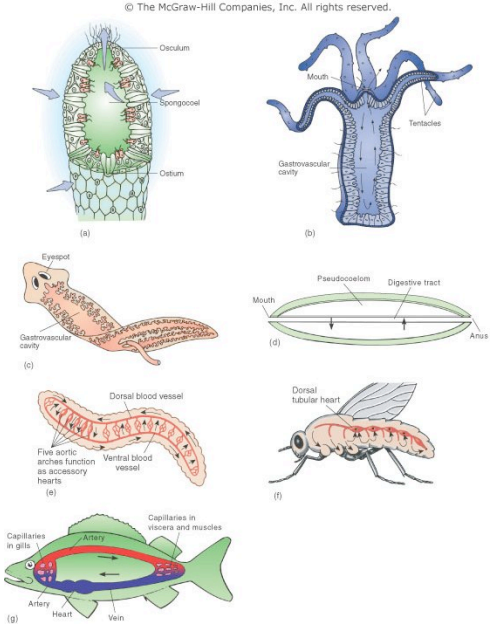
Circulatory systems

Movement of substances by **bulk flow** (convection) is needed in large animals (> ~ 1 mm) to overcome the limitations of diffusion.

Circulatory systems consist of:

- a **pump** (heart) to provide power in the form of hydrostatic pressure (may be more than one)
- a system of **tubes** (vessels) through which fluid circulates
  -- open or closed system
- a **circulatory fluid** (blood)
  -- interstitial fluid or specialized tissue (as in vertebrates)



Circulatory systems

Architecture of the circulatory vessels

Open circulations: blood contained in vessels for only part of its circuit (blood = interstitial fluid)

Closed circulations: blood always remains in vessels (blood can be different from interstitial fluid); common in active animals

Circulatory anatomy depends on animal size, how gases are exchanged, and metabolic rate

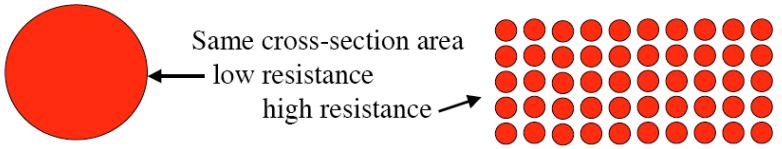
- Usually, animals with high metabolism need rapid blood circulation

Circulatory systems

Architecture of the circulatory vessels

Flow rate of blood in a vessel depends on **blood pressure** and **resistance to flow**: for high flow rates, need high pressure and low resistance

- Blood pressure depends largely on power of the heart
- resistance is largely an inverse function of vessel diameter
- large tubes are used to carry blood rapidly over long distances (less resistance to flow; less pumping power needed):



- in closed systems, narrow, thin walled **capillaries** are the sites of exchange (large surface area) -- impossible in large, thick vessels

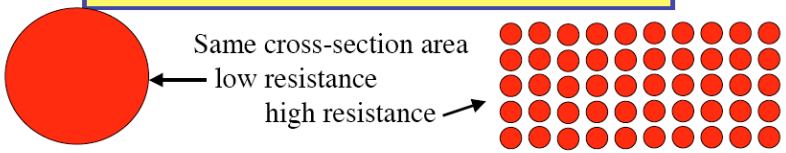
Circulatory systems

Architecture of the circulatory vessels

Flow rate of blood in a vessel depends on **blood pressure** and **resist** ure and low r

When blood at high pressure in a large vessel is forced through a network of narrow-diameter capillaries, high flow resistance causes pressure to drop.
• blood pressure falls rapidly as blood transits capillaries.

- Blo
- resi eter
- larg stances (less

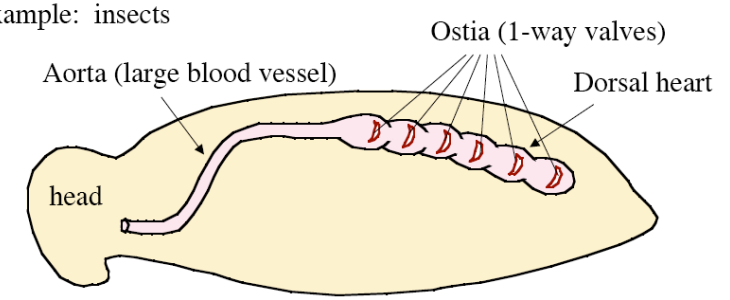


- in closed systems, narrow, thin walled **capillaries** are the sites of exchange (large surface area) -- impossible in large, thick vessels

Circulatory systems

Open circulation: blood contained in vessels for only part of its circuit (blood = interstitial fluid)

