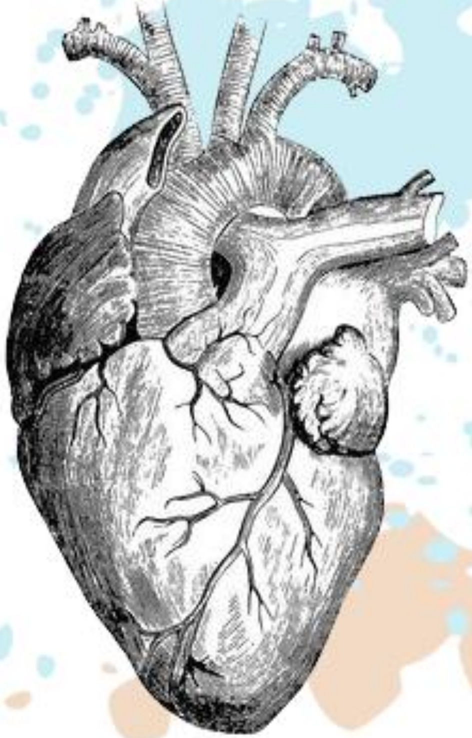


Physiology
OF THE CARDIOVASCULAR SYSTEM

Very important

Extra information

* Guyton corners, anything that is colored with grey is EXTRA explanation

Arterial blood pressure

Objectives :

- Concept of mean blood pressure, systolic, diastolic and pulse pressure.
- Normal variations in arterial blood pressure.
- Factors determined blood pressure.
- Calculation of mean blood pressure.
- Relationship between CO, BP and total peripheral resistance.

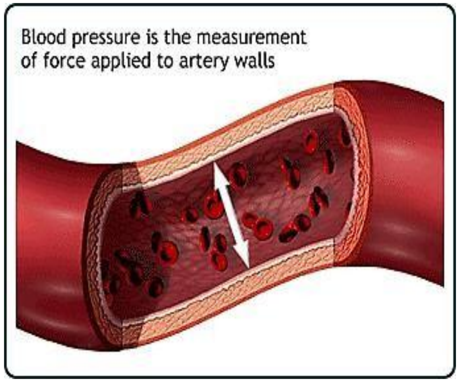
Contact us : Physiology435@gmail.com

Arterial blood pressure

- **Blood pressure** is the force exerted by blood against a vessel wall. *(Lateral pressure created by the heart as it pumps blood, against any unit area of the vessel wall.)*
- It maintains blood flow throw capillaries. *(as it causes elastic recoil → pumping of blood)*
- Blood pressure depends on: **blood volume** & **compliance** (destinsibility/ability to stretch) of blood vessels.
- Arterial blood pressure is *not constant*, it **raises** during *ventricular systole* & **falls** during *ventricular diastole*.

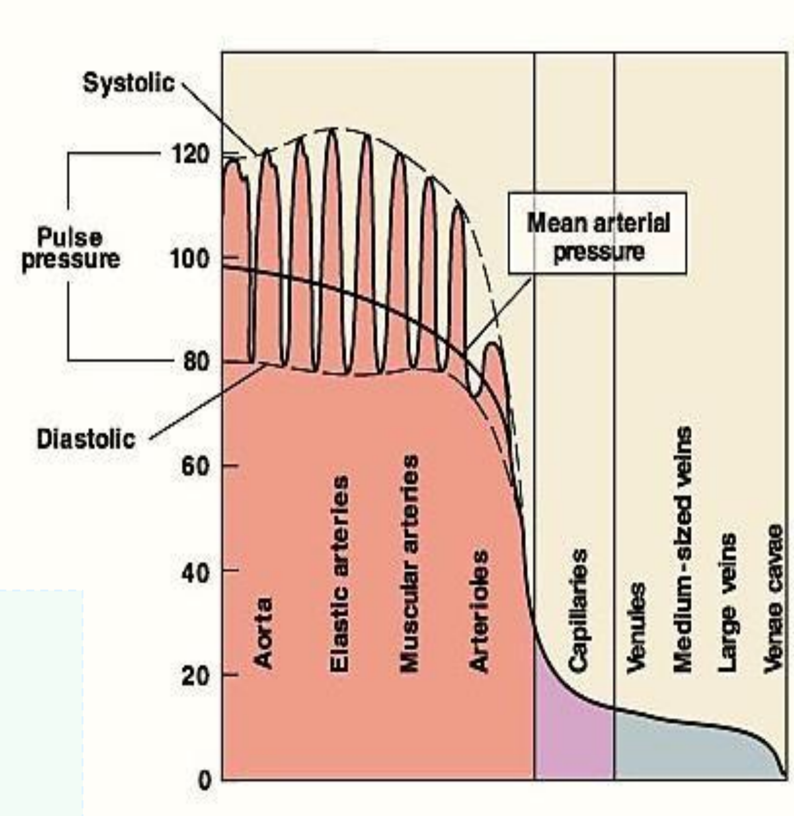
In normal adult ≈120/80 mmHg

- **Top number (Systolic)** = Pressure while the heart is beating.
- **Bottom number (Diastolic)** = Pressure while the heart is relaxing.



Pressure changes throughout the systemic circulation

- Blood flows down a *pressure gradient.*
- Highest at the heart.
- ↓ over distance.
- ↓ 90% from aorta to vena cava.
- **Greatest** drop in pressure occurs in arterioles.
- No large fluctuations in capillaries & veins.
- BP averages 120 mmHg in **aorta** & drops to 0-2 mmHg in **Right atrium**.



Variations in Arterial BP :

- **Aortic pressure:**
  - 120 mmHg systolic.
  - 80 mmHg diastolic.
- **Normal arterial pressure:**
  - 110 – 130 mmHg systolic.
  - 70 – 85 mmHg diastolic.

