CVS MODULE
PHYSIOLOGY (LECTURE 9)
THE MICROCIRCULATION

BY

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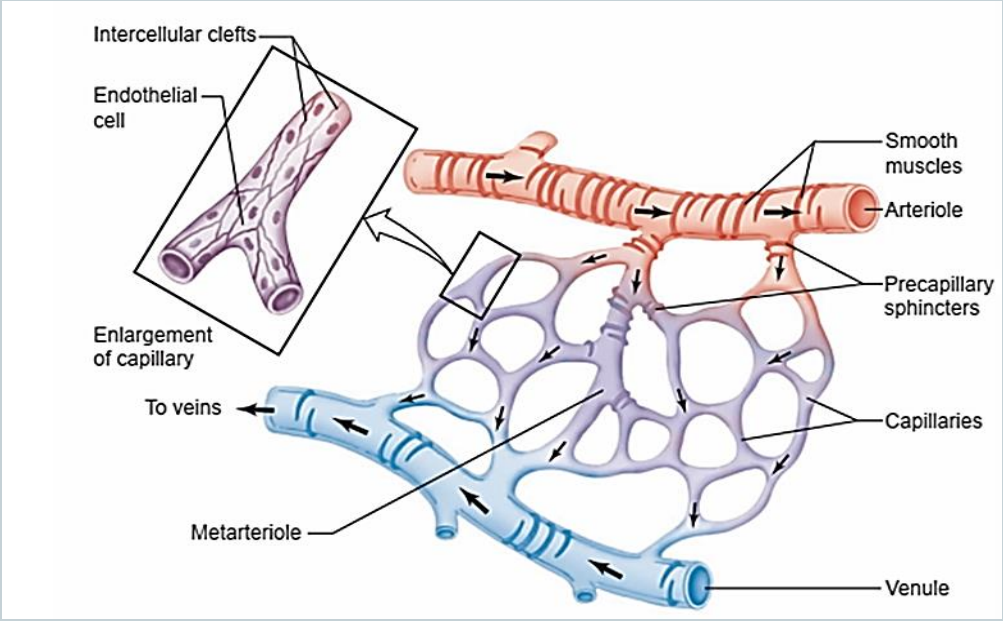
2024-2025



Microcirculation

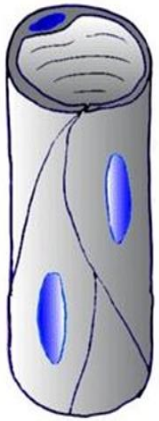
- The microcirculation consists of vessels less than 100 micrometers (μm) in diameter and includes arterioles, metarterioles, capillaries, and venules.
- Muscular arterioles may directly feed into capillaries or into metarterioles and true capillaries arise from both the arterioles and metarterioles.
- **Precapillary sphincters** are bands of smooth muscle found at the point at which blood enters capillaries.
- The thin wall of capillaries consists of a single layer of endothelial cells and the associated basement membrane. This simple structure is well adapted for the diffusion of gases, nutrients, and wastes between blood and the interstitial fluid of tissues, which occurs only in capillaries.

Characters of microcirculation

- Normally only about 25% of capillaries are open at a time.
- The cross sectional area of the open capillaries is about 3000-4500 cm^2 with an average velocity of blood flow 0.2-0.3 mm/second.
- Their walls are about 0.5-1 micron thick, and each is about 0.7 mm long (so an erythrocyte traverses an average capillary in about 2 seconds).
- The precapillary sphincters respond to various stimuli as local metabolic factors (specially O_2).
- Blood flow through capillaries depends very much on the state of the other vessels that constitute the microcirculation. Constriction and relaxation of the smallest arteries, arterioles, and precapillary sphincters regulates flow into capillary beds.