Example: insects

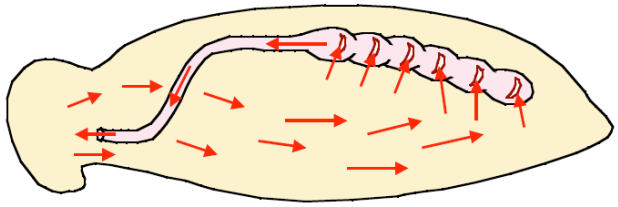


Circulatory systems

Open circulation: blood contained in vessels for only part of its circuit (blood = interstitial fluid)

Example: insects

This can support high activity (flight) because insects **don't use blood to deliver oxygen**



- Blood pumped anteriorly (forward) through aorta…
- circulates backwards through **hemocoel**…
- re-enters heart through ostia to complete circuit

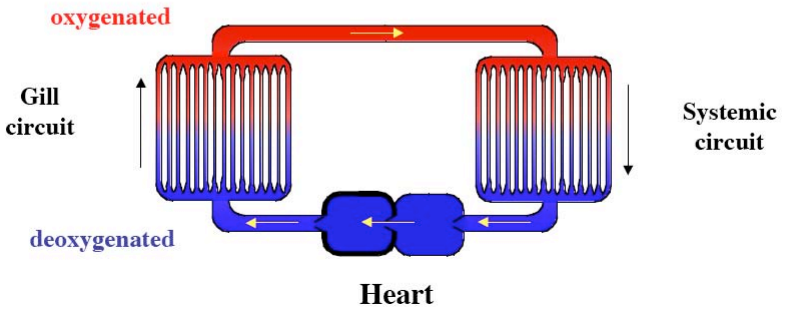
(not shown: some lateral vessels in addition to aorta)

Circulatory systems

Closed circulation: blood contained in vessels for **entire** circuit

- Common in animals that transport oxygen in blood (from gas exchange organs to other tissues)

Example: fish (gill-breather, **single circulation**):



Circulatory systems

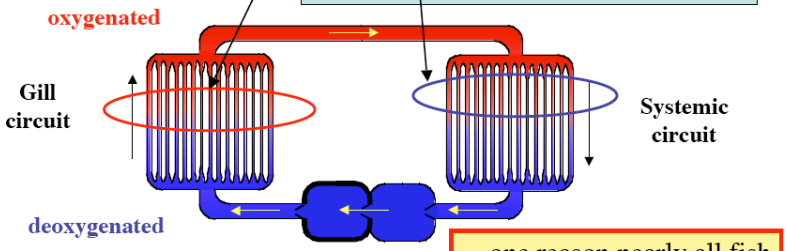
Closed circulation: blood

- Common in animals that exchange organs to other

Example: fish (gill-breathe

A limiting factor:

- **high resistance** in gill circuit
- **low pressure** in vessels leading away from gills
- **low flow rate** through systemic (in fact, the entire) circulation

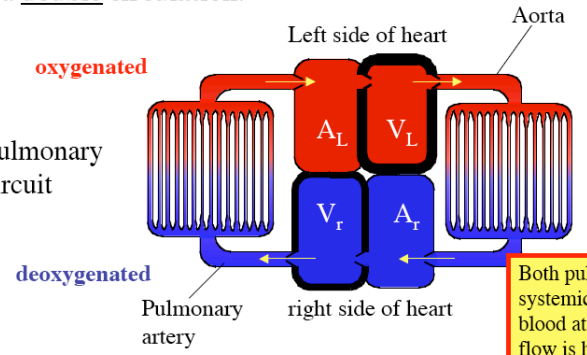


…one reason nearly all fish are **ectotherms**!

