TOPIC 20: URINARY SYSTEM: OVERVIEW AND FILTRATION

I. Overview

A. Function of Urinary System
1. Maintaining water balance in the body
2. Regulating quantity and concentration of most ECF ions (don’t forget that the ECF is composed of both blood plasma and interstitial fluid) such as Na⁺, Cl⁻ K⁺, and HCO₃⁻
3. Maintaining plasma volume
4. Maintaining acid-base balance
5. Maintaining proper osmolarity of body fluids
6. Excreting end products of bodily metabolism (e.g., urea, uric acid)
7. Excreting foreign compounds (e.g., drugs, pesticides, food additives)
8. Secreting erythropoietin (hormone that stimulates red blood cell production)
9. Secreting renin (hormone involved in salt regulation)
10. Converting vitamin D to its active form

B. Major components of urinary system (Fig 18.1 & 18.2)
1. Kidneys
   a) Two bean shaped kidneys that lie in back of abdominal cavity
   b) Produce urine from blood plasma
2. Renal artery
3. Renal Vein
4. Renal pelvis
   a) urine collecting cavity in inner core of each kidney
5. Ureter
   a) carries urine from each renal pelvis to bladder
6. Urinary bladder
   a) temporary urine storage area
7. Urethra
   a) tube from bladder to environment for elimination of urine

C. Kidney Structure (Fig 18.2)
1. each kidney composed of ~1 million microscopic functional units called nephrons
2. Arrangements of nephrons give rise to two distinct regions
   a) outer region: renal cortex
   b) inner region: renal medulla

D. Nephron structure: Can be broken into two major parts (Fig 18.6)
1. Vascular component
   a) renal artery enters kidney then subdivides
   b) into afferent arterioles, one of which supplies each nephron, and subdivide
   c) into glomerular capillaries. The glomerulus of each nephron is a ball-like tuft of these capillaries, and is where filtration occurs. The glomerular capillaries join together to form
   d) the efferent arteriole, which leaves the glomerulus. This arteriole carries blood that was not filtered in the glomerulus, and which has not yet exchanged materials with the surrounding tissue. This is the only place in the body where an arteriole leaves capillaries. The efferent arteriole quickly subdivides into
   e) the peritubular capillaries, which supply the renal tissue with blood, and are important in exchanges between the tubular system and the blood during urine production. They completely surround the tubular components.
2. Tubular component (Fig 18.3)
a) Hollow fluid filled tube formed by a single layer of epithelial cells. Even though it is continuous, it is arbitrarily divided into different segments based on differences in structure and function along its length.
b) **Bowman’s capsule** begins the tubular component, and is a doubled wall cup that surrounds the glomerulus and collects the fluid filtered from the glomerular capillaries. From there, filtered fluid passes into
c) the **proximal tubule**, which is highly coiled and lies entirely within the cortex.
d) Next is the **loop of Henle**, which forms a U-shaped loop that dips into the renal medulla. The **descending limb** goes from the cortex into the medulla; the **ascending limb** goes back up into the cortex from the medulla, and returns to the glomerular region of its own nephron.
e) The **juxtaglomerular apparatus** lies next to the glomerulus, is composed of both tubular and vascular components, and is involved in regulating kidney function. Beyond this is
f) the **distal tubule**, which is highly coiled and lies entirely within the cortex. This empties into a
g) **collecting duct**, each of which collects fluid from up to 8 nephrons.

E. The Three Basic Renal Processes (Fig 18.7)
1. Glomerular filtration
   a) blood flows through the glomerulus
   b) about 20 % of plasma that enters is filtered into Bowman’s capsule, and enters the tubular system
   c) all blood components (except proteins and red blood cells) are non-selectively filtered along with plasma at this step into the tubular system.
   d) on average, ~ 180 liters (47.5 gallons) of glomerular filtrate formed per day.
2. Tubular reabsorption
   a) As filtrate flows through tubules, substances of value to the body are returned to the peritubular capillaries and so re-enter the circulatory system.
   b) Of the 180 liters of filtrate produced per day, about 178.5 liters are reabsorbed in this process; the other 1.5 liters ultimately eliminated as urine.
3. Tubular secretion
   a) Selective transfer of substances from peritubular capillary into the tubular system.
   b) The 80% of the blood that is NOT filtered into Bowman’s capsule thus can have selected components removed by this process; in general, this is a rapid way to remove specific substances from the blood.

