Urinary System, Chapter 21

Outline of class notes

Objectives: After studying this chapter you should be able to:

1. Identify the main structures and functions of the urinary system.
2. Describe the internal and external anatomy of the kidney.
3. Describe the structures of a nephron and how they are classified.
4. Describe the structures of the renal corpuscle and how the glomerular filtrate is formed and how the regulation of glomerular filtration rate takes place.
5. Explain the function of the renal tubules.
6. Include a description of the juxtaglomerular apparatus and how antidiuretic hormone and aldosterone affect the function of the collecting ducts.
7. Describe the process of Countercurrent Multiplication.
8. Describe the functions of the Renin-Angiotensin-Aldosterone System
9. **Explain the process for the reabsorption of glucose and amino acids**
10. Discuss the Clinical Applications from the study guide and assigned Applications to Health.

Overview of Urinary System

- **Kidney Structure and function**
- **Glomerular Filtration**
- **Reabsorption along the Nephron**
  - Countercurrent multiplier system
  - Effects of ADH
  - Role of the Juxtaglomerular apparatus
- **Applications to Health:**
  - Nephroptosis
  - Kidney stones
  - Kidney transplant
  - Incontinence
  - Urinary tract infections
  - Diabetes Insipidus

Medical Specialties

- **Nephrology:** The structure, function and diseases of the kidney.
- **Urology:** Branch of medicine related to:
  - Male and female urinary systems
  - Structures of the Urinary System

- Urinary system consists of:
  - **Kidneys** (2):
  - **Ureters** (2): Convey urine to urinary bladder
  - **Urinary bladder:** Temporary storage of urine
  - **Urethra:**

Functions of the Urinary System

- **Kidneys have 2 main functions:**
  1. The regulation of extracellular fluid (plasma and intercellular fluid)
  2. The regulation of blood volume and pressure.
  - In the process the
Regulation of extracellular fluid includes:
- The concentration of waste products in the plasma such as urea, uric acid, and creatinine.
- The concentration of
  - Adjusts blood pH by controlling the levels of bicarbonate (HCO3-) and hydrogen (H+) ions.

Regulates blood volume and pressure:
- Adjusts amount of
  - Production of erythropoietin which stimulates RBC production.
  - Production of renin which increases blood pressure by activation of the renin-angiotensin aldosterone pathway.

Kidneys
- Location:
  - Attached to dorsal part of abdominal cavity just above the waist
  - Retroperitoneal:
    - Right kidney is slightly lower than the left due to presence of liver.
    - Adrenal glands are attached to the top of each kidney
      - Are not part of urinary system.

Nephroptosis
- Nephroptosis (floating kidney)
  - Kidney slips from its normal position.
  - Caused by trauma and/or significant weight loss.
  - Kinking of the ureter can result in blocked urine and retrograde pressure that damages the kidney.
  - Treatment:

Kidney Transplant
- Transfer of a kidney from a living donor or a cadaver to a recipient.
  - Donor kidney is placed in the pelvis.
    - In most cases the barely functioning existing kidneys are not removed.
  - Renal artery and vein are attached to renal external iliac artery and vein of recipient.
  - Ureter is

Kidneys: Internal Anatomy
- Renal cortex: Outer region
  - Contains the blood filtering portion of nephrons – the glomerulus.
  - Is reddish brown and granular in appearance because

- Renal medulla: Inner region
  - Consists of 8-16 cone shaped striated wedges called renal pyramids separated by renal columns
    - Appears striated because of straight tubules of

- Renal papillae: The tips of the renal pyramids that project into the renal calyces of the renal pelvis.

- Renal pelvis: Collects urine from the calyces and transports it the ureters that delivers it to the urinary bladder
Kidney: Blood Supply
• Blood flow through both kidneys is \( \approx 1200 \text{ mL per minute} \).
  – Receive ~
  – All the blood passes through the kidneys every 4-5 minutes.

