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THE HEART: MECHANICAL ACTIVITY -THE CARDIAC CYCLE-

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Objectives

To understand:

- The relationships between Electrical, Mechanical and Pressure cycles of the Heart
- How pressure changes are generated
- How pressure changes open and close valves
- The heart sounds
- The Pressure volume loop

CARDIAC CYCLE

- This is the sequence of events from one heartbeat to the next.
- It’s frequency- heart rate.
- Duration- determined by HR (at 72bpm is 0.83s)
- Co-ordinated by electrical impulses that are produced by specialized cardiac cells.

CARDIAC CYCLES

- Three cycles

1. Electrical cycle – represented by ECG
2. Mechanical cycle
3. Volume and Pressure change cycle

MECHANICAL CYCLE

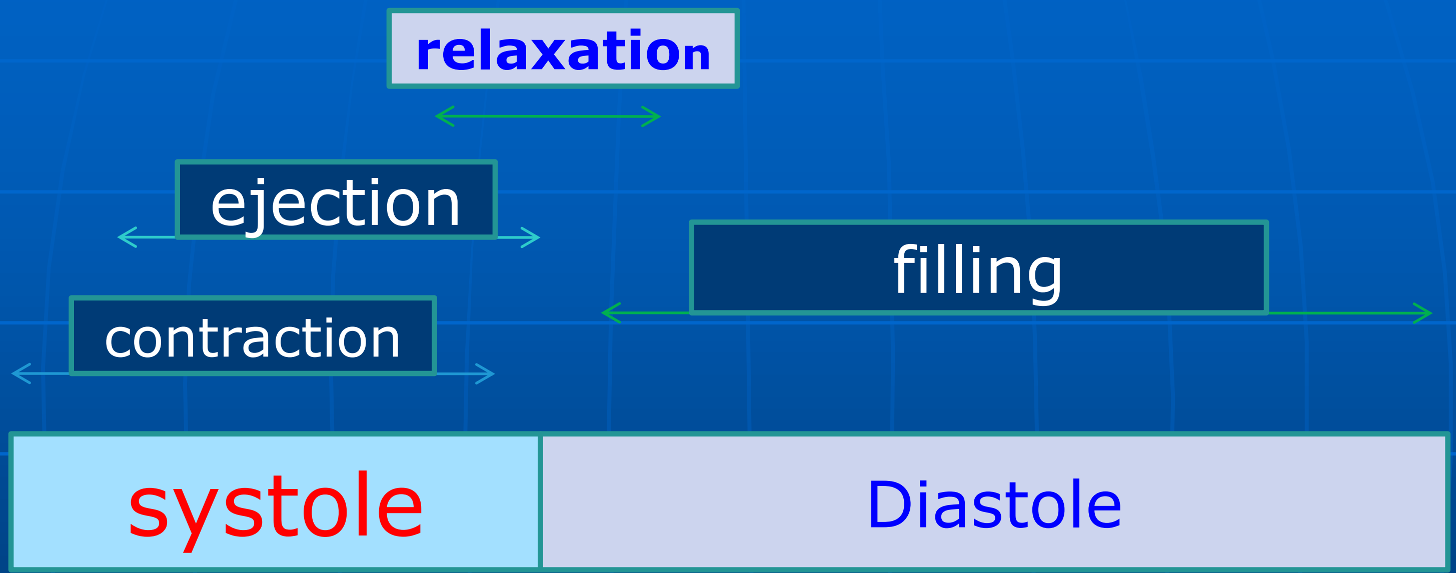
- This is the physical translation of the effects of the electrical activity of the heart.
- The impulse results in events that lead to actin-myosin interaction.
- There is Diastole (relaxation) and Systole (contraction)

VOLUME AND PRESSURE CHANGE CYCLE

- The volume of blood that enters a compartment (heart chamber or blood vessel) results in an increase in pressure in that compartment.
- The same events occur in the L and R sides but pressures are lower on the R.

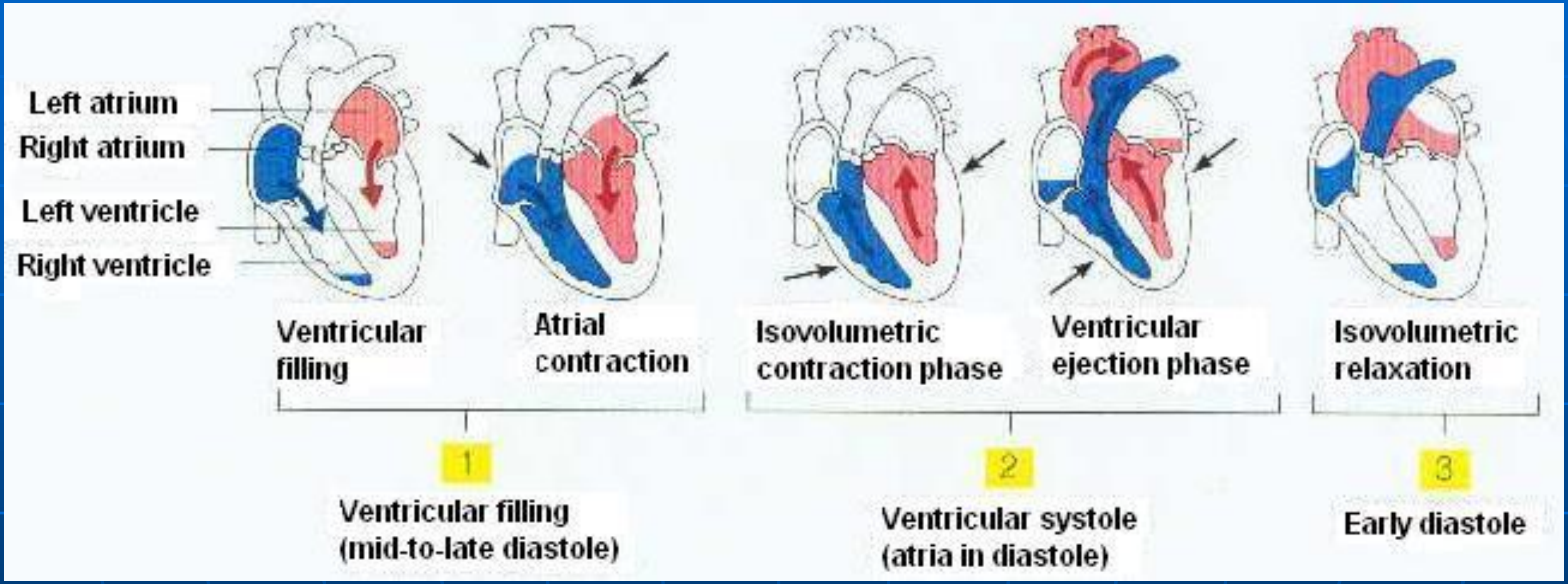
- Contraction of the myocardium generates pressure changes which result in movement of blood.
- Blood flows from an area of **high pressure** to an area of **low pressure**, unless flow is blocked by a valve.

