Physiology of Circulation

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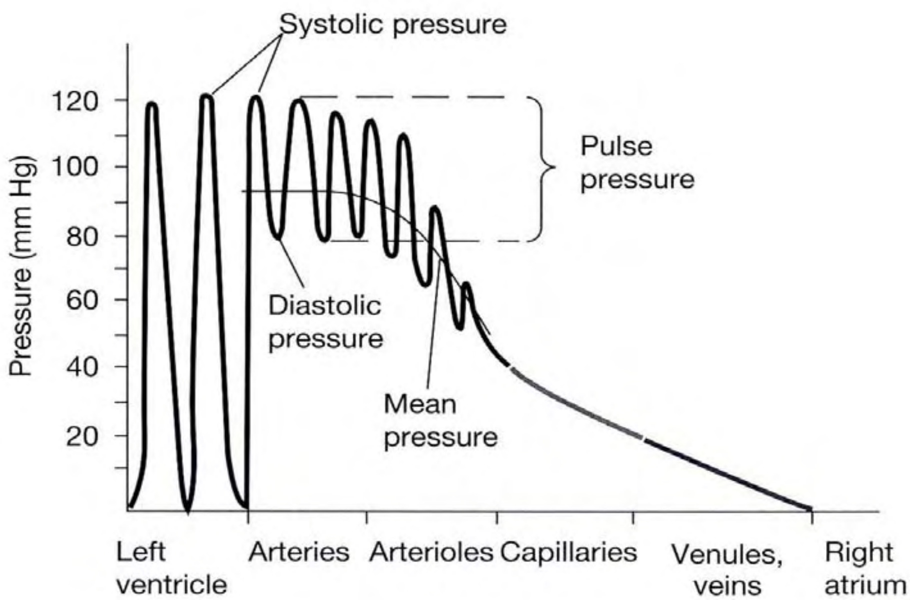
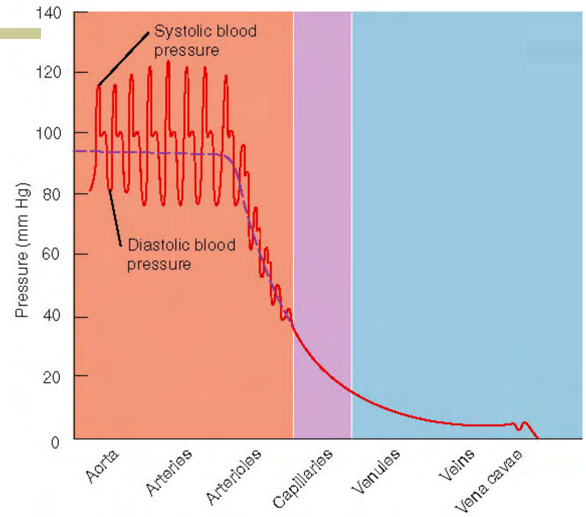
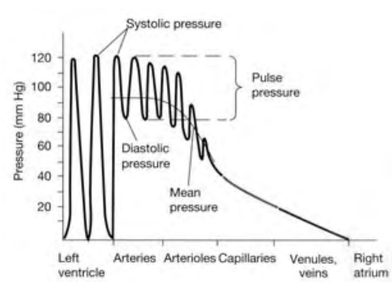


Fig.21.08



The Blood Pressure

- force exerted by the blood per unit area of the blood vessel wall.
- volume of blood is larger than the capacity of *non-distended vessels*