American Heart Association

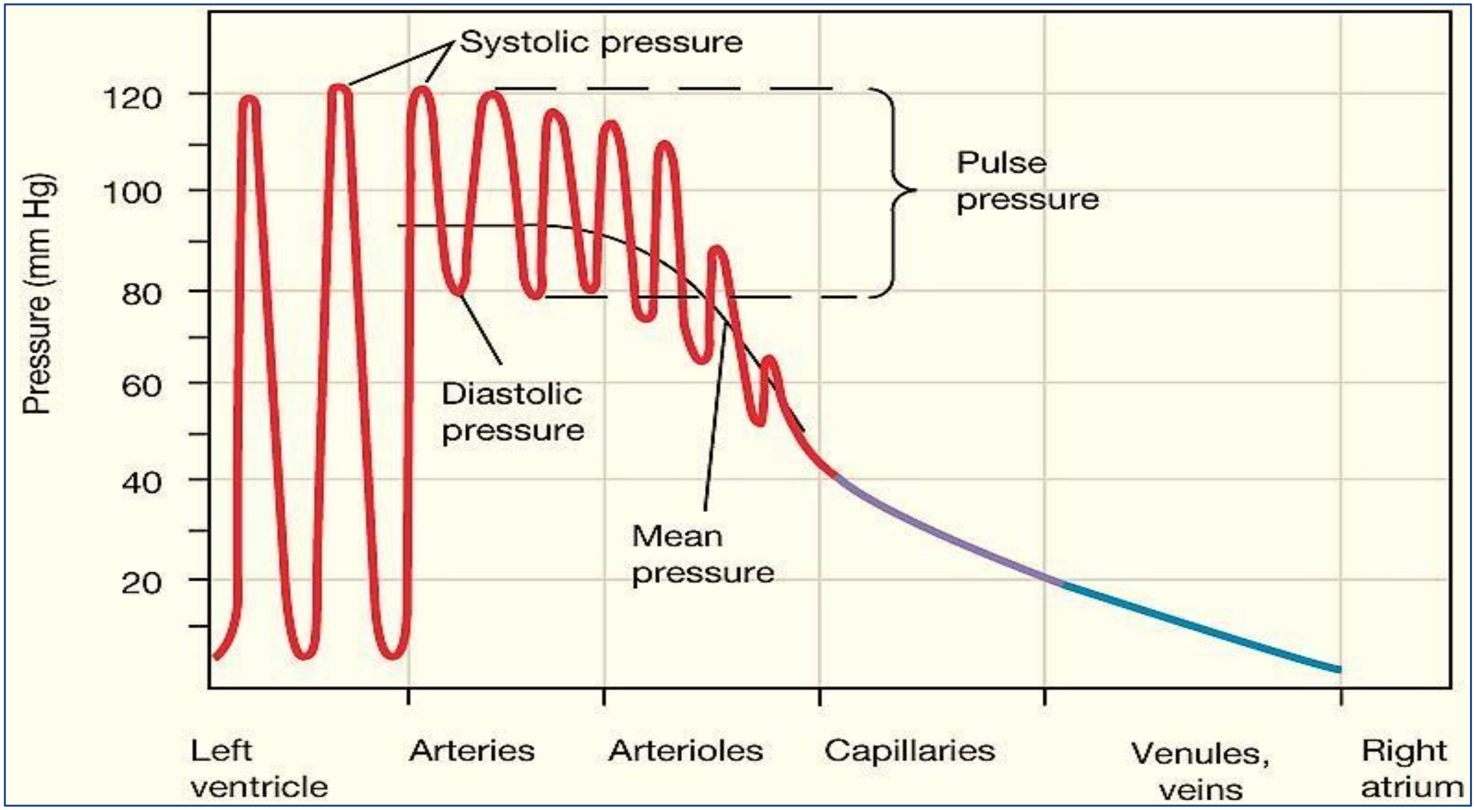
Recommended Blood Pressure Levels

Adult BP range 110 - 130 / 70 - 85 mmHg

BP Category	Systolic (mmHg)		Diastolic (mmHg)	Follow-up
Optimal	< 120	&	< 80	Recheck 2 years
Normal	< 130	&	< 85	Recheck 2 years
High Normal (Pre-hypertension)	130-<140	or	85-<90	Recheck 1 year

Pressure changes throughout the systemic circulation

- Arterial blood pressures are: **systolic BP**, **diastolic BP**, **pulse pressure**, **mean BP**.



Arterial blood pressures

Arterial blood pressures are: systolic BP, diastolic BP, pulse pressure, mean BP :

- **Systolic BP:** The peak (highest) blood pressure, it is measured during **ventricular systole,** it is 120 **mmHg** in a young person at rest.

- **Diastolic BP:** The minimum blood pressure, it is measured at the end of **ventricular Diastole**, it is 80 **mmHg** in a young person at rest.

- **Pulse pressure:** It is the difference between **systolic BP** and **diastolic BP**.
  Pulse pressure = systolic BP - diastolic BP
  (e.g. : 120 - 80 = 40 mmHg)

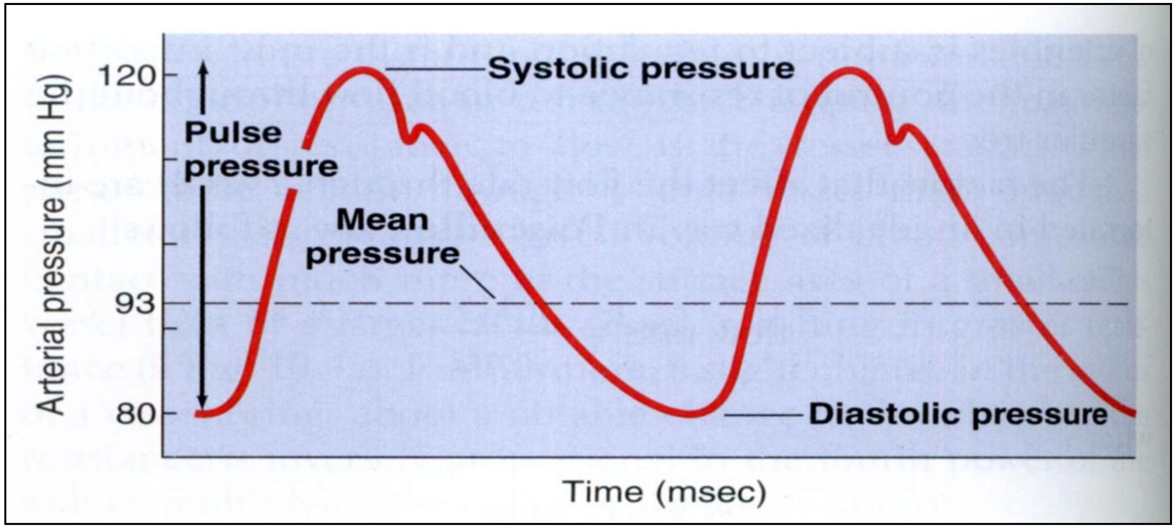
- **Mean BP:** Calculated by adding one-third of the pulse pressure to the diastolic BP
  Mean BP = diastolic pressure + 1/3 (systolic pressure – diastolic pressure)
  e.g. : if BP= 120/90 mmHg → diastolic BP= 90 , pulse pressure = 30
  Mean BP: (diastolic BP) + (one-third of pulse pressure) = (90) + (30/3) = 90+10 = 100 mmHg

More about mean arterial BP

- Mean BP depends on 2 factors: **cardiac output**, and **total peripheral resistance**.

{ **Mean BP=** C.O. x total peripheral resistance }

- **C.O.** → determines **Systolic BP**
- **Total peripheral resistance (TPR)** → determines **diastolic BP**



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More about total peripheral resistance (TPR)

Vasodilator agents	Vasoconstrictor agents
Adenosine	Noradrenaline
Atrial natriuretic peptide (ANP) - ↑ potassium or Hydrogen ions. - ↓ Oxygen or ↑ CO_2	Sympathomimetic drugs.
Histamine	Vasopressin (ADH)
Nitric oxide and lactic acid	Angiotensin II
Prostacyclin	Endothelin-1

Arterial blood pressure

Determinants of arterial BP: (the factors **determining** ABP)

- **Total peripheral resistance (TPR) :**

* Resistance depends on : 1) Size & length of blood vessel 2) Thickness (viscosity) of blood

- **Cardiac output (co).** (C.O = SV X HR)

- **Blood viscosity:**

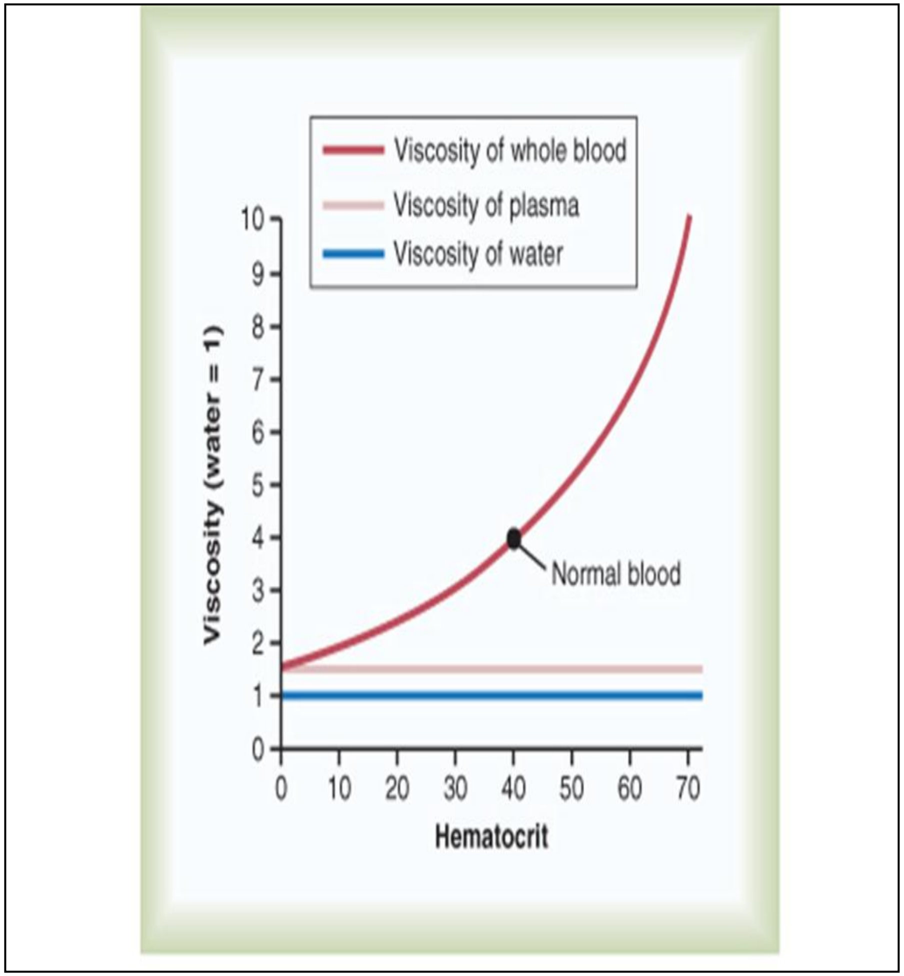
1- Increase in RBCs (hematocrit) or plasma proteins → increase total peripheral resistance → increase in BP. when hematocrit increases above normal, viscosity increases sharply and the TPR increases, as a result → O2 delivery falls. (diagrams in the coming slides will show the relations)