CAPILLARY TYPES

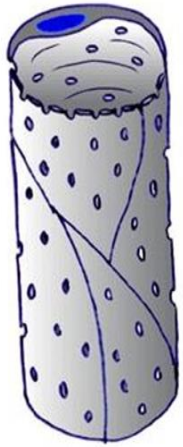
Continuous Capillary



Typical Locations

fat
muscle
nervous system

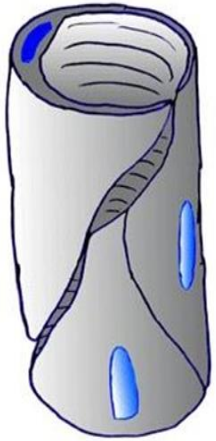
Fenestrated Capillary



Typical Locations

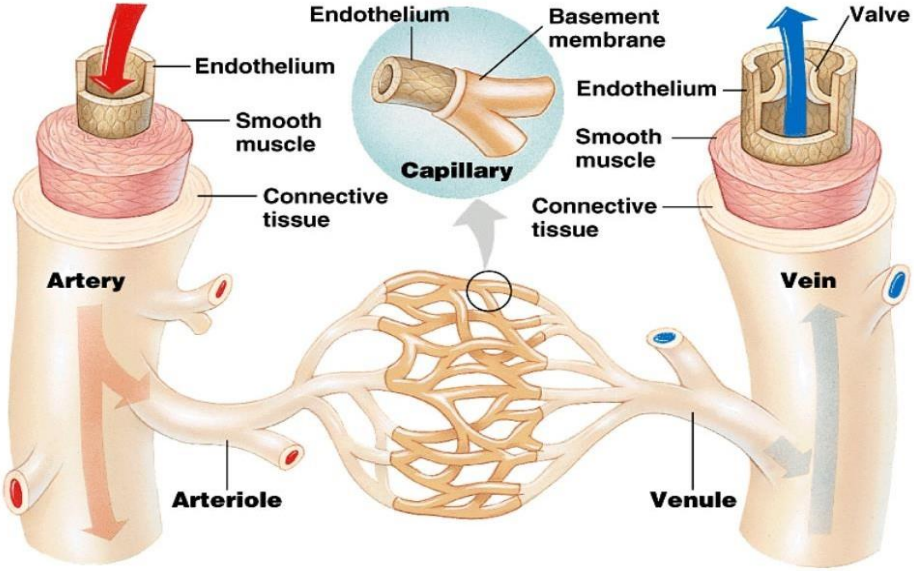
intestinal villi
endocrine glands
kidney glomeruli

