CVS

PHYSIOLOGY

Modified NO: 13

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Cardiovascular Physiology

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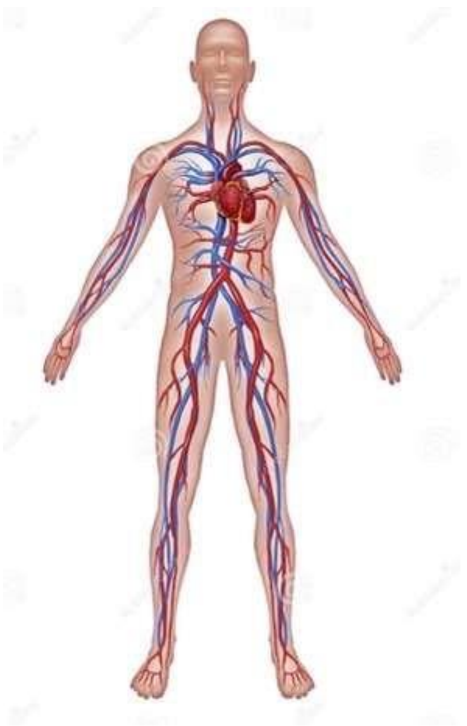

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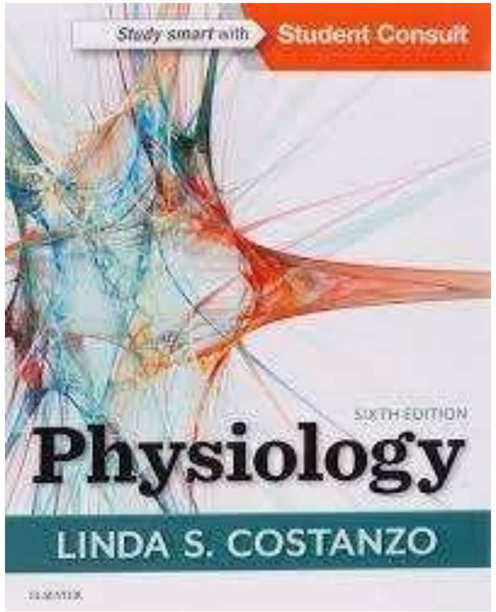
(black)	Slides
(green)	Doctor
(blue)	Additional info
(red)	Important

References



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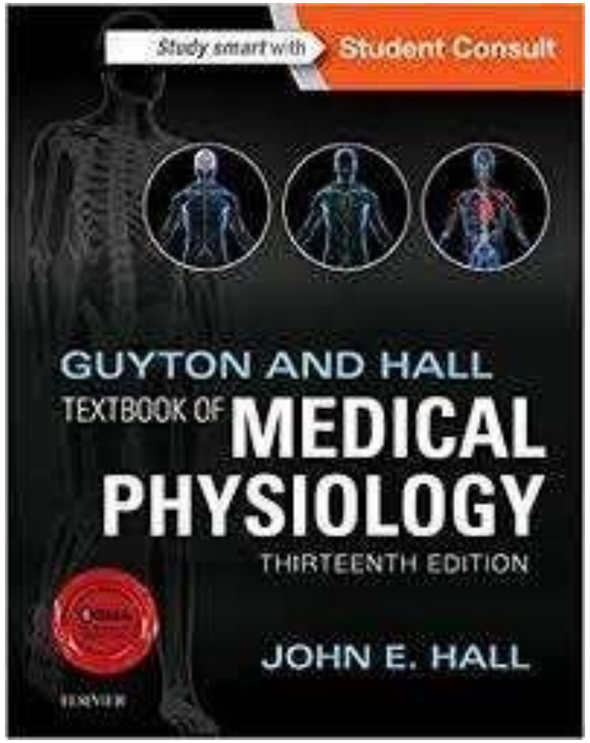

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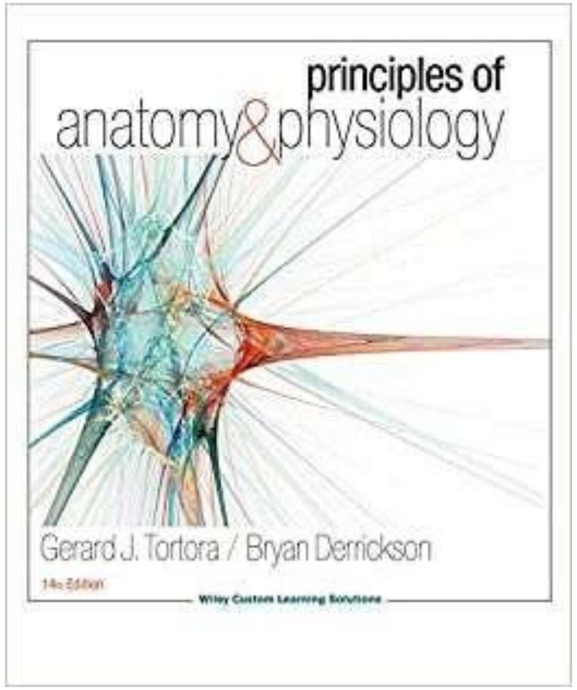


principles of
anatomy & physiology
Gerard J. Tortora / Bryan Derrickson

Human Physiology
From Cells to Systems
Lauralee Sherwood

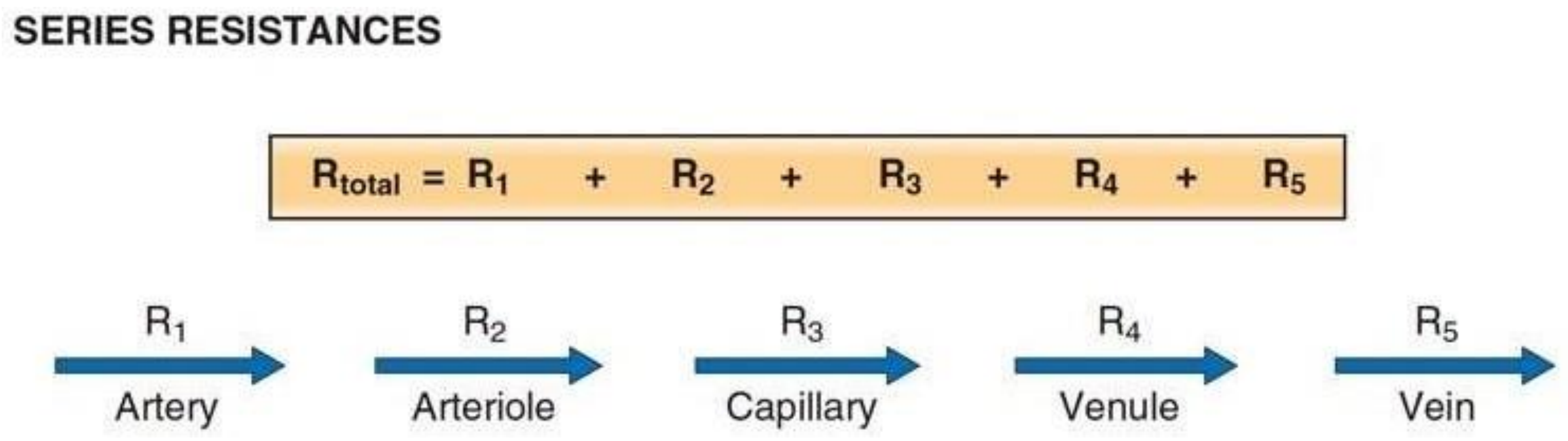
Vascular hemodynamics-2

Series resistances (e.g., in organ circulation)

- Within organ.
- The total resistance of the system arranged in series is equal to the sum of the individual resistances.
- The total resistance of a vascular bed is determined in large part by the arteriolar resistance.
- When resistances are arranged in series, the total flow at each level of the system is the same.
- This will give the following properties:

