# Cardio-Vascular System

# Physiology


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**Hemodynamics 1**

*In this lecture we'll be going over some physical laws that govern the blood flow inside our body. It's good to note that these laws apply to rigid tubes, unlike our blood vessels which experience some level of elasticity and extensibility, and to Newtonian fluids which in case of our blood isn't (mainly because it contains a cellular component).*

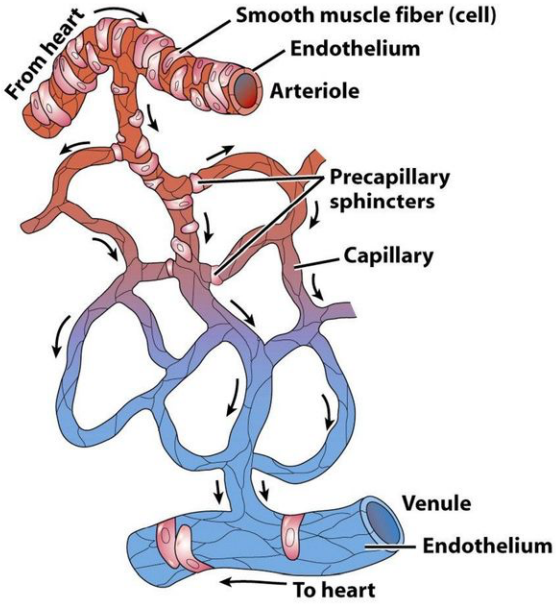
00:00

**Importance of blood flow:**

1. Delivery of O2 and removal of CO2 from tissue cells.
2. Gas exchange in lungs.
3. Absorption of nutrients from GIT.
4. Urine formation in kidneys.

**Organization of the vascular system:**

*We'll be covering the systemic circulation in this course, the pulmonary circulation will be covered in the Respiratory system.*




We start off with large arteries which divide into medium sized arteries and then into smaller and smaller arteries until we reach the arterioles, as we go down the arterial tree (from large arteries to smaller arterioles) we notice that the smooth muscles decrease.

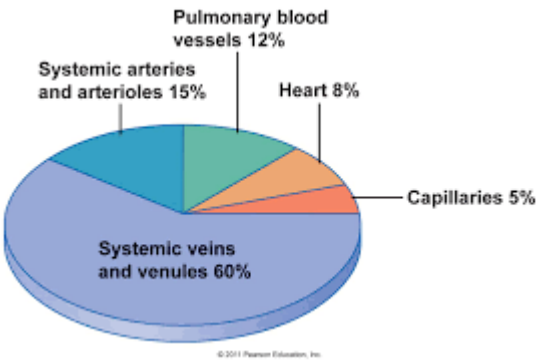
Arterioles act like valves before the capillaries, when they constrict, they decrease the blood flow and when they dilate the blood flow will increase.

The arterioles open into the capillaries which is **where the exchange of substances occur,** after that the capillaries unite to form venules, which unite to form small veins, and these veins will drain into larger and larger veins until we end up with the SVC and the IVC.

Because there is no exchange of substances except in the capillaries, the arterial blood will contain almost the exact concentration no matter where you drain it from .

**Blood volume distribution:**

The systemic circulation (called peripheral circulation) serves all the tissues except the lungs and it contains about 84% of blood volume.




The pulmonary Circulation serves the lungs and it contains 9% of blood volume.

The heart contains about 7% of blood volume.

These values may vary from one person to another but normally they are within this range.

Notice how the volume contained within the systemic veins is about 4 times as much blood as there is in the systemic arteries, and that's why we call the veins Capacitance Vessels.

The flow of blood in each compartment (capillaries, or arteries, or veins) equals the cardiac output and is almost constant in all the compartments.

**Function of veins and Blood reservoirs:**

Blood reservoirs are compartments that contain excess blood and can readily move this blood to the circulation.

