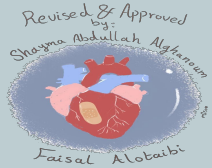
Capillary circulation



Physiology Team 439

MED439
KING SAUD UNIVERSITY

Black: in male / female slides

Red : important

Pink: in female slides only

Blue: in male slides only

Green: notes

Gray: extra information

Introductory video (recommended before reading)

Editing File

@Physiology_439

Objectives

- To describe components of microcirculation.
- To recognize different types of blood capillaries.
- To understand regulation of flow in capillary beds.
- To understand formation of the interstitial fluid.
- To understand the role of lymphatics.
- Define edema, state its causes
- To recognize mechanism of formation of edema.
- Diffusion and filtration.

Bulk Flow "We highly recommended to read it before you begin"

The mass movement of fluids into and out of capillary beds requires a transport mechanism far more efficient than mere diffusion. This movement, often referred to as bulk flow, involves two pressure-driven mechanisms: Volumes of fluid move from an area of higher pressure in a capillary bed to an area of lower pressure in the tissues via filtration. In contrast, the movement of fluid from an area of higher pressure in the tissues into an area of lower pressure in the capillaries is reabsorption. Two types of pressure interact to drive each of these movements: hydrostatic pressure and osmotic pressure.

Hydrostatic Pressure

The primary force driving fluid transport between the capillaries and tissues is hydrostatic pressure, which can be defined as the pressure of any fluid enclosed in a space. Blood hydrostatic pressure is the force exerted by the blood confined within blood vessels or heart chambers. Even more specifically, the pressure exerted by blood against the wall of a capillary is called capillary hydrostatic pressure (CHP), and is the same as capillary blood pressure. CHP is the force that drives fluid out of capillaries and into the tissues.

As fluid exits a capillary and moves into tissues, the hydrostatic pressure in the interstitial fluid correspondingly rises. This opposing hydrostatic pressure is called the interstitial fluid hydrostatic pressure (IFHP). Generally, the CHP originating from the arterial pathways is considerably higher than the IFHP, because lymphatic vessels are continually absorbing excess fluid from the tissues. Thus, fluid generally moves out of the capillary and into the interstitial fluid. This process is called filtration.

Osmotic Pressure

The net pressure that drives reabsorption—the movement of fluid from the interstitial fluid back into the capillaries—is called osmotic pressure (sometimes referred to as oncotic pressure). Whereas hydrostatic pressure forces fluid out of the capillary, osmotic pressure draws fluid back in. Osmotic pressure is determined by osmotic concentration gradients, that is, the difference in the solute-to-water concentrations in the blood and tissue fluid. A region higher in solute concentration (and lower in water concentration) draws water across a semipermeable membrane from a region higher in water concentration (and lower in solute concentration).

As we discuss osmotic pressure in blood and tissue fluid, it is important to recognize that the formed elements of blood do not contribute to osmotic concentration gradients. Rather, it is the plasma proteins that play the key role. Solutes also move across the capillary wall according to their concentration gradient, but overall, the concentrations should be similar and not have a significant impact on osmosis. Because of their large size and chemical structure, plasma proteins are not truly solutes, that is, they do not dissolve but are dispersed or suspended in their fluid medium, forming a colloid rather than a solution.

The pressure created by the concentration of colloidal proteins in the blood is called the blood colloidal osmotic pressure (BCOP). Its effect on capillary exchange accounts for the reabsorption of water. The plasma proteins suspended in blood cannot move across the semipermeable capillary cell membrane, and so they remain in the plasma. As a result, blood has a higher colloidal concentration and lower water concentration than tissue fluid. It therefore attracts water. We can also say that the BCOP is higher than the interstitial fluid colloidal osmotic pressure (IFCOP), which is always very low because interstitial fluid contains few proteins. Thus, water is drawn from the tissue fluid back into the capillary, carrying dissolved molecules with it. This difference in colloidal osmotic pressure accounts for reabsorption.

