Single-celled organisms rely on diffusion for gas/nutrient distribution

...this is fine if you’re made of one cell, but if you’re any bigger diffusion is simply too slow.

To speed diffusion, invertebrates evolved a pump

...this works well in small organisms for efficient transfer of oxygen and nutrients.
The evolution of a circulatory system—a heart pumping blood through a system of closed vessels—is a way to ensure systematic distribution of gases, signal molecules, nutrients, and wastes.

Understanding why blood flows

All fluids (gases and liquids) flow from high pressure to low pressure (i.e., down a pressure gradient).

In our bodies, the heart is the source of pressure, so blood will always flow away from the heart, through a series of arteries and veins.

Along the way, pressure is lost due to friction between the blood and vessel walls.
Pressure

When fluid moves through a tube, it exerts a dynamic, forward-moving component, but also pushes outward on the walls of the tube (hydrostatic pressure—often measured in mmHg).

Liquids cannot be compressed (unlike gases), so if we change the pressure, the volume remains unchanged...this leads to flow.

Liquids flow down a pressure gradient (ΔP).

\[ \Delta P = P_1 - P_2 \]

Flow through a tube is proportional to ΔP:

\[ \text{Flow} \propto \Delta P \]
Resistance opposes flow

All movement creates friction.

Friction is created in a blood vessel as blood moves against its wall, and creates resistance (R) to flow.

Flow $\propto 1/R$

Resistance opposes flow

How is resistance determined?

You probably can relate many of the factors to your everyday life: the radius (r) of the tube, length (L) of the tube, and viscosity ($\eta$, eta) are all important factors.

Poisuelle's Law describes the relationship:

$$ R = \frac{8L\eta}{\pi r^4} $$

8 / $\pi$ is a constant, so we can remove it from the equation:

$$ R \propto \frac{L\eta}{r^4} $$

(think about eating a milkshake...how do these variable affect that?)
How is resistance determined?

Poisuelle’s Law is a wonderful tool, but in a biological system not all variables are instructive:

The length of our circulatory system (blood vessels) remains relatively unchanged.

The viscosity of our blood can change a little bit (e.g. it gets very slightly more viscous at high altitude).

The biggest contributor to vascular resistance is blood vessel diameter:

\[ \text{Vasoconstriction} \rightarrow \text{decreased blood flow through a vessel} \]
\[ \text{Vasodilation} \rightarrow \text{increased blood flow through a vessel} \]

We make constant changes to the diameter of our vessels, in response to hot or cold, or during rest or digestion.

Redirecting blood flow

The amount of blood an individual organ receives depends on its demand.

At rest, skeletal muscle receives about 20% of our blood flow (cardiac output), but it receives as much as 85% during exercise.

We are able to redirect blood flow because (a) arterioles are arranged in parallel and (b) because total blood flow through our arterioles must always equal CO.

Blood (like all fluids) will take the path of least resistance, so if an arteriole constricts, resistance increases, and flow decreases (consequently increasing flow in other, parallel, arterioles).

Capillaries restrict blood flow by constricting or dilating precapillary sphincters.
Cardiac muscle cells are highly specialized

~ 1% of the heart's cells are able to generate spontaneous action potentials. These **autorhythmic**, or **pacemaker**, cells set the rate of the heartbeat.

These are modified muscle cells.

The muscle cells themselves:

- Have gap junctions that allow depolarization to spread from cell-cell (allows all cells to contract more or less simultaneously)
- Have smaller sarcoplasmic reticula than skeletal muscles (cardiac muscle cells rely on extracellular calcium)
- Increased mitochondrial density → due to increased energy demand. The heart must beat continuously and cannot fatigue.