

## Circulatory system.

Basic function:

To provide the body (cells) with oxygen, and remove CO<sub>2</sub>.

To provide the body (cells) with nutrients and remove wastes.

Not all organisms have a circulatory system - the smaller you are the less likely it is you need one.

Two types of circulatory systems [Fig., similar to 23.1, p. 468]:

Open - only a few large blood vessels are present; no smaller vessels and *no* capillaries.

When the heart beats, fluid moves through the heart, and then is just “dumped” into the body tissues.

The large vessels simply help to distribute the fluid a bit.

All parts of the body are “bathed” in this fluid.

Common particularly in insects and other arthropods.

Closed circulatory system - blood is always confined to blood vessels.

Small blood vessels are present throughout the tissues.

This insures that blood can get to all parts of the body.

Common in cephalopods, earthworms, and vertebrates.

Vertebrate cardiovascular systems:

The heart is composed of at least two parts: an atrium and a ventricle.

Higher vertebrates may have more than one of each.

*Atrium* - receives blood from the body, pumps blood to ventricle.

*Ventricle* - pumps blood out of the heart.

Blood vessels in the body:

Arteries - large blood vessels leading away from the heart.

Arterioles - small arteries.

Capillaries - very small blood vessels that diffuse into tissues. This is where cells get O<sub>2</sub> and get rid of CO<sub>2</sub>.

Venules - small veins (see below)

Veins - large blood vessels that lead into the heart.

Notice that some blood vessels may have different names (the aorta, for example is an artery, and the inferior vena cava is a vein).

We also have *portal veins*:

Portal veins go from one system of the body to another (they don't come from or go to the heart).

The hepatic portal vein is an example (comes from the small intestine, goes to the liver).

The flow of blood in mammals [Fig. 23.2, p. 469]:

right ventricle → lungs → left atrium → left ventricle → body → right atrium → right ventricle

Compared to other animals, all parts of the body get newly oxygenated blood.

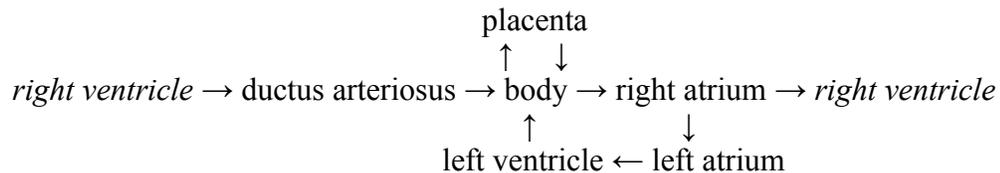
This is also under high pressure

(Notice fish get newly oxygenated blood as well, but it's under low pressure)

Blood going to the lungs is considered to be in the “pulmonary circuit”, whereas blood going to the body is in the “systemic circuit”.

This arrangement works well in adults, but not in the fetus (why?).

So we need special arrangements in a fetus: [Fig., not in book]:



Notice the following:

- 1) Blood bypasses the lungs (the right ventricle goes to the ductus arteriosus, and then back to the body).
- 2) Some blood from the right atrium goes to the left atrium, some goes to the right ventricle.
- 3) Blood is oxygenated through the placenta

Details of the human heart [Figs. 23.3 and 23.4A, pp. 469 - 470].

The figures simply provide more details and a review of the adult circulation.

Cardiac cycle, or, what happens from one heart contraction to the next?

Some definitions:

*Heart rate* - the number of times the heart beats in one minute.

The pulse is always recorded as beats/minute, though it is often measured over 15, 20 or even 30 seconds. The average resting heart rate is about 70 beats/min.

*Stroke volume* - the amount of blood pumped by *left* ventricle with one beat

The average is about 75ml per beat.

*Cardiac output* - the amount of blood pumped by left ventricle in one minute.

The average is about 5.25L, which, coincidentally, is about the amount of blood present in humans.

This can be calculated using the heart rate and stroke volume; for example:

$$70 \times 75\text{ml} = 5250\text{ml} = 5.25\text{L}$$

[Question - what about the right ventricle?]

Steps in the cardiac cycle [Fig. 23.4B, p. 470]

*Systole* refers to the contraction phase.

*Diastole* refers to the relaxation phase.

- 1) atria and ventricles are relaxed (in diastole)
- 2) atria contract (atrial systole), ventricles remain relaxed (ventricular diastole).
- 3) ventricles contract (ventricular systole), atria relax (atrial diastole).
- 4) repeat.

During step 3, “lub” sound is produced as AV (= *atrio-ventricular*) valves close.

During step 1, “dub” sound is heard as semilunar valves close.

Comments:

The AV valves prevent backflow of blood from ventricles to atria.

The semilunar valves prevent backflow of blood from “aortas” to ventricles.

A heart murmur is often caused by a backflow of blood against the valves.

Good physicians can diagnose this using just a stethoscope.

Electrical properties of heart [OVERHEAD, similar to fig. 23.5A, p. 472].

