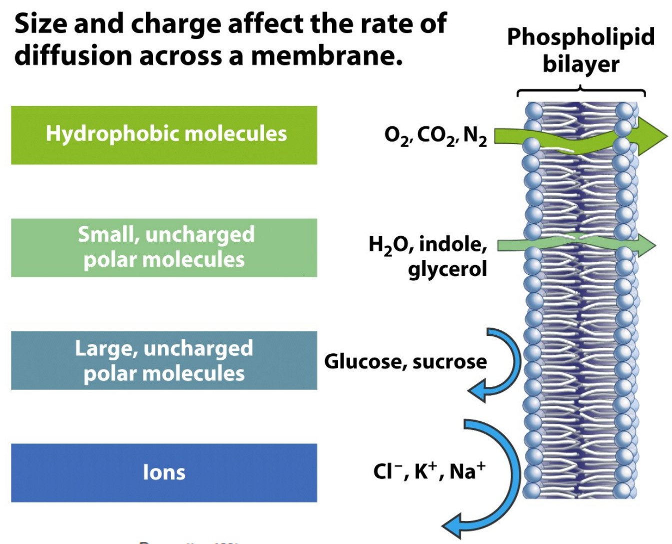
Chapter Six: The peripheral vascular system

Cardiovascular transport

The Fick Principle

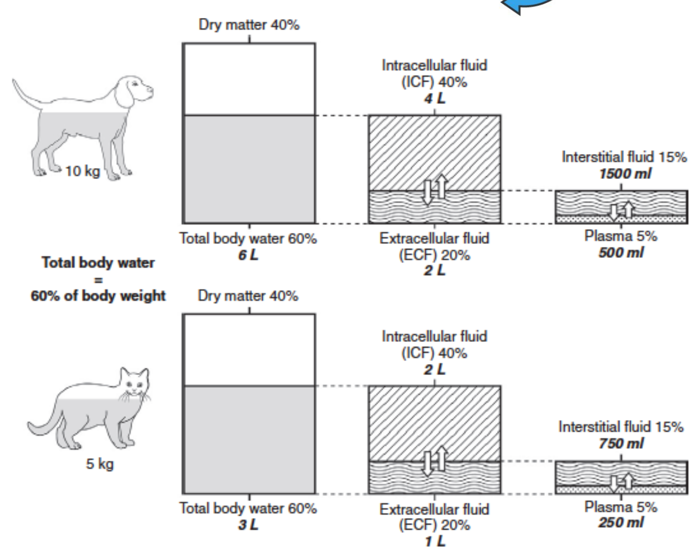
- Convective transport: mechanism by which substances are carried between organs within the CV system. Process of being swept along with the flow of the blood in which they are contained
- Transport rate (mass/time)=flow rate (volume/time) x concentration (mass/volume)
- Two methods available for altering rate a substance is carried to an organ
  - Change in blood flow rate through organ
  - Change in arterial blood concentration of substance
- Fick principle: extends convective principle to determine tissue's rate of utilization/production of substance
  - Transcapillary efflux rate (mass/time)=blood flow rate (volume/time) x [arterial concentration – venous concentration]
  - $X_{tc}=Q([X]_a-[X]_v)$
  - If tissue is producing substance that diffuses into the vascular space, equation will yield a negative utilization rate

Transcapillary Solute Diffusion



- Diffusion is typically passive from high concentration to low concentration
- Determined by four factors:
  - Concentration difference
  - Surface area for exchange
  - Diffusion distance
  - Permeability of capillary wall
- Capillary beds maximize area and minimize diffusion difference
  - Consists of single thickness endothelial cells
  - Permeability is used to describe the ease w/ which solute crosses capillary wall
- Lipid soluble substances cross capillary wall easily
  - Can occur through the entire capillary surface area
- Small polar particles diffuse much less easily, postulated capillaries are somehow perforated at intervals with channels or pores
- Capillary permeability varies by tissue type-brain is tight and kidney is leaky

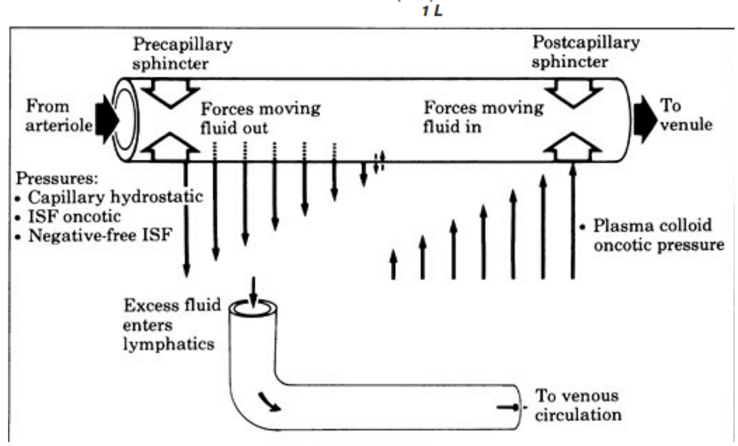
Endothelial cells



- Layer of endothelial cells lines entire cardiovascular system-including heart chambers and valves
- Contain enzymes that convert some circulating hormones from inactive to active forms
- Involved in producing substances leading to clot formation
- Produce vasoactive substances influencing arteriolar diameter

