CVS Hemodynamics

-The distribution of blood inside the circulation:
The major part of blood volume is found in the venous system 60% (2/3), that's why veins are called the <u>capacitance vessels.</u>
-Arteries contain 15%of blood volume while capillaries contain about 5%
-Systemic circulation contains 84% of blood volume while the heart and lungs contain the rest.
-Liver and spleen are considered reservoirs of blood, they are needed when in need for extra blood during hemorrhage.
-Blood flow is proportional to how much oxygen is needed for tissues. It is controlled to the minimal values because we don't have to much blood.
-Cardiac output is the sum of blood flow to the tissues (it is controlled by local tissue flow).

Change in blood pressure:
-We deal with any part of the circulation as one unit;
 -The large arteries as one unit, the small arteries as one unit, arterioles as one unit…
-The blood flow in each of these units is considered cardiac output; even though the capillaries - for example- are small, but multiplied by billions (their number; approximately 10-12 billions)
gives you the same cardiac output.
-The arterial blood pressure is variable in the aorta between the systole and diastole >> it's considered <u>pulsatile.</u> (up and down between 120-80 mmHg)
-<u>Mean arterial pressure</u> is the pressure that cause movement of the blood inside the circulation, not the systolic or diastolic
-Mean arterial pressure equals one third of the systolic pressure and two thirds of the diastolic pressure
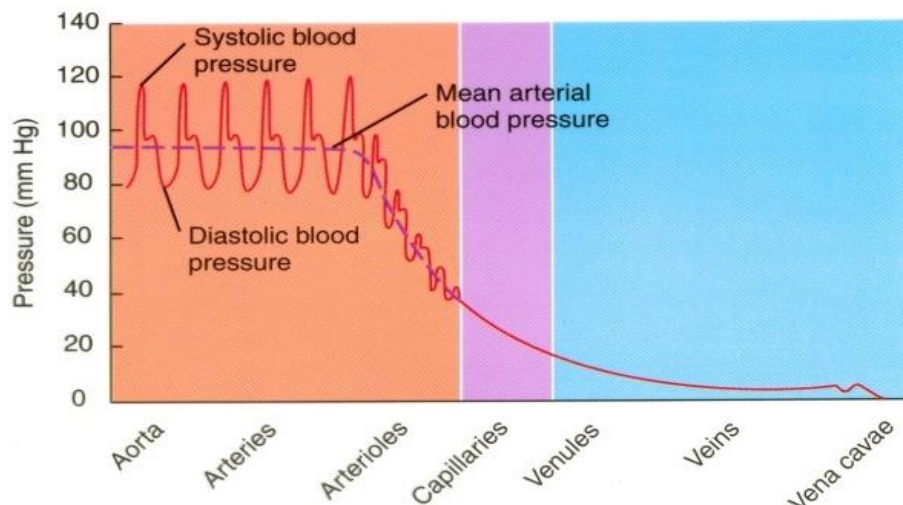
FLOW=ΔP/R

-As we said the flow in each unit is the same. So when you look at the aortic mean arterial pressure =100mmHg , while in large arteries it is 95mmHg (the difference =5mmHg), we see that there isn't much pressure drop and that is due to the small resistance in large arteries. While in the arterioles the pressure in the beginning is 85 and drops at the end to 30-35 (which is considered a high drop in the pressure, ΔP is very high), so while maintaining the same flow, the resistance is increased significantly.

**The arterioles are called resistance vessels.

-Blood pressure/Mean arterial pressure drops from the aorta to the vena cava (right atria)>> gradient is decreasing. (there is a continuous decrease).

-In the arterioles the pressure is propping? too much, and there is no pulsation, This is called Damping of the pulsation, that is because of the very high resistance in the arterioles.

