Physiology of the Cardiovascular System "CVS"

Physiology Department

Faculty of Medicine

MERIT UNUVERSITY (MUE)

Physiology of the Cardiovascular System (CVS)

List of contents

Electrophysiology of cardiac muscle and origin ofthe heart beat

ILOs:

1 .Define excitability and know action potentials in the cardiac muscle, the cause of long action potential and plateau and describe the ionic basis of each phase of the action potential, and the characteristics of the action potential in different regions of the heart, including the pacemaker potential. Describe the extrasystole and its mechanism.

2. Define rhythmicity and know the rhythmicity in different parts of the cardiac muscles and factors affecting it, vagal tone and vagal escape.

Cardiac Properties

Rhythmicity (Automaticity)

Def: It is the ability of heart to beat regular impulses independent of any nervous connection

Rhythmic cels are:

Rhythmic cell	① SAN	② AVN	③ Purkinje
Rate of Discharge	90 /min	60 /min	30 /min

Rhythmic cells are characterized by:

① Discharge spontaneously

② Membrane potential is unstable no RMP

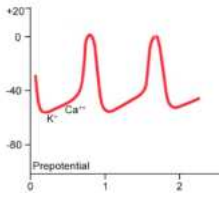
③ It has no plateau

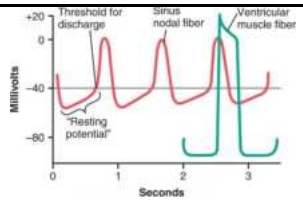
④ Membrane more permeable to Na^+ & Ca^{++}

⑤ Firing level = -40 mV

⑥ Peak of AP = + 10 mV

Action Potential of Pacemaker





Rhythmical discharge of a sinus nodal fiber.

Also, the sinus nodal action potential is compared with that of a ventricular muscle fiber

- Ionic bases:

1- Membrane potential: Decrease spontaneously:
   - From - 60 mV to -50
   - Due to: Na^+ influx.

2- At -50 mv:
   - Transient Ca^{++} channel open (T - type)
   - Ca^{++} enter cell to cause depolarization to firing level -40 mV

NB: 1, 2 are called Prepotential

3- At -40 mv:
   - Opening of long-lasting Ca^{++} channel (L-type)
   - Ca^{++} enters to cause depolarization and there is closure of transient Ca^{++} channels and Na^+ channels till +10

4- Repolarization phase: Due to:
   ❶ Outflow of K^+ (through K^+ channel)
   ❷ Closure of L -type Ca^{++} channel

5- At -60 mv: Inactivation of K^+ channels (so K^+ efflux stops)

NB: The slope of pre potential determine heart rate
   - Increase slope will increase HR (Tachycardia)
   - Decrease slope will decrease HR (Bradycardia)

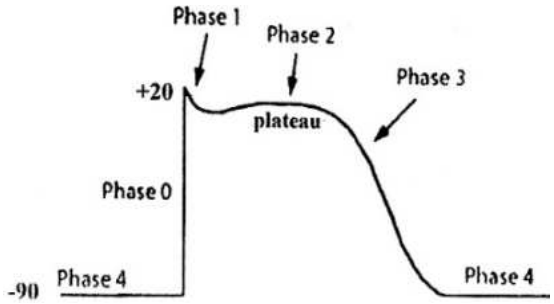
Increase slope causes Tachycardia	Decrease slope causes Bradycardia
1. Sympathetic stimulation	1. Parasympathetic stimulation
2. Catecholamine	2. Acetylcholine
3. Increase temperature	3. Ca channel blocker (CCB)
4. Hypokalemia (↓ K)	4. Hyperkalemia (↑ K)
5. Thyroxin	

N.B Heart rate during rest 70 – 80 due to vagal tone

Excitability (Action potential)

Action Potential:

- Action Potential of **ordinary cardiac muscle fibers**:
  - RMP = -90 mV (ionic bases: Like skeletal muscle)
  - AP is composed of the following phases:



Phase 0: **Depolarization**

- Rapid **depolarization** and reversal of polarity from -90 mV to +20 mV.
- Ionic bases: Na^+ influx (due to opening of fast Na^+ channels)
- **Repolarization**: Is triphasic:

Phase 1:
- Small rapid **repolarization** to + 10 mV.
- Ionic bases: ①Inactivation of Na^+ channels
  ②K^+ efflux (due to opening of fast K^+ channels)
  ③Cl^- influx

Phase 2: Plateau:

- **Repolarization** slow down & membrane potential is around zero mV for about 200 msec
- Ionic bases: Balance between: ①Ca^{++} influx (through long-lasting Ca^{++} channels) together with Na^+ influx
  ②K^+ efflux (through K^+ channels)

Phase 3:

- **Rapid repolarization** to RMP due to: ①Closure of L-lasting Ca++ channeles
  ②Inactivation of Na^+ channels
  ③Activation of K^+ channels leading to K^+ efflux

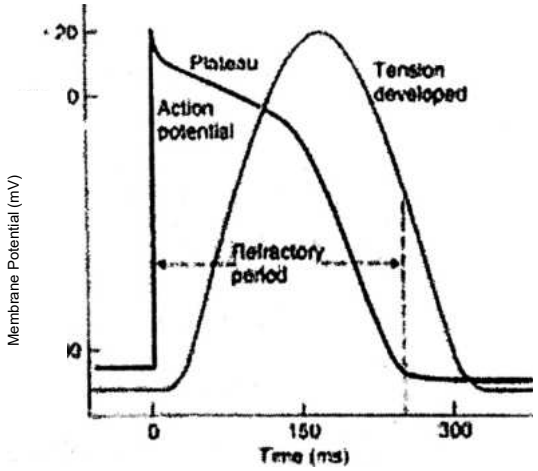
Phase 4:

- Resting membrane potential (RMP) (-90) due to: ① Selective permeability
  ② Na-K pump

- **Relation between AP and mechanical response:**
  - Contraction (mechanical response) starts just after beginning of depolarization &

reaches its maximum by end of plateau (phase 2).

- Repolarization **coincides with** first half of relaxation (diastole). (diastolic time double repolarization time).



- Relation between AP and mechanical change

1- Systole **Coincide with** period of depolarization till end of plateau

2- Diastole **Coincide with** period of rapid repolarization phase & continue in Rest because mechanical response last one & half as long as action potential

- Relation between AP & excitability change

1- Absolute Refractory period **coincides with** period of depolarization till end of plateau (the excitability is lost)

2- Relative refractory period **coincides with** the period of rapid Repolarization phase (the excitability is weak)

- Relation between AP & ECG

- QRS **Coincide with** depolarization
- S-T segment **Coincide with** plateau
- T wave **Coincide with** rapid repolarization

Cardiac muscle excitation–contraction coupling

ILOs:

1. Define cardiac pressure-volume relationships (contractility).
2. describe the excitation-contraction coupling pressure.
3. identify the regulation of cardiac contractility (frank-starling law, staircase phenomenon, homometric regulation).
4. describe the influence of heart rate.

Contractility (*Excitation-Contraction Coupling*)

Definition: It is the ability of the cardiac muscle to contract to pump blood.

Contraction starts after excitation of cardiac wave

Excitation contraction coupling

- Excitation of cardiac muscle (depolarization of AP) leads to Ca^{++} entry inside cardiac muscle.
- Ca^{++} enters sarcoplasm triggers release of large amount of Ca^{++} from sarcoplasm reticulum (through Ca^{++} release channel).
- Ca^{++} binds to **troponin-C** thus tropomyosin uncovers active site. Interaction between actin and myosin followed by sliding of actin over myosin leads to contraction.
- Removal of Ca^{++} from sarcoplasm leads to relaxation.

Factor affecting contractility:

1- All or none Rule

- Cardiac muscle contract maximally or dose not contract at all
- Increase stimulus intensity more than threshold will **not change the strength of contraction**
- Stimulation by stimulus below threshold will **produce No response**

2- Tetanus

- Tetanus means sustained contraction (successive contractions fuse & cannot be distinguished from one another)

Tetanus **cannot** occur in cardiac muscle due to: Long ARP which coincide with

systole

3- Length – Tension relationship:

- Force of contraction of heart **is directly proportional to** initial length of cardiac muscle fiber **within limit** (starling's low):
  - Increase initial length of cardiac muscle fiber will increase force of contraction to reach maximum at certain length which called **L max**
  - At L max all cross bridge of myosin bind to active site of actin
  - Increase length above L max will decrease force of contraction

4- Force - velocity relationship:

- Initial velocity of shortening of cardiac muscle is inversely related to load moved during contraction:
  - **Increase load** carried by muscle will decrease initial velocity of shortening
  - **Decrease load** will increase initial velocity of shortening

5- Staircase phenomena:

- Applying repeated stimuli to cardiac muscle within very short time:
  - The 2^{nd} contraction will be higher than the first
  - And 3^{rd} will be higher than 2^{nd}
  - Until a new level of contraction is reached
- Due to: 1- Increase Ca^{++} ion
  2- Failure of reuptake (due to weakness of Ca^{++} pump)

6- Inotropic state: (Contractility)

- The ability of cardiac muscle to develop force (contract)
- Contractile state could: ① Increase (+ve inotropic)
  ② Decrease (-ve inotropic)

Factors affecting contractility:

[A] Positive Inotropics Factors: ① Sympathetic stimulation (β1-adrenergic).
② Catecholamines
③ Glucagon hormone
④ Digitalis
⑤ Xanthines eg caffeine

N.B: All these factors act through increasing Ca^{++} in sarcoplasm

[B] Negative Inotropic Factors:
① Parasympathetic stimulation
② Acetylcholine
③ Hypoxia (due to ischemia)
④ Calcium channel blockers "CCB"
⑤ Anesthetics
⑥ Anti-arrhythmic drugs

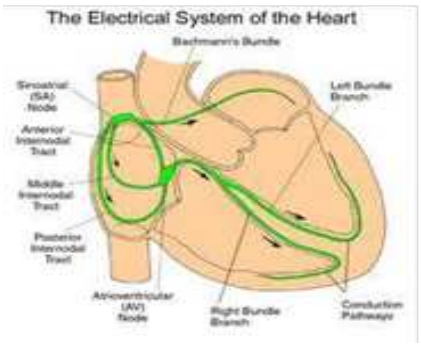
Conduction system of the heart

ILOs:

1. Describe the conductive system, initiation and propagation of cardiac impulse, conduction mechanism, pathways and conduction defects.

Definition: it is the ability of the cardiac muscle to transmit the excitation wave all over the heart.

The conducting system inside the heart consisting of:



1. ***Sinoatrial node (SAN)***: The SAN is a group of muscle cells that normally initiate the heart beats. It is located at the junction of superior vena cava and the right atrium.

2. ***Internodal fibers***: *anterior (Bachman), middle (Wenckebach) & posterior* (*Thorel*) fibers facilitate conduction in the right and left atria for the impulse to reach the AVN. conduction velocity is 1 meter / second.

3. ***AVN***: it represents the upper region of the only conducting route through the annulus fibrosus which separates the atria from ventricles. AVN is similar in structure to SAN and is situated near the interatrial septum. Conduction velocity is 0.05 meter / second. This conduction velocity is accelerated by sympathetic and slowed by parasympathetic.

4. A.V. bundle (bundle of His) & Purkinje fibers: the bundle of His transfers impulses through the annulus fibrosus to the top of the interventricular septum. Then it branches into right and left bundle branches. The left bundle divides into anterior and posterior fascicles. The bundle travels under the endocardium the walls of the septum and at the base divides into multiple fibers of the Purkinje system. This distributes the impulses over the inner walls of the ventricles. Cells of bundle of His and Purkinje system have large diameter and consequently rapid rate of conduction velocity (about 4 m/sec)

 This allows an immediate transmission of cardiac impulse to both ventricles.

 The rate of conduction in atrial & ventricular muscles is 0.5 meter/ sec.

 The slowest conduction is at the AVN, this is called (AV nodal delay). This is because the fibers of AVN are of:

1-Very small diameter (velocity α r).

2-Complex arrangement.

3-Less gap junctions between these fibers.

Significance of AV nodal delay:

a) Delay ventricular contraction to the end of atrial contraction i.e. gives time for atria to empty their content in ventricles.

b) Protect the ventricles from high pathological atrial rhythm.

Defects of conduction:

1. Heart block.

 Abnormal slow conduction in the AVN results in:

 First degree heart block: when delay is much greater than normal.

 Second degree heart block: occurs when only fraction of impulses from the atria are conducted to the ventricles (2:1 , 3:1 or 4:1)

 Complete heart block (***3rd degree heart block***): when the conduction between atria and ventricles are completely abolished. Here, the bundle of His or Purkinje system can start discharge at a rate 25-40 beats / min.

 Bundle branch block: when one branch of the bundle doesn't conduct, the part of the ventricle that it serves will still be stimulated by conduction through the myocardium from unaffected areas. This form of conduction is **delayed** and **slower**.

Electrocardiogram (ECG)

ILOs

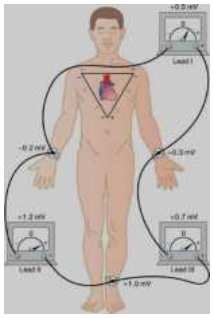
1. Describe electrocardiogram (leads, normal wave, intervals, voltage & cardiac axis).

Definition: Is the recording of the heart electric activity

Recording of ECG

- It is the record of potential changes of myocardial fibers which are conducted along body fluids (good conductor), to the body surface
- ECG is recorded by electrodes placed on the skin in special positions (called leads)
  - A lead is a fixed special position of electrodes.
  - Recording electrodes are 2 types:
    1- Exploring Electrodes : Placed on a point having electrical activity
    2- Indifferent electrode : Placed on a point having a zero potential
  - If wave of depolarization is directed:
  ① Toward the positive, it gives upward deflection
  ② Away from the positive electrode, it gives downward deflection

Types of Leads:



❶ **Bipolar leads:** Standard limb leads

① Lead I : Between Right arm (-ve) & Left arm (+ve)
② Lead II : Between Right arm (-ve) & Left leg (+ve)
③ Lead III : Between Left arm (-ve) & Left leg (+ve)

❷ **Unipolar leads**

Is a record between an exploring electrode and an indifferent electrode:

① The indifferent electrode: Is constructed by connecting the 3 limbs together through a resistance of 5000 ohm

② The exploring electrode: Placed on limbs or chest making 2 types of leads:

(A) Unipolar limb leads

- VR: Records electric potential at right arm
- VL: Records electric potential at left arm
- VF: Records electric potential at left foot

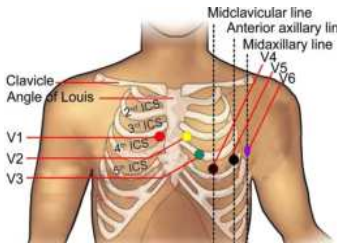
- Augmented unipolar limb leads:
  - ❶ aVR
  - ❷ aVL
  - ❸ aVF

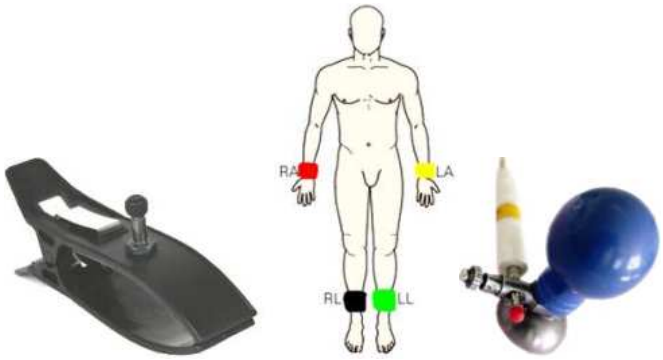
- They are similar to VR, VL, VF but:

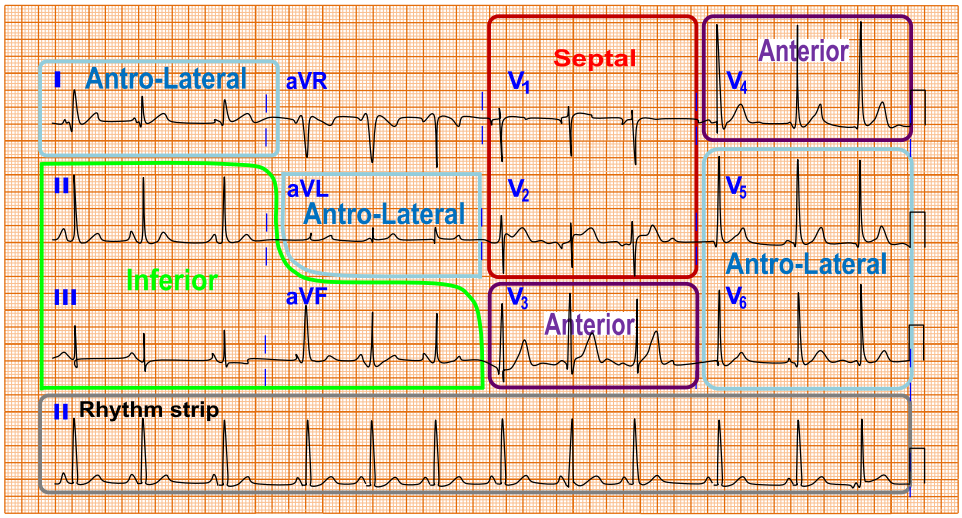
1. Measure difference between one limb and the sum of the other 2 limbs
2. Give a bigger magnitude (augmented by 50%)

