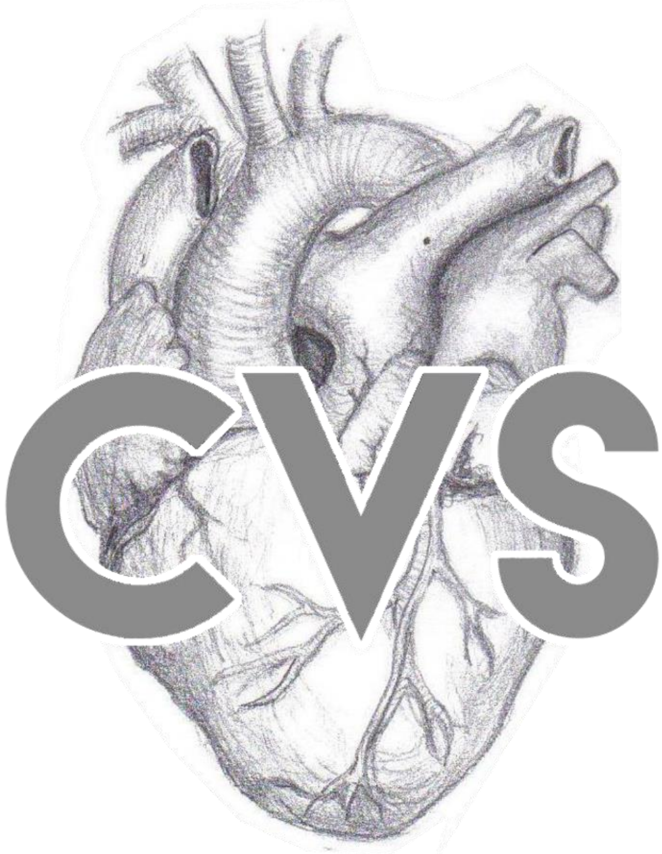

PHYSIOLOGY

☑ Sheet ○ Slide ○ Handout

Number

15

Subject

CVS Hemodynamics 2

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Date: **00/00/2016**

Price:

Changes in the velocity and the cross sectional area

- The flow of blood in a vessel equals the cross sectional area multiplied by the velocity.

$$F = A \times V$$

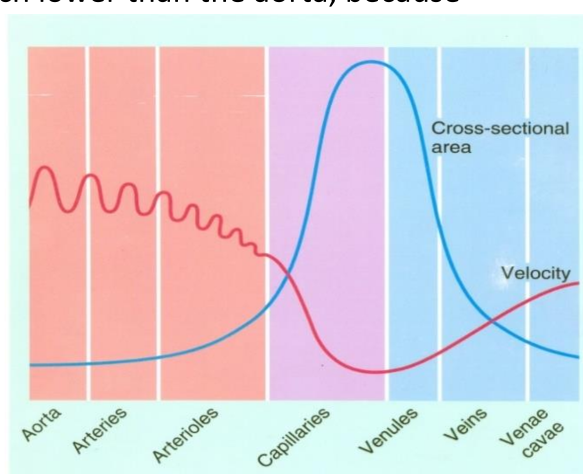
- The flow of blood in each part of the circulation is the same, and it equals the cardiac output (**F = CO**). But the total cross sectional area and the velocity are different.
- The velocity is inversely proportional to the cross sectional area.

$$V = \frac{F}{A}$$

- Now the largest cross sectional area we have is in the capillaries, why? Because we're combining the cross section of all capillaries, not just one. So, we have a very low velocity.

Vessel	Cross-Sectional Area (cm^2)
Aorta	2.5
Small arteries	20
Arterioles	40
Capillaries	2500
Venules	250
Small veins	80
Venae cavae	8

- The velocity is fastest in the aorta, because we only have one aorta and it has a small cross section (2.5cm).
- In the venules, the velocity increases again because the cross sectional area decreases.
- As you can see, the velocity in the venae cavae is much lower than the aorta, because we have two venae cavae (higher cross sectional area).
- Having a low velocity in the capillaries is very beneficial, because the capillaries are the site of exchange of material. So we're giving the capillaries enough time to exchange nutrients. In addition to that, the high cross sectional area facilitates the movement of material.