Interaction of Hydrostatic and Osmotic Pressures

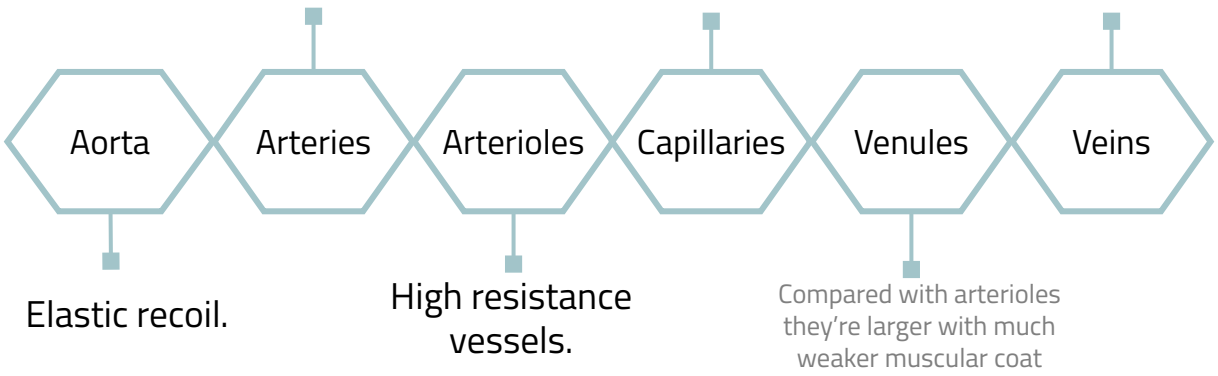
The normal unit used to express pressures within the cardiovascular system is millimeters of mercury (mm Hg). When blood leaving an arteriole first enters a capillary bed, the CHP is quite high—about 35 mm Hg. Gradually, this initial CHP declines as the blood moves through the capillary so that by the time the blood has reached the venous end, the CHP has dropped to approximately 18 mm Hg. In comparison, the plasma proteins remain suspended in the blood, so the BCOP remains fairly constant at about 25 mm Hg throughout the length of the capillary and considerably below the osmotic pressure in the interstitial fluid.

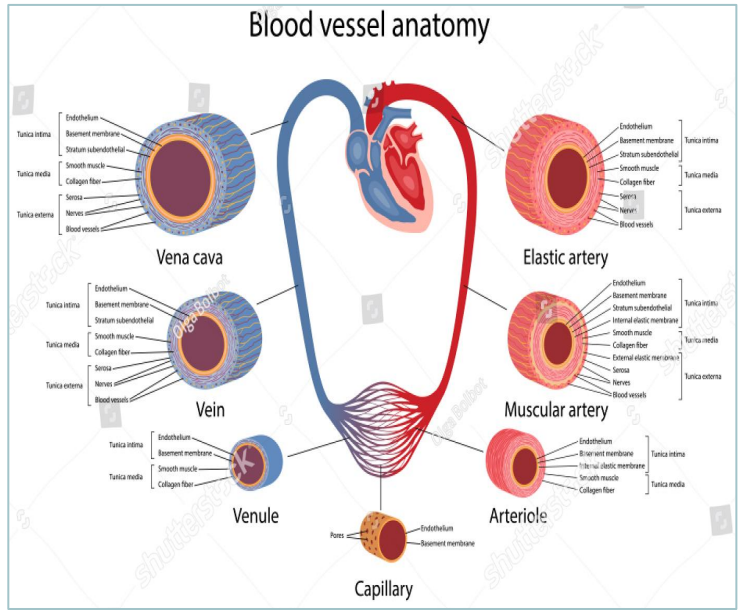
The net filtration pressure (NFP) represents the interaction of the hydrostatic and osmotic pressures, driving fluid out of the capillary. It is equal to the difference between the CHP and the BCOP. Since filtration is, by definition, the movement of fluid out of the capillary, when reabsorption is occurring, the NFP is a negative number.

NFP changes at different points in a capillary bed. Close to the arterial end of the capillary, it is approximately 10 mm Hg, because the CHP of 35 mm Hg minus the BCOP of 25 mm Hg equals 10 mm Hg. Recall that the hydrostatic and osmotic pressures of the interstitial fluid are essentially negligible. Thus, the NFP of 10 mm Hg drives a net movement of fluid out of the capillary at the arterial end. At approximately the middle of the capillary, the CHP is about the same as the BCOP of 25 mm Hg, so the NFP drops to zero. At this point, there is no net change of volume: Fluid moves out of the capillary at the same rate as it moves into the capillary. Near the venous end of the capillary, the CHP has dwindled to about 18 mm Hg due to loss of fluid. Because the BCOP remains steady at 25 mm Hg, water is drawn into the capillary, that is, reabsorption occurs. Another way of expressing this is to say that at the venous end of the capillary, there is an NFP of –7 mm Hg.

