Cardio-Vascular System

14

Physiology

Writer: Omar Ismail

S.corrector: Mahmoud Odeh

F.corrector: Lina abdelhadi

Doctor: Faisal mohammed

Hemodynamics laws:

1- Ohm's Law:

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

The cardiac output is the blood flow in the circulation:

$$CO = \frac{MAP - RAP}{TPR}$$

Normally the RAP = zero mm Hg, and this leads to the following:

$$MAP = CO * TPR$$

So, the two factors that affect the mean arterial pressure are the **Cardiac Output** and the **Total Peripheral Resistance.**

2- Poiseuille's Law:

$$F = \frac{\pi \Delta \mathrm{P}.\mathrm{r}^4}{8\eta\mathrm{l}}$$

Where F is the blood flow, ΔP is the pressure difference, r is the radius, η is the viscosity of the blood, and l is the length of the vessel.

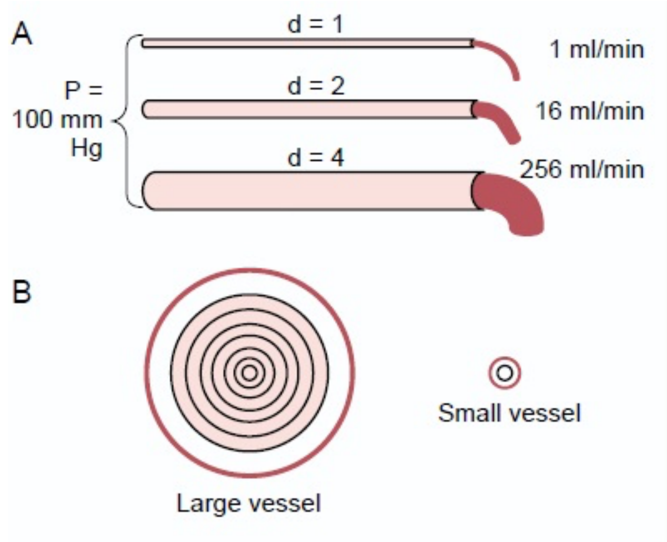
10:00

If we substitute Ohm's law with Poiseuille's law, we get the following:

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

Where R is the resistance.

From the previous equation we can see that the radius has the highest effect on the resistance of the vessel, for example if we vasodilate a vessel to double its original diameter the resistance will decrease by 16 times, and this will be reflected on the blood flow to that tissue.



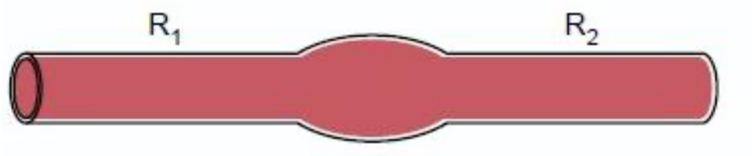
20:00

Series and Parallel Vascular Circuits:

The arteries, arterioles, capillaries, venules, and veins are arranged in series, the flow through each one of them is the same, and the total resistance is equal to the sum of the resistances of each vessel:

$$R(total) = R1 + R2 + R3 + R4 \bullet\bullet\bullet$$

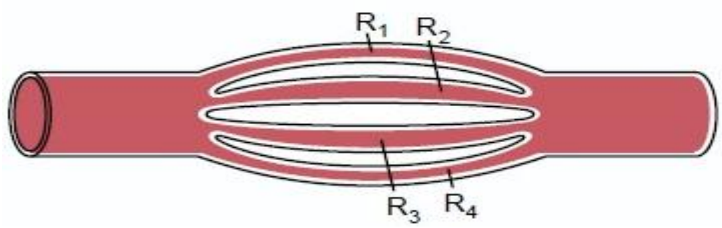
- The total resistance in series is **bigger** than every contributing resistance.



On the other hand, blood vessels branch and form parallel circuits, this parallel arrangement is important for tissues to regulate their blood flow independently of other tissues blood flow. But unlike the series circuit, the total resistance of the parallel circuit is expressed as:

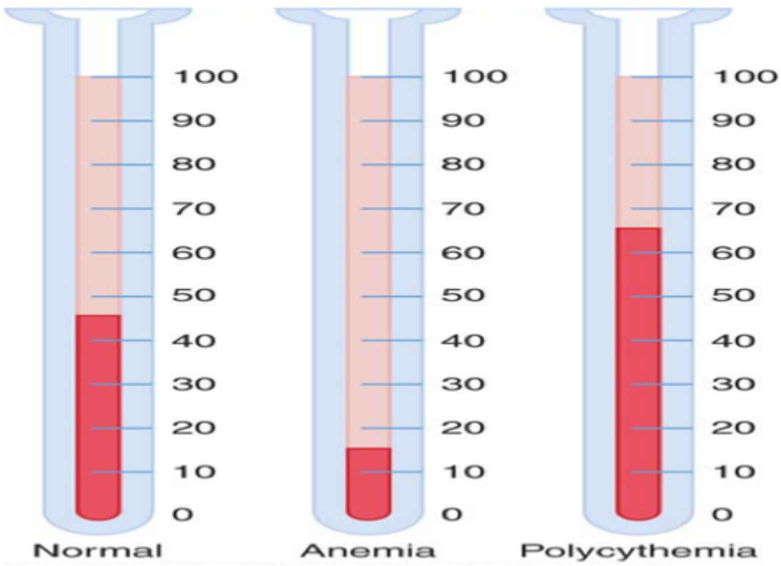
$$\frac{1}{R(total)} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \frac{1}{R4} \bullet\bullet\bullet$$

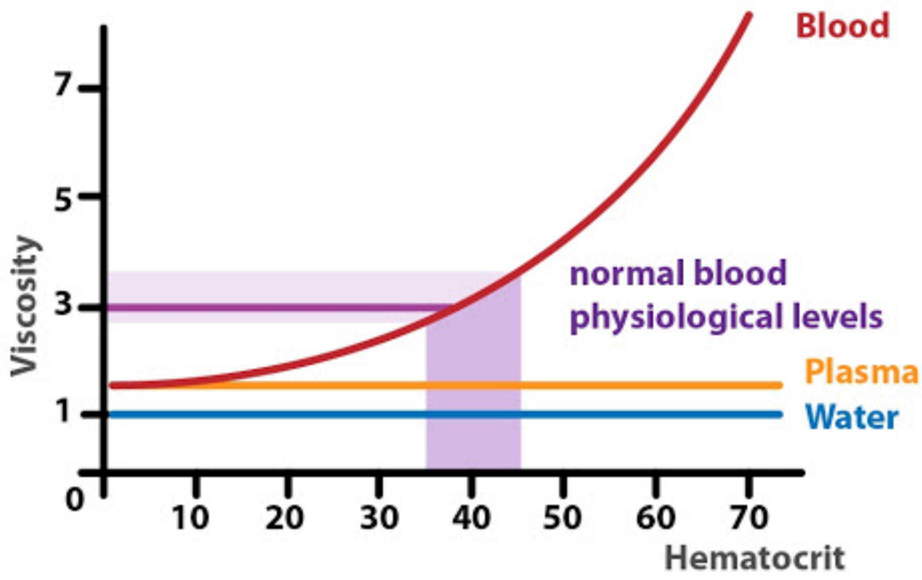
- The total resistance in parallel is **smaller** than every contributing resistance.



Factors affecting the viscosity:

1- **Hematocrit (main factor)**
When the hematocrit increases the viscosity increases.





You can notice from the image before the following:

- Plasma has a higher viscosity than water (mainly because of the plasma proteins).
- Blood has higher viscosity than the plasma because of the RBCs.
- The increase in blood viscosity in relation to the hematocrit is not linear (if we increase the hematocrit by a small fraction the viscosity will increase by a large fraction)

2- Plasma proteins (main factor)

The more the plasma proteins the higher the viscosity.

Explanation (EXTRA):

Another important factor that affects the resistance is the viscosity , the blood happens to be three times more viscose than water; this great viscosity is mainly caused by the large number of RBCs suspended in the blood, where each one of these cells adds more to the frictional drag against adjacent cells and the wall of blood vessel.

The percentage of RBCs in the total blood volume is called hematocrit, and in normal individuals it averages about 40% with the rest being plasma, and even though plasma forms the bigger portion of blood but it doesn't add much to the viscosity.

The viscosity of blood increases dramatically when the hematocrit increases, that's because increasing the hematocrit will exponentially increase the interactions between cells in the blood, and this will increase the viscosity more and more.

3- **Diameter of the blood vessel.**
   When we decrease the diameter, we will expect the RBCs to be packed more closely so the viscosity should increase, **but that's not what happens,** the RBCs in small blood vessels tend to form rouleaux, and because the RBCs are packed back to back they won't impede the flow of blood by much , that's why the diameter adds minimally to the **viscosity.**

4- **Temperature**.
   The higher the temperature the less the viscosity, because the molecules are more dispersed (not close to each other)

*REMINDER**: Resistance is the main factor that might influence the flow, by decreasing the resistance we increase the flow and vice versa.