(B)Unipolar Chest leads

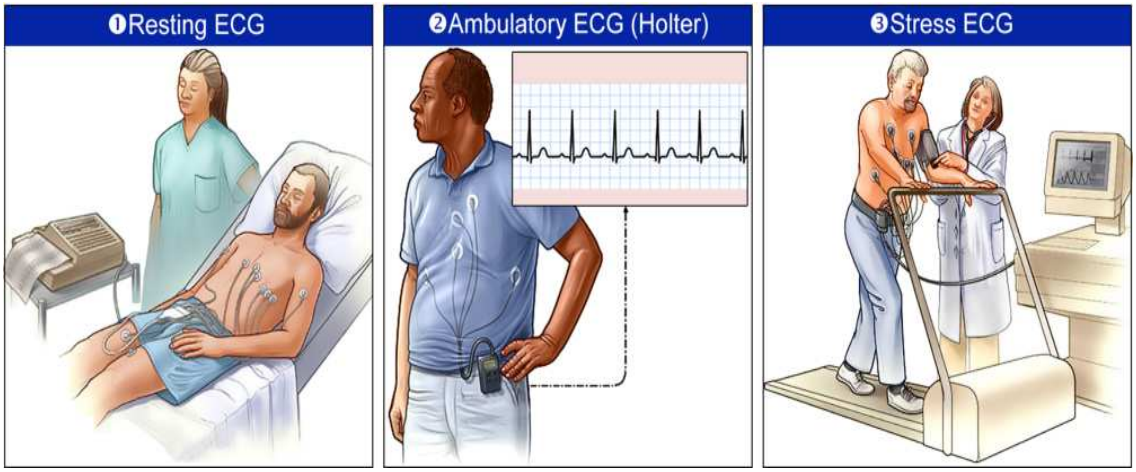
- ❶ V_1 In 4th intercostal space at right parasternal line
- ❷ V_2 In 4th intercostal space at left parasternal line
- ❸ V_3 Midway between V_2 and V_4
- ❹ V_4 In 5th intercostal space at midclavicular line.
- ❺ V_5 in 5th intercostal space at anterior axillary line
- ❻ V_6 In 5th intercostal space at mid axillary line



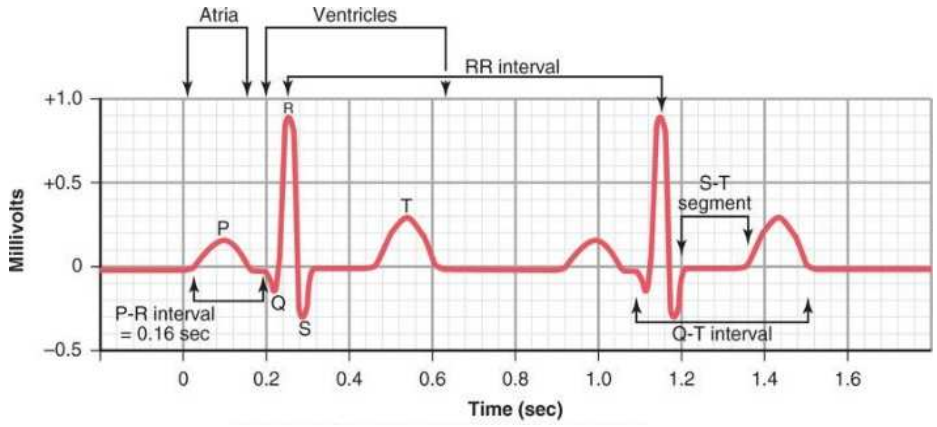




Types of ECG



Normal electrocardiogram:



ECG analysis: Should include the following items:

❶ ***Rhythm***:
- Measure successive R-R intervals
- If fixed = regular rhythm
- If variable =irregular rhythm

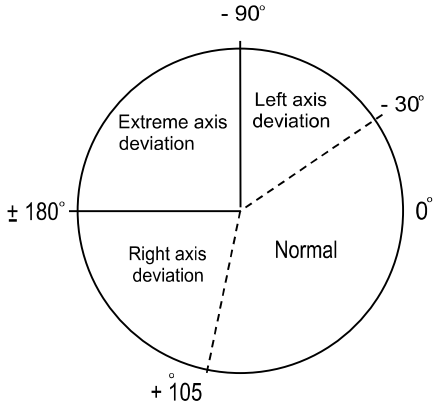
❷ ***Rate***:
- In case of **irregular** rhythm: Number of R in 30 big square (6 second) × 10
- If regular:

$$\text{Heart rate} = \frac{300}{\textit{Number of } \textbf{\textit{big}} \textit{ squa1·e between 2 successive R}}$$

$$\text{Heart rate} = \frac{1500}{\textit{Number of } \textbf{\textit{small}} \textit{ squares between 2 successive R}}$$

❸ ***Axis***: ***Mean Electrical Axis (MEA) of the Heart:***

Definition:
- It is the mean value of depolarization wave during the whole period of depolarization (that changes in direction and magnitude during depolarization spread over the ventricles)
- Mean Electrical Axis (MEA) in normal individual's lies between -30 and +105°.



Abnormalities of MEA:

[1] Right Axis Deviation (RAD): MEA is greater than 110°

- Causes: 1. Physiologically: Tall slender person
  2. Pathologically: Right ventricular hypertrophy

[2] Left Axis Deviation(LAD): MEA is less than -30°

- Causes: 1. Physiologically: Short stunted persons & full term pregnant women
  2. Pathologically: Left ventricular hypertrophy

❹ ***P wave:***

- Represents: Atrial depolarization

First half of P wave: Represents RA (Right Atrial) depolarization

Second half of P wave: Represent LA (Left Atrial) depolarization

- Normally: - Its duration: 0.08 sec
  - Its voltage: 0.25 mv
- Abnormalities: in atrial enlargement

❺ ***P-R interval:***

- Measurement: From beginning of P to beginning of QRS
- Represents: Conduction through atrium+ Av node
- Normally: Its duration: 0.18 sec (0.12 - 0.20 sec)
- Abnormalities: Denoting abnormal conduction from atria to ventricles
  - Prolonged 1- Vagal stimulation

in:

2- AV block

- Shortened in: 1- AV nodal rhythm

2- Sympathetic stimulation.

❻ ***QRS complex:***

- Represent: Ventricular depolarization where:
- Q wave represents: Depolarization of IVS (Interventricular Septum)
- R wave represents: Depolarization of apex and bulk of ventricle.
- S wave represents: Depolarization of the base of ventricles
- Its duration: 0.08 sec, (represents: Conduction in bundle branches, Purkinje fibers & ventricles)
- Its voltage: 1mv

❼ ***S-T segment:***

- Measurement: From end of S to beginning of T
- Represents: The plateau (ventricular repolarization)
- Duration: 0.12 sec
- It should be isoelectric
- Abnormalities: If raised or depressed: Means myocardial injury (infarction or angina)

❽ ***T wave:***

- Represents: The ventricular repolarization
- Its duration: 0.16 sec prolonged wave
- Its voltage: 0.25 mv (it is less than voltage of QRS, partly because of its prolonged length)
- The T wave (ventricular repolarization) is in the same direction of QRS (ventricular depolarization) because the epicardium which is the last part to depolarize is the first part to repolarize.

❾ ***Q T interval:***

- Measurement: From beginning of QRS to the end of T
- Represents: Ventricular depolarization & ventricular

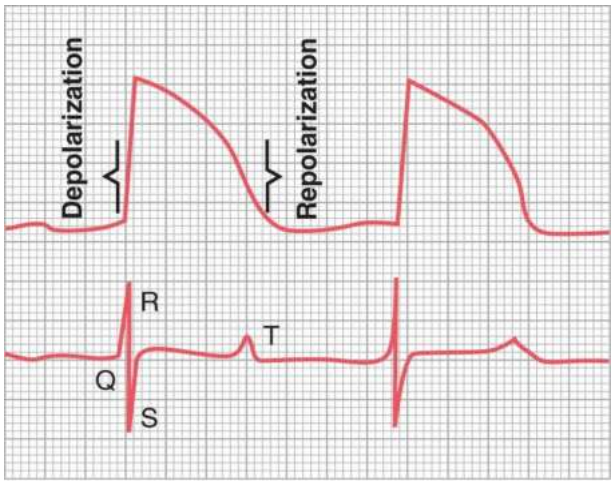
repolarization
- Its duration: 0.4 sec

⑩ ***U wave*** - Represents: Repolarization of papillary muscle
- Usually not recorded

NB: Atrial repolarization is not recorded as it is masked by ventricular depolarization, occurring in the same time with QRS and it is of low- voltage.

NB: The electrical activity of SAN + conducting tissue is not recorded due to: their relative small size

Relation between action potential of a single ventricular muscle fiber & ECG:



Above: - Monophasic AP (Action potential) from a ventricular muscle fiber during normal cardiac function
- Shows: - Rapid depolarization
- Then repolarization: - Occurring slowly during the plateau stage
- Then rapidly toward the end (Rapid phase of repolarization)

Below: Electrocardiogrann recorded simultaneously
- QRS coincides with Depolarization
- S-T segment coincides with Plateau
- T wave coincides with Rapid phase of repolarization

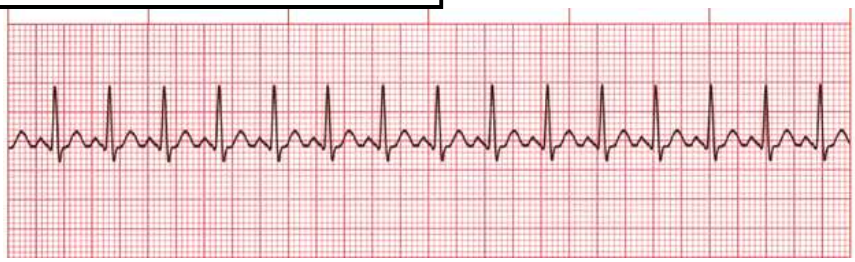
Heart function alteration Arrhythmias & abnormal ECG

ILOS

1 .Illustrate the abnormalities seen in ECG (rate, rhythm, conduction, myocardial lesion, and ECG changes.

Disorders of Rhythm:

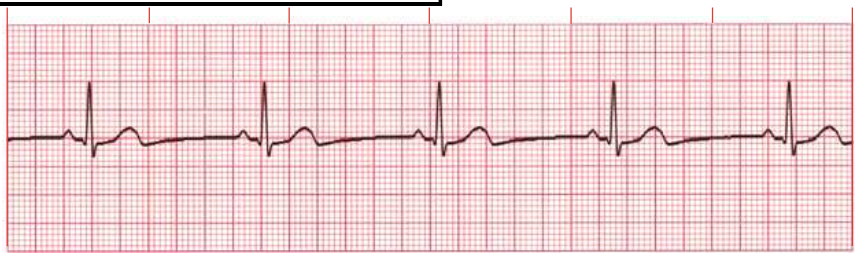
1- Sinus Tachycardia



Sinus tachycardia

- Increase rate of SAN discharge increase heart rate (100- 150 beats/min)
- It occurs in: ① Sympathetic stimulation
  ② Fever (0.5°C increases heart rate 8 beats in adult & 15 beats in children)

2- Sinus bradycardia

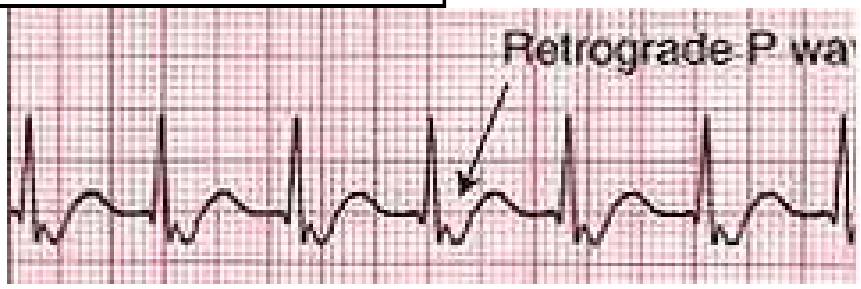


Sinus bradycardia

- Decrease rate of SAN discharge decrease heart rate (< 60 beats /min)
- It is occurs in: ① Vagus stimulation

② Athletes at rest

3- Nodal Rhythm



Sinoatrial nodal block with A-V nodal rhythm during the block period

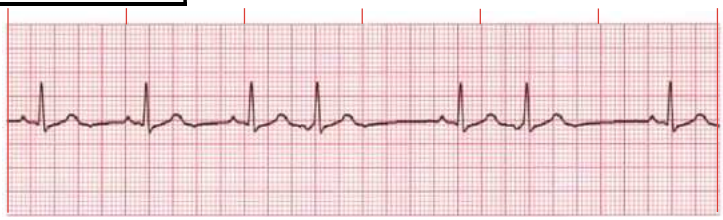
- AV nodal Rhythm:

AVN initiates the cardiac impulses at rate 60/ min.

4- Arrhythmia:

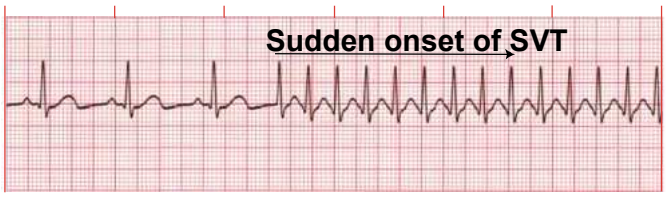
[A] Atrial arrhythmia:

Atrial Extra systole: [Atrial premature beat (PAC) "Premature Atrial Contraction"]



- Atrial ectopic focus discharges once or occasionally
- Its P wave is abnormal
- It is caused by smoking, insomnia , coffee, alcohol & abdominal distension

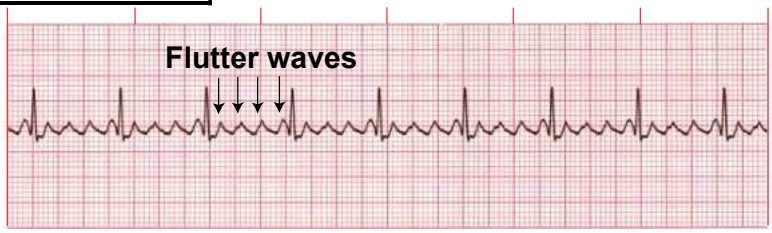
Atrial tachycardia: "SVT" Supraventricular tachycardia



Paroxysmal atrial tachycardia

- Atrial ectopic focus discharges regularly at rate < 200 beats/min
- Occurs in attacks and termed "Paroxysmal atrial tachycardia"

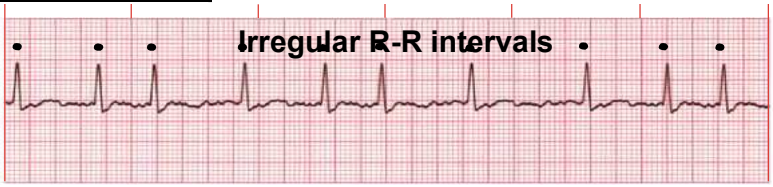
Atrial Flutter:



Atrial flutter

- Atrial ectopic focus discharges` at a regular rate 200 - 350 beats/min
- Not all impulses reach the ventricles as physiological heart block occurs (eg 4: 1)

Atrial Fibrillation(AF):



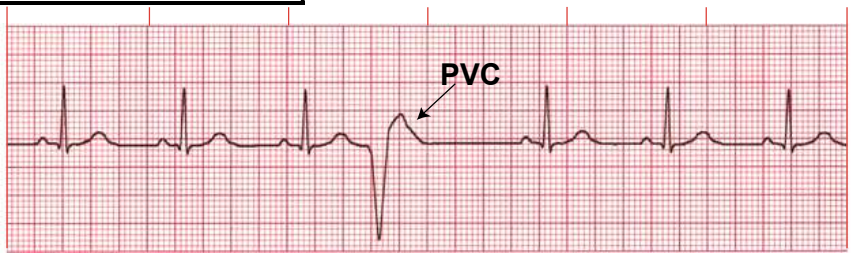
- Multiple ectopic focus discharge irregularly at very high rate up to 400 /min
- P waves are absent or very weak (fine oscillations).
- QRS are frequent, irregular but normal

- Common in rheumatic fever & diseases associated with dilated atrium.