The Nephron
• Nephron:
  – \( \approx 1 \text{ million nephrons per kidney} \).
    • Number is constant from birth.
      – Increase in kidney size due to increase in growth of nephrons.
    • Combined length of nephrons in both kidneys is \( \approx 85 \text{ miles} \).
  – Nephrons cannot

Classification of Nephrons
• Two types of nephrons: Cortical or juxtamedullary
  – Depends on

  • Juxtamedullary Nephrons (15-20%)
    – Renal corpuscle is close to the medulla
    – Have longer loops of Henle for greater reabsorption of water.

  • Cortical Nephrons (80-85%)
    – Renal corpuscle is farther out in the medulla.
    – Shorter loops of Henle that penetrate on the outer region of the medulla.
Nephron Structure
• A Nephron consists of 2 parts
  1.
  2.

Renal Corpuscle
• Renal corpuscle: Structure which filters blood plasma

• Glomerulus: A tuft of capillaries that
  - Receives blood from an **afferent arteriole** and blood drains into an **efferent arteriole**.
  - Composed of:
    - **Endothelial cells**: Form the inner layer of the capillary walls

• Glomerular (Bowman’s) capsule: Double walled epithelial cup that surrounds the glomerulus.
  - Consists of **parietal** and **visceral layers**:
    - **Parietal layer**: Lines the outer wall of the capsule.
    - **Visceral layer**: **Podocytes** envelop the glomerular capillaries with their pedicels.
      - **Pedicels**: Foot-like extensions that
        - **Filtration slits**: Spaces between the pedicels; have a membrane (**slit diaphragm**) to restrict passage of medium and small proteins.
        - **Glomerular or capsular space**: Space between the parietal and visceral layers.
Glomerular Filtration

- **Glomerular filtrate**: Fluid that is pushed out of the glomerular capillaries by **blood hydrostatic pressure** and enters the **glomerular capsule**.
  - Net filtration pressure is

- **Glomerular filtration rate (GFR)**: Volume of filtrate produced by both kidneys per minute.
  - Averages ~125 ml per minute
  - Equivalent to 7.5 L/hour or 180 L/day (~45 gallons)
  - Total blood volume (~5.5 L) is filtered through the kidneys every

Renal Tubule

- **Renal Tubule**: Structure into which the filtrate passes.
  - **Consists of 3 segments**:
    - Proximal convoluted tubule
    - Loop of Henle (Nephron loop)

**Importance of Renal Tubules**

- With an average GRF of 180 L per day, a person would urinate to death in a matter of minutes if most of this volume (99%) was not reabsorbed into the blood stream via the renal tubules.
- The kidneys normally excrete ~1 to 2 liters of urine in a 24-hour period.
  - In severe dehydration, a volume of 400 ml of urine per day is the minimum needed to excrete the metabolic wastes produced by the body
    - Referred to as

**Proximal Convoluted Tubule**

- **Proximal convoluted tubule (PCT)**: Receive the filtrate from the renal corpuscle and
  - Reabsorb virtually all the glucose, amino acids, and other organic nutrients (by active transport) and ~ 65% of NaCl and water (water by osmosis).
**Loop of Henle**
- Contain both a descending and an ascending limb.
  - Function: Reabsorption of

**Distal Convoluted Tubule and Collecting Duct**
- Distal convoluted tubule and collecting duct are lined with **epithelial cells** along with two specialized cells types—**principal cells** and **intercalated cells**.
- **Principal cells**: Stimulated by
- **Intercalated cells**: Secrete H+ into the urine to

**Diabetes Insipidus**
- **Diabetes insipidus**: Results from an inadequate secretion or action of ADH.
  - Without proper amounts or action of ADH, collecting ducts are impermeable to water so large volumes (5 to 10 L/day) of dilute urine is produced
  - Person has difficulty drinking enough water

**Renin-angiotensin-aldosterone system**

**Juxtaglomerular apparatus**
- The **juxtaglomerular apparatus** consists of **macula densa cells** and **juxtaglomerular cells**
  - Function: Regulates blood volume and pressure through the release of renin and erythropoietin
- **Macula densa cells** are located in the ascending limb and are in contact with the juxtaglomerular cells of the afferent arteriole.
  - Function: Monitor
- **Juxtaglomerular cells** are specialized smooth muscle cells located in the afferent arteriole.
  - Function: Secrete
  - See diagram of the action of renin
Reabsorption of Glucose and Amino Acids

- Glucose and amino acids are reabsorbed within the membrane carriers can achieve a maximal transport rate – called the transport maximum (Tm).
  - Tm occurs when all the membrane carriers become saturated with glucose or amino acids due to excessively high concentrations.
  - Results in excess glucose and/or amino acids being lost in the urine.