F. Important Notes:
1. Don’t forget that there is free exchange between the plasma and the interstitial fluid in the capillaries and lymph in the whole body, so **ALL the ECF is filtered through the kidneys**. Thus by performing their regulatory and excretory roles on the plasma, the kidneys maintain the proper interstitial fluid environment for optimal cell function.
2. At rest, 20% to 25% of the blood volume is pumped to the kidneys, i.e., nearly a quarter of your blood is going to get “cleansed” at any given moment.
3. The rest of Topic 20 and Topic 21 will primarily discuss in detail the 3 basic renal processes; Topic 22 and 23 cover fluid and acid base balance, in which the kidneys play a major role.

II. Glomerular Filtration
   A. Process of filtration
      1. Glomerular membrane allows **nonspecific** passage of plasma and plasma ions from vascular system into tubular system; note that the glomerular capillary walls (which are part of the glomerular membrane) are 100 times more permeable to water and small
solutes than normal capillary walls.

2. Glomerular membrane excludes > 99% of all proteins in blood from tubular system

3. Glomerular Filtration Rate (GFR) is the rate at which plasma is filtered into tubular system from vascular system

   a) filtration rate is determined by
      (1) surface area of glomerular membrane
      (2) permeability of glomerular membrane
      (3) glomerular capillary blood pressure
      (4) hydrostatic pressure (can not be regulated)
      (5) plasma osmotic pressure (can not be regulated)

   b) GFR is about 125 ml/min for males for both kidneys
   c) GFR is about 115 ml/min for females for both kidneys

B. The problem of GFR and blood pressure (Fig 18.10)

   1. **Challenge:** GFR is directly determine by the blood pressure in the glomerular capillaries: the higher the bp the higher the GFR. BUT you don’t want changes in arterial blood pressure changing the GFR. (Think about exercise: you don’t want increase in bp caused by exercise to increase GFR and hence urine output).

   2. **Solution:** The kidneys are able to regulate the blood pressure in the glomerular capillaries as long as mean arterial blood pressure does not go below 80 or above 180 mm Hg.

C. **Intrinsic** regulation of GFR via glomerular capillary blood pressure (Fig 18.11)

   1. Occurs when mean arterial pressure is between 80 and 180 mm Hg
   2. Myogenic properties of the arterioles in the kidney AND the juxtaglomerular apparatus in the kidney automatically detect changes in bp and adjust the GFR accordingly. For example, when you start exercising and your overall bp goes up, these two mechanisms reduce bp in the glomerular capillaries by vasoconstrcting the arterioles that lead to them, so that GFR goes back to normal. Likewise if your bp goes down these two mechanisms cause vasodilation of the blood vessels to increase the GFR.

D. **Extrinsic** regulation of GFR via glomerular capillary blood pressure (Fig 18.12)

   1. Occurs when mean arterial pressure outside the 80 to 180 mm Hg
   2. Recall the baroreceptor reflex response from Topic 18: baroreceptors sense changes in mean arterial blood pressure, which ultimately leads to stimulation of autonomic nervous system to either vasoconstrict or vasodilate blood vessels in the body.
   3. Drop in BP (xs sweating, bleeding): Sympathetic activity increases, causes vasoconstriction in most arterioles in body to increase total peripheral resistance as compensation
      a) afferent arterioles to the glomeruli vasoconstrict, which reduces glomerular filtration, and hence reduces urine output. This results in an increase in blood plasma volume, which helps increase mean arterial blood pressure.
   4. Increase in blood pressure: Sympathetic activity reduced, which results in vasodilation of most arterioles in body to decrease total peripheral resistance.
      a) afferent arterioles to the glomeruli vasodilate, glomerular filtration increases so urine output increases, which reduces plasma volume and mean arterial bp.