Under various physiological conditions, blood is transferred from these reservoirs into the arterial system to maintain the arterial pressure. The spleen, liver, large abdominal veins, and the venous plexuses all serve as reservoirs and the spleen also serves as a special reservoir for red blood cells (packed RBCs in the red pulp).

10:00

**Basic theory of circulatory function:**

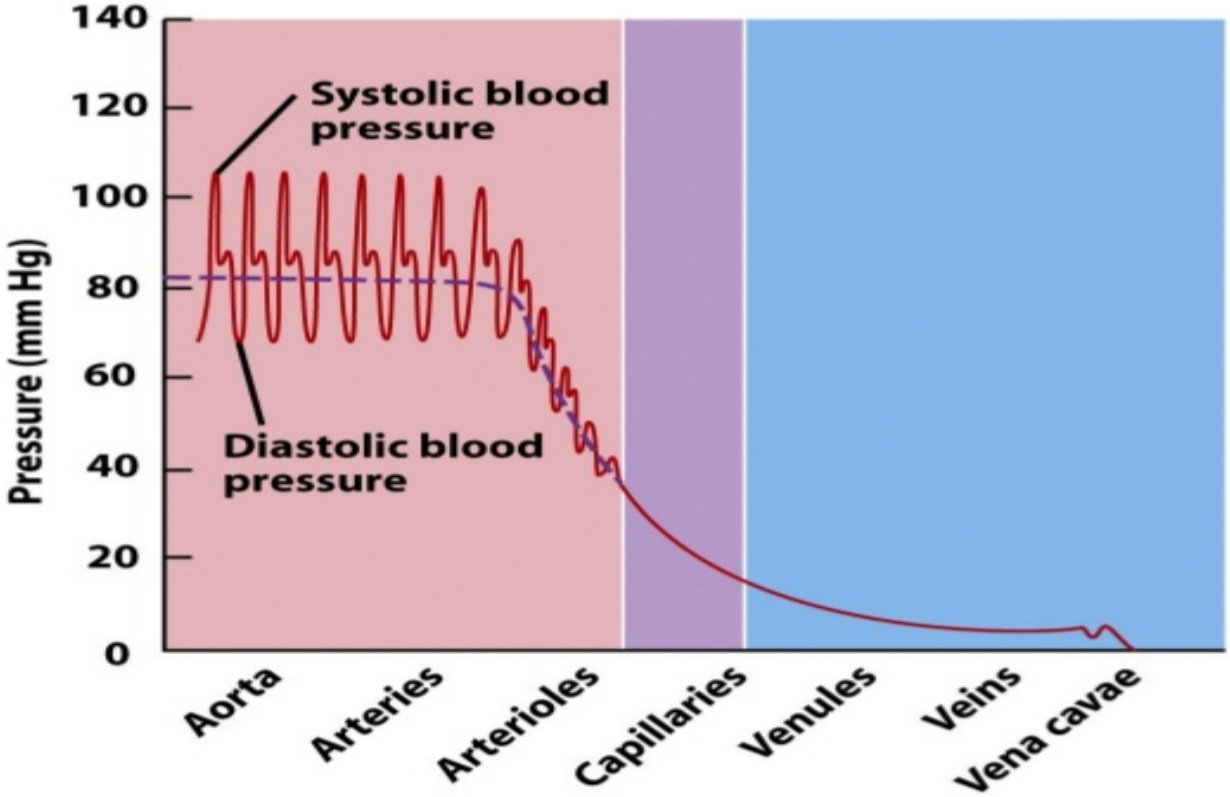
Blood flow to tissues is controlled in relation to tissue needs, so if the tissue needs more oxygen the blood flow to that tissue will increase.

Cardiac output is mainly controlled by local tissue flow (remember that the cardiac output equals the blood flow in all tissues) so if a certain tissue needs more blood the cardiac output will increase.

Arterial pressure is controlled independent of either local blood flow control or cardiac output control.