1. additive property of resistance: R (total) = R1 + R2 + R3 + ……
2. Current uniformity: the same flow rate in all the vessels of the series
3. Pressure decrease throughout the resistances resulting in → higher ΔP
4. Vulnerability to obstruction : lead to reduced overall flow

- Vessels are found in different arrangements
- usually, series or parallel arrangements.
- In this example, blood is moving from aorta to the brain , in a series



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

In subsequent vessels:

- Here the flow is uniform
- The pressure is decreased, lead to higher pressure difference
- The resistance is increased due to increased length

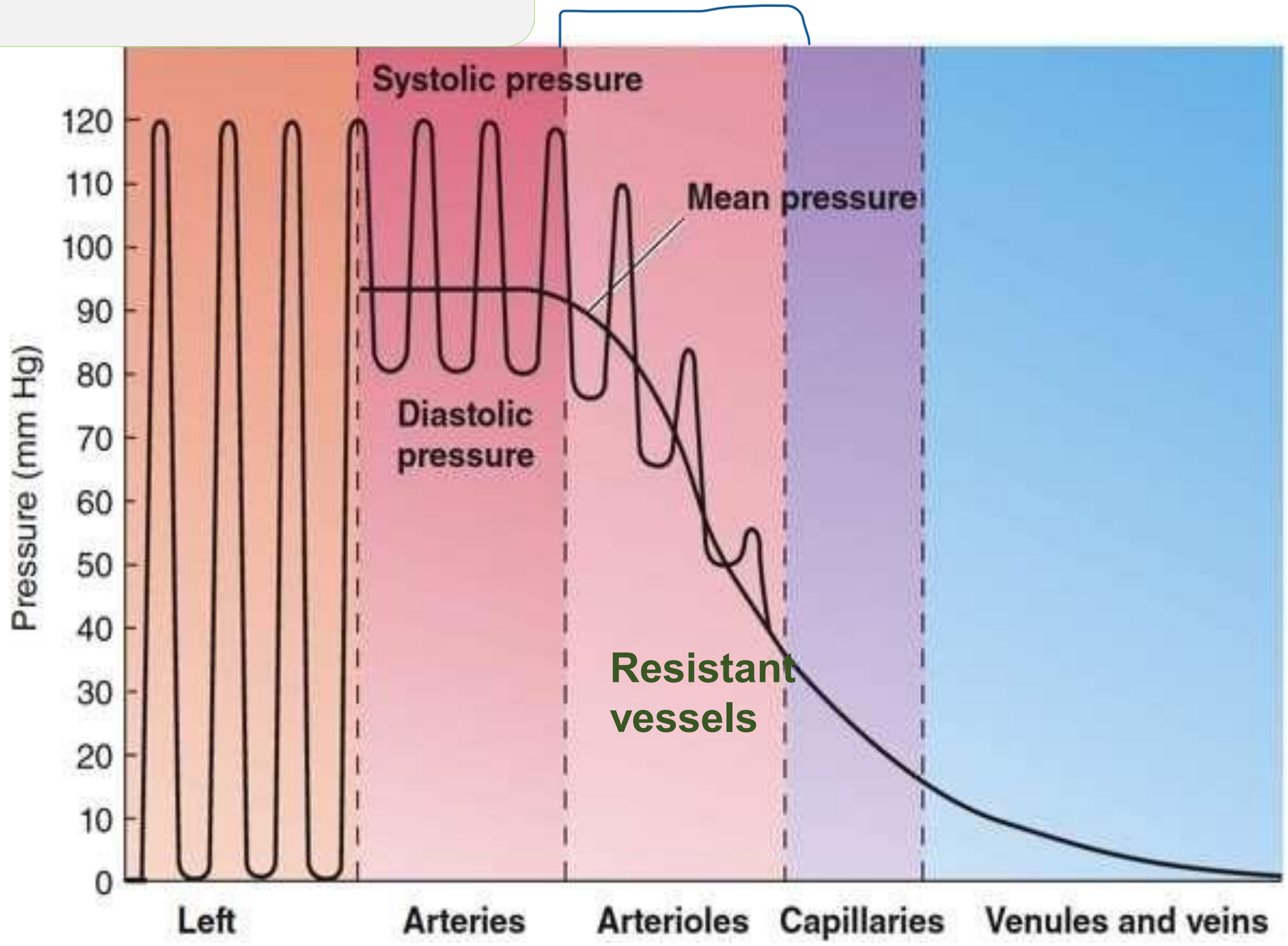
For example,
The resistance in artery is 5, arteriole 10, capillary 2, venule 1, vein 1, how much is the total resistance?
5+10+2+1+1 = 19

Series resistances

- Although total flow is constant at each level in the series, the pressure decreases progressively as blood flows through each sequential component.
- The greatest decrease in pressure occurs in the arterioles because they contribute the largest portion of the resistance.

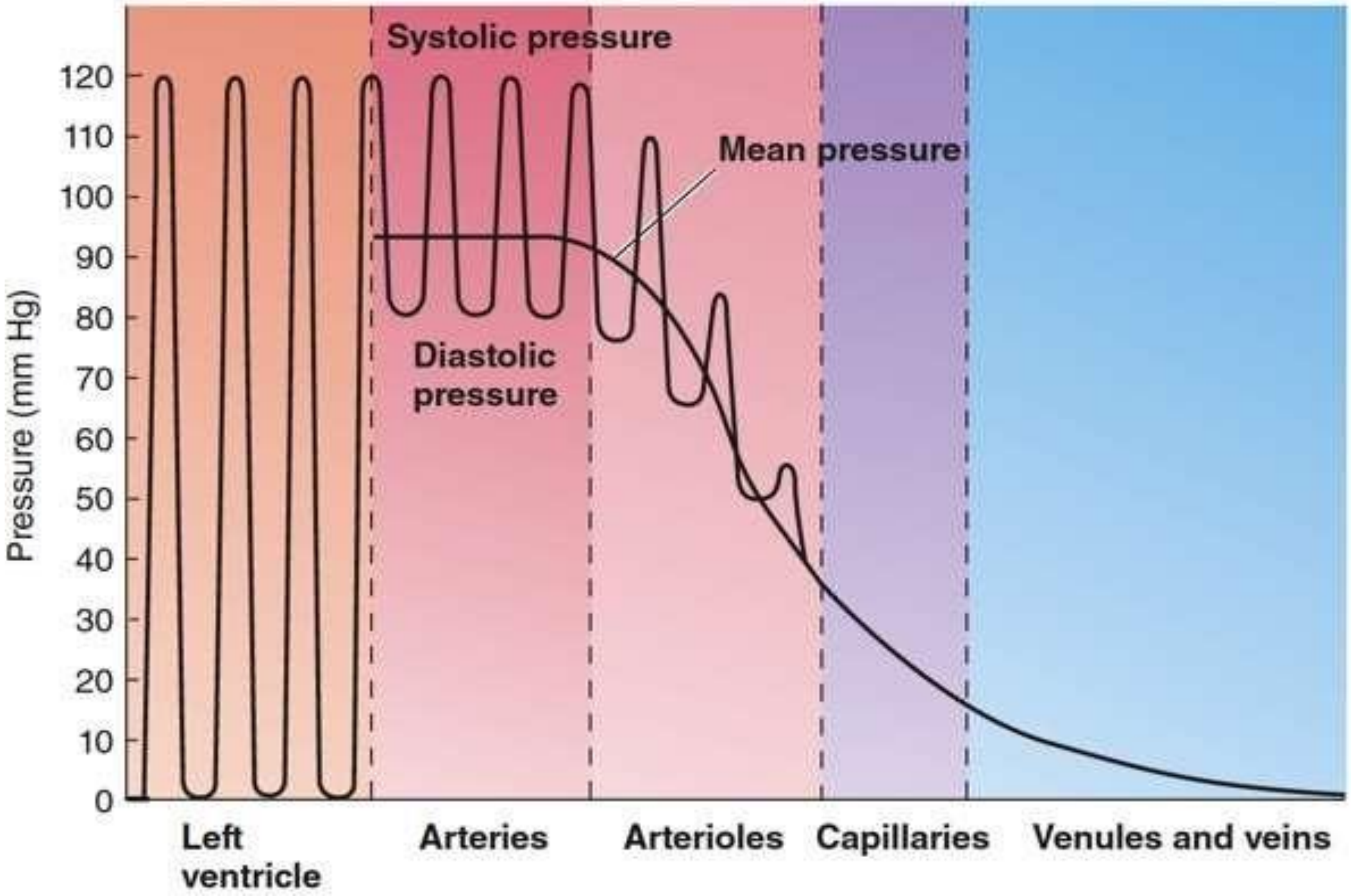
In Series resistance: Pressure decrease throughout the resistances as you can see here

The left ventricular pressure changes , showing the difference between systolic and diastolic , the systolic pressure is the highest and during diastole the pressure is almost zero (relax and fill).