Basic phases of cardiac cycle



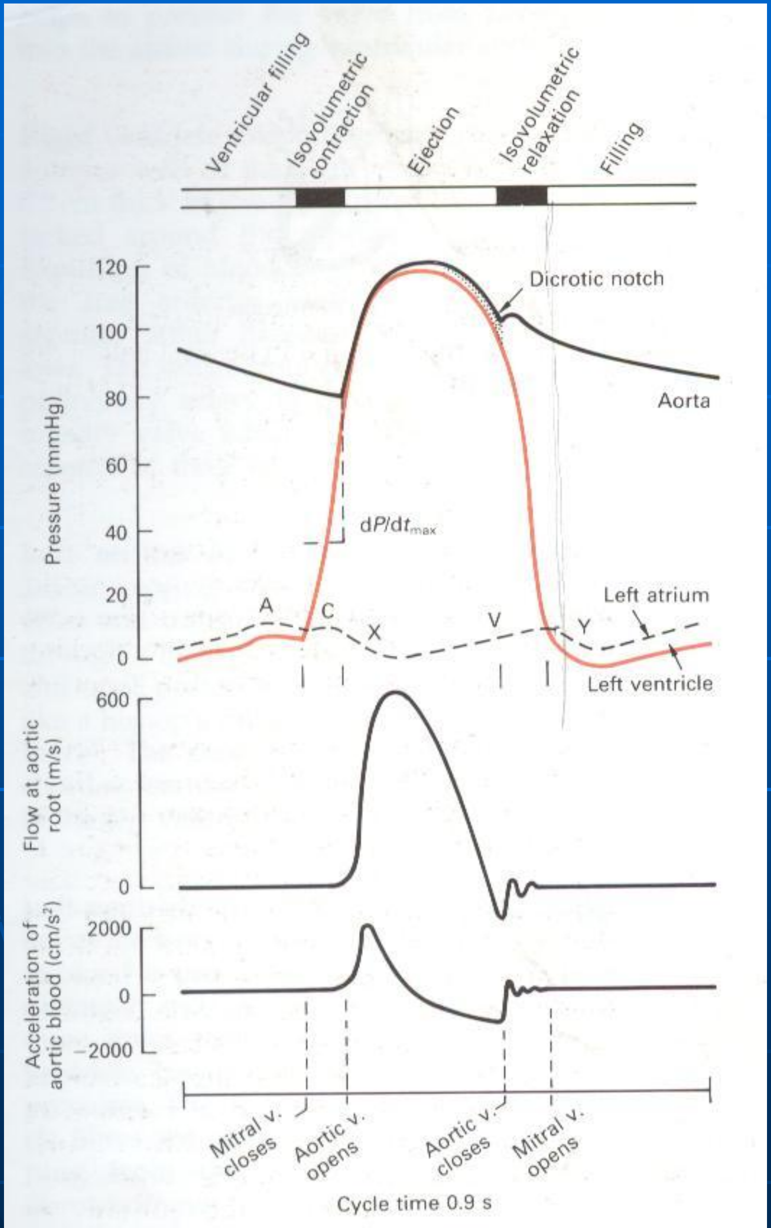
- Systole begins with contraction and ends when ejection ceases.
- Diastole begins when ejection ceases as ventricles relax and filling occurs

Events of the Cardiac Cycle



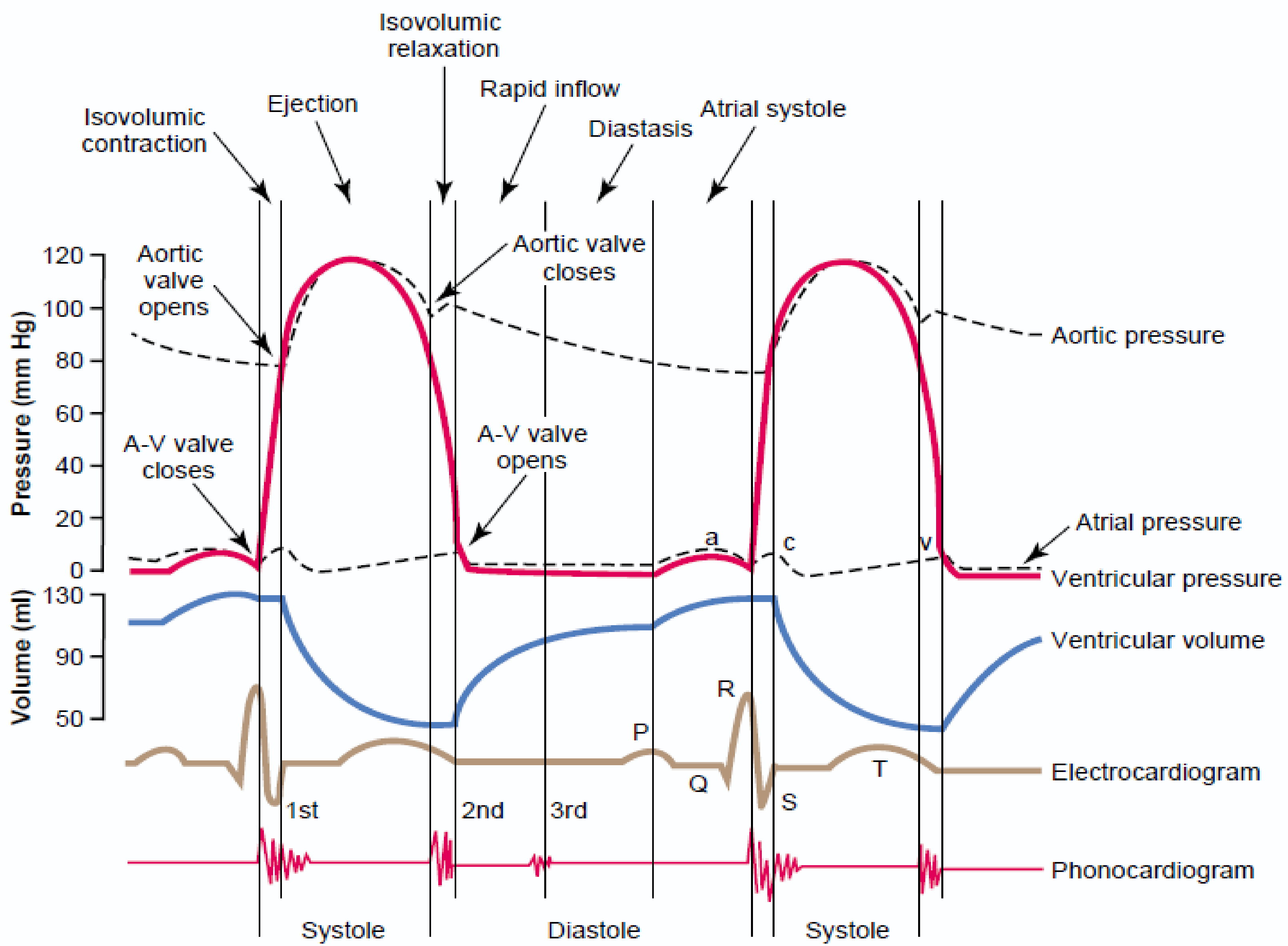
5 phases of the mechanical cycle

Pressure and outflow: left ventricle



- Ventricular Filling
  - Duration: 0.5 sec
  - Inlet valves (MV+TV) open (PV + AV) closed
- Isovolumetric contraction
  - Duration: 0.05 sec
  - Inlet valves – closed
  - Outlet valves – closed
- Ejection
  - Duration: 0.3 sec
  - Inlet valves – closed
  - Outlet valves – open
- Isovolumetric relaxation
  - Duration: 0.08 sec
  - Inlet valves – closed
  - Outlet valves – closed

CARDIAC CYCLES



Diastole

- Ventricular Filling: Early (rapid phase) and Late (Slow phase)

- The duration of systole is more fixed than diastole - when HR increases diastole is shortened than systole.

- Ventricular filling occurs in diastole.
- Up to 180 BPM with ample VR filling is adequate (CO/min is increased by an increase in rate.
- At very high HR filling is compromised, CO/min falls and symptoms of heart failure develop.