Transcapillary Fluid Movement

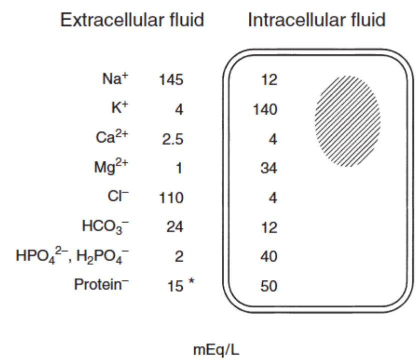
- Fluid shifts responsible for
  - Maintenance of blood circulating volume
  - Interstitial fluid formation
  - Tissue edema formation
  - Saliva, sweat and urine production
- Filtration: movement of fluid out of capillaries
- Reabsorption: movement of fluid into capillaries



- Hydrostatic and osmotic pressure influences transcapillary fluid movement
  - Osmotic pressure: the hydrostatic pressure necessary to prevent osmotic water movement into the test solution when it is exposed to pure water across a membrane permeable only to water
    - Proportional to the total number of solute particles in the solution

- Oncotic pressure: portion of a solution's total osmotic pressure due to particles that do not move freely across capillaries
- Normal hydrostatic pressure: intracapillary 25 mmHg, interstitial 0 mmHg
- Normal osmotic pressure: plasma 5000 mmHg
- Normal oncotic pressure: plasma 25 mmHg, interstitial fluid 0 mmHg

- Starling hypothesis: relationship among the factors that influence transcapillary fluid movement
  - Net filtration rate = $K[(P_c-P_i)-(\pi_p-\pi_i)]$
    - P=hydrostatic pressure of the intracapillary and interstitial fluid
    - π=oncotic pressure of the intracapillary and interstitial fluid
    - K=constant expressing how readily fluid can move across the capillary



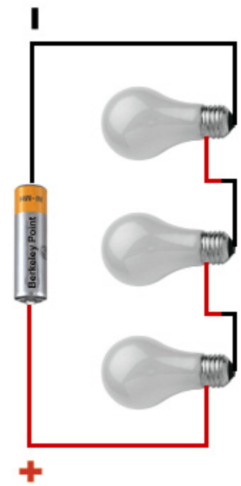
Lymphatic system

- Represents a pathway by which large molecules reenter the circulating blood
- Begins in tissues w/ blind end lymphatic capillaries, similar in size to regular capillaries
  - Very porous and collect large particles and interstitial fluid with ease
- Lymph flow promoted by
  - Increased tissue interstitial pressure
  - Contractions of lymphatic vessels themselves
  - Valves prevent backward flow

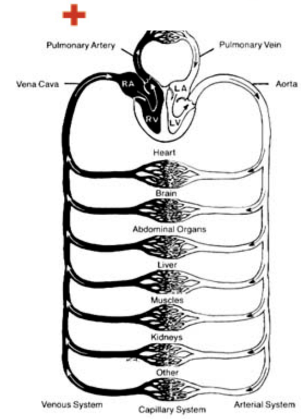
Basic Vascular Function

Resistance to flow in Networks of Vessels

- Can be interpreted by evaluated individual elements in a network and how they are connected
- Series orientation of resistance
  - $R_s=R_1+R_2+...+R_n$
  - R_s represents resistance in a series
  - Flow through this network would be $Q=\Delta P/R_s$
  - Pressure drop across any element in the series can be calculated by applying basic flow equation to that element
    - Ie $\Delta P_1=QR_1$

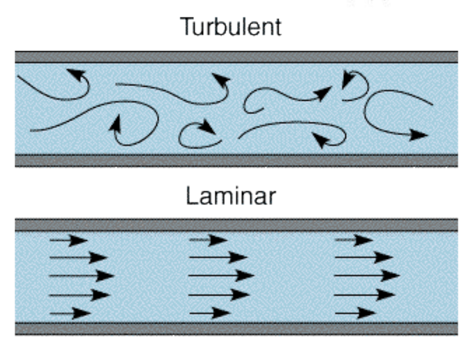


- Parallel orientation of resistance
  - $1/R_p=1/R_1+1/R_2+....+1/R_n$
  - Total flow would be $Q=\Delta P/R_p$
  - Overall resistance will always be less than that of any element in the network
  - Generally the more parallel elements in a network, the lower the overall resistance of the network