Changes of pressure from left ventricle to veins:

1. There is minimal change in pressure in arteries, which is important
2. The highest resistance and the largest ΔP is in arterioles
3. As you can see, the left ventricle pressure oscillate between a very high pressure (systolic) and close to zero pressure during relaxation (diastolic).
4. Meanwhile, the diastolic pressure in arteries doesn't go back to zero, why? Simple, we need to maintain high pressure enough to form gradient for blood to flow from arteries to vein, ensuring not cutting the flow even for a fracture of second.



Parallel resistances (e.g., systemic circulation)

- the total resistance in a parallel arrangement is less than any of the individual resistances.
- When blood flow is distributed through a set of parallel resistances, the flow through each organ is a fraction of the total blood flow.
- The effects of this arrangement are that there is no loss of pressure in the major arteries and that mean pressure in each major artery will be the same and be approximately the same as mean pressure in the aorta.
- **The aorta branch into many arteries →many arteriole →many capillaries; this save the cardiac output "the flow rate, this will give the following properties:**

1. **Reduced total resistance: R (total) = 1/R1 + 1/R2 + 1/R3 + ……**

   the total resistant is less than the resistant in any individual pathway

2. **Flow division between the branches** : the flow in each branch is different according to the area it's supply

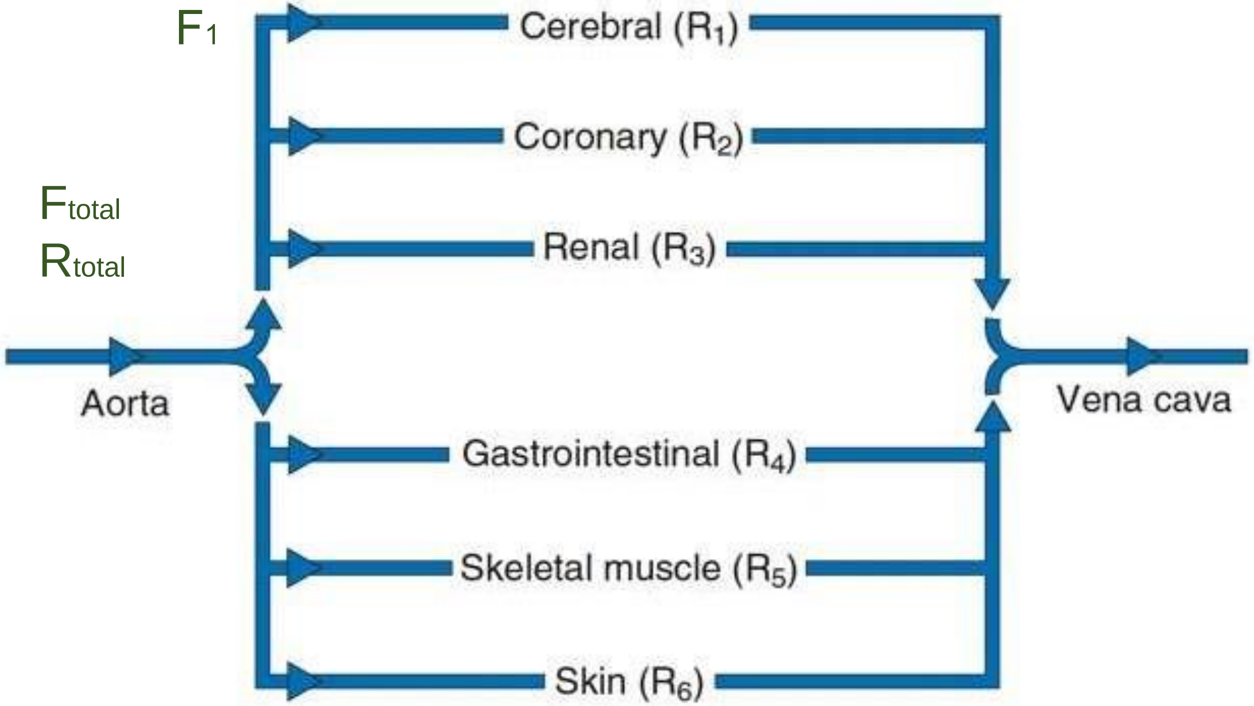
3. **Pressure uniformity.**

4. **Redundancy and protection : if one branch get blocked, other branches can compensate**

The flow rate is decreasing as we go to the major branches , it is part of the total flow (we said before distribution is different in different organs ;$F_{total} > F_1$). To keep the total pressure conserved (as we said in previous lecture), the resistance must increase

PARALLEL RESISTANCES

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5} + \frac{1}{R_6}$$



$\downarrow F = \frac{\Delta P}{\uparrow R}$ ➞ $\downarrow F \times \uparrow R = \Delta P$ (fixed)

In branches:

- ΔP is fixed and same for all
- Here the flow is decreased according to distribution (F_1) so:
- The resistance is increased (R1) to keep ΔP fixed
- example: ΔP = 5 // F=1 ➞ R=5
  if flow decreased(as I enter branch) ➞
  ΔP =5 // F= 0.5 ➞ R=1
- Example to show difference between the branch and the main artery,

The resistance each artery is 10,there are 5 resistances, how much is the total resistance?

$$\frac{1}{10} + \frac{1}{10} + \frac{1}{10} + \frac{1}{10} + \frac{1}{10} = \frac{5}{10}$$

