentration and excretion of wastes

Reproductive system
- various male and female reproductive organs
- epithelial, smooth muscle and connective tissue
- functions – making progeny

Digestive System
http://www4.tpgi.com.au/users/amcgann/body/digestive.html





Mouth
Teeth bite off and chew food into a soft pulp that is easy to swallow. Chewing mixes the food with watery saliva, from 6 salivary glands around the mouth and face, to make it moist and slippery.

Oesophagus
The oesophageus, or gullet, is a muscular tube. It takes food from the throat and pushes it down through the neck, and into the stomach. It moves food by waves of muscle contraction called peristalsis.

Stomach
The stomach has thick muscles in its wal. These contract to mash the food into a sloppy soup. Also the stomach lining produces strong digestive juices. These attack the food in a chemical way, breaking down and dissolving its nutrients.

Pancreas
The pancreas, like the stomach, makes powerful digestive juices called enzymes which help to digest food further as it enters the small intestines.

Gall Bladder
This small baglike part is tucked under the liver. It stores a fluid called bile, which is made in the liver. As food from a meal arrives in the small intestine, bile flows from the gall bladder along the bile duct into the intestine. It helps to digest fatty foods and also contains wastes for removal.

Small Intestines
This part of the tract is narrow, but very long - about 20 feet. Here, more enzymes continue the chemical attack on the food. Finally the nutrients are small enough to pass through the lining of the small intestine, and into the blood. They are carried away to the liver and other body parts to be processed, stored and distributed.

Liver
Blood from the intestines flows to the liver, carrying nutrients, vitamins and minerals, and other products from digestion. The liver is like a food-processing factory with more than 200 different jobs. It stores some nutrients, changes them from one form to another, and releases them into the blood acccording to the activities and needs of the body.

Large Intestine
Any useful substances in the leftovers, such as spare water and body minerals, are absorbed through the walls of the large intestine, back into the blood. The remains are formed into brown, semi-solid faeces, ready to be removed from the body.

Rectum and Anus
The end of the large intestine and the next part of the tract, the rectum, store the faeces. These are finally squeezed through a ring of muscle, the anus, and out of the body.

Digestive System Details
http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/G/GITract.html

The strategy

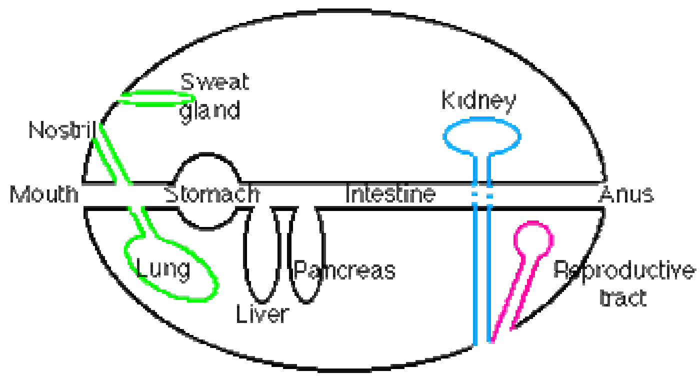
Humans (and most animals) digest all their food extracellularly; that is, outside of cells.

- Digestive enzymes are secreted from cells lining the inner surfaces of various **exocrine glands**.
- The enzymes hydrolyze the macromolecules in food into small, soluble molecules that can be
- absorbed into cells.

The topology

The diagram shows the major topological relationships in the body. The linings of all

- exocrine glands, including digestive glands,
- nasal passages, trachea, and lungs,
- kidney tubules, collecting ducts, and bladder,
- reproductive structures like the vagina, uterus, and fallopian tubes



are all continuous with the surface of the body. Anything placed within their lumen is, strictly speaking, outside the body. This includes

- the secretions of all **exocrine glands** (in contrast to the secretions of **endocrine glands**, which are deposited in the blood).
- Any indigestible material placed in the mouth which will appear, in due course, at the other end.

Ingestion

Food placed in the mouth is

- ground into finer particles by the teeth,
- moistened and lubricated by saliva (secreted by three pairs of **salivary glands**)
- small amounts of starch are digested by the **amylase** present in saliva
- the resulting bolus of food is swallowed into the **esophagus** and
- carried by **peristalsis** to the stomach.

The stomach

The wall of the stomach is lined with millions of **gastric glands**, which together secrete 400–800 ml of gastric juice at each meal. Three kinds of cells are found in the gastric glands

- parietal cells
- "chief" cells
- mucus-secreting cells

Parietal cells

Parietal cells secrete

- hydrochloric acid
- intrinsic factor

Hydrochloric acid (HCl)

Parietal cells contain a **H^+ ATPase**. This transmembrane protein secretes H^+ ions (protons) by active transport, using the energy of ATP. The concentration of H^+ in the gastric juice can be as high as 0.15 M, giving gastric juice a pH somewhat less than 1. With a concentration of H^+ **within** these cells of only about 4×10^{-8} M, this example of active transport produces more than a million-fold increase in concentration. No wonder that these cells are stuffed with mitochondria and are extravagant consumers of energy.

Intrinsic factor

Intrinsic factor is a protein that binds ingested **vitamin B_{12}** and enables it to be absorbed by the intestine. A deficiency of intrinsic factor — as a result of an autoimmune attack against parietal cells — causes **pernicious anemia**.

"Chief" Cells

The "chief" cells synthesize and secrete **pepsinogen**, the precursor to the proteolytic enzyme **pepsin**.

Pepsin cleaves peptide bonds, favoring those on the C-terminal side of tyrosine, phenylalanine, and tryptophan residues. Its action breaks long polypeptide chains into shorter lengths.

Secretion by the gastric glands is stimulated by the hormone gastrin. Gastrin is released by endocrine cells in the stomach in response to the arrival of food.

Absorption in the stomach

Very little occurs. However, some water, certain ions, and such drugs as aspirin and ethanol are absorbed from the stomach into the blood (accounting for the quick relief of a headache after swallowing aspirin and the rapid appearance of ethanol in the blood after drinking alcohol).

As the contents of the stomach become thoroughly liquefied, they pass into the **duodenum**, the first segment (about 10 inches long) of the small intestine.

Two ducts enter the duodenum:

- one draining the gall bladder and hence the **liver**
- the other draining the exocrine portion of the **pancreas**.

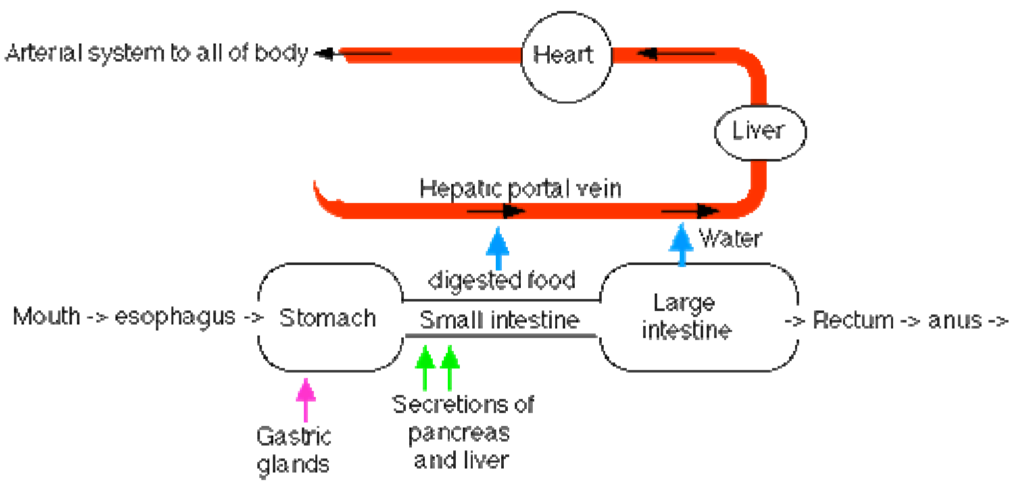
The liver

The liver secretes **bile**. Between meals it accumulates in the gall bladder. When food, especially when it contains fat, enters the duodenum, the release of the hormone cholecystokinin (CCK) stimulates the gall bladder to contract and discharge its bile into the duodenum.

Bile contains:

- **bile acids**. These amphiphilic steroids emulsify ingested fat. The hydrophobic portion of the steroid dissolves in the fat while the negatively-charged side chain interacts with water molecules. The mutual repulsion of these negatively-charged droplets keeps them from coalescing. Thus large globules of fat (liquid at body temperature) are emulsified into tiny droplets (about 1 µm in diameter) that can be more easily digested and absorbed.
- **bile pigments**. These are the products of the breakdown of hemoglobin removed by the liver from old red blood cells. The brownish color of the bile pigments imparts the characteristic brown color of the feces.

The hepatic portal system



The capillary beds of most tissues drain into veins that lead directly back to the heart. But blood draining the intestines is an exception. The veins draining the intestine lead to a second set of capillary beds in the liver. Here the liver removes many of the materials that were absorbed by the intestine:

- Glucose is removed and converted into **glycogen**.
- Other monosaccharides are removed and converted into glucose.
- Excess amino acids are removed and deaminated.
  - The amino group is converted into **urea**.
  - The residue can then enter the pathways of cellular respiration and be oxidized for energy.
- Many nonnutritive molecules, such as ingested drugs, are removed by the liver and, often, detoxified.

The liver serves as a gatekeeper between the intestines and the general circulation. It screens blood reaching it in the hepatic portal system so that its composition when it leaves will be close to normal for the body.