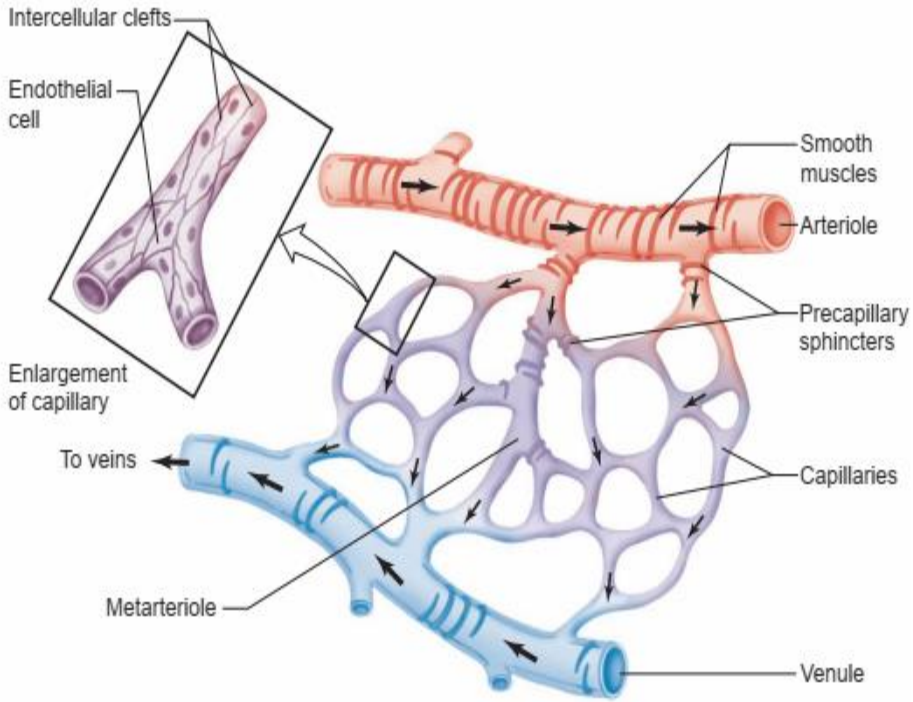
Discontinuous Capillary



Typical Locations

liver
bone marrow
spleen





VASOMOTION

- Vasomotion means intermittent opening and closure of the capillaries.
- It causes intermittent blood flow to the tissues.
- It is a normal phenomenon that occurs at variable rates (i.e. every few seconds to few minutes).
- It occurs as a result of rhythmic contraction and relaxation of metarterioles and precapillary sphincters.
- Its rate is controlled mainly by oxygen level in the tissues.

(O_2 lack prolongs the capillary opening periods and shortens their closure period and vice versa).

Function of capillaries

- Capillaries contain about **5%** of blood volume at time.
- However, **they perform the main function of CVS** because **they constitute the site at which exchange of various substances between the blood and interstitial fluid occurs**.
- It is across the capillary walls that O_2 and various nutrients enter the interstitial fluid, while CO_2 and various waste products enter the blood, and such **exchange** is essential to life. Therefore, capillaries **maintain** constant **communication** between **plasma** and **interstitial fluid**.