Congrats! You finished the lecture

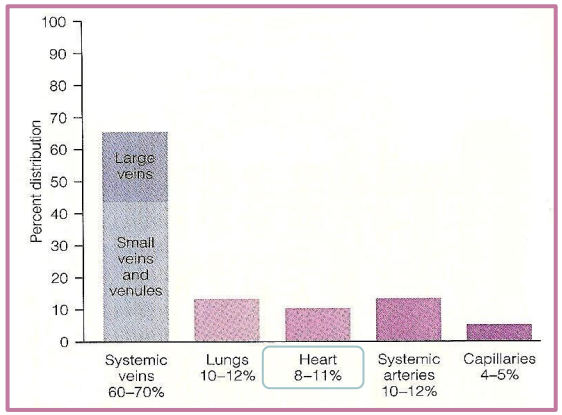
Classification of the Vascular System | Comparison of Blood Vessels



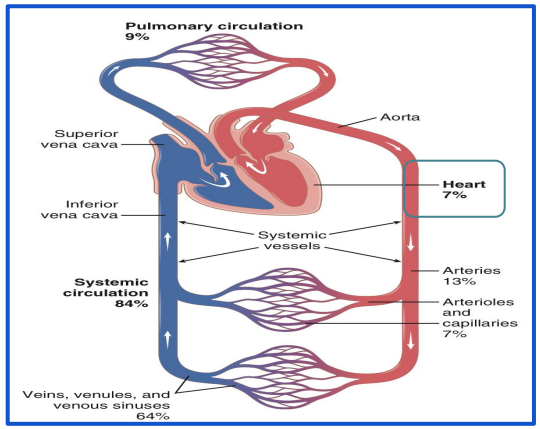


Distribution of Blood Within The Circulatory System At Rest

in female slides

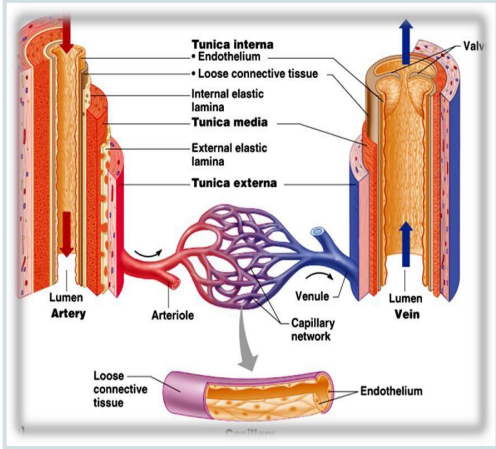


in male slides



The Capillaries: the smallest blood vessels

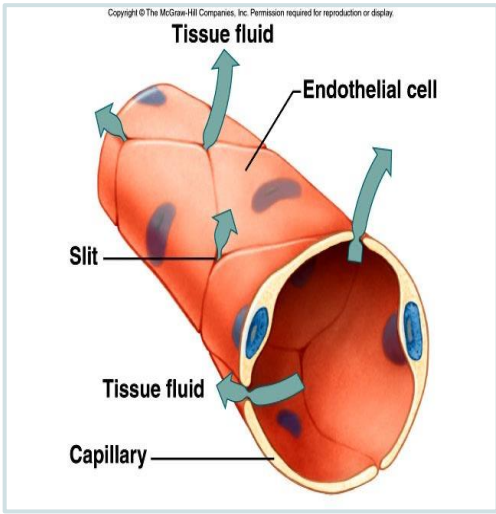
- Capillaries are the smallest blood vessels (microcirculatory vessels) in the vascular system.
- At rest, 5% of circulating blood is present in capillaries. as you saw in previous slide
- There are over 10 billion capillaries in the body.
- **They're exchange vessels.**
- **Provide** direct access to the cells.
- **Most permeable.**
- **Permits** (allow) exchange of nutrients & waste products.



