PHYSIOLOGY WEEK 9

vascular physiology - ED Primary Exam Teaching

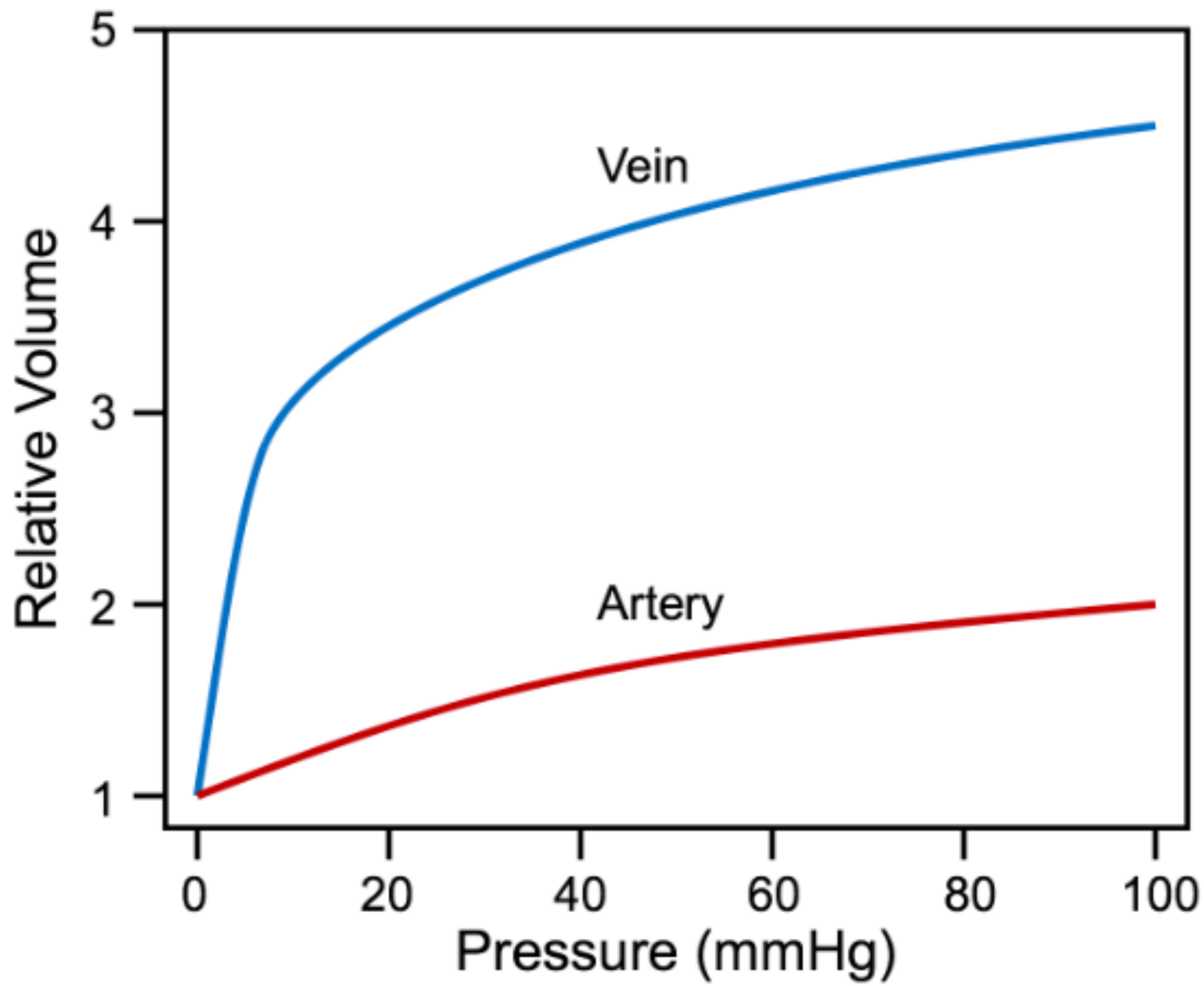
CONCEPTS OF BLOOD FLOW

- **Vascular distensibility** - when pressure in the arterioles is increased, this dilates the arterioles and therefore decreases their resistance, resulting in increased blood flow
  - This distensible nature of arteries allows them to accommodate the pulsatile output of the heart
  - Calculated by: Increase in volume/(increase in pressure x original volume)
  - Thus if 1mmHg causes a vessel that originally contained 10mL of blood to increase by 1mL , the distensibility would be 0.1 per mmHg
  - Veins are 8 times as distensible as arteries