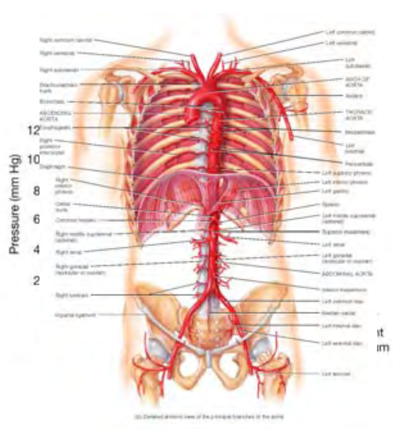


Blood Pressure in Various Parts of the Systemic Circulation

- The Mean Blood Pressure
- The Arterial Blood Pressure
- The Pulse Pressure

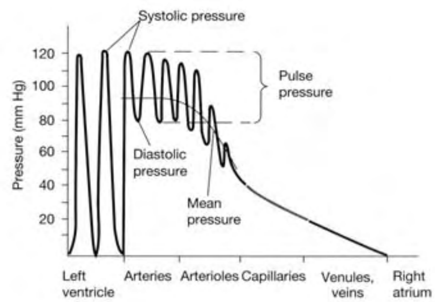
The Mean Blood Pressure

- average pressure attained in any segment of the CVS during the cardiac cycle.
- Large arteries→ very little change
- Arterial Blood Presure→ Capillary pressure→ Venous pressure→ Central Venous Pressure (CVP)
    - M.A.P= (P.sys + [2 x P.dia])/3
    - (120+[2x 80])/3
    - 280/3
    - 93.3 mmHg



The Arterial Blood Pressure

- Systolic Pressure
- Diastolic Pressure
- Mean Arterial Blood Pressure



Mean Arterial Blood Pressure

- is not the average of the systolic and diastolic pressure.
- measure the <u>area</u> under the pressure curve from peak to baseline by integration
- PLANIMETER
- area divided by the cycle length yields the average <u>height</u> of the curve

Mean Arterial Blood Pressure

- pressure necessary to drive the volumetric rate of flow (Q_p)through the existing total peripheral resistance (TPR)

$$P=Q_p \times TPR$$

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MEAN ARTERIAL BLOOD PRESSURE

- Alteration of the Arterial Capacity or Distensibility without an accompanying change in the Arterial Blood Volume
  - Effect of Change of Cardiac Output on Pressure
  - Effect of Change of TPR on P
  - Effect of Concomitant Change of Arterial Capacity and Distensibility.

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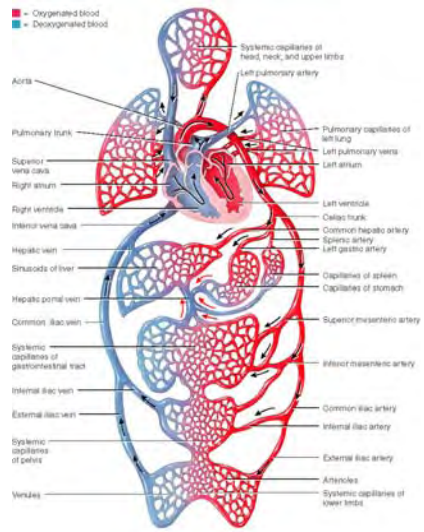
Effect of Change of Cardiac Output on Pressure

- Increase CO→ accumulation of blood and rise of pressure in the aorta→ P rises to the level at which peripheral blood flow = CO



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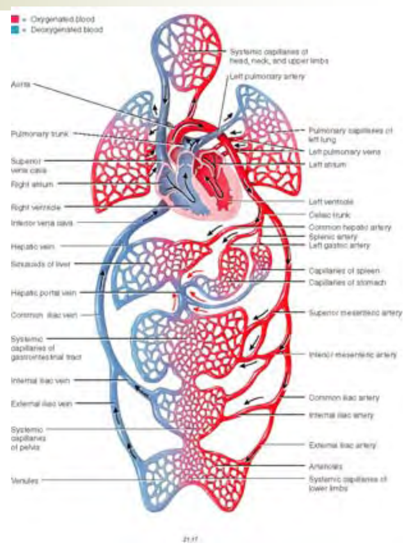
Effect of Change of TPR on P

- Increase of TPR→ decreased run off of blood from the aorta→ "damming" of blood in the aorta.
  - increased arterial blood volume→ increased arterial distention and rise of P until a level of P is attained at which the Q_p through the elevated resistance equals CO



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NOTE:

- TPR increased←→ increased of R in one or several beds

or

large increase of R in one bed even though there will be a small decrease in another bed

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Effect of Concomitant Change of Arterial Capacity and Distensibility.