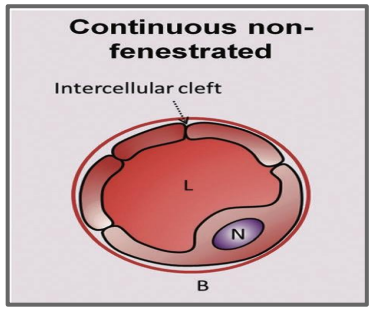
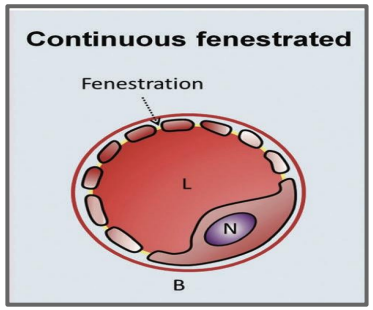
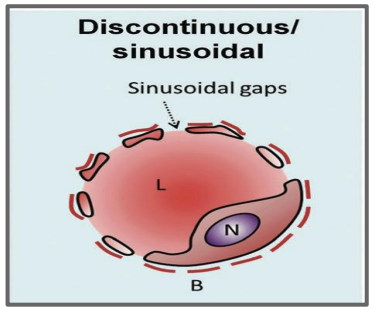
Capillary Structure *only in female slides

➔ Capillary is a small blood vessel of 0.5 mm long - 0.01 mm in diameter.

➔ It consists **ONLY** of the Tunica Interna **with** a single layer of endothelial cells **surrounded by** a basement membrane

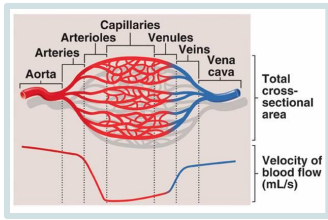


Types of Capillaries (IMPORTANT)

Classified by permeability (size & diameter of pores)		
Continuous	**Fenestrated**	**Sinusoidal**
• Do not have fenestrae. • Allow only very small molecules to pass. • Found in **brain** (that is why a lot of molecules cannot cross the BBB), **muscles**, **lung**, & **adipose tissue**. • **Water-soluble** substances such as water itself, ions, glucose, and amino acids are not lipid soluble; thus, they cannot cross the endothelial cell membranes. The diffusion of water-soluble substances is limited to the aqueous clefts between endothelial . • Why can't proteins cross the cleft? because they're too large .	• Have wider pores. • Allow large substances to pass but **not plasma proteins**. • Found in **kidney glomeruli**, **small intestine**, & **endocrine glands.**	• Large diameter with large fenestrae (wider gaps between the cells). • The endothelium is discontinuous. • Found in **liver**, **spleen**, **bone marrow**, **lymphoid tissue,** & some **endocrine glands.**
	 pores are smaller than fenestrae	

Capillaries Cross-Sectional Area

- The velocity of blood flow within each segment of the circulatory system is inversely proportional to the total cross-sectional area of the segment.
  - **Because** the aorta has the smallest total cross-sectional area of all circulatory segments, it has the highest velocity of blood flow.
- As the diameter of blood vessel decreases, the total cross-sectional area increases & velocity of blood flow decreases.
- Total capillary surface area of 700-1000 m^2 ,**the capillaries has the largest total cross sectional area**, which means it has a slow blood flow, and that slow flow is useful in order for gas exchange to occur.



Diameter of blood vessel ↓→ The total cross-sectional area ↑→ velocity of blood flow ↓

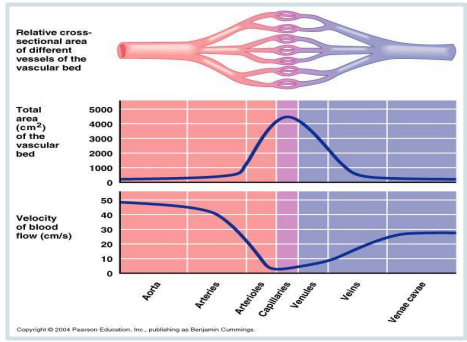
Capillaries Cross-Sectional Area: Cont.

Big boi ninja explained this beautifully in 6 minutes (11:35 - 17:43)

From Guyton:

Cross-Sectional Areas and Velocities of Blood Flow.
If all the systemic vessels of each type were put side by side, their approximate total cross-sectional areas for the average human being would be as follows:

Vessel	Cross-Sectional Area (cm^2)
Aorta	2.5
Small arteries	20
Arterioles	40
Capillaries	2500
Venules	250
Small veins	80
Venae cavae	8



Note particularly that the cross-sectional areas of the veins are much larger than those of the arteries, averaging about four times those of the corresponding arteries. This difference explains the large blood storage capacity of the venous system in comparison with the arterial system.

