General Physiology-2024

Lecture 31

Microcirculation and capillary fluid exchange

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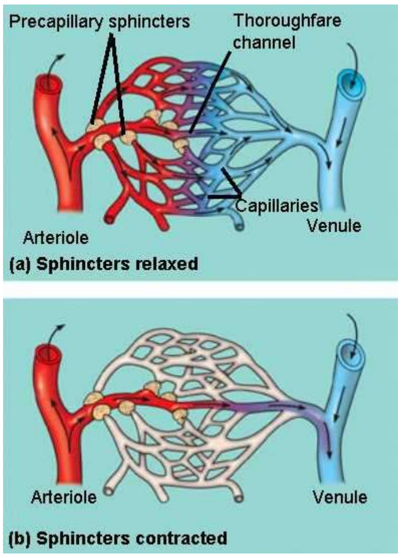
Objectives

- Review the structure and the function of systemic capillary.
- List various types of capillaries and their properties
- Describe how capillary wall permeability to a solute is related to the size and lipid solubility of the solute.
- List the factors (Starling forces) that influence transcapillary fluid movement
- Given data, predict the direction of transcapillary fluid movement at arterial end and the venous

Capillary Circulation



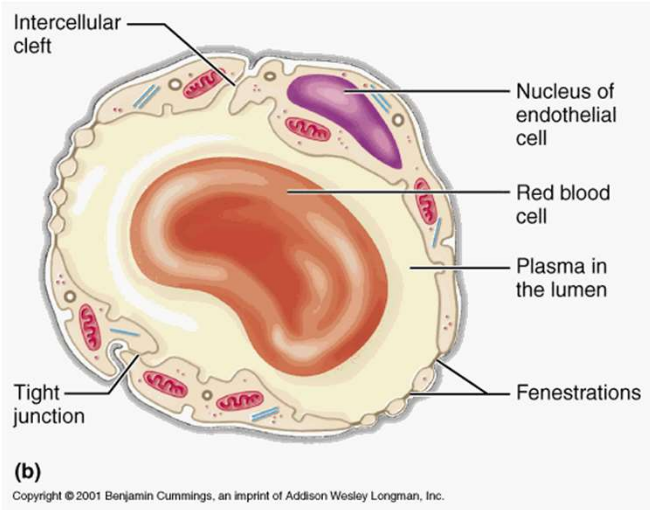
Capillary Circulation

- Capillaries contain 5-7% of the circulating blood.
- The main function of capillaries is exchange of materials with interstitial fluid.

Structure of the Capillary Bed:

- ***Metarterioles:*** Are the terminal divisions of arterioles. They have smaller muscle wall. They terminate into true capillaries (figure 74).
- Sometimes, the metarteriole is connected directly with the venule by a preferential channel ***(thoroughfare vessel).***
- ***Precapillary sphincters:*** Have little smooth muscle cells. They surround the openings of the true capillaries.
- Meta-arterioles and precapillary sphincters receive sympathetic innervation.
- Both meta-arterioles and precapillary sphincters respond to local and circulatory vasoactive substances.
- **Capillary wall:** is very thin (about one μm thick) being made up of a single layer of endothelial cells resting on a basement membrane.

The structure of the capillary wall varies from organ to organ and is closely related to their functions.


Intercellular cleft
Nucleus of endothelial cell
Red blood cell
Plasma in the lumen
Fenestrations
Tight junction
(b)
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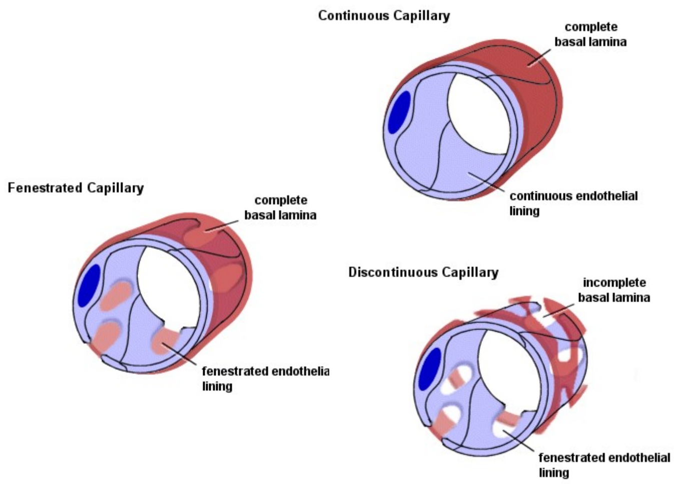
Continuous Capillary
complete basal lamina
continuous endothelial lining
Fenestrated Capillary
complete basal lamina
fenestrated endothelia lining
Discontinuous Capillary
incomplete basal lamina
fenestrated endothelial lining

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Three distinct types of capillary wall can be described:

1- *Continuous Capillary wall*:
The endothelium forms a continuous barrier between blood and interstitial space. Tight junctions are present between endothelial cells. The permeability of this type is very low. This type of endothelial wall is seen for example in central nervous system, muscle, lungs and adipose tissues.

