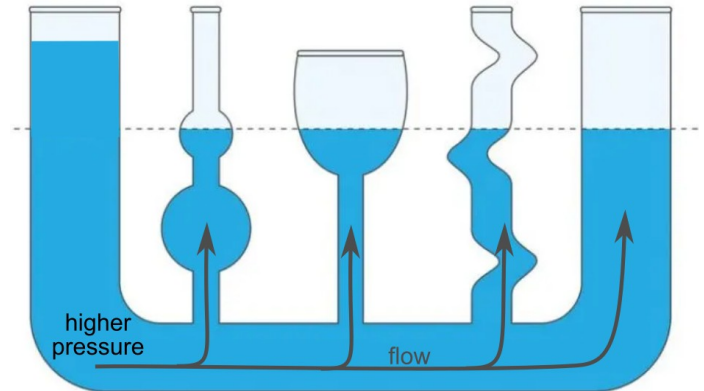


Hydrostatics and Hydrodynamics: Exploring Pressure and Fluid Flow

- **Pressure** increases with depth below the surface of a fluid. A continuous fluid at rest has the same pressure at all points with the same depth.
- **Pascal's Law:** A fluid will flow from a high pressure region to a low pressure region, until all open surfaces are at the same height.
- **Siphons** allow a fluid to flow uphill
- The rate of flow depends on the fluid's **viscosity** and the width and connectivity of conducting channels.



Part 1: Water Pressure and Depth

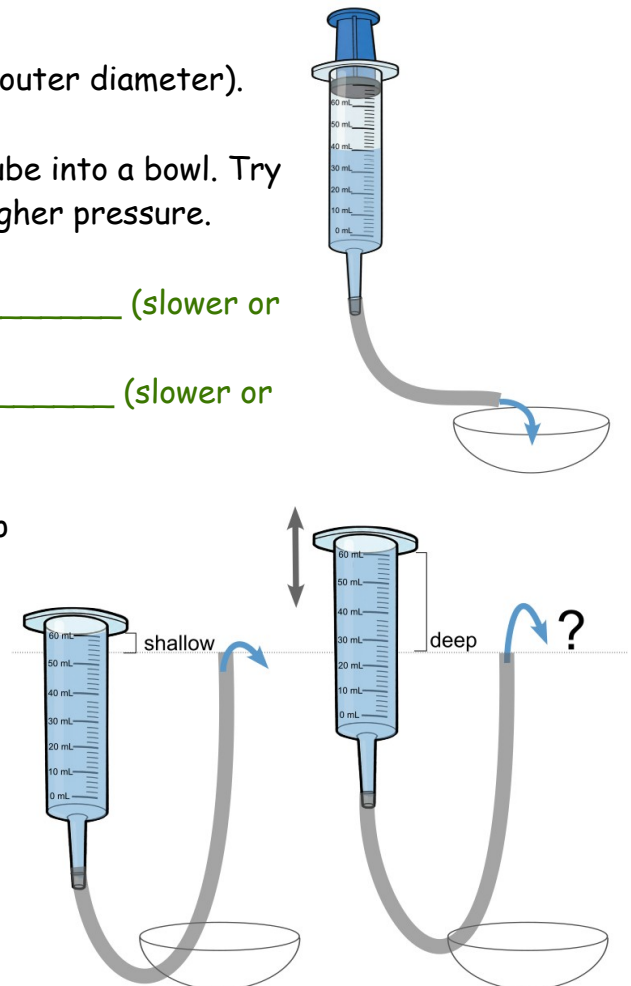
1. Suck 40mL of water into the syringe.
2. Cut a 30cm-long piece of thick plastic hose (8mm outer diameter).
3. Working with your partner, point the tip of the tube into a bowl. Try gently pressing the plunger, applying low and then higher pressure.

Low pressure makes the water squirt out _____ (slower or faster?)

High pressure makes the water squirt out _____ (slower or faster?)

4. Remove the plunger from the syringe. Hold the tip of the hose above the syringe, with a bowl underneath it. Fill the syringe with water.

5. Keeping the tip of the hose at the same height, move the syringe up and down. Keep an eye on how fast the water squirts out of the hose.