VASCULAR COMPLIANCE

- Vascular compliance - the total quantity of blood that can be stored in a given portion of the peripheral circulation for each mmHg rise in pressure
  - Increase in volume/increase in pressure
- Compliance vs Distensibility
  - A highly distensible vessel that has slight volume will have far less compliance than a much less distensible vessel that has a large volume
    - Compliance = distensibility x volume
    - Hence the compliance of systemic vein is about 24 times the corresponding artery as it is 8 times as distensible and has 3 times the volume

DISTENSIBILITY CURVES



VOLUME PRESSURE CURVES

- Arterial curve
  - Average adult when filled with 750mL, the pressure is approximately 100mmHg, when this drops to 500mL the pressure drops to 0
- Venous curve
  - Volume normally ranges from 2500 - 3000 and a large change in volume is required to alter the pressures
- Effects of sympathetic stimulation
  - Increases the pressure at each volume of the arteries of veins
  - Shifts large volume of blood to the heart

ARTERIAL PROPERTIES

- Were it not for the distensibility of the arterial system - blood flow through the tissues would occur only curing cardiac systole
  - However the compliance of the arterial tree reduces the pressure pulsations to almost zero allowing the tissue blood flow to be mainly continuous
  - Difference between SBP and DBP is called pulse pressure
    - Two factors effect pulse pressure - SV and compliance of the arterial tree

VENOUS PRESSURES

- Blood from all systemic veins flow in the right atrium - therefore pressure at the RA is the central venous pressure
- RAP is regulated by a balance between
  - The ability of the heart to pump blood out of the RA and RV into the lungs
  - Tendency for blood to flow from the PV into the RA
  - Normal RAP is about 0, can increase to 25 - 30 in RHF

VENOUS COMPLIANCE CURVES

MICROCIRCULATION – STRUCTURE

- Nutrient artery enters and organ —> 6 - 8 branches —> Arterioles (20 micrometers) —> 2 - 5 branches —> Capillaries (5 - 9 micrometers) —> venules
- At the point where each true capillary originates from a meta arteriole, a smooth muscle finer encircles the capillary called the PRE CAPILLARY SPHINCTER - this means that local conditions cause changes in blood flow
- Structure of a capillary wall
  - unilayer of endothelial cells surrounded by a basement membrane - total thickness of 0.5 micrometers
  - Pores - formed by intracellular clefts between endothelial cells which allows fluid and soluble ions through the cells. Special types occur in certain organs
    - Brain - tight junctions only allow small molecules to pass (CO_2, H20, O_2)
    - Liver - large clefts that allow plasma protiens to pass into the liver tissues
    - Kidney - Contain numerous fenestrae

MICROCIRCULATION – FUNCTION

- Exchange of nutrients between blood and interstitial fluids
  - Diffusion through capillary membrane: by far the most important mechanism of transfer
  - Lipid soluble substances - can diffuse directly though the cell membranes of the capillary endothelium e.g. O2 and CO2 - the rates of transport for these agents are high because of large surface area (no need for pores)
  - Water soluble - diffuse through intracellular pores e.g. water and Na, Cl and glucose - velocity is great and overcomes the decreased surface area
  - Molecule size - width of channel is 6 - 7 nm, plasma protiens are bigger than this and his determines the permeability of otherwise water soluble substances

FORCES IN CAPILLARIES

- **Capillary pressure** - 17 mmHg - tends to force fluid outward through the capillary membrane
- **Interstitial fluid pressure** - forces fluid inward when -ve and outward then + ve
- **Plasma colloid osmotic pressure** - proteins are the only significantly dissolved constituents that do not readily penetrate the pores of the capillary membranes - normal value for human plasma is about 28 mmHg - 19 mmHg is contributed by dissolved protein and 9mmHg contribute by cations held by the DONNAN effect
- **Interstitial fluid colloid osmotic pressure** - average concentration of the interstitial pressure is usually 40% of that in plasma
- Net outward force at the arterial end is about 13mmHg and net inward force at the venous end is 7 mmHg
- If the mean capillary pressure rises above 17mmHg, the net force tending to cause filtration increases

STARLING FORCES

- The rate of filtration at any point int he capillary is according to the balance of Starling's forces
- Hydrostatic pressure gradients, osmotic pressure gradients
- Fluid generally moves out at the arterial end and into the vessel at the venous end
- Thus Fluid movement = k[(Pc - Pi) - (Cc - Ci)]
  - k = capillary filtration coeffiecient
  - P = hydrostatic pressure
  - C = colloid osmotic pressure