Late Filling: Function of Atria as Primers

- Blood normally flows continually from the great veins into the atria:
- 80% of the blood flows directly through atria into the ventricles even before the atria contract
- Atrial contraction usually causes an additional 20% filling of the ventricles
- Therefore atria simply function as primer pumps that increase the ventricular pumping effectiveness as much as 20%

Function of Ventricle as a Pump

- **Filling of the ventricles**

  After systole is over ventricular pressures fall again to their low diastolic values, the moderately increased pressures that have developed in the atria during ventricular systole immediately push the A-V valves open and allow blood to flow rapidly into the ventricles. This is the period of rapid filling of the ventricles

  Lasts the first 1/3rd of diastole

Mid Diastole: Diastasis

- During the middle 1/3rd of diastole-only a small amount of blood flows into the ventricles
- During the last 1/3rd of diastole - the atria contract and give an additional thrust to the inflow of blood into the ventricles
- This accounts for ~20%of the filling of the ventricles during each cardiac cycle

Increased HR and Diastole

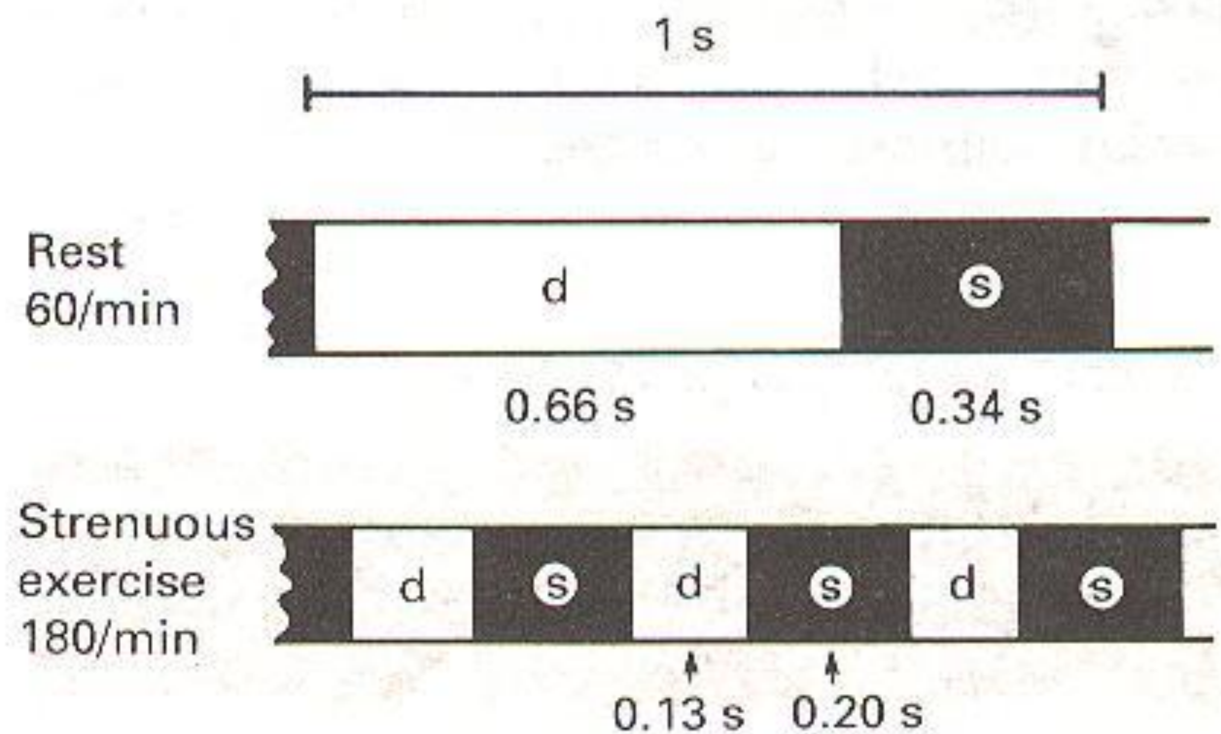


Figure 2.6 Effect of heart rate on the diastolic period available for filling. d, diastole; s, systole. Diastole is curtailed more than systole as heart rate increases

Emptying of the ventricles during systole

- **Period of isovolumic (isometric) contraction**

Immediately after ventricular contraction begins, the ventricular pressure rises rapidly causing the A-V to close

An additional 0.02 – 0.03 sec is required for the ventricle to build up sufficient pressure to push the semilunar (aortic and pulmonary) valves open against the pressures in the aortic and pulmonary artery

Isovolumetric contraction

- During this period ,contraction is occurring in the ventricles, but there's no emptying
- The tension is increasing in the muscle but little or no shortening of the muscle is occurring

- **Period of Ejection**

When the left ventricular pressure rises slightly above 80 mmHg (Rt ventricular pressures slightly above 8 mmHg),the ventricular pressures push the semilunar valves open

Immediately, blood begins to jet out of the ventricles,~70% 1st 1/3rd of the period of ejection (period of rapid ejection),~30% emptying during the next 2/3rds (period of slow ejection)

- **Period of isovolumic (isometric) Relaxation**

  At the end of systole, ventricular relaxation begins suddenly, allowing both the right and left intraventricular pressures to decrease rapidly

  The elevated pressures in the distended large arteries that have just been filled with blood from the contracted ventricles immediately push blood back toward the ventricles, which snaps the aortic and pulmonary valves closed

- For another 0.03 – 0.06seconds,the ventricular mm continue to relax, the ventricular vol does not change- isovolemic or isometric relaxation
- During this period, the intraventricular pressures decrease rapidly back to their low diastolic levels
- The A-V valves open to begin a new cycle of ventricular pumping

Ventricular Volumes

- **End – diastolic volume**

During diastole, normal filling of ventricles increases the vol of each ventricle to about 110-120 ml

- **Stroke volume output**

Amount of blood ejected from the ventricle in one contraction

As the ventricles empty during systole, the volume decreases ~70-80 ml

- **End –systolic volume**

The remaining volume in each ventricle,~ 40-50 ml

- **Ejection fraction**

The fraction of the end – diastolic volume that is ejected,~60%

STROKE VOLUME

- Ventricular stroke volume is the difference between ventricular end diastolic volume (EDV) and end systolic volume (ESV)

$$SV=EDV-ESV$$

In normal heart SV is the same as blood ejected in the aorta during systole

Ejection fraction

- It is the fraction of blood ejected by the ventricles relative to its filled volume

$$EF = \frac{SV}{EDV} = \frac{EDV-ESV}{EDV}$$

EF is the measure of ability of the heart to eject blood

EF is normally about 0.55-0.65 (55-65%)