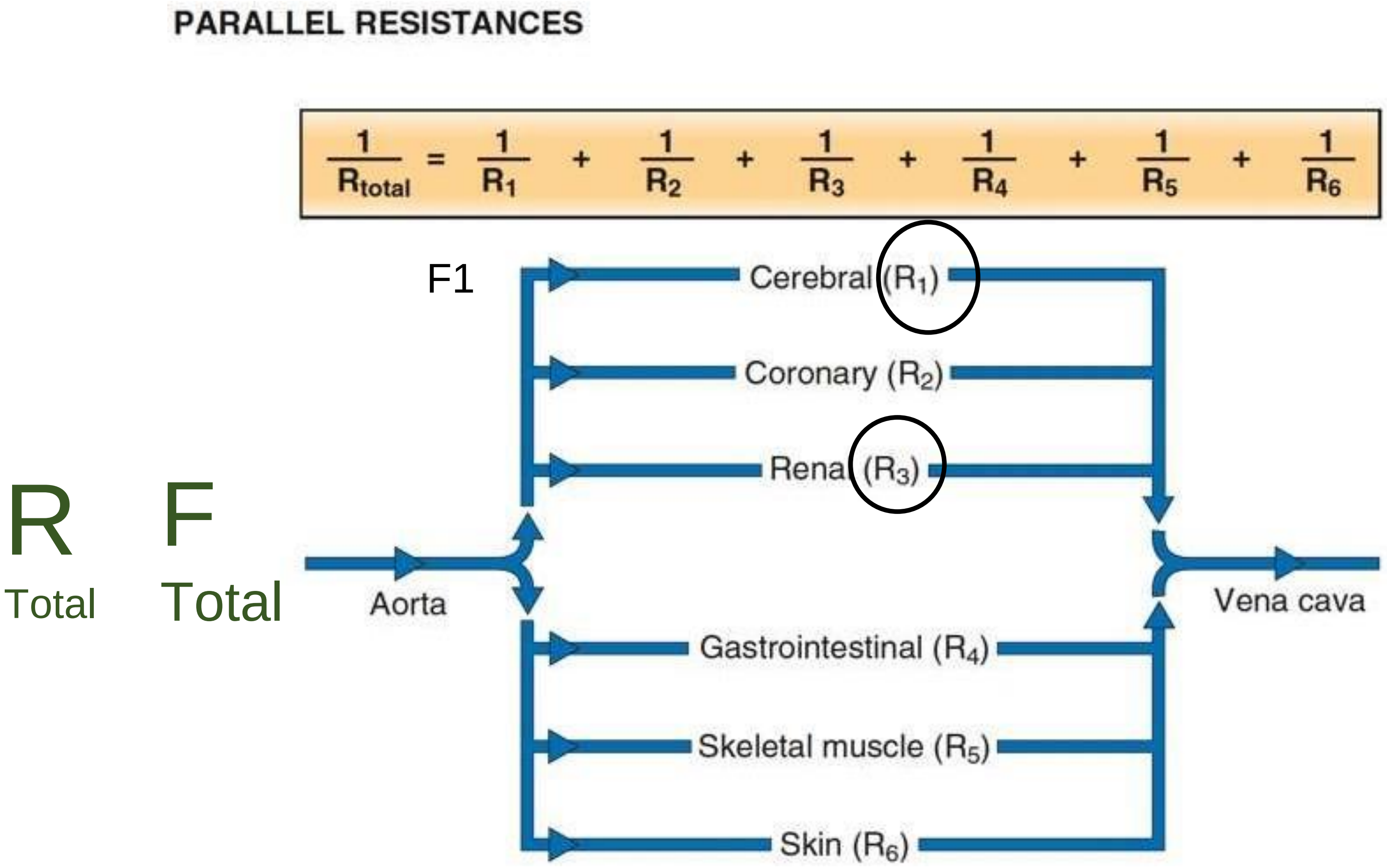
$$R\ total = \frac{10}{5} = 2$$

→ As you can see, the total resistance(=2) is less than individual branch resistance(=10).

→ (note that the resistance is not necessary the same in all resistances, here is just example)

** F = flow rate

- R1 must be larger than the R total ,
- F 1 must be lower than F total
- Be careful, make sure to convert 1/R to R at last step of calculation (check underlined step)



When you decrease the number of branches (the sub -resistance) , the total resistance will increase .

For example,
The resistance each artery is 10,there are 5 resistances, how much is the total resistance?

$$\frac{1}{10}+\frac{1}{10}+\frac{1}{10}+\frac{1}{10}+\frac{1}{10}=\frac{5}{10}$$

R total $= \frac{10}{5} = 2$

→ While if we have 4 resistances and each one =10 , how much total resistance would be?

$$\frac{1}{10}+\frac{1}{10}+\frac{1}{10}+\frac{1}{10}=\frac{4}{10}$$

R total $= \frac{10}{4} = 2.5$

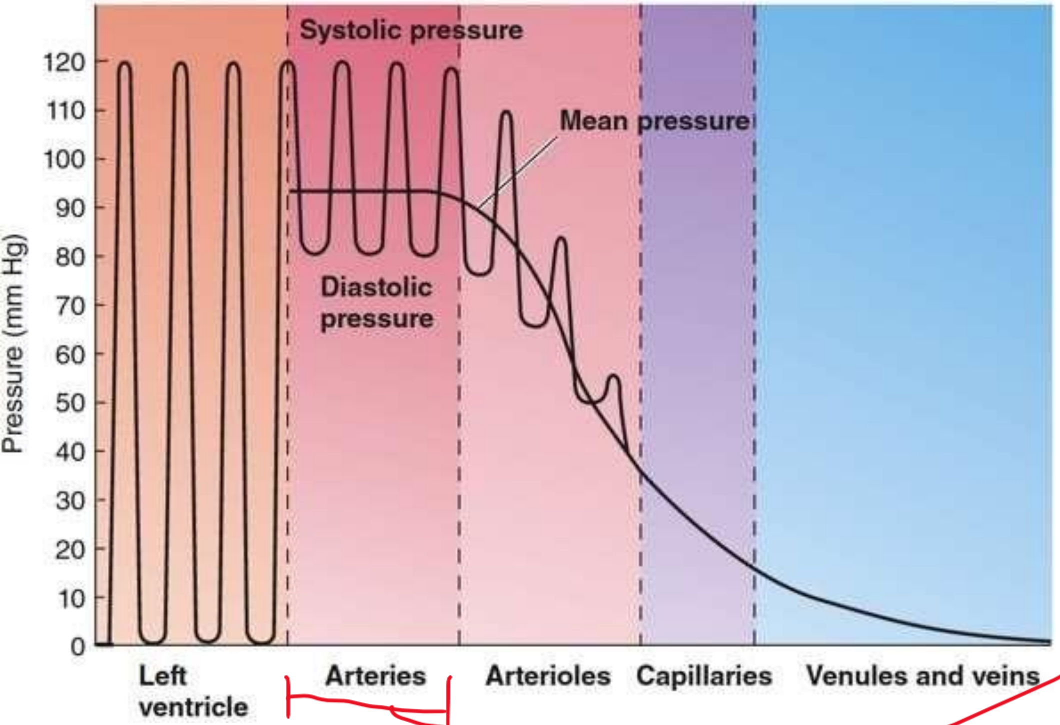
** As you can see when we decreased no. of branches, R Total increase

Parallel resistances

- Another predictable consequence of a parallel arrangement is that adding a resistance to the circuit causes total resistance to decrease. If based on the previous example, and the added resistance is also 10, who much is the total resistance? $\frac{1}{10}+\frac{1}{10}+\frac{1}{10}+\frac{1}{10}+\frac{1}{10}+\frac{1}{10}=\frac{6}{10}$ →R total = $\frac{10}{6}=1.66$

- And removing a resistance (a branch, for example nephrectomy), will increase the resistance. If based on the previous example who much is the total resistance? $\frac{1}{10}+\frac{1}{10}+\frac{1}{10}+\frac{1}{10}=\frac{4}{10}$ →R total = $\frac{10}{4}=2.5$

- if the resistance of one of the individual vessels in a parallel arrangement increases, then total resistance increases.