- decrease distensibility and capacity→ ↑P
- increase Qp
- Change of distensibility without change of capacity→ without change
  - Reserve effects would accompany an increase of arterial capacity

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PULSE PRESSURE

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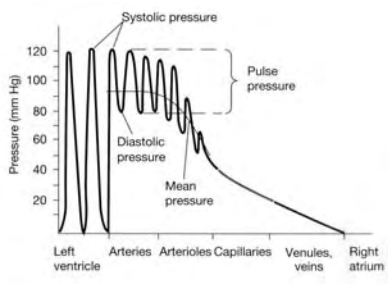
Pulse Pressure

- represents the rise of pressure produce by distention of the arterial tree produced by the entrance of 1 stroke volume during 1 systole.
- proportional to stroke volume regardless of the level of P



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Pulse Pressure

A. Effect of Change of Cardiac Output
B. Effect of Change of TPR
C. Effects of Change of Arterial Distensibility

Pulse Pressure

- Effect of Change of Cardiac Output

A. Effects of change only of stroke volume
  - *increase SV, constant HR → increase pulse pressure and P*

B. Effects of change only of heart rate
  - increase of heart rate, constant SV → elevate P

Pulse Pressure

- Effect of Change of TPR
  - increase TPR (constant SV, HR, AD)→ increase pressure but does not change pulse pressure→ SP and DP rise equally

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Pulse Pressure

Effects of Change of Arterial Distensibility

decrease arterial distensibility→ increase Pulse Pressure

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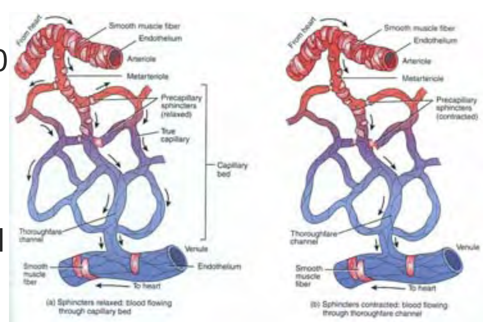
Capillaries

- transport nutrients
- remove cellular excreta
- thin structures
- 10 billion capillaries
- 500-700 square meters
- 20-30 micrometers away from a capillary

Structure of the Microcirculation and Capillary System

- artery branches 6-8 times→ arterioles (<20 micrometers)→2-5 times (5-9 micrometers) capillaries.
- Metarterioles (terminal arterioles)
- Preferential Channels
- True capillaries
- *Precapillary sphincter*
- *Venules*



(a) Sphincters relaxed: blood flowing through capillary bed
(b) Sphincters contracted: blood flowing through thoroughfare channel

Arterioles

- higly muscular
- diameter change manyfold

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Metarterioles

- do not have continuous muscular coat
- smooth muscle fibers encircle the vessel at intermittent points

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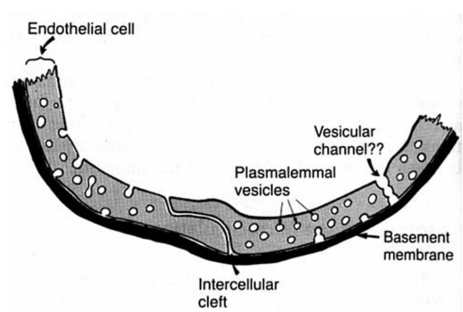
Venules

