Physiology

Dr-022

Summary for

Microcirculation

- **Main topics in this chapter:**
  1- Structure of the microcirculation and capillary system
  2- Flow of blood in the capillaries “VASOMOTION”
  3- Exchange if water, nutrients, and other substances between the blood and interstitial fluid
  4- Interstitium and interstitial fluid
  5- Fluid filtration is determined by hydrostatic and colloid osmotic pressure and the capillary filtration coefficient
  6- Lymphatic system

Structure of the microcirculation and capillary system

Microcirculation: is a part of the cardiovascular system which is composed of the heart and blood vessels.

- Important in the transport of nutrients to tissues + the site of waste product removal

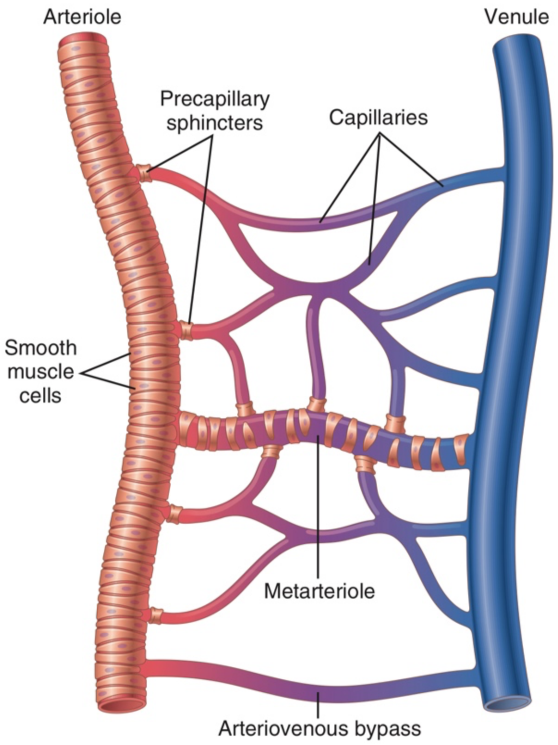


Figure 16-1. Components of the microcirculation.

Nutrient artery > Arteriole (supply blood to the capillaries) > capillaries > venules > vein

The arterioles are highly muscular, and their diameters can change manyfold. Their terminal end called <u>metarteriole</u> that does not have a continuous muscular coat, but smooth muscle fibers encircle the vessel at intermittent points.

Each true capillary originates from a metarteriole, a smooth muscle fiber usually encircles the capillary. This structure is called **the precapillary sphincter.** This sphincter can open and close the entrance to the capillary, which makes blood flow intermittently not continuously.
- over 10 billion of capillaries with surface area of 500-700 m^2 perform function of solute and fluid exchange.

The venules are larger than the arterioles and have a much weaker muscular coat. Yet the pressure in the venules is much less than that in the arterioles, venules can still contract considerably despite the weak muscle.

The metarterioles and the precapillary sphincters are in close contact with the tissues they serve. Therefore, <u>**the local conditions of the tissues**</u> can cause direct effects on the vessels to control local blood flow in each small tissue area.

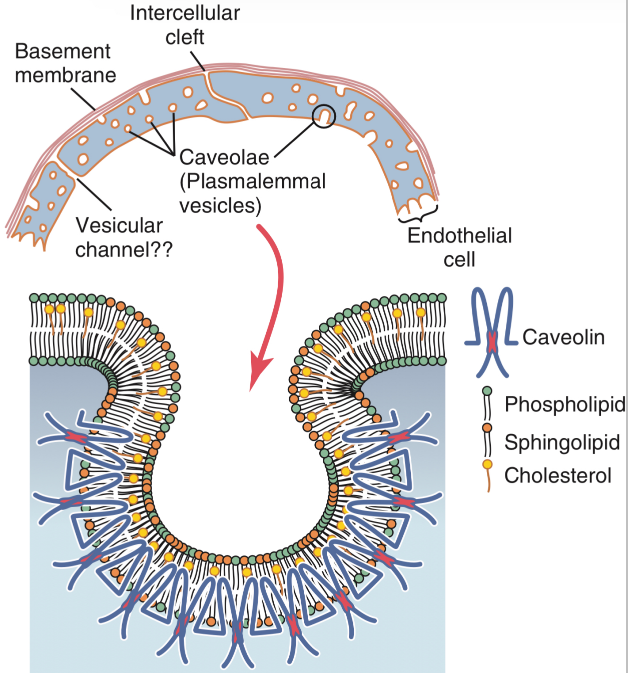
1- the concentrations of nutrients
2- products of metabolism
3- hydrogen ions, and so forth