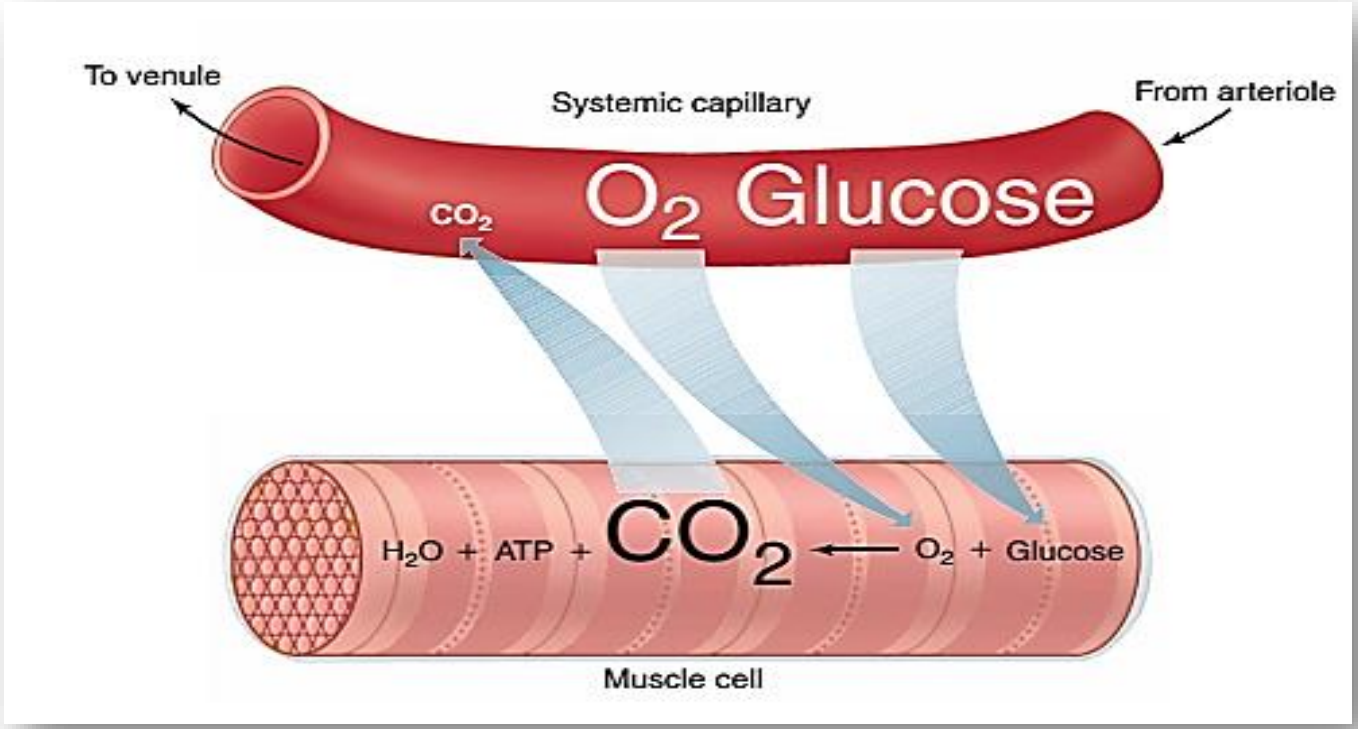
Transcapillary exchange mechanisms

The transport of fluids and various materials across the capillary walls occurs by the following mechanisms:

1. **Diffusion.**
2. **Filtration (Bulk flow).**
3. **Transcytosis (vesicular transport).**

1. Diffusion

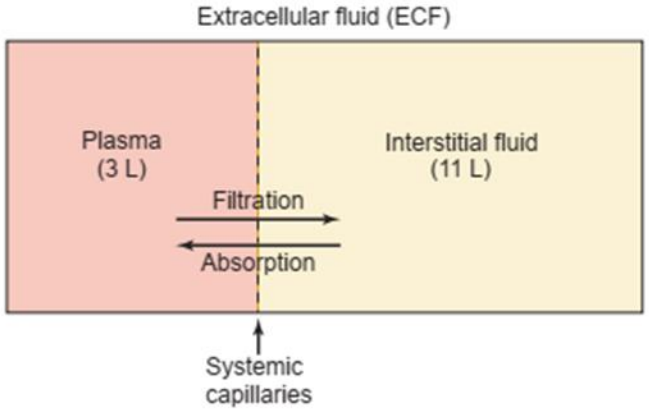
- This is the process by which substances move down their concentration gradient (passive transport).
- Diffusion is the only important means in almost all capillaries (by which net movement of nutrients, oxygen, and metabolic end products occurs across the capillary walls.
- Water and water soluble substances (e.g. glucose, urea, Na^+, Cl^- & K^+) diffuse only through intercellular clefts (slit pores) and fenestrae and their diffusion rates are inversely proportionate to their molecular sizes.
- Fat soluble substances diffuse across the whole capillary wall. Since they dissolve in the phospholipid bilayer of endothelial cell membranes.
