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

  Flow (F) = Pressure (P)/ 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
  - autoregulatory mechanisms
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 \( \mu \)m 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
    - \( V = \frac{F}{A} \text{ (cm/s) = cm}^3/\text{s/cm}^2 \)
• structure of capillary wall
  o exchanges possible across cell
    ▪ diffusion
    ▪ vesicular transport
  o exchanges possible between cell junctions
    ▪ exact amount regulated by state of junction -- tight junction integrity and dynamics
  o exchanges possible via "pores" in cells, fenestrations

- a capillary bed and regulation of capillary perfusion:

  • arteriole
  • metarteriole -- thoroughfare channel
  • true capillaries
    o 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)
    o 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
    o outward pressures
      ▪ capillary hydrostatic pressure
      ▪ ISF osmotic pressure
    o inward pressures
      ▪ plasma osmotic pressure
      ▪ ISF hydrostatic pressure
  • in most capillaries outward pressures prevail and arteriolar end and inward pressure greater at venule end
    o some capillaries reabsorption along full length
    o 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
- 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
  
-origin in VM center (VC)

2. innervation of heart (sympathetic)
  
-origin in VM center (CA)

3. innervation of heart (PS)
  
-origin 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