Chapter 23

Urine Formation II
Tubular Reabsorption and Secretion of the Urinary System
Step Two in Urine Formation: 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.

3 steps involved include:
- Tubular reabsorption
- Tubular secretion
- Water conservation.
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 in the Proximal Convoluted Tubule

- 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

- Reclaimed fluid and solute 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 Na⁺ and another solute such as glucose, amino acids or lactate
  – a Na⁺ - H⁺ antiport that pulls Na⁺ into the cell while pumping out H⁺ into tubular fluid

• sodium is prevented from accumulating in the epithelial cells by **Na⁺ - K⁺ pumps** in the basal surface of the epithelium
  – pumps Na⁺ out into the extracellular fluid
  – picked up by peritubular capillaries and returned to the blood stream
  – ATP consuming active transport pumps
  – **secondary active transport** – Na⁺ transporting symports in apical cell membrane do not consume ATP, are considered an example of secondary active transport for their dependence on the Na⁺ - 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 Cl⁻ in exchange for other anions they eject into the tubular fluid – K⁺ - 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. Reabsorption is 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 favor absorption.
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

- each solute has its own transport maximum
  - any blood glucose level above 220 mg/dL results in glycosuria

- if all transporters are occupied as solute molecules pass through the tubules, excess solutes appear in urine

- if all transporters are saturated, transport maximum is reached when transporters can no longer reabsorb the solute

- if all transporters are not saturated, solute molecules pass through the tubules without reabsorption

- glucose is reabsorbed in the proximal convoluted tubules

- if glucose is not reabsorbed, it appears in the urine

- if blood glucose levels are high, glucose appears in the urine (glycosuria)

- normoglycemia results in normal urine volume, glucose-free

- hyperglycemia results in increased urine volume, with glycosuria
• **The tubular secretions** – process in which the renal tubule extracts chemicals from the capillary blood and secretes them into proximal tubular fluid and nephron loop

• two type of secretions go into the 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.

- **Secondary function** is electrolyte reabsorption from filtrate:
  - thick segment reabsorbs 25% of Na⁺, K⁺, and Cl⁻:
    - ions leave cells by active transport and diffusion
      - 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 with 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 → renin release → angiotensin II formation → 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)** is secreted by atrial myocardium of the heart in response to high blood pressure.

- It 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

- ADH release in response to dehydration and/or 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** reabsors 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