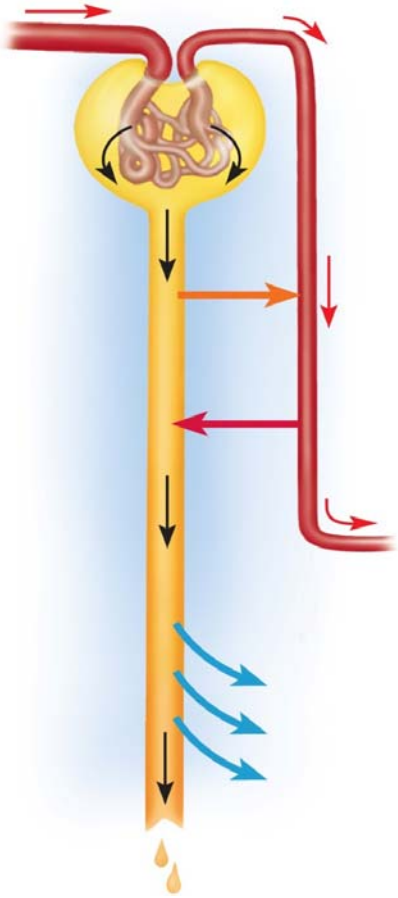
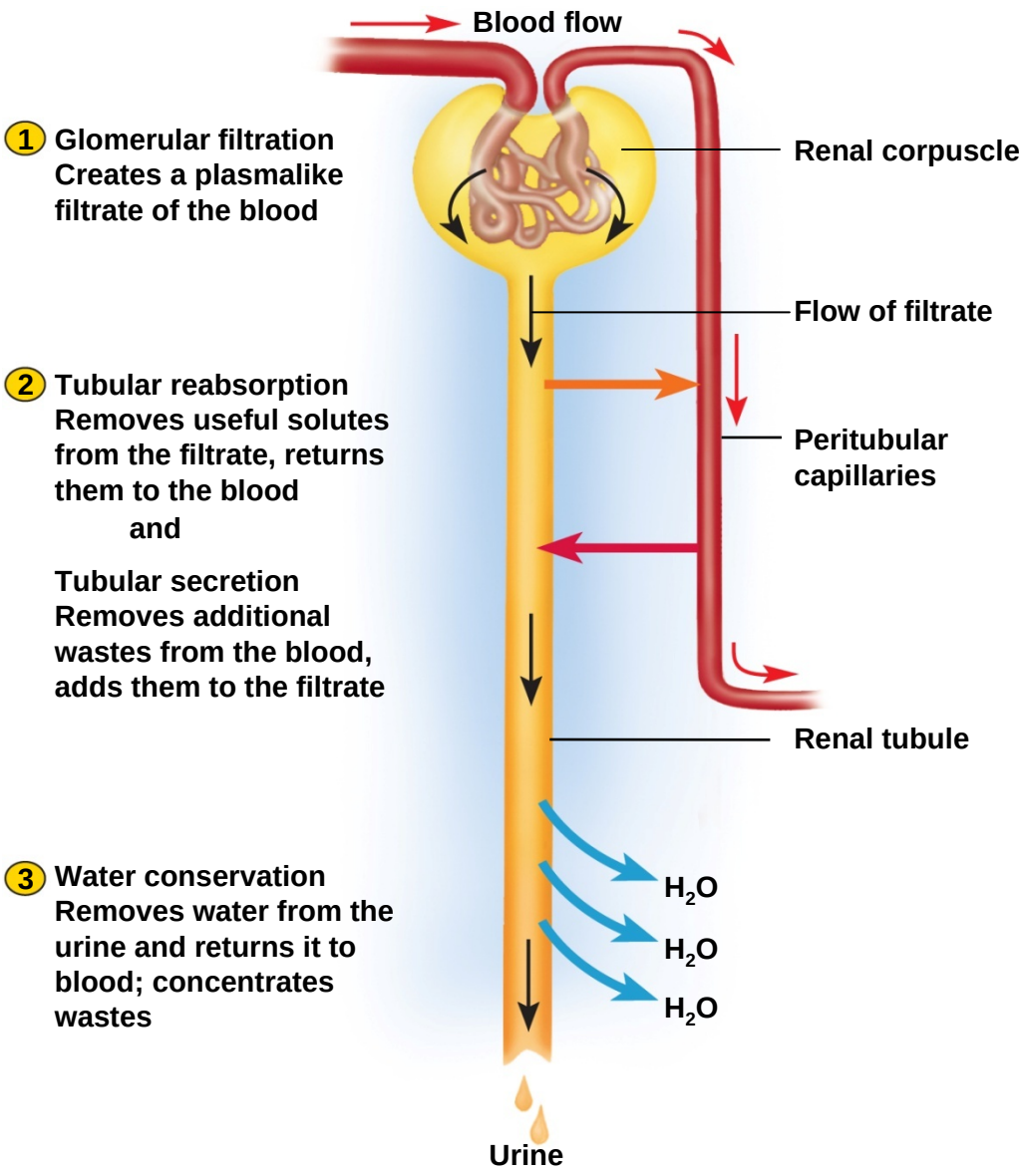
Chapter 23