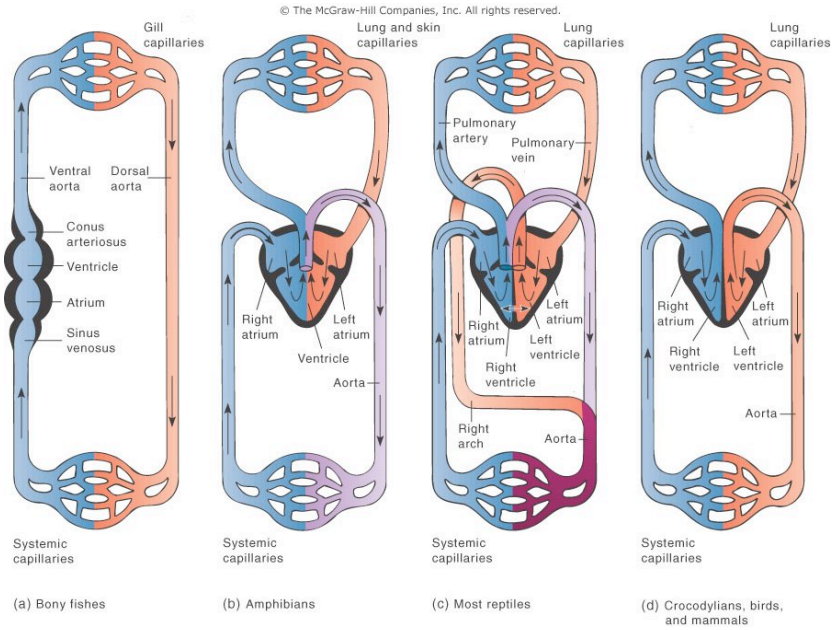
Circulatory systems

How do **endothermic** birds and mammals support their very high metabolic rates (and need for lots of circulation)?

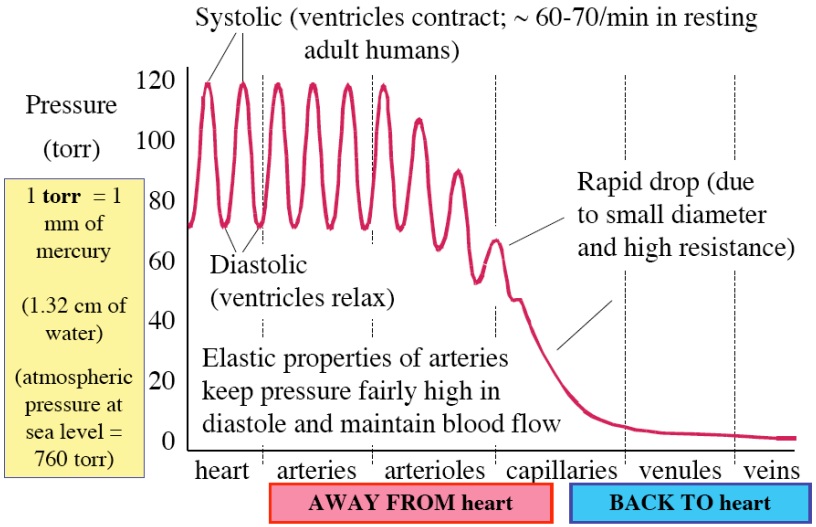
They evolved a **second pump** to keep systemic pressure high:
a **double circulation**:



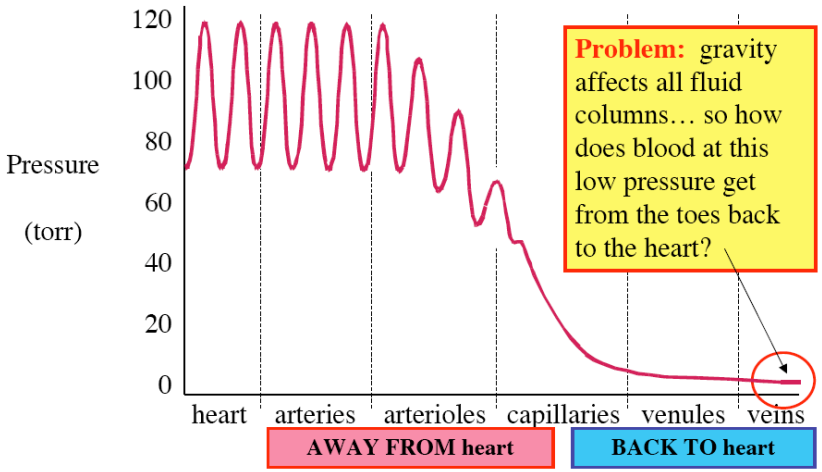
Both pulmonary and systemic circuits receive blood at high pressure -- so flow is high in ***both*** circuits.



Blood pressure in various vessels



Blood pressure in various vessels

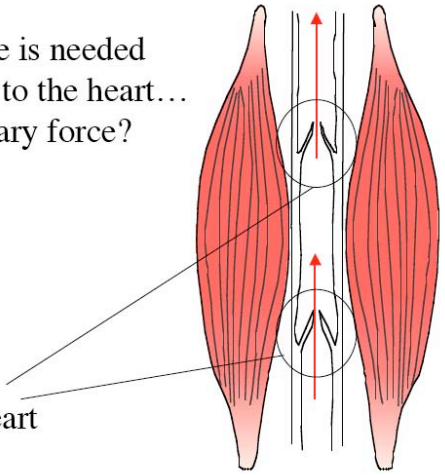


Venous return from the lower limbs

In leg veins, residual blood pressure is ~15 torr (maybe even lower)

About 100 torr of pressure is needed to lift blood from the feet to the heart… What provides the necessary force?

