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 exchange 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
  - \( \text{Flow (F)} = \frac{\text{Pressure (P)}}{\text{Resistance (R)}} \)
B. Factors influencing resistance

- \( R = 8\eta L/\pi r^4 \)
  - viscosity (\( \eta \)) -- 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 pCO₂
      - decreased pO₂
      - increased lactic 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 α receptors -- generalized vasoconstrictor effect
       - can bind β receptors -- vasodilatory effect
     - epinephrine
       - most abundant of medullary hormones
       - high affinity for β 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)
   - \( CO = \frac{BP}{R} \rightarrow CO = BP \times r^4 \)
   - since resistance is varied by altering arteriolar diameter, resistance is peripheral in circulation -- total peripheral resistance (TPR)
   - \( CO = \frac{BP}{TPR} \rightarrow BP = CO \times TPR \)
- 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
      - $V = \frac{F}{A}$ (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
  o this fluid returned to circulation by lymphatics
  o other roles of lymphatics -- immune, GI absorption of fat
- clinical example of capillary dynamics -- edema
  • reduced concentration of plasma proteins
    o renal failure
    o liver failure
    o protein deficient-diet
  • increased permeability of capillary walls
  • increased venous pressure
    o 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
    o valve dysfunction
      ▪ varicose veins
      ▪ hemorrhoids
- factors that affect venous capacity will influence venous return and thus cardiac output (Starling's law):
  • effect of vasomotor sympathetic tone on venous return
    o vasoconstriction decreases venous capacity and increases venous return
    o vasodilation increases venous capacity and decreases venous return
• effect of skeletal muscle activity on venous return
  o increased skeletal muscle activity milks veins -- increases venous return
• effect of respiratory pump
  o 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