Summary: LV Volume cycle

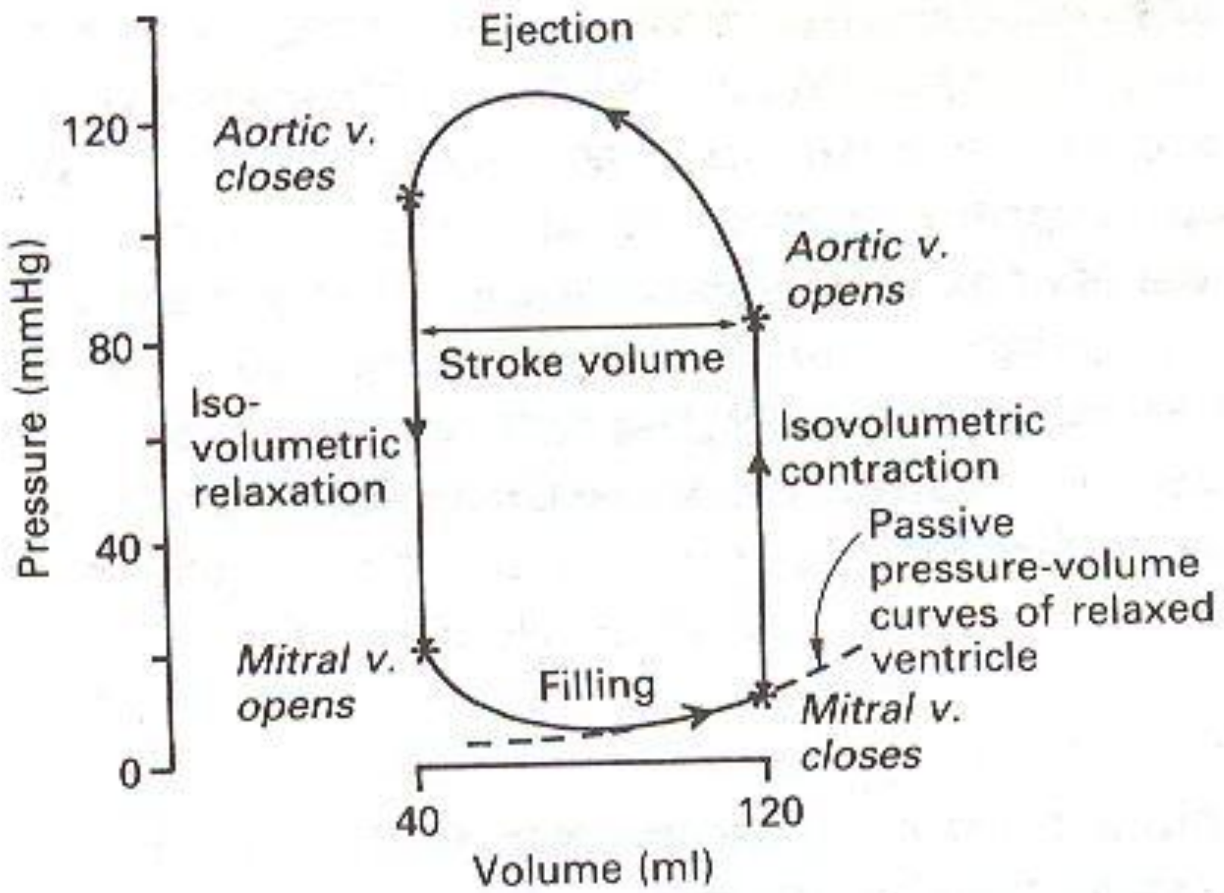
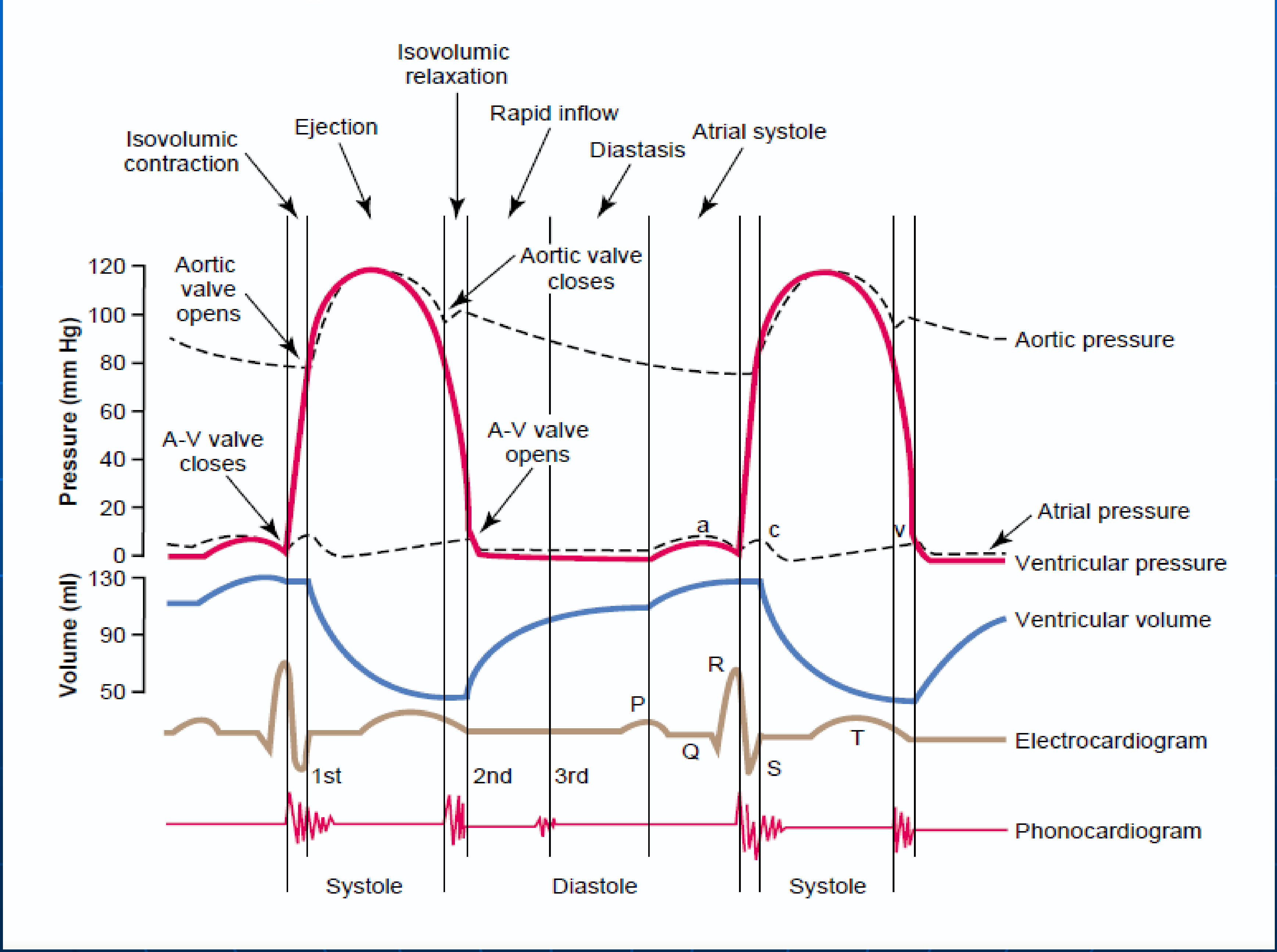


Figure 2.5 Pressure–volume cycle of human left ventricle

Jugular Venous Pulse

- The *a wave* is caused by atrial contraction. The *right* atrial pressure increases 4 to 6 mm Hg during atrial contraction, and the *left* atrial pressure increases about 7 to 8 mm Hg.
- The *c wave* occurs when the ventricles begin to contract; it’s partly due to slight backflow of blood into the atria and by bulging of the tricuspid backward toward the atria because of increasing pressure in the ventricles.
- The *v wave* occurs toward the end of ventricular contraction; due to slow flow of blood into the atria from the veins while the A-V valves are closed during ventricular contraction.

Jugular Venous Pressure



Heart sounds

- First sound (lub) – closure of mitral & tricuspid valve at start of ventricular systole.
- Second sound (dub) – closure of aortic & pulmonary semilunar valves just after the end of ventricular systole
- Third sound – coincides with inrush of blood during rapid ventricular filling
- Fourth heart sound – atrial contraction

Venous pressure and venous return

- Peripheral venous pressure (PVP) – the pressure in the peripheral veins
- Central venous pressure – the pressure in the proximal vena cava and right atrium
- Venous return depends on
  - The difference between PVP and CVPe
  - Venous resistance