[B] Ventricular Arrhythmia

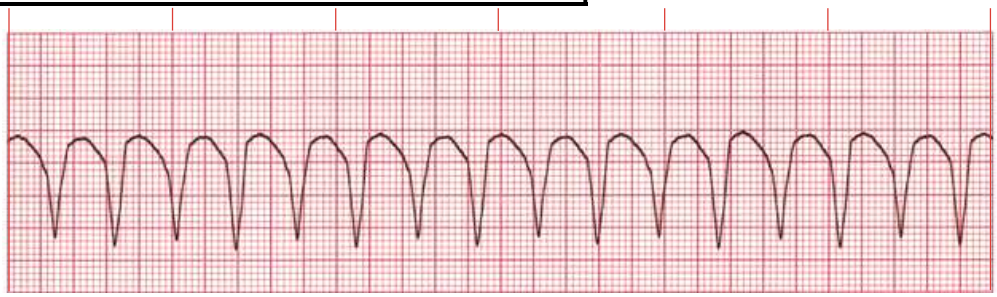
Ventricular Extra systole:

"PVC" Premature Ventricular Contraction



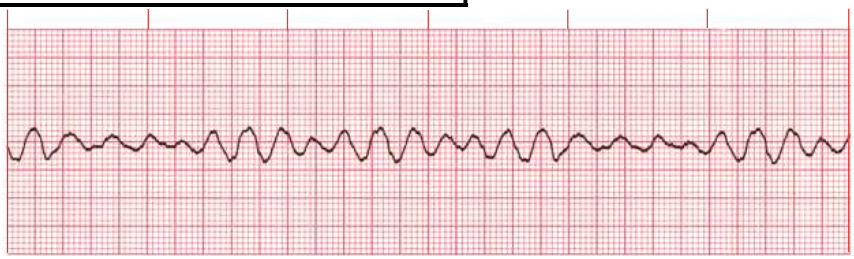
- Ventricular ectopic focus discharge once → premature beat with wide deformed QRS.

Paroxysmal Ventricular Tachycardia (VT):



- The ventricle focus discharges rapidly at a rate of 150 - 200 beats/min

Ventricular Fibrillation (VF):



Ventricular fibrillation

- Multiple ventricular ectopic foci discharge irregularly.
- It is fatal due to: Loss of pumping.

Disorders of Conduction: Heart block

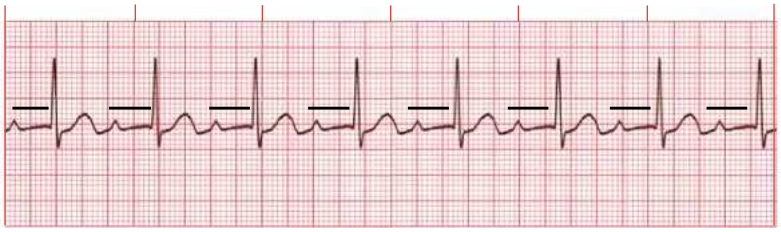
May be due to ischemia or inflammation of conductive system

Incomplete heart block:

- Conduction between the atria and ventricles is slowed but not completely interrupted

❶ First degree heart block

All atrial impulses reach ventricles but there is delay in AV conduction resulting in prolonging P-R



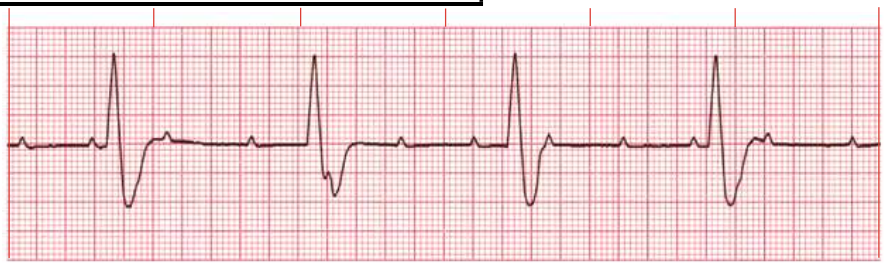
Prolonged P-R interval caused by first degree A-V heart block

❷ Second degree A-V block

Not all atrial impulses are conducted to ventricles (2:1 or 3:1 block)

Second degree A-V block, showing occasional failure of the ventricles to receive the excitatory signals

Complete heart block (third degree):



Complete A-V block

- When conduction from atria to ventricles is completely interrupted
- SAN discharges normally but none of its Impulses reach the ventricle
- The ventricles beat at a low rate (idioventricular rhythm) (35- 45 b/min) independently of the atria (100 b/min)
- There is complete dissociation between P waves & QRS

Myocardial Infarction (MI) " Heart Attack"

Acute MI AMI (Acute myocardial Infarction):

- ECG changes: ST is raised & T wave is inverted in certain leads according to site of injury

Old MI Old infarction, persistent pathological Q wave.

Cardiac Cycle

ILOs

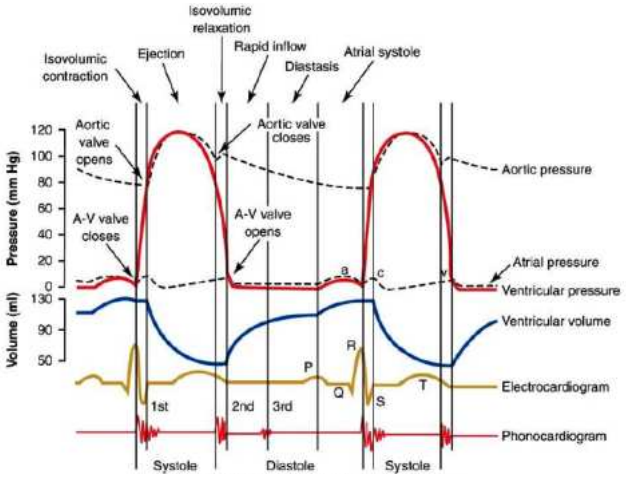
1. Identify the cardiac cycle and its phases. Correlate cycle events with heart sounds, murmurs and ECG.

- It is the period from the beginning of one heart beat to the beginning of next beat
- Each cycle consists of systole & diastole
- Atrial systole precedes ventricular systole
- If heart rate is 75/min, the duration of each cycle = $\frac{60}{75}$ = 0.8 sec
- For atria: - Atrial systole = 0.1sec
  - Atrial diastole = 0.7 sec
- For ventricles: - Ventricular systole = 0.3 sec
  - Ventricular diastole = 0.5 sec
- Changes in heart rate affects mainly <u>diastole</u> which is important because the following occurs during diastole:

1- Ventricular filling (during early diastole)

2- Maximum coronary blood flow

3- The heart rests



Events of the cardiac cycle for left ventricular function, showing:

① Changes in left atrial pressure ② Left ventricular pressure

③ Aortic pressure ④ Ventricular volume

⑤ Electrocardiogram ⑥ Phonocardiogram

During each phase of cardiac cycle different changes of parameters are recorded:

1- **Pressure changes: (Using cardiac catheter)**
   - **Atrial pressure**
   - **Ventricular pressure**
   - **Aortic pressure**
   - **Pulmonary pressure**
2- **Ventricular volume : (Using Echocardiography)**
3- **Heart sounds (Using phonocardiogram)**
4- **Electrocardiogram (ECG)**
5- **Valves (opened or closed)**

Phases of cardiac cycle:

❶ **Atrial systole (Atrial contraction)** 0.1 sec

- Atrial contraction: Evacuates 25 - 30 % of blood into ventricles
- NB: 70 % of ventricular filling occurs passively during diastole
- Ventricular volume: - Increases
  - At the end called End Diastolic Volume (EDV) = 135 ml
- Ventricular pressure: increases then decreases (as ventricles relax more to accommodate the more coming blood)
- Atrial pressure: + ve a: Atrial systole causes initial increase in atrial pressure
  - ve a: ① Blood passes from atria to ventricle
  ② The opening of veins in atria is compressed by atrial systole so no blood enters atria
- Aortic & pulmonary pressure: Decrease (As blood escapes from them)
- Valves: - AV valves: Opened
  - Semilunar valves: Closed
- 4th heart sound: - Is produced by atrial contraction to eject blood into ventricles
  - Normally: it is faint (not heard)
- ECG: P wave: Begins before atrial contraction by 0.02 sec

❷ Isometric Contraction Phase 0.05 sec

- Ventricular contraction while all valves are closed
- Ventricular volume: constant
- Ventricular pressure: 1- Left ventricular pressure from Zero to 80 mmHg Increases:
  2- Right ventricular pressure from zero to 10 mmHg
- Atrial pressure: - Shows sharp increase (+ve C wave)
  - Due to: bulging of AV valve cusps into atrial cavity
- Aortic & Pulmonary pressure: ↓↓
- Valves: Blood tends to regurgitate to atria but it is prevented by sudden closure of AV valves (produces 1st component of **1st heart sound**)
- Semilunar valves are still closed: - So the ventricles now are closed chambers
  - contraction without change in volume (isometrically) as blood is incompressible

- It ends by: Opening of semilunar valves
- ECG:Q wave: Precedes this phase by 0.02 sec

❸ Maximum Ejection Phase 0.15 sec

- Starts by opening of semilunar valves as ventricular contraction leads to increase ventricles pressure: Blood ejected by ventricles to aorta & pulmonary artery

- Ventricular volume: Decreases due to ejection of blood
- Ventricles pressure Increase:
  - 120 mmHg in left [exceeds the aortic diastolic pressure (80 mmHg)]
  - 25 mmHg in right [exceeds the pulmonary diastolic pressure (10 mmHg)]
  - Atrial pressure:
    - Shows a sharp decline (-Ve C wave)
    - Due to descent of cusps of AV ring down.
  - Aortic & pulmonary pressure:
    - Increase (anacrotic)
      - Aortic p =120 mmHg
      - Pulmonary p = 25 mmHg
    - This is because blood coming to them is more than that leaving
- Vibration of blood in aorta + pulmonary artery produce first heart sound component
- ECG: T wave: Begins in this phase

❹ Reduced Ejection Phase 0.1 sec

- Blood ejected by ventricles is less
- Ventricular volume: Decreases
- Ventricular pressure: Decreases gradually
- Atrial pressure:
  - Increases (+V wave)
  - Due to accumulation of venous return
- Aortic pressure & pulmonary pressure:
  - Begin to decrease (catacrotic)
  - This is because blood coming to them is less than blood leaving them
- ECG:
  - T wave

❺ Protodiastole Phase 0.04 sec

- Very short phase between ventricular systole & diastole
- Ventricular volume: Constant
- Ventricular pressure: - Drops more rapidly
  - Due to relaxation
- Atrial pressure: Gradually increases (+ve V wave)
- Valves: AV valve still closed

ECG: T wave

❻ Isometric Relaxation Phase 0.06 sec

- Ventricular relaxation while all valves are closed
- Ventricular volume: Is constant
- Ventricular pressure: Drops to zero
- Atrial pressure: Increases by venous return (+V wave)
- Aortic pressure: Drops (forming diacrotic notch)
- When ventricles start to relax ventricular pressure becomes lower than aortic & pulmonary pressures → blood tends to regurge to ventricles but, this is prevented by: Sudden closure of semilunar valves (producing the **<u>second heart sound</u>**)
- The ventricles now are closed chamber
- ECG : T wave ends

❼ Rapid Filling phase 0.1sec

- Starts by opening of AV valves: as ventricular relaxation → atrial pressure exceeds ventricular pressure:
- Blood passes passively (by pressure gradient) from atria to ventricles
- Ventricular volume: Increases rapidly
- Ventricular pressure: - Decrease
  - As ventricles relax more
- Aortic & pulmonary pressure: - Decrease
  - As blood leaves to periphery
- 3rd heart sound: - Produced by: blood vibrating ventricles

- Not heard normally (except in children)

❽ Reduced Filling Phase 0.2 sec

- AV valves are still opened: blood still flows from atria to ventricles (but at a lesser rate)
- Ventricular volume: Increases
- Ventricular pressures: Not increase as they relax to accommodate the coming blood from atria
- Aortic & pulmonary pressures: Decrease to diastolic pressure

N.B: 70 - 75°/o of blood passes passively (by pressure gradient) during filling phases from aria to ventricles

Summary of Phases of cardiac cycle:

AP (Atrial pressure)	VP (Ventricular pressure)	VV (Ventricular volume)	Aortic & Pulm. pressure	HS (Heart Sounds)	ECG	Valves
❶ Atrial systole (Atrial contraction) [0.1 sec]						
↑→↓	↑→↓	↑	↓	**S4**	**P**	**AV Valves: Opened**
						Semilunar Valves: Closed
❷ Isometric Contraction Phase [0.05 sec]						
↑	↑	**Constant**	↓	**S1**	**QRS**	**AV Valves: closed**

						Semilunar Valves: Closed
❸ Maximum Ejection Phase [0.15 sec]						
↓	↑	↓	↑	**S1**	**T**	**AV Valves: Closed**
						Semilunar Valves: opened
❹ Reduced Ejection Phase [0.1 sec]						
↑	↓	↓	↓	**-**	**T**	**AV Valves: <u>Closed</u>**
						Semilunar Valves: opened
❺ Protodiastole Phase [0.04 sec]						
↑	↓	**Constant**	↓	**S2**	**T**	**AV Valves: <u>Closed</u>**
						Semilunar Valves: Closed
❻ Isometric Relaxation Phase [0.06 sec]						
↑	↓	**Constant**	↓	**S2**	**End of T**	**AV Valves: <u>Closed</u>**
						Semilunar Valves:

						Closed
❼ Rapid Filling phase [0.1sec]						
↓	↑→↓	↑	↓	**S3**	**-**	**AV Valves : opened**
						Semilunar Valves: Closed
❽ Reduced Filling Phase [0.2 sec]						
↓	**↓ (not increase)**	↑	↓	**-**	**-**	**AV Valves: opened**
						Semilunar Valves: Closed

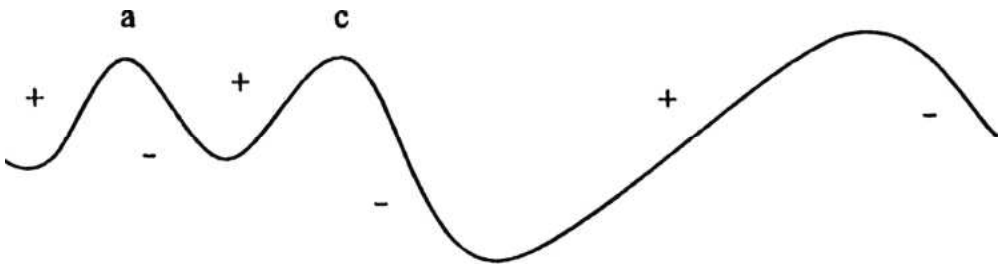
N.B: Phases 2, 3, 4 are called ventricular systole

Phases 5, 6, 7, 8, 1 are called ventricular diastole

Jugular venous pulse curve

ILOs:

1. After the lecture, students should be able to:
2. Define arterial pulse wave (pulse pressure curve) and its significance.
3. Describe the jugular venous pulse and its significance.
4. Identify heart sound (normal and abnormal, characters and causes).



- Pressure changes in right atrium during cardiac cycle are transmitted to right external jugular vein are recorded in the form of a curve (jugular venous pulse curve) composed of:

A wave	
(refer to atrium change) Consists of + ve part & -ve part	
Positive A wave	Negative A wave
Atrial pressure: - Increase - Due to: Atrial contraction (during atrial systole)	Atrial pressure: - Decrease - Due to: Atrial relaxation (during atrial diastole)

C wave	
(refer to cusp) Consists of + ve part & -ve part	
Positive C wave	Negative C wave
Atrial pressure: - Increase	Atrial pressure: - Decrease

- Due to: Bulge of A-V of cusps into atria (during isometric contraction)	- Due to: Decent of A-V cusps (during maximum ejection)

V wave	
(refer to venous return) Consists of + ve part & -ve part	
Positive V wave	Negative V wave
Atrial pressure: - Increase - Due to: Accumulation of venous return (during reduced ejection, Protodiastole, isometric relaxation)	Atrial pressure: - Decrease - Due to: Rapid flow of blood from atria to ventricle (during rapid filling & reduced filling phases)

Aortic pressure changes during cardiac cycle

- Pressure changes in aorta during cardiac cycle are recorded in the form of a curve composed of:

Anacrotic limb

- **It coincides with maximum ejection phase of left ventricles.**
- Aortic pressure: - Increases (As blood coming to aorta is more than that leaving it)
  - Reaches of 120 mmHg (SBP "Systolic Blood Pressure)

Catacrotic limb

❶ Beginning of catacrotic limb:

- Coincides with reduced ejection phase & Protodiastole
- Aortic pressure: Starts to decrease (As blood coming to aorta is less than that leaving it)

On catacrotic limb: There is diacrotic notch & diacrotic wave:

❷Diacrotic

1- Diacrotic Notch = Incisura

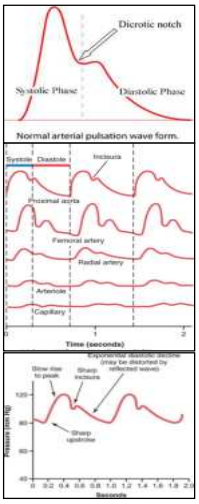
Aortic pressure: - Sharp small drop
- Due to Sudden closure of aortic valve at beginning of isometric relaxation phase

2- Diacrotic wave:

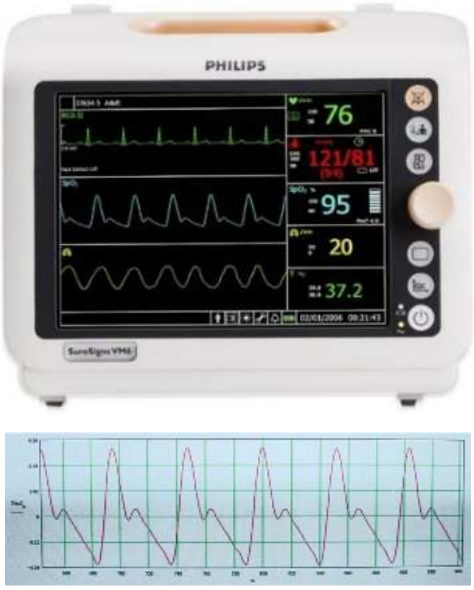
Aortic pressure: - Increases (Due to elastic recoil of distended aorta)

❸ Remaining part of catacrotic limb:

- It coincides with early, mid and late diastole & isometric contraction phase
- Aortic pressure: Decreases (As blood leaves aorta to tissues) reaches 80 mmHg (DBP "Diastolic Blood Pressure")



Pressure pulse contour in the ascending aorta



Heart sounds

ILOs

1. Identify the anatomical and physiological origins of the four primary heart sounds (S1, S2, S3, S4), stating the events that generate them.
2 .Describe the precise timing of S1 and S2 within the cardiac cycle and explain their relationship to the closure of the atrioventricular (AV) and semilunar valves.