Furthermore, this homeostatic mechanism works both ways. When, for example, the concentration of glucose in the blood drops between meals, the liver releases more to the blood by

- converting its glycogen stores to glucose (glycogenolysis)
- converting certain amino acids into glucose (gluconeogenesis).

The pancreas

The pancreas consists of clusters if endocrine cells (the islets of Langerhans) and exocrine cells whose secretions drain into the duodenum.

Pancreatic fluid contains:

- **sodium bicarbonate** ($NaHCO_3$). This neutralizes the acidity of the fluid arriving from the stomach raising its pH to about 8.
- pancreatic **amylase**. This enzyme hydrolyzes starch into a mixture of maltose and glucose.
- pancreatic **lipase**. The enzyme hydrolyzes ingested fats into a mixture of fatty acids and monoglycerides. Its action is enhanced by the detergent effect of bile.
- 4 **"zymogens"** — proteins that are precursors to active proteases. These are immediately converted into the active proteolytic enzymes:
    - **trypsin.** Trypsin cleaves peptide bonds on the C-terminal side of arginines and lysines.
    - **chymotrypsin.** Chymotrypsin cuts on the C-terminal side of tyrosine, phenylalanine, and tryptophan residues (the same bonds as pepsin, whose action ceases when the $NaHCO_3$ raises the pH of the intestinal contents).
    - **elastase.** Elastase cuts peptide bonds next to small, uncharged side chains such as those of alanine and serine.
    - **carboxypeptidase.** This enzyme removes, one by one, the amino acids at the C-terminal of peptides.
- **nucleases**. These hydrolyze ingested nucleic acids (RNA and DNA) into their component nucleotides.

The secretion of pancreatic fluid is controlled by two hormones:

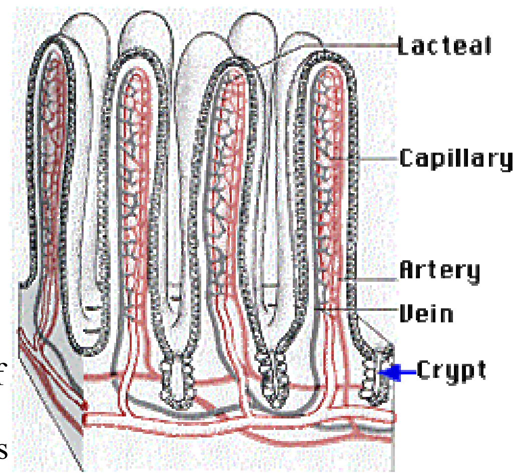
- secretin, which mainly affects the release of sodium bicarbonate, and
- cholecystokinin (**CCK**), which stimulates the release of the digestive enzymes.

The small intestine

Digestion within the small intestine produces a mixture of disaccharides, peptides, fatty acids, and monoglycerides. The final digestion and absorption of these substances occurs in the **villi**, which line the inner surface of the small intestine.

This scanning electron micrograph (courtesy of Keith R. Porter) shows the villi carpeting the inner surface of the small intestine.

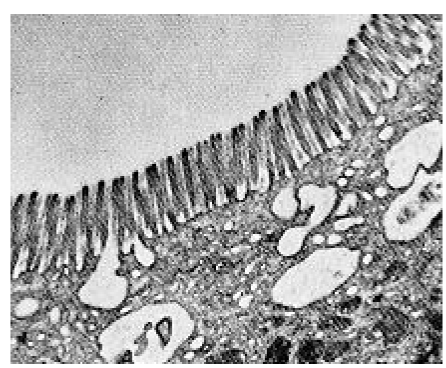
The **crypts** at the base of the villi contain **stem cells** that continuously divide by mitosis producing



- more stem cells
- cells that migrate up the surface of the villus while differentiating into
    1. columnar epithelial cells (the majority). They are responsible for digestion and absorption.
    2. **goblet cells**, which secrete mucus;
    3. **endocrine cells**, which secrete a variety of hormones;
- **Paneth cells**, which secrete antimicrobial peptides that sterilize the contents of the intestine.

All of these cells replace older cells that continuously die by apoptosis.

The villi increase the surface area of the small intestine to many times what it would be if it were simply a tube with smooth walls. In addition, the apical (exposed) surface of the epithelial cells of each villus is covered with **microvilli** (also known as a "brush border"). Thanks largely to these, the total surface area of the intestine is almost 200 square meters, about the size of the singles area of a tennis court and some 100 times the surface area of the exterior of the body.



The electron micrograph (courtesy of Dr. Sam L. Clark) shows the microvilli of a mouse intestinal cell.

Incorporated in the plasma membrane of the microvilli are a number of enzymes that complete digestion:

- **aminopeptidases** attack the amino terminal (N-terminal) of peptides producing amino acids.
- **disaccharidases**These enzymes convert disaccharides into their monosaccharide subunits.
    - **maltase** hydrolyzes maltose into glucose.
    - **sucrase** hydrolyzes sucrose (common table sugar) into glucose and fructose.
    - **lactase** hydrolyzes lactose (milk sugar) into glucose and galactose.

  Fructose simply diffuses into the villi, but both glucose and galactose are absorbed by active transport.

- **fatty acids and monoglycerides**. These become resynthesized into fats as they enter the cells of the villus. The resulting small droplets of fat are then discharged by exocytosis into the lymph vessels, called **lacteals**, draining the villi.

The large intestine (colon)

The large intestine receives the liquid residue after digestion and absorption are complete. This residue consists mostly of water as well as materials (e.g. cellulose) that were not digested. It nourishes a large population of bacteria (the contents of the small intestine are normally sterile). Most of these bacteria (of which one common species is E. coli) are harmless. And some are actually helpful, for example, by synthesizing vitamin K. Bacteria flourish to such an extent that as much as 50% of the dry weight of the feces may consist of bacterial cells.

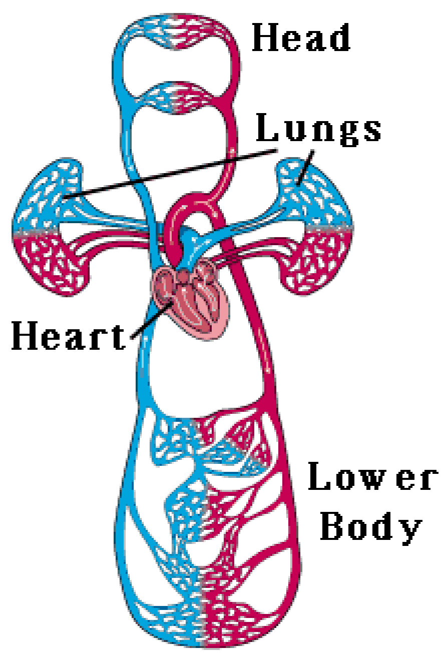
Reabsorption of water is the chief function of the large intestine. The large amounts of water secreted into the stomach and small intestine by the various digestive glands must be reclaimed to avoid dehydration. If the large intestine becomes irritated, it may discharge its contents before water reabsorption is complete causing **diarrhea**. On the other hand, if the colon retains its contents too long, the fecal matter becomes dried out and compressed into hard masses causing **constipation**.

Cardiovascular System
http://www.chelationtherapyonline.com/articles/p198.htm

Vertebrates, and a few invertebrates, have a closed circulatory system. Closed circulatory systems (evolved in echinoderms and vertebrates) have the blood closed at all times within vessels of different size and wall thickness. In this type of system, blood is pumped by a heart through vessels, and does not normally fill body cavities. Blood flow is not sluggish. Hemoglobin causes vertebrate blood to turn red in the presence of oxygen; but more importantly hemoglobin molecules in blood cells transport oxygen. The human closed circulatory system is sometimes called the cardiovascular system.

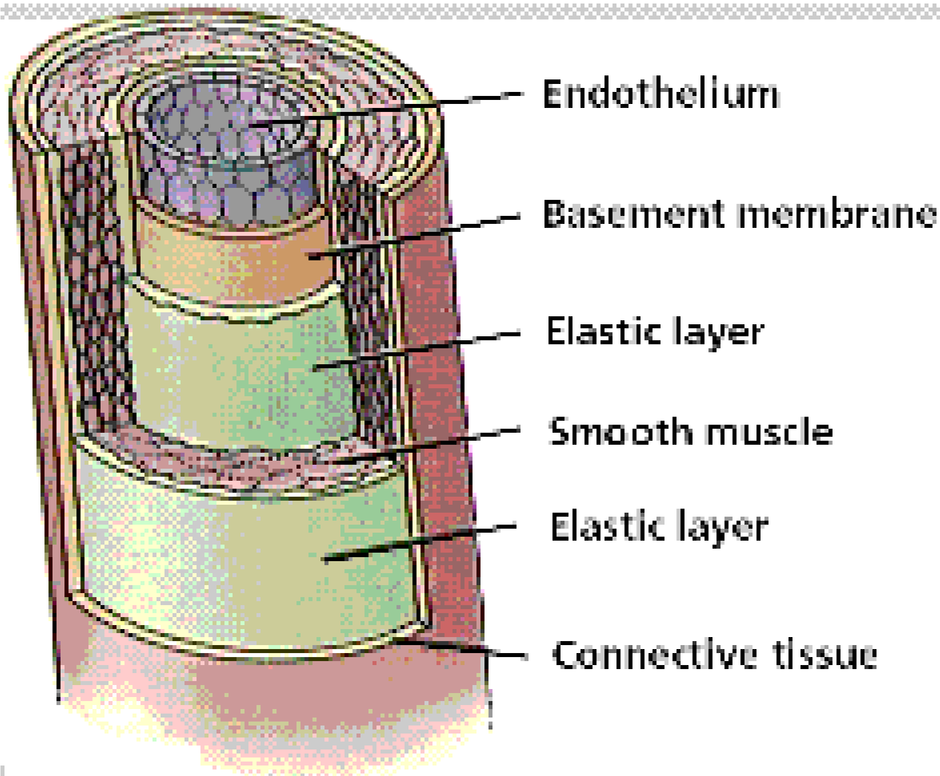
A secondary circulatory system, the lymphatic circulation, collects fluid and cells and returns them to the cardiovascular system.