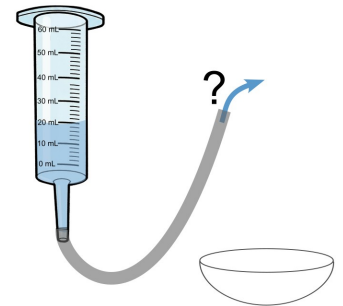


6. Fill in the sentences below:

When the tip of the hose is deep below the open surface of the water reservoir, the outflow is _____ (fast/slow). When the tip of the hose is at a shallow level below the open surface, the outflow is _____ (fast/slow).

Think of what you learned in Step 3 about how the flow speed is related to pressure. This means the pressure is _____ (high/low) deep below the water surface, and the pressure is _____ (high/low) at a shallow point just below the water surface.

What happens if the tip of the hose is held higher than the water level in the syringe?



For a continuous chunk of water, pressure increases with depth below the surface. We can work out an equation describing the relationship between depth (h) and pressure (P).

Suppose you have a cubical tank, with base area A . The tank is filled with water to a height h . Water has a density ρ = mass per volume = 1 g/cm^3 .

In terms of the variables A , h , ρ :

- What is the total mass of water in the tank? _____
- What is the weight of the water pressing down on the bottom of the tank? _____
- What is the pressure (force per area) on the tank bottom? _____

Applications:

For a serious bleeding cut, first aid advice often includes elevating the affected limb above heart level. Can you explain why this is helpful? Use the words pressure, height, and flow speed.

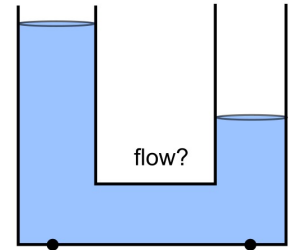


Why might your ears hurt when you dive to the bottom of a pool?



Part 2: Pascals' Law and Siphons

1. In the diagram to the right, mark which part of the bottom has higher pressure and which side has lower pressure.

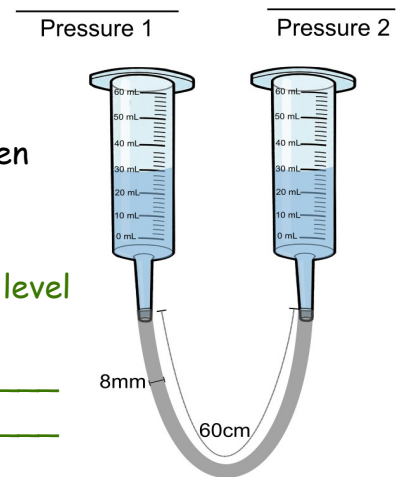


Will the water stay still or flow? If flow, then which way?

1. Cut a 60-cm long piece of thick hose. Attach the ends of the hose to the nozzles of two syringes.

2. Hold both syringes next to each other (same height) with the open ends up. Slowly pour 75 mL of water into one of the syringes.

What happens to the water level in the other syringe? What is the level in both syringes when the water stops moving?



3. Now hold one syringe higher than the other, so that the 0mL mark on one lines up with the 60mL mark on the other.

When the water stops moving, how does the water in the two syringes compare?

(circle all that are true)

- a) Water is at 60mL mark on one and 0mL mark on the other
- b) Water is close to 30mL mark in both
- c) Water is at 60mL mark in both
- d) Water is at the same absolute height in both

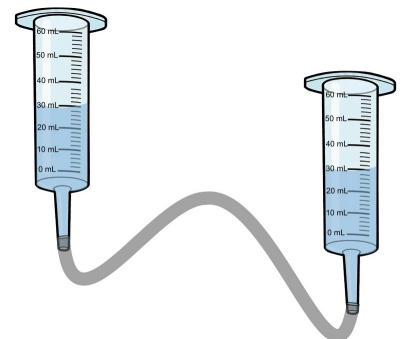
4. Play around with moving the syringes up and down, slowly.

Which of the above statements is generally true?

Pascal's Law states: "Water seeks its own level".

A connected mass of water keeps flowing until it reaches the same height under every open surface.