- Thus, the diffusion of fat soluble substances as gases (O_2 and CO_2) is normally greater and faster than water-soluble substances.


To venule
Systemic capillary
From arteriole
CO_2
O_2 Glucose
H_2O + ATP + CO_2
O_2 + Glucose
Muscle cell

2. Filtration (Bulk Flow)

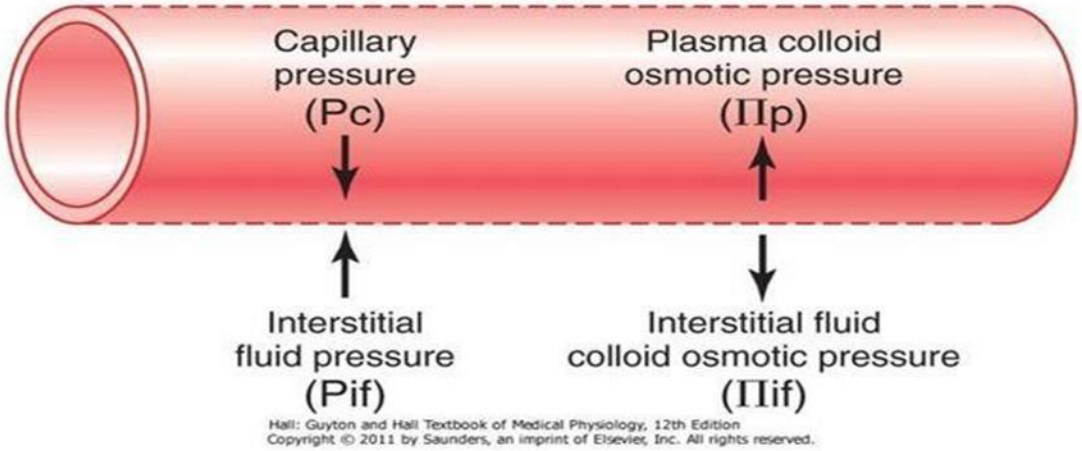
- Most capillary walls are highly permeable to water and to almost all plasma solutes, except plasma proteins.
- Filtration is the process by which fluid and dissolved solutes (**protein-free plasma)** are forced through the pores in the capillary membrane due to a difference in hydrostatic pressure on the 2 sides.
- The force of filtration is opposed by the force of osmosis, and both forces are concerned with the **bulk flow of fluids and solutes across the capillary walls** through **formation and drainage of the interstitial fluid**.