2- *Fenestrated capillary wall*:
The endothelial wall has fenestrations (fenestra = windows) between endothelial cells giving this type of capillaries greater permeability than continuous capillaries. Fenestrated capillaries are typically found in kidney and intestine.

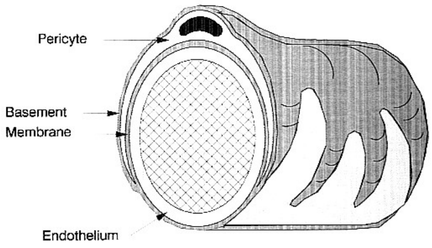
3- *Discontinuous capillary wall*:
In this type, there are large gaps between endothelial cells. These capillaries are highly permeable, even to large molecules like proteins. They are typically seen in liver and spleen.

- ***Pericytes:*** Some Capillaries have pericytes outside the endothelial cells. These cells are characterized by:
  - The have long processes that surround the vessels.
  - They are contractile and release a wide variety of vasoactive agents.
  - They regulate the flow through the junctions between endothelial cells.

Pericyte

contractile

release vasoactive agents



regulate the flow through the junctions between endothelial cells

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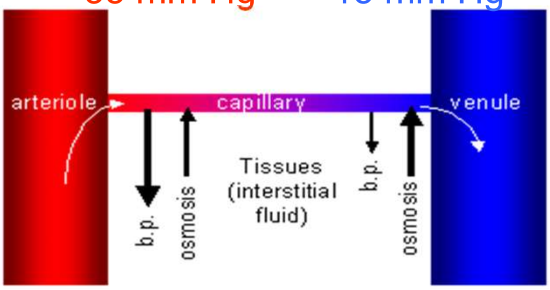
Capillary Pressure

35 mm Hg 15 mm Hg



Wall tension is low (T = P x r)

abnormally fragile

Old age.
Some allergic conditions.
Ascorbic acid deficiency (scurvy)

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Capillary Pressure:

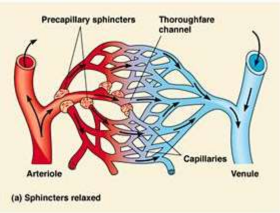
- The capillary pressure in human nail bed capillaries equals 35 mm Hg at the arterial end, and 15 mm Hg at the venous end. However, capillary pressure is not the same in different parts of the body.
- Although capillary wall is very thin, yet it can withstand high pressure. This is explained by ***Laplace law***.
- According to Laplace law: $T = P \times r$. Thus, the very small radius of the capillaries prevents marked increase in wall tension even with considerable increase in capillary pressure.

Capillary Blood Flow

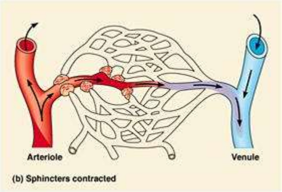
very slow (about 0.5 mm/s)   enough time for exchange

intermittent   *vasomotion*

Active tissue →



Resting tissue →



Capillary Blood Flow:

- The capillary blood flow is ***very slow*** (about 0.5 mm/s) because the total cross-sectional area of the capillary bed is large.
- This slow flow is important to give enough time for exchange of materials between blood and interstitial fluid.
- Capillary blood flow is also ***intermittent***. This is due to the phenomenon known as ***vasomotion***. Vasomotion is alternating contraction and relaxation of the metarterioles and precapillary sphincters in respond to metabolites of tissue activity (O_2 lack, CO_2 excess, lactic acid, potassium ions).
  - In resting tissue: most of the capillaries are closed and blood flows through the thoroughfare vessels. Metabolites accumulate and cause relaxation of metarterioles and precapillary sphincters. More capillaries open and capillary blood flow increases. This washes out metabolites and leads again to constriction of metarterioles and precapillary sphincters and the cycle repeats itself. This alternating opening and closure of capillaries occurs at a rate of 6-12 times per minute.
  - In active tissues: concentration of metabolites increases. This leads to opening of larger number of capillaries. Vasomotion cycles occur more rapidly too.