⇒ **Structure of capillary wall**: unicellular layer of endothelial cells and is surrounded by a thin basement membrane on the outside of the capillary (diameter 4-9 microns)

⇒ **Pores in the capillary membrane**: give 2 passageways:

1- **Intercellular cleft:**

- the thin-slit, curving channel that lies at the top of the figure between adjacent endothelial cells.
- slightly smaller the diameter of an albumin protein molecule.



2- **Plasmalemmal vesicles (caveolae):**

- form from oligomers of proteins called caveolins that are associated with molecules of cholesterol and sphingolipids.
- they are believed to play a role in endocytosis (the process by which the cell engulfs material from outside the cell) and transcytosis of macromolecules across the interior of the endothelial cells.
- the caveolae at the surface of the cell appear to imbibe small packets of plasma or extracellular fluid that contain plasma proteins. These vesicles can then move slowly through the endothelial cell. Some of these vesicles may coalesce to form vesicular channels all the way through the endothelial cell.
- special types of pores:
  a) Brain: the junctions between the capillary endothelial cells are mainly tight junctions that allow only extremely molecules such as H_2O, O_2, and CO_2 to pass into or out of the brain tissues.
  b) Liver: (opposite of the brain) the clefts between the capillary endothelial are wide.
  c) Gastrointestinal capillary membranes: midway in size (muscles + liver)
  d) Glomerular capillaries of the kidney: numerous small oval windows called fenestrae penetrate all the way through the middle of the endothelial cells

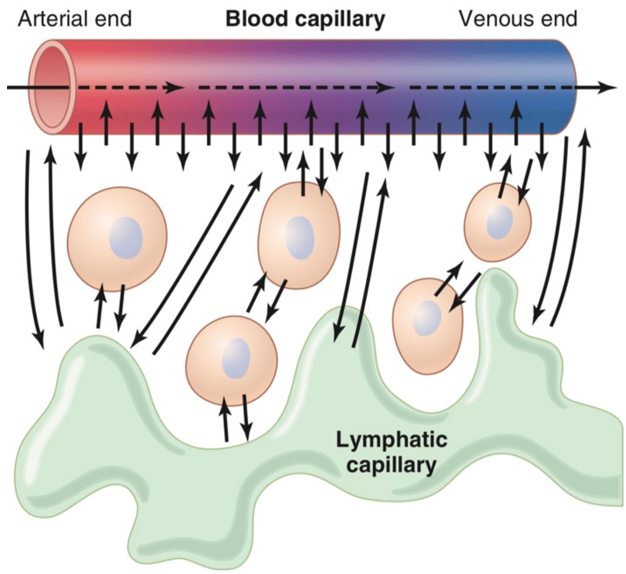
Flow of blood in the capillaries “VASOMOTION”

Blood usually does not flow continuously through the capillaries. Instead, it flows intermittently, turning on and off every few seconds or minutes. The cause of this intermittency is the phenomenon called **vasomotion**, which means intermittent contraction of the metarterioles and precapillary sphincters (and sometimes even the very small arterioles).

Exchange if water, nutrients, and other substances between the blood and interstitial fluid

DIFFUSION THROUGH THE CAPILLARY MEMBRANE

- results from thermal motion of the water molecules and dissolved substances in the fluid, with the different molecules and ions moving first in one direction and then another, bouncing randomly in every direction.
- the blood flows along the lumen of the capillary, tremendous numbers of water molecules and dissolved particles diffuse back and forth through the capillary wall, providing continual mixing between the interstitial fluid and the plasma



ure 16-3. Diffusion of fluid molecules and dissolved substances ween the capillary and interstitial fluid spaces.