The vertebrate cardiovascular system includes a heart, which is a muscular pump that contracts to propel blood out to the body through arteries, and a series of blood vessels. The upper chamber of the heart, the atrium (pl. atria), is where the blood enters the heart. Passing through a valve, blood enters the lower chamber, the ventricle. Contraction of the ventricle forces blood from the heart through an artery. The heart muscle is composed of cardiac muscle cells.



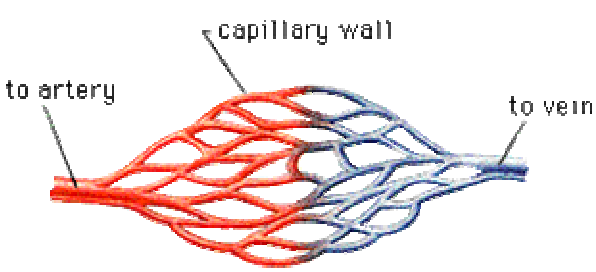
The basic circulatory patterns of blood flow in a mammal.
The image at right is from
http://johns.largnet.uwo.ca/shine/health/heart.htm.

Arteries are blood vessels that carry blood away from heart. Arterial walls are able to expand and contract. Arteries have three layers of thick walls. Smooth muscle fibers contract, another layer of connective tissue is quite elastic, allowing the arteries to carry blood under high pressure.

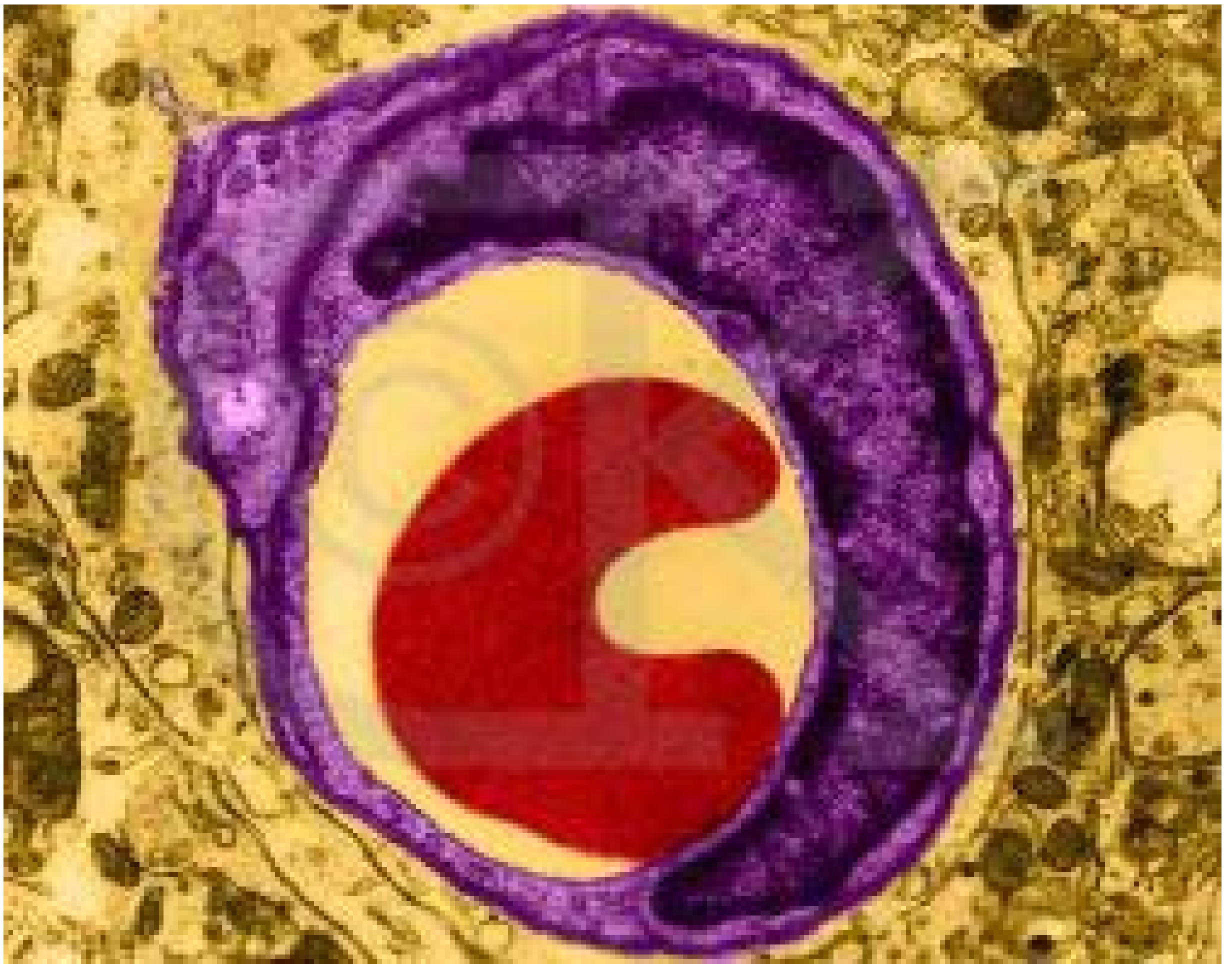


Structure of an artery. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

The aorta is the main artery leaving the heart. The pulmonary artery is the only artery that carries oxygen-poor blood. The pulmonary artery carries deoxygenated blood to the lungs. In the lungs, gas exchange occurs, carbon dioxide diffuses out, oxygen diffuses in. Arterioles are small arteries that connect larger arteries with capillaries. Small arterioles branch into collections of capillaries known as capillary beds.

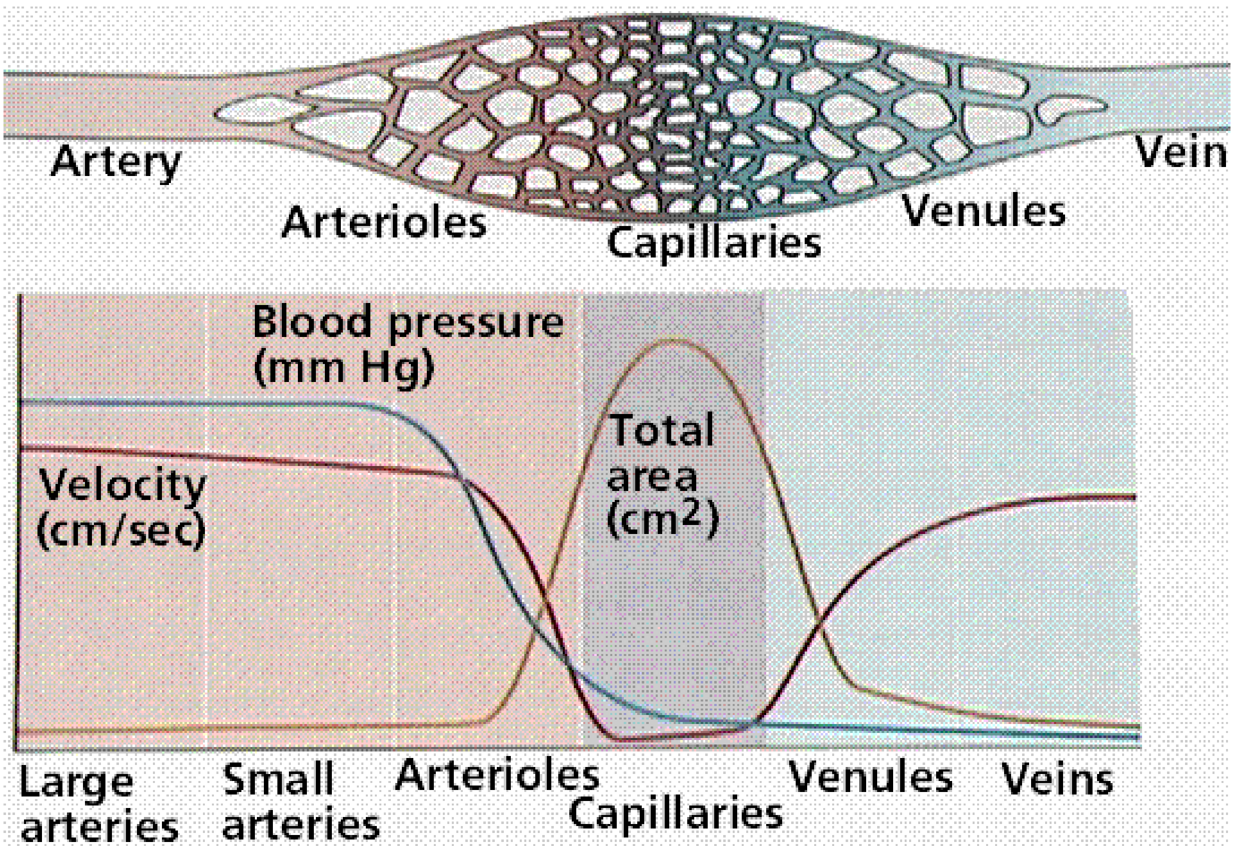


Structure and blood flow through a vein. The above illustration is from http://www.prs.k12.nj.us/schools/PHS/Science_Dept/APBio/pic/capillary.gif.