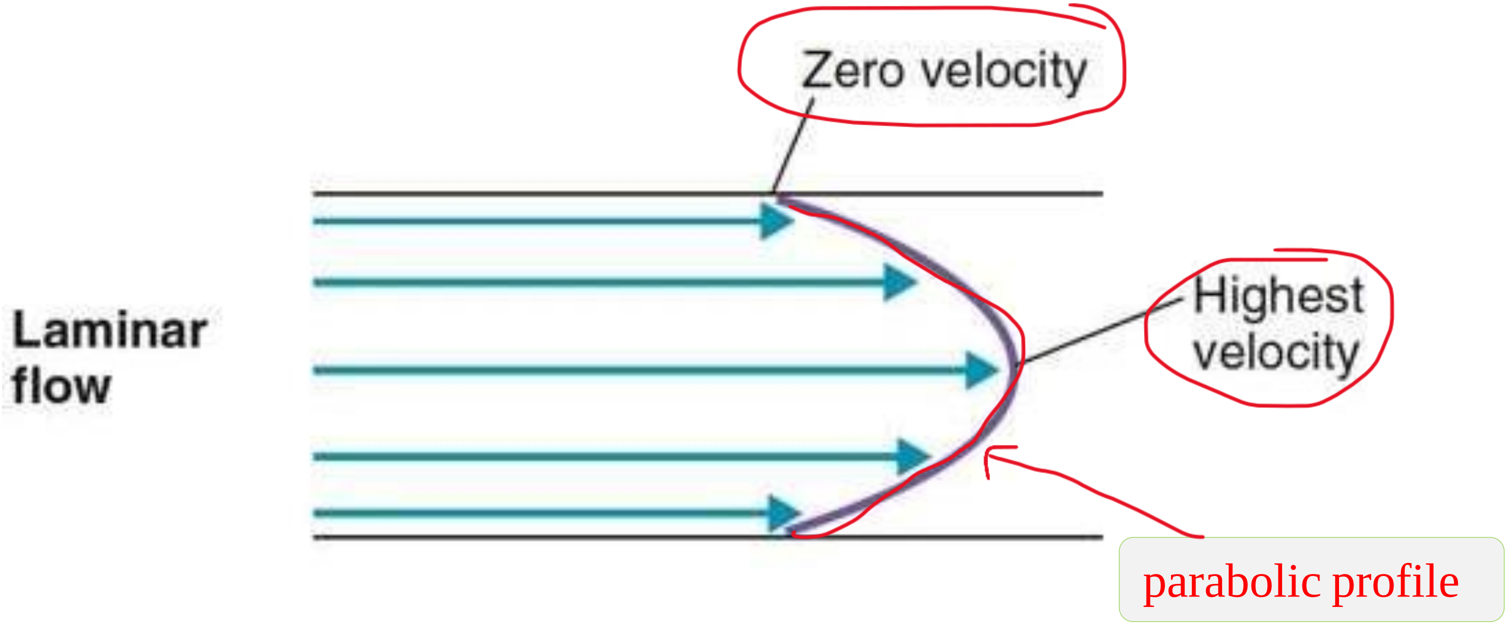
In parallel resistance: Pressure is the same throughout the resistances as you can see here

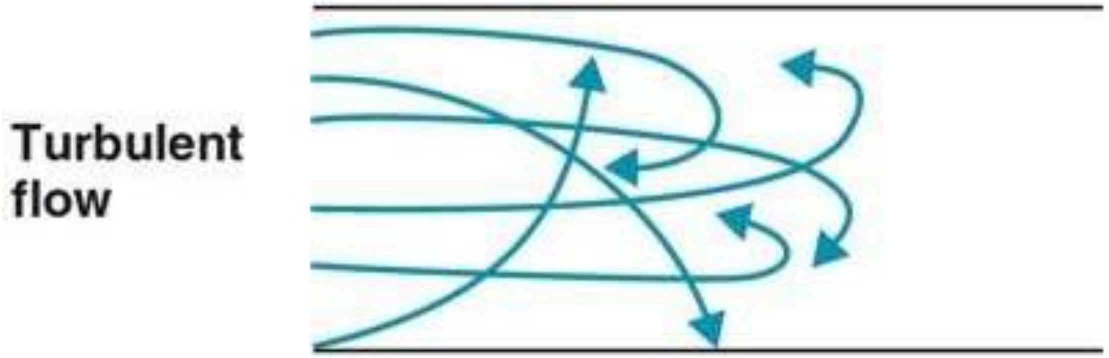
Extra table

Aspect	Total resistance	Flow distribution	pressure	Effect of obstruction	example
Series	Higher (additive)	Same flow throughout all segments	Progressive drop across segment	Affect entire system	Blood supply to organ
Parallel	Lower (inverse summation)	Flow can vary between branches	Uniform across all branches	Limited to the obstructed branch	Arteries → arterioles → capillaries →veins

Laminar blood flow

- Ideally, blood flow in the cardiovascular system is laminar, or streamlined.
- In laminar flow, there is a smooth parabolic profile of velocity within a blood vessel, with the velocity of blood flow highest in the center of the vessel and lowest toward the vessel walls (because of the friction with the vessel wall).


Zero velocity
Laminar flow
Highest velocity
parabolic profile


Turbulent flow

Laminar blood flow

- The parabolic profile develops because the layer of blood next to the vessel wall adheres to the wall and, essentially, does not move.
- The next layer of blood slips past the motionless layer and moves a bit faster.
- Each successive layer of blood toward the center moves faster yet, with less adherence to adjacent layers.
- Thus, the velocity of flow at the vessel wall is zero, and the velocity at the center of the stream is maximal.

Turbulent blood flow

- In turbulent flow, the fluid streams do not remain in the parabolic profile; instead, the streams mix radially and axially.
- Because kinetic energy is wasted in propelling blood radially and axially, more energy (pressure) is required to drive turbulent blood flow than laminar blood flow.
- Laminar flow is silent, while turbulent flow is audible.

Measuring blood pressure:

Instruments Used:

Manual :Sphygmomanometer and stethoscope.

Digital :Automated monitors (just press the button and the devise will measure automatically).

- Steps (manual Method):

1. Cuff Placement: The cuff is wrapped snugly around the upper arm at heart level.(Above the wrist)
2. Inflation: The cuff is inflated using a pump to temporarily occlude the brachial artery, no sound heard here since no flow.
3. Deflation: The cuff is slowly deflated while listening with a stethoscope placed over the brachial artery. The reappearance of blood flow (turbulent flow) produces the sound, indicating SBP. Unobstructed flow (laminar flow) occurs when the cuff pressure drops below DBP, causing the sounds to disappear.

- Sound heard is:

1. First Sound: The pressure at which the first faint “tapping” sound is heard corresponds to SBP. It marks the return of blood flow as the cuff pressure falls below systolic pressure.

   → arterial systolic blood pressure:

   Arterial: since we measure in artery

   Systolic: since the sound start during contraction

   Pressure: the force acting on the vessel wall

Last Sound: The pressure at which the sounds disappear corresponds to DBP. It marks the point where blood flow is unrestricted

Reynold number

- A dimensionless number that is used to predict whether blood flow will be laminar or turbulent.
- If Reynolds number is less than 2000, blood flow will be laminar.
- If Reynolds number is greater than 3000 always predict turbulent flow.
- Normally, in our body it is between 200-400 ; which means it is a laminar blood flow

Increase Reynolds number means turbulent

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

where

N_R = Reynolds number

ρ = Density of blood

d = Diameter of blood vessel

v = Velocity of blood flow

η = Viscosity of blood

Notes about the previous slide

- There are different factors that are used to calculate Reynold number.

1- Density of blood (p), when it increases Reynold number increases ➡ turbulence
2- Diameter of blood vessel (d), when it increases Reynold number increases ➡ turbulence
3- Velocity (v), when it increases Reynold number increases ➡ turbulence
4- Viscosity (n), when it increases Reynold number **decreases** ➡ laminar

- **Difference between density and viscosity :**
  - density: it is the mass per volume (it reflects the spaces between the particles in the fluid)
  - viscosity: it reflects the friction between particles (RBCs) in the fluid

- Let's talk about another factor that affect Renold number :
- We know $v = Q/SA = Q/\pi r^2$ & diameter $= 2r$ => $N_R = 2rpQ/n\pi r^2$ ...this make a confusion (r increase or decrease Reynold number?! 🤔)
- Here we break it down : since the r in the denominator is raised to the power of 2 so it has higher effect
- Doctor said to not get confused, we will look to velocity and viscosity
  - **Let's insure you get the idea via examples in next slide**

Notes about the previous slide

- In polycythaemia , ⬆viscosity =⬇ Reynold number ➡ laminar flow, this make sense because cells will have high friction, so they do not have the space to cause turbulence.