Cardiac muscle cells will contract without any kind of external stimulus.

Something needs to coordinate these cells:

The SA (= *sino-atrial*) node which is located in the wall of the right atrium releases the signal to beat.

Intercalated disks (at the ends of cardiac cells) allow rapid dissemination of this electrical stimulus, and the atria contract.

The signal then reaches the AV (= atrio-ventricular) node.

The signal is delayed (to ensure atria get done contracting),

Then specialized muscle fibers transmit the signal to the ventricles which then contract.

Note: when cells do not beat in a coordinated fashion, blood is not pumped to the body (different parts of the heart beat at different times).

The heart needs to be “reset”.

A defibrillator is very useful here - it “stops” the heart, so that the signal can start again in a coordinated fashion.

These “electrical” signals can be picked up with an EKG / ECG (same thing).

These signals *are* electrical in nature, and while they correspond to the various steps in the cardiac cycle, they do not directly measure such things as “ventricles contracting”.

The measure the electrical signal that causes the ventricles to contract.

A subtle but important difference!

Some examples of things that can influence heart rate:

Hormones - epinephrine, for example, causes an increase in heart rate.

Body temperature - fever can increase the heart rate; hypothermia can lower heart rate.

Food - things like caffeine can increase heart rate, other foods can decrease heart rate.

Condition - if one is in excellent condition, the heart rate is often much lower

If the average heart rate is around 70. someone in good condition might have a heart rate as low as 50 or even lower.

Similarly, if someone is in really bad shape, their resting heart rate can be higher.

Stimuli from nerves - stimuli from nerves that connect to the SA node can speed up or slow down the heart.

This is how your heart knows to increase the pulse when you're exercising, etc.

Two things affect the flow of blood around the body:

- 1) Heart rate: how fast the heart is beating (we just got done discussing this).
- 2) Blood pressure [**Fig 23.9 page 476**]:

Blood pressure:

First some definitions:

Systolic pressure - maximum pressure when ventricles contract.

Diastolic pressure - minimum pressure when ventricles are relaxed.

Blood pressure is measured in mm Hg.

A typical 'average' blood pressure is 120 / 80

Notice that systolic pressure is ALWAYS in the numerator.

Why is there a minimum pressure? Why is this 0?

Several reasons:

- 1) the elasticity of artery walls - this helps spread out the high pressure pulse.
- 2) peripheral resistance - the increase in resistance (friction) when blood enters capillaries.

This slows the blood down dramatically, and as a result, blood that is in between two high pressure pulses is squeezed.

(Blood from the first pulse slows down, but blood from the second pulse is still moving fast).

Go through sphygmomanometer function using the figure.

Some comments about blood pressure:

As one moves away from the heart, blood pressure drops.

It makes a difference where you measure blood pressure - it's not always the forearm (sometimes this is used diagnostically).

Blood pressure drops dramatically (and smooths out) as blood moves into the capillaries and finally into the veins [**Fig. 23.8A, p. 475**].

Venous blood pressure is so low that blood needs assistance to move back to heart [**Fig. 23.8B, p. 475**]:

Valves in veins

There is a really nice and simple demonstration of the valves in your veins. Your lab instructor may show it to you.

Skeletal muscles contracting, squeezing the veins.

Capillary function:

Many capillary beds can be turned off by muscles (sphincters) that control access to the capillaries [Fig. 23.10, p.477].

This is very useful; some examples:

When exercising diverts blood from the digestive system.

When hot shunts blood to the skin

When suffering from blood loss blood is shunted to vital systems.

There is not enough blood in the body to turn everything on (to provide all your capillaries with blood at the same time.

A nasty example of this is anaphylactic shock.

This is a life threatening allergic reaction - massive amounts of histamine are released, this causes capillary beds to open.

If too many open all at once, this causes a drastic fall in blood pressure.

It's a little like bleeding to death without losing blood - suddenly there isn't enough blood to go around.

An epi-pen can be a life saver here - it releases adrenalin (epinephrine) which causes the digestive system to shut down.

Adrenalin causes an increase in heart rate, but also shuts down non-essential systems; it gives you an extra burst of energy to "fight or run away" from danger.

Details of how oxygen is actually diffused into the tissues are in your text if you're interested. But do note that this is where increased blood pressure is important.

Lymphatic system [Fig., similar to fig. 24.4, p. 489]:

Fluid leaves the capillaries as they enter the tissues.

Not all of this fluid is returned to the capillaries.

The leftover fluid enters the lymphatic system.

This "lymph" or lymphatic fluid is carried by small lymphatic vessels that come together to form bigger vessels.

The lymphatic fluid is eventually dumped into the circulatory system right near the heart (near the right atrium).

Lymph vessels function very much like veins in moving lymph back to heart.

Lots of valves, assisted by muscular contractions.

Throughout the lymphatic system are lymph nodes.