Venous pressure

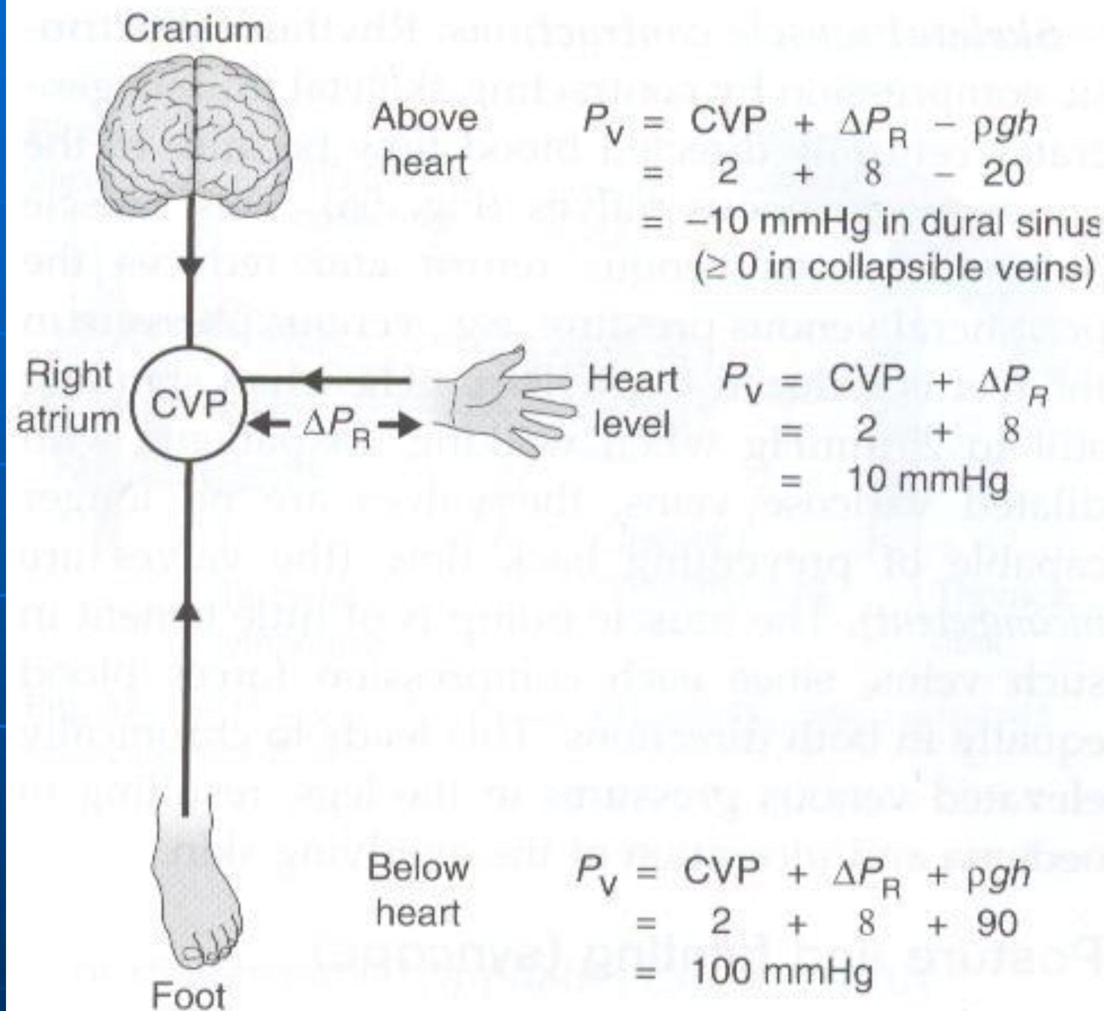
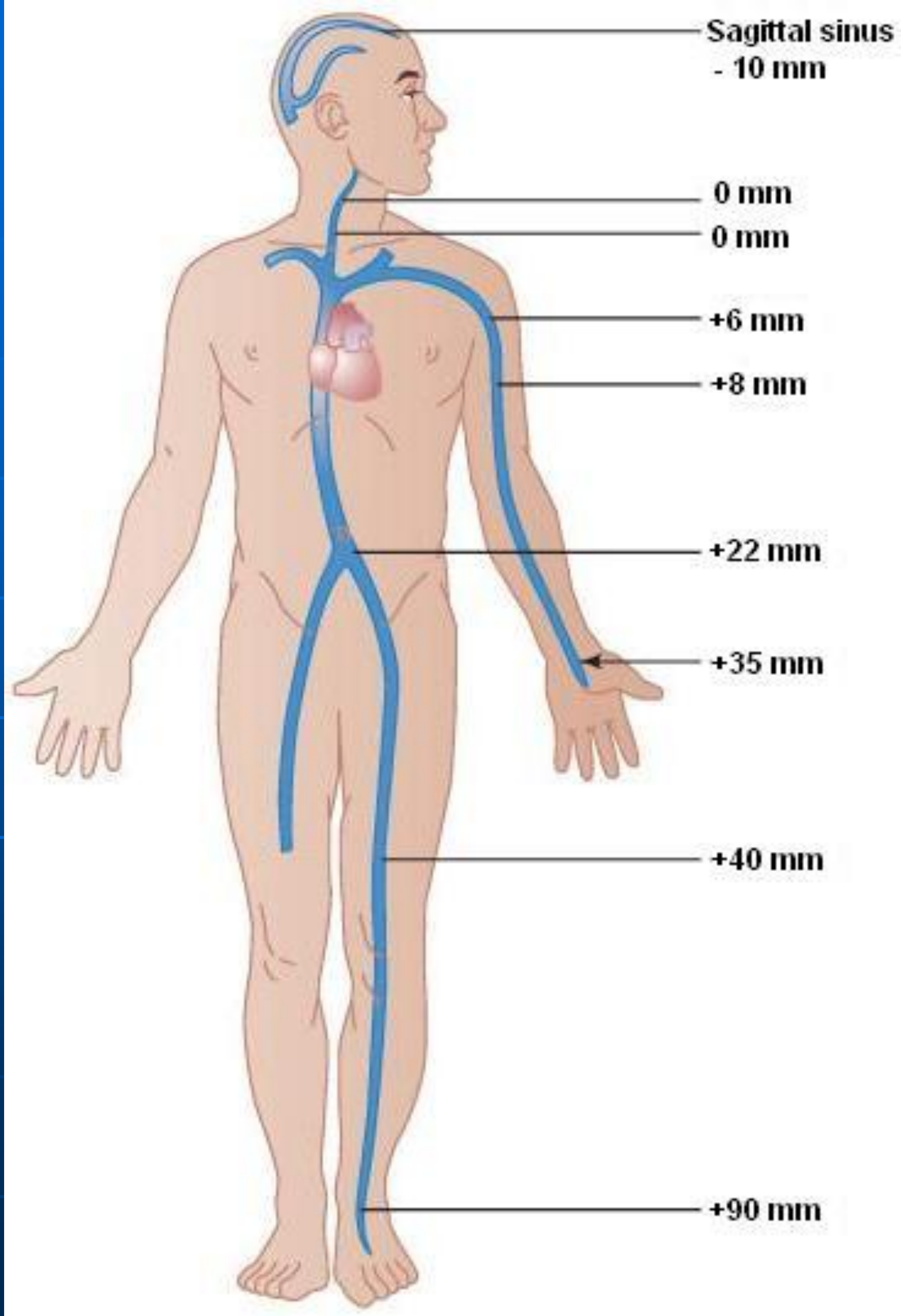


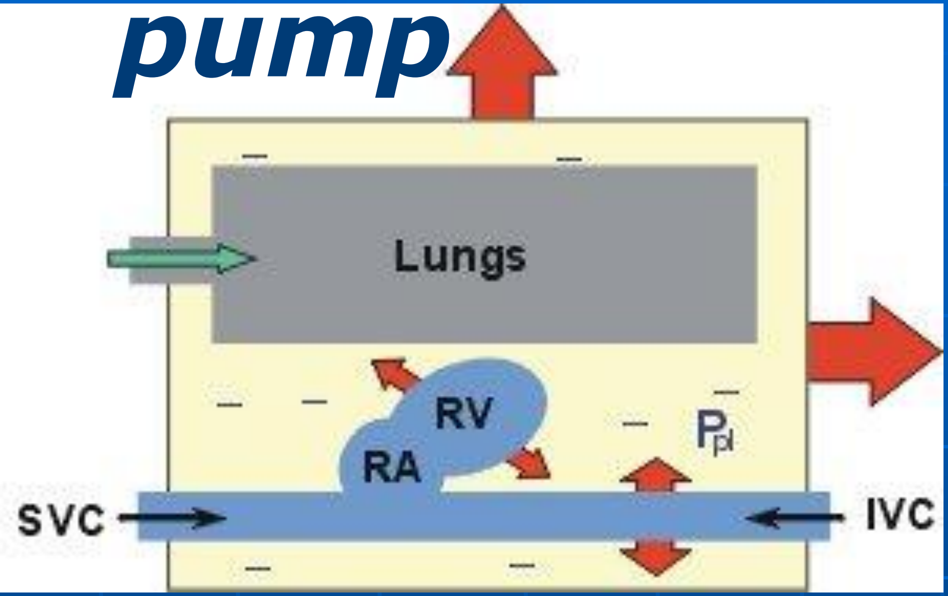
Fig. 55 Factors contributing to peripheral venous pressure for veins at different levels relative to the heart. Above the heart negative pressures may occur in semi-rigid intracranial veins.