- In anaemic patients, 1) ⬇ viscosity = ⬆ Reynold number ➡ turbulence flow , cells have less friction in between so more space , more turbulence.
  2) Furthermore, in anaemia body has compensatory mechanism (increase cardiac output which means ⬆velocity =⬆ Reynold number ➡ turbulence flow) so we hear noise due to this turbulent flow.
  (be careful..! 2 causes here behind the increase of Reynold number)

- In thrombosis, ⬇radius = ⬆velocity =⬆ Reynold number ➡ turbulence flow , blood running smoothly and suddenly it faces the thrombus, so this will make turbulence

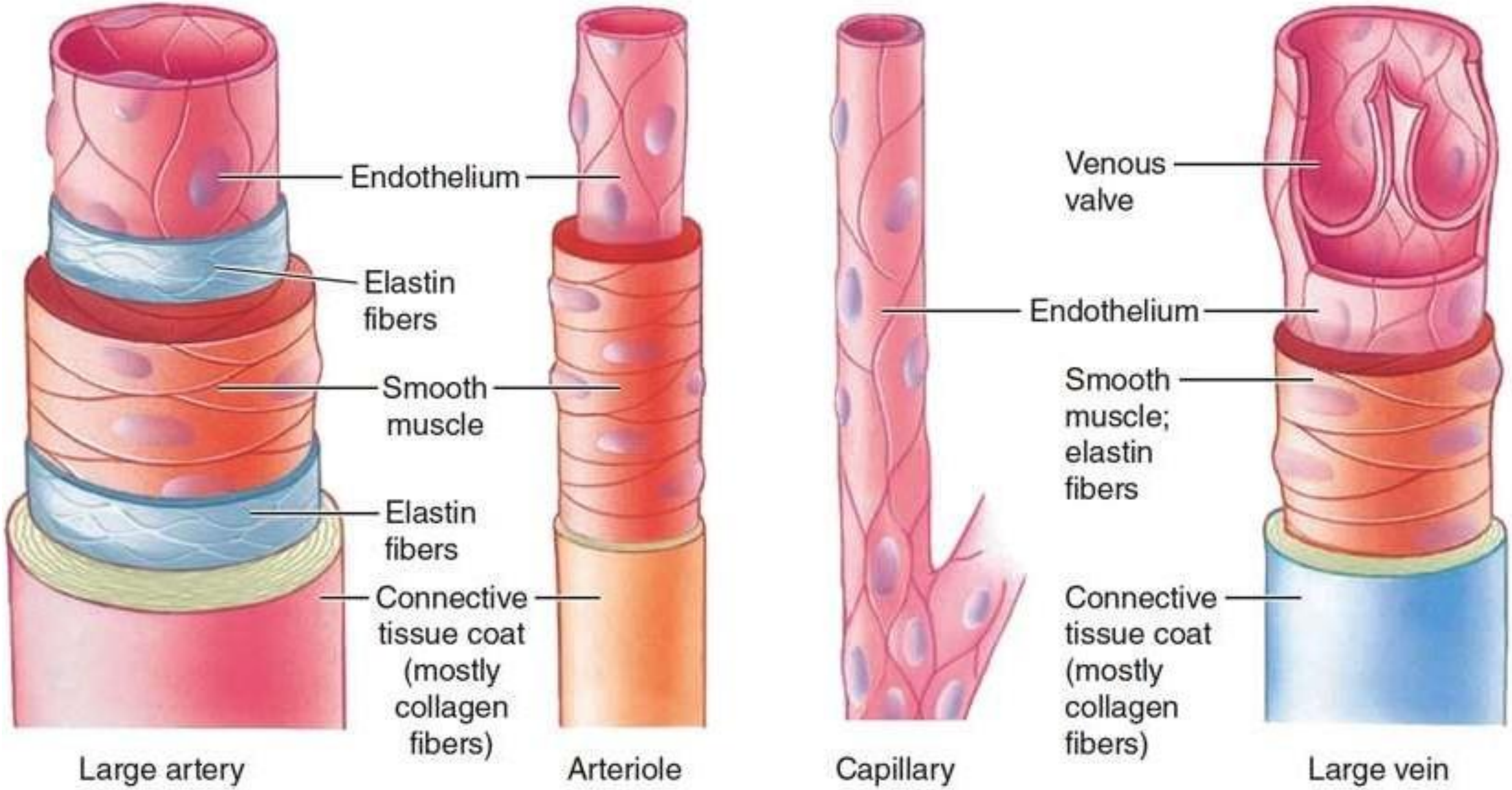
Reynold number

- Anemia:

- Reynolds number is increased in anemia due to decreased blood viscosity.
- A second cause is a high cardiac output, which causes an increase in the velocity of blood flow.

Reynold number

- Thrombi:
- narrow the diameter of the blood vessel, which causes an increase in blood velocity at the site of the thrombus, thereby increasing Reynolds number and producing turbulence.


Endothelium
Elastin fibers
Smooth muscle
Elastin fibers
Connective tissue coat (mostly collagen fibers)
Large artery
Arteriole
Capillary
Venous valve
Endothelium
Smooth muscle; elastin fibers
Connective tissue coat (mostly collagen fibers)
Large vein

Notes about the previous slide

- This image represents the histology of the blood vessels, You can see they differ in their structure.

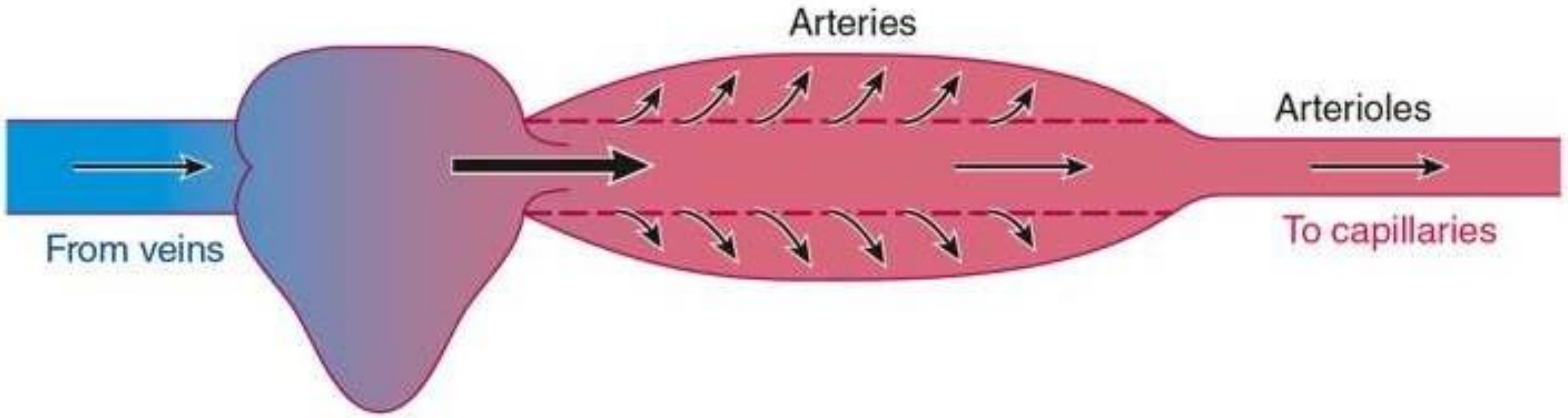
- Advice from the doctor:" Always when you look at a structure in our body, think of how this structure serve its function, it is there for a reason! "

- Large arteries: like Aorta & major branches. We classify them into 1- elastic (Aorta & major branches) 2- muscular (when we go downstream)