Because the same volume of blood flow (F) must pass through each segment of the circulation each minute, the velocity of blood flow (v) is inversely proportional to vascular cross-sectional area (A):

$$v = \frac{F}{A}$$

Thus, under resting conditions, the velocity averages about 33 cm/sec in the aorta but is only 1/1000 as rapid in the capillaries—about 0.3 mm/sec. However, because the capillaries have a typical length of only 0.3 to 1 millimeter, the blood remains in the capillaries for only 1 to 3 seconds, which is surprising because all diffusion of nutrient food substances and electrolytes that occurs through the capillary walls must be performed in this short time.

*only in female slides

Functions of capillaries

1-Exchange vessels between blood and tissue

- **Provide direct** access to the cells.
- **Most permeable:** They form a selectively permeable barrier between the circulatory system & the tissues supplied.
- **Transport** nutrients & Oxygen from blood to the tissues**.**
- **Remove** CO_2 and cellular waste products from the tissues to the blood.

2-Capillary tone

3- Play a metabolic role

- **Produce** PgI2, growth factors for blood cells, fibroblast GF, platelet GF & in the lungs, angiotensin converting enzyme.
- **Inactivation** of intercellular messengers.
- Antithrombotic function.

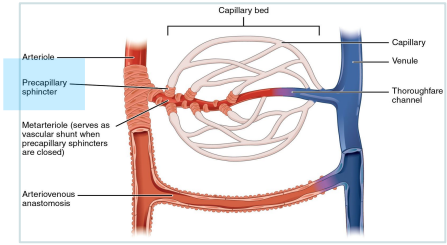
4-*Play role in temperature regulation:

- Blood vessel dilatation (**vasodilatation**), Increase heat loss across epidermis.
- Blood vessel constriction (**vasoconstriction**), Heat conservation across epidermis.

*only in female slides

*Capillary Beds (Network) | Components of Microcirculation

- Capillaries are arranged in capillary beds.
- Arterioles divides into a number of metarterioles, which **do not** have a continuous smooth muscle coat.
- Blood flow through the metarteriole to **enter** capillary bed via **precapillary sphincters**.
- Venules drain capillary network.
- Arteriolar smooth muscle, metarterioles, and precapillary sphincters regulate the blood flow in capillary network.
- Blood flows from arterioles through metarterioles, then through capillary network → Venules drain network.



The **Precapillary sphincter** can constrict and prevent blood to flow to the true capillaries, so the blood will flow through the **Metarteriole**. The **Thoroughfare** differ from the **Metarteriole** on Not having smooth muscles (Precapillary sphincter).

Capillary beds consist of two types of vessels

Vascular shunt (Anastomosis)

Directly connect an arteriole to a venule.

من غير ما يحصل **exchange** الدم اللي جاي من الارتيري هو نفسه اللي راح يدخل الفين

True capillaries

exchange vessels.

- O_2 and nutrients cross to cells
- CO_2 and metabolic waste products cross into blood.

Mechanisms of trans-capillary exchange

only in female slides

1

Simple diffusion of lipids soluble gases (O_2 and CO_2) according to concentration gradient (passive diffusion)

Guyton: If a substance is lipid soluble, it can diffuse directly through the cell membranes of the capillary without having to go through the pores.

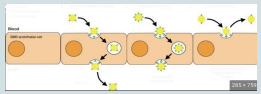
2

Filtration bulk flow(please check first slide to know the meaning of bulk flow) for fluid transfer by starlings force according to pressure gradient

The **direction of fluid movement** can be either into or out of the capillary. When net fluid movement is *out of* the capillary into the interstitial fluid, it is called **filtration;** when net fluid movement is from the interstitial fluid *into* the capillary, it is called **absorption.**

3

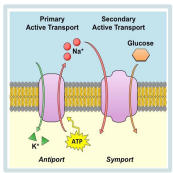
Vesicular transport: Transcytosis (Endocytosis then Exocytosis)



4

Mediated (membrane) transport occurs only in capillaries of the **brain** and involves secondary active transport,e.g. transport of glucose moves by co-transports in cell membrane"

if you recall in foundation block
Na+/K+ pump: تطلع الصوديوم وتدخل البوتاسيوم
وينتج عن هذا طاقة الطاقة هذي تستخدم في انتقال الجلوكوز لذالك سميناه سكندري لانه يعتمد على مصدر ثاني في الطاقة ، ينتقل الجلوكوز بمساعدة الصوديوم داخل الخلية وبهذي الطريقة نقدر نسمي انتقال الجلوكوز mediated transport والصوديوم هو الCo-transport



Formation of Interstitial Fluid (IF)

- High content of proteins in plasma accounts for its higher osmotic pressure compared to that of the interstitial fluid (IF). **Note** that the Osmotic pressure is determined by the protein concentration.
- High plasma osmotic pressure will **attract** fluid and dissolved substances from tissue spaces into the **circulation**.
- Opposing this osmotic force, hydrostatic pressure of the blood tends to force fluids **out** of the circulation into the tissue spaces.
- **Equilibrium** between osmotic and hydrostatic pressures is always maintained.

