Revised & Reviewed by: Abdulaziz & Bahammam
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MED441
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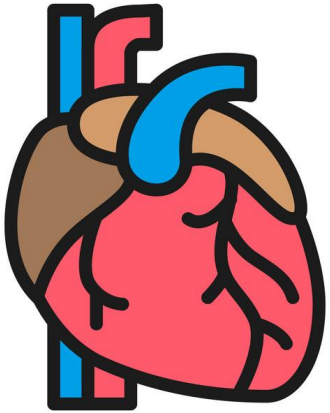

Capillary Circulation

Color Index:
- Main text
- Important
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Editing File

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.

Classification of the Vascular System and Comparison of Blood Vessels

Aorta: Elastic recoil.

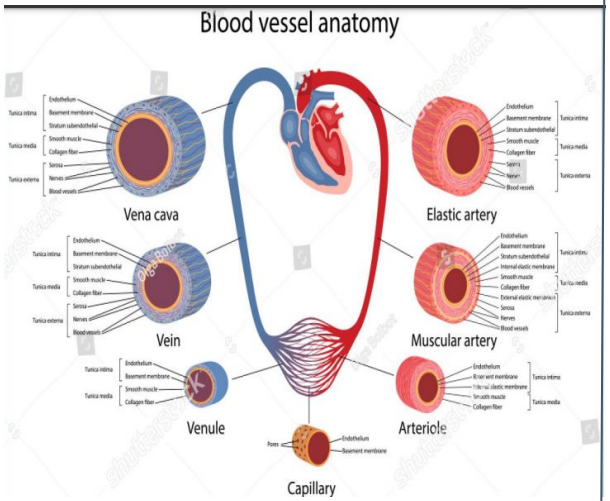
Arteries: Muscular, low resistance vessels.

Arterioles: High resistance vessels

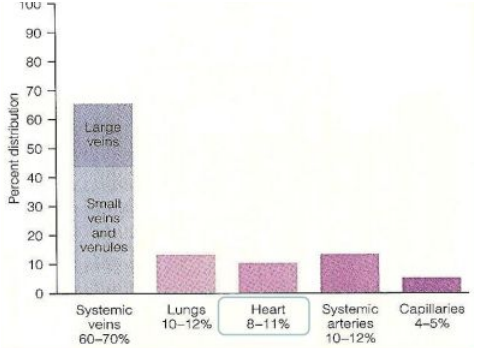
Venules :weaker muscular coat

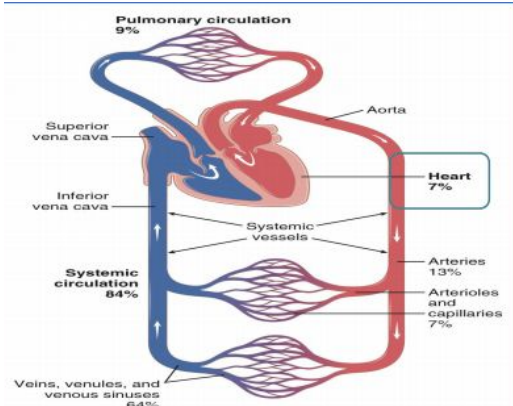
Veins: Capacitance vessels

Capillaries: Exchange vessels.



Distribution of Blood Within The Circulatory System At Rest

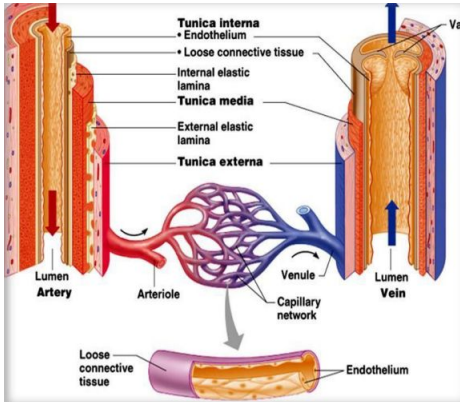


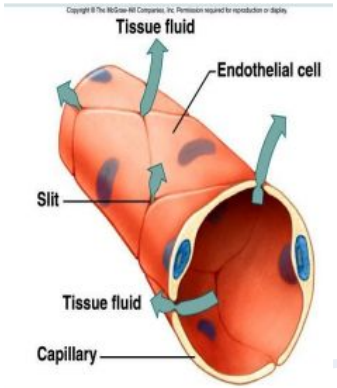


The Capillaries and Their Structure

- ★ capillaries are the smallest blood vessels (microcirculatory vessels) in the vascular system