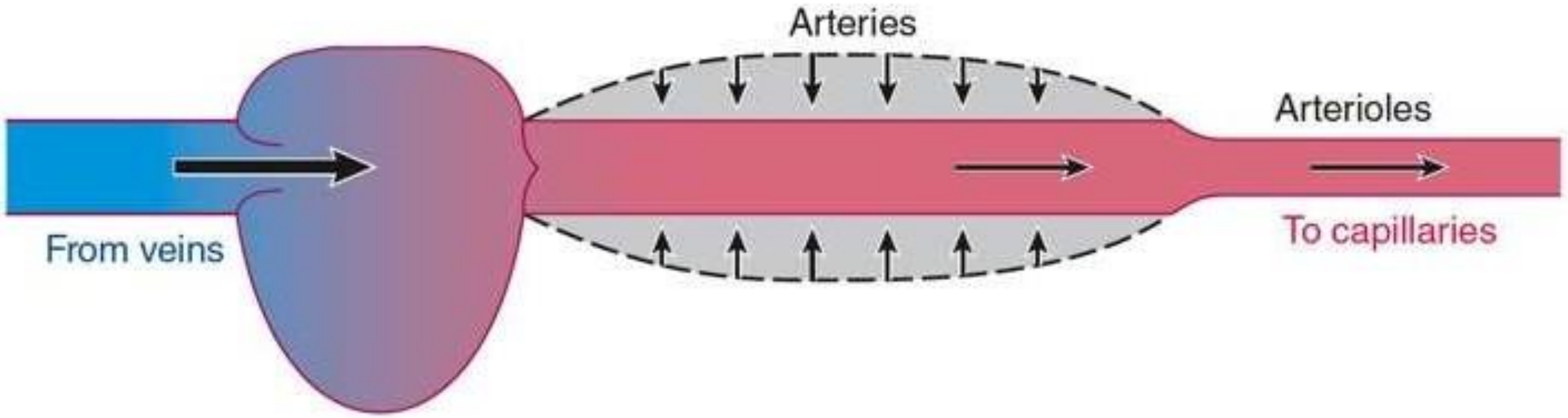
- Distinct feature for elastic arteries (our topic here) are 1) they have elastic fibres (2 layers) 2) their cross-sectional area is small (remember from previous lect.) so ⬆velocity which is important for **their first function** (rapid-transit passageways for blood from the heat to the organs)

Arteries

- Arteries are specialized
- (1) to serve as rapid-transit passageways for blood from the heart to the organs.
- (2) to act as a pressure reservoir to provide the driving force for blood when the heart is relaxing.



(a) Heart contracting and emptying



Heart during relaxing and filling

Notes about the previous slide

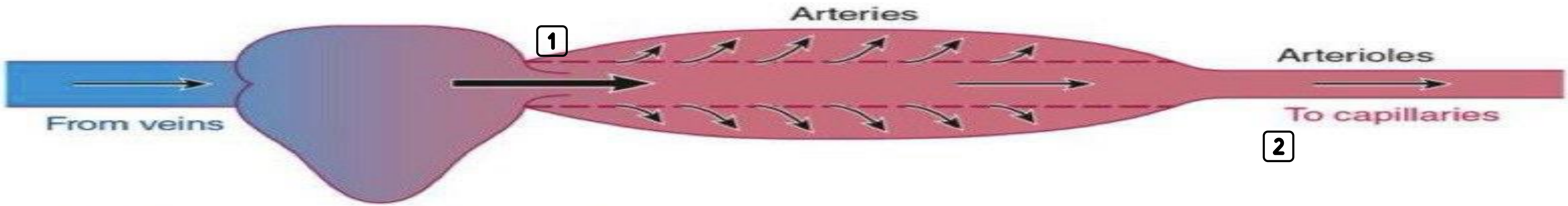
- This image represents **the second function** which is acting as a pressure reservoir to provide the driving force for blood when the heart is relaxing.

- During systole, Lt. Ventricle contract & eject the blood outside the heart toward aorta & the major arteries. So, this high volume, pressure and velocity blood will get out of Lt. ventricle toward aorta & major branches and this volume of blood will exert pressure on the wall and since it is during systole we call "systolic arterial blood pressure"

- While during Diastole, Aortic valve closes, the heart is relaxing and filling blood, no more blood is getting out of the heart to the arteries, so no blood is coming to the capillaries which is very dangerous why? since capillaries are the sites of nutrients exchange, so they should receive continuously blood to continuously exchange wastes & nutrients **But** heart cannot do this since they need time to relax and refill in order to eject blood next time (it can do this during systole when it is contracting and ejecting)

- So, what is the solution to supply capillaries with a continuous blood flow ? Who would help us? **our best friends elastic arteries** (aorta & major branches)

(let's continue in next slide)



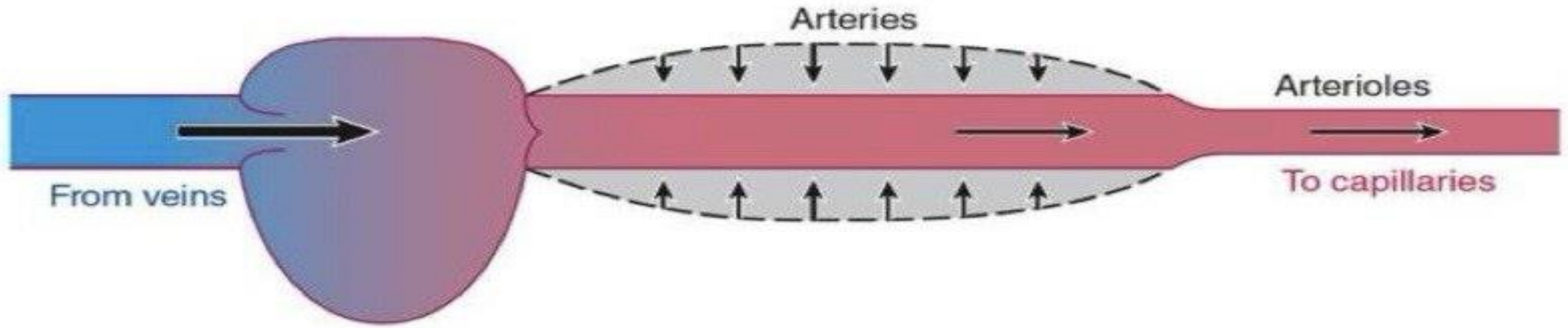
(a) Heart contracting and emptying

Notes about the previous slide

- During systole, large volume of the blood leave the heart, and because of the high elastin content in the aorta it can expand and accommodate this high pressure & volume, restoring this extra amount of blood within its walls during systole. 1
- Remnant amount of blood will go to the capillaries
- So when we talk about systolic blood pressure, we also call it "**Stressed** volume " and this is because the blood in the **arteries** is under high pressure while blood in **veins** isn't under high pressure, so we call it (**unstressed** pressure)

2

- **notice that the volume that reaches the capillaries is NOT the same as the volume left the Lt. Ventricle (it is less- look at the thickness of the arrows).** This is highly important, why? Because if this high volume of blood reach the capillaries, it will cause endothelial cells damage so as a protective mechanism we reduced the pressure and volume coming to these capillaries during systolic phase.



Notes about the previous slide

- During diastole, no more blood is coming out of the heart so aorta act like a balloon (it distend during filling- which is systole- and it will undergo elastic recoil (relaxing of elastin) – in diastole- it returns back to its original state ejecting the stored blood in its walls . In balloon it is similar when you fill it with air (systole) and once you leave it air get out (as in diastole)

- Even though the blood that leaves the aorta to capillaries at this time insured continuous supply, the volume that is getting downstream isn't large so the pressure in the wall is not as large as during systole, so we call this pressure "Diastolic blood pressure"

- so keep in mind this is the importance of elastic fibers which guarantee a continuous supply to the capillaries.

Elastic arteries

- Elastic large arteries expand to temporarily hold the excess volume of ejected blood, storing some of the pressure energy imparted by cardiac contraction in their stretched walls.
- When the heart relaxes and temporarily stops pumping blood into the arteries, the stretched arterial walls passively recoil.
- This elastic recoil exerts pressure on the blood in the large arteries during diastole.
- The pressure pushes the excess blood contained in the arteries into the vessels downstream, ensuring continued blood flow to the organs when the heart is relaxing and not pumping blood into the system.

