Chapter 23

Urine Formation II
Tubular Reabsorption and Secretion of the Urinary System
Urine Formation II: Tubular Reabsorption and Secretion

- Conversion of glomerular filtrate to urine involves the removal and addition of chemicals by tubular reabsorption and secretion.
  - Occurs through PCT to DCT.
  - Tubular fluid is modified.

- Steps involved include:
  - Tubular reabsorption.
  - Tubular secretion.
  - Water conservation.

1. Glomerular filtration
   - Creates a plasmalike filtrate of the blood.

2. Tubular reabsorption
   - Removes useful solutes from the filtrate, returns them to the blood.
   - Tubular secretion
     - Removes additional wastes from the blood, adds them to the filtrate.

3. Water conservation
   - Removes water from the urine and returns it to blood; concentrates wastes.
Proximal Convoluted Tubule

- reabsorbs about 65% of glomerular filtrate from the PCT segment
  - removes some substances from the blood, and secretes them into the tubular fluid for disposal in urine
  - prominent microvilli and great length
  - abundant mitochondria provide ATP for active transport
  - PCTs alone account for about 6% of one’s resting ATP and calorie consumption

- tubular reabsorption – process of reclaiming water and solutes from the tubular fluid and returning them to the blood

- two routes of reabsorption
  - transcellular route
    - substances pass through the cytoplasm of the PCT epithelial cells and out their base
  - paracellular route
    - substances pass between PCT cells
    - junctions between epithelial cells are quite leaky and allow significant amounts of water to pass through
    - solvent drag – water carries with it a variety of dissolved solutes

- taken up by peritubular capillaries
Sodium Chloride

• **sodium reabsorption** is the key to everything else
  – creates an osmotic and electrical gradient that drives the reabsorption of water and other solutes
  – most abundant cation in filtrate
  – creates steep concentration gradient that favors its diffusion into the epithelial cells

• **two types of transport proteins** in the apical cell surface are responsible for sodium uptake
  – symports that simultaneously bind \( \text{Na}^+ \) and another solute such as glucose, amino acids or lactate
  – a \( \text{Na}^+ - \text{H}^+ \) antiport that pulls \( \text{Na}^+ \) into the cell while pumping out \( \text{H}^+ \) into tubular fluid

• sodium is prevented from accumulating in the epithelial cells by \( \text{Na}^+ - \text{K}^+ \) pumps in the basal surface of the epithelium
  – pumps \( \text{Na}^+ \) out into the extracellular fluid
  – picked up by peritubular capillaries and returned to the bloodstream
  – ATP consuming active transport pumps
  – secondary active transport – \( \text{Na}^+ \) transporting symports in apical cell membrane do not consume ATP, are considered an example of secondary active transport for their dependence on the \( \text{Na}^+ - \text{K}^+ \) pumps at the base of the cell

• negative **chloride ions** follow the positive sodium ions by electrical attraction
  – various antiports in the apical cell membrane that absorb \( \text{Cl}^- \) in exchange for other anions they eject into the tubular fluid – \( \text{K}^+ - \text{Cl}^- \) symport
Reabsorption in the PCT Other Electrolytes

- potassium, magnesium, and phosphate ions diffuse through the paracellular route with water
- phosphate is also cotransported into the epithelial cells with Na⁺
- some calcium is reabsorbed through the paracellular route in the PCT, but most Ca⁺² occurs later in the nephron
- glucose is cotransported with Na⁺ by sodium-glucose transport (SGLT) proteins.
- urea diffuses through the tubule epithelium with water – reabsorbs 40 – 60% in tubular fluid
  - kidneys remove about half of the urea from the blood - creatinine is not reabsorbed at all
Water Reabsorption

- Kidneys reduce 180 L of glomerular filtrate to 1 or 2 liters of urine each day.
- Two-thirds of water in filtrate is reabsorbed by the PCT.
- Reabsorption of all the salt and organic solutes makes the tubule cells and tissue fluid hypertonic.
  - Water follows solutes by osmosis through both paracellular and transcellular routes through water channels called aquaporins.
  - In PCT, water is reabsorbed at constant rate called obligatory water reabsorption.
Uptake by the Peritubular Capillaries

- After water and solutes leave the basal surface of the tubular epithelium, they are reabsorbed by the peritubular capillaries
  - Reabsorbed by osmosis and solvent drag

- Three factors promote osmosis into the capillaries
  - Accumulation of reabsorbed fluid around the basolateral sides of epithelial cell creates **high interstitial fluid pressure** that drives water into the capillaries
  - Narrowness of efferent arterioles lowers **blood hydrostatic pressure** in peritubular capillaries so there is less resistance to absorption
  - Proteins remain in blood after filtration, which elevates **colloid osmotic pressure**
    - High COP and low BHP in the capillaries and high hydrostatic pressure in the tissue fluid, the balance of forces in the peritubular capillaries favors absorption
Transport Maximum of Glucose