OVERVIEW OF THE CIRCULATION

- Functionally acts to
  - Transport nutrients, remove waste, hormonal transport
- Physical characteristics of the circulation
  - Systemic
  - Pulmonary
- Functionally divided into multiple parts
  - Arteries —> Transport blood under high pressures to the tissues
  - Arterioles —> Last small branches for eh arterial system which act as control conduits through which blood is passed into the capillaries
  - Capillaries —> Function is to exchange fluid, nutrients, electrolytes and hormones
  - Venules —> Collect blood from capillaries, gradually coalescing into progressively larger veins
  - Veins —> Function as conduits for transport of blood from the tissues back into the heart
- Volumes
  - 84% in systemic circulation, 16% in pulmonary circulation
    - Of 84%
      - 64% in veins
      - 13% in the arteries
      - 7% in the systemic arterioles and capillaries

CIRCULATION CONCEPTS

- Velocity of blood flow is inversely proportional to vascular cross sectional area
  - high rate of flow in aorta vs slow flow in capillaries
- Pressures in the various portions of the circulation
  - Mean pressure in aorta is high (100mmHg) - as blood flows through the circulation mean pressure drops to zero in the R atrium
  - Systemic capillaries - arteriolar end 35mmHg and venous end is around 10 mmHg
  - Pulmonary circulation is much lower pressure, systolic pressure of 25mmHg and diastolic of 8mmHg, MAP of 17mmHg, yet same volume of blood must flow through.
    - Flow is proportional to pressure, therefore lower pressures = lower flow rates and therefore longer for gas exchange

FLOW, PRESSURE AND RESISTANCE

- Relationships between pressure, flow and resistance
- Flow through a vessel is determines by two factors
  - Pressure difference of the blood between the two ends of the vessel
  - The vascular resistance
- Flow = Change in pressure/Resistance

LAMINAR FLOW

- When blood flows at a steady rate through a smooth vessel the flow streamlines with each layer staying the same distance from the vessel wall
- When laminar flow occurs the velocity of flow at the centre is greater than at the outer edges of the vessel
- This creates a parabolic velocity profile which is caused because molecules touching the vessel wall hardly move because of adherence to the wall, with progressively increasing slippage
- Reynold's number determines the likelihood of turbulent flow
  - proportional to density, diameter of tube, velocity of flow
  - Reynold's number < 2000 usually laminar flow, > 3000 is turbulent flow

POISEUILLE LAW:

- In very small vessels the central, very rapidly moving portion of blood does not occur as essentially all the blood is near the wall
- Poiseuille's law states:
  - Flow = (Pi x change in pressure x r^4)/(8 x viscosity x length)
  - RATE OF BLOOD FLOW IS DIRECTLY PROPORTIONAL TO THE FOURTH POWER OF THE RADIUS OF THE VESSEL
  - About two thirds of the total systemic arteriolar resistance is int he small arterioles - a change in internal diameter can effect flow significantly
  - THE GREATER THE VISCOSITY THE LOWER THE FLOW
    - Hence increased haematocrit i.e polycythaemia can decrease flow

NERVOUS REGULATION OF THE VASCULAR SYSTEM

- Autonomic nervous system
  - Anatomy of sympathetic nervous system
    - Vasomotor fibers leave the spinal cord through all the thoracic and the first one or two lumbar segments
    - Pass immediately into the sympathetic chain
    - Pass by two routes into the circulation
      - Through specific sympathetic nerves that innervate mainly the vasculature of the internal viscera of the heart
      - Via spinal nerves which are then distributed to the vasculature of the peripheral areas
    - Sympathetic outflow goes to all blood vessels except capillaries, pre capillary sphincters and most of the meta arterioles
    - Innervation of the small arteries and arterioles —> increase resistance and decrease rate of blood flow
    - Innervation of large vessels na veins —> allows transaction of blood from these reservoirs back to the heart —> increases CO

NERVOUS REGULATION OF VASCULAR SYSTEM

- Vasomotor center
  - Located bilaterally in the reticular substance of the medulla
  - Vasoconstrictor area - anterolateral portions of the upper medulla
  - Vasodilator area - anterolateral portions of the lower medulla
  - Sensory area - bilaterally in the NTS - sensory nerve signals through the vagus and glossopharyngeal nerves - baroreceptor reflex