-If you want to feel pulsation you search for it beyond the arterioles

-If you feel pulsation in the capillaries> abnormal

-If you feel pulsation in the veins> abnormal
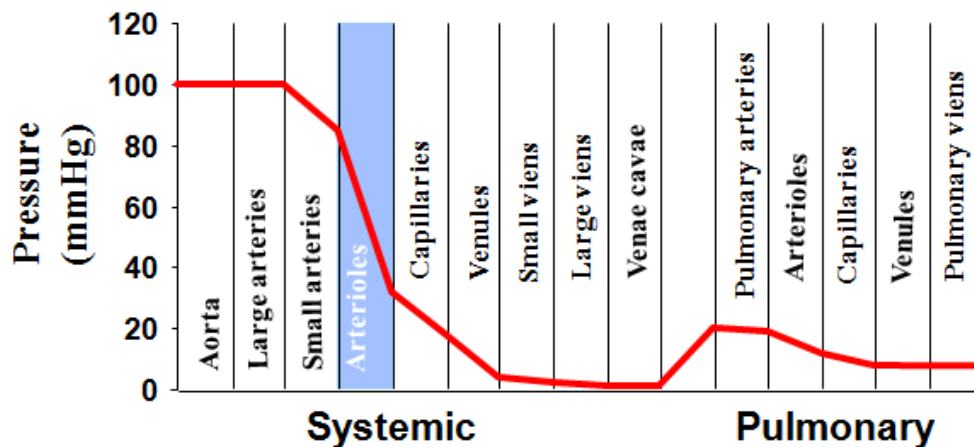
*High pressure in the arterial tree, low pressure in the venous circulation (including the pulmonary)

*Notice:- the high difference in pressure in the pulmonary comparing to the systemic circulation. (120/80 and 25/8)

The doctor said that the mean arterial pressure in the systemic circulation is six times more than the pulmonary circulation.

       -Large pressure drop across the arteriolar-capillary junction (arterioles> resistance vessels).

Changes in velocity and cross sectional area:

Flow (through a vessel)= cross sectional area × velocity (A*V)

Flow is the same (constant)> the velocity is inversely proportional to the area.>> increase in cross sectional area will decrease the velocity.

Velocity of Blood Flow =   _____Blood Flow_____

                                                  Cross sectional area

Area: Aorta……………………..2.5 cm2
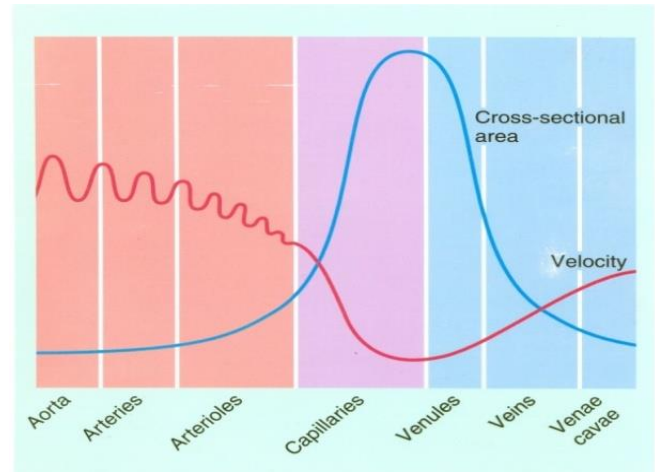
          Small arteries………. Increase in area

          Arterioles……………..more increase

          Capillaries……………..have the highest

cross sectional area

Velocity: in the aorta is very high, and then it drops down till it reaches the capillaries with the least velocity.

>> this is perfect for the capillaries which are the site for <u>exchange</u>: with high cross sectional area (since the exchange depends on the area) and a slow flow that provides enough time for the exchange to occur.

-After the capillaries the velocity increases in the venules and then more in the veins (drop in cross sectional area with maintaining the same flow)

-The velocity in the vena cavae is less than the aorta's because we have one aorta and two vena cavae.

-The changes in velocity is different from the changes in pressure: the pressure drops from the aorta to vena cavae, but the velocity (which is proportional to area) drops until capillaries then increases.

Blood flow:

Blood flow: means simply the quantity of blood that passes a given point in the circulation in a given period of time (mL/Sec).

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

ΔP : pressure gradient (P1-P2)

R : resistance inside the vessel

-Pressure gradient: difference between mean arterial pressure and the right atrial pressure

-Right atrial pressure = zero

So the flow = C.O.

-Pressure gradient produced by heart pumping moves blood in the system from the arterial to the venous side, 5 L/min

- Fluid pressure expands cardiac chambers and blood vessels.

- $F = A \times V$ >>>Velocity (V) is proportionate to flow (F) divided by cross sectional area of the blood vessel (A).