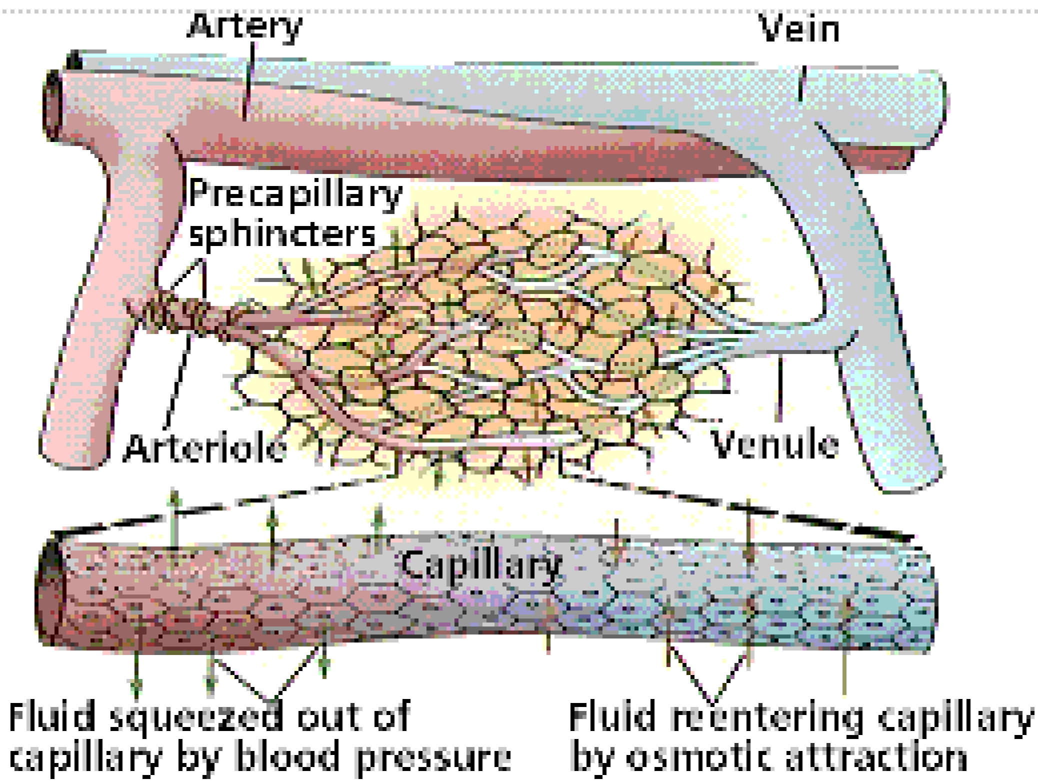
Capillary with Red Blood Cell (TEM x32,830). This image is copyright Dennis Kunkel at www.DennisKunkel.com,

Capillaries are thin-walled blood vessels in which gas exchange occurs. In the capillary, the wall is only one cell layer thick. Capillaries are concentrated into capillary beds. Some capillaries have small pores between the cells of the capillary wall, allowing materials to flow in and out of capillaries as well as the passage of white blood cells. Nutrients, wastes, and hormones are exchanged across the thin walls of capillaries. Capillaries are microscopic in size, although blushing is one manifestation of blood flow into capillaries. Control of blood flow into capillary beds is done by nerve-controlled sphincters.



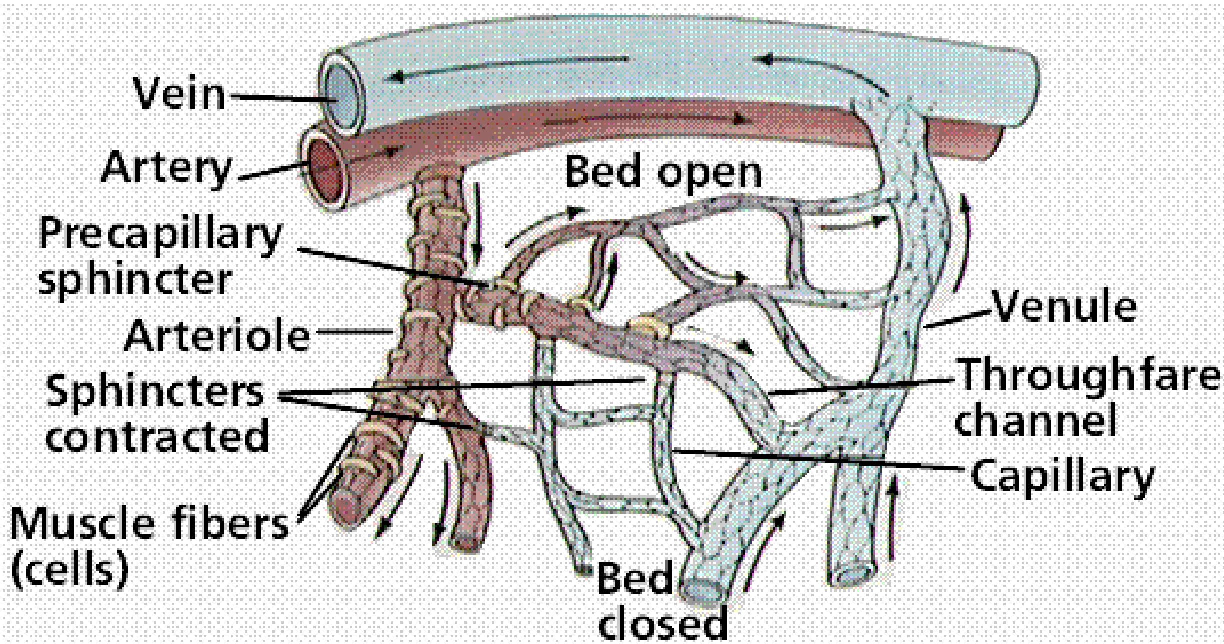
Changes in blood pressure, velocity, and the area of the arteries, capillaries, and veins of the circulatory system. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com),

The circulatory system functions in the delivery of oxygen, nutrient molecules, and hormones and the removal of carbon dioxide, ammonia and other metabolic wastes. Capillaries are the points of exchange between the blood and surrounding tissues. Materials cross in and out of the capillaries by passing through or between the cells that line the capillary.