- Heart sounds are 4
- 2 of them can be heard normally with stethoscope (the first and second heart sounds).
- Sounds occur when: 1- Valves close.
  2- Blood flow is very rapid or turbulent.

❶ First heart sound (S1)

Causes: 1-**Sudden closure of A-V valves**: During isometric contraction phase.
2-Vibrations of contracting ventricular & papillary muscles.

3-Vibrations of aortic and pulmonary walls during maximum ejection phase

Timing in cardiac cycle: Isometric contraction & maximum ejection

Characters of the sound: 1-Low pitched sound (frequency 30 Hertz)

2-Heard as lub

3-Long duration 0.15 sec.

Best heard at: 1-Mitral component: Heard at: left fifth intercostal space in midclavicular line (at the apex of the heart)

2-Tricuspid components: Heard at: Just to the left of lower the end of sternum

❷ Second heart sound (S2)

Cause: **Sudden closure of the semilunar valves.**

Timing in cardiac cycle: Isometric relaxation

Characters of the sound: 1-It is high-pitched sound (frequency 50 Hertz)

2-Heard as dup.

3-Shorter duration than first sound (0.1second)

Best heard at: 1-Aortic component (A_2):

- Due to: Sudden closure of aortic valve
- Heard at: Second right intercostal space at right sternal border

2-Pulmonary Components (P_2):

- Due to: Sudden closure of pulmonary valve
- Heard at: Second left intercostal space at left sternal border

❸ Third heart sound (S3)

Cause: Rapid flow of blood from atria to ventricles

Timing in cardiac cycle: Rapid filling phase

Characters of the sound: 1- Low pitched sound.

2- Non-audible normally (except in children)

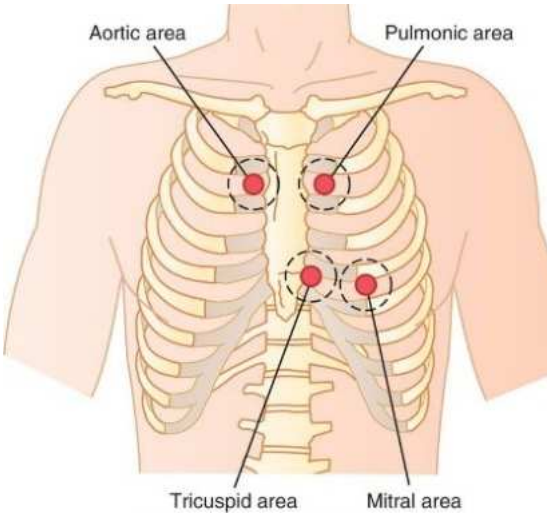
❹ Fourth heart sound (S4)

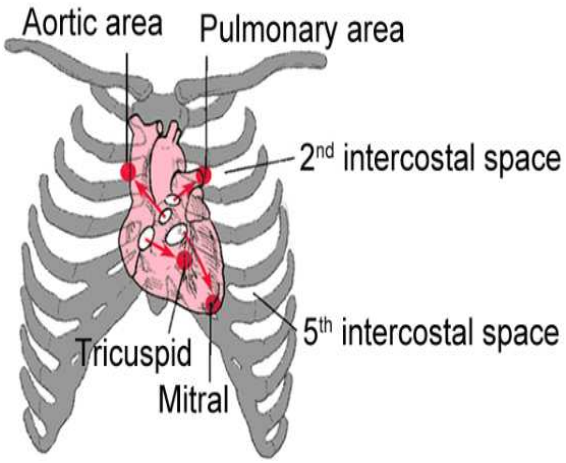
Cause: Rapid flow of blood from atria to ventricles

Timing in cardiac cycle: Atrial systole

Characters of the sound: 1- Low pitched sound.

2- Non-audible.





Chest areas at which sound from each valve is best heard

Heart rate Regulation and cardiovascular reflexes

ILOs

1. State the Vaso sensitive areas (baroreceptors, chemoreceptors and their role in regulation of circulation), heart rate and its regulation.
2. Describe the effect of exercise and posture on CVS.

THE CARDIOVASCULAR CENTERS

 These are the nervous centers which control heart rate, contractility, and diameter of blood vessels.

 located in the reticular formation or the medulla oblongata and lower part of the pons and are also called the vasomotor Center.

 They control diameter of the arterioles and venules through affecting the discharge in then autonomic system that supply these structures.

 These centers are divided into

A- **Sensory area** in the nucleus tractus solitarius (which receives the input signals from baroreceptors, chemoreceptors via sensory neurons

B- **Motor centers:** include

(1) Vasoconstrictor center (VCC): Stimulation of this center *increases the sympathetic discharge* to

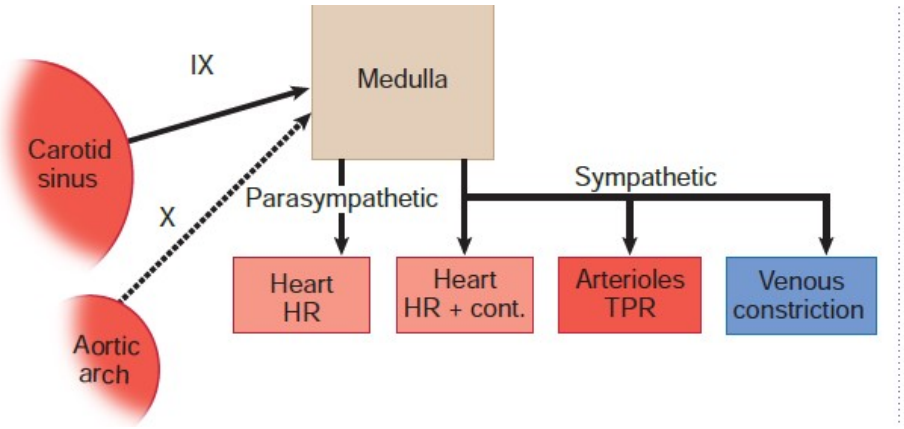
(a) All blood vessels (leading to generalized (VC)

(b) The adrenal medullae (leading to secretion of catecholamines)

(c) The heart (leading to increase in the heart rate and cardiac contractility). The part of the VCC which produces these cardiac effects is sometimes called the *cardiac accelerator center (CAC).*

(2) Vasodilator center (VDC): Stimulation of this center leads to generalized V.D. *through inhibiting the activity of the VCC.*

(3) The cardiac center: This consists *mainly of a* ***cardiac Inhibitory center (CIC)*** which, when excited, *stimulates the adjacent nuclei* of *the vagus nerve,* and these in turn transmit *signals that decrease the heart rate and atrial contractility.* The *CAC is related to the VCC as described above.*



The cardiovascular receptors

1- Baroreceptors: sense the degree of stretch in the wall of the blood vessels. They are situated in most blood vessels. But 3 of them are the most important: **arterial baroreceptors, atrial baroreceptors, and ventricular baroreceptors.**

2- Chemoreceptors: sense certain chemical substances like blood gases level, hydrogen ion concentration, or metabolite levels**. Also include: arterial chemoreceptors, coronary and pulmonary chemoreceptors.**

3- **Other receptors which affect heart rate: e.g.** proprioceptors and temperature receptors.

The sympathetic tone on the heart:

The sympathetic stimulation increases cardiac contractility by (20:25%), increases conductivity, and increases heart rate up to 150 beat/min, but the latter effect is antagonized by the stronger vagal tone.

The vagal tone on the heart

This is a continuous inhibitory effect exerted by the vagi nerves on the heart during rest. It dominates over the sympathetic tone at the S-A node, reducing its rhythmicity from about 100 to about 75 impulses/minute (but it doesn‘t affect ventricular contractility because the vagi do not supply the ventricles).

Mechanism (nervous pathway) of the vagal tone

The cardiac vagal tone is a reflex which occurs as follows:

The initiating stimulus: the increase in arterial blood pressure.

Receptors: arterial baroreceptors in the walls of the aortic arch and carotid sinus.

Afferent neurons*:* aortic nerve and sinus nerve which are branches from vagus and glossopharyngeal nerves Impulses.

***Center**:* the impulses reaching the center stimulate the CIC. which in turn discharge tonic inhibitory impulses to:

Efferent vagal nerve fibers.

***Response**:* depress the inherent high autorhythmicity of the SA node.

THE VAGAL ESCAPE:

It means that the ventricles have no inhibitory efferent supply from the vagus nerve. So if there was strong bilateral vagal stimulation, this will totally inhibit the SA node for short time and stop the heart, after that, the ventricles start beating by their own idiovcntricular rhythm (25-40 /minute).

Importance: it allows the ventricles to continue beating by their idioventricular rhythm trying to maintain the cardiac output in cases of complete heart block in which vagal stimulation can‘t further decreases this ventricular rhythm (but it can be increased by sympathetic stimulation).

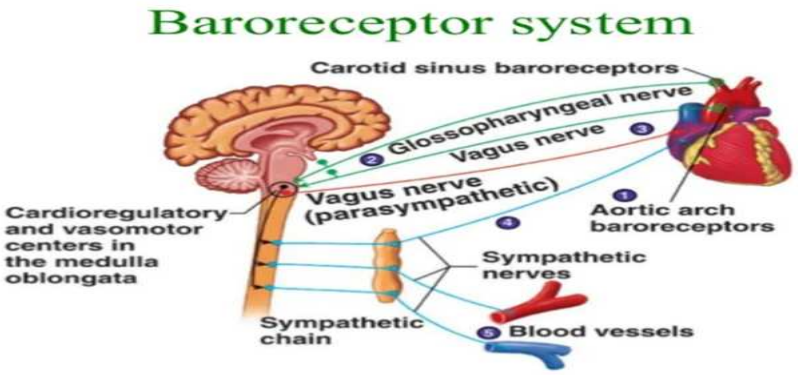
REGULATION (CONTROL) OF THE HEART RATE

 Normal: 60: 90beat/min.

 Bradycardia less than 60beat/min.

 Tachycardia more than 90beat/min

 Variable according to age, sex, sleep



Physiological variations: such as

(1) Age: it is about 120 beat/ min in infants (due to absence of the vagal tone).

(2) It is more in females than in males (due to less vagal tone in females).

(3) Slowest in athletes (due to a stronger vagal tone than in sedentary persons).

(4) It increases on changing from the recumbent to the upright posture.

The frequency of discharge of the S-A node (which determine the heart rate) is affected (or regulated) by:

A- Nervous regulation

B- Humeral regulation

C- Effect of temperature

NERVOUS REGULATION OF THE HEART RATE

The heart rate is nervously regulated by changing the activity of the cardiac and vasomotor centers in the brain-stem. These centers receive impulses from:

A- Impulses from supraspinal centers.

B- Impulses from circulatory system (most important).

C- Impulses from respiratory system.

D- Impulses from other parts of the body.

(A) SUPRASPINAL CENTERS THAT AFFECT THE HEART RATE

(1) The cerebral cortex

The cortical influence on the heart rate is evident by alteration of the heart rate as a response in many conditioned reflexes. Also, through such cortical Influence, some individuals can voluntarily control their heart rates.

(2) The hypothalamus and limbic system

These structures are concerned with emotional reactions. Most emotions are associated with tachycardia (e.g. before starting a race). However, severe emotions are frequently associated with bradycardia.

(3) The respiratory center: can affect heart rate as occurs *in respiratory sinus arrhythmia:*

 commonly occur in children

 Heart rate increased during inspiration and decrease during expiration.

 Stimulus: stretch receptors in lung

 Centre: inspiratory center inhibits CIC

 Response: increase heart rate.

(B) REFLEXES INITIATED FROM THE CVS

Impulses originated from

1- Arterial baroreceptors.

2- Atrial baroreceptors .

3- from peripheral chemoreceptors.

1- Impulses from the arterial baroreceptors:

 These are stretch receptors include aortic arch and carotid sinus.
 Respond to changes in arterial blood pressure.
 Strategically located to monitor the mean arterial blood pressure in the arteries that supply blood to the brain (carotid sinus baroreceptor) and to the rest of the body (aortic arch baroreceptor).
 The brain is able to reset the baroreflex to allow increases in MABP to occur (e.g. during exercise and the defense reaction).
 Ageing, hypertension and atherosclerosis *decrease arterial wall compliance, reducing baroreceptor r*eflex sensitivity.

Effects- of stimulation of the arterial baroreceptors (by increased blood pressure)

(1) Stimulation of the CIC (*resulting in reflex bradycardia*)
(2) Stimulation of the VDC (*resulting in generalized V.D*. *decreases blood pressure*).
(3) Inhibition of respiratory center, so decreases rate of breathing
(4) Inhibition of secretion of the antidiuretic hormone (ADH).

(1) Arterial baroreceptor reflexes (Marey's reflex)

"A rise of the arterial blood pressure (ABP) leads to a decrease of the heart rate and vice versa, provided other factors affecting the heart rate remain constant". It is initiated by stimulation of the arterial baroreceptors.

The carotid sinus syndrome

In some individuals, the carotid sinus is abnormally hypersensitive, so that mild pressure on the carotid sinus behind the angle of the mandible (e.g. during shaving or by a tight collar) leads to bradycardia and generalized V.D. that may be severe enough to decrease the cardiac output and ABP to the extent or producing brain ischemia, syncope or fainting).

On the same basis, an attack of paroxysmal atrial tachycardia can be terminated through initiating carotid sinus reflex (by light massaging of the carotid sinus).

(2) Atrial mechanoreceptors: with myelinated vagal afferent. **Located** mainly at the junction of the atria and great veins.

Stimulus: increased atrial volume and pressure

Response:

1- Sympathetically mediated **tachycardia** (**Bainbridge reflex**).

2- Decreases the secretion of **antidiuretic hormone** (vasopressin), **cortisol** and **renin**, causing diuresis.

Importance: This reflex helps to control blood volume and heart rate.

2. Mechanoreceptors in the left ventricle and coronary arteries with mainly non-myelinated vagal afferents.

Stimulus: increased ventricular diastolic pressure and afterload.

Response: vasodilatation.

3. Ventricular chemoreceptors: which are stimulated by substances such as bradykinin and prostaglandins released during cardiac ischemia. These receptors activate the **coronary chemoreflex**. This response, also termed the **Bezold – Jarisch effect**, occurs after the intravenous injection of many drugs, and involves marked bradycardia and widespread vasodilatation.

4. Pulmonary mechanoreceptors, stimulated by marked lung inflation, especially if oedema is present, causing tachycardia and vasodilatation.

(C)- IMPULSES FROM THE RESPIRATORY SYSTEM:

1- Chemoreceptor reflexes

Chemoreceptors activated by **hypoxia**, **hypocapnia** and **acidosis** are **located in the aortic and carotid bodies.**

Stimulated during asphyxia, hypoxia and severe hypotension.

Response: stimulating breathing= tachypnea, tachycardia, sympathetic constriction of (mainly skeletal muscle) arterioles, splanchnic venoconstriction

importance: This reflex is important in maintaining blood flow to the brain at arterial pressures too low to affect baroreceptor activity.

2-Pulmonary mechanoreceptors: mentioned previously.

3-**Central chemoreceptors**: stimulated according to CO_2 and H^+ in the cerebrospinal fluid.

(D)- IMPULSES FROM other parts in the body:

The CNS ischemic response

Brainstem hypoxia stimulates a powerful generalized peripheral vasoconstriction. This response develops during severe hypotension, helping to maintain the flow of blood to the brain during shock. It also causes the **Cushing reflex**, in which vasoconstriction and hypertension develop when increased cerebrospinal fluid pressure (e.g. due to a brain tumor) produces brainstem hypoxia.

Extrinsic reflexes

Stimuli that are external to the cardiovascular system also exert effects on the heart and vasculature via extrinsic reflexes.

1- Moderate pain causes sympathetic stimulation in form of tachycardia and increases mean arterial blood pressure

2- Severe pain has the opposite effects.

3- Cold causes cutaneous and coronary vasoconstriction, possibly precipitating angina in susceptible individuals.

4- From skeletal muscles: voluntary contraction of skeletal muscle increases heart rate. Receptors are the proprioceptors in skeletal muscles.

5- From the eyes (oculo-cardiac reflex)

"Applying pressure to the eyeball results in reflex decrease in the heart rate ". Impulses from the eye are transmitted to the nervous system where they stimulate the CIC. Such response can be used to terminate an attack of paroxysmal atrial (but not ventricular) tachycardia.