5. Have one partner hold up the central part of the hose so that it makes a hump. Raise one syringe higher than the other to make water flow. Experiment with humps of different heights.



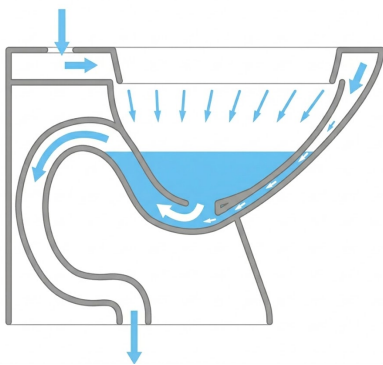
For which of the following situations will water flow from one syringe to another? Circle all that apply.

- (a) Very low hump, water at equal level on both sides
- (b) Very low hump, water surface is higher on one side than another
- (c) Hump that is above the low water level but below the high water level
- (d) Hump that is above the high water level, with water surface higher on one side than another.

Explain your observations using Pascal's Law:

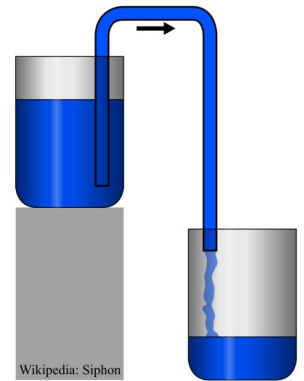
A **siphon** is a tube full of fluid that allows water to flow over a hill as it tries to "seek its own level" between a higher source and lower sink.

Application: Modern toilets use siphons in their flushing mechanism.



Left is a diagram of a toilet bowl. What do you think will happen if you pour a couple cups of water into the bowl?

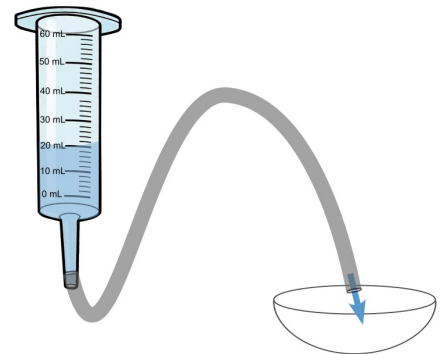
What will happen if you pour enough water into the bowl to make its level rise above the high point of the siphon tube?



6. Simulate a toilet bowl using your syringe + hose system! Make a hump with the hose so that the top of the hump is level with the 40mL mark on the syringe. The other end of the hose should point into a container. Slowly pour 35 mL of water in the syringe. Let it reach equilibrium.

Which part represents the toilet bowl? _____

Which part is the siphon? _____



7. Now "flush" the toilet by pouring 20 mL more water into the syringe. What happens?

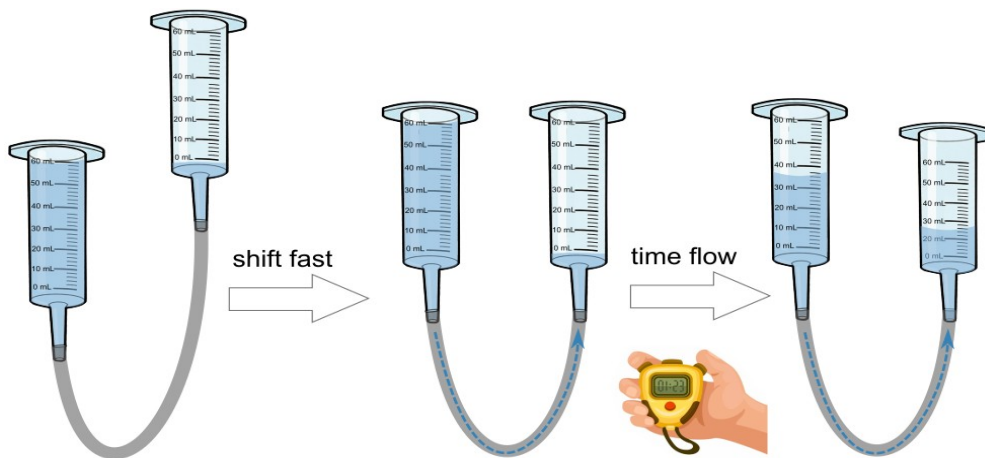
- (a) The water level rises and then stops.
- (b) The added 20 mL of water drain out.
- (c) All of the water drains out, emptying the syringe.