REMINDER: The main factor that influences the resistance is the radius (remember r^4)

Conductance:

Conductance is the reciprocal of resistance; it is an expression of how much blood can flow through a vessel under a specific pressure gradient.

$$Conductance = \frac{1}{Resistance}$$

And just like resistance, conductance is mainly influenced by the radius.

30:00

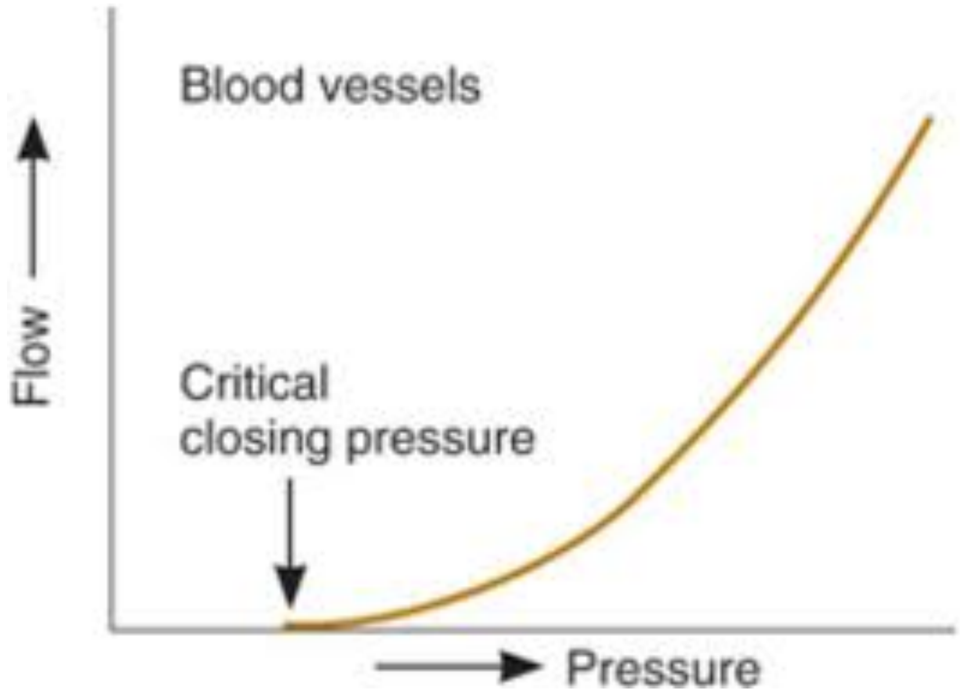
Critical closing pressure:

The blood vessels' walls have smooth muscles, and these smooth muscles are under the tonic activity of the sympathetic nervous system (in other words, they are partially contracted).

The tonic contraction of these smooth muscle cells causes tension to develop in the vessel wall, and this tension is a force that is pushing the vessel to close, so what causes the vessel to open?

If the blood pressure inside the vessel was large enough to counter the tension in the wall the vessel will open, and the blood will flow.

The blood pressure at which the blood starts to flow is called **Critical Closing Pressure**, because if the pressure falls below that point the vessel will close and the flow will stop.



We can find what is the closing pressure of a blood vessel if we know the diameter of that vessel and the tension developed in its wall, according to the Law of Laplace:

$$Tension = Pressure * Radius$$

From this law we can find that the critical closing pressure is equal to:

$$Pressure = \frac{Tension}{Radius}$$

Distensibility and Compliance:

An important characteristic of blood vessels is their elasticity, that means that when they are met by an increased force (pressure) they will distend and accommodate bigger volumes of blood. There are two ways to express this ability:

1. **Distensibility** which is the fractional increase in the volume of the blood vessel to its original volume for each mm Hg increase in pressure:

$$Distensibilty = \frac{increase\ in\ volume}{increase\ in\ pressure \times\ original\ volume}$$

2. **Compliance (a.k.a Capacitance)** is how much does the volume of the blood vessel increase for each mm Hg increase in pressure.
->(the total quantity of blood that can be stored in a given portion of the circulation for each mmHg)

$$Compliance = \frac{increase\ in\ volume}{increase\ in\ pressure}$$

$$Compliance = Distensibility \times\ Original\ Volume$$

IMPORTANT NOTE:

Compliance and Distensibility are very different, a highly distensible vessel indicate that for small increase in pressure a big fraction of its original volume will be increased, but if the original volume was small then the increase in volume will be small. On the other hand, a highly compliant vessel means that for small increase in pressure there will be a huge increase in its absolute volume.