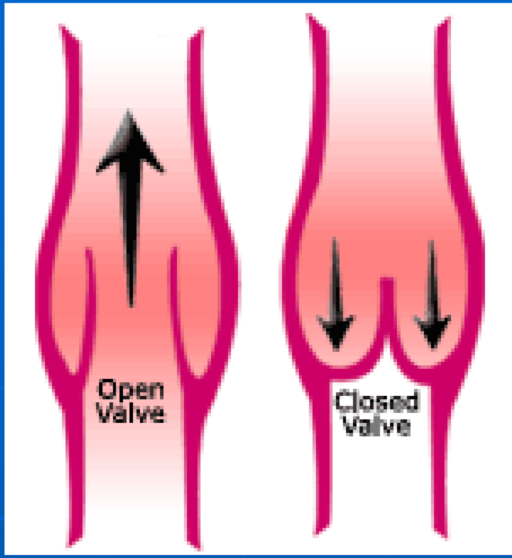
Factors regulating venous return

- Cardiac contractile force
- Posture (gravity)
- Skeletal muscle pump
- Respiratory (abdominothoraxic) pump

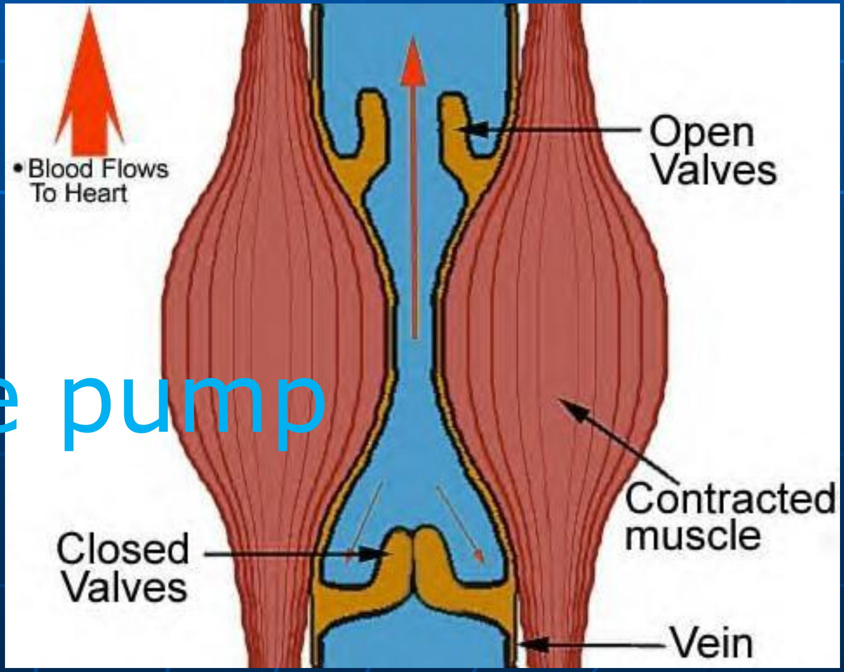


Respiratory pump





Venous valve



Skeletal muscle pump

CAPILLARY CIRCULATION

Microcirculation: Anatomy

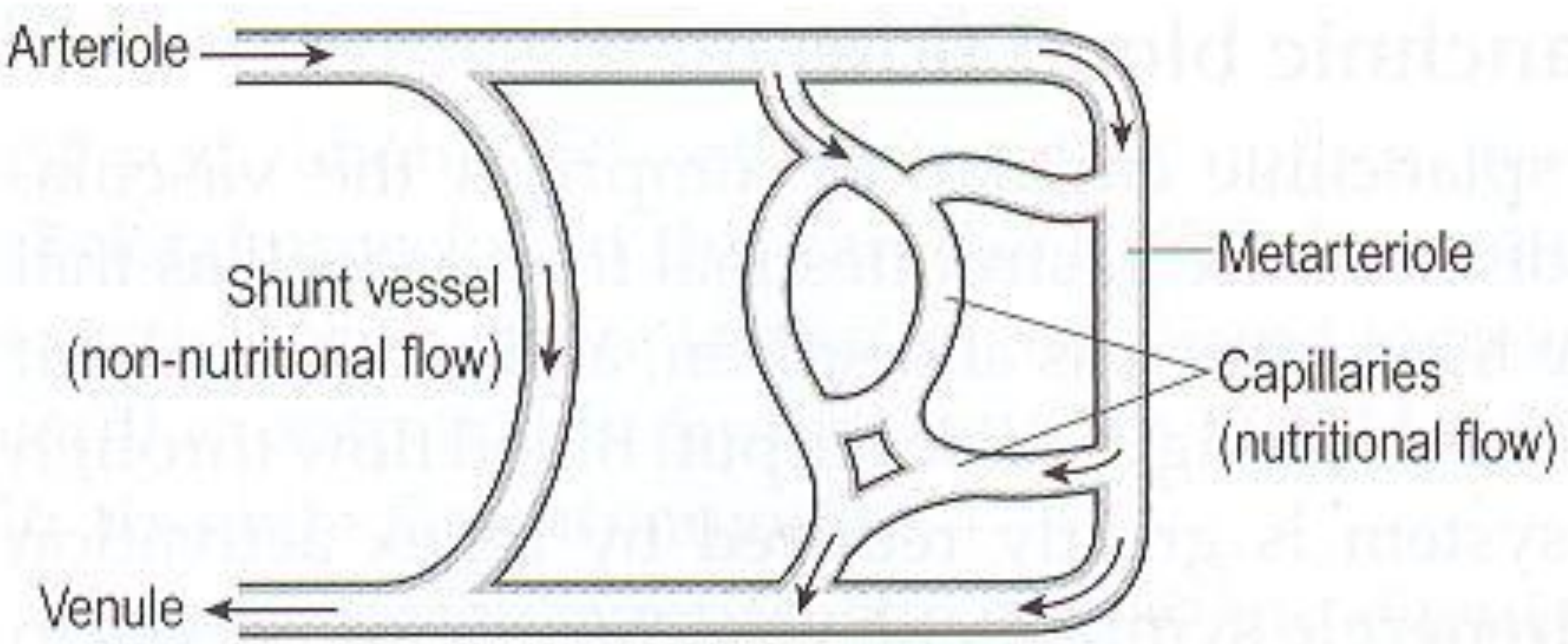


Fig. 52 Outline of the elements of the microcirculation.