- larger
- weaker

- pressure is less than arterioles--contract

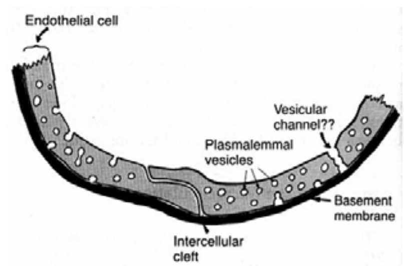
Structure of the Capillary Wall

- unicellular layer
- 0.5 micrometer
- 4-9 micrometers



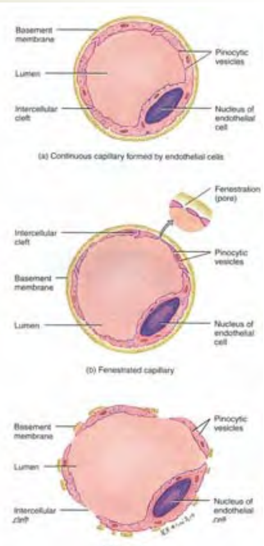
Pores in the Capillary Membrane

- intercellular cleft
  - spacing with a width 6-7 nanometers
- Plasmalemmal vesicles



Special Types of Pores

- Brain
- Liver- *wide, all dissolved substances can pass*
- Glomerular tufts of the kidney
  - small oval windows (*fenestrae*)→ penetrate directly through the middle of the endothelial cells, so that substances can be filtered through the glomeruli w/o passing through the clefts.



Flow of Blood in the Capillaries

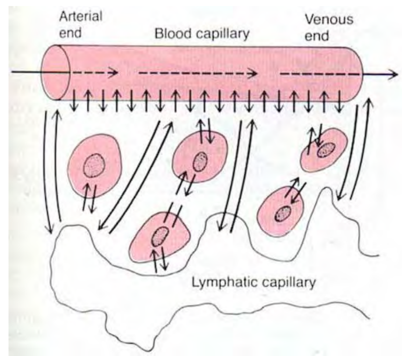
- Intermittently
- Vasomotion
  - Regulation of vasomotion
    - oxygen
      - increase rate of oxygen usage→ increase intermittent periods of blood flow, duration of flow

EXCHANGE

NUTRIENTS AND OTHER SUBSTANCES BETWEEN BLOOD AND AND INTERTITIAL FLUID

Diffusion

- results from thermal motion of the water molecules and the dissolved substances in the fluid
- the different particles moving first in one direction and then another
- moving randomly in every direction.

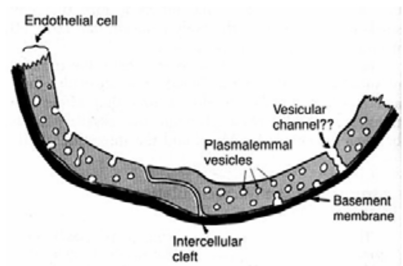


Diffusion Through the Capillary Membrane

- Lipid-soluble substances can diffuse directly through the cell walls of the capillary endothelium
- Water-soluble substances diffuse only through intercellular “pores” in the capillary membrane
- Effect of molecular size on passage through the pores
- Effect of concentration differences on net rate of diffusion through the capillary membrane

Diffusion

- Lipid-soluble substances can diffuse directly through the cell walls of the capillary endothelium
  - oxygen
  - carbon dioxide



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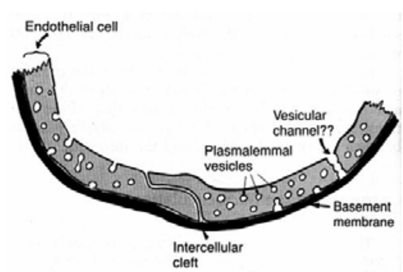
Diffusion

- Water-soluble substances diffuse only through intercellular "pores" in the capillary membrane
  - water
  - sodium
  - chloride
  - glucose



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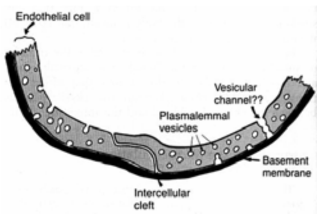
Diffusion