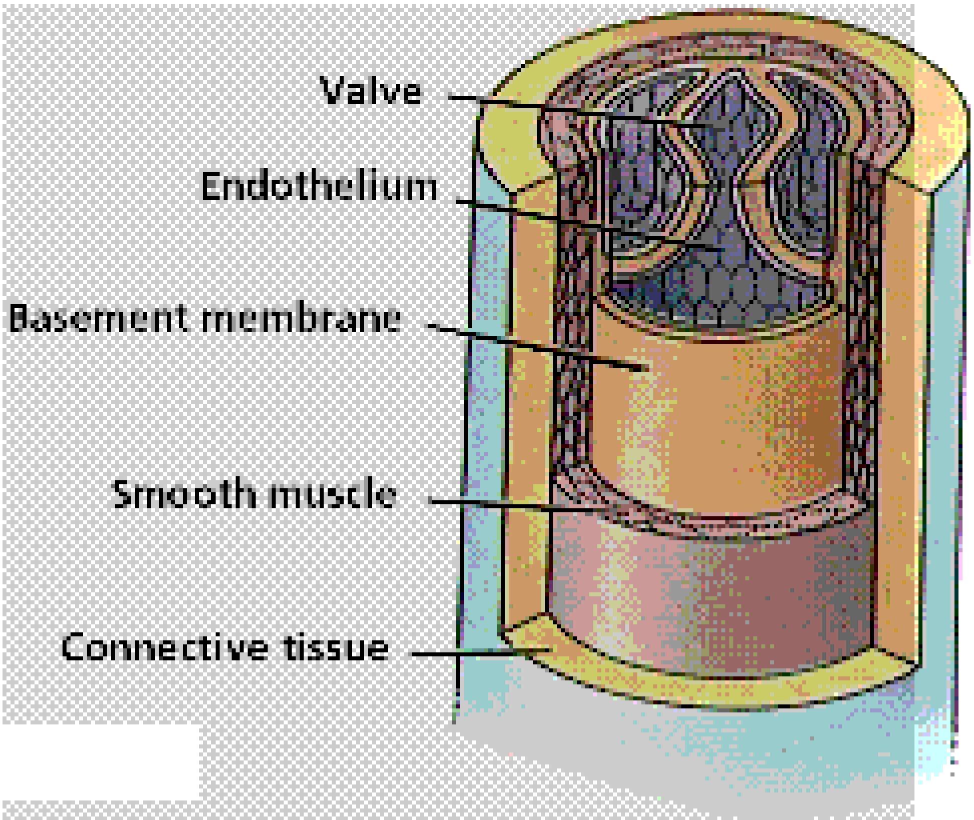


Capillary structure. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

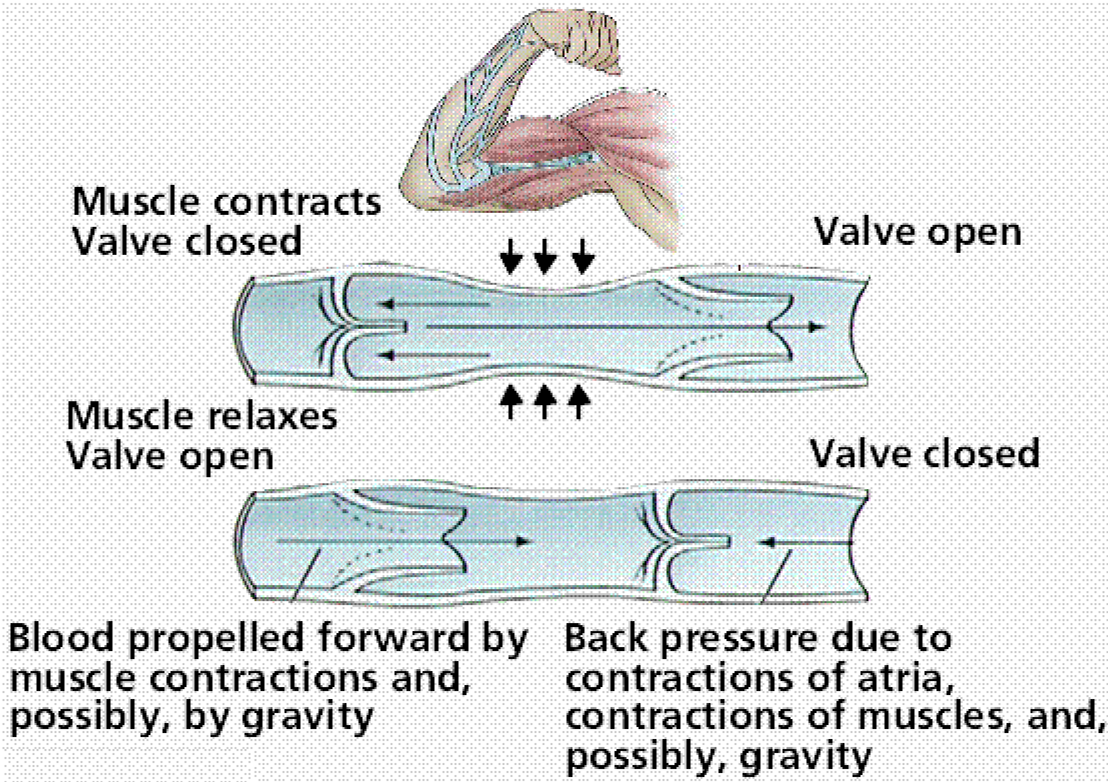
The extensive network of capillaries in the human body is estimated at between 50,000 and 60,000 miles long. Thoroughfare channels allow blood to bypass a capillary bed. These channels can open and close by the action of muscles that control blood flow through the channels.



Capillary beds and their feeder vessels. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com)



Blood leaving the capillary beds flows into a progressively larger series of venules that in turn join to form veins. Veins carry blood from capillaries to the heart. With the exception of the pulmonary veins, blood in veins is oxygen-poor. The pulmonary veins carry oxygenated blood from lungs back to the heart. Venules are smaller veins that gather blood from capillary beds into veins. Pressure in veins is low, so veins depend on nearby muscular contractions to move blood along. The veins have valves that prevent back-flow of blood.



Structure of a vein (top) and the actions of muscles to propel blood through the veins. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com),

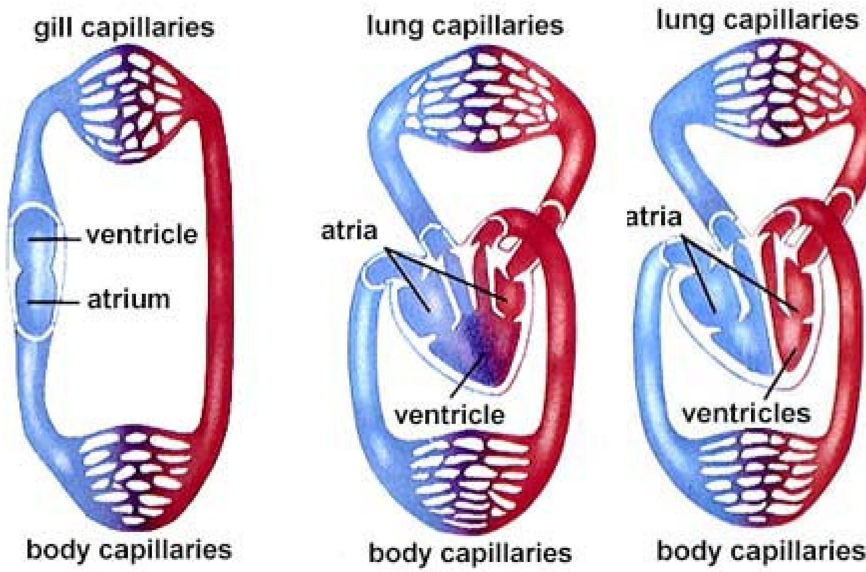
Ventricular contraction propels blood into arteries under great pressure. Blood pressure is measured in mm of mercury; healthy young adults should have pressure of ventricular systole of 120mm, and 80 mm at ventricular diastole. Higher pressures (human 120/80 as compared to a 12/1 in lobsters) mean the volume of blood circulates faster (20 seconds in humans, 8 minutes in lobsters).

As blood gets farther from the heart, the pressure likewise decreases. Each contraction of the ventricles sends pressure through the arteries. Elasticity of lungs helps keep pulmonary pressures low.

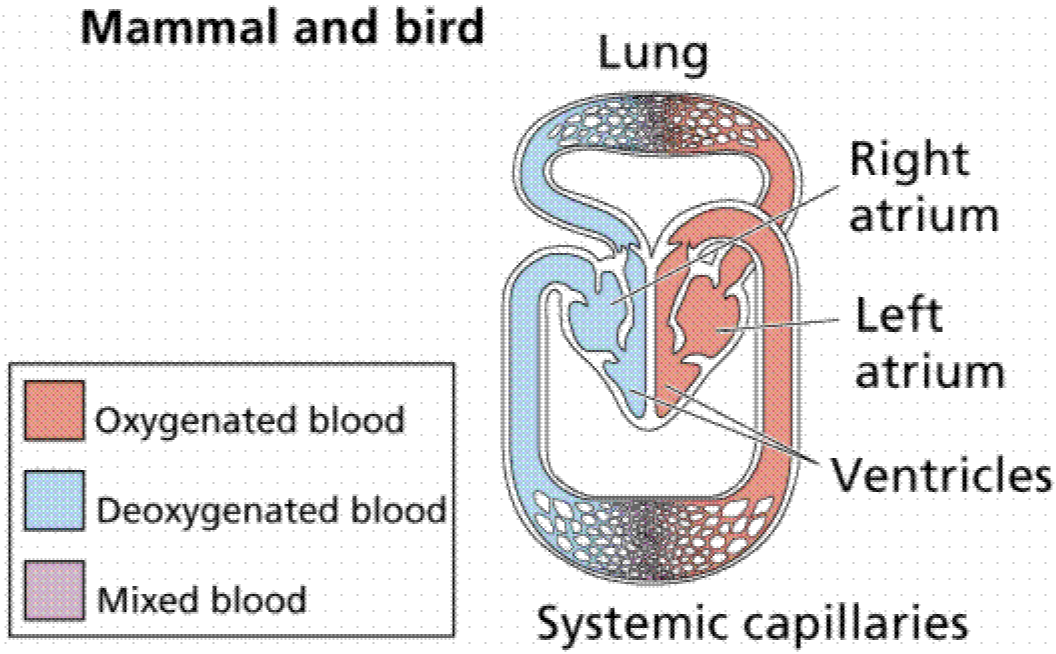
Systemic pressure is sensed by receptors in the arteries and atria. Nerve messages from these sensors communicate conditions to the medulla in the brain. Signals from the medulla regulate blood pressure.

Vertebrate Vascular Systems | **Back to Top**

Humans, birds, and mammals have a 4-chambered heart that completely separates oxygen-rich and oxygen-depleted blood. Fish have a 2-chambered heart in which a single-loop circulatory pattern takes blood from the heart to the gills and then to the body. Amphibians have a 3-chambered heart with two atria and one ventricle. A loop from the heart goes to the pulmonary capillary beds, where gas exchange occurs. Blood then is returned to the heart. Blood exiting the ventricle is diverted, some to the pulmonary circuit, some to systemic circuit. The disadvantage of the three-chambered heart is the mixing of oxygenated and deoxygenated blood. Some reptiles have partial separation of the ventricle. Other reptiles, plus, all birds and mammals, have a 4-chambered heart, with complete separation of both systemic and pulmonary circuits.



The above images are from http://www.biosci.uga.edu/almanac/bio_104/notes/may_7.html.
Diagram of a fish circulatory system (left), amphibian (center) and bird/mammal (right).