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

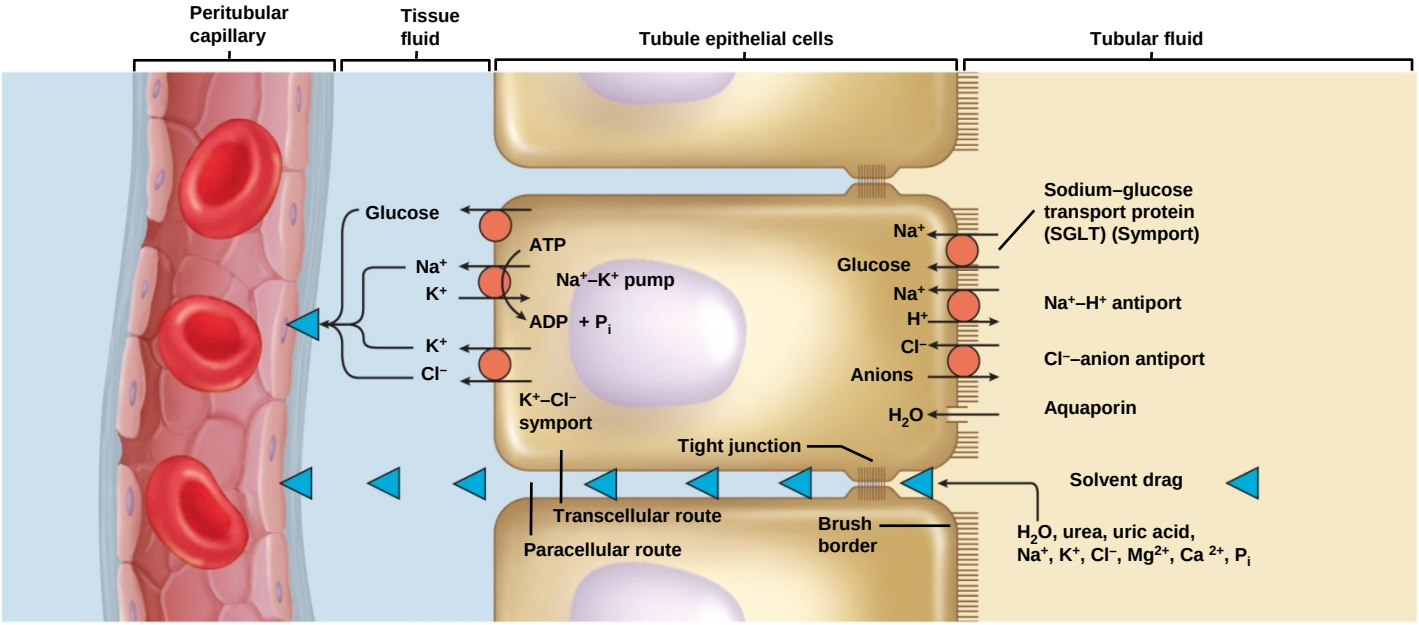
- process of reclaiming water and solutes from the tubular fluid and returning them to the blood
- two routes of reabsorption
  - transcellular route /// substances pass through the cytoplasm of the PCT epithelial cells and out their base
  - paracellular route /// substances pass between PCT cells
    - 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 /// reabsorbed by osmosis and solvent drag

- three factors promote osmosis into the capillaries

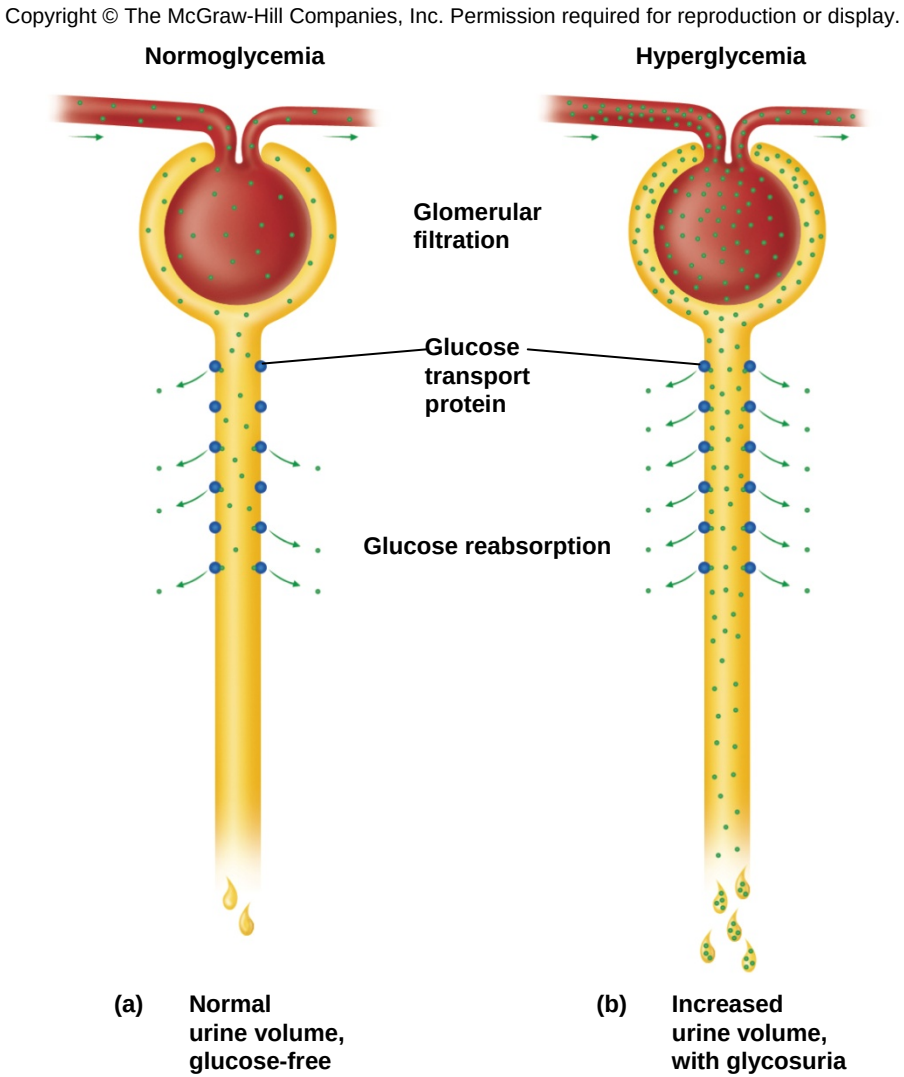
  – accumulation of reabsorbed fluid around the basolateral sides of epithelial cell creates **high interstitial fluid pressure** that drives water into the capillaries