Glucosuria

- **Glucosuria:**
  - Results when more glucose passes through the tubules than can be reabsorbed.
  - **Diabetes mellitus:** Caused by an inadequate secretion (Type I) or action (Type II) of insulin, which can result in hyperglycemia and glucosuria.
    - Person also excretes a large volume of urine because the excess glucose that is not reabsorbed carries water with it as a result of the osmotic pressure it generates within the tubules.

Diuretics

- **Diuretic:** Substance that increases the rate of urine production thereby lowering blood volume and pressure.
  - Used to treat:

Urine

- **Urine consists of:**
  - Water
  - Nitrogenous wastes
    - **Urea:** formed by the deamination of amino acids at liver
    - **Creatinine:** Breakdown of creatine phosphate in skeletal muscle.
    - **Uric acid:** Breakdown of purines
  - **Ammonia (minor amounts):** Deamination of amino acids by liver and kidney
  - **Bilirubin:** Breakdown product of hemoglobin – specifically the heme group.
    - Color due to:
      - **Nutrients** and metabolites (relatively few): carbohydrates, lipids, ketone bodies, amino acids.
      - **Ions:** Sodium, chloride, calcium, magnesium
      - Rare, but could see red blood cells and white blood cells
      - **Urine pH** is usually

Micturation (urination) Reflex

- **Micturition:** Occurs via a combination of involuntary and voluntary muscle contractions.
  - **Micturition Reflex:** At a urine amount of 200 to 400 ml, stretch receptors in the bladder wall transmit nerve impulses to the micturition center of the sacral spinal cord.
    - **Micturation center** sends nerve impulses to contract the **detrusor muscle** and relax the internal urethral sphincter.
      - Will also send signals to cerebral cortex giving the
  - As the bladder continues to fill the cycle of nerve stimulation and bladder muscle contraction increases and the urgency to urinate is felt.
  - Relaxation of **external urethral sphincter muscle** (voluntary control) is required for urination unless the bladder fills beyond control.
    - Muscle located within
Urinary Incontinence
  - Urinary incontinence:
    - In infants and toddlers (below 2-3 years of age):
      - Involuntary control over urination is normal because neurons to the external urethral sphincter muscle are not completely developed.
    - In Adults: Over 10 million in the U.S.
      - **Stress incontinence**: Physical stresses that increase abdominal pressure – coughing, sneezing, laughing, exercising, pregnancy
      - **Injury** to nerves controlling the urinary bladder
      - **Emotional stress**

Kidney Stones: Renal Calculi
  - **Calculi**: Insoluble salt crystals that can form anywhere within the kidney tubules, ureters, urinary bladder, or urethra.
  - Types of stones/composition:
    - Calcium oxalate (70%), calcium phosphate (5-10%), struvite (10%), uric acid (10%) and cystine (1%).
  - **Cause**: Components of urine (minerals and acids) are out of balance, become concentrated and then crystallize.
    - Most caused from
      - Some from anatomical malformations of the urinary tract or may have a genetic predisposition, or due to diet.
  - **Treatment**:
    - Drink lots of water: May be able to move a stone through your urinary tract simply by drinking plenty of water — as much as 2 to 3 quarts (1.9 to 2.8 liters) a day — and by staying physically active.
    - **Shock wave lithotripsy**: Uses shock waves to break the stones into tiny pieces that are then passed in your urine.
    - **Surgery**: Stones removed through a small incision in your back using an instrument called a nephroscope.