- ★ At rest, 5% of circulating blood is present in capillaries
- ★ There are over 10 billion capillaries in the body
- ★ They're exchange vessels.
- ★ Provide direct access to the cells
- ★ Most permeable.
- ★ Permits (allows) exchange of nutrients & waste products
- ★ 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

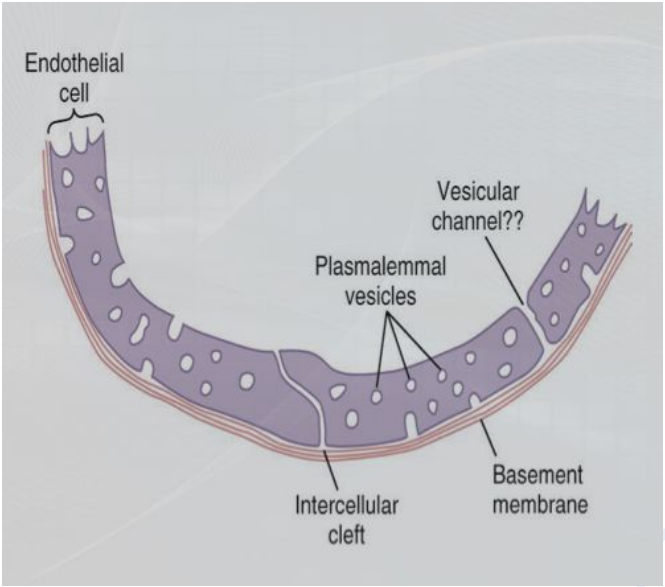




Girls' Slides Only

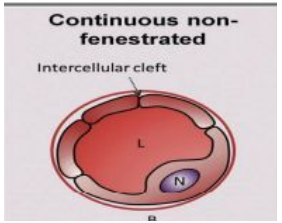
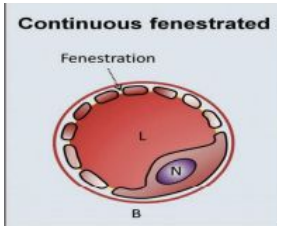
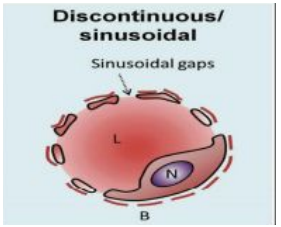
Capillary Wall

- Single layer of simple squamous epithelia.
- Of 0.5 micrometers in thickness
- Of 3 types: Continuous (true), Fenestrated, & Sinusoidal.
- Regulates transfer of fluid from blood to the interstitial fluid space & vice versa.



Types of Capillaries

Classified by permeability (size & diameter of pores)

Continuous	Do not have fenestrae. Allow only very small molecules to pass Found in brain, muscles, lung, & adipose tissue.	
Fenestrated	Have wider pores. Allow large substances to pass but **not plasma proteins.** Found in kidney glomeruli, small intestine, & endocrine glands.	
Sinusoidal	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.	

Organ Variability of Capillary Filtration

Brain & Muscle	**Small**
subcutaneous	**Moderate**
Intestines	**Large**
Liver & Kidneys	**Extremely large**

Why is there such a difference?
Because of their permeability.
How does the permeability change?
Altered size of Clefts/Pores between cells.

Capillaries Cross-Sectional Area

Video

- The velocity of blood flow within each segment of the circulatory system is inversely proportional to the total cross-sectional area of the segment.