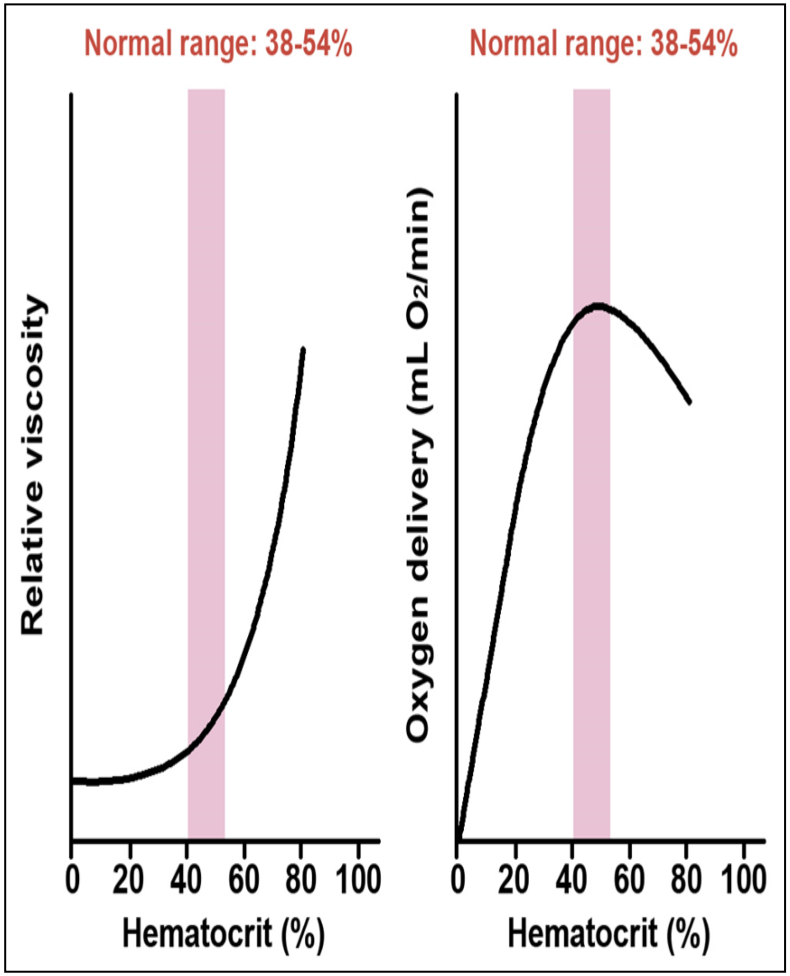
2- Decrease in plasma proteins → decrease in BP , this is called Hypoalbumenimia, can be due to **burns** or **malnutrition**.

- **Blood volume:**

changes in blood volume affect arterial BP by changing cardiac output.
↑ blood volume → ↑end diastolic volume (ventricular preload) → ↑ stroke volume (by Frank-Starling low) → ↑ cardiac output → ↑ arterial BP.
* Blood volume depends on : fluid intake & fluid loss.

Blood viscosity curves

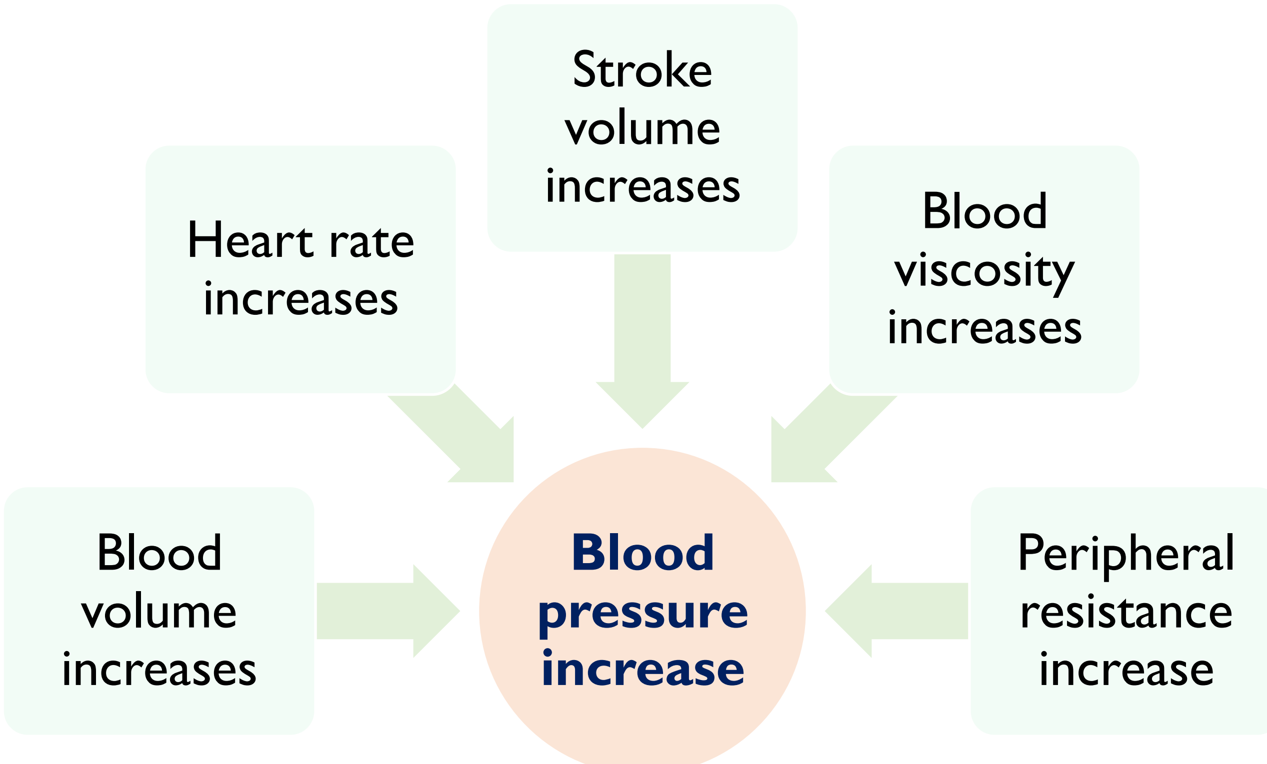




Factors affecting Arterial BP

Physiological variations in BP:

- Age (systolic BP increases with age)
- Sex (BP is usually lesser in female, BUT at menopause males BP = females BP)
- Body mass index (greater body mass = greater systolic BP)
- Meals
- Exercise (↑ systolic/ normal or slightly ↓ diastolic)
- Posture (وضع/حالة الوقوف والجلوس)
- Anxiety ↑
- During inspiration: ↓ slightly
- During expiration: ↑ slightly
- Pregnancy ↑ (↑ metabolism)
- Sleep ↓ (↓ venous return)
- Temperature (heat : vasodilation .. Cold : vasoconstriction)
- Emotions ↑ (neural factors)
- Hormones ↑ (Adrenaline, noradrenaline, thyroid H)
- Gravity (↑ lower limbs > upper limbs)
- Race (dietary factors, or stress)


Stroke volume increases
Heart rate increases
Blood viscosity increases
Blood volume increases
Blood pressure increase
Peripheral resistance increase

Arterial blood pressure

Blood pressure must be regulated

or

↙ ↘

low blood pressure:
blood will not reach all tissues, specifically those where gravity is acting against the flow, most importantly the brain.

high blood pressure:
-heart is placed under greater stress
-excess plasma leakage to interstitium
- at the extreme (very high BP), Capillaries burst.