*only in female slides

Diffusion at Capillary Beds (Fluid Balance – Starling's Forces)

Outward force ↓ out of the capillaries				Inward force ↑ into the capillaries	
Capillary blood pressure	**Interstitial fluid pressure**	**Interstitial fluid colloidal osmotic pressure**	**TOTAL**	**Plasma colloidal osmotic pressure**	**Interstitial hydrostatic pressure**
Pc= 35 or 40 to 15 mmHg	P_{IF}= 0 mmHg	µIF= 3 mmHg	38 to 18 mmHg	µc=25 or 28 mmHg	P_{IF}=0 mmHg
The value for Pc is determined by both arterial and venous pressures	-	πi is determined by the interstitial fluid protein concentration. Normally, because there is little loss of protein from capillaries, there is little protein in interstitial fluid, making µIF quite low.	-	it is determined by the **protein concentration** of capillary blood. Therefore, increases in protein concentration of blood cause increases in µc	-

*Interstitial Hydrostatic Pressure

Interstitial hydrostatic pressure (P_{IF}) = 0 mmHg. P_{IF} varies from one organ to another:	
Location	Pressure
Subcutaneous tissues	-2mmHg.
Liver, Kidney:	+1mmHg.
Brain	As high as +6mmHg.

*Regulation of Capillary & Interstitial Fluid Exchange

*only in female slides

- Blood pressure, capillary permeability & osmosis affect movement of fluid from capillaries.
- A net movement of fluid occurs from blood into tissues will be affected by balance of net forces found in the capillaries & tissue spaces.
- Fluid gained by tissues is removed by **lymphatic system.**

Normal Forces at The Arterial & Venous Ends of The Capillary;

Forces Analysis

Arterial end (Forces Tending to Move Fluid **Outward**)	
Capillary (Blood) (Hydrostatic) pressure	35 mm Hg 40 mmHg
Interstitial fluid colloid osmotic pressure	3 mm Hg
TOTAL OUTWARD FORCE	38 mm Hg
Arterial end (Forces Tending to Move Fluid **Inward**)	
Plasma colloid osmotic pressure	-25 mm Hg -28 mmHg
Summation of Forces	38-25=13
NET OUTWARD FORCE : cause filtration	13 mm Hg

Venous end (Forces Tending to Move Fluid **Outward**)	
Capillary (Blood) (Hydrostatic) pressure	15 mm Hg
Interstitial fluid colloid osmotic pressure	3 mm Hg
TOTAL OUTWARD FORCE	18 mm Hg
Venous end (Forces Tending to Move Fluid **Inward**)	
Plasma colloid osmotic pressure	-25 mm Hg
Summation of Forces	18-25= -7
NET INWARD FORCE : cause reabsorption	-7 mm Hg