تذكروا العطر

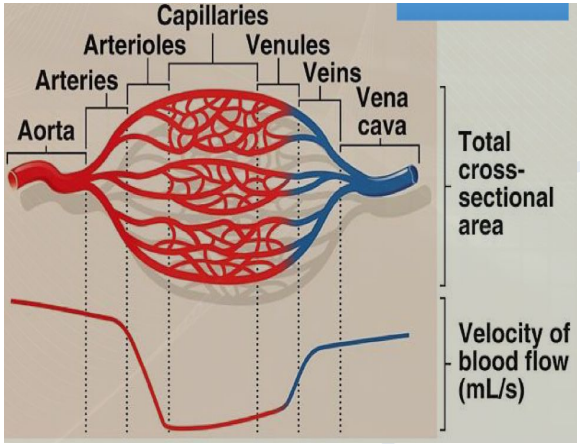
- Because the aorta has the smallest total cross-sectional area of all circulatory segments, it has the highest velocity of blood flow.

$$V = Q / A$$

- 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 m2
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

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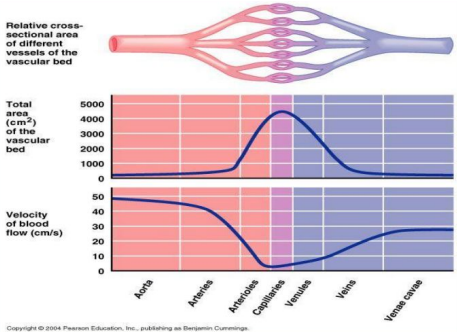
From Guyton:

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 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):

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

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.

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 CO2 and cellular waste products from the tissues to the blood.

2

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.

3

Play role in temperature regulation
-Blood vessel dilatation (vasodilatation), Increase heat loss across epidermis.
- Blood vessel constriction (vasoconstriction), Heat conservation across epidermis.

4

Capillary tone

Capillary Beds (Network)

-Capillaries are arranged in capillary beds.

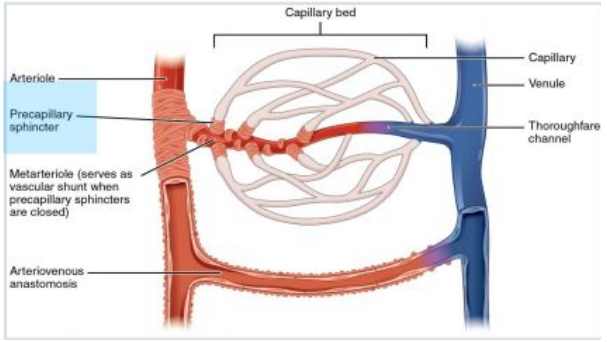
-**Arterioles** divides into a number of **metarterioles**, *which do not have a continuous smooth muscle coat.*

-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.



439: 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).

Components of Microcirculation

Capillary beds consist of two types of vessels	
Vascular shunt (Anastomosis) Directly connect an **arteriole** to a **venule** WITHOUT exchange	**True capillaries** exchange vessels. -O2 and nutrients cross to cells -CO2 and metabolic waste products cross into blood

Girls' Slides Only

Mechanisms of trans-capillary exchange

Video

Simple diffusion	For lipids soluble gases (O2 and CO2) according to concentration gradient (passive diffusion) by cell membrane bilayer
Filtration (bulk flow)	for fluid transfer by starlings force according to pressure gradient (hydrostatic pressure and osmotic pressure) 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.
Vesicular transport:	Transcytosis (Endocytosis and Exocytosis)
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" زي لما الجلوكوز او الكالسيوم ينتقل مع k and Na pump

Capillary Fluid Transfer

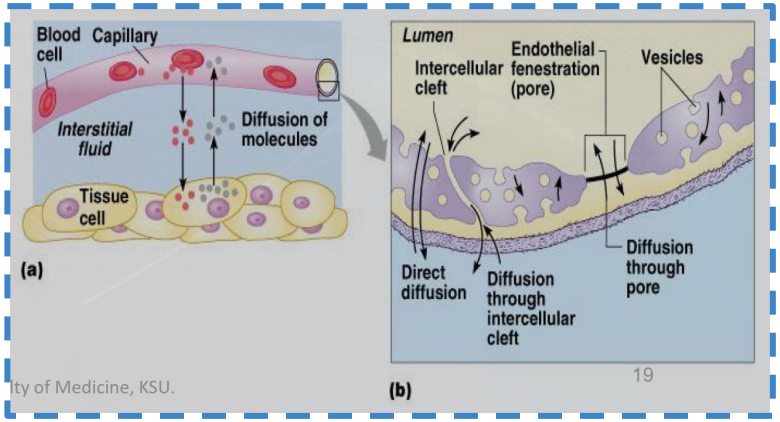
Filtration (Bulk Flow):