Stressed vs unstressed volumes

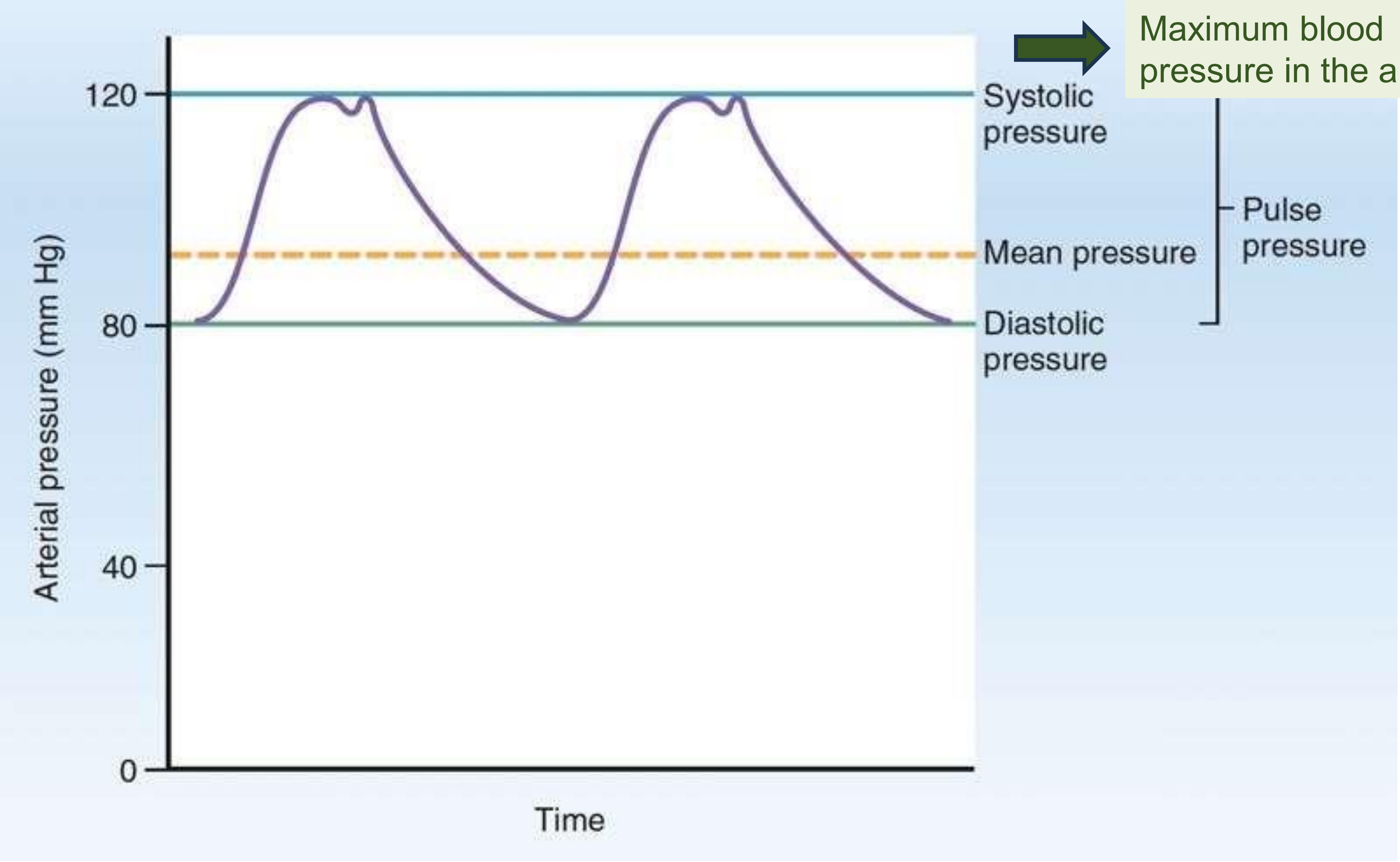
- The volume of blood contained in the arteries is called the stressed volume (meaning the blood volume under high pressure).

- The volume of blood contained in the veins is called the unstressed volume (meaning the blood volume under low pressure).

Blood pressure

- Blood pressure: the force exerted by the blood against a vessel wall.
- depends on the volume of blood contained within the vessel and the compliance, or distensibility, of the vessel walls (how easily they can be stretched).
- Systolic pressure (SBP): the maximum pressure exerted in the arteries when blood is ejected into them during systole.
- Diastolic pressure (DBP): the minimum pressure within the arteries when blood is draining off into the rest of the vessels during diastole.

Maximum blood pressure in the arteries



Notes about the previous slide

- Systolic pressure is the maximum blood pressure in the arteries.

- Diastolic pressure is the minimum blood pressure in the arteries

- Puls rate when we measure it, we feel it as if it is pushing our finger this is caused by systolic pressure (force against the vascular wall during the systole ,when we have high pressure and volume, so we can feel it , while the diastole we cannot feel it)
- so, pulse rate is a reflection for the heart rate , and it is the difference between systolic and diastolic pressures.
- So, to sum up we feel it in systolic when ejection take place, while we do not feel it in diastolic so it like a deflection of the heart rate , and that's why we use pulse rate to measure heart rate.
- In the previous image pulse pressure = 120(systolic) - 80 (diastolic)= 40

- There is another parameter we call it "mean pressure", mean is the average & it is between systolic and diastolic pressure

- Although it is in between them, in previous image it isn't 100 (mathematically it is correct but physiologically it is NOT)why? Because we mentioned previously that we spend more time in diastole (2/3 of the whole time) so it is not fair to put it midway in between them. So, it will be proximal to diastolic pressure.

Blood pressure

- Although ventricular pressure falls to 0 mm Hg during diastole, arterial pressure does not fall to 0 mm Hg.
- Pulse pressure (PP): the difference between systolic and diastolic pressures.
- Because the pulse can be felt each time the ventricles pump blood into the arteries, the pulse rate is a measure of the heart rate.

Mean arterial pressure

- The mean arterial pressure (MAP) is the average pressure driving blood forward into the tissues throughout the cardiac cycle.
- MAP, not the systolic or diastolic pressure, is the pressure that is monitored and regulated.
- MAP is not the halfway value between systolic and diastolic pressure.
- The reason is that arterial pressure remains closer to diastolic than to systolic pressure for a longer portion of each cardiac cycle.
- At resting heart rate, about two thirds of the cardiac cycle is spent in diastole and only one third in systole.

Arterial blood pressure

- MAP = DBP (Diastolic pressure) + 1/3 PP (Pulse pressure)
- Because arteries offer little resistance to flow, only a negligible amount of pressure energy is lost in them because of friction.
- Therefore, arterial pressure—systolic, diastolic, pulse, or mean—is essentially the same in all arteries.

- MAP is important & we measure it.

- Kindly keep in mind and don't forget the effect of heart rate changing on cardiac cycle time, and remember the most affected is the diastolic phase (shortening when HR increase--> at this time we cannot use this equation) SO this equation is only applied when heart rate is normal at rest

- E learning question :
- You measure a BP in a patient, and it was 110/80 mm Hg, what is the MAP?
- MAP = DBP + 1/3 PP
- PP = Systolic – diastolic
- PP= 110 - 80 =30
- DBP = 80
- MAP= 80 + 1/3 *30 =
- MAP = 80 +10 = 90

Thank you

Additional sources

sQ˥DWCʌhttps://youtu.be/qgUm

VERSIONS	SLIDE #	BEFORE CORRECTION		AFTER CORRECTION
V1→ V2	20	The number changed from 2000 -4000		200 – 400
V2→V3	11 12			Further clarifications in boxes

امسح الرمز و شاركنا بأفكارك لتحسين أدائنا!!