- Tissue Hydrostatic Pressure= 0 mmHg
- Tissue Osmotic Pressure= 3 mmHg

Thanks to team 438

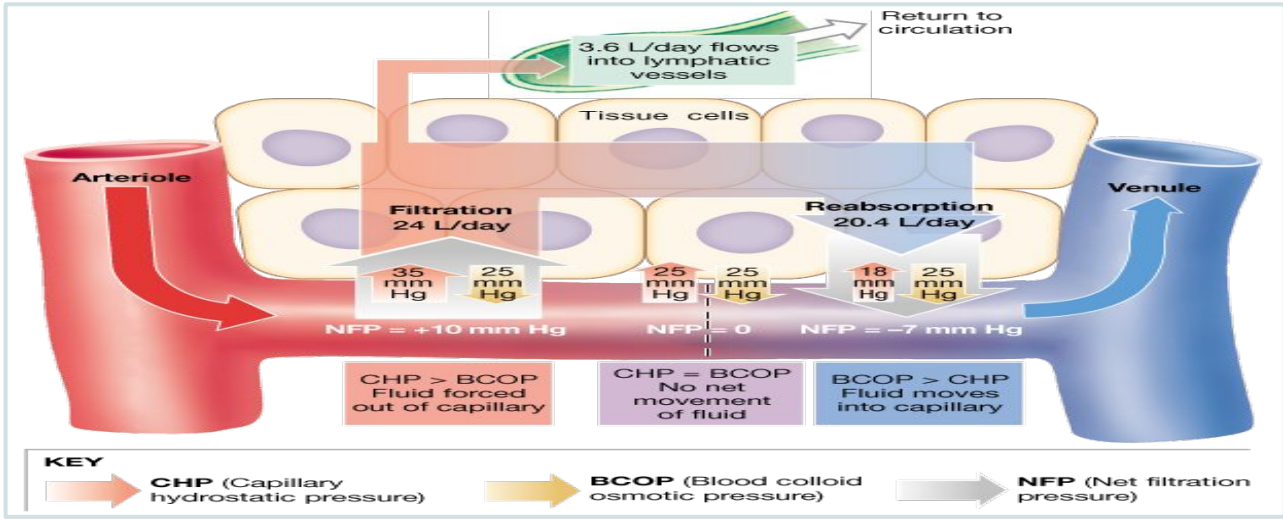
Normal Forces at The Arterial & Venous Ends of The Capillary; Cont

At Arterial End

- Hydrostatic pressure **dominates** at the arterial end, as a net sum of pressure forces (blood hydrostatic pressure + Interstitial fluid (IF) osmotic pressure) flow fluid **out** of the circulation.
- Water moves **out** of the capillary with a net filtration pressure **(NFP) of** +13 mmHg sometimes +10 mmHg
- 13 mmHg NFP causes an average of 1/200 of plasma in flowing blood to filter out of arterial end of the capillary into the interstitial space.

At venous End

- Oncotic pressure **dominates** at the venous end, as a net sum of pressure forces (blood osmotic pressure + Interstitial fluid (IF) hydrostatic pressure) flow fluid into the bloodstream.
- Water moves into the capillary with a **NFP of** -7 mmHg.



Big boi ninja explained this beautifully as well (5:40-15:00)

Clinical Significance of Capillary Filtration

Blood loss

Vasoconstriction of arterioles

sympathetic stimulation

⇊

Decrease capillary hydrostatic pressure

⇊

Osmotic pressure of plasma proteins favours absorption of interstitial fluid

fluid shift mechanism

⇊

Increase Blood volume

Congestive heart failure

Venous pressure rises

⇊

build-up of blood in capillaries

⇊

Increase capillary hydrostatic pressure

⇊

Increase filtration

⇊

oedema

Hypoproteinemia

(Starvation ,liver disease)

Decrease plasma protein colloid osmotic pressure

⇊

loss of fluid from capillaries

⇊

oedema

Inflammation

Increase The gaps between the endothelial cells (because of the inflammatory mediators)

⇊

Increase the movement of proteins into the interstitium

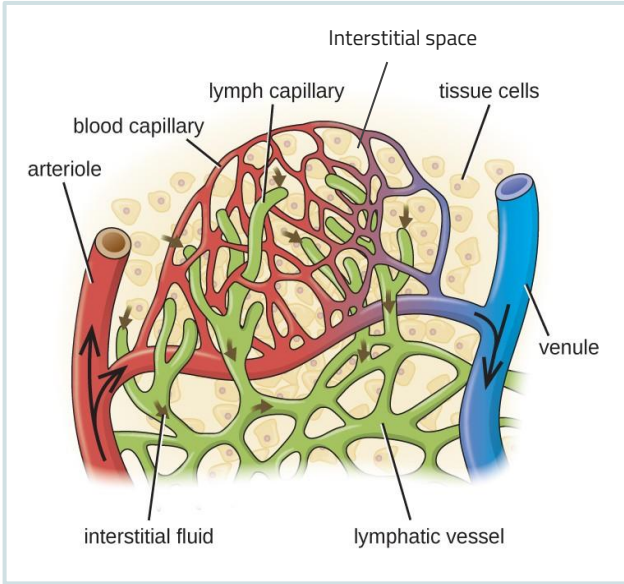
⇊

oedema

*Lymphatic system

*only in female slides

- Lymphatic vessels present between capillaries
- 3 basic **functions** :



- Drain excess interstitial (tissue) fluid back to the blood, in order to maintain original blood volume.
- Transports absorbed fat from small intestine to the blood.
- Helps provide immunological defense against pathogens.