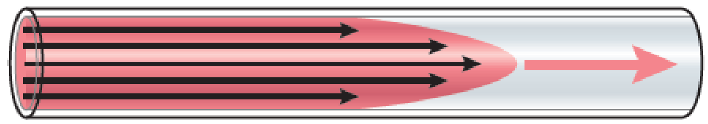


Blood flow is the quantity of blood that passes a given point in the circulation in a given period of time (mL/sec). And it equals the change in pressure over the resistance. We will talk about this later.

Laminar vs. turbulent flow

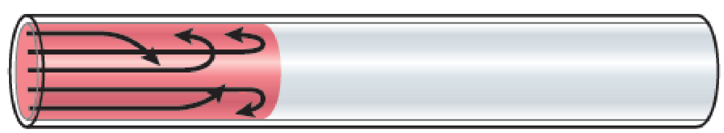
- Blood does not flow as a plug in large vessels, because our vessels are not rigid.
- We have two types of blood flow in our vessels:

1. Laminar or stream line flow:
   - It is more effective than turbulent flow.
   - It is usually silent (we can't hear it).
   - Laws are applied mainly to it.



   - When the blood is flowing inside the vessel, there's a very high resistance on the wall, and the resistance decreases when you go to the center. So because of the high resistance on the wall the velocity is low there and larger in the center. And this results of what we call: **parabolic structure**.
   - This produces layers of blood with uniform speeds at certain distances from the wall.
   - If the flow rate is increased, the trend for turbulence will increase.

2. Turbulent flow:
   - Blood goes in all directions, described as "eddy currents" (not effective).
   - It is not silent, turbulence of blood produces sounds.
   - Heart sounds are due to turbulence of blood around the closed valves.



   - When we measure the blood pressure using the sphygmomanometer, we increase the pressure above the systolic level to close the brachial artery (no flow). Then we slowly release the pressure in the cuff. As the pressure in the cuff falls, a whooshing sound is heard when blood flow starts again in the artery. This sound is due to turbulent flow of blood, because the vessel was constricted. The pressure at which this sound began is recorded as the systolic blood pressure. The cuff pressure is further released, the flow gradually turns into laminar flow until the sound can no longer be heard. This is recorded as the diastolic blood pressure.

- Causes of turbulent flow:
  - High velocities.
  - Sharp turns in the circulation (curvatures).
  - Rough surfaces.
  - Rapid constrictions.

- Pathological causes:
  - Atheromas.
  - Severe anemias.
  - Stenotic or incompetent cardiac valves.

- Turbulent flow could be dangerous in cases of atherosclerosis because it predisposes to the formation of a thrombus, which can lead to embolism and infarction.
- Normally, turbulent flow is present at the branching of blood vessels and in the roots of the aorta and pulmonary arteries.

Reynold's number

- It is a quantity that is used to help predict the flow pattern in different situations. It's defined as:

$$Re = \frac{\rho v d}{\eta}$$

  Where:

  - ρ (Rho) is the density of blood.
  - v is the velocity.
  - d is the diameter of the vessel.
  - η (Eta) is the viscosity of the blood.

- If Reynold's number (Re) was lower than 400 the flow is laminar. If it was above 1000 the flow is turbulent.

- If the number is between 400 and 1000 then it depends on the condition; if there's atheroma or curvature it's more turbulent than laminar. If there's nothing and the vessels are normal then it's more laminar than turbulent.

The Peripheral Resistance

- It is the resistance to blood flow through a vessel caused by friction between the moving fluid and the vascular wall, most of it occurs in arterioles (50%) and capillaries (25%) so it is called peripheral resistance.

Ohm's Law

- In relating Ohm's law to blood flow, the current is the blood flow. The voltage difference is the pressure difference. And the resistance is the resistance to flow of blood offered by the vessels.

$$\boldsymbol{F = \frac{\Delta P}{R}}$$

- For the flow in a blood vessel, ΔP is the pressure difference between any two points along a given length of the vessel.
- When describing the flow for a certain organ, pressure difference is generally expressed as the difference between the arterial and the venous pressure.
- In the systemic circulation, the flow of blood equals the cardiac output.
- Therefore, if we re-write Ohm's law for the hemodynamics of cardiac output we get:

$$\boldsymbol{CO = \frac{mean\ arterial\ pressure - right\ atrial\ pressure}{total\ peipheral\ resistance}}$$

- And since the right atrial pressure equals zero, then:

$$\boldsymbol{CO = \frac{mean\ arterial\ pressure}{total\ peipheral\ resistance}}$$

- The cardiac output is directly proportional to mean arterial pressure, and inversely proportional to the vascular resistance.
- If you need to change the mean arterial pressure, you change the cardiac output or the total peripheral resistance or both.
- You change the cardiac output by changing the stroke volume or heart rate or both.