  $V=F/A$

Blood Flow Types:

two types:

1. Laminar flow: (stream line flow) our laws are applied to this type. (the effective flow)
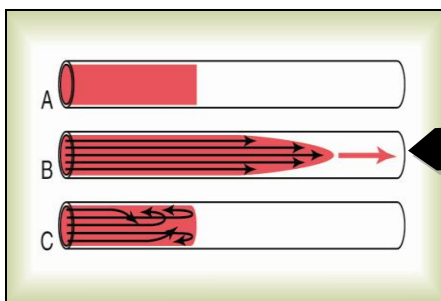
    -the flow here is parabolic: lower speed at the sides(beside the walls, *resistance)

    And higher speed toward the center (reaches maximum velocity in the center).

    -this produces laminae (layers) with uniform speed at certain distance from the wall >> a parabolic shape

So it can be called parabolic flow.

This is copied from the slide:

(((Blood usually flows in streamlines with each layer of blood remaining the same distance from the wall, this type of flow is called *laminar flow.*

When laminar flow occurs, the velocity of blood in the center of the vessel is greater than that toward the outer edge creating a parabolic profile.)))

2. Turbulent flow: (Eddy current) not an effective flow.

    -unpredictable velocities

When the flow becomes Turbulent, there is an equation concerning it:

$$\text{Reynold's No (Re)} = \frac{v.d.\rho}{\eta}$$

v : velocity, d : diameter, ρ : density, η : viscosity of fluid

From this you can notice that an increase in the diameter, velocity, or the density increase (Re), while viscosity decreases it.

1- If this number is less than 400= the flow is stream line (laminar)

2- If this number is between 400 and 1000= (grey area) the flow might be laminar or turbulent, depending on the situation.

What makes the flow turbulent?

- Constriction: example: kinking of the axillary artery

-atherosclerosis: a plaque inside> constriction> in case of very high velocity

3- If this number is higher than 1000= the flow is turbulent

-**Critical velocity**: where beyond this velocity you have Reynold's number higher than 1000> turbulent.

So you pass the critical velocity, it takes a progressively greater force to increase flow
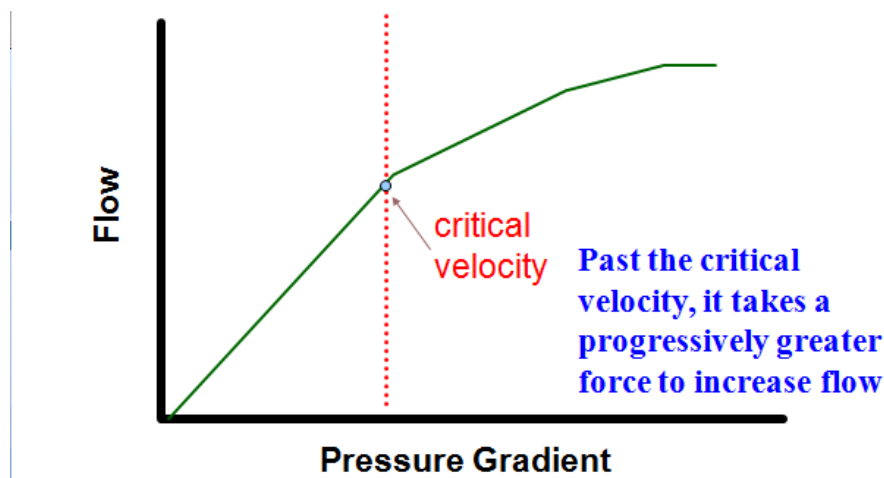
*The following is copied from the slide:
(((Causes of turbulent blood flow:
   • high velocities
   • sharp turns in the circulation
   • rough surfaces in the circulation
   • rapid narrowing of blood vessels
• Laminar flow is silent, whereas turbulent flow tend to cause *murmurs.*

- Murmurs or *bruits* are important in diagnosing vessels stenosis, vessel shunts, and cardiac valvular lesions.)))

Heart sounds: turbulence of blood around closed valves.
Without turbulence there is no sound>> important for measurement of blood pressure.
>>>> when you measure the blood pressure, you wrap the cuff around the arm and raise the pressure above the systolic pressure (at this point there is no flow, so no sound will be heard lower than the cuff), when you start to decrease the pressure gradually and it reaches just below the systolic then there is flow during systole>> you hear a sound (through a stethoscope). But still it is above the diastolic (80mm/Hg) so no flow or sound , here there is a constriction in the artery.
You continue to lower it till you reach a pressure less than diastolic pressure. Now there is no compression and no constriction. Here there is no sound, which mean that the flow is luminar.
***The sound you hear is due to the turbulence of blood flow around a <u>constricted</u> artery. The sound is called <u>korsakoff sound</u>.

