Chapter 15 - The Urinary System

I. Introduction

- Body's water always wants to leave the body, following it's [ ] gradient leading to dehydration.

*Organ controlling this water loss = KIDNEY. *controls water balance & blood pressure *RENAL = "of the kidney"

- another function: filter out & reabsorb salts, nutrients, toxins, etc. (HOH soluble solutes) = HOH & ELECTROLYTE BALANCE. * = EXCRETION (kidney = excretory organ). * also: pH control with H+ & bicarb balance

-also, produces several hormones; especially:
  *water & electrolyte control, influencing BP: RENIN (chpt 27), aldosterone, ADH, ANH
  *RBC production: ERYTHROPOIETIN (stimulates RBC production in the marrow).

-Also metabolizes vitamin D into it's active form.

- **URINARY SYSTEM** includes kidney, ureters, bladder, urethra.
A. Kidneys

1. Location and Structure

- bean-shaped, retroperitoneal position in superior lumbar region.

- lateral surface = convex; medial surface concave w/ cleft (RENAL HILUS)
  = blood flow & tubes carrying urine enter/leave here. URINE = end
  product of excretion = water + dissolved nitrogenous
  wastes + not-needed electrolytes.

*MAIN POINT:
blood brings stuff into kidney tissue -------->

  tissue of kidney filters out excess water,
  electrolytes and wastes into RENAL TUBULES,
  which dump into the ureters ------------>

  lead out of body. Kidney also REABSORBS
  stuff it wants to keep (HOH, electrolytes, etc.)
  into VENOUS RETURN.

All this enters/leaves through the HILUS.

2. Tissue Layers - 2 distinct tissue layers:

1) RENAL CORTEX ("shell") -superficial.

2) RENAL MEDULLA -deepest, lighter in color; characterized by
structures that you can see as darker tissue = RENAL PYRAMIDS. These
point towards the inner cavity = CALYX & RENAL PELVIS.
-NOTE: arterial blood flows from hilus into cortex.

Here, it is filtered, & reabsorption of stuff we want to keep takes place.

Stuff you want to get rid of end up in the microtubules.

These drain through the medullary layer, & converge on larger openings (PAPILLAE), which then converge into the calyces, which then converge into the pelvis.

Pelvis then dumps it's contents into the URETER, which leads to the bladder for storage.

**II. Anatomy**

**A. Gross**

- Against the dorsal body wall
- At the level of T12 to L3
- The right kidney is slightly lower than the left
- Attached to ureters, renal blood vessels, and nerves at renal hilus
- Atop each kidney is an adrenal gland

-Coverings:
  - Renal capsule surrounds each kidney
  - Adipose capsule
-Surrounds, provides protection to the kidney
-Helps keep the kidney in its correct location
- Sagittal section:
  * Renal cortex - outer region
  * Renal medulla - inside the cortex
  * Renal pelvis - inner collecting tube

- Medullary pyramids - triangular regions of tissue in the medulla
- Renal columns - extensions of cortex-like material inward
- Calyces - cup-shaped structures that funnel urine towards the renal pelvis
  * Walls of calyces, pelvis & ureter have small muscles that help "push" urine along.

*Pyelitis* - bacterial infection from E. coli that normally live in digestive tract is very common in females. Tissue swells, abscess form, pelvis fills with pus.

**B. Blood Supply**

- Renal artery branches off the aorta, taking 25% of systemic blood to the kidneys for filtration. After filtration & reabsorption process, blood returns via the renal vein to the inferior vena cava, where it is returned to the heart.

- *Path of blood flow:*

  ![Diagram of blood flow]

  Blood flows past nephron under VERY high pressure, where almost everything is filtered into the renal tubules.

  ![Diagram of blood flow]

  Cleansed blood
III. Nephrons and Urine Formation

A. Nephrons

- The structural and functional units of the kidneys
- Responsible for forming urine
- Main structures of the nephrons:
  - Glomerulus + other capillaries
  - Renal tubule

1. Glomerulus
   - A specialized capillary bed
   - Attached to arterioles on both sides
   - Maintains high pressure
   - Large afferent arteriole
   - Narrow efferent arteriole
   - Capillaries are covered with podocytes from the renal tubule
   - The glomerulus sits within a glomerular capsule (the first part of the renal tubule)

2. Renal Tubule
   a. Glomerular Capsule (Bowman's Capsule)
   b. Proximal Convoluted Tubule (PCT)
   c. Loop of Henle (LOH)
   d. Distal Convoluted Tubule + beginning of Collecting Duct (DCT + CD)

