Blood vessels and blood pressure

I. Introduction

- distribution of CO at rest

II. General structure of blood vessel walls

- walls are composed of three distinct layers:

1. Tunica intima is the innermost layer; it is composed of single layer of endothelial cells and a thin layer of loose connective tissue (basement membrane, BM)

2. Tunica media is the middle layer; it is composed of a mixture of circularly arranged smooth muscle cells and sheets of elastin, the proportion of each depending on artery type; the smooth muscle cell layer is innervated by vasomotor fibers (ANS), innervation can produce vasoconstriction

3. Tunica adventitia is the outermost layer; it is composed of loosely woven connective tissue infiltrated by nerves, blood vessels and lymphatics

III. Basic organization of the CV system

- elastic arteries -- conducting vessels
- muscular arteries -- distributing vessels
- arterioles -- resistance vessels
- capillaries -- sites of nutrient, fluid, and gas excahnge with tissues
- venules
- small veins --> large veins -- capacitance vessels

IV. Hemodynamics overview

A. Blood flow, blood pressure, resistance

- blood flow: volume of blood flowing through vessel/organ/ circulation per minute; as far as systemic circulation, blood flow = CO

- blood pressure: pressure gradient between 2 points in vasculature

-resistance: opposition to flow due to friction

- **Flow (F) = Pressure (P)/ Resistance (R)**

B. Factors influencing resistance

- $R = 8\eta L/\pi r^4$
    - viscosity (h) -- friction of fluid molecules as they slide over one another
        - hematocrit
        - plasma protein concentration
        - constant for CV system
    - length -- longer the vessel, greater surface area, greater resistance to flow
        - constant for CV system
    - radius -- changing radius greatly alters surface area of vessel exposed to a given volume of blood
        - decreasing radius -- tremendously increases resistance
        - increasing radius -- tremendously decreases resistance

- by simplification: $R = 1/r^4$

V. Arteries -- functional characteristics

A. Low-resistance vessels -- blood rapidly moves from heart to tissues

B. Pressure reservoirs -- provide driving force for blood during diastole, secondary pumps

- note that despite contraction-relaxation cycles, blood pressure and blood flow through capillaries does not fluctuate -- not pulsatile
    - during systole more blood enters arteries from heart than leaves them due to resistance of smaller vessels downstream
        - arteries expand temporarily, hold "excess" ejected blood
    - during diastole heart does not pump blood into arteries, stretched arterial walls recoil, "excess" blood pushed to vessels downstream
    - thus arteries play role in dampening pressure fluctuations occurring during cardiac cycle in ventricles

C. Arterial pressure

- arterial pressure not constant as volume of blood entering arteries during systole is 1/3 greater to volume of blood leaving arteries during diastole

- systolic pressure: highest pressure in arteries at peak of ejection (120 mm Hg)
    - only 1/3 of blood that enters arteries during this period leaves these vessels
- diastolic pressure: lowest pressure in arteries during cardiac cycle (70 mm Hg)
    - lowest pressure achieved in arteries as blood is draining into remainder of vessels during diastole
- pulse pressure: systolic pressure - diastolic pressure
- mean arterial pressure: (map) average pressure in artery throughout 1 turn of the cardiac cycle
    - (diastolic + 1/3PP)

VI. Arterioles

A. Functional characteristics

- media proportionately the predominant layers, composed primarily of smooth muscle

- are the major resistance vessels of the vascular tree

- mean arterial pressure before arterioles is 93 mm Hg; pressure of blood leaving arterioles is 37 mm Hg
- arteriolar resistance also converts pulsatile systolic-diastolic pressure swings in arteries to non-pulsatile pressure seen in capillaries
- resistance changes achieved by varying radius of vessels
    - small change in radius, large change in resistance to blood flow and thus blood pressure
        - vasodilation
        - vasoconstriction
    - thus arterioles are prime controllers and regulators of blood pressure

