Urinary System Physiology

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Urinary System Physiology

• Three Major Process of Urine Formation

1 Filtration
   – driving force is blood pressure at glomerular capillaries.
   – process is selective - fenestrated capillaries, basement membrane, and filtration slits

2 Reabsorption
   – removal of water and solutes across tubular membrane

3 Secretion
   – transport from peritubular fluid into tubular fluid
Sites of Occurrence

- Filtration occurs at renal corpuscle
- Absorption mostly at proximal convoluted tubule (obligatory water absorption)
- Secretion mostly at proximal and distal convoluted tubules
- Water regulation (facultative - ADH) mostly at distal convoluted tubule and collecting ducts
Nephron - Glomerulus

• Glomerulus
  – Is a group of blood capillaries fed by afferent arteriole and drained by efferent arteriole.
  – Surrounded by glomerular (Bowman’s) capsule.
    • Outer layer, which forms wall of capsule, is called the parietal layer and consists of simple squamous epithelium
    • Inner layer, which lines the capillaries, is called the visceral layer and consists of specialized cells called podocytes.
  – Produces fluid called filtrate by process of filtration
Glomerular Filtration Membrane

• Consists of
  – Fenestrated endothelium of capillaries
  – Visceral membrane of glomerular capsule
  – Basement membrane (between endothelium and visceral membrane)

• What passes through the filtration membrane is a function of the pore size of the filtration membrane.
Filtration

• Capillary endothelium
  – permits passage of large molecules but stops the movement of blood formed elements

• Basement membrane
  – restricts large plasma proteins

• Filtration slits
  – blocks most of the smaller plasma proteins

• Filtrate contains water, ions, and some very small organic molecules
Pressures

• Hydrostatic pressure
  – The pressure of water (against a membrane)
  – Produced by the heart (blood pressure)
  – Produced as a result of osmosis

• Osmotic pressure
  – Osmosis is the movement of water across a selectively permeable membrane. Movement results because of unequal distribution of water because of differences in the solute concentration
  – Water distribution may produce a environments of different pressures gradient
Filtration Pressures

- Filtration will occur when forces promoting filtration are greater than those opposing filtration
- **NET FILTRATION PRESSURE (NFP)** =
  - net hydrostatic pressure (NHP) - net colloid osmotic pressure (NCOP);
- **Net hydrostatic pressure (NHP)** =
  - Glomerular hydrostatic pressure – capsular hydrostatic pressure (NHP = GHP - CHP)
- **Net colloid osmotic pressure (NCOP)** =
  - Blood colloid osmotic pressure – capsular colloid osmotic pressure NCOP= BCOP – CCOP
  - Colloid osmotic pressure results because of presence of suspended proteins (and other solutes)
Hydrostatic Filtration Pressures

- Glomerular hydrostatic pressure (GHP)
  - Blood pressure in glomerular capillaries averages about 50mm Hg.
  - Adjustment of glomerular hydrostatic pressure
    - Afferent arteriole’s size large and efferent arteriole’s is small - creates higher filtration pressure
    - Myogenic mechanism - smooth muscle constricts if systemic pressure increases or dilates if pressure drops
    - Sympathetic innervation to afferent and efferent arterioles
Hydrostatic Filtration Pressures

• Capsular hydrostatic pressure (CHP)
  – pressure of water which is in capsular space and averages about 15 mm Hg.
  – results because of resistance along nephron tubules and conducting system
  – tendency to push filtrate back into capillaries

• Thus NHP = GHP (50) - CHP (15) = 35 mm Hg.
Colloid Osmotic Pressures

• Blood colloid osmotic pressure (BCOP)
  – tends to move water from filtrate into plasma; averages about 25 mm Hg.
Colloid Osmotic Pressures

• Capsular colloid osmotic pressure
  – force which moves water from plasma into filtrate; insignificant because capsule contains very few proteins, thus, averages about “0”
  – (May become significant if due to injury or disease proteins leak into filtrate; thus promotes filtration)

• Thus, NCOP = BCOP (25) - CCOP (0) = 25 mm Hg.
Net Filtration Pressure

• Net Filtration Pressure (NFP) is equal to net hydrostatic pressure (NHP) - net colloid osmotic pressure (NCOP);

• NFP = NHP (35) - NCOP (25) = 10 mm Hg.
Hydrostatic Pressure

- Hydrostatic pressure is pressure of water (against a wall / membrane)
- Hydrostatic pressure is produced by
  - Contraction of heart – blood pressure
  - Gravity
  - Solute gradients / osmosis
  - Blockage of fluid pathways such as
    - **Hydronephrosis** results when a ureter is blocked and back pressure results in damage to kidney
    - **Hydropyonephrosis** results due to accumulation of pus and fluids within the pelvis of the kidney
Glomerular Filtration Rate