Capillary circulation: pressures

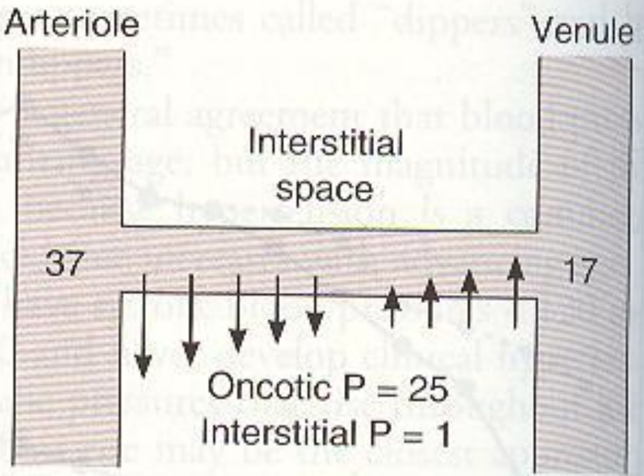


Figure 30–20. Schematic representation of pressure gradients across the wall of a muscle capillary. The numbers at the arteriolar and venular ends of the capillary are the hydrostatic pressures in mm Hg at these locations. The arrows indicate the approximate magnitude and direction of fluid movement. In this example, the pressure differential at the arteriolar end of the capillary is 11 mm Hg ([37 – 1] – 25) outward; at the opposite end, it is 9 mm Hg (25 – [17 – 1]) inward.

Capillary circulation: volumes

- At any given time 5% of circulatory volume in the capillaries
- Important for O2 and nutrient exchange
- Pressures – 35 mmHg arteriolar end and 15 mmHg venous end
- Pulse pressure approx 5 mmHg arteriolar end and 0 at venous end
- 24 L of fluid filtered per day ; 85% reabsorbed – capillaries and lymphatics

Distribution of blood

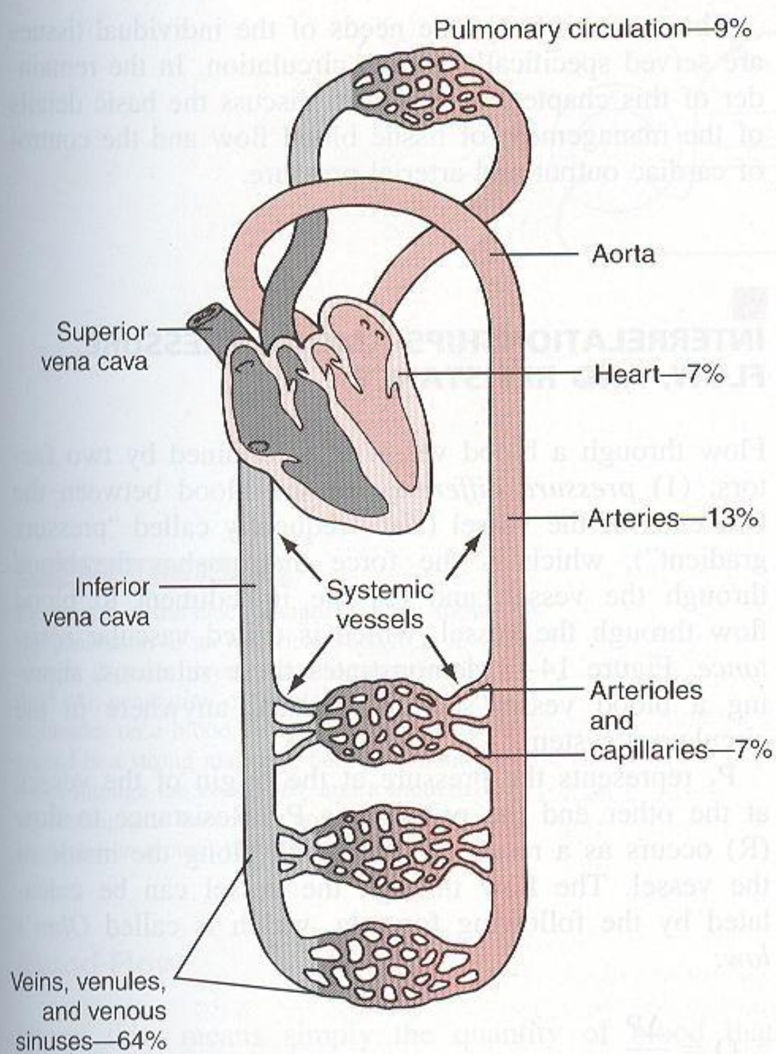


FIGURE 14 – 1

Distribution of blood (in percentage of total blood) in the different parts of the circulatory system.

Capillary circulation oedema - formation

- Filtration depends on Starling forces – hydrostatic pressure gradient = [capillary hydrostatic pressure – interstitial hydrostatic pressure]

  - hydrostatic pressure varies from organ to organ - +ve in the liver and kidneys and very high 6 mmHg in the brain
- Osmotic Pressure gradient = [plasma colloid osmotic pressure – interstitial colloid osmotic pressure]
- Values: OP = (25 mmHg) – (1 mmHg)

Fluid exchange across capillaries

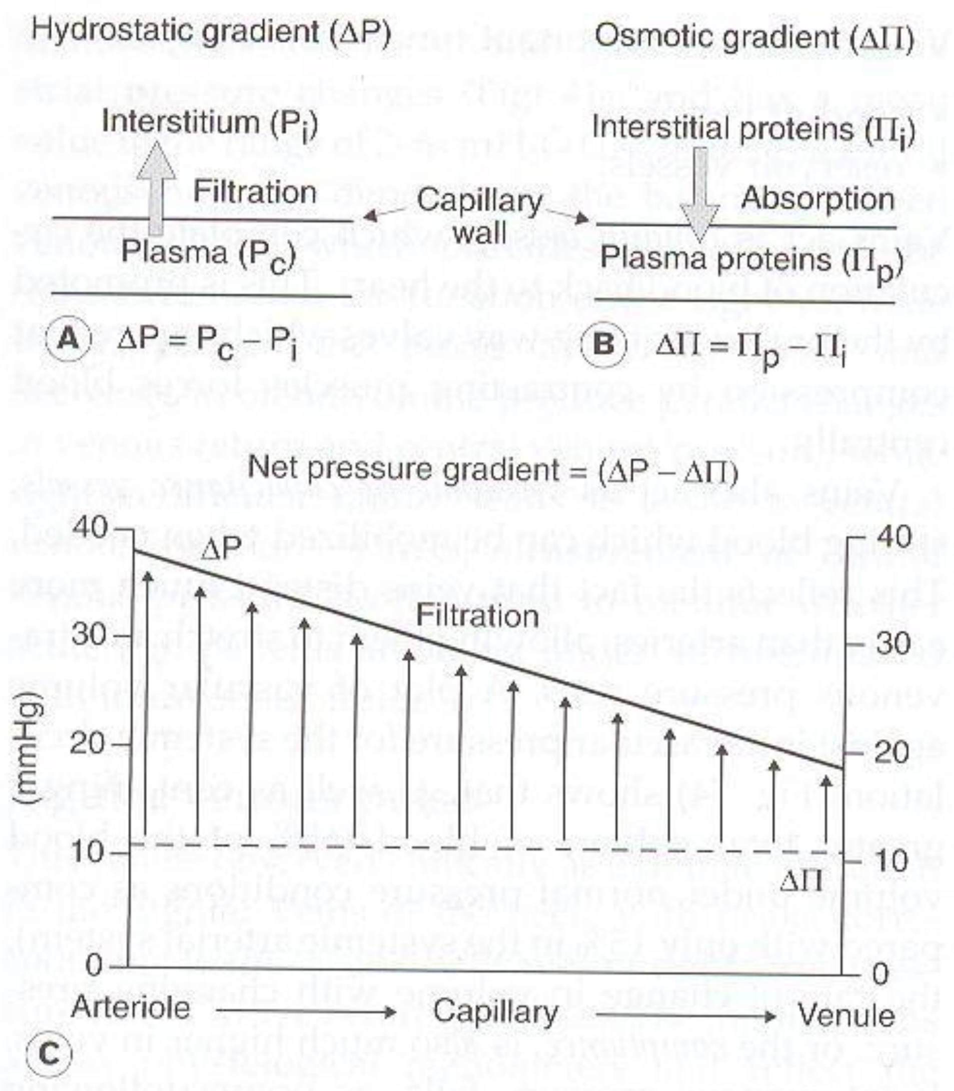


Fig. 53 Factors controlling fluid exchange across the capillary wall (see text). (A) The hydrostatic gradient. (B) The colloid osmotic gradient. (C) The net pressure gradient.