**Pressure changes through the circulation:**

The blood pressure in the aorta varies between systole and diastole and this makes the pressure pulsatile (it rises in systole and falls in diastole), and this pulsation causes a pulse wave in the walls of the arteries and this is what we feel when we put our finger on the radial artery to check for the **PULSE**. This pulsation continues throughout the arterial tree but ends at the level of the arterioles( if the pulsation continues it is abnormal).




We can calculate the MAP by the following equation:

$$MAP = \frac{1}{3} * Systolic\ pressure + \frac{2}{3} * Diastolic\ pressure$$

The diastolic pressure contributes more than the systolic pressure because the heart is in diastole for two thirds of the cardiac cycle, and is in systole for only one third of the cycle.

Reminder:

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

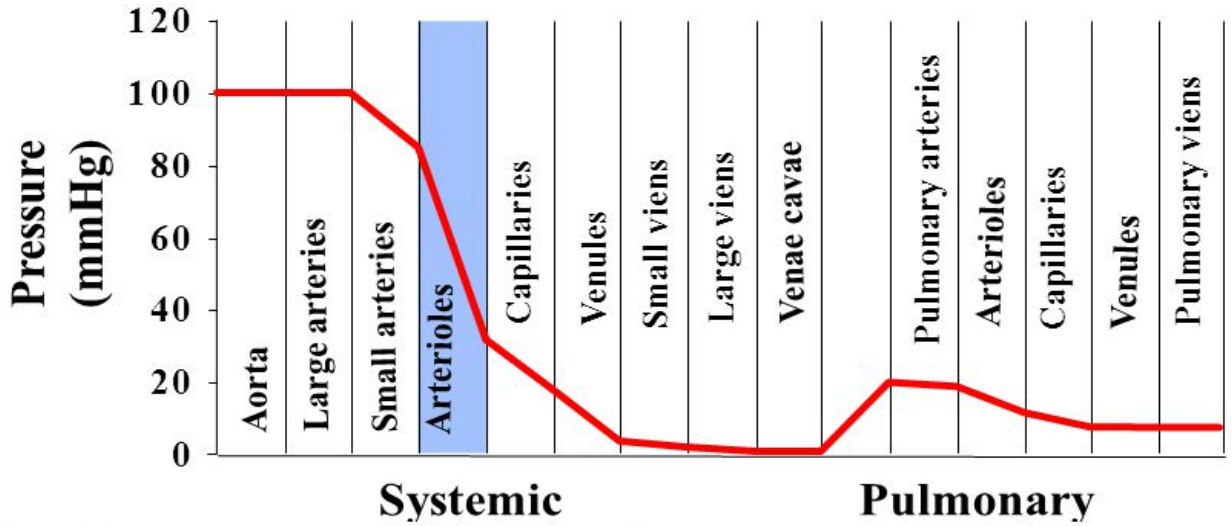
And the cardiac output equals the blood flow through all the arteries or through all the capillaries or through all the veins, and according to Ohm's Law:

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

The flow in the large arteries should equal the pressure gradient across the arteries over the resistance in these vessels. (Make sure to check the examples and questions at the end)

Notice the huge pressure drop in the arterioles, this is because of the high resistance in these vessels, which is why we call the arterioles "Resistance Vessels".

20:00




The high pressures are in the arterial tree, while the low pressures are in the venous side of the circulation, and there is a large pressure drop across the arteriolar-capillary junction.

*The pulmonary circulation is just like the systemic circulation but with lower pressures.

**Flow, Velocity, and the Cross-sectional area:**

The flow inside any vessel equals:

$$F = V * A$$

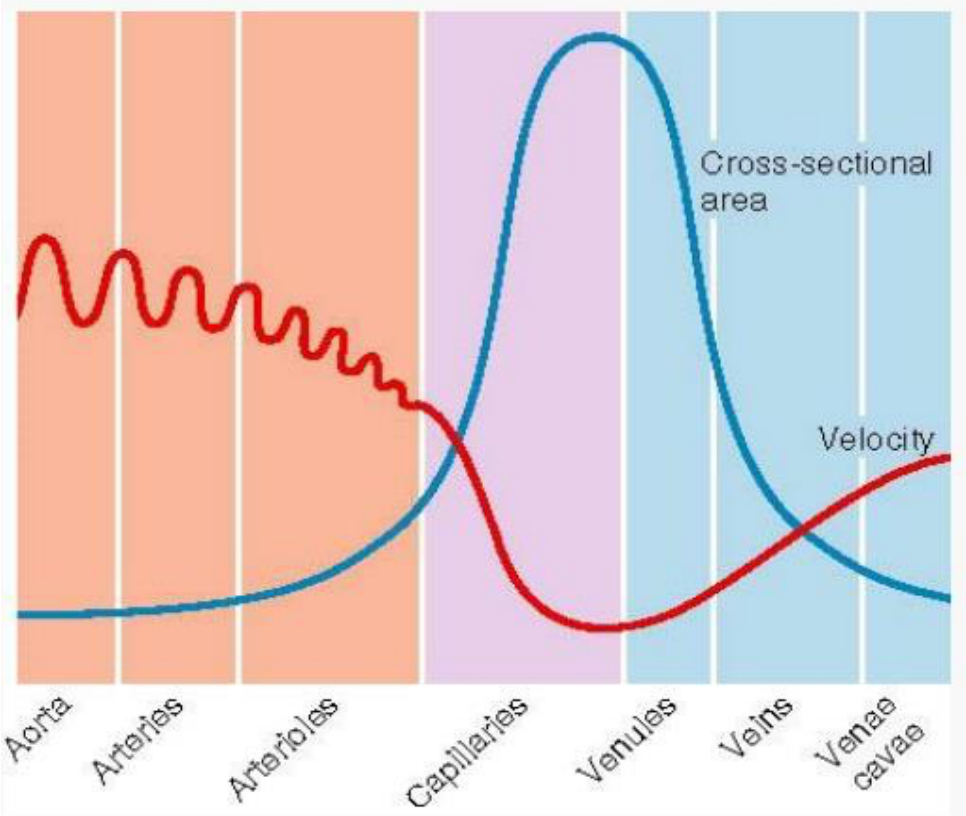
V: velocity of blood flow inside the vessel.

A: cross sectional area of the vessel.

The flow in each part of the circulation is the same and equals the Cardiac Output, and because the area of each part is different, we expect the velocity to be different as well.

- The Velocity is inversely related to the Area, so when we have a part with smaller area, we will expect it to have higher velocity of flow.

*Remember when we talk about a part of the circulation, we mean all the vessels. (all the capillaries together, all the large arteries together, etc.)




The velocity starts high and pulsatile in the aorta and falls the more the vessels branch (the area increases), and after the capillaries the velocity starts to rise again until it reaches the Venae Cavae, but the velocity won't reach the level of the Aorta because we have one Aorta and two Venae Cavae.

Notice how the capillaries have the highest cross sectional area and the lowest velocity, and this is advantageous because the capillaries are the only site where there is exchange between the blood and the tissues, and we can't hurry that process.

30:00

| **Part** | **Diameter (cm)** |
|---|---|
| Aorta | **2.5 (important)** |
| Small arterioles | 20 |
| Arterioles | 40 |
| Capillaries | **2500 (important)** |
| Venules | 250 |
| Small veins | 80 |
| Venae Cavae | **8 (important)** |

Velocity of blood flow can be described by the following equation:

$$V = F/A$$

This means that the smaller the cross-sectional area the higher the velocity.

Velocity in the Aorta > V in arterioles > V in small veins > V in capillaries.

**Blood Flow:**

Blood flow (F) simply means the quantity of blood that passes a given point in the circulation in a given period of time (mL/Sec). {we can use different units of volume (L) and time (minute)}

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

F: Blood flow.

ΔP: is the Pressure gradient produced by heart pumping; it moves the blood in the system from the arterial side to the venous side. (this pressure expands the blood vessels and causes the pulsation that we feel)

R: Resistance that impedes blood flow.