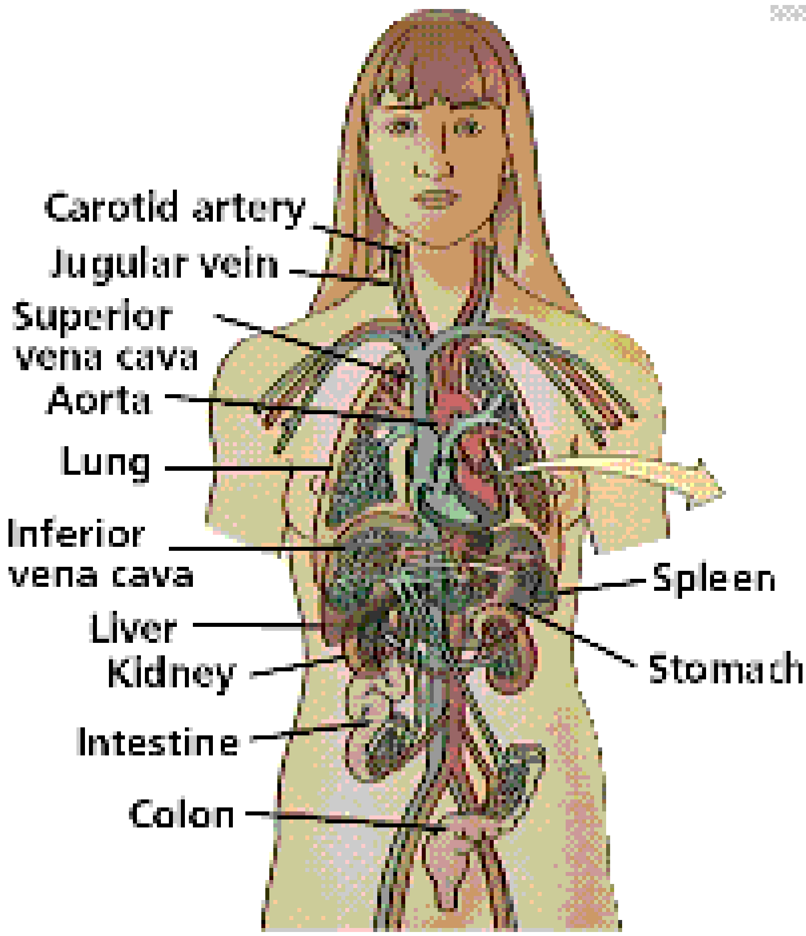
Circulatory systems of several vertebrates showing the progressive evolution of the four-chambered heart and pulmonary and systemic circulatory circuits. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

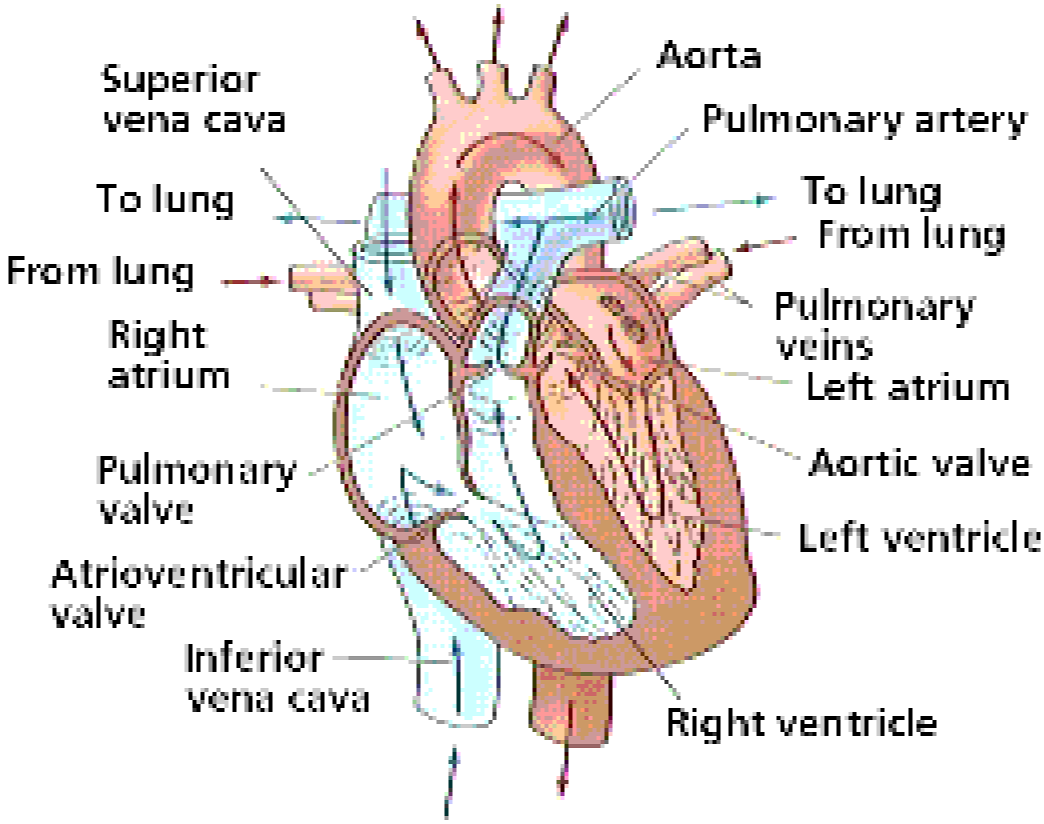
The Heart

The heart is a muscular structure that contracts in a rhythmic pattern to pump blood. Hearts have a variety of forms: chambered hearts in mollusks and vertebrates, tubular hearts of arthropods, and aortic arches of annelids. Accessory hearts are used by insects to boost or supplement the main heart's actions. Fish, reptiles, and amphibians have lymph hearts that help pump lymph back into veins.

The basic vertebrate heart, such as occurs in fish, has two chambers. An auricle is the chamber of the heart where blood is received from the body. A ventricle pumps the blood it gets through a valve from the auricle out to the gills through an artery.

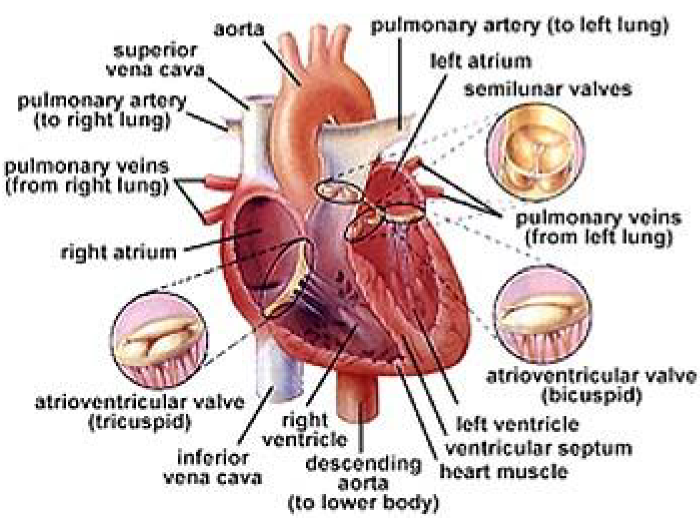
Amphibians have a three-chambered heart: two atria emptying into a single common ventricle. Some species have a partial separation of the ventricle to reduce the mixing of oxygenated (coming back from the lungs) and deoxygenated blood (coming in from the body). Two sided or two chambered hearts permit pumping at higher pressures and the addition of the pulmonary loop permits blood to go to the lungs at lower pressure yet still go to the systemic loop at higher pressures.


Carotid artery
Jugular vein
Superior vena cava
Aorta
Lung
Inferior vena cava
Liver
Kidney
Intestine
Colon
Spleen
Stomach



The relationship of the heart and circulatory system to major visceral organs. Below: the structure of the heart. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com).

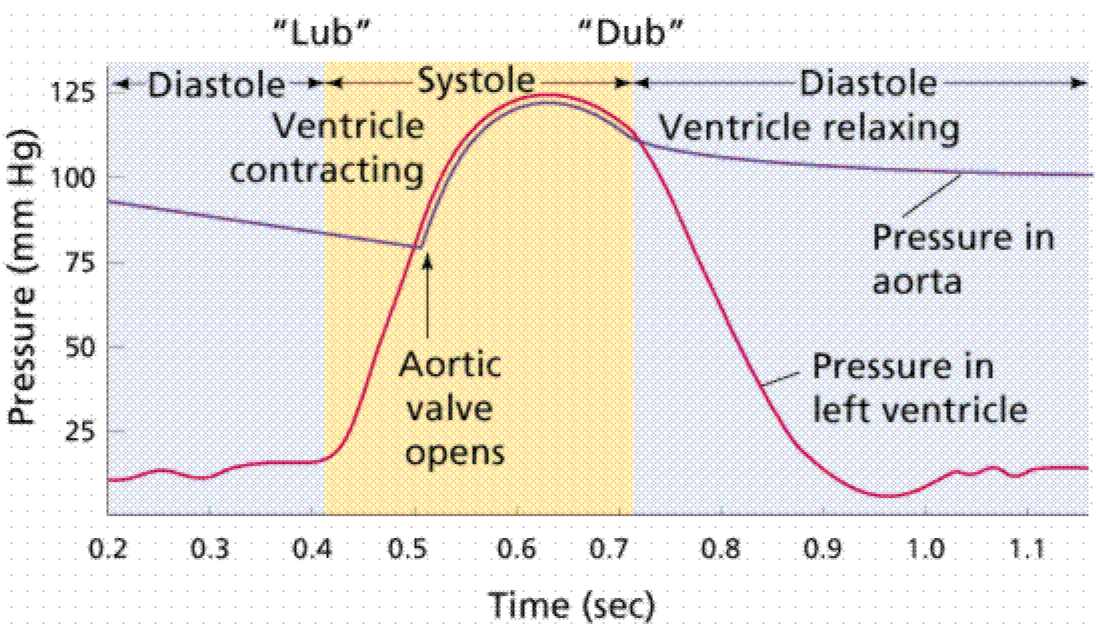
Establishment of the four-chambered heart, along with the pulmonary and systemic circuits, completely separates oxygenated from deoxygenated blood. This allows higher the metabolic rates needed by warm-blooded birds and mammals.



The above image is from http://www.biosci.uga.edu/almanac/bio_104/notes/may_7.html.

The human heart is a two-sided, 4 chambered structure with muscular walls. An atrioventricular (AV) valve separates each auricle from ventricle. A semilunar (also known as arterial) valve separates each ventricle from its connecting artery.

The heart beats or contracts 70 times per minute. The human heart will undergo over 3 billion contraction cycles during a normal lifetime. The cardiac cycle consists of two parts: systole (contraction of the heart muscle) and diastole (relaxation of the heart muscle). Atria contract while ventricles relax. The pulse is a wave of contraction transmitted along the arteries. Valves in the heart open and close during the cardiac cycle. Heart muscle contraction is due to the presence of nodal tissue in two regions of the heart. The SA node (sinoatrial node) initiates heartbeat. The AV node (atrioventricular node) causes ventricles to contract. The AV node is sometimes called the pacemaker since it keeps heartbeat regular. Heartbeat is also controlled by the autonomic nervous system.