- ★ **Occurs by Diffusion or by vesicular transport.**
- ★ **Diffusion occurs through,**

  the cells: for lipid soluble molecules.

  the intercellular clefts between cells:for non-lipid soluble molecules.

- ★ **Concentration gradients, cleft size (permeability) & hydrostatic pressure influence the fluid movement (varies by organ & situation).**



Formation of Interstitial Fluid (IF)

❖ Formation of the Interstitial Fluid (IF) is regulated by the rate of net fluid movement (filtration & absorption) at the two ends (arterial & venous) of the Capillary bed.

❖ **Regulation of Capillary & Interstitial Fluid Exchange:**

- ❖ 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**.

How Do We Calculate The Net Movement at The Capillary Bed?

❖ *Filtration rate of fluid at the Capillary:*

Equals to the **Net Filtration Pressure (NFP)** multiplied by the **Filtration Coefficient (Kf).**

Filtration Rate = K_f * NFP

❖ **Filtration Coefficient** (Kf) is a product of surface area times the hydraulic conductivity of membrane (membrane permeability).

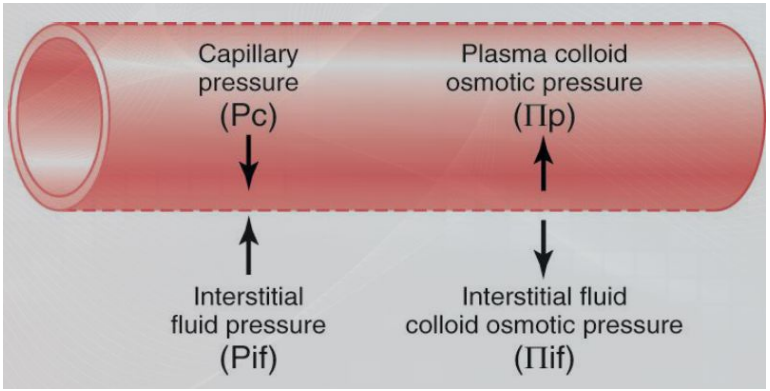
❖ **If NFP = positive, then fluid is lost from capillary.**

❖ **If NFP = negative, then fluid is gained by capillary.**

Starling's Equation for Capillary Filtration

$$\text{Flux} = K_f [(P_c - P_{if}) - \sigma (\pi_p - \pi_{if})]$$

- **K_f =** Capillary filtration coefficient (surface area & permeability)
- **P_c =** Capillary hydrostatic pressure
- **P_{if} =** Interstitial hydrostatic pressure
- **σ =** Capillary reflection coefficient (0 to 1)
  1 = impermeable to proteins
- **π_c =** Capillary colloid osmotic pressure
- **π_{if} =** Interstitial colloid osmotic pressure



What Does this All Mean?

Fluid transfer depends on the relative balance between hydrostatic pressure & osmotic pressure.

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= 30 or 35 to 15 mmHg	PIF= 0 mmHg	μIF= 3 mmHg	38 to 18 mmHg	μc=25 or 28 mmHg	PIF=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	-

Hydrostatic Pressure (Outward Force):

❖ **Average normal Capillary hydrostatic pressure:** Is ≅17.3 mmHg. Pressure normally ranges from 30-35 mmHg on the **arterial end** to 10-15 mmHg on the **venous end**.

❖ **Interstitial fluid pressure:** In most tissues is negative 3.

Encapsulated organs have positive interstitial pressures (+5 to +10 mmHg).

Negative Interstitial fluid pressure: Is caused by pumping of lymphatic system.