There are two types of flow:

1- Laminar flow (streamline)
2- Turbulent flow (Eddy currents)

Our laws are appliable only to laminar flow.

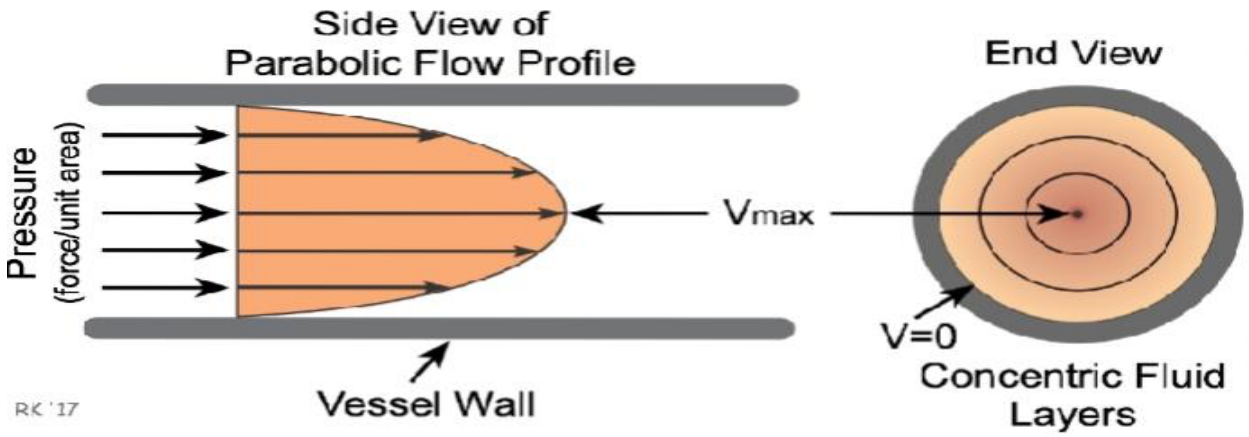
Turbulent flow produces sounds, while laminar flow is silent.

When blood flows (Laminar flow) through the blood vessel, it is met by resistance from the vessel wall (friction), and this causes the blood near the wall to slow down (almost not moving at all), while the blood in the center isn't met by much resistance, so it flows faster.

This flow produces layers of blood, each layer is at a certain distance from the wall and moves at a uniform speed.

This type of flow is called parabolic flow profile.

The overall flow in the circulation of an adult is 5L/min which is the cardiac output.




Explanation (extra):

Laminar (streamline) flow occurs when blood flows at a steady rate through a straight smooth vessel, and it moves in layers, where each layer slides over the layer above and below, each layer maintains its distance from the vessel wall throughout its course.

When these layers slide, they are met by resistance in the form of friction. Two important points to highlight are: first, the friction between the closest layer to the wall and the vessel wall is very high that the blood almost doesn't move. Second ,the friction between two layers is determined by their speed, in other words if a layer slides over a slow moving layer, then the friction between these two layers will be high, but if a layer was to slide over a fast moving layer then the friction is low. These two points cause the blood layers to move faster the farther they are from the vessel walls, where the centermost layer is the fastest, this is called the *parabolic profile for velocity of blood flow* and it causes the blood to flow in a parabolic manner.

40:00

**Reynold's number:**

Reynold's number is used to describe the tendency of the blood to flow in a turbulent manner, and it is calculated by the following equation:

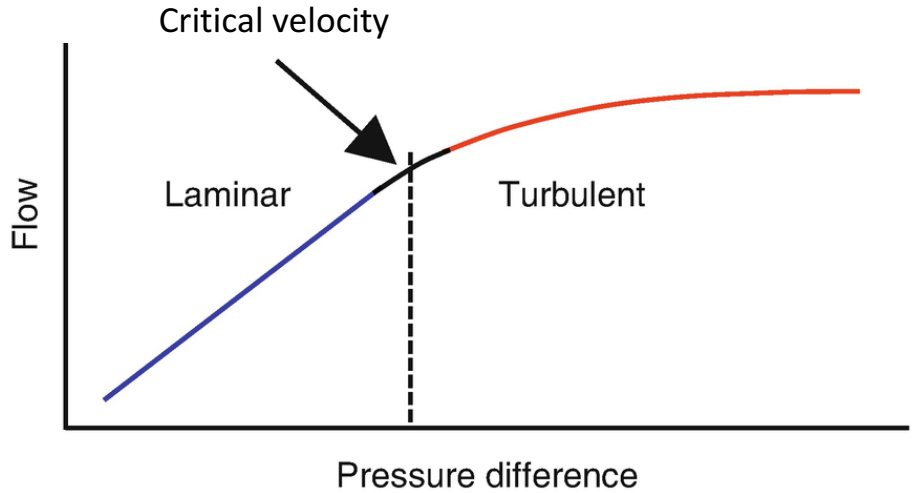
$$Re = v * d * \frac{\rho}{\eta}$$

Where Re is *Reynold's number* which represents the tendency for the flow to become turbulent, v is the velocity of blood flow, d is the diameter of the vessel, ρ is the density of blood, and η is the viscosity of blood.

If Re < 400 then the flow is laminar.

If Re > 1000 then the flow is turbulent.

If Re is between 400 and 1000, then the flow may become turbulent if there was a constriction (as in atherosclerosis) or when the blood takes a sharp turn (as in the axillary artery).




$Re = \rho v D/\eta$
with

$\rho$ = blood density
$v$ = blood velocity
$D$ = diameter
$\eta$ = blood viscosity

When the pressure gradient increases, the flow will increase and so will the velocity, until the velocity is high enough for the flow to become turbulent (Re is big), this velocity is called **critical velocity**. After it, the slope of the curve will become smaller (dF/dP will decrease) and so the velocity will increase in a slower manner with increased pressure.

The disordered flow increases the resistance because the eddy currents add to the friction of the flow, and this will cause the velocity to increase less when we increase the pressure.

*Turbulent flow predisposes to thrombosis.

50:00

Causes of turbulent blood flow:

1- High velocities (anemia decreases the resistance).
2- Sharp turns in the circulation (could be normal or abnormal).
3- Rough surfaces in the circulation (as in atherosclerosis).
4- Rapid narrowing of blood vessels (as in atherosclerosis and thrombosis).

Laminar flow is silent, whereas turbulent flow tends to cause murmurs or bruits, and these are important in diagnosing vessels stenosis, vessel shunts, and cardiac valvular lesions.

**Significance of turbulence:**

Turbulence can occur normally at the branching of vessels ,the roots of aorta and the pulmonary arteries.

But it can be pathological in these circumstances:

1. Constriction of arteries by atherosclerotic plaque.
2. Severe anemia.
3. Stenotic and incompetent (regurgitation) cardiac valves.

**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 the resistance to blood flow occurs in arterioles (50%) and capillaries (25%) so it is called peripheral resistance.

Exercise:

If you know that the CO of an individual is 5L/min, the MAP of the aorta is 95mm Hg, find the following:

1- The resistance of the aorta and the large arteries if the end blood pressure is 80mm Hg?
2- The pressure gradient across the arterioles if you knew that the resistance in the arterioles is 9 peripheral resistance units?
3- If the individual took a drug that caused the arterioles to dilate and reduced their resistance to 5 peripheral resistance units, what will the new CO be?

1- Solution:

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

$$5L/min = \frac{95 - 80}{R}$$

$$R = \frac{15}{5}$$

$$R = 3\ peripheral\ resistance\ units$$

2- Solution:

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

$$\Delta P = F * R$$

$$\Delta P = 5 * 9$$

$$\Delta P = 45\ mm\ Hg$$

3- Solution:

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

$$F = \frac{45}{5}$$

$$F = 9L/\min = CO$$