Explain what happens when you hit the flush on a toilet:

Part 3: Rate of Flow Through a Tube

We've explored Pascal's Law, which tells us when water will sit still versus start to flow. Now let's consider the **rate** at which water will flow through a narrow tube.

1. Attach both ends of your 60cm-long thick hose to the nozzles of two syringes. Hold both syringes vertically (nozzle downwards), with the 60mL mark on one syringe lined up to the 0mL mark of the other.
2. Carefully pour in enough water into the lower syringe so that the water sits at the 60mL mark of one and the 0mL of the other. Try to avoid bubbles



3. Have one partner start the timer while another quickly brings the syringes to the same level (0mL marks lined up). Time how long it takes for the water level in the fuller syringe to drop down to the 35mL mark.

Do two trials of the measurement:

Trial	Time to drop from 60mL to 35 mL (thick tube)
1	
2	

What do you notice about the rate of the water flow? Does it:

- (a) Flow at a constant rate
- (b) Speed up as the water levels on both sides become more similar.
- (c) Slow down as the water levels on both sides become more similar.

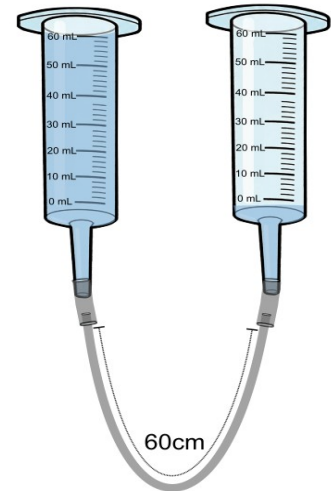
Fill in the following sentence:

A greater difference in heights means a _____ pressure difference pushing water from one syringe to the other. Higher pressure means _____ rate of flow.

List at least 2 other factors besides the pressure difference that might change the rate of flow:

4. Remove the tube from the syringes. From your shorter piece of thick hose, snip two small 3cm pieces. Use these as adapters to attach a long 60-cm stretch of thin hose (6mm outer diameter) between the two syringes. Repeat the experiment above.

Trial	Time to drop from 60mL to 35mL (thin tube)
1	
2	

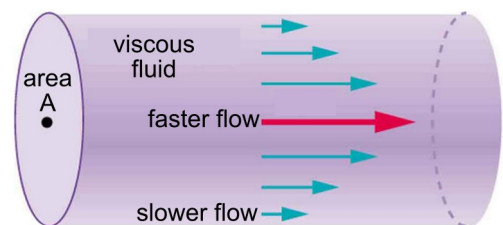


How does the flow rate with the thin tube compare?
 faster slower about the same

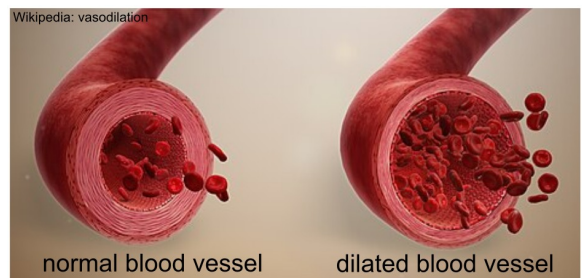
Calculate the ratio of flow rates:

flow rate through thick tube ÷ flow rate through thin tube
 = average time (thin tube) ÷ average time (thick tube) = _____

Thinner tubes have higher **flow resistance** (more friction as fast-flowing layers of fluid in the middle rub against slow-moving layers at the wall). What's more, even when friction is low, the total volume that passes through a narrow tube in a given time interval is smaller.