Poiseuille's law

- Developed by the French physicist Jean Marie Poiseuille.
- It describes blood flow in relation to the pressure gradient, the radius, the viscosity and the length of the blood vessel.

$$\boldsymbol{F = \frac{\Delta P \pi r^4}{8\eta L}}$$

- In order to know the effect of a certain factor we must fix all the other factors and change only one factor.
- By fixing all factors and changing ΔP, Poiseuille found that the flow is increasing linearly by increasing ΔP. And decreasing linearly by decreasing ΔP. Which means that the flow is directly proportional to the pressure gradient.
- By changing the length, he started by measuring the flow in a vessel with a length of 10cm. He cut the tube in half (5cm) and measured the flow again and found that it was doubled. Which means that the flow is inversely proportional to the length.
- The length of the vessels does not change that much in our bodies (it changes a bit in children because they are growing), so it is the least changing factor.
- By changing the viscosity, he brought a fluid with a viscosity of 1 the flow was 1L/min. He changed the viscosity to 2, the flow is now 0.5L/min. So, he concluded that the flow is inversely proportional to the viscosity.
- The last one is the diameter, he brought a vessel with 1mm radius the flow was 1L/min. He changed the radius into 2mm, the flow was 16L/min. 3mm radius, flow was 81 L/min. That means that the flow is directly proportional to the radius to the power of four (r^4).
- The flow of blood is exquisitely sensitive to change in radius.

$$\boldsymbol{F = \frac{\Delta P \pi r^4}{8\eta L}} \qquad \boldsymbol{F = \frac{\Delta P}{R}}$$

And by combining the two equations to get ***R***:

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

- Therefore, a vessel having twice the length of another vessel (each having the same radius) will have twice the resistance to flow. Similarly, if the viscosity of the blood increases two folds, the resistance will increase by two folds.

- In contrast, an increase in radius will reduce resistance to the power of four of the change in radius.
- For example: a two-fold increase in radius decreases the resistance by 16 folds!
- So, the main factor that changes the resistance is the radius.
- Note: the conductance is the same as the resistance.

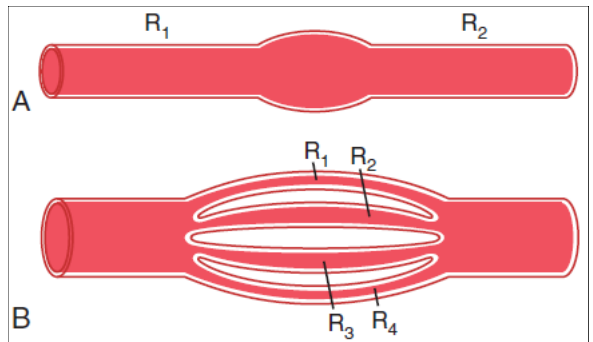
The resistance of the vessels

- If the resistors are in series, total resistance would be higher than the highest resistance.

$$R_{total} = R_1 + R_2 + R_3$$

- If the resistors are parallel, total resistance would be lower than the lowest resistance. (Like in arterioles and capillaries).

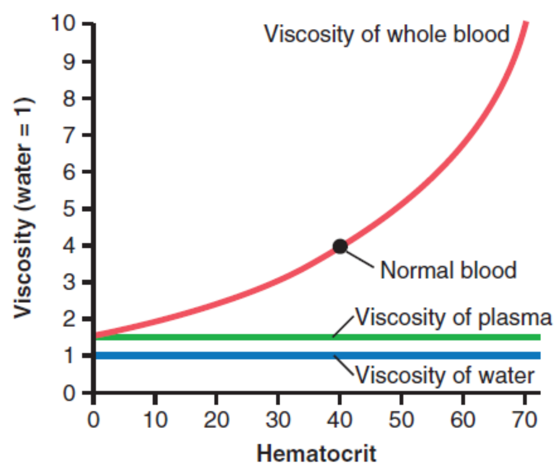
$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$



A, in series and **B,** in parallel

Factors affecting the viscosity

- Number of RBCs (Hematocrit).
  - Normally it's 45%.
  - When the hematocrit increases the viscosity increases **curvilinearly** (not linear).
  - For example: when hematocrit increases from 45% to 60%, the viscosity increases more than eight times.
  - This is very hazardous because when the viscosity increases too much, the flow will decrease (according to the previously mentioned equation).
  - And the decrease in flow (stasis) will predispose to thrombosis and ischemia in some cases.
  - <u>We can increase the flow by decreasing the resistance</u> (vasodilation).