- Effect of molecular size on passage through the pores

RELATIVE PERMEABILITY OF MUSCLE CAPILLARY PORES TO DIFFERENT-SIZED MOLECULES

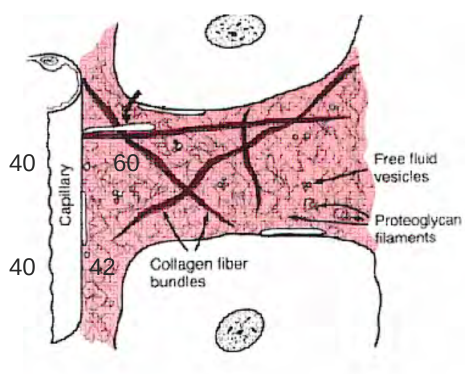
Substance	Molecular Weight	Permeability
Water	18	1.00
NaCl	58.5	0.96
Urea	60	0.8
Glucose	180	0.6
Sucrose	342	0.4
Inulin	5000	0.2
Myoglobin	17,600	0.03
Hemoglobin	68,000	0.01
Albumin	69,000	.001

Modified from Pappenheimer, *Physiol. Rev.*, *33*:387, 1953.



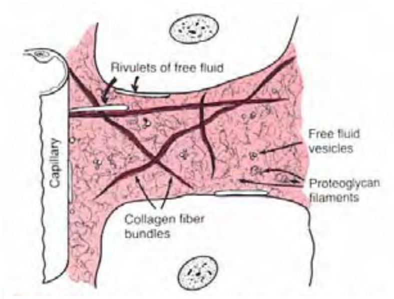
Diffusion

- Effect of concentration differences on net rate of diffusion through the capillary membrane
  - *the "net" rate of diffusion of a substance through any membrane is proportional to the concentration difference.*



THE INTERSTITIUM AND INTERSTITIAL FLUID

- Interstitium
  - Two Major Types of Solid Structure
    a. collagen fiber bundles- tensile strength
    b. proteoglycans filaments- form a mat. 98% HA, 2% CHON
  - Gel- tissue gel
    - pf + intertitial fluid



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THE PROTEINS

IN THE PLASMA AND INTERSTITIAL FLUID MAINLY DETERMINE THE PLASMA AND INTERTITIAL FLUID VOLUMES

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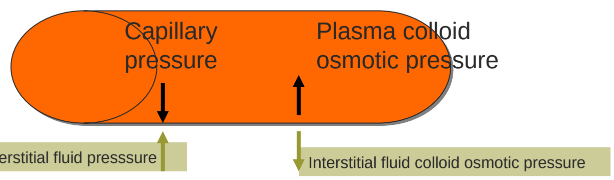
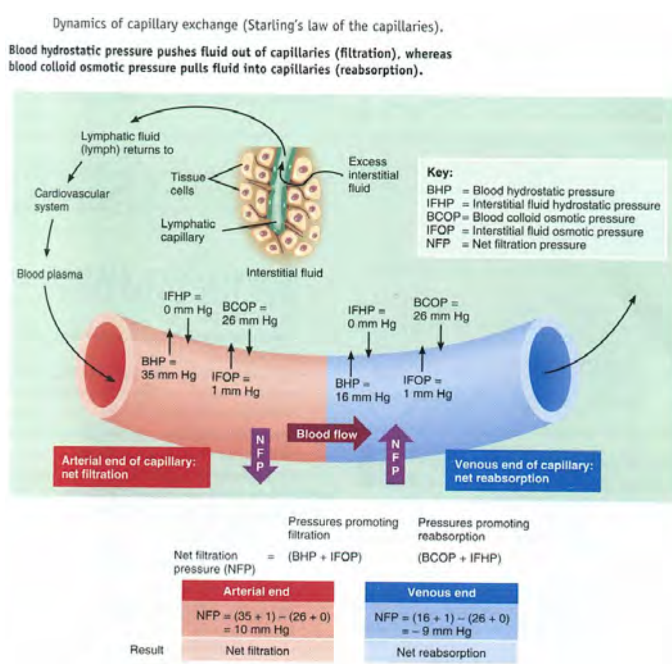
Four Primary Forces that Determine Fluid Movement through the Capillary Membrane