40:00

Arterial Pulsation:

When the heart pumps blood directly into the aorta, the increased volume in the aorta will increase the pressure, this continuous pattern of rise and fall in the pressure results in what is called pulse pressure. During systole, the blood pressure in the aorta rises to 120 mm Hg and during diastole the pressure falls to 80 mm Hg, and the difference between these two values (40 mm Hg) is the pulse pressure.

This pulsatile pressure is only present in the arterial side of the circulation.

$$pulse\ pressure = systolic\ pressure - diastolic\ pressure$$

These pulsations cause a pulse wave to move in the arterial walls, and the speed of this pulse wave depends on the compliance of the vessel.

High compliance means that the blood vessel can easily change its size when the pressure changes, so in systole the high pressure will make the compliant vessel expand, and when the pressure drops during diastole the vessel will go back to its original size (pulse), this means that the vessel can accommodate higher volumes of blood than non-compliant vessels.

If the compliant vessel can accommodate high volumes of blood, then this blood won’t be pushed immediately to the next segment of the vessel, and the next segment won’t expand immediately after the first segment, this will make the pulse wave in the arterial wall to move slowly.

On the other hand, if the vessel wasn’t compliant, the extra pressure won’t cause a great increase in the vessel size, so the blood vessel won’t be able to accommodate the extra blood volume, so this extra volume will be pushed immediately to the following segment, and the pulse wave will move at a higher speed in non-compliant vessels.

*The velocity of the pulse wave can be a great indicator for the compliance of the blood vessels, for example, in atherosclerosis the arteries become less compliant and so the pulse wave moves at a higher velocity (Velocity of the wave is inversely proportional to compliance).

We can think of the pulse pressure as the pressure increase that resulted from the volume increase because of the heart pumping, and this will lead us to another equation:

$$pulse\ pressure = \frac{stroke\ volume}{arterial\ compliance}$$

This equation highlights the important factors that control the pulse pressure and it can help us to understand the different pulse pressures in different pathological states.

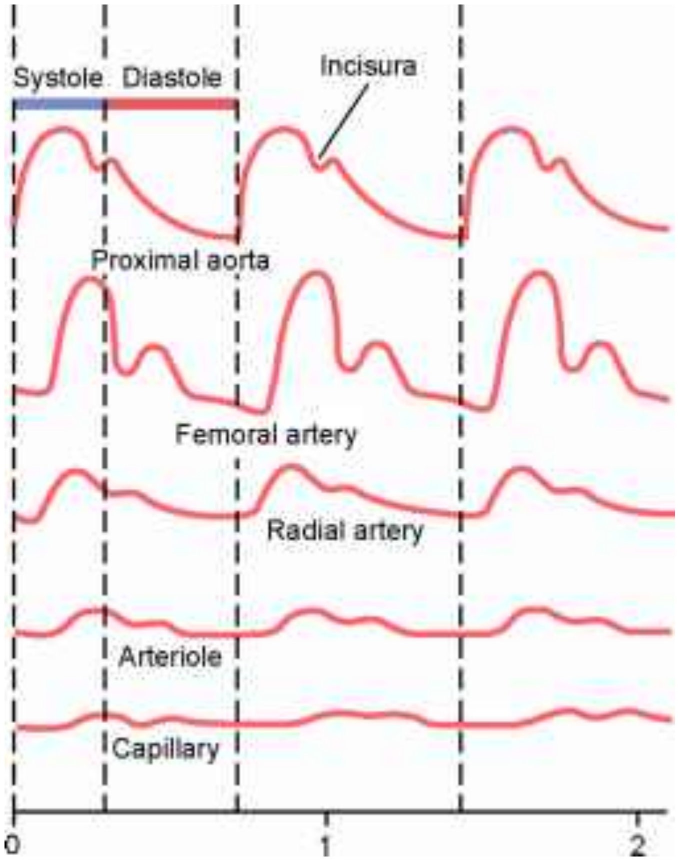
- *Stroke volume:*
  When the stroke volume increases the systolic pressure will increase thus increasing the pulse pressure.

- *Arterial compliance:*
  When the arterial compliance decreases the pressure in the blood vessel will increase more during systole, and this will increase the pulse pressure.

Damping of pulse pressures in peripheral arteries:

As the pulse pressure moves through the arteries it falls gradually, this means that the difference between the systolic and the diastolic pressures grows smaller and smaller the farther we go from the heart, and we call this process **Damping of pulse pressure.**

The degree of damping is proportional to the resistance of small vessels and arterioles and the compliance of the larger vessels; therefore, the intensity of the pulses becomes progressively less in the smaller arteries.