-Clinical significance of turbulence:
 normally in the branching of vessels, root of aorta and pulmonary arteries.
-Pathologically:
1- Constriction of arteries by atherosclerotic plaque>> the flow is turbulent there>> it precipitate to thrombosis (because it's not going with steady velocity).
*** Complication of atherosclerosis is thrombosis because of Eddy's current.
2-In severe anemia: Reynold's No. is inversely proportional to viscosity, the viscosity in severe anemia is low, this means high Reynold's No.>> this gives you turbulence.
This might precipitate to thrombosis
3- stenotic or incompetent cardiac valves.
Endocarditis (plaque) is one of the compications of abnormal valves.

<u>Peripheral Resistance:</u>

-It is the resistance of blood flow through a vessel (in the whole peripheral circulation) caused by friction between the moving fluid and the vascular wall.
-Most of the resistance to blood flow occur in arterioles
Remember : major resistance vessels: Arterioles
           Capacitance vessels :Veins

Ohm's law: F =ΔP/R

F = Flow, ΔP = Change in Pressure,   R = Resistance

Flow = Cardiac Output.

$$CO = \frac{MAP - Rt.AtrialP}{TPR}$$

CO = cardiac output, MAP = mean arterial pressure, TPR = total peripheral resistance. Since Rt. Atrial pressure = 0 , then:

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

>>>MAP = CO× TRP

Poiseuille's law:

--our laws apply to stream line flow just like engineers. Stream line flow is made for rigid tubes and while our vessels are not rigid we use them none the less.

It is also called Hagen-Poiseuille's equation:

F= π ΔP r^4 / 8ηL

>> F = ΔP/R   also   F = A × V

>>$A = \pi r^2$

>> main V is in the Parabolic flow; where the velocity is slowest near the walls and fastest in the center

>>here we have an integration dv/dd (change in velocity over distance)from the center to the wall.

The following is an explanation of poisuille's law:

So what we have here is a reservoir, filled with fluid, so we measured the flow in it and the length of the tube and the viscosity of fluid and the pressure gradient, keeping the flow constant, we changed the rest to see it's effect:

1- first we changed the pressure gradient (ΔP): we found that the flow (F) is directly proportional to the pressure gradient (ΔP)>> increase in gradient=increase in flow, decrease in gradient=decrease in flow.

2-we changed the length of the tube: we found that the length is inversely proportional to the flow>> increase in the length=decrease in flow, decrease in length=increase in flow

**but in our circulation we can't change the length of the tube(it is the least changeable factor), except in few cases , such as: growing child

So this means it's the least important one to change.

Q) if we double the tube's length the flow is : half its initial value.

3-we changed the viscosity= we found that the flow is inversely proportional to viscosity>>

Increase in viscosity=decrease in flow, decrease in viscosity= increase in flow

4-change in radius : flow is directly proportional to the 4th power of radius

If we had a vessel with 1 mm diameter>> here the flow is going to be 1ml/min, but if you double the diameter to 2mm>> the flow is going to increase to 16ml/min and so on:

Diameter	flow
1mm	1ml/min
2mm	16ml/min
3mm	81ml/min
4mm	265ml/min

So the increase in flow is proportional to the fourth power of radius (r^4).

While decrease it to ½ mm will give you 1/16 ml/min flow, 1/3 → 1/81...

Then the Flow is proportional to $\Delta Pr^{4}/\eta L$

F= constant *$\Delta Pr^{4}/\eta L$

The constant = $\pi/8$

Poiseuille's law>>

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

Then Hagen derived the same law mathematically !!