Effect of Molecular Size on Passage Through the pores:

- The width of the capillary intercellular cleft-pores, (6 to 7 nanometers)
- the permeability of the capillary pores for different substances varies according to their molecular diameters
- the capillaries in various tissues have extreme differences in their permeabilities.

Substance	Molecular Weight	Permeability
Water	18	1.00
NaCl	58.5	0.96
Urea	60	0.8
Glucose	180	0.6
Sucrose	342	0.4
Inulin	5000	0.2
Myoglobin	17,600	0.03
Hemoglobin	68,000	0.01
Albumin	69,000	0.001

Effect of Concentration Difference on Net Rate of Diffusion Through the Capillary Membrane

- the **greater** the difference between the concentrations of any given substance on the two sides of the capillary membrane, the **greater** the net movement of the substance in one direction through the membrane
- for example the $[O_2]$ in $CB_{(capillary\ blood)}$ > in $IF_{(interstitial\ fluid)}$, so large quantities of oxygen normally move from the blood toward the tissues. (CO_2 is the opposite)

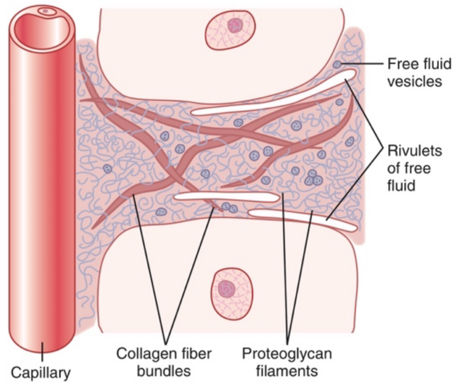


Figure 16-4. Structure of the interstitium. Proteoglycan filaments are everywhere in the spaces between the collagen fiber bundles. Free fluid vesicles and small amounts of free fluid in the form of rivulets occasionally also occur.

Interstitium and interstitial fluid

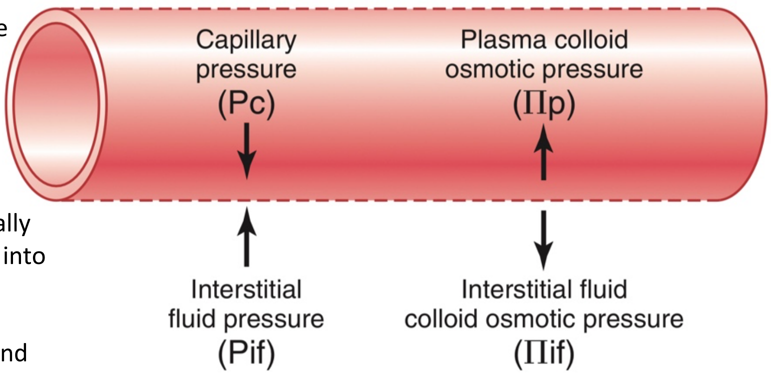
Interstitium: spaces between cells.

Interstitial fluid: the fluid in these spaces.

- = 1/6 of the total volume of the body.
- Contains 2 major types of solid structure:
  1- proteoglycan filaments (they *are extremely thin coiled or twisted molecules composed of about 98 percent hyaluronic acid and 2 percent protein.)*
  2- collagen fiber bundles (They are extremely strong and therefore provide most of the tensional strength of the tissues)
- GEL: the fluid in the interstitium is derived by filtration and diffusion from the capillaries.
- FREE FLUID: Although almost all the fluid in the interstitium normally is entrapped within the tissue gel, occasionally small rivulets of “free” fluid and small free fluid vesicles are also present, which means fluid that is free of the proteoglycan molecules and therefore can flow freely.

Fluid filtration is determined by hydrostatic and colloid osmotic pressure and the capillary filtration coefficient

The hydrostatic pressure in the capillaries tends to force fluid and its dissolved substances through the capillary pores into the interstitial spaces. Conversely, osmotic pressure caused by the plasma proteins (called colloid osmotic pressure) tends to cause fluid movement by osmosis from the interstitial spaces into the blood. This osmotic pressure exerted by the plasma proteins normally prevents significant loss of fluid volume from the blood into the interstitial spaces.
Also important is the lymphatic system, which returns to the circulation the small amounts of excess protein and fluid that leak from the blood into the interstitial spaces



Hydrostatic and Colloid Osmotic Forces Determine Fluid Movement Through the Capillary Membrane.