Lymphatic Capillaries System

- Interstitial fluid enter the lymphatic capillaries through loose junctions between endothelial cells.
- Lymph flow back to the thoracic duct with the help of contraction of both the lymphatic vessel walls smooth muscle & the surrounding skeletal muscle.
- Failure of lymphatic drainage can lead to **edema**

- Lymphatic capillaries are small, thin-walled , micro-vessels located in the spaces between cells except CNS. Serve to drain and process ECF.
- Lymphatic capillary carries lymph into lymphatic vessels, connects to a lymph node to the venous circulation .
- Lymphatic capillaries are slightly larger in diameter than blood capillaries, allow interstitial fluid to flow into them but not out.

only in female slides

Edema

❖ **Edema**: Is the term used to describe unusual accumulation of interstitial fluid.

Occurs **when there are :**

alteration in Starling forces balance:

-Any **Decrease** in plasma protein (albumin) concentration will lead to a decrease in plasma osmolarity, allowing fluid to escape from circulation to the interstitial space

-Any **Increase** in capillary hydrostatic pressure

By far, the most important mechanism for fluid transfer across the capillary wall is **osmosis**, driven by hydrostatic and osmotic pressures. These pressures are called the Starling pressures or **Starling forces.**

Failure of lymphatic drainage

-We call it lymphedema occurs when your lymph vessels are unable to adequately drain lymph fluid, usually from an arm or leg. Lymphedema can be either primary or secondary. This means it can occur on its own (primary lymphedema), or it can be caused by another diseases or conditions like cancer or surgery (secondary lymphedema)

Secondary to :

-Histamine, Bradykinin administration, where they increase capillary permeability leading to edema

Hormones Involved In Edema

Activation of Anti-diuretic hormone (**ADH**) (Vasopressin) leading to **water retention**.

Activation of Renin-Angiotensin-Aldosterone System (**RAAS**) which will cause secondary Hyperaldosteronism, leading to **Na+ retention.**

Quiz:

1-Which one of the following is a high resistance blood vessel?
A) Arteries
B) Aorta
C) Arterioles
D) Capillaries

2-Where can Continuous Capillaries be found in?
A) Brain
B) Kidney
C) Liver
D) Bone Marrow

3-Which type of the blood vessels is the most permeable?
A) Arteries
B) Aorta
C) Arterioles
D) Capillaries

4-Vascular shunt directly connect an Arteriole to
A) metarterioles
B) capillaries
C) venule
D) Aorta

5-Mediated (membrane) transport occurs only in capillaries of
A) Liver
B) Kidney
C) Lungs
D) Brain

6-Interstitial hydrostatic pressure in the Subcutaneous tissues is
A) 0
B) -2
C) +1
D) +6

7-Which of the following is a Hormone involved in regulation of edema
A) ADH
B) Glucagon
C) Histamine
D) Insuline

8-which of the following lead to increase the blood volume
A) congenital heart disease
B) blood loss
C) Hypoproteinemia
D) Inflammation

9-Edema can occur due to Decrease of which protein
A) albumin
B) elastin
C) collagen
D) fibrin

10- which of the following is true about Sinusoidal Capillaries:
A) Have pores, allow large substances to pass but not plasma proteins
B) Do not have fenestrae
C) Large diameter with fenestrae
D) serves as reservoirs for blood

Answer Key: 1C - 2A - 3D - 4C - 5D
6B - 7A - 8B- 9A - 10C

Quiz:

1- Describe the capillaries structure?

2-Describe the velocity of blood flow through a decreased diameter vessel ?

3-What are the functions of capillaries?

4-What are the Mechanisms of trans-capillary exchange?

5-List the basic functions of lymphatic system

6- Define Edema

A1: It consists **ONLY** of the Tunica Interna **with** a SINGLE Layer of endothelial cells **surrounded by** a basement membrane

A2: As the diameter of blood vessel decreases, the total cross-sectional area increases & velocity of blood flow decreases.

A3: Exchange vessels between blood and tissues -capillary tone -play a metabolic role -temperature regulation.

A4: Simple diffusion -Filtration-Vesicular transport - mediated (membrane) transport.

A5:
1- Drain excess interstitial (tissue)fluid back to the blood, in order to maintain original blood volume.
2-Transport absorbed fat from small intestine to the blood
3-Help to provide immunological defenses against pathogens

A6: Is the term used to describe unusual accumulation of interstitial fluid

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