The forces that affect tissue fluid formation and drainage:
Starling's forces (= the hydrostatic and osmotic forces that act across the capillary walls).



Starling forces

Starling Forces Acting Across Capillary Membrane



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- Four primary forces determine whether fluid moves in or out of blood "***Starling forces***":
  - Capillary "***hydrostatic***" pressure → out of blood.
  - IF "***hydrostatic***" pressure → into blood if +ve and out of blood if -ve.
  - Plasma ***colloid osmotic*** pressure → into blood.
  - IF ***colloid osmotic*** pressure → out of blood.

Starling forces

1) The **capillary hydrostatic pressure**: this forces fluid **out of** the capillary.
2) The **interstitial fluid pressure:** this forces fluid **into** The **capillary if +ve** and **out of capillary if –ve**.
3) The **plasma colloid osmotic pressure**: it causes osmosis of fluid **into** the capillary.
4) The **interstitial fluid colloid osmotic pressure:** this causes osmosis of fluid **out of** the capillary.

✓ Therefore, the net filtration pressure (NFP) depends directly upon the algebraic sum of the four variables.

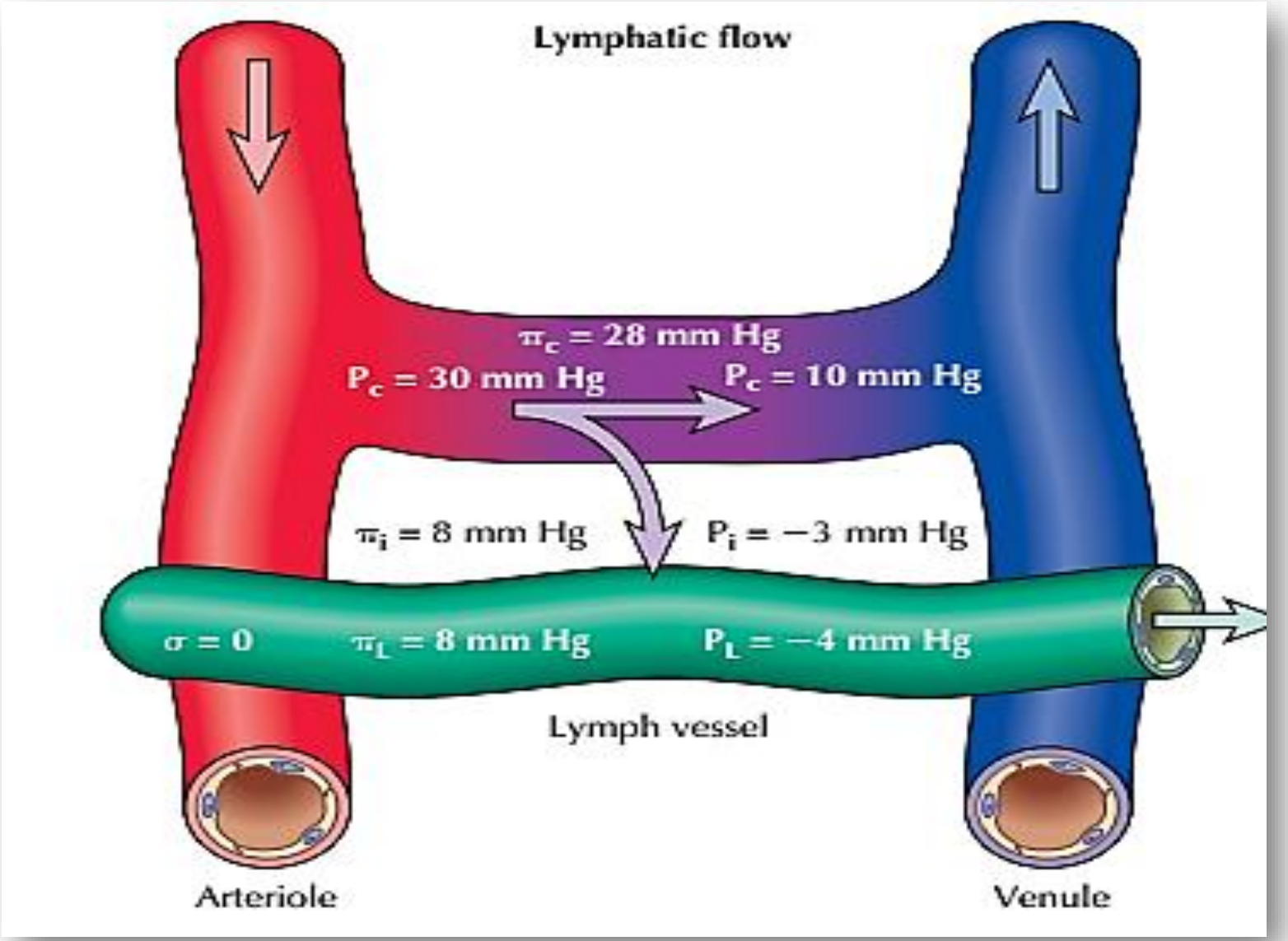
Forces Causing Filtration at the Arterial End of the Capillary