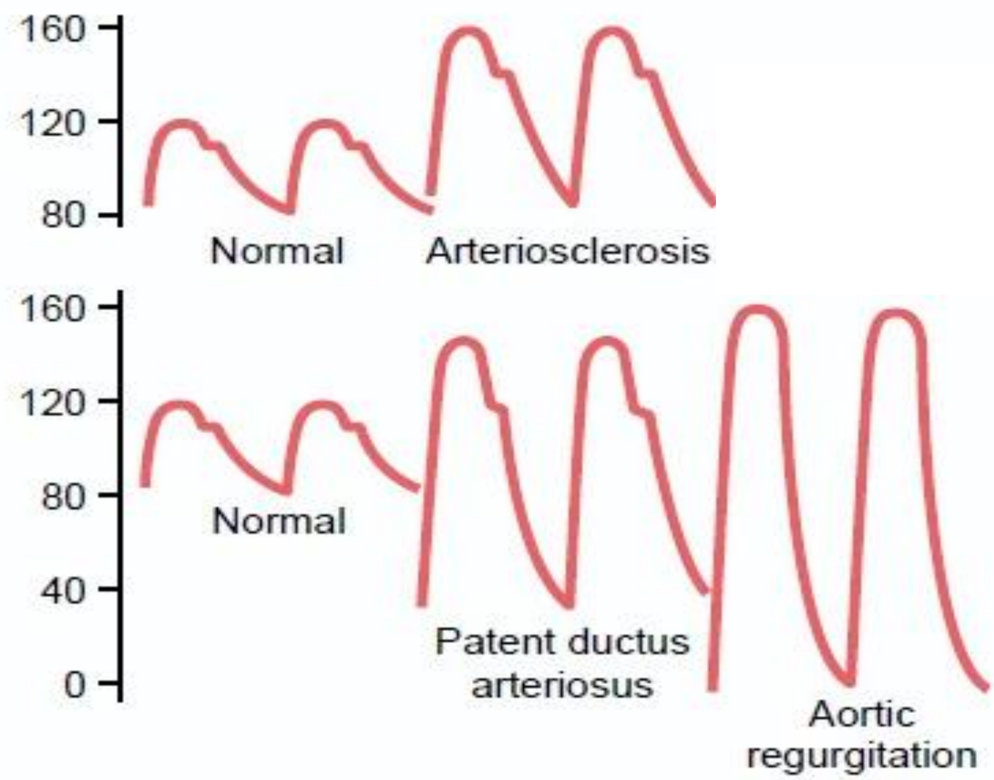


Abnormal pulse pressure:

- **Arteriosclerosis**: in this condition the arteries become hardened and therefore less compliant, this causes the systolic pressure to rise, therefore, the pulse pressure increases.

- **Patent ductus arteriosus**: in this condition a duct will allow the blood to flow from the aorta (high pressure) into the pulmonary circulation (low pressure), which will decrease the blood volume during diastole thus ***decreasing the diastolic pressure***, and this blood will flow back through the pulmonary veins into the left side of the heart, which will cause more blood to enter the left atrium and ventricle ; this will increase the stroke volume (increased preload) thus ***increasing the systolic pressure***, and this will lead to increased pulse pressure. (note that the incisura might be weak or absent)

- **Aortic regurgitation**: in this condition the aortic valve doesn't close correctly allowing blood to flow back from the aorta into the heart, the flow back will cause more blood to accumulate in the left ventricle (increased preload) leading to a larger stroke volume, and at the same time decreasing the blood volume during diastole, this will cause increase in systolic pressure and decrease in diastolic pressure, an important thing to note is the possibility of absent incisura in the pulse pressure because the aortic valve doesn't close properly .



Vascular distensibility:

As mentioned before , it is calculated by the following equation:

$$Distensibilty = \frac{increase\ in\ volume}{increase\ in\ pressure \times\ original\ volume}$$

Pulmonary arteries are relatively distensible (more than the distensibility of the systemic arteries).

Veins are 8 times more distensible than arteries, because their media isn't as developed as the arteries.

Remember that the compliance can be described by the following equation:

$$Compliance = Distensibility \times\ Original\ Volume$$

And because the veins contain about 3 to 4 times the volume of blood as contained in the arteries, the compliance of the veins is about 24 times the compliance of the arteries.

1:00:00

Volume-Pressure relationship:

- Any given change in volume within the arterial tree results in larger increase in the pressure than in veins.
- When veins are constricted, large quantities of blood are transferred to the heart, thereby increasing the cardiac output.

When the veins constrict, the mean systemic filling pressure (MSFP) increases, which increases the venous return (VR) to the heart, and by increasing the preload the cardiac output (CO) will increase.