1. Capillary pressure
2. Interstitial Fluid Pressure
3. Plasma Colloid Osmotic Pressure
4. Interstitial fluid colloid osmotic pressure





Interstitial Fluid Pressures in Tightly Encased Tissues

- CSF Fluid Pressure +10 mmHg→ Brain Interstitial Fluid Pressure average +4-6 mmHg.
- Kidney→ capsular pressure surrounding the kidney +13mm Hg→ interstitial fluid pressure +6mmHg

GENERAL CONSENSUS

- True Interstitial Fluid Pressure in loose SC tissue is slightly less than atmosperic pressure
  - -3mmHg
- However in all tissues with tight fibrous or facial coverings that hold the tissues tightly together, such as the kidneys, the pressures underneath are usually more positive

Plasma Colloid Osmotic Pressure

- Proteins in the plasma cause colloid osmotic pressure
  - plasma 3x > than IF
    - 7.3gm/dl plasma
    - 2-3 gm/dl IF

Plasma Colloid Osmotic Pressure

- Donnan Equilibrium effect on the Colloid Osmotic Pressure
  - *Donnan equilibrium effect causes the colloid osmotic pressure of the plasma to be about 50% greater than that cause by the protein alone.*
  - *Protein –negative ions*
  - *Sodium- positive ions*

Plasma Colloid Osmotic Pressure

- Normal Values for Plasma Colloid Osmotic Pressure

plasma- 28mmHg

19mmHg dissolve CHON

9mmHg cations Donnan effect

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Plasma Colloid Osmotic Pressure

- Diminishment of the COP caused by protein molecules leaking through the capillary pores- “ The Reflection Coefficient”
  - *Reflected*- do not pass through
    - *reflection coefficient*- 1.0 (brain, muscle capillary)
    - *reflection coefficient*- 0.0 (liver sinusoids)

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Plasma Colloid Osmotic Pressure

- Effect of the Different Plasma Proteins on COP
  - albumin MW= 69,000
  - globulins MW= 140,000
  - fibrinogen MW= 400,000
  - osmotic pressure is determine by the *number of molecules dissolved in a fluid*

	gm/dl	Πp *(mm Hg)*
Albumin	4.5	21.8
Globulins	2.5	6.0
Fibrinogen	0.3	0.2
Total	7.3	28.0

Exchange of Fluid Volume Through the Capillary Membrane

- Analysis of the force Causing Filtration at the Arterial End of the Capillary

	mm Hg
Forces tending to move fluid outward:	
Capillary pressure	30
Negative interstitial free 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	13

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Exchange of Fluid Volume Through the Capillary Membrane

- Analysis of reabsorption at the Venous End of the Capillary

	mm Hg
Forces tending to move fluid inward:	
Plasma colloid osmotic pressure	28
TOTAL INWARD FORCE	28
Forces tending to move fluid outward:	
Capillary pressure	10
Negative interstitial free fluid pressure	3
Interstitial fluid colloid osmotic pressure	8
TOTAL OUTWARD FORCE	21
Summation of forces:	
Inward	28
Outward	21
NET OUTWARD FORCE	7

inward

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Starling Equilibrium For Capillary Exchange

- E.H. Starling- amount of fluid filtered out equals almost the quantity reabsorbed
  - *net filtration*
  - *2ml/min normal rate of net filtration*

	mm Hg
Mean forces tending to move fluid outward:	
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 force tending to move fluid inward:	
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