Equilibrium with Interstitial Fluid

Diffusion

Trans-Capillary Filtration

Vesicular Transport

Capillary permeability

-Continuous

-Fenestrated

-Discontinuous

Factors related to the substance

-concentration gradient

-Lipid solubility

- Molecular size

Equilibrium with Interstitial Fluid

The main function of capillaries is to exchange materials with interstitial fluid.
Three mechanisms are involved in this exchange:

1. ***Diffusion:***
   This is quantitatively the most important mechanism for exchange of materials across the capillary wall. The rate of diffusion of substances across the capillaries depends on capillary permeability and factors related to the substance itself as follows:

   a- Capillary permeability: Continuous capillaries have the lowest permeability. Fenestrated capillaries have higher permeability while discontinuous capillaries have the highest permeability. Capillary permeability can change under different conditions, e.g. during inflammation permeability increases.

   b- Factors related to the substance:
   - *concentration gradient*, which is directly proportional to rate of diffusion
   - *Lipid solubility*: lipid soluble substances can diffuse through either cell membrane and cytoplasm of endothelial cells or through pores and gaps between these cells. The more the substance is lipid soluble the more will be its rate of diffusion.
   - *Molecular size*: this determines the rate of diffusion of substances through pores. This is particularly important for water-soluble substances. The smaller the molecular size of a water-soluble substance the more its rate of diffusion will be.

Equilibrium with Interstitial Fluid

2. Trans-Capillary Filtration (Bulk flow): "Starling Forces".

depends on the balance of hydrostatic pressure gradient and osmotic pressure gradient:

- Mean forces tending to move fluid outwards from capillaries into interstitial space:
  - Capillary hydrostatic pressure (P_c), and
  - Interstitial colloid osmotic pressure (π_i).
- Mean forces tending to move fluid inwards from interstitial space into capillaries:
  - Interstitial hydrostatic pressure (P_i), and
  - Capillary colloid osmotic pressure (π_c)

$$\textbf{Fluid movement} = k\,[(P_c + \pi_i) - (P_i + \pi_c)]$$

Equilibrium with Interstitial Fluid

2. Trans-Capillary Filtration (Bulk flow): "Starling Forces".

- The interstitial colloid osmotic pressure (π_i) is usually very small and can be ignored.

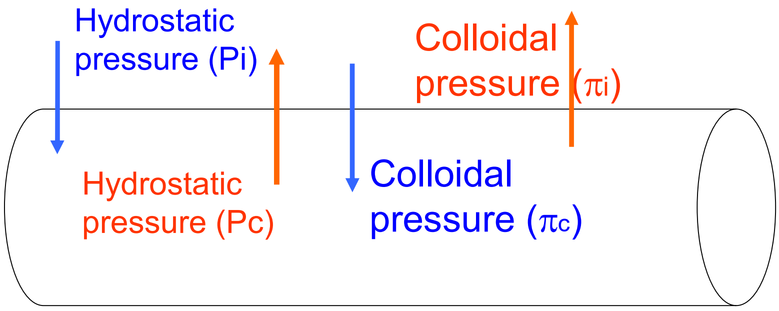
- The capillary filtration coefficient (k) is proportionate to the permeability of the capillary wall and the area available for filtration.

- Along a muscle capillary the net force is as follows (Figure 75):
  - At arteriolar end: (37 + 0) – (1 + 25) = 11 mmHg
    i.e. fluid moves out from capillary into the interstitial space at the arteriolar end under a force of 11 mmHg.
  - At venular end: (17 + 0) – (1 + 25) = - 9 mmHg. i.e., fluid moves into the capillary from the interstitial space at the venular end under a force of 9 mmHg.

Equilibrium with Interstitial Fluid

Trans-Capillary Filtration

Bulk flow



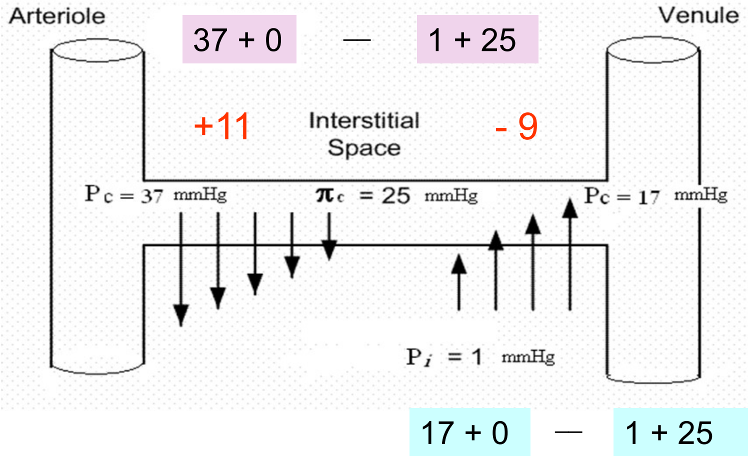
$$\text{Net force} = [(Pc + \pi i)] - [(Pi + \pi c)]$$