Peripheral Blood Flow Velocities

- Blood flows most rapidly in the region w/ the smallest total cross-sectional area (the aorta) and most slowly in the region with the largest total cross-sectional area (capillary beds)
- Laminar flow
  - Most flow in CV system is laminar
  - Flow velocity is highest along central axis
  - Concentric layers of fluid with different velocities slip over one another
  - Little mixing occurs
  - Due to viscosity, blood exerts shear stress on walls of vessels
    - Proportional to the rate of flow through a vessel
    - Endothelial cells are able to sense shear stress and thus rate of blood flow
- Turbulent flow
  - When blood is forced to move with too high velocity through a narrow opening
  - Significantly increases resistance to flow



Peripheral Blood Volumes

- Peripheral venous pool: circulating blood pool within the veins of systemic organs-very large
- Central venous pool: circulating blood pool within the great veins of the thorax and right atrium-a bit smaller
- Constriction of peripheral veins results in displacement of peripheral pool to central pool
  - Increases central venous volume and pressure
  - Enhances cardiac filling
  - Augments stroke volume according to the Frank-Starling law of the heart

Peripheral Blood Pressures

- Blood pressure decreases in consecutive segments
  - Only a small drop of pressure is seen in the arterial system
  - Large pressure drop occurs in arterioles, and pulsatile nature of blood is nearly lost
  - Average capillary pressure is 25 mmHg
  - Central venous pressure is normally close to 0 mmHg

Peripheral Vascular Resistances
- Minimal decrease in the arteries
- Modest decrease in mean pressure in the capillaries
- Large chances in an organ's blood flow are achieved by changes in its overall vascular resistance to blood flow
- Overall vascular resistance of organ must equal the sum of the resistances of consecutive vascular segments:
  - $R_{organ}= R_{arteries}+R_{arterioles}+R_{capillaries}+R_{venules}+R_{veins}$
  - Overall organ vascular resistance determined to large extent by the resistance of arterioles
    - Arteriolar resistance determined predominantly by its radius
  - Arteriolar constriction drops capillary and vein pressure while increasing arterial pressure
  - Arteriolar dilation increases organ blood flow and drops arterial pressure and increases capillary pressure

Total Peripheral Resistance
- Total peripheral resistance-overal resistance to flow through the entire systemic circulation
- Since organs are in parallel, $1/TPR=1/R_{organ1}+R_{organ2}+...+R_{organn}$

Elastic Properties of Arteries and Veins
- Important to overall cardiovascular function b/c they act as reservoirs for substantial amounts of blood
- Compliance (C)= $\Delta V/ \Delta P$
- Arterial compartment at normal pressure (100mHg) compliance is about 2 mL/mmHg
  - Elastance allows them to act as a reservoir on a beat-to-beat basis
  - Increased volume during systole and decreased volume at end of diastole
- Venous compartment at normal pressure (5-10 mmHg) compliance is over 100 mL/mmHg
- Small changes in peripheral venous pressure can cause significant a amount of blood movement to or out of the peripheral venous pool

Determinants of Arterial Pressure

Mean Arterial Pressure
- Related to cardiac output and peripheral resistance
- MAP=CO X TPR, assuming that central venous pressure is approximately zero
- Calculating true mean requires averaging arterial pressure waveform over 1 or more complete heart beats
- Rule of thumb: MAP is approximately = to diastolic pressure plus 1/3 of difference between systolic and diastolic pressures

Arterial Pulse Pressure
- Defined as systolic pressure minus diastolic pressure
- Tends to increase with age
- Is also equal to approximately stroke volume divided by arterial compliance
- Minimally effected by changes in total peripheral resistance, as this causes parallel changes in both systolic and diastolic pressures

Questions

1) Determine the net direction of fluid movement given the following data:
   a) Plasma oncotic pressure: 8 mmHg
   b) Interstitial oncotic pressure: 10 mmHg
   c) Plasma hydrostatic pressure: 18 mmHg
   d) Interstital hydrostatic pressure: 20 mmHg

2) Which of the following would result with normal MAP but high pulse pressure?
   a) Low stroke volume
   b) High heart rate
   c) Decreased peripheral resistance
   d) Increased arterial stiffness
3) Calculate an estimated mean arterial pressure from the following: systolic 140, diastolic 67

4) What four factors will determine rate of diffusion?

5) Calculate the transcapillary carbon dioxide flux w/ the following information:
   a) Blood flow rate: 60 mL/min
   b) P_aCO2: 35 mmHg
   c) $P_{MV}CO2$: 47 mmHg

6) Which of the following is the correct formula to determine compliance?
   a) $\Delta P/\Delta V$
   b) $\Delta Q/\Delta R$
   c) $\Delta V/\ \Delta P$
   d) $\Delta R/\Delta Q$