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Regulation of blood pressure*

Regulation of Blood Pressure

- **Nervous Mechanism**
  - By Vasomotor Center and Impulses from Periphery
- **Renal Mechanism**
  - By Regulation of ECF Volume and renin – angiotensin mechanism
- **Hormonal Mechanism**
  - By Vasocons- -trictor and Vasodilator Hormones
- **Local Mechanism**
  - By Local Vasocons- -trictors and Vasodilators

*****_This is taken from the doctor’s slides, will be discussed better in the next lecture ._

Hemodynamics

Hemodynamics:

It is the branch of physiology concerned with The physical principles governing : **Pressure**, **Flow**, **Resistance**, **Volume**, and **Compliance** as they relate to the CVS.

- **Resistance to blood flow results from :**

1- The *inner friction* (which increases with vasoconstriction).
2- *Viscosity* of blood.

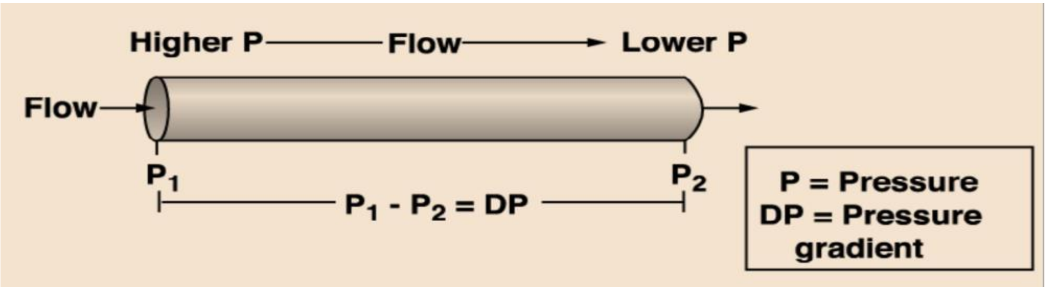
Blood flow	Resistance (R)	TPR
• Amount of blood moving through a vessel in a given time period. • Generally is equal to Cardiac output (CO.) • Affected by: pressure & resistance. $Q = \frac{\Delta P}{R}$ • **Directly proportional** to pressure differences. • **Inversely proportional** to resistance.	• = tendency of vascular system to oppose flow • Flow = 1/R • **Influenced by:** Length of the tube (**L**), radius of the tube (**r**), & viscosity of the blood (η) • In a normal human, length of the system is fixed, so blood viscosity & radius of the blood vessels have the largest effects on resistance.. • **Poiseuille's Law** = (FIRST FORM OF LAW): $R = 8\eta L/\pi r^4$ (SECOND FORM OF LAW): $Q = \frac{(Pi - Po)\ \pi r^4}{8\eta L}$ *r=radius , L=length, η = viscosity*	$R = \Delta P / Q$ • **Systemic Circulation:** $TPR = \frac{\text{Aortic Pressure - RAP}}{\text{Flow}}$ $TPR = \frac{100 - 0\ mmHg}{83.3\ ml/sec\ (5\ L/min)}$ **TPR =** 1.2 (PRU's) • **Pulmonary Circulation:** $PUL.\ R. = \frac{\text{Pul. Art. P. - LAP}}{\text{Flow}}$ $PUL.R = \frac{15 - 5\ mmHg}{83.3\ ml/sec}$ **Pul. R.** = 0.12 (PRU's)

Poiseuille's Law

- **Fluid Flow (Q) through Cylindrical Tubes.**
- **Flow decreases (↓) when resistance increases.**
- **Flow resistance decreases (↓) when vessel diameter increases.**

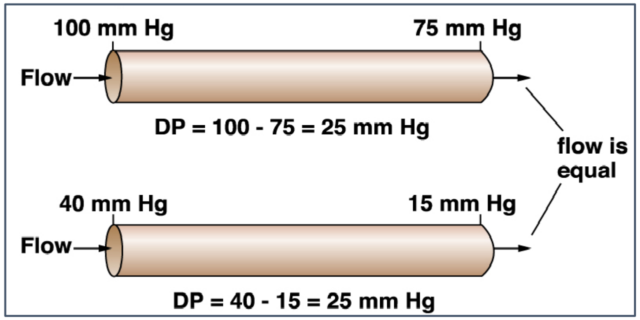
Blood Flow and Pressure

- P directly proportional to F
- Blood flows down a pressure gradient.
- Absolute value of pressure is not important to flow, but the difference in pressure (DP or gradient) is important to determining flow.



****What happens to pressure if we decrease the fluid volume? As in ventricles during systole Resulting pressure is called the driving pressure in vascular system***

Note how the flow is equal in these two vessels



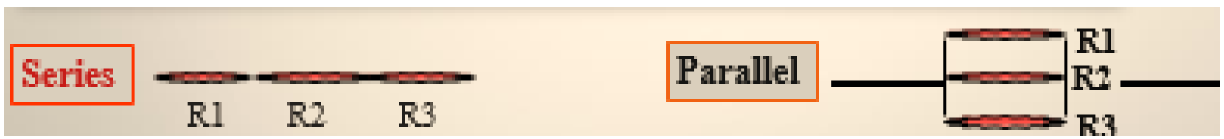
Blood Flow and Pressure

Resistance to Flow in the Cardiovascular System

Basic Concepts

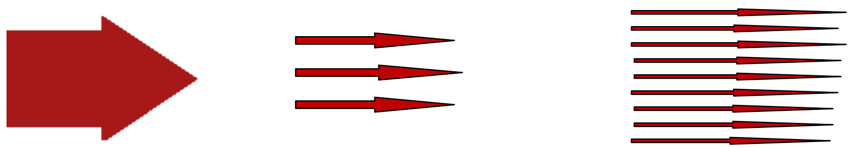
Rt = R1 + R2 + R3 → Series Resistance

1/Rt = 1/R1 + 1/R2 + 1/R3 → Parallel Resistance



What Really Happens in the CVS?

Lower R | Higher R | Lower R



Artery | **Arterioles** | **Capillaries**

Resistance to Flow in the Cardiovascular System

If: $R_1 = 2$; $R_2 = 4$; $R_3 = 6$ Peripheral Resistance Units (PRU's)

- **Series arrangement gives:**

  $R_T = R_1 + R_2 + R_3$ $R_T = 12$ (PRU's)

- **Parallel arrangement gives:**

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} = 1.94 \text{ (PRU's)}$$

Pressure, Flow and Resistance

- **Pressure, flow and resistance Are related by : Ohm's Law**

$$Q = \Delta P/R$$

Where:

Q = *blood flow*.

ΔP = *the pressure difference between the two ends of the vessel.*

R = *Resistance*

Resistance depends on: The Radius & Length of the blood vessel and the Viscosity (لزوجة) of blood.

To calculate the **Resistance** on the blood: **R = V x L / r 4** , Where: "**V**= Viscosity of blood" , "**L**= Length of blood vessel" .

SO to calculate the blood **Flow** when **Resistance** is "***UNKNOWN*** "

Q = ΔP x r 4 / V x L

Look at small R :)

Viscosity **rarely** changes enough to have a significant effect on resistance **"Length is Fixed in normal Human"**

But when the arteriolar radius changes a little bit it can cause a large change on the blood flow.

Viscosity is the thickness of fluids that affects their ability to flow. **Viscosity** of blood is directly proportional to Resistance and inversely proportional to flow; therefore, any condition that causes **Viscosity** to increase will also increase resistance and decrease flow.