6- Signals from certain sensitive areas in the body known as the trigger areas (e.g. the larynx, testes and epigastric region) also result in cardiac slowing, and blows to these areas may lead to cardiac arrest

Cardiac Output (CO) & Cardiac reserve

ILOS

1. Describe cardiac output and state components controlling it.
2. Define various related terms, including stroke volume, cardiac index, end diastolic and end systolic volumes.
3. Explain the importance of cardiac reserve, mechanisms and limitations, and heart failure (pathophysiology, causes and consequences).

Definition: **Cardiac output (CO):** Is the volume of blood pumped by each ventricle per minute

- Normally = 5 L/min

NB: Cardiac Index (CI):
- Volume of blood pumped by each ventricle per minute **per** square meter body surface area
- Normally = 3.2 L/min/m^2

Calculation: **Cardiac output** (CO): = SV × HR

Normally: CO = 70 × 70 = 5 L/min

***Cardiac output depends on*:**

❶ Heart rate

❷ Stroke Volume (SV):

Definition: Is the volume of blood pumped by each ventricle per beat

Calculation: SV = EDV - ESV

EDV: End Diastolic Volume

ESV: End Systolic Volume

- Normally: SV = 135 - 65 = 70 ml

EDV: Is the volume of blood In the ventricle at end of diastole

ESV: Is the volume of blood In the ventricle at end of systole

Ejection Fraction (EF):

Definition: EF is the fraction of the EDV that is ejected with each beat

Calculation:

$$EF = \frac{\text{Stoke volume}}{\text{End diastolic volume}} \times 100$$

Normally: Ejection fraction is 55-75%

Importance : Assessment of Contractility.

Variations of cardiac output (CO):

Unchanged in
1. Sleep
2. Moderate changes in external temperature

Increased in
1. Excitement (50- 100%)
2. Exercise (300%)
3. Exposure to high temperature

4. Eating (30 %)
5. Epinephrine secretion
6. End of pregnancy
7. Inspiration
8. Shifting from standing to recumbent position

Decreased in
1. Sitting or standing from lying position
2. Rapid arrhythmia
3. Heart failure

<u>Control of the cardiac output</u>

❶ **<u>Heart rate (HR)</u>**

An increase of HR up to 200/min. (eg during exercise) leads to an increase of CO

❷ **<u>Change of Preload</u>**

- Preload determines muscle length before start of contraction.
- Ventricular preload is determined by EDV
- EDV depends on venous return
- According to **Starling's Law**:
  - The more the end diastolic volume the more is the force of contractions; within limits.
  - An increase of EDV (preload) leads to increase SV with consequent increase of CO
  - Preload is affected mainly by venous return
  - Factors that increase venous return: Means increase filling of ventricles increased EDV → increased myocardial contractility → increased SV → increased cardiac output
  - **<u>Factors that affect ventricular preload</u>:**
    - ① Venous Return (VR): Increased venous return will increase preload
    - ② Ventricular compliance: Decreased ventricular compliance will decrease preload eg myocardial infarction

③ Heart rate: Increased rate more than 200/min leads to a decrease of preload due to shortening of diastole decreased ventricular filling

❸ **Effect of afterload on SV**

- After load is the load against which the ventricle contracts and eject blood
- The main after load for left ventricle is the aortic pressure
- An **increase** of after load leads to a **decrease** of SV → decrease CO
- **Decreased** after load leads to **increase** of SV → increase CO

❹ **Effect of contractility (inotropic state) on SV**

- Positive inotropics increase contractility of the ventricle → ejecting more blood → increase SV → increase CO

Cardiac Reserve "CR"

Definition: It is difference between cardiac output pumped by the heart under ordinary circumstances & its maximum capacity for pumping blood
In normal young adult: the CR is 300%

Assessed by: Low-dose dobutamine stress echocardiography

Mechanisms:

1) +ve chronotropic condition:

(Heart rate reserve)	**During rest:**	HR = 70	
	During exercise:	HR =200	(so, COP can increase 3 time)
	Limitation:	Diastolic period is shortened	

2) Factors ↑ preload:	**During rest:**	= 135 ml
(EDV reserve)	**During exercise:**	Venous return increase led to **increase** ventricular filling → **increase** EDV → lead to **increase** force of contraction

3) Factors ↓ afterload Decrease total peripheral resistance

4) +ve inotropic condition: **During rest:** = 65 ml

(ESV reserve) **During exercise:** Sympathetic stimulation **increases** force of contraction lead to decrease ESV → increase SV → COP

Limitation: Amount of blood

5) Cardiac hypertrophy: - increase force of contraction → increase SV → COP
- Cardiac hypertrophy may be: 1. Physiological
2.Pathological

6) Venous oxygen reserve: **During rest:**
- O_2 content in each 100 ml arterial blood: **20 ml O_2**
- O_2 content in each 100 ml venous blood: **15 ml O_2**
- Thus, blood supply to tissue = **5 ml O_2**

During exercise: Blood supply to tissue increases up to 12 ml

Limitation: Amount of O_2 in venous blood

If there is no matching between COP & body needs: so, this Heart is Failed (HF)

Heart Failure

ILOs

1. Describe cardiac output and state components controlling it.
2. Define various related terms, including stroke volume, cardiac index, end diastolic and end systolic volumes.
3. Explain the importance of cardiac reserve, mechanisms and limitations, and heart failure (pathophysiology, causes and consequences).

***Def.*:** It is a clinical syndrome in which the heart is unable to pump an adequate amount of blood to satisfy metabolic requirements of the body

***Etiology*:**

❶ CAD: Ischemic heart disease (most common cause)

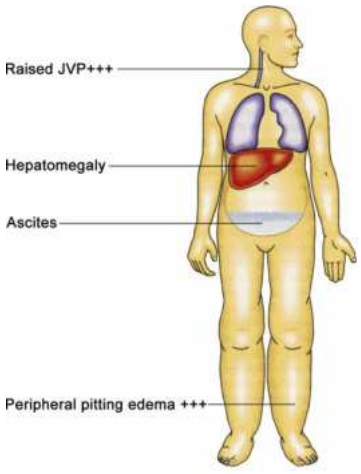
❷ Valvular Diseases

❸ Systemic Hypertension

❹ Myocardial Diseases: eg Cardiomyopathy

C/P:

Right-Sided Heart Failure		Left-Sided Heart Failure	
❶ **Backward manifestations (Systemic congestion)**	: eg: - Lower Limb edema - Ascites - Congested neck veins (↑↑ JVP) - Congested liver	❶ **Backward manifestations (Pulmonary congestion)**	: eg - Dyspnea - Cough - Hemoptysis - Recurrent chest infection
❷ **Forward manifestations (Low COP manifestations)**	: eg syncope, fatigue	❷ **Forward manifestations (Low COP manifestations)**	: eg syncope, fatigue
❸ **Cardiovascular manifestations** S_3 & gallop		❸ **Cardiovascular manifestations**	S_3 & gallop



Investigations:

❶ CXR:

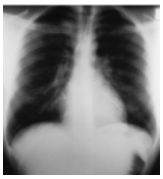
"Chest X-Ray"

Cardiac Size

- Comment on heart size only with PA view "Postro-Anterior View" chest-x-ray

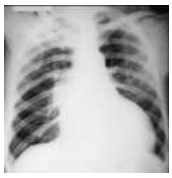
❶ Normal

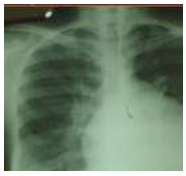
Normally: CT ratio should be < 0.5



❷ In chronic HF: Dilated cardiac ventricles

Causes of ↑ CT ratio > 0.5:





❷ Echocardiography: Assess:

Ventricular Function "Performance": Systolic Functions:

Through: EF "Ejection Fraction" (N: 55-75%)

Treatment:

❶ Medical:

① ↓ Preload:
- ❶ Rest: Semi-sitting or sitting
- ❷ Diet: Salt restriction (< 2 gm/day)
- ❸ Diuretics
- ❹ VenoDilators: eg Nitrates "Nitroglycerin"

② ↓ Afterload: Arteriodilators: eg Ca channel blocker (CCB) : Diltiazem

③ ↑ Contractility: Inotropic drugs: eg:
1. Digitalis
2. Dobutamine

❷ Interventional:

① ↓ Preload: Mechanical removal of fluids: By Dialysis

② ↓ Afterload: Mechanical assistance of circulation: By IABP "Intra-Aortic Balloon Pump"

③ ↑ Contractility: CRT (Cardiac Resynchronization Therapy)

❸ Surgical: Cardiac transplantation

Self-assessment Question

(1) Describe the pulmonary circulation

(2) Recognize the importance of intercalated Discs

(3) Explain why action potential spreads very rapidly in cardiac muscle

(4) Compare between SAN (Sinoatrial Node) & AVN (Atrio-ventricular Node)

(5) Describe the conducting system of heart

(6) Enumerate cardiac Properties

(7) Describe the ionic bases of action potential of pacemaker

(8) What is the effect of hyperkalemia on action potential & subsequently heart rate

(9) Compare between the action potential of pacemaker and that of ordinary cardiac muscle fiber

(10) Enumerate factor affecting contractility

(11) Enumerate phases of cardiac cycle

(12) Differentiate between the Atrial pressure changes & Aortic pressure changes during cardiac cycle

(13) What is cause of the following: ① A wave ② C wave ③ V wave

(14) Describe heart sound & mention the areas they are best heard in

(15) Describe waves of ECG & illustrate your answer with a draw

(16) Describe sites where we connect chest leads to the patient

(17) Mention how to Calculate the Ejection Fraction (EF)

Hemodynamics

ILOs

1. Define blood flow, mention factors determining blood flow (resistance) through the blood vessel.
2. Describe the physical characters of blood flow, mechanism of murmurs.
3. Determine relationships between pressure, resistance and flow.
4. Describe different mechanisms involved in blood flow regulation.

- The four major components of vascular system are:

1- The large arteries : Rich in elastic fibers & show phenomenon of compliance & elastic recoil.

2- The arterioles : Have strong muscular coat & are the resistance vessels

3- The capillaries : Have thin wall & are the exchange vessels.

4- The veins : Have thin wall & are the major reservoir of the blood

- **Basic Principles**: Physical factors controlling fluid Flow (F) in a tube:

1- **Pressure gradient (Δ P):**

$F \propto \Delta P$

2- Resistance (R):

$F \propto \frac{1}{R}$

So $F \propto \frac{\Delta P}{R}$

F : Flow
Δ P: Pressure gradient
R : Resistance
n : Viscosity of fluid
L : Length
r : Radius

$\Delta P \propto F \times R$

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

Factors determining resistance (R):

1) Radius (r): $R \propto \frac{1}{r^4}$

2) Length (L): $R \propto L$

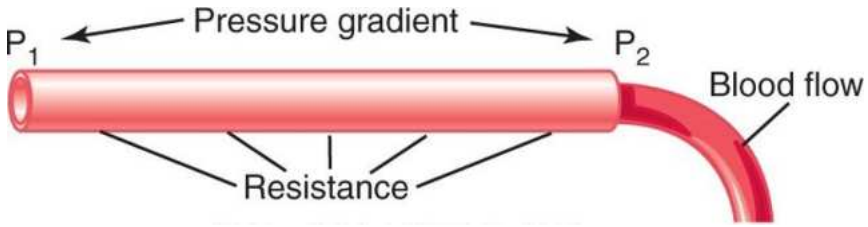
3) Viscosity of fluid (n): $R \propto n$

$$\therefore R \propto \frac{Ln}{r^4}$$

$$\therefore R = \frac{8\,Ln}{\pi r^4}$$

$\frac{8}{\pi}$ = constant

$$\therefore F = \frac{\pi \Delta P r^4}{8\,Ln}$$ ←This is known as Possielle's Law



Inter relationships among pressure, resistance, & blood flow

Resistance (R)

- Applying the previous principles on cardiovascular system:

	Arteries	Arterioles	Capillaries	Veins
- Pressure difference	120-85	85-35	30-10	10-0
- % of total **resistance**	15%	50%	25%	10%

- The arteriolar resistance:

- Greatest resistance (as they have the narrowest total cross-sectional area)
- Represents 50 % of resistance as they are: 1- Rich in smooth muscle fibers
  2- Poor in elastic fibers
- Vasoconstriction of arterioles → Increase R
- Vasodilatation of arterioles → Decrease R

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

Δ P: The **resistance** of any part is observed by: Recording the **drop of blood pressure before & after** crossing this part

F: The overall blood flow in the circulation: Is the cardiac output

In Systemic Circulation

The total peripheral resistance (TPR) is calculated as follows:

$$R = \frac{\text{Mean aortic pressure - Right atrial pressure}}{\text{Cardiac output}}$$

Normally:

$$R = \frac{90-0}{5} = \frac{90}{5} = 18 \text{ mmHg/L/min}$$

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

- In Exercise: CO increases and ΔP is constant, so **R is decreased**
- In systemic Hypertension: CO is constant and ΔP increases, so **R is increased**

In Pulmonary Circulation The Resistance (R)

$$R = \frac{\text{Mean pulmonary artery pressure - Left atrial pressure}}{\text{Cardiac output}}$$

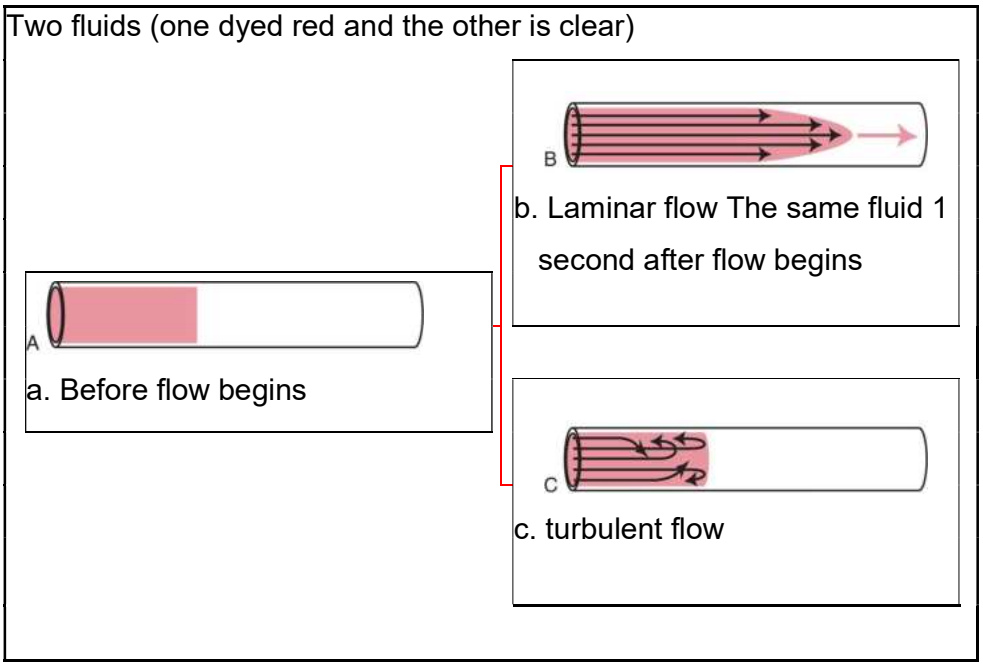
Normally:

$$R = \frac{20-5}{5} = \frac{15}{5} = 3 \text{ mmHg/L/min}$$

Blood Flow

Definition - The volume of blood that passes a certain point in the circulation (L/min or ml/min)

- The overall blood flow in the circulation: Is the cardiac output



Types

❶ ***Laminar flow*** Blood flows in parallel layers (laminae)

- The blood in contact with the vascular wall does not move
- The next layers slide over the stationary layer
- The velocity is maximal at the center
- It is silent (ie not heard by stethoscope)

❷ ***Turbulent flow***: - Occurs when blood flow velocity **exceeds** a critical velocity as in:

1. Narrowing of arterioles eg Atherosclerosis or constriction

2. Decrease viscosity as in anemia

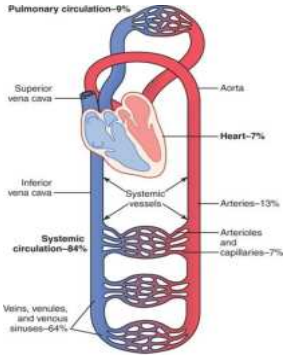
- Turbulent flow produces a sound

Velocity Velocity of blood flow:

- In Aorta: = 0.5 meter/sec [It is a high velocity to ensure rapid delivery of blood to tissues]
- In Capillaries: = 0.5 mm/sec [It is a slow velocity to gives enough time for exchange]

NB: Kidney has the highest blood flow /100-gram tissues

Organ	% of CO **at rest**	Change **at activity**
Skeletal ms	20%	10 times
Skin	5%	4times
Heart	5%	4times
Kidney	20%	decrease
Liver	25%	decrease
Brain	15%	No change



Arterioles:

- Responsible for 50% of circulatory resistance
- Arterioles possess the narrowest total cross-sectional area being:
  1. Rich in muscular wall
  2. Poor in elastic fibers

Regulation of the vasculature by endothelium

ILOs

1. Describe Endothelium-derived relaxing factors and Endothelium-derived constricting factors.
2. Describe other factors affecting vascular tone.