F = flow,
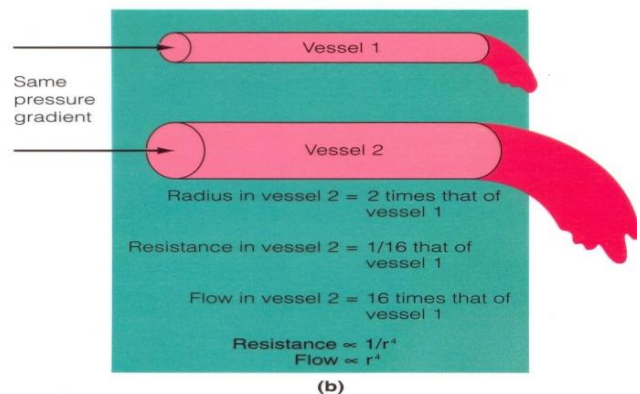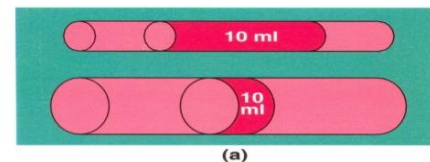
ΔP = change in pressure,

r = radius of the vessel

η   (eta) = viscosity

L = length of the vessel

F= ΔP/ R   >>> R = ΔP/ F

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

Relationship of Resistance and Flow to the Vessel Radius

10 ml

10 ml

(a)

Vessel 1

Same pressure gradient

Vessel 2

Radius in vessel 2 = 2 times that of vessel 1

Resistance in vessel 2 = 1/16 that of vessel 1

Flow in vessel 2 = 16 times that of vessel 1

Resistance ∝ 1/r^4
Flow ∝ r^4

(b)

-Resistance is mainly affected by radius (r^4); double the radius will decrease the resistance too much and decrease the radius for half its value will increase the resistance .

-blood flow to the tissue: we don't change the pressure (it should remain constant), but when we want to increase or decrease the flow to the tissues, we are causing vasoconstriction or vasodilation.

>>>> Vasoconstriction= increase the resistance and decreases the flow

Vasodilation= increase the diameter decrease the resistance and increase the flow
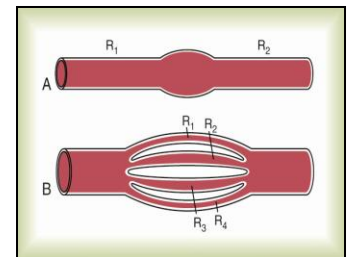
-ΔP is not the major contributory like R

Resistance:

When vessel resistance is in series; the total resistance is higher than the highest of them

$$R_{total} = R_1 + R_2 + R_3 + R_4 \ldots$$

And when vessels are parallel; the resistance is lower than the lowest of them

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \ldots$$

-The resistance is affected by the radius, and is affected by the viscosity

What are the factors that changes the viscosity??

1- hematocrit: polycythemia (increase), anemia(decrease)

2-plasma protein: mainly albumin, fibrinogen and globulin

3-diameter of blood vessel: the smaller the diameter the higher the viscosity.

But in the capillaries the RBCs are connected to each other like a spring, so the viscosity here is the same as the large vessels

4-temperature: increase in the temperature decreases the viscosity

**How is the viscosity affected by the hematocrit?

The viscosity of water is 1, the plasma doesn't change in viscosity, and so what changes is the amount of blood in term of units of viscosity.

The normal hematocrit is 40, viscosity 2.5

**In Polycythemia: Increase in the hematocrit (increase in the RBC count) will increase the viscosity too much (not linearly but in a curve→Curvilinear) >>> this will lead to increase in the resistance therefore decrease the flow.. this will precipitate blood for thrombosis

