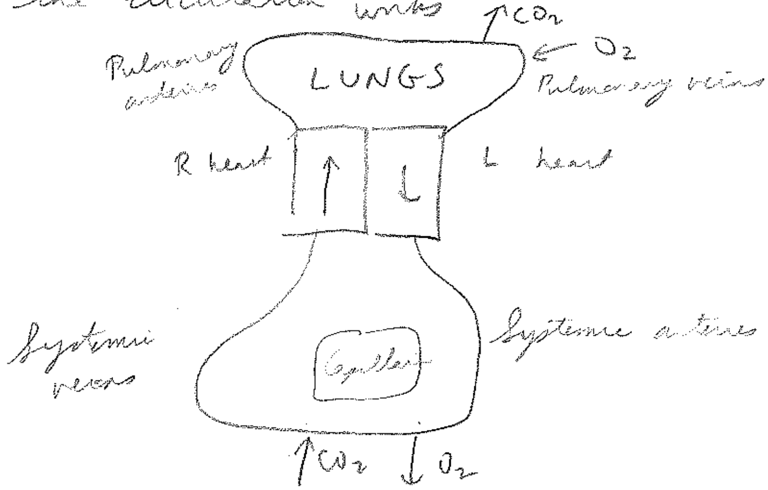
09/13/2022

Building blocks of the circulation

How the circulation works



L heart - receives oxygenated blood → systemic arteries

Arteries get progressively smaller until they send blood to systemic capillaries. This is where O_2/CO_2 exchange takes place.

Systemic veins carry blue-ish blood to R heart, where it's sent pumped to the lungs.

Average time to make circuit = 1 min.

<u>The physical variables</u>

Volume of blood = L. total blood volume $V_0 \approx 5$ L

Flow rate of blood Q (L/min)

Most important flow: <u>cardiac</u> output = volume of blood pumped per unit time (by either side of heart)

Cardiac output = (Stroke volume)(Heart rate)
(Vol/beat)(Beats/min.)

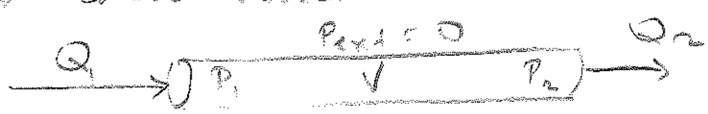
Typical values: (0.07 L)(80) = 5.6 L/min

Pressure - mm Hg (height of a column of mercury that can be supported by the pressure)

pressure <u>differences</u> matter, not absolute pressure. Pressure of outside atmosphere can be treated as 0.

<u>Resistance and compliance vessels</u>

Typical blood vessel



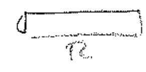
$\frac{dV}{dt} = Q_2 - Q_1$

At steady state, $\frac{dV}{dt} = 0 \rightarrow Q_1 = Q_2 = Q$

How do we relate Q, V, P_1, P_2?

two separate properties: resistance to blood flow and compliance to pressure changes, two separate kinds of vessel

First suppose vessel is rigid, which known constant. Model blood vessel has $\boxed{Q = \frac{P_1 - P_2}{R}}$



Vessels of this sort are called resistance vessels. Analogy to electricity $I = \Delta V/R \longleftrightarrow Q = \Delta P/R$.

Now suppose vessel is elastic, with no resistance to blood flow $\Rightarrow$ pressures are equal on both sides. Now relate V and P via $\boxed{V = CP}$

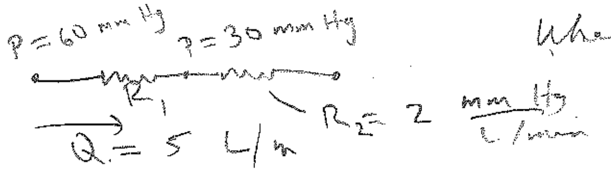
where C is called compliance of vessel. Compliance vessels are why you have a pulse!

Alternative. $V = V_d + CP$, where V_d = (volume at $P = 0$) $\neq 0$

These two kinds of vessels are idealizations. In reality vessels are both. HOWEVER, body really distinguishes arteries and veins are compliance vessels, while tissues themselves are resistance vessels.

Exercises

Resistance in series



What is R_1? $R_1 = \frac{30 \text{ mm Hg}}{5 \text{ L/}} = 6 \frac{\text{mm Hg}}{\text{L/m}}$

P_2? $\Delta P_2 = (5 \text{ L/m})(2 \frac{\text{mm Hg}}{\text{L/m}})$

$= 10$ mm Hg.

$\rightarrow P_2 = 20$ mm Hg.

Compliance vessels: suppose you have (V, P) measurements of a compliance vessel (1.5 L, 50 mm Hg) and (0.7 L, 10 mm Hg). What is V_d and C?

$1.5 = V_d + 50C$

$-\ 0.7 = V_d + 10C$

$0.8 = 40C \Rightarrow \boxed{C = 0.02 \text{ L/mm Hg}}$

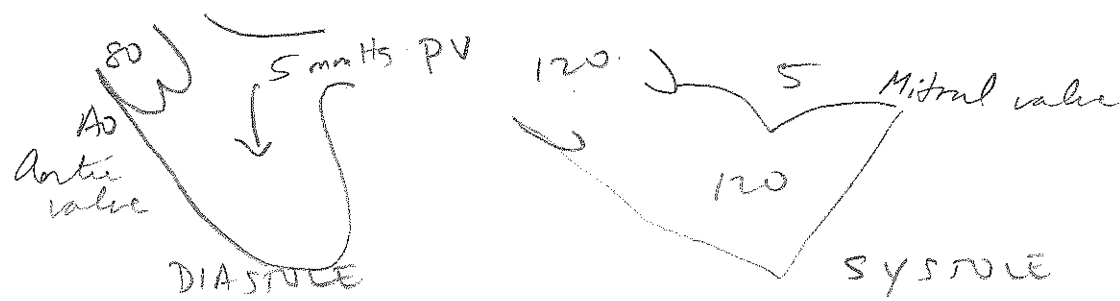
$\boxed{V_d = 0.5 \text{ L}}$

The heart as a pair of pumps

Remember the relationship between P and Q: $Q = \Delta P / R$.
So Q and ΔP have the same sign. Fluid flows from high pressure → low pressure.
What if we want to move fluid from low pressure to high?
We need a *pump* to do work on the fluid. The *rate of work* pump does is $\boxed{\dot{W} = Q \Delta P}$

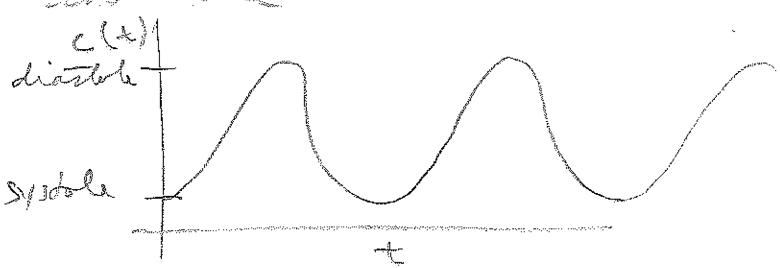
$Q \sim V/\text{time}$ $P: F/A \rightarrow W = E/\text{time}$.

The left heart is a pump from the pulmonary veins to the systemic arteries $P_{pv} = 5$ mm Hg $P_{sa} = 100$ mm Hg! (under normal conditions). The heart pumps blood in 2 phases.



To *model* this, regard the left ventricle as a *compliance vessel with compliance* that changes with time.
then $\boxed{V(t) = V_d + C(t)P(t)}$

and note



Then we construct a pressure-volume diagram