$$\text{Filtration} \propto [(Pc + \pi i)] - [(Pi + \pi c)]$$

$$\text{Filtration} = K\,[(Pc + \pi i)] - [(Pi + \pi c)]$$

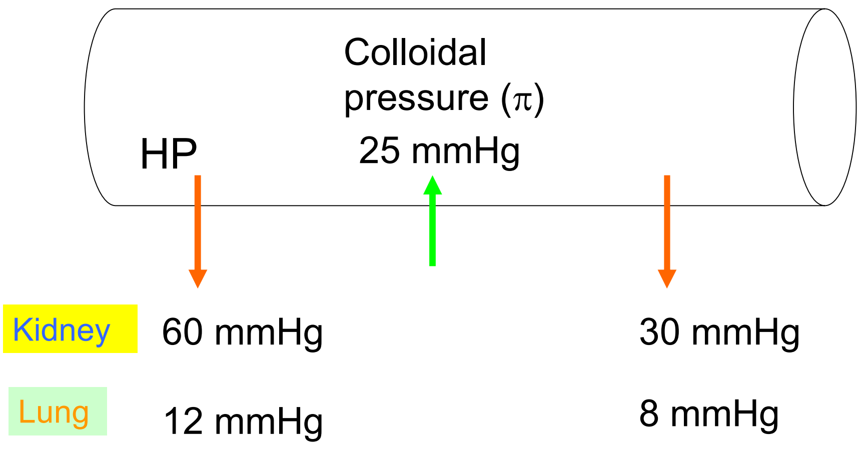
Equilibrium with Interstitial Fluid

Net force = [(Pc + πi)] – [(Pi + πc)]



- The balance of Starling forces is different in other capillaries. Fluid moves *out* along the entire length of the capillaries in the renal glomeruli. On the other hand, fluid moves *in* along the entire length of the capillaries in the intestines and lungs.
- It has been estimated that about 24 L of fluid are filtered through the capillaries per day (0.3% of the COP), about 85% of the filtered fluid is reabsorbed at the venous end of the capillaries, and the remainder returns to the circulation via the lymphatics.

Equilibrium with Interstitial Fluid



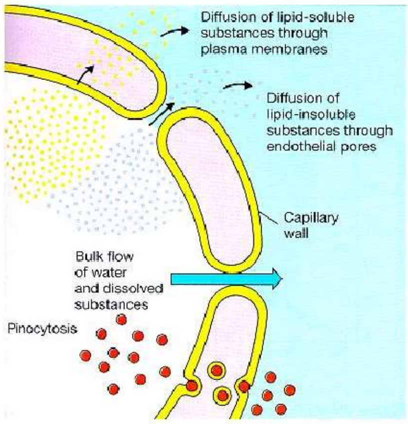
Equilibrium with Interstitial Fluid

3. Vesicular Transport:

By this transport mechanism large lipid-insoluble molecules e.g., proteins, are transported across endothelial cells. These molecules are engulfed by the endothelial cells at the vascular border. The engulfed molecule is contained in a vesicle that moves across the endothelial cell to be released at the interstitial border by exocytosis. This mechanism may be important to provide tissues with molecules of high molecular weight e.g. antibodies, cytokines and protein-bound hormones.

Equilibrium with Interstitial Fluid

Vesicular Transport



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- In a capillary, the hydrostatic capillary pressure (P_c) is 18 mmHg, the colloidal osmotic pressure of plasma proteins (π_p) is 27 mmHg and the interstitial fluid colloidal osmotic pressure (π_{IF}) is 7 mmHg. Based on these values the flow of the fluid out of the capillary will be zero if the interstitial fluid hydrostatic pressure (P_{IF}) is:

a- -4mmHg
b- -2mmHg
c- 0 mmHg
d- +1 mmHg
e- +2 mmHg

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thank you