  – 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**

- **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

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- 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 $\rightarrow$ 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 <u>reducing blood volume and pressure</u>
  - dilates afferent arteriole, constricts efferent arteriole - ↑ 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

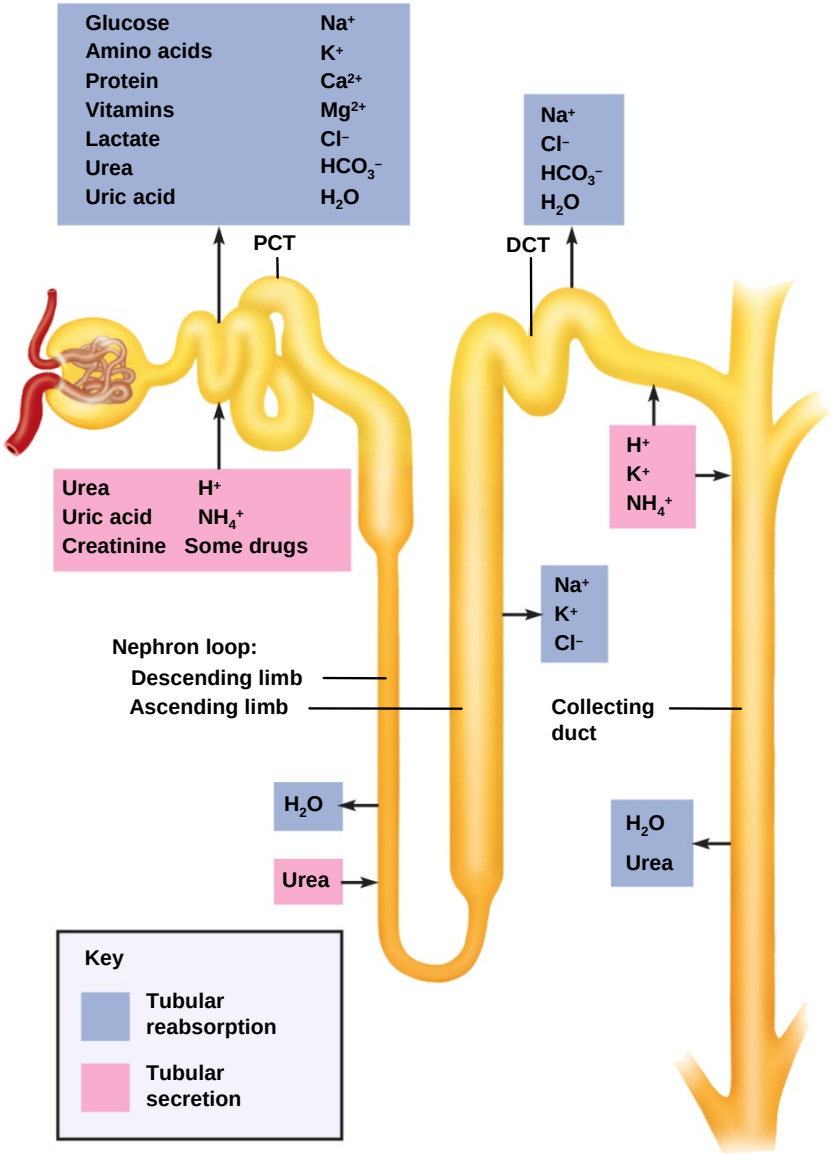
- action - make collecting duct more permeable to water

  – 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** 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