The Control of arteriolar diameter Consists of 2 major mechanisms (methods):

❶ Central Mechanisms

-**Aim:** Of central regulation is to regulate the total peripheral resistance (TPR) to maintain a constant ABP to ensure adequate blood supply to vital organs (heart & brain)

- Central mechanisms includes (consists of) 2 mechanisms:

① Neural mechanism

Consists of 2 types of fibers:

1. **Vasoconstrictor fibers (CV): One type**
   - All VC fibers to arterioles are sympathetic
   - Through α-adrenergic receptors
   - To all arterioles except heart+ brain
2. **Vasodilator fibers (VD):** 3 types
   - ❶ Sympathetic VD fibers:
     1-To blood Vessels of skeletal muscles
     - Originate in cerebral cortex, descend to **LHCs** directly
     - Through cholinergic receptors
     - Produce VD even before the start of exercise

     2- To coronary vessels: Through B1 adrenergic receptors
   - ❷ Parasympathetic VD fibers:
     - To genital tract: Only parasympathetic which is truly VD. It causes erection
     - Other VD which occurs as a result of parasympathetic is secondary to increase metabolic activity
   - ❸ Antidromic VD impulses: Stimulation of skin pain receptors

② Vasoactive substances

Consists of 2 types:

1. **Circulating VD substances**:

❶ Kinins:

- **Types**: 1- Bradykinin (Nano peptide)
  2- Lysyl Bradykinin
- **Chemical nature**: Both are peptides
- **Formation:** From precursor proteins: 1-High MW kininogen (HMW)
  2-Low MW kininogen (LMW)
- **Functions**: 1- Relaxes smooth ms of Bl. Vessels→ VD & decrease ABP.
  2- Contracts smooth ms of hollow viscera.
  3- Increase capillary permeability.
  4- +Ve chemotaxis effect.
  5- Stimulates pain receptors.

❷ANP "Atrial Naturetic Peptide":

- **Chemical nature:** Peptides
- **Secreted by**: Atrial muscle cells
- **Stimuli for its release**: 1- Increase NaCl in plasma
  2- Increase ECF volume
- **Actions:** 1- Naturesis is increase Na^+ excretion, which is accompanied by Cl loss & H_2O loss (Diuresis)
  2- Anti-aldosterone effect: It inhibit Na-K ATPase
  3- Decrease the response of smooth muscle of BV to circulating VC substances
  4- Decrease conversion of prorenin into renin
  5- Decrease secretion of: - Vasopressin
  - Aldosterone
  - Opposes action of Angiotensin II
  6- Decrease ABP

❸ Histamine VD specially in allergic and inflammatory conditions

2. **Circulating VC substances**: Includes

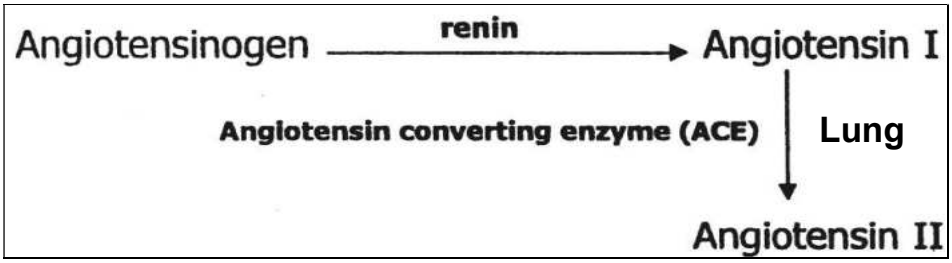
❶ Catecholamines ① Adrenaline
② Noradrenalin

NB: Noradrenaline has a stronger VC effect than adrenaline

- Adrenaline causes VD in liver & skeletal muscle

❷ Angiotensin II

- **Chemical nature**: Octapeptide (8 a.a.)
- **Stimulus of secretion**: Decrease renal blood flow as in hemorrhage
- **Formation:** Renal ischemia→ renin (released by Juxta Glomerular Cells)



- **Functions:** Increase ABP by 2 mechanisms:

1) Powerful VC: In seconds (rapid)

- VC of arterioles → increase TPR "Total Peripheral Resistance" →↑ CO →↑ABP

- VC of veins → increase venous returns (VR) →↑ CO → ↑ABP

2) Salt & water retention:

- increase ECF volume→ increase VR→ ↑ CO increase ABP

❸**Vasopressin = ADH "Antidiuretic Hormone"**

- Water reabsorption
- Vasoconstriction

❷ Local Mechanisms

- It regulates blood flow according to the local metabolic needs of tissues
- Local mechanisms include (consists of) 2 mechanisms:

① Auto regulation

Definition: It is the ability of a tissue to regulate its own blood flow

Site: Autoregulation is well developed in: ①Heart ④Skeletal muscle
②Kidney ⑤Liver
③Brain ⑥Mesentery

Theories:

1. **Myogenic theory**: - It is Bayliss response (intrinsic response)
   - Stretch of smooth muscle → contraction
2. **Metabolic theory**: - On increase tissue activity or decrease blood flow, vasodilator metabolites accumulate → VD → Increase blood flow
   - VD metabolites are:
     1- Low O_2 & Low pH in most tissues
     2- Increase CO_2 in brain, skin
     3- K+ in skeletal muscle
     4- Adenosine in cardiac muscle
     5- Lactate + Increase temperature of tissue activity
     6- Histamine in inflammation

② Substances secreted by Endothelium:

Include:
1- Prostacyclin
2- EDRF
3- Endothelins

- Act as a paracrine hormone.
- Regulate cardiovascular functions:

1) **Prostacyclin**:
   - **Chemical nature:** Is derived from arachidonic acid via cyclooxygenase enzyme (COX)
   - **Formed by**: Endothelial cells
   - **Functions:**
     1- Decrease platelets aggregation
     2- VD
2) **Endothelium derived relaxing factor**: EDRF (Nitric Oxide "NO"):

- **Chemical nature**:
  - It Is Nitric Oxide (NO)
  - Synthesized from Arginine by calmodulin dependent NO synthetase.
- **Mechanism of action**: It activates Guanylate cyclase enzyme producing cGMP

which relaxes the smooth muscles

- **Functions**: ❶ Role in CVS: 1- It is inactivated by Hb.
  2- Its tonic release is necessary for normal ABP
  3- Its deficiency causes hypertension
  4- It is released by:
    1. Acetylcholine: Which is vasodilator, but if applied to a vessel with removed endothelium → VC
    2. Bradykinin, VIP, substance P
    3. Product of platelet aggregation if endothelium is intact

  ❷It causes penile erection

  ❸Involved in pathogenesis of atherosclerosis

  ❹ It is produced by macrophages & is necessary for its cytotoxic action & kills cancer cells.

  ❺ It plays a role in brain (via cGMP)

  ❻ Nitroglycerine [in treatment of angina] acts by increase cGMP

3) **Endothelins:** Most potent VC produced by endothelium

- **Chemical nature:** 21 amino acids polypeptides 4 types:
  - ET1 (Enodothelin 1)
  - ET2
  - ET3
  - VIC (vasoactive intestinal contractor)
- **Receptors:** 2 types
  1. ETA receptor: Responds to Etl
  2. ETB receptor: To all.
- **Cardiovascular effects:**
  1. Contracts vascular smooth muscle, veins > arteries.
  2. VC of coronaries (intense VC).
  3. VC of renal vessels → Increase resistance.
  4. Decrease renal blood flow → decrease GFR (glomerular filtrate rate).
  5. +Ve inotropic and+ Ve chronotropic effects.
  6. Increase catecholamine, renin, aldosterone & ANP.

Blood pressure and flow in the arteries and Arterioles

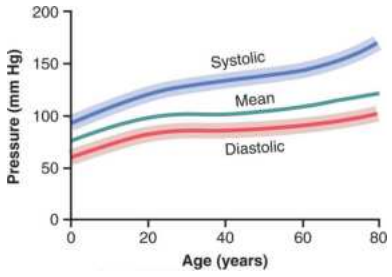
1. Describe innervation of blood vessels, vasomotor tone, its mechanism, factors influence the diameter of arterioles.
2. Describe arterial blood pressure (physiological variations, factors determine ABP, renin angiotensin system).
3. Know the arterial blood pressure control mechanisms (rapidly acting, intermediate, and long-term mechanisms.
4. Describe different types, mechanism and pathophysiology of hypertension.

Definitions:

- Arterial Blood Pressure (ABP): It is the pressure of blood on arterial wall
- Systolic Blood Pressure (SBP): - It is the maximum pressure reached during systole
  - Normally it equals: 120 mmHg (90 -150)
- Diastolic Blood Pressure (DBP): - It Is the minimum pressure reached during diastole
  - Normally it equals: 70 mmHg (60 - 90)
- Pulse pressure: - = Systolic pressure - diastolic pressure
  - Normally it equals = 50 mmHg
- Mean systemic arterial pressure (MAP) : It is the average pressure in arteries throughout the cardiac cycle

  MAP = DBP + ⅓ Pulse pressure

  = 70 + ½× 50= 90 mmHg.



- **Changes in ABP with age:**

  ① SBP systolic

  ② DBP diastolic

  ③ MAP and mean arterial

pressures

Measurement: 2 methods:

❶ Direct : By cardiac catheter (invasive method)

❷ Indirect : By sphygmomanometer (noninvasive method)

Physiological Variations in ABP:

1- <u>Age:</u> ABP increases with age due to loss of elasticity

- New born = 80/40
- 4 years = 100/65
- 20 years = 120/70
- 60 years = 150/90

2- <u>Sex:</u>

- Below 45 y female have less ABP than male
- Above 45 y the pressure increases in female due to hormonal changes

3- <u>Race:</u> Europeans+ Americans > Orientals due to: stress & high cholesterol in diet

4- <u>Emotions:</u> Sympathetic →Increase ABP especially SP

5- <u>Exercise:</u> → Increase SP +decrease DP

6- <u>Gravity:</u>

- each 1 cm below heart increases ABP by 0.77 mmHg
- Each 1 cm above the heart decreases ABP by 0.77 mmHg

7- <u>Respiration:</u> Traube-Herring waves are fluctuations of ABP during respiration:

- At start of resp.: Decrease ABP, as inspiration → VD (via vagus)
- The highest increase in ABP at late inspiration + early expiration

Factors which determine normal ABP (ABP = Co **×** TPR)

❶ Cardiac output COP= SV × HR

- Stroke volume: If HR is kept *constant*
  - Increase SV will increase systolic pressure
  - Decrease SV will decrease systolic pressure
- Heart rate: If SV is kept *constant*
  - Increase HR will increase diastolic pressure

- Decrease HR will decrease diastolic pressure

❷ **Elasticity** - Elastic fiber of aorta act as buffer to prevent excessive rise in systolic pressure and excessive drop in diastolic pressure

❸ **Volume of blood in relation to capacity of circulation**

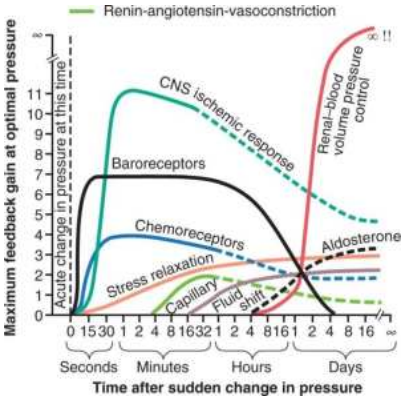
- If capacity is kept *constant*: - Increase volume of blood lead to increase ABP
  - Decrease volume of blood lead to decrease ABP
- If volume is kept *constant*: - Increase capacity (V.D) lead to decrease ABP
  - Decrease capacity (V.C) lead to increase ABP

❹ **Total peripheral resistance**

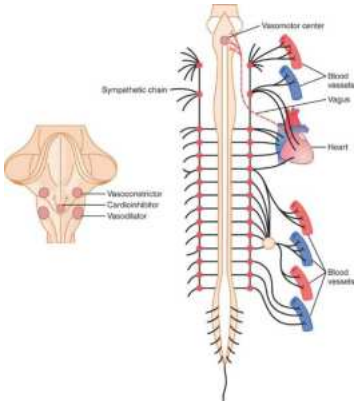
- TPR depend on diameter of arterioles and viscosity of blood
- Diameter of arterioles - VC lead to increase TPR & ABP
  - VD lead to decrease TPR & ABP
- Viscosity of blood - Increase viscosity lead to increase TPR & ABP
  - Decrease viscosity lead to decrease TPR & ABP

Regulation of Arterial Blood Pressure:

Regulated by 3 mechanisms: 1- Rapid : Nervous mechanism
2- Intermediate : Capillary fluid shift mechanism
3- Slow : Hormonal & renal mechanisms



Approximate potency of various arterial pressure control mechanisms at different time intervals after onset of a disturbance to the arterial pressure. Note especially the infinite gain (∞) of the renal body fluid pressure control mechanism that occurs



Anatomy of sympathetic nervous control of the circulation.
Also shown by the dashed red line, a vagus nerve that carries parasympathetic signals to the heart

after a few weeks time

Regulation of Arterial Blood Pressure

❶Nervous Mechanism: *Rapid Mechanism*

Cardiovascular centers are present in medulla: 2 areas:

	❶ Pressor Area (PA)	❷ Depressor Area (DA)
Site	- Lateral reticular formation	- Central + dorsal to PA
Formed of	2 Centers: 1. Cardiac Stimulatory Center (CSC) 2. Vasoconstrictor Center (VCC)	2 Centers: 1. Cardiac Inhibitory Center(CIC) 2. Vasodilator Center (VDC)

CSC	VCC	CIC	VDC
- Its discharge reaches heart via sympathetic:	- It has a continuous tone under resting conditions known as Vasoconstrictor tone.	- Its discharge reaches heart via vagus	- It inhibits the VCC

- Increase atrial properties → increase heart rate → ↑	- Increase ventricular properties → Increase SV → increa	- VC of arterioles → increase TPR → increase ABP	- VC of veins → increase VR → increase CO → increa	- Decrease atrial properties →decrease heart rate →decr	- No effect on ventricles

CO ↑ ABP	se CO → increa se ABP		se ABP	ease CO → decrea se ABP	

NB: There is reciprocal innervations between PA & DA (ie a stimulus which stimulate PA will inhibit DA)

NB: ABP = CO × R So increase CO or increase R lead to increase ABP

The activity of these centers is modified by afferents from:

① Receptors inside CVS

❶ Arterial Baroreceptors

Type: - Mechanoreceptors: - Present in adventitia
- Respond to stretch of the wall.

Site: 1- Aortic Arch
2- Carotid sinus

Nervous connection: - Both aortic arch nerve and carotid sinus nerve are buffer nerves: 1- Aortic Arch: → 10th cranial nerve
2- Carotid sinus: → 9th cranial nerve

Stimuli: ABP between 60-180 mmHg.
- Between 60- 180, the more the pressure, the more the impulses coming out.
- Maximal rate of discharge occurs at 180 mmHg.
- Above 180, no more increase in discharge

Adaptation: - Non adapting receptors as they receive very important data.

Function: - They send inhibitory impulses to (PA)

- If ABP decreases as in hemorrhage → decrease in inhibitory Impulses to presser area (PA) → PA is released from inhibition → PA raises ABP (discuss).

NB: Carotid Sinus Syndrome:

Very sensitive carotid sinus reflex, in some people, carotid sinus baroreceptors respond to mild pressure (eg shaving, collar, turning head) & causing marked decrease in ABP, cerebral ischemic & subsequently fainting

❷ Atrial volume receptors

Type: Stretch receptors

Site: Wall of both atria (near opening of big veins)

Nervous connection: 10th nerve

Stimuli: Increase CVP (central venous pressure) as a result of:

a- Increased blood volume

b- Increased venous return (VR)

Function: (Response)

A. **If CVP increased:**→VD → decrease ABP

B. **If CVP decreased**: →

1- Increase sympathetic activity → ++ PA→ ++ ABP

2- Increase renin → increase aldosterone [Salt & water retention (increase blood volume ↑ VR ↑ CO ↑ ABP)]

3- Increase Vasopressin → water retention (increase blood volume ↑ VR ↑ CO ↑ ABP)

❸ Peripheral Chemoreceptors

Type: Beside their main role in respiration, it also regulates ABP

Site: 1- Aortic bodies: At aortic arch

2- Carotid bodies: At carotid bifurcation

Nervous connection: Buffer nerves: 1- Aortic bodies: → Branch of 10th nerve

2- Carotid bodies: → Branch of 9th nerve

Stimuli: 1- Low O_2 tension

2- Increased CO_2 tension

3- Increased H^+

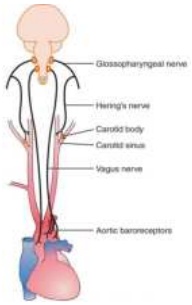
4- Hypotension (40 - 60 mmHg) due to hemorrhage:

This drop in ABP causes stagnant hypoxia of chemoreceptors which leads to their stimulation

Response: - Stimulate PA → VC & Increase CO & ↑ ABP

❹ **Left Ventricular Receptors**

- Considerable ventricular distension: Stimulates mechanoreceptors in the wall → decrease HR →decrease ABP
- In myocardial infarction (MI): The infracted muscle fibers release chemical substances which stimulate mechanoreceptors decrease HR & ABP



The baroreceptor system for controlling arterial pressure

❺ **Pulmonary Receptors**

- Distension of pulmonary vessels - decrease HR & ABP

② Receptors outside CVS

1- **Cutaneous pain:** Increase HR → increase ABP due to adrenaline secretion

2- **Visceral pain:** Decrease HR decrease ABP & may be shock

3- **Alam-Smirk Reflex:** Muscle exercise → stimulation of **proprioceptors** → increase HR → increase ABP

③ Effect of Higher Centers

1- **Cerebral Cortex:** Before the beginning of exercise, it send impulses to reach medullary CVS centers through hypothalamus → increase HR & ABP.