Effect of Abnormal Imbalance of Forces at the Capillary Membrane

- Capillary pressure ↑ above 17mmHg→ ↑ filtration→ *edema*

The Lymphatic System

- accessory route
- carry CHON and large particles

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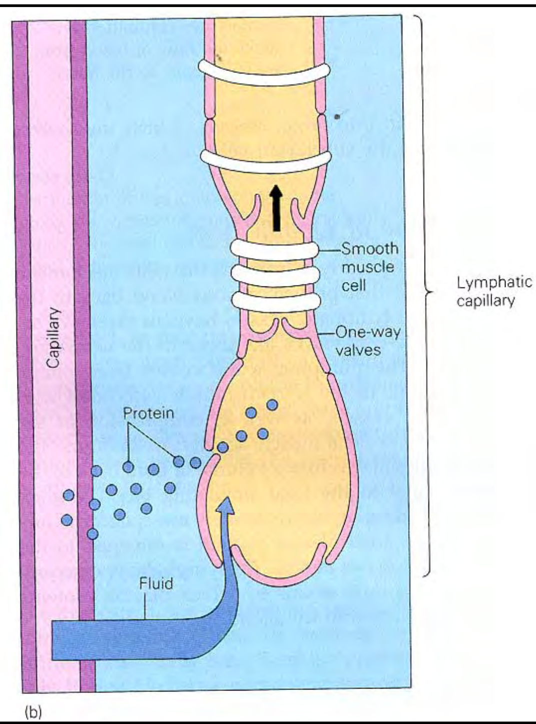
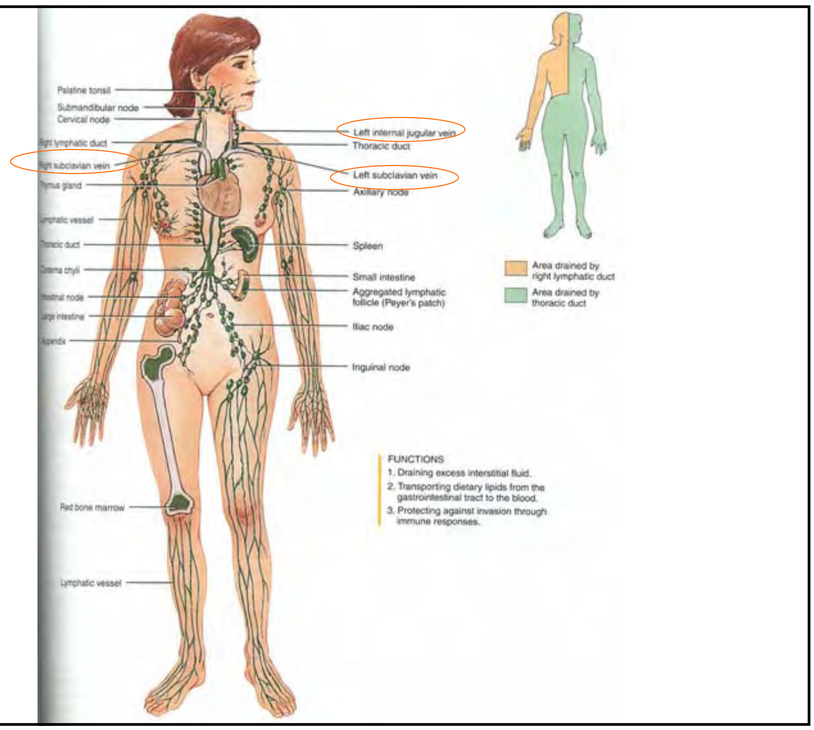


Lymph Channels of the Body

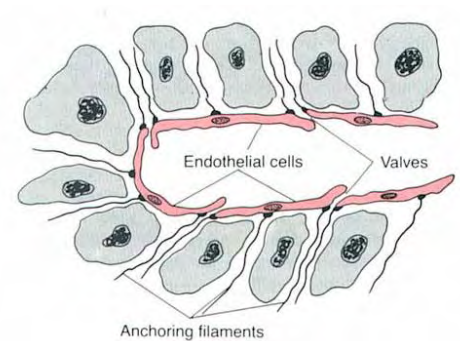
- superficial portion of the skin
- CNS
- deeper portion of peripheral nerves
- endomysium of muscle
- bones