Extra Explanation

Vessel Radius (r):

The most important factor determining resistance is the radius of the vessel.

If resistance changes, then the following occurs:

- Increased resistance decreases blood flow, increases upstream pressure, and decreases downstream pressure.
- Decreased resistance increases blood flow, decreases upstream pressure and increases downstream pressure.

Vessel Length (L):

The greater the length, the greater the resistance.

- If the length doubles, the resistance doubles.
- If the length decreases by half, the resistance decreases by half.
- Vessel length is constant; therefore, changes in length are not a physiologic factor in regulation of resistance, pressure, or flow.

Remember hematocrit in Foundation block? ☺

***Viscosity (V):**

The greater the viscosity, the less the flow in a vessel if all other factors are constant.

Furthermore, the viscosity of normal blood is about three times as great as the viscosity of water.

#Note:

very **Small** changes in vessel diameter lead to **Large** changes in resistance. Vessel length **does not change** significantly and blood viscosity normally stays within a small range (**except when hematocrit changes**).

*This information is taken from Guyton and hall Textbook 13th edition p.164, last Paragraph.

Pressure flow and resistance

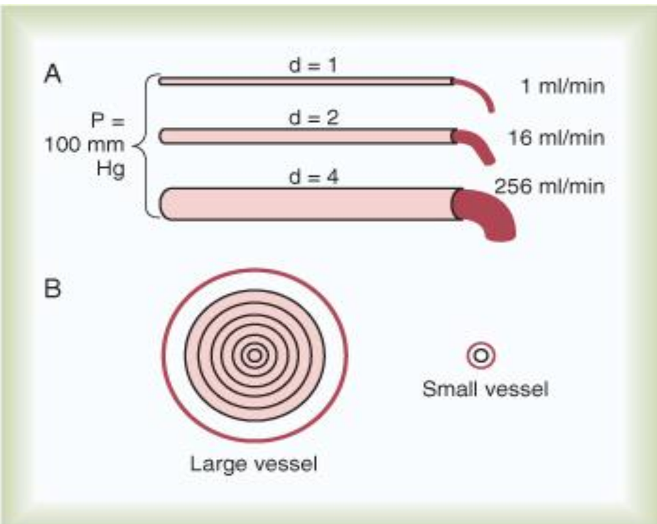
When Radius **increase** the blood flow will **Largely increase**

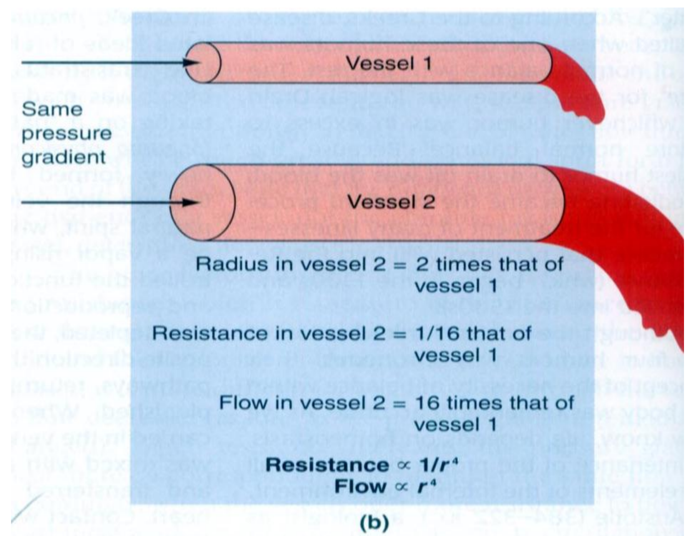
$$Q \sim r^4$$

When Resistance increases the **Radius** will **decrease** the blood flow will **decrease**.

$$R \sim 1 / r^4$$

Understanding figures:





***Note:**

- **Arterioles** & **small arteries** are called(**Resistance Vessels**).
- **THEY** determine the **Mean** Arterial blood pressure

Cross sectional area

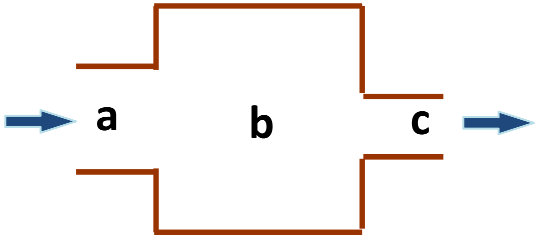
As diameter of vessels decreases :

- The total **cross-sectional area** increases ↑
- **Velocity** of blood flow decreases ↓

Velocity and cross sectional area :

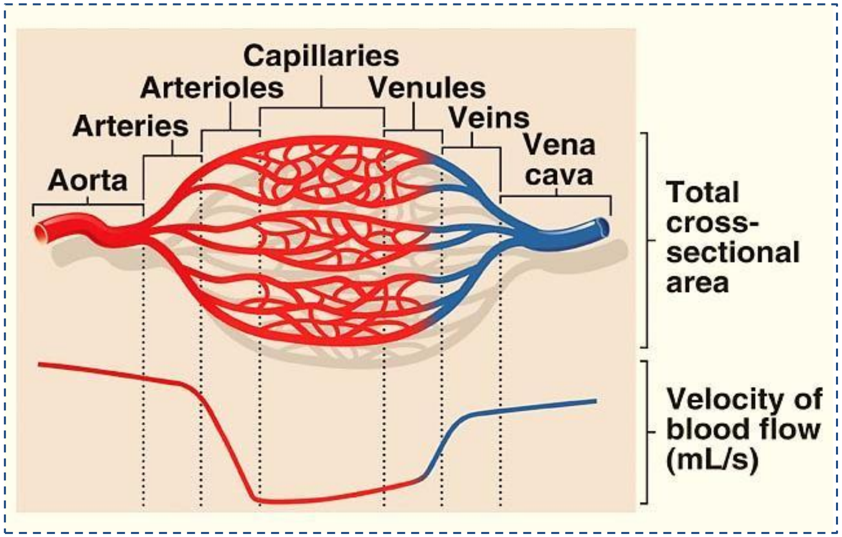
V = Q / A

Example :



- Q= 10 ml/s
- A : **a=** 2 cm^2 , **b=** 10 cm^2 **c =** 1 cm^2
- V : **a=** 5 cm/s , **b=** 1 cm/s , **c=** 10 cm/s

“The highest velocity : point **C** because 10/1= 10”



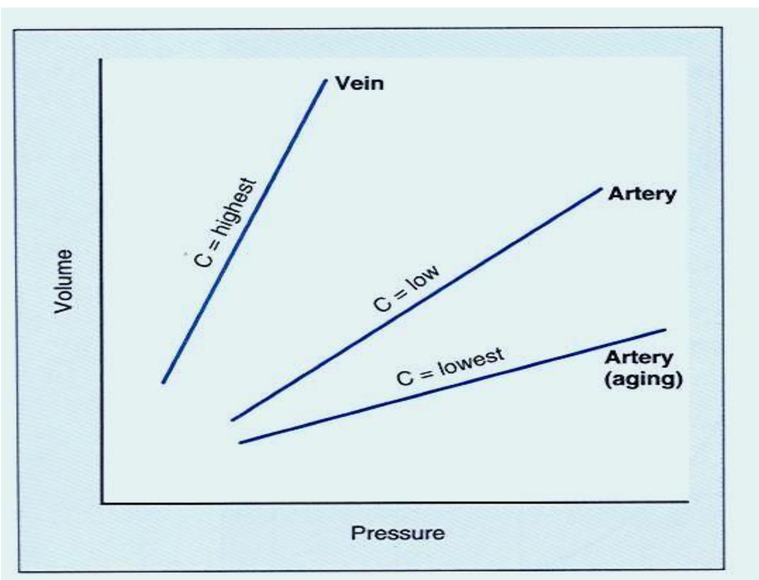
* Total cross sectional area **Highest** at capillaries

Compliance of Blood vessels

- **Compliance** is the volume of blood that the vessel can hold at a given pressure. *(Compliance = distensibility).*

$$C = V / P$$

- **Venous system** has a large compliance & acts as a blood reservoir (*high* volume & *low* pressure)