- Kidneys filter about 180 liters (50 gal) and reabsorb 99% (produce about 1 liter of urine) in a single day

- Three processes control glomerular filtration rate (GFR)
  - Autoregulation (myogenic mechanism)
  - Hormonal regulation (tubuloglomerular mechanism and renin-angiotensin mechanism)
  - Autonomic regulation (extrinsic mechanism maintains systemic blood pressure)
Autoregulation of GFR

• Changes diameters (myogenic mechanism) of afferent arteriole, efferent arteriole, and glomerular capillaries
  – decrease pressure results in dilation of afferent arteriole, dilation of glomerular capillaries, and constriction of efferent arterioles
  – increase pressure results in constriction of afferent arteriole
Hormonal Regulation of GFR
(tubuloglomerular feedback mechanism)

Mostly involves **macula densa** cells of juxtaglomerular apparatus
  – Monitor filtrate flow and osmolarity

• Low filtrate flow and/or low osmolarity
  – Macula densa promotes vasodilation of afferent arteriole. Promotes increased NFP and GFR

• High filtrate flow and/or high osmolarity
  – Macula densa promotes vasoconstriction of afferent arteriole. Promotes decreased NFP and GFR
Hormonal Regulation of GFR

- **Renin released** from JG cells when
  - blood pressure declines
  - osmolarity of distal convoluted tubule decreases

- **Renin causes**
  - vasoconstriction of systemic capillaries
  - constriction of efferent arteriole
  - release of ADH mostly promoting water reabsorption
  - promotes release of aldosterone promoting sodium (thus, water) reabsorption at DCT
Autonomic Regulation of GFR

- Sympathetic nervous system causes constriction of afferent arteriole which decreases GFR
Reabsorption

- Both passive and active processes
- Organic molecules such as glucose and amino acids are completely reabsorbed
- Inorganic molecules such as water and ions are regulated to fit needs of the body
Reabsorption

- Most abundant cation in filtrate is \( \text{Na}^+ \)
- Reabsorption of \( \text{Na}^+ \) is mostly by active mechanisms
- Movement of \( \text{Na}^+ \) establishes electrochemical gradient and negative ions such as \( \text{HCO}_3^- \) and \( \text{Cl}^- \) follow.
- Water follows by obligatory reabsorption
- Solvent drag pulls along many other solutes (as solvent moves solute concentration is changed, thus, now moves from high concentration to low (if passive)
Reabsorption (con’t)

• Cotransport (along with Na\(^+\) moves most positive ions, vitamins, glucose, amino acids, etc.).

• Non-reabsorbed or partially reabsorbed - (1) lack carriers, (2) are not lipid soluble, or (3) too large to enter membranes. Include creatinine and urea

• Transport maximum is determined by active transport carriers. Saturation of carriers would allow substances to be excreted in urine (diabetes mellitus results in glucose excretion).
Tubule Regions & Reabsorption

- Proximal convoluted tubule is most active
  - All glucose, amino acids, 65 – 70% of Na\(^+\) and ions associated with its transport, HCO\(_3^-\), Cl\(^-\), K\(^+\), 65 – 70% of water

- Loop of Henle
  - Water permeable to descending limb but not permeable at ascending limb, also absorption of Na\(^+\), Cl\(^-\), HCO\(_3^-\)

- Distal convoluted tubule
  - largely under hormonal control. Na\(^+\) and water reabsorption are mostly dependent upon hormones – ADH and aldosterone
Aldosterone

• Aldosterone
  – Originates from adrenal cortex when BP, or Na⁺ (hyponatremia) is low or when K⁺ (hyperkalemia) is high. Also at play (low PB) may be renin-angiotensin pathway. Angiotensin targets adrenal cortex and promotes release of aldosterone.
  – Aldosterone targets distal convoluted tubule and collecting duct promoting reabsorption of Na⁺ and excretion of K⁺. Water follows osmotic gradient and is an example of facultative water reabsorption.
Atrial natriuretic peptide

• Produced by atrial cardiac cells when blood pressure of volume is high.
  – Targets collecting ducts to inhibit sodium ion absorption
  – Results in reduction of aldosterone production by adrenal cortex
Secretion

• Removes from the blood (or tubule cells) substances such as $H^+$, $K^+$, creatinine, ammonium ions, etc.

• Functions in the
  – Regulation of blood pH
  – Removal of excess potassium ions
  – Help to eliminate substances reabsorbed by passive transport such as urea
  – Removal of substances not normally found in the filtrate (medications)
Control of Urine Volume

• Obligatory water reabsorption
  – water movement cannot be prevented (osmotic)
  – Mostly in proximal convolute tubule as ions (such as sodium) are actively reabsorbed water follows, about 65% of water is reabsorbed.

• Facultative water reabsorption
  – water movement can be controlled – hormonal mostly under control of ADH