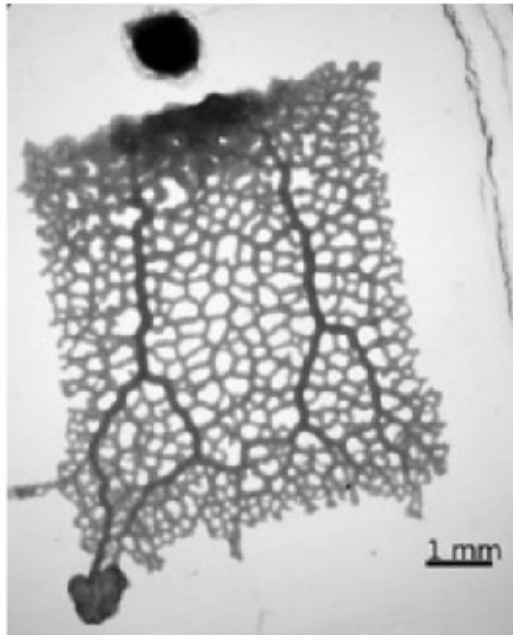
Application: Narrow blood vessels result in a slower rate of flow. Your blood vessels **dilate** (get wider) when your body needs to deliver more blood to a certain area. For example: when you exercise (to carry more oxygen to your muscles), when you are hot (to bring more warm blood to the surface for cooling), or when a wound is inflamed (to deliver more immune cells).



Can you think of 2 situations when your blood vessels might **constrict** in order to reduce blood flow?

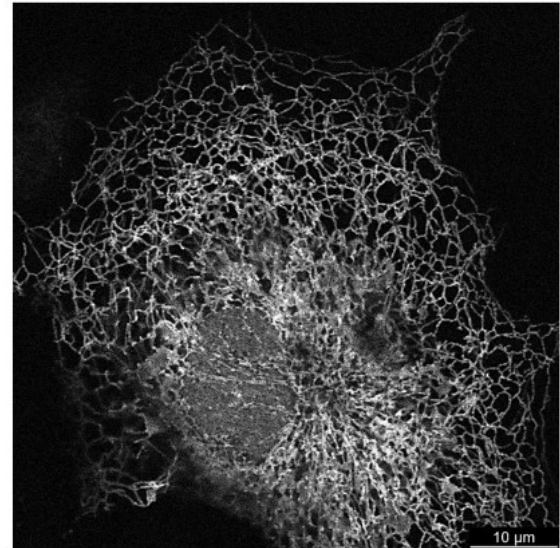
Flow networks in the intracellular world: At the microscopic scale, individual cells also rely on transport of fluids through tubes to deliver nutrients, ions, and building blocks from one side of the cell to another.

The single-celled slime mold *Physarum polycephalum* builds a network of tubules as it grows and explores. Tubes that lead towards a nutrient source thicken, enabling more nutrients to be carried to the rest of the cell. These cells use tube thickness to store memory of nutrient location.



Kramar and Alim, PNAS, 2021. "Encoding memory in tube diameter hierarchy of living flow network"

Inside each human cell, the endoplasmic reticulum forms a network of hollow tubes made of membrane surrounding a fluid interior with high Ca^{2+} concentration. Mutations that narrow the tubes decrease the amount of Ca^{2+} ions that the network can deliver, and can lead to neurodegenerative disease.