- There is a limit to the amount of solute that the renal tubules can reabsorb.
- Limited by the number of transport proteins in the plasma membrane.
- If all transporters are occupied as solute molecules pass, excess solutes appear in urine.
- Transport maximum is reached when transporters are saturated.
- Each solute has its own transport maximum.
  - Any blood glucose level above 220 mg/dL results in glycosuria.
Tubular Secretion

- **tubular secretion** – process in which the renal tubule extracts chemicals from the capillary blood and secretes them into tubular fluid

- two purposes in proximal convoluted tubule and nephron loop
  - **waste removal**
    - urea, uric acid, bile acids, ammonia, catecholamines, prostaglandins and a little creatinine are secreted into the tubule
    - secretion of uric acid compensates for its reabsorption earlier in PCT
    - clears blood of pollutants, morphine, penicillin, aspirin, and other drugs
      - explains need to take prescriptions 3 to 4 times/day to keep pace with the rate of clearance
  - **acid-base balance**
    - secretion of hydrogen and bicarbonate ions help regulate the pH of the body fluids
Function of Nephron Loop

- **primary function of nephron loop** is to generate salinity gradient that enables collecting duct to concentrate the urine and conserve water

- electrolyte reabsorption from filtrate
  - thick segment reabsorbs 25% of $\text{Na}^+$, $\text{K}^+$, and $\text{Cl}^-$
    - ions leave cells by active transport and diffusion
      - $\text{NaCl}$ remains in the tissue fluid of renal medulla
      - water can not follow since thick segment is impermeable
  - tubular fluid very dilute as it enters distal convoluted tubule
DCT and Collecting Duct

- Fluid arriving in the DCT still contains about 20% of the water and 7% of the salts from glomerular filtrate
  - If this were all passed as urine, it would amount to 36 L/day

- DCT and collecting duct reabsorb variable amounts of water salt and are regulated by several hormones
  - Aldosterone, atrial natriuretic peptide, ADH, and parathyroid hormone

- **Two kinds of cells** in the DCT and collecting duct
  - Principal cells
    - Most numerous
    - Have receptors for hormones
    - Involved in salt and water balance
  - Intercalated cells
    - Involved in acid/base balance by secreting $H^+$ into tubule lumen and reabsorbing $K^+$
DCT and Collecting Duct

• **aldosterone** - the “salt-retaining” hormone
  – steroid secreted by the adrenal cortex
    • when blood Na\(^+\) concentration falls
    • when K\(^+\) concentration rises
    • drop in blood pressure $\rightarrow$ renin release $\rightarrow$ angiotensin II formation $\rightarrow$ stimulates adrenal cortex to secrete aldosterone

• **functions of aldosterone**
  – acts on thick segment of nephron loop, DCT, and cortical portion of collecting duct
    • stimulates the reabsorption of more Na\(^+\) and secretion of K\(^+\)
    • water and Cl\(^-\) follow the Na\(^+\)
    • net effect is that the body retains NaCl and water
      – helps maintain blood volume and pressure
    • the urine volume is reduced
    • the urine has an elevated K\(^+\) concentration
DCT and Collecting Duct

- **atrial natriuretic peptide** (ANP)
  - secreted by atrial myocardium of the heart in response to high blood pressure

- has four actions that result in the excretion of more salt and water in the urine, thus *reducing blood volume and pressure*
  - dilates afferent arteriole, constricts efferent arteriole - $\uparrow$ GFR
  - inhibits renin and aldosterone secretion
  - inhibits secretion of ADH
  - inhibits NaCl reabsorption by collecting duct
DCT and Collecting Duct

• **antidiuretic hormone** (ADH) secreted by posterior lobe of pituitary
• in response to dehydration and rising blood osmolarity
  – stimulates hypothalamus
  – hypothalamus stimulates posterior pituitary
• action - make collecting duct more permeable to water
  – water in the tubular fluid reenters the tissue fluid and bloodstream rather than being lost in urine
DCT and Collecting Duct

• parathyroid hormone (PTH)
  – secreted from parathyroid glands in response to calcium deficiency (hypocalcemia)
  – acts on PCT to increase phosphate excretion
  – acts on the thick segment of the ascending limb of the nephron loop, and on the DCT to increase calcium reabsorption
  – increases phosphate content and lowers calcium content in urine
  – because phosphate is not retained, the calcium ions stay in circulation rather than precipitating into the bone tissue as calcium phosphate
  – PTH stimulates calcitriol synthesis by the epithelial cells of the PCT
Summary of Tubular Reabsorption and Secretion

- **PCT** reabsorbs 65% of glomerular filtrate and returns it to peritubular capillaries
  - much reabsorption by osmosis & cotransport mechanisms linked to active transport of sodium

- **nephron loop** reabsorbs another 25% of filtrate

- **DCT** reabsorbs Na\(^+\), Cl\(^-\) and water under hormonal control, especially aldosterone and ANP

- the tubules also extract drugs, wastes, and some solutes from the blood and secrete them into the tubular fluid

- **DCT** completes the process of determining the chemical composition of urine

- collecting duct conserves water