- arterioles display a state of partial constriction, vascular tone -- establishes a baseline resistance to blood flow

- state of partial constriction largely due to:
  - sympathetic fibers innervate media -- vasomotor fibers
    - tonically discharge
    - release norepinephrine -- in most beds maintains basal vascular tone
    - no parasympathetic innervation to arterioles
      - vasoconstriction -- increase sympathetic discharge
      - vasodilation -- decrease sympathetic discharge

B. Local control of arteriolar radius -- **autoregulation: capacity of tissues to regulate own blood flow**

- variably distributes cardiac output among various systemic beds so that blood flow matches tissues' metabolic needs
  - metabolic hypothesis
    - accumulation/absence of metabolites produces vasodilation/vasoconstriction of arterioles
    - the following produce relaxation of arteriolar smooth muscle (arteriolar dilation):
      - increased pCO_2
      - decreased pO_2
      - lincreased actic acid
      - adenosine release
      - increased K^+
      - increased temperature
  - myogenic hypothesis
    - vessel responds to increased stretch by reflex contraction
    - vessel responds to decreased blood flow by myogenic relaxation -- increases blood flow through area
  - example of reactive hyperemia -- response of blood vessel to occlusion
    - what happens when occlusion removed
    - what is role of myogenic and metabolic autoregulation processes in response?

C. Systemic control of arteriolar radius

1. control by hormones- systemic regulation of arteriolar diameter

- norepinephrine/epinephrine
  - norepinephrine
    - released by vasomotor fibers in arteriole media
    - high affinity for a receptors -- generalized vasoconstrictor effect
    - can bind b receptors -- vasodilatory effect
  - epinephrine
  - most abundant of medullary hormones
  - high affinity for b receptors -- vasodilatory effect
    - dilates vessels in skeletal muscle
- atrial natriuretic factor (ANF)
  - decreases blood pressure by promoting fluid loss from plasma
- vasopressin (ADH) -- elevates blood pressure
  - promotes water reabsorption in kidneys
  - vasoconstrictor
- angiotensin II
  - part of renin-angiotensin-aldosterone cascade
  - important in maintenance of blood pressure during hemorrhage and shock
- histamine
  - inflammatory response

2. Neural regulation - systemic regulation of cardiovascular function

- Flow (F) = Pressure (P)/ Resistance (R)

- CO = BP/R --> CO = BP x r^4

- since resistance is varied by altering arteriolar diameter, resistance is peripheral in circulation -- total peripheral resistance (TPR)

- CO = BP/TPR --> BP = CO x TPR

- thus can vary blood pressure by changing cardiac output and varying resistance of arterioles

- vasomotor tone maintains vascular tone of arterioles
    - maintains adequate driving pressure of blood to all systemic beds
        - if all arterioles dilate, blood pressure falls substantially, lose adequate driving force for blood flow
    - individual beds can use autoregulatory and local mechanisms to fine adjust amount of blood flow -- however need pressure head to drive flow

IV. Capillaries

- sites of exchanges (solutes and fluids) between blood and the tissues

- exchanges between blood and the tissues are passive
    - diffusion -- solutes
    - bulk flow -- fluid
- capillary structure permits such functions:
    - diffusing molecules travel very short distances between blood and ISF and cells
    - capillaries very narrow
    - capillaries are very thin -- 1 mm diameter
        - single layer of flattened endothelial cells
    - total surface area of capillaries is tremendous
        - influence on velocity of blood flow: recall that velocity is displacement per unit time (cm/s) while flow is volume per unit time (cm^3/s)
        - velocity (V) is proportional to flow (F) divided by area
        - **$V=F/A$ ($cm/s = cm^3/s/cm^2$)**
    - structure of capillary wall
        - exchanges possible across cell
            - diffusion
            - vesicular transport
        - exchanges possible between cell junctions
            - exact amount regulated by state of junction -- tight junction integrity and dynamics