The figure shows the four primary forces that determine whether fluid will move out of the blood into the interstitial fluid or in the opposite direction. These forces, called **"Starling forces"** in honor of the physiologist Ernest Starling, who first demonstrated their importance, are:

1. The capillary pressure (Pc), which tends to force fluid outward through the capillary membrane.

2. The interstitial fluid pressure (Pif), which tends to force fluid inward through the capillary membrane when Pif is positive but outward when Pif is negative.

3. The capillary plasma colloid osmotic pressure (Πp), which tends to cause osmosis of fluid inward through the capillary membrane.

⇒ Generally colloid osmotic pressure is caused by presence of large proteins: 75% of its total results from the presence of **Albumin** and 25% is due to **Globulins**.

4. The interstitial fluid colloid osmotic pressure (Πif), which tends to cause osmosis of fluid outward through the capillary membrane.

- **the net filtration pressure:** the sum of these forces

$$NFP = Pc - Pif - \ p - \ if$$

- **the capillary filtration coefficient (K_f):** a measure of the capacity of the capillary membranes to filter water for a given NFP and is usually expressed as ml/min per mm Hg NFP.

$$Filtration = K_f \times NFP$$

- **starling equilibrium for capillary exchange:** the amount of fluid filtering outward from the arterial ends of capillaries equals almost exactly the fluid returned to the circulation by absorption (90% of the filtrated fluid). The slight disequilibrium that does occur accounts for the fluid that is eventually returned to the circulation by way of the lymphatics (the remaining 10% of the filtrated fluid).

Mean Forces Tending to Move Fluid Outward	mm Hg
Mean capillary pressure	17.3
Negative interstitial free fluid pressure	3.0
Interstitial fluid colloid osmotic pressure	8.0
TOTAL OUTWARD FORCE	28.3

Mean Forces Tending to Move Fluid Inward	mm Hg
Plasma colloid osmotic pressure	28.0
TOTAL INWARD FORCE	28.0
Summation of Mean Forces	
Outward	28.3
Inward	28.0
NET OUTWARD FORCE	0.3

- effects of abnormal imbalance of forces at the Capillary Membrane:

- If the mean capillary pressure rises above 17 mm Hg, the net force tending to cause filtration of fluid into the tissue spaces rises and to prevent accumulation of excess fluid in these spaces would require 68 times the normal flow of of fluid into the lymphatic system which too much for them to carry away → fluid will begin to accumulate in the interstitial spaces and edema will result.

- Conversely, if the capillary pressure falls very low, net reabsorption of fluid into the capillaries will occur instead of net filtration and the blood volume will increase at the expense of the interstitial fluid volume. These effects of imbalance at the capillary membrane in relation to the development of different kinds of edema

➔ **Edema**: the too much filtration which has caused edema, is due to either: too much driving force, or too much permeability, or too much of both, (keep that in mind).

Lymphatic system

- The lymphatic system represents an accessory route through which fluid can flow from the interstitial spaces into the blood.
- Most important, the lymphatics can carry proteins and large particulate matter away from the tissue spaces, neither of which can be removed by absorption directly into the blood capillaries.
- Important to prevent edema
- Important role in immune system