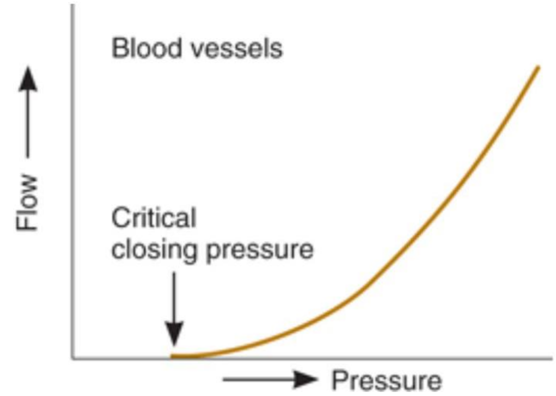
- Concentration of plasma proteins.
- Temperature (the higher the temperature the less the viscosity).
- The diameter of the vessel.

Relation between the pressure and the flow

- Sometimes, you might have pressure in the vessel without any flow. This is called critical closing pressure. Meaning that there is pressure but the radius is zero.
- Critical closing pressure depends on the law of Laplace "the tension on the wall equals the distending pressure multiplied by the radius".

$$T = P \; x \; r \; \rightarrow P = \frac{T}{r}$$

- We will talk about this concept in more details in the respiratory system.



Distensibility and compliance

- Distensibility is the proportional change in volume per unit change in pressure.

$$D = \frac{\Delta V}{\Delta P \; x \; V} = \frac{increase \; in \; vloume}{increase \; in \; pressure \; x \; the \; original \; volume}$$

- If I have 100ml volume (the original volume), how much volume (increase in volume) do I need to increase the pressure 1mmHg?
- If I need 10ml, the distensibility would be:

$$D = \frac{10ml}{1mmHg \; x \; 100ml} = \frac{10}{100} \text{ and it's a proportion, so: } \frac{10}{100} x100\% = 10\%$$

- Compliance is the total distensibility. It is how much a vessel can accommodate volume per unit change in pressure.

$$C = D \; x \; V = \frac{\Delta V}{\Delta P}$$

- Let's apply to the same example above:

$$C = 10\% \; x \; 100ml = \frac{10ml}{1mmHg} = 10$$

- Veins are 6 to 8 times more *distensible* than arteries. That means than they are 24 to 32 times more *compliant* than arteries. Because the veins hold about 60% of our blood volume, and arteries about 15% so $60\%/15\% = 4$. Therefore, the veins are more compliant than arteries by $D \; x \; V = (6 \; to \; 8) \; x \; 4 = 24 \; to \; 32$ times.

Pulse pressure

- The difference between the systolic and the diastolic pressure readings is called the pulse pressure.
- It represents the force that the heart generates each time it contracts.
- If the resting blood pressure is 120/80 mmHg, pulse pressure is 40 mmHg.
- Pulse Pressure gives us the pulsations in the circulation. If there was no difference between the systolic and the diastolic pressure, there won't be any wave of pulsation.

Factors affecting the pulse pressure

- Increase in the systolic pressure will increase the pulse pressure and vice versa.
- Increase in the diastolic pressure will decrease the pulse pressure and vice versa.
- When blood is pumped through the aorta, the aorta will distend. But it's compliance is limited, so, the pressure must increase.
- The aortic pressure increases when the aorta recieves blood volume (storke volume). If the storke volume is higher, you expect that the systolic pressure is higher, thus a higher pulse pressure.