❖ **Capillary hydrostatic pressure:** Is opposing the Capillary osmotic pressure & tends to force fluids out of the circulation into the tissue spaces.

Oncotic (osmotic) Pressure (Inward Force):

❖ **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.

❖ **Plasma osmotic pressure:** Is high (25-28 mmHg) & will attract fluid & dissolved substances from tissue spaces into the circulation.

❖ **Colloid osmotic pressure:** Is caused by presence of large proteins.

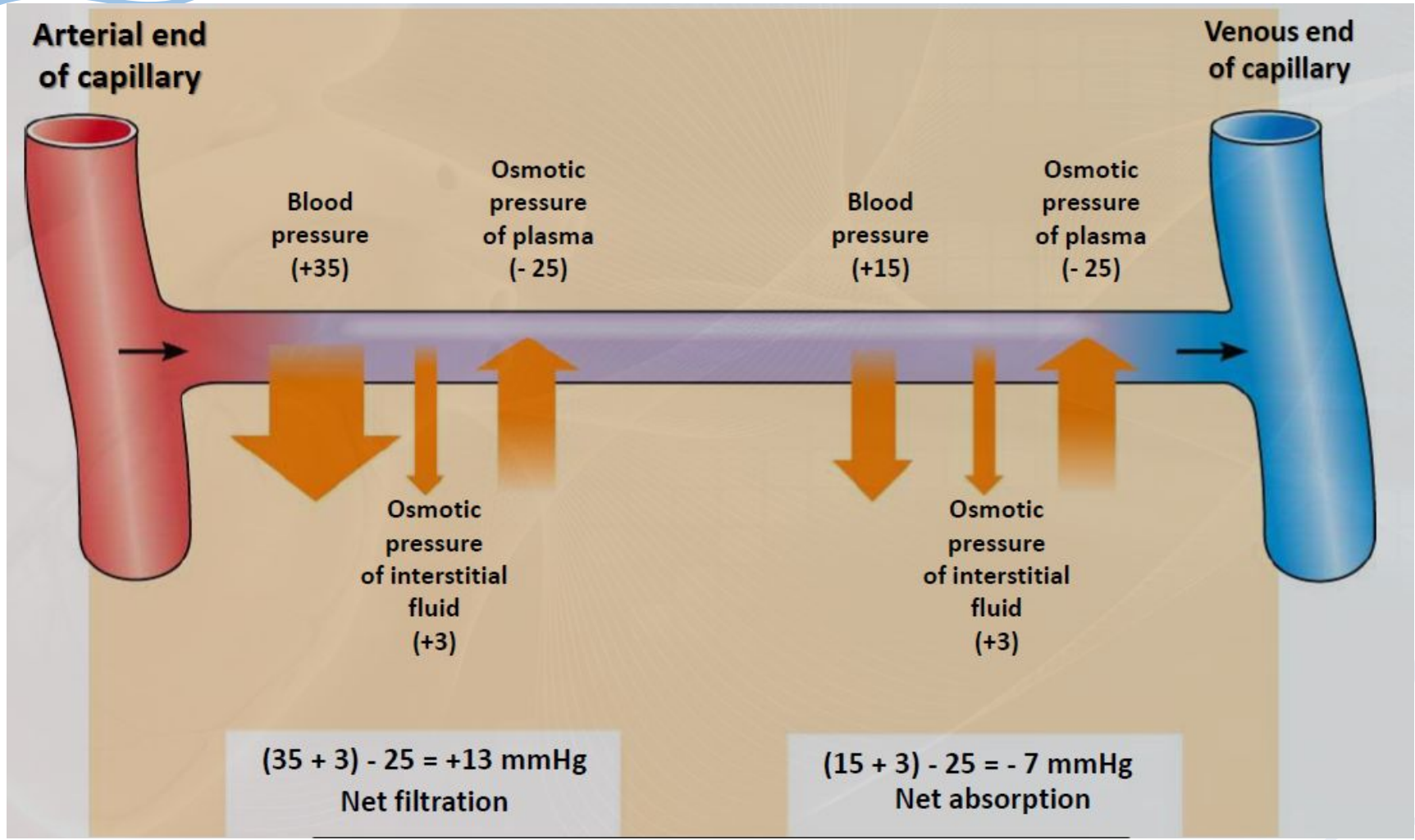
❖ **Equilibrium between osmotic and hydrostatic pressures is always maintained.**