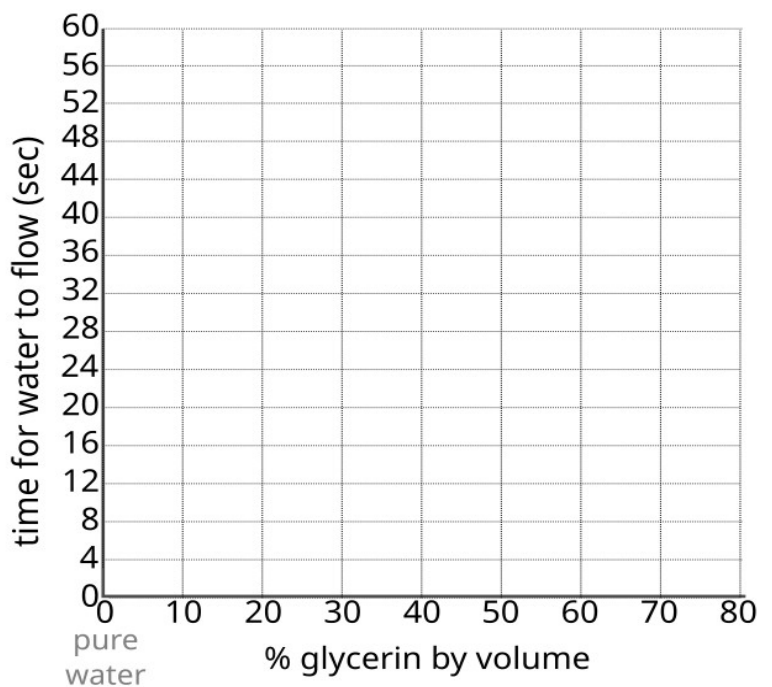


Crapart, et al, PNAS, 2024. "Luminal transport through intact endoplasmic reticulum limits the magnitude of localized Ca^{2+} signals"

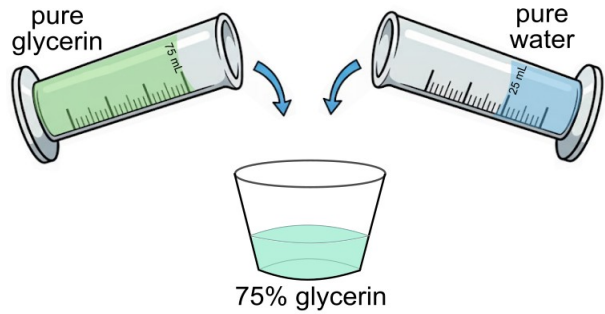
Part 4: Fluid Viscosity

The **viscosity** of a fluid describes its resistance to flow (the amount of friction generated between layers of the fluid flowing past each other). Different fluids have different viscosities, measured in units of "centipoise".

1. Go back to the system with one 60cm-long thick hose connecting two syringes. Look back to your first flow rate experiment (beginning of Part 3) and plot the average time on the graph, above the 'pure water' label.



2. In a cup, add 75mL of glycerin + 25 mL water.



3. Repeat your first flow rate experiment (beginning of Part 3), using the 75% glycerin solution.

Trial	Time to drop 60mL to 35 mL (thick tube, 75% glycerin)
1	

Plot the time on the graph above.

4. Pour all of your mixture back into the cup. Add another 25mL water. You now have a solution with 75mL glycerin + 50mL water.

What is the percentage glycerin in this mixture? _____

Trial	Time to drop 60mL to 35 mL (thick tube, _____ % glycerin)
1	
2	

Find the average time and plot it in the graph.

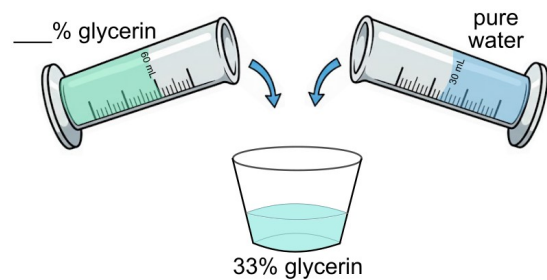
5. Again pour all the mixture back into the cup. Add another 25mL of water. You now have a solution with 75mL glycerin + 75 mL water.

What is the percentage glycerin in this solution? _____

Repeat the experiment again. Find the average time and plot the result in the graph.

Trial	Time to drop 60mL to 35 mL (thick tube, _____ % glycerin)
1	
2	

6. In a separate cup, mix 60mL of your solution + 30mL of water. You should now have a solution that is 33% glycerol. Repeat the experiment, measuring flow rate one more time and plotting it in the graph.



Trial	Time to drop 60mL to 35 mL (thick tube, 33% glycerin)
1	
2	

The flow rate (Q) for a viscous fluid flowing through a long narrow tube is **inversely proportional** to the fluid viscosity (η) : $Q \sim 1/\eta$.

The viscosity of water is $\eta_{\text{water}} = 1$ centipoise (a unit of viscosity).

Use the data in your graph to estimate:

Viscosity of 75% glycerin: _____

Viscosity of 60% diluted glycerin: _____

Viscosity of 50% diluted glycerin: _____

Viscosity of 33% diluted glycerin: _____

Can you think of other fluids that you would expect to flow even more slowly in this experiment (even higher viscosity than glycerin)?