    - exchanges possible via "pores" in cells, fenestrations

- a capillary bed and regulation of capillary perfusion:

- arteriole
- metarteriole -- thoroughfare channel
- true capillaries
    - precapillary sphincters -- open or close in response to metabolic status of tissue; work with arteriole autoregulation in control of perfusion through vascular bed
- post-capillary venule

- capillary exchanges -- diffusion of solutes across capillary wall

- exchanges occur between plasma and ISF (80% ECF)
    - composition of ISF reflects composition of plasma (20% ECF)
        - thus regulate composition of plasma to regulate composition of ISF (most ECF)
- exchanges of solutes by simple or facilitated diffusion

- capillary exchanges -- bulk flow

- movement of protein-free plasma out of capillary into ISF (filtration) at arterial end of capillary; movement of protein-free fluid from ISF into capillary (reabsorption) at venule end of capillary
- occurs because of differences between hydrostatic and osmotic pressures of plasma and ISF
    - outward pressures
        - capillary hydrostatic pressure
        - ISF osmotic pressure
    - inward pressures
        - plasma osmotic pressure
        - ISF hydrostatic pressure
- in most capillaries outward pressures prevail and arteriolar end and inward pressure greater at venule end
    - some capillaries reabsorption along full length
    - some capillaries filtration along full length

- note that on average more fluid filters out at arteriole end than at venule end
    - this fluid returned to circulation by lymphatics
    - other roles of lymphatics -- immune, GI absorption of fat

- clinical example of capillary dynamics -- edema

- reduced concentration of plasma proteins
    - renal failure
    - liver failure
    - protein deficient-diet
- increased permeability of capillary walls
- increased venous pressure
    - pregnancy -- edema in legs
- blockage of lymph vessels -- elephantiasis

V. Veins

- veins are capacitance vessel -- on average 64% of blood in circulatory system at one time found in veins

- pressure gradient that drives flow through veins very small; veins have structural adaptation that allow them to perform their function -- return blood to heart -- despite this low gradient:

- very thin walls, little elastin
- little myogenic tone
- large radii -- offer very little resistance to flow
- have valves -- unidirectional flow of blood through veins
    - valve dysfunction
        - varicose veins
        - hemorhoids

- factors that affect venous capacity will influence venous return and thus cardiac output (Starling's law):

- effect of vasomotor sympathetic tone on venous return
    - vasoconstriction decreases venous capacity and increases venous return
    - vasodilation increases venous capacity and decreases venous return

- effect of skeletal muscle activity on venous return
    - increased skeletal muscle activity milks veins -- increases venous return
- effect of respiratory pump
    - inspiration -- intra-thoracic pressure less than intra-abdominal -- suction of blood to heart
- cardiac suction

VI. Regulation of blood pressure

1. Short term regulatory mechanisms: neural regulation of BP

- cardiovascular center (CV) in the medulla:

- Vasomotor center (VM): gives rise to sympathetic fibers that innervate smooth muscles of arterioles and veins; tonically discharges, arterioles always partially constricted, vasomotor tone; increased sympathetic activity will increase vasomotor tone (vasoconstriction); decreased sympathetic activity will decrease vasomotor tone (vasodilation)
- Cardioaccelerator center (CA): gives rise to sympathetic fibers that when activated increase HR and contractility of cardiac muscle
- Cardioinhibitory center (CI): gives rise to parasympathetic fibers that cause a decrease in HR.

    1. innervation of blood vessels (sympathetic)

    -adrenergic fibers

    -originate in VM center (VC)

    2. innervation of heart (sympathetic)

    -originate in VM center (CA)

    3. innervation of heart (PS)

    -originate in CI center

    -examine tonic discharge of each

    - tonic discharge of VC- affects to veins and arterioles
    - tonic discharge of CA vs CI- which one predominates

    4. Afferents to cardioregulatory center
        a. baroreceptors
        b. chemoreceptors -- role in blood pressure regulation