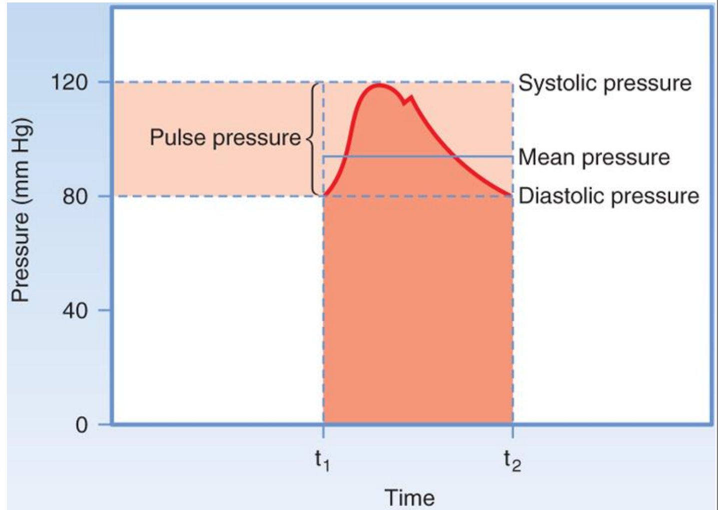
The pulse pressure directly related to the stoke volume.

- If the vessel is compliant, it can enlarge without increase in pressure.
- If the vessel is rigid, in case of atherosclerosis, its compliance is low, and that means high pulse pressure.
- If the compliance is high, that means there is no change in pressure (low pulse pressure).

The pulse pressure is inversley related to the compliance.

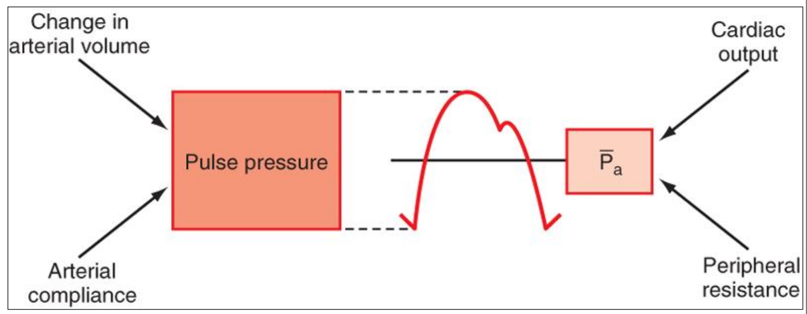
- So, the pulse pressure is a ratio that depends on both the stroke volume and the compliance. You might increase or decrease both of them without any increase in pulse pressure.
- Pulse wave travels through the arterial wall. <u>And the velocity of travel is inversely proportional to compliance</u>.

- The speed of transmission in the aorta (high compliance) is around 5m/s. The speed in a medium sized artery 10m/s. while the speed in small arteries is around 40m/s. That's why when you feel the radial pulse, it comes almost with the first heart sound.



- Now how to calculate the Mean Arterial Pressure?
  We calculate the area under the curve then we divide it by the time using this integration:

$$\overline{\mathbf{P_a}} = \frac{\int_{t_1}^{t_2} \mathbf{P_a}\, \mathbf{dt}}{\mathbf{t_2 - t_1}}$$



- And as we talked before, the factors that affect the mean arterial pressure are the CO and peripheral resistance. And the factors that affect the pulse pressure are the stroke volume and and the compliance.

Abnormal pulse pressure contours

- <u>Atherosclerosis</u>: there is a very high pulse pressure because of decreased compliance.
- <u>Patent ductus arteriosus</u>: blood escapes to the pulmonary arteries and flows back to the left ventricle. This will increase the stroke volume, and a higher stroke volume means a higher systolic pressure and thus a higher pulse pressure. The diastolic pressure will drop, because there's no volume in the aorta, elastic recoil is pushing the blood through ductus arteriosus. This low diastolic pressure will increase the pulse pressure even more.
- <u>Aortic regurgitation</u>: blood is pumped to the aorta, but during diastole, part of it will go back to the left ventricle. So, the diastolic pressure will drop. The systolic pressure will increase (left ventricle is pumping more blood). Pulse pressure will increase due to lower diastolic and higher systolic.
- 120/0 pressure indicates a severe case of aortic regurgitation (severe aortic incompetance) what happens to the aortic pressure curve in this case?
  The dicrotic notch (incisora) will be absent, due to incompetant aortic valve.

Notes:

- Any given change in volume within the arteries results in larger increases in pressure than in veins, because their compliance is low.
- When veins are constricted, large quantities of blood are transferred to the heart (higher venous return) because the mean systemic filling pressure depends on volume. And thereby higher cardiac output.

The Sheet is Over