↓ pressure = ↑ compliance [Veins]

↑ pressure = ↓ compliance [Arteries]

Types of blood flow

There are two type of blood flow:

1- Laminar (Stream-lined) flow :

Smooth flow at a steady rate. The central portion of blood stays in the center of the vessel → *Less friction*. [the outermost layer moving slowest, and the center moving fastest]

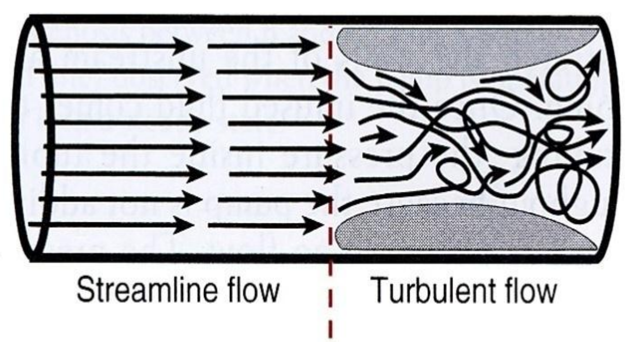
2-Turbulent flow (تدفق عشوائي) : "Interrupted"

High flow rate Blood flow in all directions (Mixing), leading to increase in resistance (by narrowing in vessel wall) → *slow the flow rate.*

Fluid passes a constriction, sharp turn, rough surface.

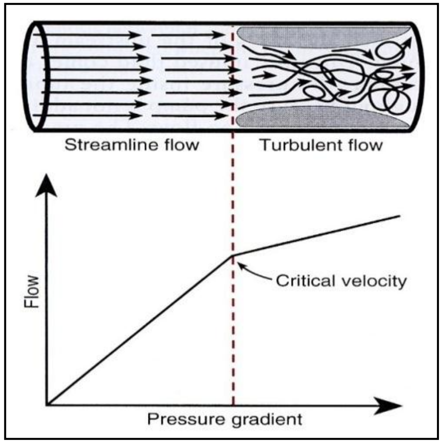
Characteristics of laminar flow:
- As shown in Figure laminar flow is flow in layers.
- Laminar flow occurs throughout the normal cardiovascular system,
excluding flow in the heart.
- The layer with the highest velocity is in the center of the tube.

Characteristics of turbulent flow:
As shown in Figure, turbulent flow is non layered flow.
- It creates murmurs. These are heard as bruits in vessels with severe stenos1s.
- It produces more resistance than laminar flow.

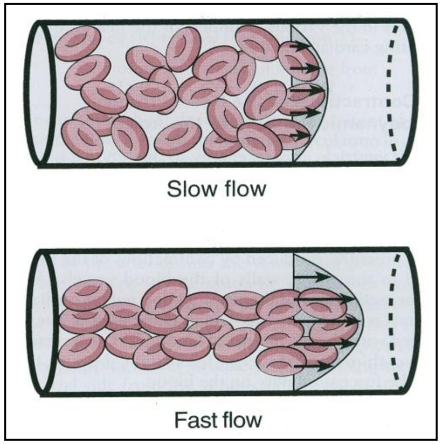


Types of blood flow

The Blood flow is streamlined until a critical flow velocity is reached. When the critical velocity is reached, turbulent flow starts (This Will Produce MURMUR Sounds).
In the presence of turbulent flow, flow does not increase as much for a given rise in pressure because energy is lost in the turbulence.



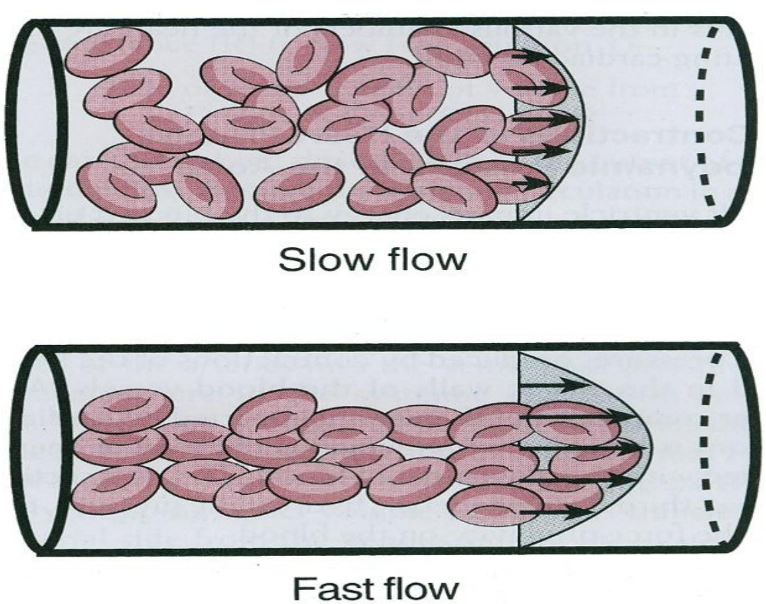
Axial streamline and flow velocity :
The distribution of red blood cells in blood vessel depends on ***<u>Flow Velocity</u>***.
As flow velocity increases, red blood cells move toward the **<u>Center</u>** of the blood vessel (axial streaming) where velocity is highest. Axial streaming of red blood cells lowers the apparent **Viscosity** of blood



Axial streamline and flow velocity

- The distribution of red blood cells in blood vessel depends on flow velocity.
 As flow velocity ***increases***, red blood cells move toward the center of the blood vessel (axial streaming) will ***increase*** .

- increase distribution of red blood cells lowers the ***viscosity*** of blood



Measurement of B.P.

- **Two methods:** Direct & indirect

Sphygmomanometer:

Indirect method, "Estimate of pressure"

Has many types:

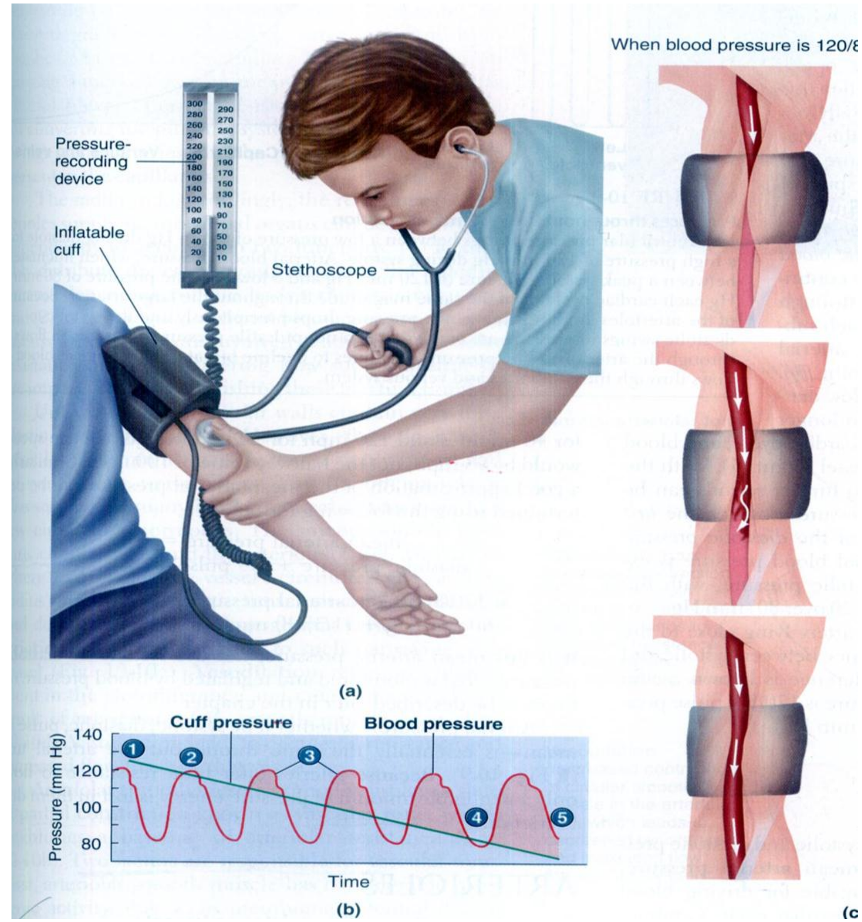
- Mercury sphygmomanometer
- Aneroid equipment
- Automatic equipment