Conductance: just like flow:
-is very sensitive to change in *diameter* of vessel.
- The conductance of a vessel increases in proportion to the *fourth power of the radius*
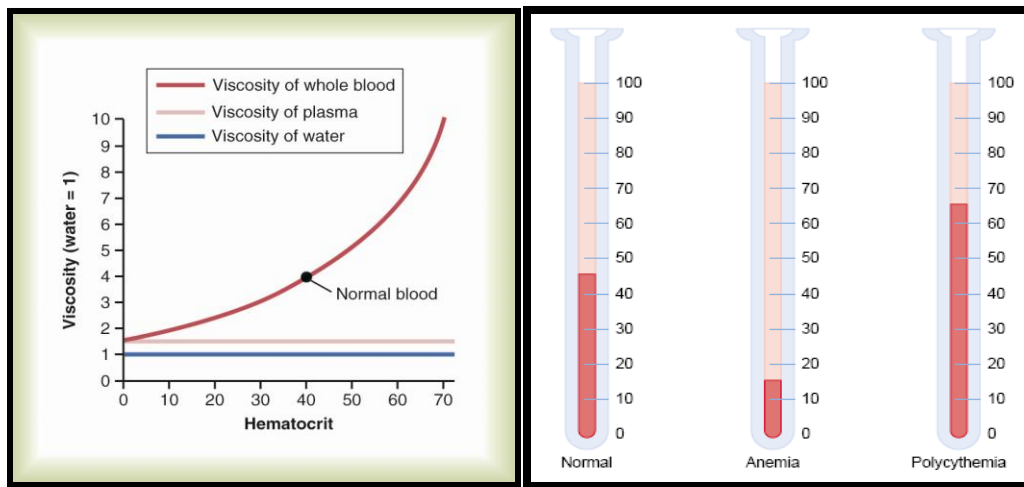
-You might have zero flow in vessels with some pressure inside them>>> Critical closing pressure
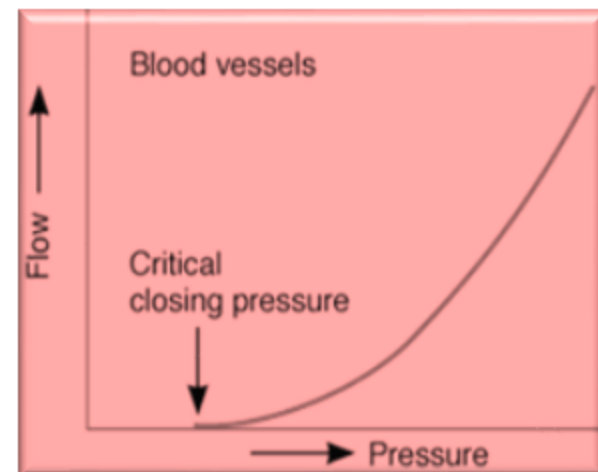-The vessel is closed although there is pressure because the tension around it is very high

This is explained by Laplace law:
As in alveoli
Total tension around it (T)= the distending pressure(P) × radius
If r=0, whatever the pressure is, the tension =0

Law of Laplace:
i.e. T = P x r and P = T/r

Relation between distending pressure (P) and wall tension (T) in a hollow viscus

***__Dispensability__ = __proportional change__ in volume per unit increase in pressure (how much the vessel is elastic, it is the ability of the vessel to distend, extend or dilate)>> this is a proportional increase in pressure.

$$D = \Delta V/\Delta P * V$$

Proportional>> so there is a percentage

V=total volume

- If the total volume is 100ml and we added 10ml , then increased the pressure 1mmhg
  >> dispensability= 10/ 1× 100

  = 0.1

***__Compliance__= __total change__ in volume per unit change in pressure (total distensibilty)

$$C = (\Delta V/\Delta P) = D * V$$

From above; the compliance=0.1 × 100

=10

In arteries and veins:

-The dispensability of veins is 6 times more than arteries

- How much compliance?

Veins contain 4 times more blood compared to arteries (=Volume difference), so if the dispensability of the veins is 6× more, then the compliance of veins is 24× more than arteries

-the volume in veins is 60% of the total volume, which is 4× more than the volume of arteries (15%).

Pulse pressure:

   *Difference between systolic and diastolic pressure

   =systolic-diastolic

   =120-80 = 40 mmHg

Factors affecting the Pulse Pressure :

Affected by : A)stroke volume   B)compliance of vessels

   A) Increase in stroke volume = increase in blood toward the aorta= increase in the systolic pressure= which increases pulse pressure

>>>> increase in stoke volume increases pulse pressure

   B) Compliance:

When compliance is low (rigid)>> little volume and more pressure

Increase in compliance will decrease the pulse pressure (more elastic)
Decrease in compliance will increase the pulse pressure

Pulse pressure is affected by ratio of stroke volume over compliance (SV/C)
Change in both in the same ratio will not affect the pulse pressure

Factors affecting Pulse Pressure:
- ➢ *Stroke volume*—increases in
 stroke volume increase pulse   pressure, conversely decreases
in stroke volume decrease
pulse pressure.
- ➢ *Arterial compliance*—decreases in compliance increases pulse pressure; increases in compliance decrease pulse pressure.

Factors Affecting the mean Arterial pressure (MAP):
1)Cardiac output (CO).
2)Total peripheral resistance (TPR).

Please Refer to the slides .

Sorry for any mistake, and good luck :D