Forces tending to move fluid outward:	mm Hg
Capillary pressure (arterial end of capillary)	30
Negative interstitial fluid pressure	3
Interstitial fluid colloid osmotic pressure	8
total outward force	41
Forces tending to move fluid inward:	
Plasma colloid osmotic pressure	28
total inward force	28
Summation of forces:	
Outward	41
Inward	28
Net outward force (at arterial end)	13

Analysis of Reabsorption at the Venous End of the Capillary

The low blood pressure at the venous end of the capillary changes the balance of forces in favor of absorption as follows:

	mmHg
Forces tending to move fluid inward:	
Plasma colloid osmotic pressure	28
Total inward force	28
Forces tending to move fluid outward:	
Capillary pressure (venous end of capillary)	10
Negative interstitial fluid pressure	3
Interstitial fluid colloid osmotic pressure	8
total outward force	21
Summation of forces:	
Inward	28
Outward	21
net inward force	7


Lymphatic flow
π_c = 28 mm Hg
P_c = 30 mm Hg
P_c = 10 mm Hg
π_i = 8 mm Hg
P_i = −3 mm Hg
σ = 0
π_L = 8 mm Hg
P_L = −4 mm Hg
Lymph vessel
Arteriole
Venule

N.B.

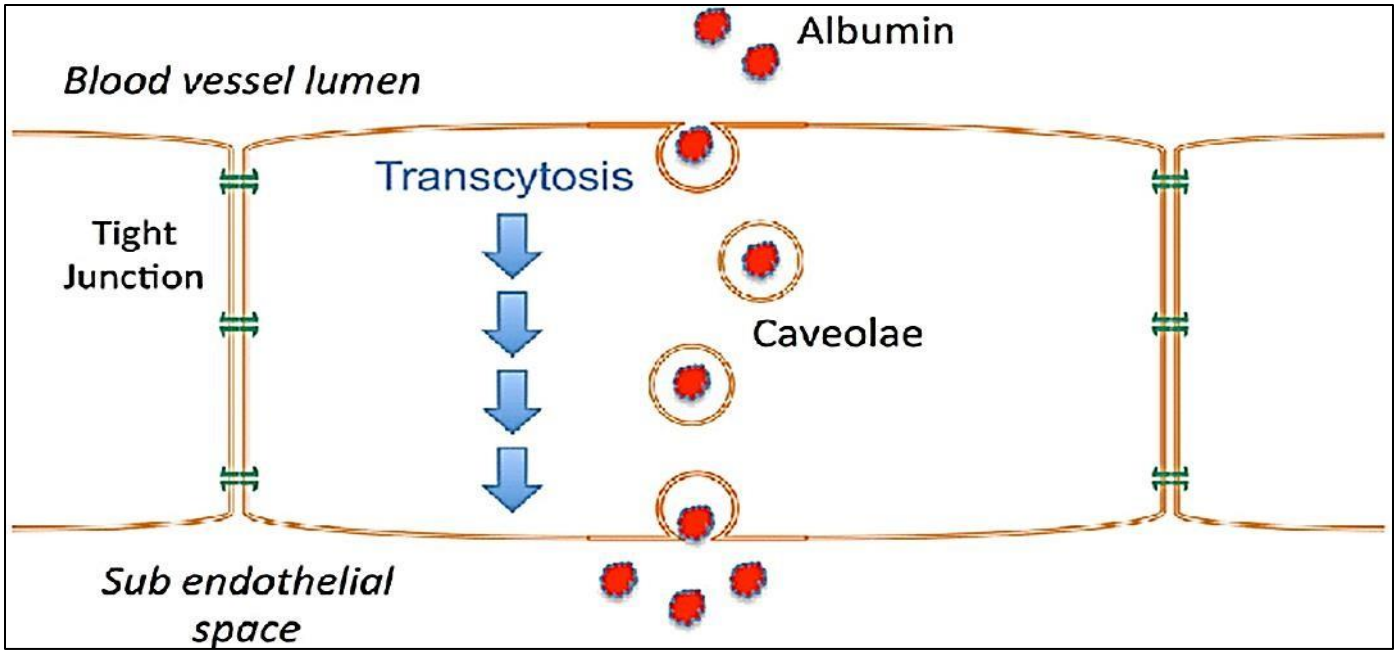
- ✓ The Starling forces vary greatly in different organs depending on their functions e.g. the balance of these forces cause fluid filtration from almost the entire length of the renal glomerular capillaries, while they cause reabsorption in almost the entire length of the intestinal capillaries.

3. Transcytosis (vesicular transport)

This is the mechanism of transport of **large molecules** across the capillary membrane.

The large molecules are transported by endocytosis at the endothelial side followed by exocytosis at the interstitial side.

Normally, small amounts of **proteins** are transported by this mechanism.



Response of capillaries to mechanical stimuli

✓ **White line (reaction):**

Stroking the skin lightly with a blunt pointed object leads to pallor of the stimulated part within about 15 seconds. This is due to direct contraction of precapillary sphincters and blood drains out of the capillaries by the mechanical stimulus.

✓ **Triple response:**

A response that commonly occurs in skin as a result of either injury (heavy stroking) or insect bites. It consists of 3 reactions:

- **Red Line** (appears in about 10 seconds): Due to capillary dilatation secondary to relaxation of precapillary sphincters as a direct response to heavy stroke.
- **Spreading Flare**: diffuse reddening that appears within about half a minute around the area of injury due to arteriolar vasodilatation (by antidromic local axon reflex mechanism through liberation of substance P).
- **Wheal (swelling)**: Local oedema that appears within a few minutes around the injured area due to increased capillary permeability → extravasation of fluid from capillaries due to liberation of vasodilators (histamine and substance P).

Capillary Fragility (CF)

- The capillaries are normally not fragile i.e. not vulnerable to rupture although they are very delicate.
- This is because according to **Laplace's law** (T= P X r); the tension in their walls is very low due to their extremely small radius.
- The CF is increased in diseases e.g. scurvy (vitamin C deficiency) and purpura.

Edema

Definition:

Accumulation of excessive amounts of interstitial fluid.

Causes:

- An increase of capillary hydrostatic pressure: due to elevation of venous pressure (e.g. venous obstruction and right sided heart failure) or arteriolar V.D.
- Decreased plasma colloid osmotic pressure: due to hypoproteinemia.
- Increased capillary permeability: as in allergic reactions (histamine).
- Inadequate lymph drainage (lymphedema) : blockage of lymph vessels that often occurs in cancer.
- Salt and water retention in body.

Thank You