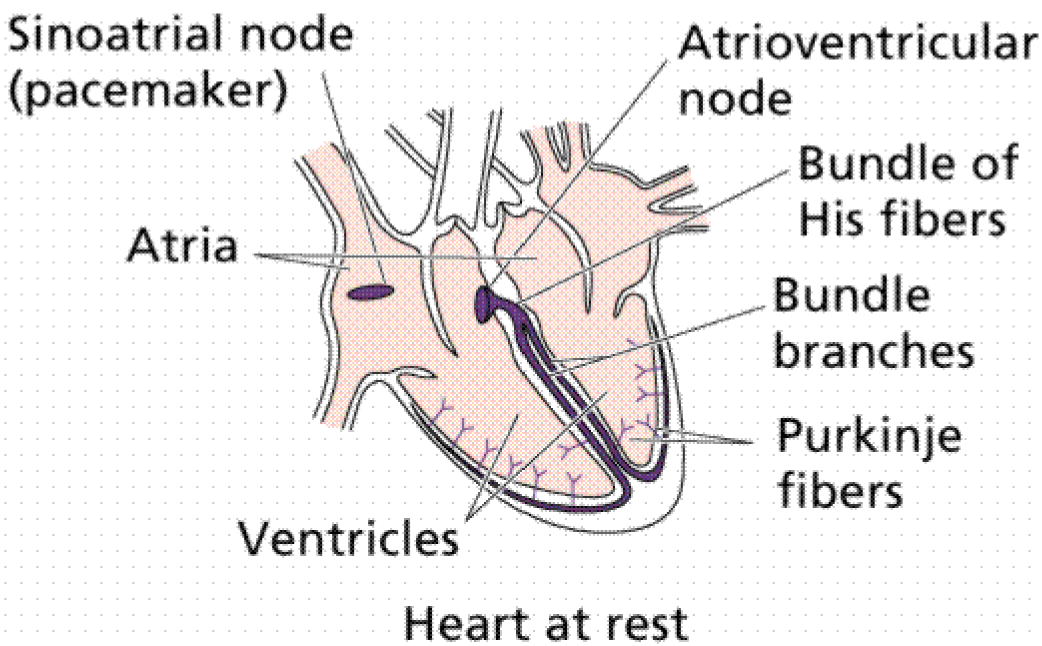


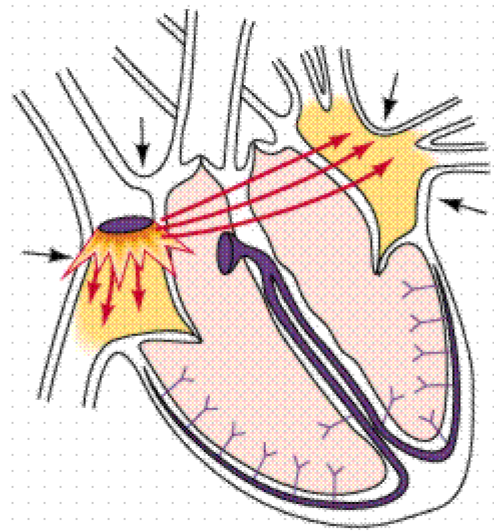
The cardiac cycle. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com).

Blood flows through the heart from veins to atria to ventricles out by arteries. Heart valves limit flow to a single direction. One heartbeat, or cardiac cycle, includes atrial contraction and relaxation, ventricular contraction and relaxation, and a short pause. Normal cardiac cycles (at rest) take 0.8 seconds. Blood from the body flows into the vena cava, which empties into the right atrium. At the same time, oxygenated blood from the lungs flows from the pulmonary vein into the left atrium. The muscles of both atria contract, forcing blood downward through each AV valve into each ventricle.

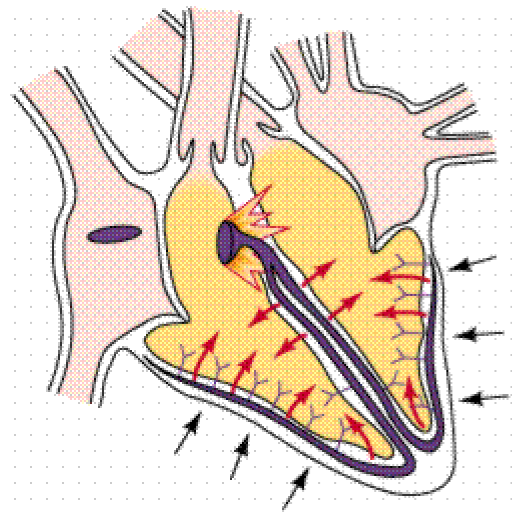
Diastole is the filling of the ventricles with blood. Ventricular systole opens the SL valves, forcing blood out of the ventricles through the pulmonary artery or aorta. The sound of the heart contracting and the valves opening and closing produces a characteristic "lub-dub" sound. Lub is associated with closure of the AV valves, dub is the closing of the SL valves.

Human heartbeats originate from the sinoatrial node (SA node) near the right atrium. Modified muscle cells contract, sending a signal to other muscle cells in the heart to contract. The signal spreads to the atrioventricular node (AV node). Signals carried from the AV node, slightly delayed, through bundle of His fibers and Purkinjie fibers cause the ventricles to contract simultaneously.





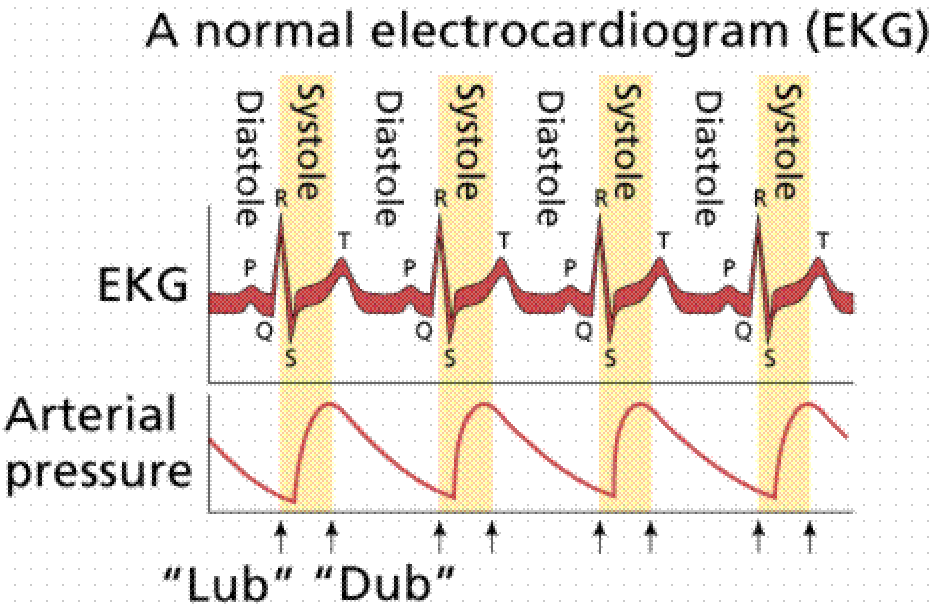
Sinoatrial node fires, action potentials spread through atria which contract

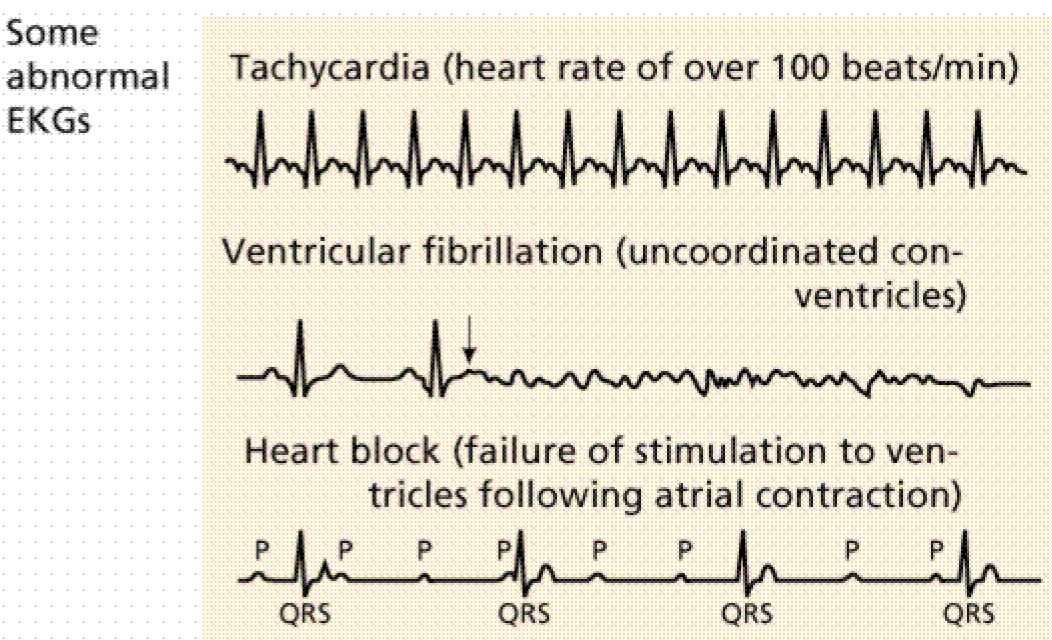


Atrioventricular node fires, sending impulses along conducting fibers; ventricles contract

The contraction of the heart and the action of the nerve nodes located on the heart.
Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com).