Application: The viscosity of human blood depends, among other things, on the temperature, the number of red blood cells produced, and your overall hydration level. When oxygen-deprived for prolonged periods, your body produces more red blood cells, increasing the viscosity of your blood. This

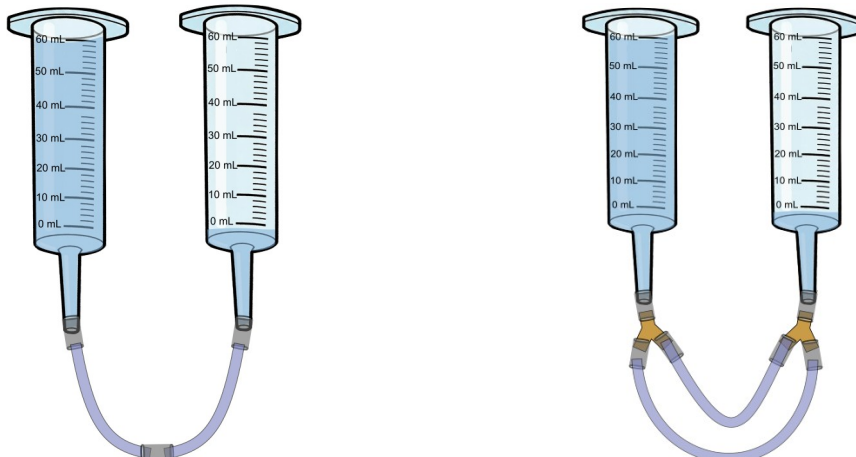


(mailsonplgnata/500px/Getty Images)

can happen when living at high altitude, or suffering from a severe COVID infection. The resulting high blood viscosity means that the heart has to supply higher blood pressure to maintain flow, which can contribute to headaches, clotting, and other health problems.

Extension (if extra time): Flow Resistance in Series and in Parallel

1. Cut your thin hose (6mm outer diameter) into two equal 30cm-long pieces. The pictures below show two different ways of connecting them: **in series** (water flows through one then the other), or **in parallel** (water can choose between two paths).



Make a prediction: In which system will the water flow faster out of the full syringe into the empty one?

2. Set up the series with 2 thin hoses connected in series. Measure two trials of the time for the water level to drop from 60mL to 35mL

Trial	Time to drop from 60mL to 35mL (in series)
1	
2	

3. Set up the system with hoses connected in parallel. Use small sections of thick tube to attach narrow tubes to Y-connectors and to the syringe tips.

Trial	Time to drop from 60mL to 35mL (in parallel)
1	
2	

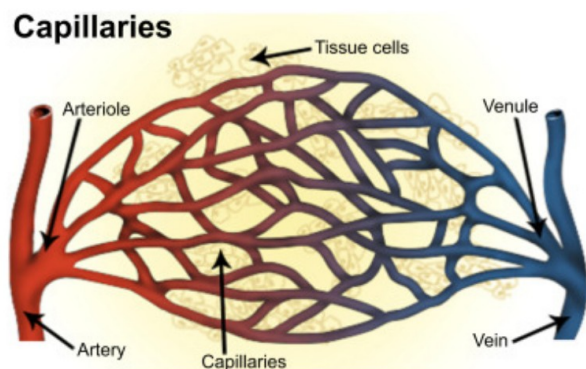
Which set of tubes allowed the water to flow faster? How much faster?

flow rate in series ÷ flow rate in parallel

= average time (parallel) ÷ average time (series) = _____

Can you explain why one of the systems above allowed the water to fill the second syringe faster?

Application: Your blood is pumped from the heart through thick arteries to thinner arterioles to webs of many thin capillaries, then back through the veins. From what you learned about connecting tubes in series and parallel, what is one way your body can restructure to consistently deliver to more total blood flow to a certain region?



An Atlas of Comparative Vertebrate Histology, Ch. H, 2018

Add more capillaries connected in _____ (parallel / series?)

Cardiovascular exercise and endurance training triggers your body to begin **angiogenesis** - the formation of more capillaries to deliver more oxygen and blood flow to the muscles.