- veins are buried deep within skeletal muscle
- muscle contraction squeezes veins
- one-way valves force blood to move towards heart



Cardiac output and circulatory control

Demand on the circulatory system can change quickly and dramatically (shift from resting to intense activity, for example).

This is handled at several levels: **Total blood flow**, **flow to different body regions**, **blood pressure control**

- Total blood flow: **cardiac output**

  cardiac output (ml/min) = **heart rate** X **stroke volume**

  -- cardiac output varies by 5-8 fold (humans)
  -- both heart rate and stroke volume are adjusted

  -- to account for 15-20 fold change in metabolic rate, the amount of oxygen delivered to tissues per ml of blood changes also (next lecture)

Cardiac output and circulatory control

Demand on the circulatory system can change quickly and dramatically (shift from resting to intense activity, for example).

This is handled at several levels: **Total blood flow**, **flow to different body regions**, **blood pressure control**

- **Flow adjustments to different body regions:**
  -- total vessel volume is much bigger than blood volume; at any time, many vessels are not perfused
  (loss of perfusion control = **'shock'** -- may be fatal)
  -- blood is selectively routed to whatever organs are active
  (muscular valves on arterioles open or close - **vasodilation**; **vasoconstriction**)

  Examples:
  exercise: blood routed away from gut to skeletal muscles
  digestion: blood routed away from muscles to gut
  (hard to do both at once!)

Cardiac output and circulatory control

Demand on the circulatory system can change quickly and dramatically (shift from resting to intense activity, for example).

This is handled at several levels: **Total blood flow, flow to different body regions, blood pressure control**

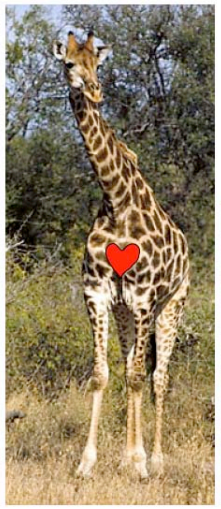
- **Blood pressure control:**
  - -- blood pressure needs to stay relatively constant despite changes in cardiac output, muscle perfusion, and position
  - -- blood pressure is a function of cardiac output and vascular resistance…and gravity

Example: **giraffe**

Cardiac output and circulatory control

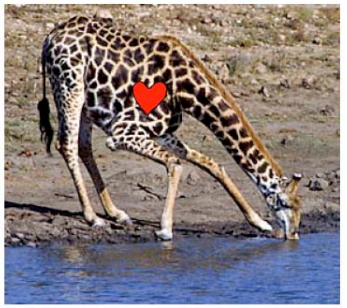
Head up:

- heart 2.5 m above ground; head 2.5 m above heart
- systolic pressure at heart > 250 torr!



Head down:

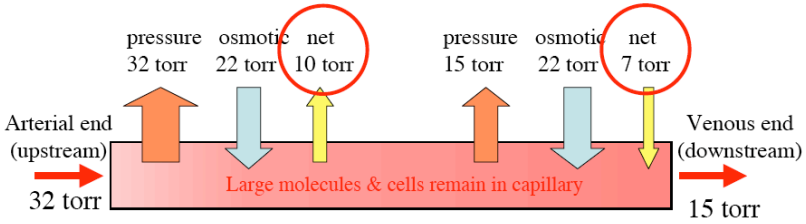
- heart ~ 2 m above ground; head 2 m <u>below</u> heart!



Special valves and sinus at base of skull maintain brain perfusion

Material and fluid exchange in capillaries

- Some substances are exchanged by endo- and exocytosis
- Many exchanged by **diffusion** (O_2, CO_2, etc.)
- Less fluid leaves capillary than enters:



More fluid is **lost** from capillary than is **regained**.

Excess (lymph) is collected by **lymphatic system** and returned to general circulation (lymphatic system is an important part of the immune system)

Blood Composition (vertebrates)

Blood is mostly fluid (**plasma**), which transports ***many*** substances in solution or suspension. There are also several specialized cell types:

- **Erythrocytes (red blood cells)** (35-50% of blood volume), **transport oxygen** with the protein hemoglobin (more about that in the next lecture).
- **Lymphocytes (white blood cells)** -- **defensive responses** -- are one of the most important components of the immune system.
- **Thrombocytes (platelets)** enable the blood to **clot** in case of injury.