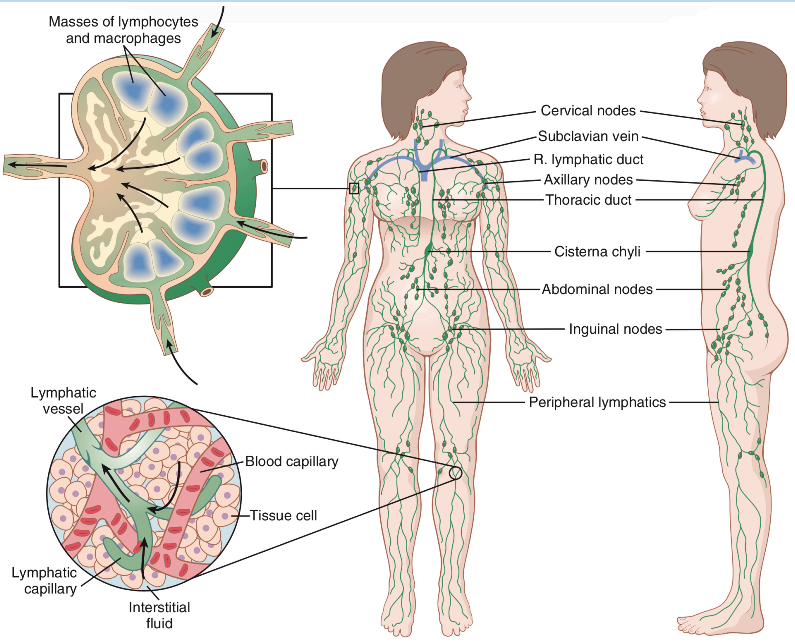
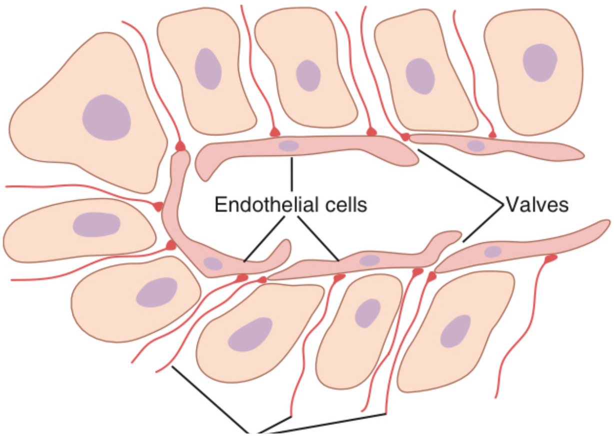


Figure 16-7. The lymphatic system.

- Works along with cardiovascular system and helps in digestion and absorption
- It works with the microcircular system to return back the unreturned fluid or unabsorbed fluid
- In some tissues it maintains the negative sign of the pressure in the interstitium and develop filtration process.



The lymphatic pump:

Existed in the lymphatic vessels which work as a pump having valves, squeezes the fluid from the bottom to the top of the vessels, there also muscles surround the lymphatic vessels help in the flow of the fluid or the lymph upwards which cause the lymph to pour into the blood circulation.

The of activity of the lymphatic pump:

- The increased interstitial fluid hydrostatic pressure causes the lymph flow to increase.

- When the fluid quantity in the interstitium increases the pumping or lymph flow increases and becomes more efficient.

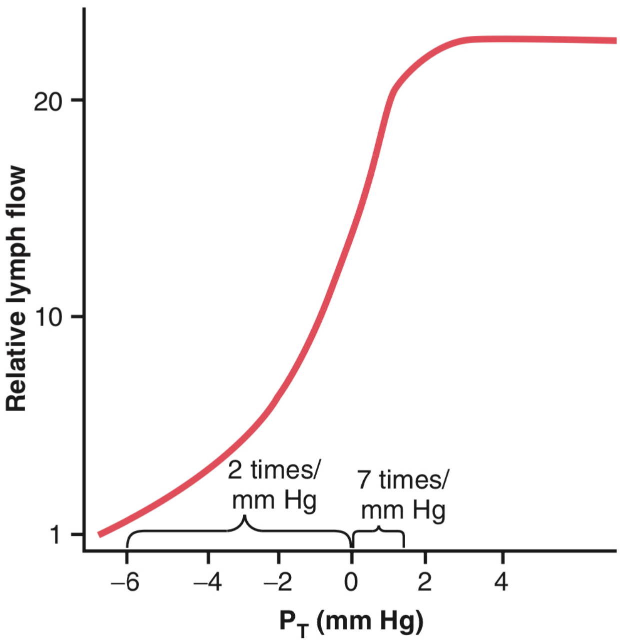


Figure 16-9. Relation between interstitial fluid pressure and lymph flow in the leg of a dog. Note that lymph flow reaches a maximum when the interstitial pressure, P_T, rises slightly above atmospheric pressure (0 mm Hg). *(Courtesy Drs. Harry Gibson and Aubrey Taylor.)*