REFLEX MECHANISMS FOR MAINTAINING NORMAL ARTERIAL PRESSURE

- Baro-receptor reflexes
  - Initiated by stretch receptors (baro receptors) located in the walls of several large systemic arteries
  - Rise in pressure —> stretch of baro-receptor —> Vagus and GN nerve —> CNS —> Feedback to reduce arterial pressure
  - Baro-receptors are located in
    - Carotid sinus: wall of ICA above bifurcation
    - Wall of aortic arch
  - Receptors respond to a change in pressure - carotid sinuses are not stimulated until pressures > 50mmHg - reach a maximal response at around 180mmHg
  - Aortic arch is similar but around 30mmHg higher
  - Optimal range is around 100mmHg, meaning a small change in pressure causes a strong baro-receptor response

BARO-RECEPTOR REFLEX

- Baro-receptor reflex carried to NTS
  - Secondary signals inhibit vasoconstrictor tone and excite vagal parasympathetic center
    - Vasodilation
    - Decreased HR
    - Decreased arterial pressure
  - Conversely low pressure has opposite effect
  - This reflex is very important during changes in body posture and position
- Resetting of baro-receptors
  - Is of little or no importance in long term blood pressure management
  - Reset themselves in 1 - 2 days
  - If BP rises acutely then receptors fire off numerous impulses
  - Rate of firing diminishes considerable and eventually ceases despite continued elevation of BP

CHEMORECEPTOR REFLEXES

- Chemoreceptors are located in:
  - Carotid bodies
  - Aortic bodes
  - Excited by deceased O2 and increased CO2
- If arterial pressure drops below critical levels, the above stimulus result in chemo receptor activation —> excite the vasomotor centre and elevates arterial pressure

ARTERIAL REFLEXES AND OTHER ORGANS

- Also cause significant reflex dilation of the afferent arterioles of the kidneys —> increases GFR —> increase filtration of kidneys into the renal tubules
- Cardiac reflexes
  - ANP —> stimulated by atrial stretch —> release of ANP —> causes natriuresis and secondary fluid diuresis
  - Bainbridge reflex —> increase atrial stretch —> stretches SA node —> 40 - 60% increase in HR
- CNS ischemic response
  - Blood flow to the vasomotor centre in the lower brainstem becomes decreased severely enough to cause nutritional deficiency —> cerebral ischemia —> excites neurones in the vasomotor centre —> increases blood pressure —> can increase MAP dramatically
  - Cushing's response
    - Increases pressure of CSF —> becomes close to pressure of venous system —> occludes cerebral vessels —> initiates response to cause a rising arterial pressure to overcome the increased CSF pressure —> vicious cycle

VASCULAR AUTO REGULATION

- Local control of tissue responds to tissue needs
  - Oxygen
  - Other nutrients
  - Removal of CO2
  - Removal of H2 ions
  - Maintenance of proper concentration of other ions in the tissue
  - Transport of various hormones
- Mechanisms of blood flow control
  - Acute vs Chronic

MECHANISMS OF VASCULAR AUTO REGULATION

- Autoregulation is the ability of tissues to maintain a stable tissue perfusion at a wide range of blood pressures
  - e.g. reflex vasoconstriction of stretched vascular smooth muscle to maintain steady blood flow
- Some metabolites are though to be vasodilators that contribute to this
  - And so, when there is a low flow circuit, these accumulate, vasodilate to increase flow, this increased flow washes these metabolites aware

FACTORS AFFECTING AUTOREGULATION

- Prostacycline PGI2
  - Prostaglandin that inhibits platelet activation and is a vasodilator
- Thromboxane A2
  - Released from platelets
  - Promotes platelet aggregation and potent vasoconstrictor
- EDRF - Endothelium derived relaxing factor
  - Best known is NO (increase cGMP —> reduce Ca 2+ —> smooth muscle relaxation)
- Endothelins:
  - Vasoconstrictor
- Hormones:
  - Kinins - protiens involved in pain, inflammation, coagulation and BP control e.g. brady kinin
  - ADH
    - Increased osmolarity sensed in the hypothalamus —> ADH released from posterior pituitary —> vasoconstriction (by vasopressin) and increased aquaporins inserted in apical membrane of renal collecting ducts —> increased water reabsorption —> osmolarity reduces
    - There are other stimulators of ADH release —> angiotensin II, CCK, pain, emotion, surgery
    - Inhibitors of ADH release = ethanol, ANP