Lymphatic system

Lymphatic system: Structure I

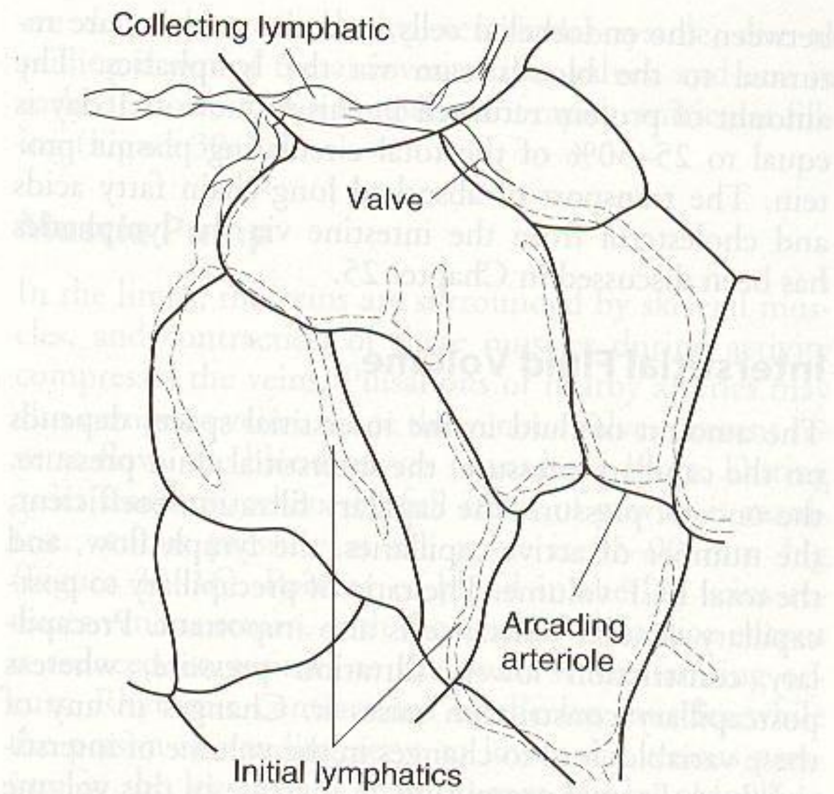


Figure 30–22. **Initial lymphatics draining into collecting lymphatics in the mesentery. Note the close association with arcading arterioles, indicated by the single black lines.** (Reproduced, with permission, from Schmid-Schönbein GW, Zeifach BW: Fluid pump mechanisms in initial lymphatics. News Physiol Sci 1994;9:67.)

Lymphatic system: Structure II

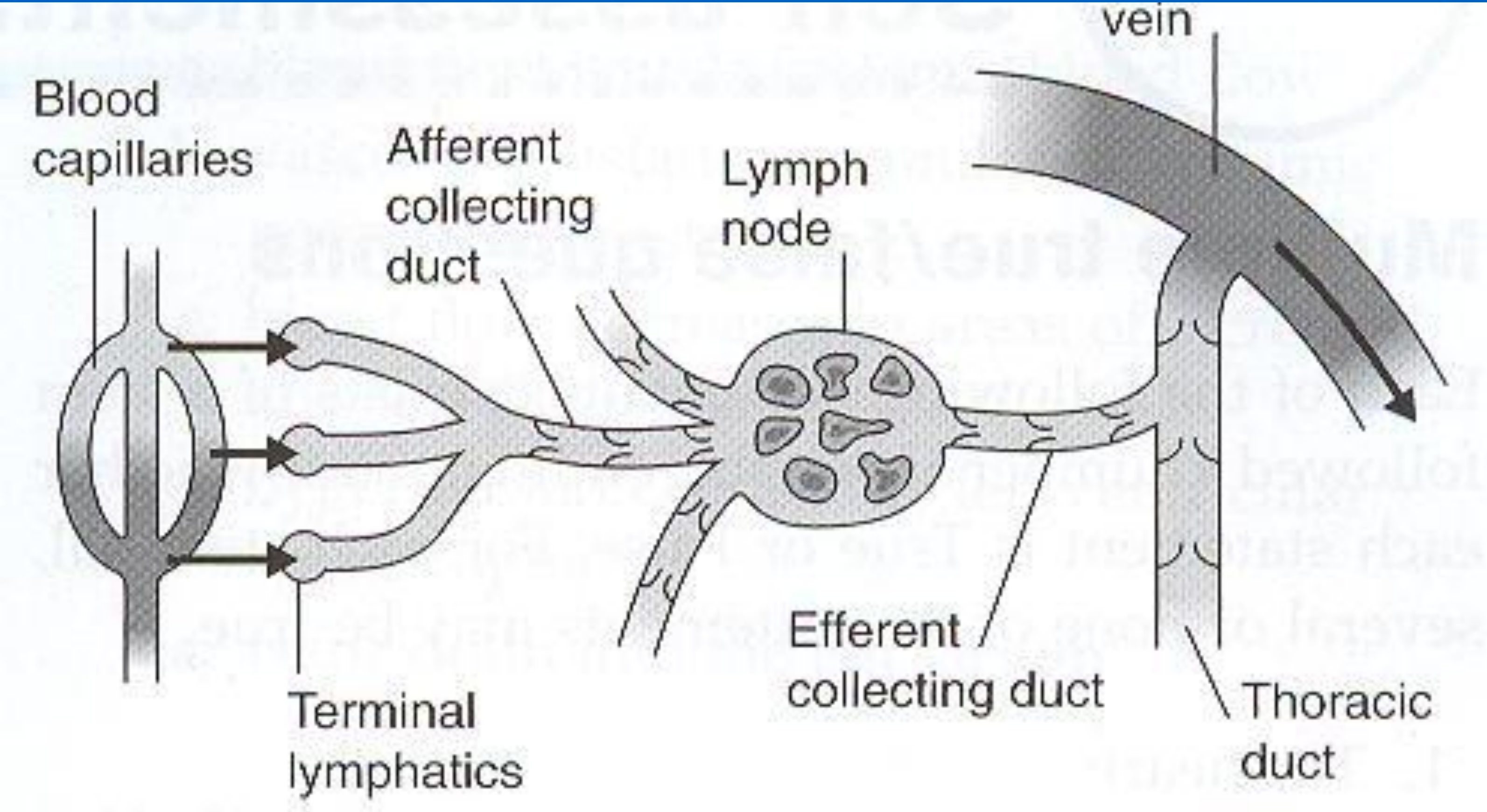


Fig. 57 The structure of the lymphatic system. Lymph is formed from interstitial fluid.

Lymphatics: Structure III

- Begin as endothelial bulbs (lymphatic capillaries or terminal lymphatics)
- More permeable than capillaries – allow proteins or whole cells to pass
- Filled with lymph – tissue fluid in the lymphatics
- Affarent ducts to Lymph nodes
- Efferent ducts out of Lymph nodes

Lymphatics: Functions

- Filtration – filtered fluid/proteins in 24 hours is equal to entire plasma volume
- Immune functions – Foreign antigens trapped in the Lymph nodes
- Transport of lipids – lymphatics in the small intestines.

For further questions

- Email <fbukachi@uonbi.ac.ke>