- *Prelymphatics*



Terminal Lymphatic Capillaries and their Permeability

- one tenth- enters the lymphatic capillaries
  - 2-3 liters/day
- minute quantity of fluid returns is extremely important
- endothelial cell overlaps the edge of the adjacent cell--- free to flap inward



Formation of Lymph

- interstitial fluid
- protein concentration
  - 2 gm/dl- average (most tissue)
  - 6 gm/dl- liver
  - 3-4 gm/dl- intestine
  - 2/3 of lymph derived from liver and intestine
  - 3-5 gm/dl- THORACIC LYMPH

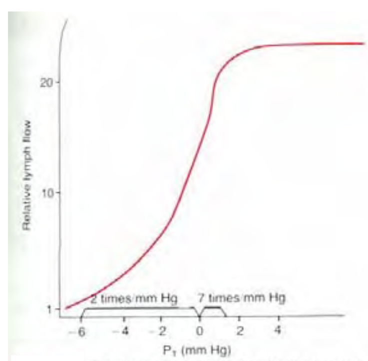
Rate of Lymph Flow

- 100ml/hr- thoracic duct
- 20ml/hr- other channels
- 120ml/hr
- 2-3 liters/day

- *Effect of interstitial fluid pressure on Lymph Flow*
- *The Lymphatic Pump increases Lymph Flow*
- *Lymphatic Capillary Pump*

Rate of Lymph Flow

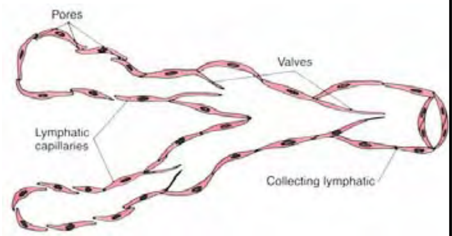
- Effect of interstitial fluid pressure on Lymph Flow
  - Elevated capillary Pressure
  - Dec plasma colloid osmotic pressure
  - Inc interstitial fluid protein
  - Inc permeability of the capillaries



. Relation between interstitial fluid pressure and lymph flow. Note that lymph flow reaches a maximum as the interstitial pressure rises slightly above atmospheric pressure (0 mm Hg). (Courtesy of Drs. Harry Gibson and Aubrey Taylor.)

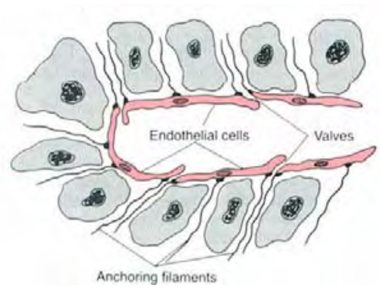
Rate of Lymph Flow

- The Lymphatic Pump increases Lymph Flow
  - Intrinsic Pumping by the Collecting Lymphatics and Larger Lymph Vessels
    - stretch with fluid→ smooth muscle automatically contract
  - Pumping caused by External Intermittent Compression of the Lymphatics
    - Contraction of the surrounding muscle- 10-30 fold
    - Movement of the parts of the body
    - Arterial pulsations
    - Compression of the tissues by objects outside the body



Rate of Lymph Flow

- Lymphatic Capillary Pump
  - walls of lymphatic capillaries adherent to tissue cells→ a. filaments→ excess fluid pull the lymphatic capillary open.
  - tissue is compressed→ pressure inside the capillary increases → overlapping edges close



Oedema from Reduced Lymph Flow

Filariasis causes the formation of edema and swelling of the afflicted areas as illustrated here. (© Science VU/Visuals Unlimited.)

Elephantiasis (Filariasis) is produced by blockage and of lymphatic vessels and reduced lymph flow.

The blockage is produced by parasitic worms colonising the lymphatic system and lymph nodes.

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SUMMARY

- The concentration of proteins in the interstitial fluids
- The volume of interstitial fluid
- The interstitial fluid pressure

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THANK YOU!

FOR NOT LISTENING

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