Lymph nodes filter the lymphatic fluid and attack viruses, bacteria and other pathogens (they “clean” the lymph).

Details on this when we do the immune system.

Blockage of the lymphatic system can be painful and cause serious deformities.

For example, filarial worms (nematodes) that causes elephantiasis.

Nature of blood [**Fig. 23.12 p. 479**]:

55% blood plasma - fluid that contains water, solvents, ions, proteins, nutrients, etc.

45% living components:

red blood cells - transport of oxygen, carbon dioxide;

white blood cells - body defense and immunity;

platelets - blood clotting;

Some comments:

Each RBC contains about 250 million molecules of hemoglobin.

Cells in the blood are all generated from “stem cells” that exist in the bone marrow [**Fig. 23.15, p. 481**].

Occasionally, this may malfunction, leading to overproduction of certain types

For example, leukemia can be caused by overproduction of leukocytes.

Blood clotting:

Involves a complicated pathway [**Fig. similar to 23.14A, p. 480**].

Essentially, if platelets encounter a rough surface, they become sticky and release a substance that causes nearby platelets to become sticky as well.

So platelets stick together and begin to plug the injury.

The platelets also release chemicals that change **prothrombin** into **thrombin**

**Thrombin** then changes **fibrinogen** into **fibrin**.

**Fibrin** is a long but strong protein that weaves itself in and around the injury, binding up platelets, blood cells and other material. It helps form the “clot”.

[Comment: why might you want “two” steps here?]

## Addendum on Heart Disease:

### I. Causes (risk factors) [Fig., not in text].

#### Preventable factors:

##### Diet:

Cholesterol is thought to increase the tendency to form blockages in vessels (this is LDL cholesterol or “bad” cholesterol). We're still not exactly sure of the mechanism.

Other types of cholesterol (HDL) may actually help prevent blockages.

An overall level of 200 mg/dl is borderline high cholesterol, although the ratio of LDL to HDL is also very important.

##### Exercise (mostly aerobic):

Helps strengthen the heart muscle and increase circulatory system efficiency.

Helps increase HDL levels (good cholesterol levels).

Approximately halves the risk of having a heart attack.

##### Smoking:

Decreases levels of HDL (good cholesterol)

Constricts blood vessels surrounding the heart (nicotine acts as a “vaso-constrictor”)

We've already discussed the effects of smoking on the respiratory system.

Approximately doubles the risk of having a heart attack.

#### Factors that can't be prevented:

##### Aging:

Your condition deteriorates as you get older. Plaques and other blockages start to form, blood vessels become less flexible.

##### Family history:

Things like high cholesterol and heart disease can run in families.

Not much that can be done about genetic history (except take medication).

##### Disease:

Diseases can cause heart disease

High fevers can damage heart valves

Infections can interfere with the correct functioning of the heart (even cause buildup along the heart valves).

Others.

Being male:

Males are more prone to heart disease.

## II. Hypertension (= high blood pressure):

Causes increased stress on the heart (has to work harder).

Increased pressure can cause damage to the blood vessels, which in turn can lead to the buildup of plaque and then to atherosclerosis (blockages).

Often leads directly to heart attack, stroke, or kidney disease.

Has many of the same risk factors as above, and is directly related to heart disease.

(High blood pressure often leads to (or is responsible for) heart disease, the opposite isn't always true).

## III. Some types of heart disease:

Most of these can be minor (e.g., require a pacemaker), or major (e.g. heart attack).

Congenital heart disease:

Genetic or birth defect in the heart.

Arrhythmias (irregular heart beat).

Covers a lot of ground - any irregular heart beat can be termed an arrhythmia, and some are quite benign.

Heart valve disease.

For example, mitral valve prolapse, in which the valve allows blood to leak “back” from the left ventricle to the left atrium (mitral is another term for the left AV valve).

Heart failure.

Simply, the heart does not work as well as it should.

Has many, many causes.

While it can be benign, usually it's more progressive and will eventually cause serious problems.

## Heart attack [Fig. 23.6A & B, p. 473]

Often caused by a blockage of the coronary arteries

The coronary arteries supply the blood to the actual heart muscle.

The blockage is formed by atherosclerosis.

Deposits of plaque on the walls of the arteries; this causes a narrowing of the blood vessel.

This narrowing is more likely to become blocked by a blood clot.

The blockage can also slowly become severe enough to cause problems on its own.

As a result of a heart attack, the parts of the heart served by the blocked vessel can die (the heart muscle cells need lots of oxygen).

If a large enough area is affected, the result can be death.

Blockages can be treated in a number of different ways:

Bypass, stents, drilling, etc. (details in class).

In general, heart disease can be treated with drugs or surgery.

It can be prevented by life style changes (diet/exercise/stopping smoking).

Heart disease is the # 1 killer of people in the U.S.

Incidentally, strokes, 80% of which are caused by blockages in the blood vessels to the brain, are the # 3 killer [Fig., not in text].