Blood Pressure Cuff Size:

- Small – children & small adults
- Average
- Large – overweight & large adults

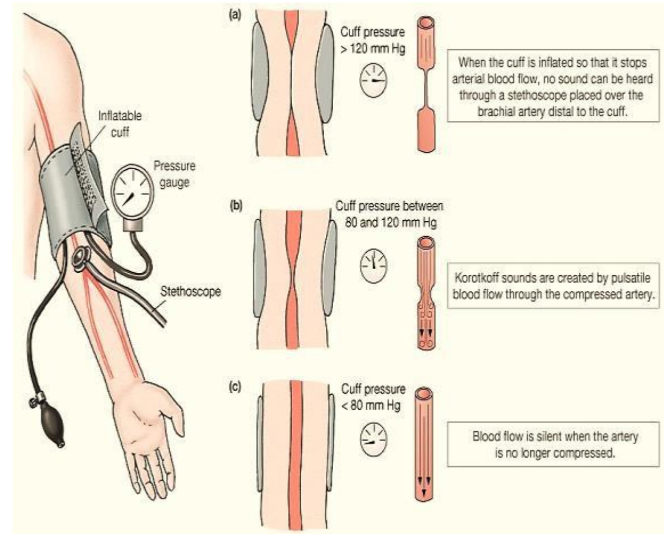
Measurement of B.P.

the cuff is normally placed around an upper arm, at the same vertical height as the heart then Increase the pressure to 150 manual instrument, listening with a stethoscope to the brachial artery at the elbow, then slowly releases the pressure in the cuff. As the pressure in the cuffs falls, a "whooshing" or pounding sound is heard (Korotkoff sounds) when blood flow first starts again in the artery. The pressure at which this sound began is noted and recorded as the systolic blood pressure. The cuff pressure is further released until the sound can no longer be heard. This is recorded as the diastolic blood pressure.

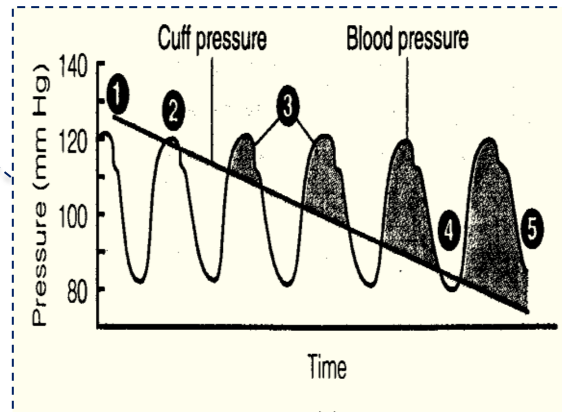


Measurement of B.P.

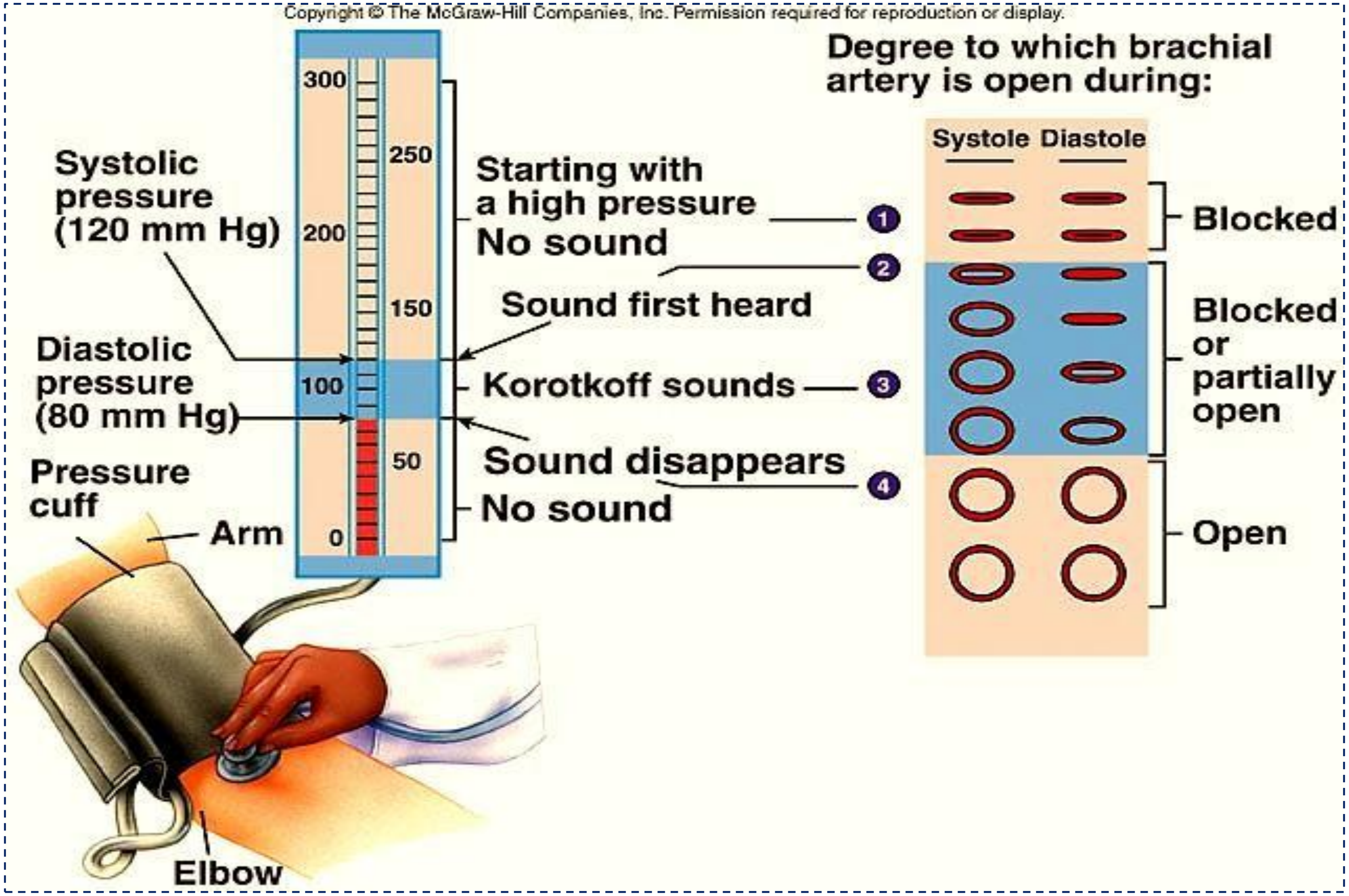
- BP is measured by listening for Korotkoff sounds produced by turbulent flow in arteries:
  - **Systolic pressure**
    = when 1st sound is heard
  - **Diastolic pressure**
    = when last sound is heard



- **Cuff pressure > systolic** blood pressure : No sound
- The first sound is heard at peak systolic pressure.
- Sounds are heard while **cuff pressure < blood pressure.**
- Sound disappears when **cuff pressure < diastolic pressure.**



Measurement of B.P.



Measurement of B.P.

- Hypertension in adults is a BP greater than 140/90.
- BP at or below 120/80 is normal.
- Values between 121/81 and 139/89 indicate a state of pre-hypertension.
- Effect of Hypertension :

  Hypertension increases the work load of the heart → enlargement of the left ventricle → ↑ muscle mass → ↑ oxygen demand.

- Insufficient coronary circulation → symptoms of ischemic heart disease.