2- **Hypothalamus:** Emotions+ exercise → stimulate PA & inhibit DA → increase HR & ABP

④ Effect of Changes in Blood Gases

1- **Indirect mechanism:** Role of chemoreceptors on CVS (as before).

2- **Direct mechanism:** ie direct action on PA & DA.

Mild decrease O_2 & increase CO_2→ increase ABP.

Severe decrease O_2 & increase CO_2 → decrease ABP & death.

❷ **Capillary Fluid Shift Mechanism** *Intermediate Mechanism*

1- **If blood volume is increase** →increase ABP → increase capillary hydrostatic pressure → increase filtration of fluid from plasma to the tissue fluid → decrease plasma volume → decrease VR → decrease ABP

2- **If blood volume is Decrease** → decrease ABP → decrease capillary hydrostatic pressure → decrease filtration of fluid at arteriolar end of capillaries → increase reabsorption at venular end → increase plasma volume → increase VR → increase ABP.

ie Tissue fluid acts as a reservoir for plasma

❸ **Role of Kidney = Hormonal Regulation of ABP** *Slow Mechanism*

1- Kidney regulates ABP by regulating plasma volume (and ECF "Extra Cellular Fluid" volume)

2- It is the most important mechanism for ABP regulation

3- If ABP decreases → It is increased by 2 mechanisms:

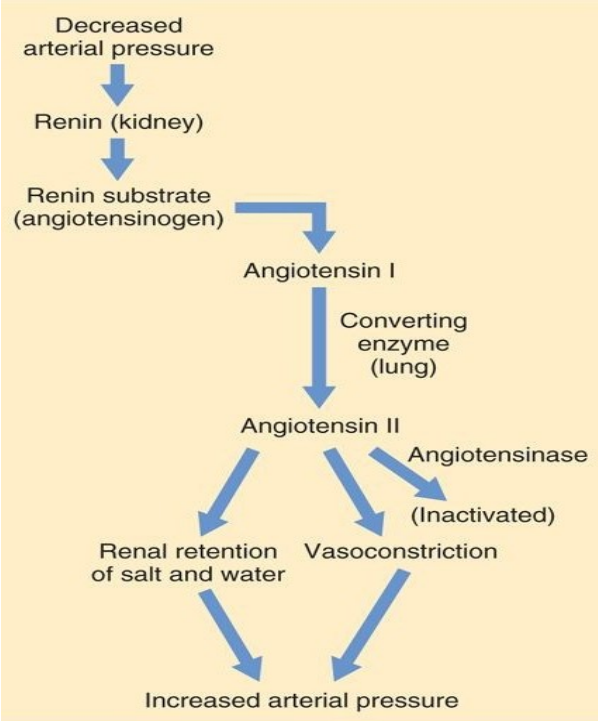
① **Atrial Mechanoreceptor**

Decrease ABP → decrease blood volume → decrease CVP → decrease discharge from atrial receptors → increase secretion of aldosterone & ADH → **increase salt & H_2O Retention** → increase ECF volume → increase VR → increase ventricular filling → increase CO → increase ABP.

② **Renin-Angiotensin system**

- Decrease ABP → **renal ischemia** → renin release. ……. discuss

- NB: Increase ABP will cause increase excretion of salt & H_2O



Renin-angiotensin vasoconstrictor mechanism for arterial pressure control

Shock& Heamrrhage

1. Describe hemorrhage and the compensatory reactions during haemorrhage (Immediate compensation, medium, long-term compensation).
2. Describe circulatory shock (definition, classifications, mechanisms, and stages), types, mechanism, and stages of shock.

- **Definition:** Tissue hypo perfusion as a result of relative or absolute inadequate cardiac output.
- **Types & Causes**:

1- **Hypovolemic shock**: Caused by:

- Blood loss (Hemorrhage) → Hemorrhagic shock
- Plasma loss: as in burns
- Fluid loss: as in excessive diarrhea

2- **Distributive** (Vasogenic or low resistance shock)

❶ Anaphylactic shock Widespread antigen-antibody reaction

❷ Septic shock: Bacterial toxins produce VD

❸ Neurogenic shock: pain produces sudden autonomic activity → VD & fainting

3- **Cardiogenic shock** (heart disease → decrease CO)

- Myocardial Infarction (MI)
- Arrhythmias

4- **Obstructive shock:** Obstruction of blood flow: eg

- Tension pneumothorax (PTx)
- Pulmonary embolism (PE)
- Cardiac tamponade

Hemorrhagic shock:

- It is the major form of hypovolemic shock

- Manifestations: ❶ Drop of ABP (hypotension)

❷ Increase HR (rapid weak pulse)

❸ Increase respiratory rate

❹ Low skin temperature (cold & pale skin)

❺ Thirst

❻ Oliguria

❼ Acidosis (in severe cases lactate level increases from 1 to 9 mmol which depresses the myocardium)

❽ Restlessness (due to stimulation of reticular formation)

- Compensatory Reactions:

❶ Rapid compensatory reactions

- Aim: They are protective to maintain ABP for adequate perfusion of heart & brain
- Mechanisms: include 2 types:

① Nervous factors

There is: 1- Stimulation of PA (presser area)

2- Inhibition of DA (depressor area)

Due to the following causes:

Causes: 1- Decrease inhibitory impulses from **arterial baroreceptors**

If ABP < 60 → arterial baroreceptors are not working. The pressure is maintained by chemoreceptors

2-Decrease Inhibitory impulses from atrial volume receptors

Decrease **atrial** discharge results also in increase release of ADH & aldosterone → salt & H_2O retention → increase blood volume

3- Increase excitatory impulses from **peripheral chemoreceptors**

Peripheral chemoreceptor stimulation: Results also in stimulation of respiration during shock

Results: 1- VC of arterioles →increase TPR →increase ABP

NB:	- VC of all arterioles except brain & heart - VC is marked in skin → pallor + cold skin - VC of viscera & kidney [if prolonged → renal failure]

2- VC of veins →increase VR → increase CO → increase ABP

3- Increase HR→ increase CO → increase ABP

4- Increase SV → increase CO → increase ABP

② Humoral factors

Release of:

① Catecholamine From adrenal medulla
1. VC: Little VC → Increase TPR → increase ABP
2. Stimulate reticular formation → restlessness

② Angiotensin II	
1- VC	2- salt and water retention
3- It also causes thirst	

③ Vasopressin (ADH "Antidiuretic Hormone")
1. VC effect
2. Antidiuretic effect (decrease H_2O in urine)

❷ Long term Compensatory Reactions

Aim: They are restorative

① Correction of plasma volume

In 12 - 72 hours by:

❶ Tissue fluid shift:

Decrease ABP → Decrease Hydrostatic Pressure of capillary → Increase

fluid absorption into capillaries

→Increase volume of plasma → most of the retained fluid is protein free causing dilution of blood

❷ **Thirst sensation:** Due to: 1. Increased osmotic pressure
2. Decreased tissue fluid

❸ **Aldosterone secretion:**

Is increased due to decrease atrial volume receptors discharge

NB: Hematocrit drops: For hours because tissue fluid absorbed into capillaries is protein free & dilute plasma proteins & blood cells

② **Correction of plasma proteins**

In 3 - 4 days:

❶ Rapid release of stored albumin from liver into circulation

❷ Hepatic synthesis replaces the loss in 3-4 days

③ **Correction of red cell mass**

In 4 - 8 weeks:

❶ Erythropoietin

❷ 2, 3 DPG increases & shift to Rt of oxygen dissociation curve

❸ Squeezing of stored blood by contraction of splenic capsule

**** Outcome of shock state:**

- According to amount of blood loss & how fast we treat the patient:

1- If blood loss < 20%: Recovery by compensatory mechanisms & treatment

2- If blood loss > 20%: - Compensatory mechanisms are not sufficient, rapid blood transfusion should be done

3- Irreversible shock: Progressive with no response to treatment, decrease CO "Cardiac Output" & death

Treatment: 1. Removal of the cause

2. Restoration of blood volume:
   - In hemorrhagic shock: Blood transfusion
   - In burn shock: Plasma expanders
3. Drugs: - Epinephrine (Adrenalin)

- Norepinephrine (Nor Adrenalin)
- Glucocorticoids
- Sedatives

4. Supine position

Refractory shock (Irreversible shock)	
Definition	Shock becomes resistant to treatment [cardiac output remains low even if blood volume is normal or above normal]
Mechanisms	1. Spasm of precapillary sphincters & venules (especially in the splanchnic region) 2. Sever cerebral ischemia 3. Sever cardiac ischemia

microcirculation and the venous system

1. Describe capillary blood flow and pressure and factors affecting/regulating them, capillary fragility, pulsation.
2. Illustrate how the water moves across the capillary wall.
3. demonstrate the mechanisms of pulmonary and systemic oedema.
4. Define venous pressure, factors that influence it.

Introduction:
- Capillaries contain 5% of blood
- They are exchange vessels
- They are 10 billion capillaries
- Diameter 10 um
- Length 700 um
- Surface area 100 m^2
- Capillary wall is formed of: Single layer of endothelium resting on a thin basement membrane with pores (fenestrations 80-90 A) in diameter.

Capillary blood flow is intermittent:

Due to vasomotor intermittent contraction of arterioles and precapillary sphincter 6 -12 times/min

NB: If all capillaries are opened at one time (as in burns), CVS capacity will exceed blood volume causing marked decrease in ABP ie circulatory shock

Velocity of Blood flow in capillaries: Velocity = 0.5 mm/sec [as the total cross sectional area of capillaries= 5000 cm^2 (enough time for exchange)]

Capillary Fragility:

Laplace law: $T = P \times r$

T: Tension

P: Pressure

r: Radius

- According to Laplace law:
  - Capillaries can withstand a pressure of 100 mmHg (although their walls are very thin)

- As they have very small diameter
- So tension is not markedly increased

Causes of capillary fragility

a- Capillary wall defect: 1. Vitamin C deficiency

Clinical Application
Scurvy (↓ vit. C) bleeding as results in bleeding gums

2. Senility
3. Allergy
4. Toxins

b- Blood diseases: Thrombocytopenic purpura

Capillary reactions to mechanical influences:

a- White line: Gentle stroking of skin by a blunt object → white line for few minutes, caused by VC of capillaries

b- Triple Response: Firm stroking of skin →

1. Red line: At site of injury due to capillary VD by histamine
2. Spreading flare: Around red line due to arteriolar VD by Antidromic response
3. Local edema (wheal): Due to increase capillary permeability due to the dilatation. It occurs due to inflammation + insect bites

Equilibrium with interstitial fluid:

Exchange of materials across capillary wall occurs through: 2 Mechanisms:

1- Diffusion:
- Quantitatively, it is more important than Filtration
- It is passive
- Occurs in both directions
- It is concerned with H_2O & dissolved substances
- **Factors affecting diffusion:** Diffusion Rate (DR)

① **Factors in substance:**	②**Factors in capillary permeability:**
1- **Concentration Gradient**: DR	1- **Liver capillaries**, large

α Conc. gradient. 2- **Solubility**: 1. H_2O sol + lipid insoluble → diffuse through the pores 2. Lipid sol, diffuse through pores & cell membrane 3- **Molecular Weight**: 1. MW < 5000 → Easy diffusion eg H_2O, NaCl, glucose 2. MW > 5000 → progressive difficult. However, albumin (70,000) diffuse easy (cigar shape)	fenestration, faint interrupted basement membrane → high permeability. Tissue fluid contains > 4% protein 2- **Muscle, skin & heart, lung capillary**: No fenestration + well developed basement membrane → low permeability. Tissue fluid <1% 3- **Kidney intestine capillaries** are thin fenestrated wall + continuous faint basement membrane → moderate permeability

NB: Capillary permeability increases by histamine

2- Filtration
- Bulk flow across capillary wall
- It is a passive process
- It is the Bulk transport of H_2O, electrolytes & crystalloid

- **Factors affecting filtration:**

❶ Mean forces tending to move fluid outwards:

1- Hydrostatic capillary Pressure = 35 mmHg at arteriolar end, 15 mmHg at venular end.

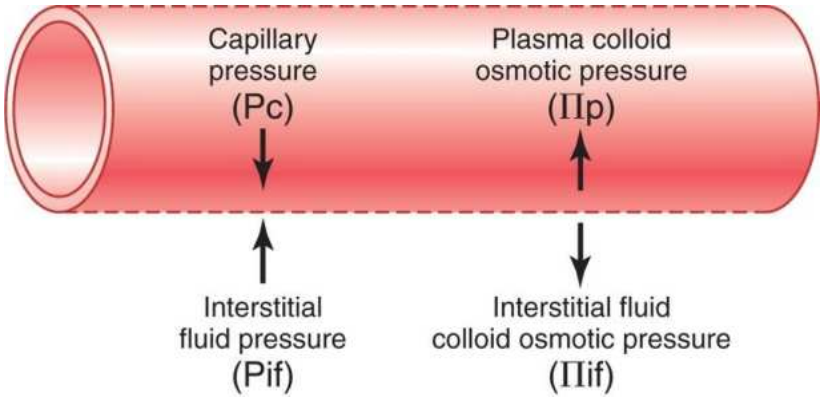
2- Interstitial fluid Colloidal OP = 3 mmHg (caused by 1% albumin)

❷ Mean forces tending to move fluid Inwards:

1- Colloidal OP of plasma protein = 25 mmHg (mainly albumin)

2- Hydrostatic pressure of interstitial fluid = 3 mmHg

Summation of mean forces:



Fluid pressure and colloid osmotic pressure forces operate at the capillary membrane. tending to move fluid either outward or inward through the membrane pores

❶ At arteriolar end = 10 mmHg outwards → filtration of fluid from blood to tissues as a bulk

❷ At venular end = 10 mmHg inwards → Reabsorption of a nearly equal amount of fluid into blood (yet, it is smaller, the remaining is taken by lymphatics)

Variation in bulk flow:

1- Decreases Colloidal OP of plasma protein: as in liver & kidney diseases → increases filtration

2- Increase capillary hydrostatic pressure as in venous obstruction → Increase filtration

3- Increase capillary permeability eg activity, inflammation → albumin goes out → Increase filtration

Edema

Definition: Is excessive accumulation of interstitial fluid in abnormal large amount

Cause:

1- Increase Capillary Hydrostatic Pressure: Which is the filtration pressure

- Filtration pressure: Is pressure tend to move fluid outward capillary
- So increase in capillary hydrostatic pressure causes edema
- Causes:
  1. Right side HF or congestive heart failure.
  2. Obstruction of vein by thrombus (DVT "Deep Venous Thrombosis") or tumor.
  3. Incompetent valves of vein as in varicose vein.
  4. Compression on veins (as in pregnancy).
  5. Portal hypertension (PHT).

2- Salt & water retention

- Increase salt and water retention causing edema
- Causes of Increase salt & water retention:
  1. Increase aldosterone
  2. Increase ADH

3- Decrease Plasma Osmotic Pressure:

- Osmotic pressure of plasma protein is force which returns fluid back to circulation capillary
- So decrease in plasma osmotic pressure will causes edema
- Causes:
  1. Liver disease: decrease hepatic synthesis of plasma proteins esp. albumen
  2. Kidney disease: Increase loss of plasma protein in urine

4- Increase of capillary permeability:

- Increase capillary permeability causing edema
- Increase capillary permeability occur in:
  1. Allergic conditions
  2. Inflammatory conditions
- By:
  1. Kinins
  2. Histamine substance

5- Lymphatic Obstruction:

- Lymphatic vessel play important role in absorption of excess fluid so obstruction of lymphatic lead to increase edema.
- Obstruction of Lymphatic vessel occur in: 1. Filariasis
  2. Tumor compress on lymphatics.