An electrocardiogram (ECG) measures changes in electrical potential across the heart, and can detect the contraction pulses that pass over the surface of the heart. There are three slow, negative changes, known as P, R, and T. Positive deflections are the Q and S waves. The P wave represents the contraction impulse of the atria, the T wave the ventricular contraction. ECGs are useful in diagnosing heart abnormalities.





Normal cardiac pattern (top) and some abnormal patterns (bottom). Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com).

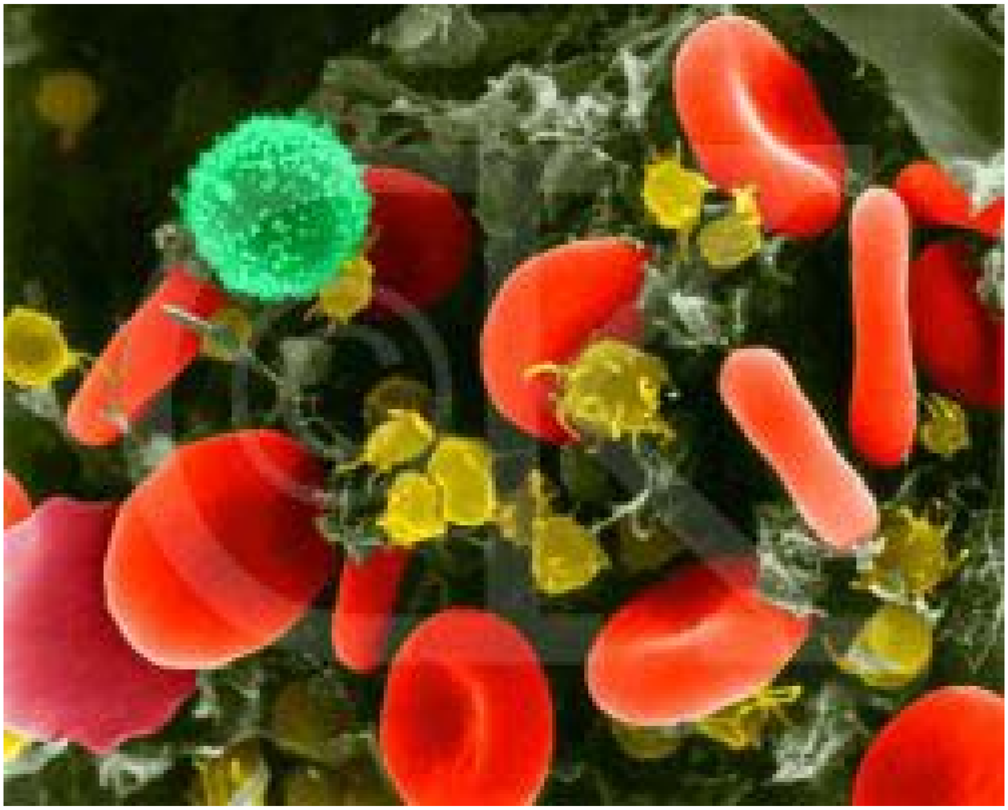
Blood

Plasma is the liquid component of the blood. Mammalian blood consists of a liquid (plasma) and a number of cellular and cell fragment components. Plasma is about 60 % of a volume of blood; cells and fragments are 40%. Plasma has 90% water and 10% dissolved materials including proteins, glucose, ions, hormones, and gases. It acts as a buffer, maintaining pH near 7.4. Plasma contains nutrients, wastes, salts, proteins, etc. Proteins in the blood aid in transport of large molecules such as cholesterol.

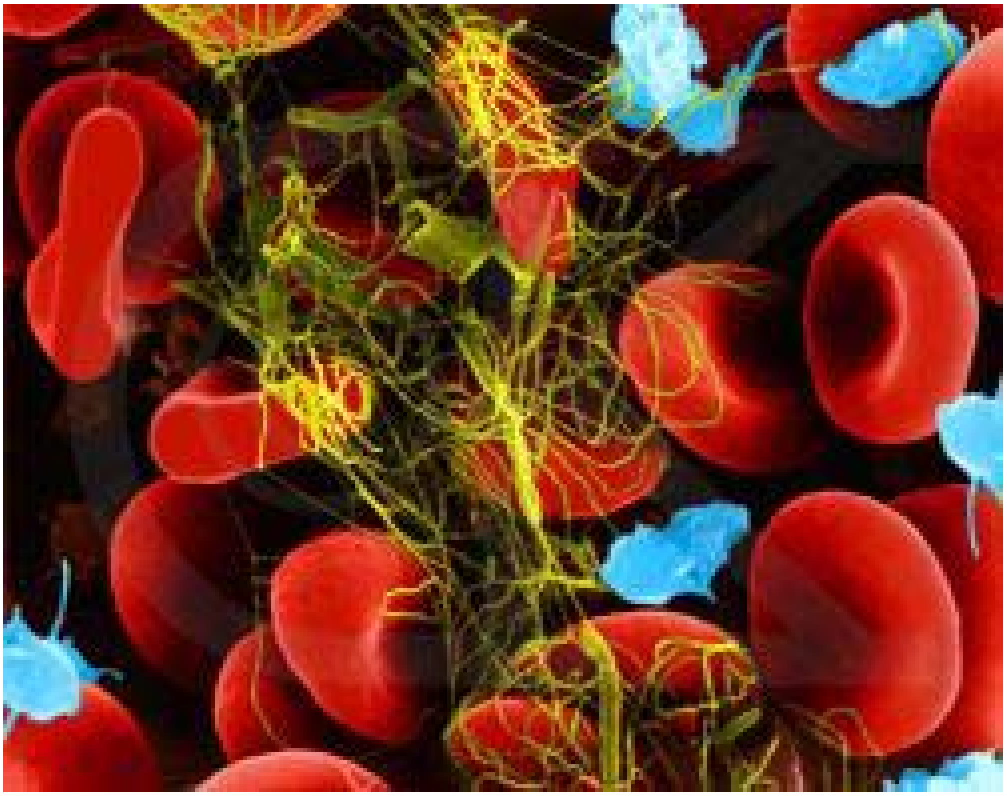
Red blood cells, also known as erythrocytes, are flattened, doubly concave cells about 7 µm in diameter that carry oxygen associated in the cell's hemoglobin. Mature erythrocytes lack a nucleus. They are small, 4 to 6 million cells per cubic millimeter of blood, and have 200 million hemoglobin molecules per cell. Humans have a total of 25 trillion (about 1/3 of all the cells in the body). Red blood cells are continuously manufactured in red marrow of long bones, ribs, skull, and vertebrae. Life-span of an erythrocyte is only 120 days, after which they are destroyed in liver and spleen. Iron from hemoglobin is recovered and reused by red marrow. The liver degrades the heme units and secretes them as pigment in the bile, responsible for the color of feces. Each second 2 million red blood cells are produced to replace those taken out of circulation.

White blood cells, also known as leukocytes, are larger than erythrocytes, have a nucleus, and lack hemoglobin. They function in the cellular immune response. White blood cells (leukocytes) are less than 1% of the blood's volume. They are made from stem cells in bone marrow. There are five types of leukocytes, important components of the immune system. Neutrophils enter the tissue fluid by squeezing through capillary walls and phagocytozing foreign substances. Macrophages release white blood cell growth factors, causing a population increase for white blood cells. Lymphocytes fight infection. T-cells attack cells containing viruses. B-cells produce antibodies. Antigen-antibody complexes are phagocytized by a macrophage. White blood cells can squeeze through pores in the capillaries and fight infectious diseases in interstitial areas

Platelets result from cell fragmentation and are involved with clotting. Platelets are cell fragments that bud off megakaryocytes in bone marrow. They carry chemicals essential to blood clotting. Platelets survive for 10 days before being removed by the liver and spleen. There are 150,000 to 300,000 platelets in each milliliter of blood. Platelets stick and adhere to tears in blood vessels; they also release clotting factors. A hemophiliac's blood cannot clot. Providing correct proteins (clotting factors) has been a common method of treating hemophiliacs. It has also led to HIV transmission due to the use of transfusions and use of contaminated blood products.



Human Red Blood Cells, Platelets and T-lymphocyte (erythocytes = red; platelets = yellow; T-lymphocyte = light green) (SEM x 9,900).



Blood Clot Formation (blood cells, platelets, fibrin clot) (SEM x10,980).

The Lymphatic System

Water and plasma are forced from the capillaries into intracellular spaces. This interstitial fluid transports materials between cells. Most of this fluid is collected in the capillaries of a secondary circulatory system, the lymphatic system. Fluid in this system is known as lymph.

Lymph flows from small lymph capillaries into lymph vessels that are similar to veins in having valves that prevent backflow. Lymph vessels connect to lymph nodes, lymph organs, or to the cardiovascular system at the thoracic duct and right lymphatic duct.

Lymph nodes are small irregularly shaped masses through which lymph vessels flow. Clusters of nodes occur in the armpits, groin, and neck. Cells of the **immune system** line channels through the nodes and attack bacteria and viruses traveling in the lymph.

Links

- American Heart Association Page
- The Circulatory System A health-related view of the heart and its associated organs.
- The Heart Clear text and some nice graphics, including an animated beating heart.
- The Respiratory and Circulatory Systems A clickable map from Japan.
- The Circulatory System Yes, another page with the same good descriptive title.
- The Heart and the Circulatory System Roger B. Phillips from Access Excellence Collection. Historical overview of the development of our understanding of circulatory systems.