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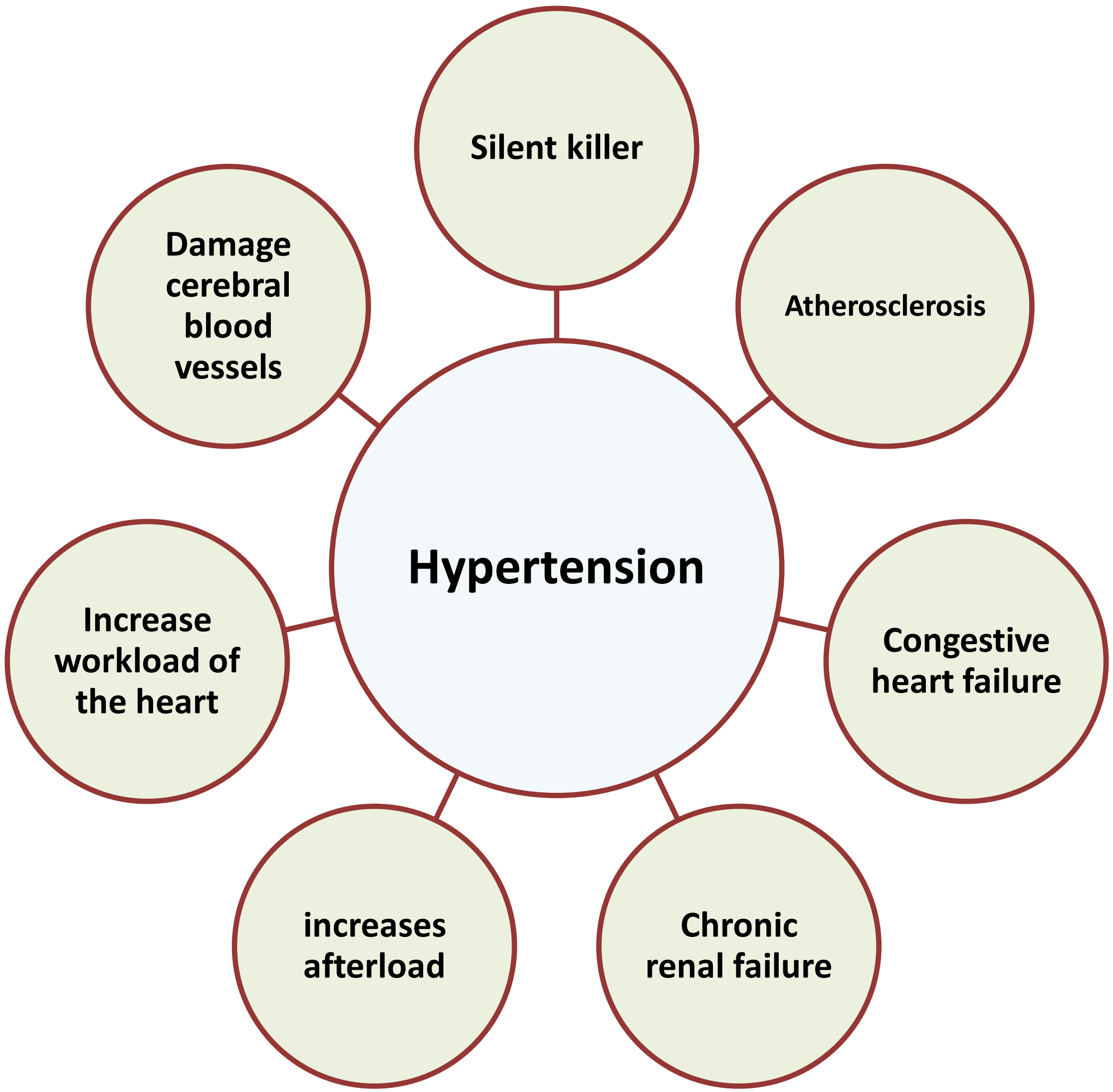
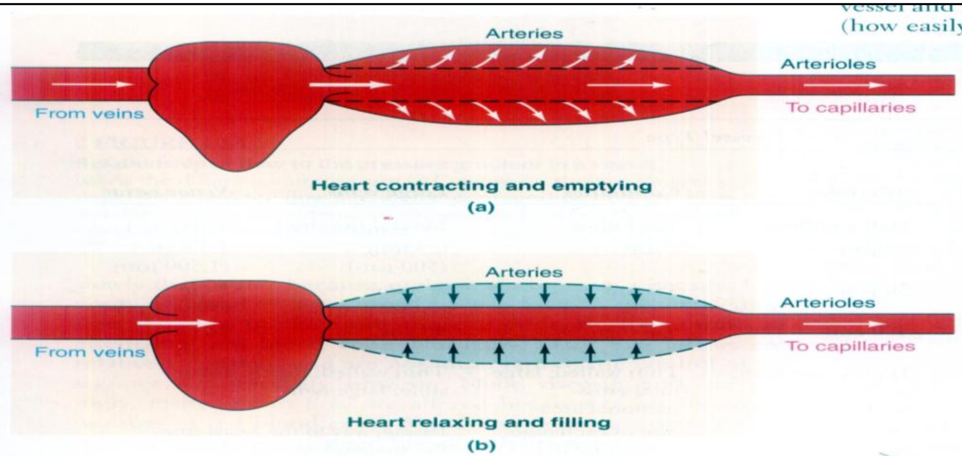
Dangers of hypertension



Elastic rebound

- During systole the arterial BP and the volume of blood will ***increase*** so the artery walls expand to handled the extra amount of blood pumped by the ventricles.

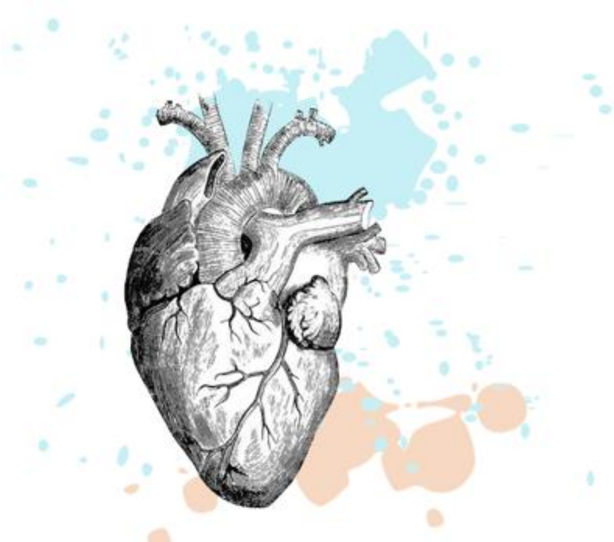
- But During diastole the arterial BP ***falls*** and the Volume of blood will ***decrease*** so the arteries wall will recoil to their original dimensions :
  (Elastic rebound) →to maintains blood flow in the arteries when the ventricle is in diastole.



■ FIGURE 10-6
Arteries as a pressure reservoir
Because of their elasticity, arteries act as a pressure reservoir. (a) The elastic arteries distend during cardiac systole as more blood is ejected into them than drains off into the narrow, high-resistance arterioles downstream. (b) The elastic recoil of arteries during cardiac diastole continues driving the blood forward when the heart is not pumping.

Physiology Leaders :

Khawla Alammari
Nojood Alhaidri
Rawaf Alrawaf



Girls team :

- Atheer Alnashwan
- Asrar Batarfi
- Afnan Almalki
- Alhanouf Aljlaoud
- Deema AlFaris
- Elham Alzahrani
- Johara Almalki
- Lojain alsiwat
- Malak Alsharif
- Monirah Alsalouli
- Monera Alayuni
- Nurah Alqahtani
- Nouf Alabdulkarim
- Nora Albusayes
- Nora Alsomali
- Norah Alakeel
- Reem Alageel
- Rawan Aldhuwayhi
- Reham Al-Obaidan
- Samar AlOtaibi
- Shamma Alsaad

Boys team :

- Abdullah Aljaafar
- Omar Alotaibi
- Abdulrahman Albarakah
- Adel Alshehri
- Abdulaziz Alghanaym
- Abdulmajeed Alotaibi
- Khalil Alduraibi
- Hassan Albeladi
- Omar Alshehri
- Saleh Alshawi
- Abdulaziz Alhammad
- Faisal Alabdulatif
- Abdulnasser Alwabel
- Saad Almutairy