Venous Circulation& venous pressure

Central Venous Pressure (CVP):

- Definition: It is the pressure in right atrium & veins opening into it

- Value: 0 - 2 mmHg (yet, it fluctuates with respiration and cardiac cycle)

- Measurement: 1. Invasive: Direct through insertion of a central venous line (catheter) into IJV or subclavian vein

2. Non-invasive: Clinically: It is measured by observing the degree of filling of external jugular vein while the patient is in a semi sitting position

Normal: It does not fill above level of angle of Luis

- Importance: 1. It is an index of blood volume

2. It is the cardiac filling pressure.

- Variation: 1. CVP decreases in: Hemorrhage

2. CVP increases in: Heart failure

Functions of Veins:

❶ Transport Vessels: Offering little resistance to blood flow, as there is a slight drop of pressure across veins (10 mmHg). Thus, veins allow rapid return of blood to heart with minimal energy

- The velocity of blood flow in great veins is ¼th that in aorta (slower than arteries but faster than venules +capillaries)

❷ Capacitance vessels (blood reservoir):

$$\text{Capacity is a ratio} = \frac{\text{Change in volume}}{\text{Change in Pressure}}$$

$$\text{ie } \boxed{C = \frac{\Delta V}{\Delta P}}$$

- Veins have large capacity (ie contain a large volume of blood under low

pressure)

- Capacity of venous system = 200 ml/mmHg
- Arterial system capacity = 1 ml/ mmHg
- During exercise, a small volume of blood is shifted from venous to arterial system resulting in: 1)Marked rise in ABP (small capacity)
  2)Minimal change in CVP (large capacity) which is the cardiac filling pressure ie cardiac filling is unaffected

Venous return

- Definition:

- It is blood flow that return to the heart in minute
- It is normally = cardiac output = 5L/min

- Venous return is:

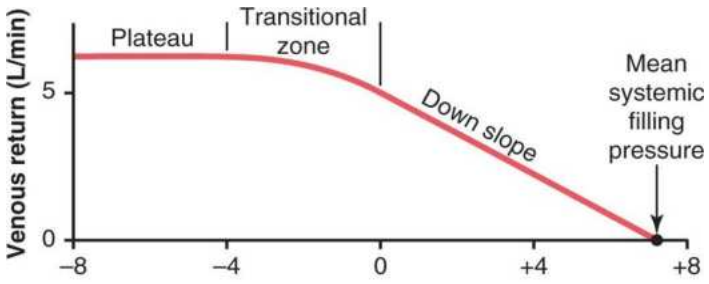
❶ **Directly proportional to** pressure gradient between MSFP & RAP

NB:
- MSFP: "Mean Systemic Filling Pressure"
  - Def. : It is pressure in circulation if pumping action of heart stop
  - It equal 6-8 mmHg.
- RAP: "Right Atrial Pressure"
  - Def. : It is pressure in right atrium
  - It equal 0-2 mmHg

❷ **Inversely proportional to** resistance in venous system

NB: Resistance: In venous system can be calculated by:

R= Δ P/F = **MSFP-RAP/CO** = 7-0/5 = **1.4 mmHg /liter/ min**



RAP (Right Atrial Pressure)

Normal venous return curve. The plateau is caused by collapse of the large veins entering the chest when the RAP (Right Atrial Pressure) falls below atmospheric pressure. Note also that venous return becomes zero when the RAP rises to equal the MSFP (Mean Systemic Filling Pressure)

- Factors help venous return against gravity:

1- **Contraction of voluntary muscle**:

As calf muscle (the peripheral heart) when muscle contract they will press on near vein pushing the blood toward the heart & the valve in veins prevent blood from return

Clinical Application
Prolonged recumbence causing sluggish circulation in LL which predispose to DVT

2- **Pressure gradient between MSFP & RAP**:

- The higher the pressure gradient the higher the VR
- The lower the pressure gradient the lower the VR

3- **Arterial pulsation**: Press on nearby vein, helping VR

4- **Diameter of arterioles**: Vasoconstriction increase VR

5- **Tone of veins**: - VD of veins decrease VR
- VC of veins increase VR

6- **Tone of capillaries**:
- VD of capillaries wills ↓ VR
- VC of capillaries will ↑ VR

7- **Thoracic pump**:

- During inspiration: IPP became more negative lead to increase VR
- During expiration: IPP become less negative lead to decrease VR

8- **Cardiac suction**:

1. Systolic suction: Occur during: Maximum ejection in which blood ejected from ventricle to aorta
2. Diastolic suction: Occur during: Rapid filling phase in which blood pass passively from atria to ventricle

9- **Contraction of spleen**: Lead to increase blood volume & VR

10- Gravity: - Above the level of heart: Gravity helps VR
- Below the level of heart: Gravity interferes with VR

-Effect of Gravity on Venous system:

1- **Orthostatic Hypotension**:

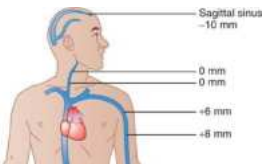
- During orthostatic (ie changing the position from lying down to erect)
- If significant amount of blood shifts from thoracic veins to lower limb veins → decrease CVP, decrease cardiac filling → decrease CO → decrease ABP (ie orthostatic hypotension)
- Person feels dizzy
- In normal person: Compensatory mechanisms occur rapidly to correct this hypotension

2- **Hydrostatic Indifferent Point [HIP]**:

- During orthostatic: The pressure in veins: Increase in lower limb, decrease in thorax
- There must be a transitional zone in which the venous pressure remains constant independent on body posture
- This zone is called HIP
- It lies 5 - 7 cm below diaphragm
- The pressure at HIP = 10 - 11mmHg
- HIP position is related to capacity of thoracic & lower limb veins.
- If the body is immersed in H_2O (swimming), the LL (Lower Limbs) veins capacity is decreased → shift of HIP upwards, lying almost at the level of the heart → So the CVP does not vary on changing position → Orthostatic hypotension not occur on swimming.

3- **The pressure in different veins**:

- **During orthostatic**: prolonged standing



The pressure in leg veins increases from 20 to 80 mmHg, thus on this high venous pressure results in:

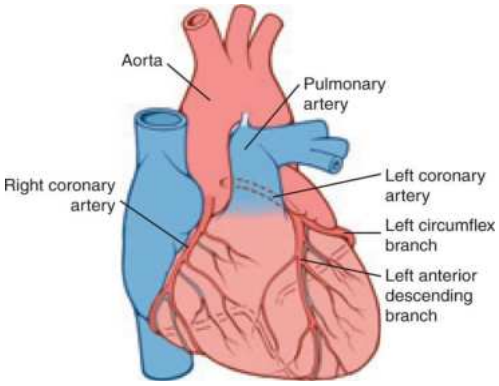
❶ Varicose veins (ie dilatation & elongation on LL veins)

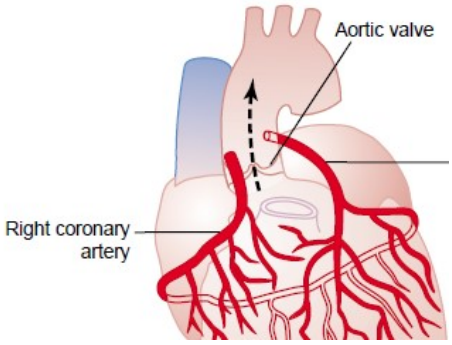
❷ Edema: Due to increase filtration

The Coronary Circulations and vascular smooth muscle excitation-contraction coupling

1. Describe coronary blood flow and factors affecting it.
2. Illustrate vascular smooth muscle excitation-contraction coupling, define constricting mechanisms and vasodilator mechanisms.
3. Describe ischemic heart disease (character of pain, mechanism of pain, ECG changes).

Anatomical considerations:





The coronary arteries

Coronary arteries:
- (Rt & Lt) arise from coronary sinuses above aortic valve
- Lt Coronary artery: Supplies anterior + lateral parts of left ventricle
- Rt Coronary Artery "RCA": Supplies right ventricle and posterior part of left ventricle

Venous Drainage:
- Of left ventricle: Drains into Rt atrium [through coronary sinus] (75% of coronary blood)
- Of right ventricle: Drains directly into Rt atrium [through small anterior cardiac veins]

Coronary capillaries:
- One capillary for each cardiac muscle fiber
- On ventricular hypertrophy capillary number does not increase → myocardial ischemia → ischemic

cardiomyopathy → heart failure later on

Functional consideration:

- At rest: heart extracts 70 - 80 % of O2 in coronary blood, so, to satisfy increased cardiac demands the only way is to increase coronary blood flow
- Many anastomoses exist among small arteries, of great value in obstruction of one coronary artery

Coronary Artery Diseases (CAD) "IHD":

❶ **Decrease coronary blood flow** → Hypoxia → Angina pectoris

❷ **Complete Cessation or Severe decrease coronary blood flow**

→

Myocardial infarction (MI)

- Causes of death in myocardial infarction:
  1. Decrease cardiac output → shock
  2. Acute Pulmonary edema
  3. Arrhythmia: Ventricular fibrillation
  4. Rupture of infarcted area

Assessment of coronary blood flow:

1- Fick 's principle:

- Using N_2O (Key method) 15%
- For 10 minutes
- Arterial sample is taken from any artery
- Venous sample is taken from coronary sinus
- Serial samples are taken

$$\text{Coronary blood flow} = \frac{N_2O \text{ taken by the heart/min}}{\text{(A-V) coronary } N_2O \text{ difference}}$$

= 80 ml/100 gram heart tissue/min at rest

= 600 ml/100 gram heart tissue/min at exercise.

2- MPI "Myocardial Perfusion Imaging"

① Thallium: Detects areas of ischemia which will have low uptake

② Technetium: Detects areas of ischemia which will have much more uptake

3- Coronary Angiography: ① Convention by: Cardiac catheter angiography

② By MSCT " Multi slice computerized tomography "

Shows the distribution of coronary artery

Regulation of Coronary blood flow:

1- Auto regulation: Intrinsic mechanism

- Increase Cardiac work as in → coronary VD

Hypoxia, increase CO_2, Increase H^+, K^+, lactate, prostaglandin and adenosine

- Hypoxia is the most important VD by 2 ways:
  1. Direct effect on coronary vessels
  2. Release of VD substances, mostly Adenosine

2- Mechanical Regulation:

- Variation in coronary blood flow during cardiac cycle
- Left coronary artery is much more affected than Rt one by systole and diastole due to stronger Lt ventricular contraction

1- **During Systole**: Decrease coronary blood flow

a- Isometric contraction phase: Minimal coronary flow

b- Maximal ejection phase: Relative increase due to Increase aortic pressure.

c- Reduced ejection phase: Relative decrease due to decrease aortic pressure

2- **During Diastole**: Increase coronary blood flow

a- Isometric Relaxation phase: Maximal increase

b- Rest of diastole: Coronary flow decrease gradually due to decrease aortic pressure

NB: Coronary flow **decrease** in:

1- Paroxysmal tachycardia: Shortened diastole

2- Aortic Regurgitation: Due to decreased DBP

3- Aortic Stenosis: Due to decreased mean ABP

3- Neural factors: ❶ Sympathetic:

Coronary artery contains 2 types of receptors:

- α adrenergic receptors: Mediate VC
- β adrenergic receptors: Mediate VD
- However sympathetic stimulation →VD due to increase work

❷ Vagus (parasympathetic): Cause VC

Management of coronary heart disease:

1 Optimize life style: ① Diet: Low fat Diet

② Exercise: Regular dynamic exercise

2 Strict control of Diabetes Mellitus (DM) and Hypertension (HTN)

3 Medical: ① Nitrates: Venous dilatation: decrease VR → decreases myocardial O_2 demands

② In acute MI: Thrombolytic: *Lysis of the clot*: By drugs which increase fibrinolysis

eg: 1. Streptokinase (SK)

2. Tissue plasminogen activator (tPA)

4 Interventional: PCI: "Percutaneous Coronary Intervention": By a catheter

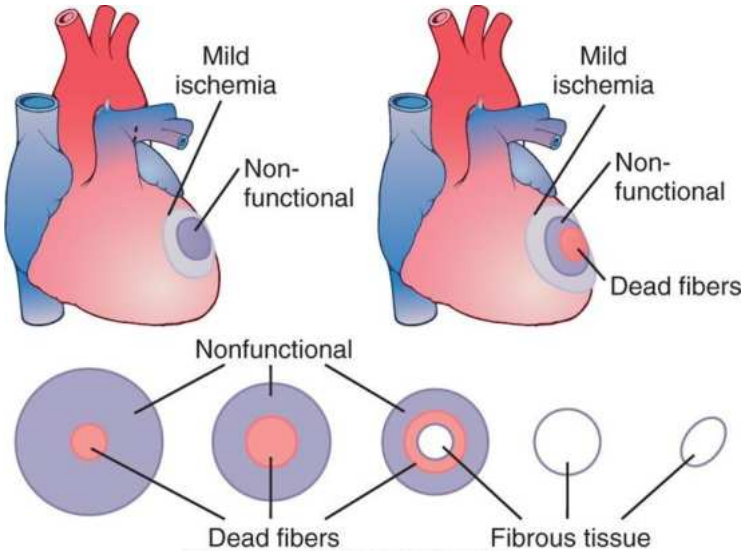
Angioplasty: Balloon dilatation followed by stent insertion

5 Surgical CABG: *"Coronary Artery Bypass Grafting"* **:**

Bypass operation: Bypass the obstruction by graft

Using eg: 1. Saphenous Vein Graft "SVG"

2. Internal Mammary Artery "IMA"



Top : Small and large areas of coronary ischemia

Bottom : Stages of recovery from myocardial infarction

Cardiovascular reflexes and cardiovascular effects of exercise

IIOs

1. Describe the Intrinsic and extrinsic reflexes, central and autonomic control of CVS.
2. Describe the effect of exercise and posture on CVS.

Exercise & CVS

- An adequate O2 supply is essential for performance of muscular exercise. The resting O2 consumption (=250 ml/min) may increase 20 times or more during exercise. The skeletal muscles at rest receive about 20% of the COP. This increases to 80-90% during exercise. The circulatory adjustments during exercise aim at increasing the muscular blood flow. This can be increased as result of both:
- Systemic circulatory changes.
- Local changes in active muscles.

A) Systemic circulatory changes:

1- Increase cardiac output:

Through an increase in both **stroke volume** and **heart rate** (reaches 180-200 beats/min).

A- **Causes of increased stroke volume during exercise:**

***1. Increased preload*:**

- Sympathetic activity venoconstriction increased venous pressure increasing venous return to the heart.
- Skeletal muscle pump.
- Increase depth and rate of respiration.
- Arteriolar dilatation at skeletal muscles increases the venous return from them.

2. Increased myocardial contractility:

- By positive inotropic effect of sympathetic stimulation and catecholamine release.
- By effect of increased preload (Frank-Starling law).

B- **Causes of increased heart rate during exercise:**

1. ***Sympathetic stimulation*** even before the start of the exercise by impulses from the cerebral cortex and hypothalamus stimulate CAC.
2. **Increase the venous return**: distension of right atrium increase the HR by Bainbridge reflex.
3. Hyperventilation during the exercise (Respiratory center inhibits the CIC).
4. Hypoxia, hypercapnia & acidosis stimulate chemoreceptors at aortic and carotid bodies

5. **Alam smirk reflex**: contraction of skeletal muscles leads to increase in heart rate through muscle proprioceptors.
6. Adrenaline secretion.
7. Increase body temperature.

2- Increase in the arterial blood pressure:

- ABP is directly proportionate with changes in COP (SV & HR) and changes in the peripheral resistance.

- Increase in SV increases the systolic blood pressure mainly while; HR and resistance mainly affect the diastolic blood pressure.
- During exercise, the SV increases leading to an increase in the systolic blood pressure but diastolic blood pressure changes according to the type of exercise.
- In exercises requiring isotonic contractions as playing football or swimming the arterioles at skeletal muscles dilate fall in peripheral resistance drop in diastolic BP and water hammer pulse results.
- In exercises requiring isometric contractions as weight lifting all the arterioles are constricted and compressed by the contracting muscles elevation in diastolic BP.
- In areas other than skeletal muscles, generalized vasoconstriction occurs specially in blood vessels supplying the GIT and skin so blood is redistributed to the active areas (skeletal muscles and the heart).

Causes of generalized vasoconstriction during exercise:

1. Hypoxia, hypercapnia & acidosis stimulate chemoreceptors at aortic and carotid bodies.
2. Sympathetic activity even before the start of exercise.
3. Emotions (fear or desire of winning).
4. Loven's reflex: increased activity of an organ leads to vasoconstriction everywhere and vasodilatation to the active organ.
5. Catecholamine secretion.

B) Local changes in active muscles

There is VD of the muscle arterioles: that increases the skeletal muscle blood flow.

Causes of VD of skeletal muscle blood vessels:

- Sympathetic stimulation even before the start of exercise.
- Accumulation of the vasodilator metabolites (K+ and adenosine).
- Local hypoxia (↓ O2), hypercapnia (↑CO2) and acidic metabolites as lactic acid (↑ H+).
- Excess heat liberated during exercise.

These effects also relax the precapillary sphincters that leads to more blood flow to the muscles and increase in the capillary pressure and widening of pores that leads to increase filtration of plasma carrying O2 and nutrients to the contracting muscles

Self-assessment Questions

1- What are factors affecting resistance?

2- What are types of blood flow?

3- Describe regulation of diameter of arterioles.

4- Enumerate vasoconstrictor substances and vasodilator substances.

5- Explain mechanisms of regulation of ABP.

6- What are factors determining normal ABP?

7- Define shock and mention its types.

8- Explain compensatory reactions to hemorrhagic shock.

9- Describe factors affecting filtration in capillaries.

10-Enumerate causes of Edema.

11-Describe factors help venous return against gravity.

12-What is the effect of gravity on venous system?

13-Compare between systemic circulation and pulmonary circulation.

14-**Describe regulation of coronary blood flow.**

List of Refrences

1-The Cardiovascular System at a Glance, ohn Wiley & Sons, Aug 31, 2012

2- Guyton and Hall Textbook of Medical Physiology, Elsevier Health Sciences, 2016

3- Cardiovascular Physiology Concepts, Lippincott Williams & Wilkins/Wolters Kluwer, 2012