Diffusion at Capillary Beds
Fluid Balance – Starling's Forces

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

Arterial end (forces tending to move fluid **outward**)	
Capillary (Blood) (**Hydrostatic**) pressure	30 mm Hg 35 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


Arterial end of capillary
Venous end of capillary
Blood pressure (+35)
Osmotic pressure of plasma (- 25)
Blood pressure (+15)
Osmotic pressure of plasma (- 25)
Osmotic pressure of interstitial fluid (+3)
Osmotic pressure of interstitial fluid (+3)
(35 + 3) - 25 = +13 mmHg
Net filtration
(15 + 3) - 25 = - 7 mmHg
Net absorption

Normal Forces at the Arterial & Venous Ends of the Capillary

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.

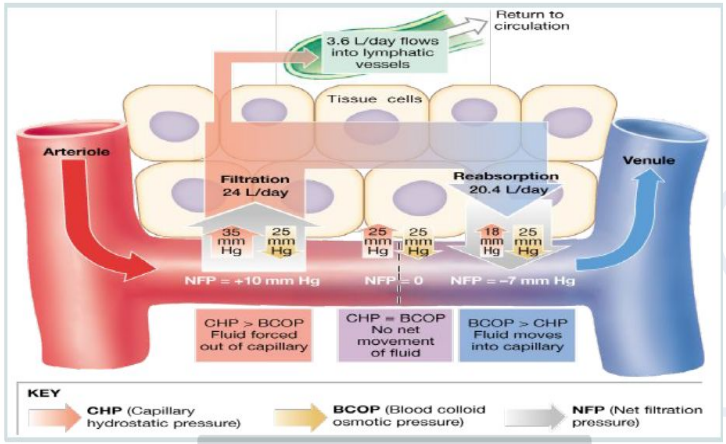
❖ Water moves out of the capillary with a net filtration
pressure **(NFP) of** +13 mmHg sometimes +10 mmHg

❖ 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.



Interstitial Hydrostatic Pressure

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

Summary of Factors Affecting Capillary Filtration	
1.Blood pressure	2. Permeability
3. Organ structure (encapsulated of not?)	4. Osmotic pressure

Under normal circumstances, Which of the following has the greatest influence on capillary fluid exchange ? (الترتيب مهم)	
1.Blood pressure	2. Permeability
3. Osmotic pressure	4. Lymphatic pressure

Female only

Which of the following is altered by the body to increase capillary filtration?	
1.Blood pressure	2. Permeability
3. Osmotic pressure	4. Lymphatic pressure

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)

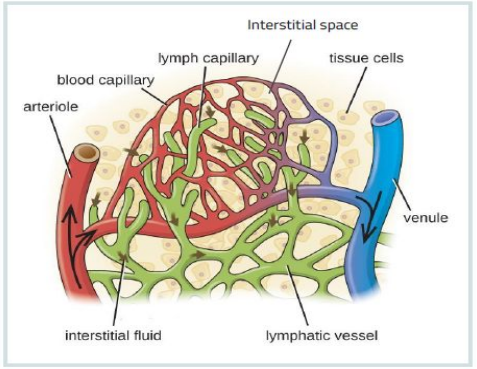
↓

Increase the movement of proteins into the Interstitium

↓

oedema

Lymphatic system



- Lymphatic vessels present between capillaries
- 3 basic **functions** :
  - Helps provide immunological defense against pathogens.
  - Transports absorbed fat from small intestine to the blood.
  - Drain excess interstitial (tissue) fluid back to the blood, in order to maintain original blood volume.

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.

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.**

Team Leaders

Rand aldajani

Nawaf Alshehri

QBank Team

Sub Leader

Samiah AlQutub

Team Members

Reem Alkulaibi

Feras Alzahrani