3. Peritubular Capillaries
   - Arise from efferent arteriole of the glomerulus
   - Normal, low pressure capillaries
   - Attached to a venule
   - Cling close to the renal tubule
   - Reabsorb (reclaim) some substances from collecting tubes
B. Urine Formation & Excretion

3 steps:
1. Filtration
2. Reabsorption
3. Secretion

1. Filtration: Renal glomerulus + Glomerular capsula (Bowman's Capsule)
   - Nonselective passive process. No hormone control. BP is the only determinate.
   - Water and solutes smaller than proteins are forced through capillary walls
   - Blood cells, proteins cannot pass into the tubules
   - Filtrate is collected in the glomerular capsule and leaves via the renal tubule

   - What gets filtered through his membrane? EVERYTHING smaller than a medium-sized protein.

   - Some fun facts about filtration:

     1) Filtration membrane is 1000 x more permeable to HOH & solutes than normal capillary.
     2) Glomerular blood pressure is much greater than that of regular capillary = maximize filtration. We filtrate 180 liters (~180 quarts) of filtrate/day, and only have ~5.25 liters of blood in our bodies!! How do we not dry out? We RESORB IT! You only urinate ~ 1.5 liters/day.
     * Keeping plasma proteins in capillary maintains osmotic pressure of glomerular blood, preventing the loss of HOH in the tubules.
2. Reabsorption
- The peritubular capillaries reabsorb several materials
- Some water
- Glucose
- Amino acids
- Ions
- Some reabsorption is passive, most is active
- Most reabsorption of ions + water occurs in the proximal convoluted tubule
  **"obligatory" = no hormonal control**
  *about 65%*
- Then, water + sodium reabsorbed in LOH. Reabsorb sodium, let water follow by osmosis. Obligatory.
  *another 15% of water*
- Then, sodium, other ions, and water reabsorption is selective in DCT + CD. Hormonal controlled depending on body's needs.
  *0-20% H2O water is reabsorbed.
3. Secretion
   - Some materials move from the peritubular capillaries into the renal tubules
   - Hydrogen and potassium ions
   - Creatinine
   - Materials left in the renal tubule move toward the ureter

4. Urine:
   - About 1.5 liters/day
   - Colored somewhat yellow due to the pigment urochrome (from the destruction of hemoglobin) and solutes
   - Sterile
   - Slightly aromatic
   - Normal pH of around 6

5. Bladder Facts:
   - Smooth, collapsible, muscular sac
   - Temporarily stores urine
   - Trigone - three openings
     * Two from the ureters
     * One to the urethra
   - Three layers of smooth muscle (detrusor muscle)
   - Mucosa made of transitional epithelium
   - Walls are thick and folded in an empty bladder
   - Bladder can expand significantly without increasing internal pressure

6. Urethra & Micturition Facts:
   - Release of urine is controlled by two sphincters
     * Internal urethral sphincter (involuntary)
     * External urethral sphincter (voluntary)
   - Both sphincter muscles must open to allow voiding
   - The internal urethral sphincter is relaxed after stretching of the bladder
   - Activation is from an impulse sent to the spinal cord and then back via the pelvic splanchnic nerves
   - The external urethral sphincter must be voluntarily relaxed
   - Males share it with reproductive tract
   - Incontinence versus retention
IV. Control of Blood Composition by the Kidneys

i. Excretion of Nitrogen-Containing Wastes

ii. Maintaining Water and Electrolyte Balance of Blood

iii. Maintaining Acid-Base Balance of Blood

A. Water Balance

- Normal amount of water in the human body
  - Young adult females - 50%
  - Young adult males - 60%
  - Babies - 75%
  - Old age - 45%

- Water is necessary for many body functions and levels must be maintained

- Distribution of fluids:
  - Intracellular fluid (inside cells)
  - Extracellular fluid (outside cells)
  - Interstitial fluid
  - Blood plasma

- Link between salt reabsorption + water:
  - Changes in electrolyte balance causes water to move from one compartment to another
  - Alters blood volume and blood pressure
  - Can impair the activity of cells

- Water intake must equal water output

- Sources for water intake
  - Ingested foods and fluids
  - Water produced from metabolic processes
Sources for water output
- Vaporization out of the lungs
- Lost in perspiration
- Leaves the body in the feces
- Urine production

-Dilute urine is produced if water intake is excessive, less urine (concentrated) is produced if large amounts of water are lost

B. Electrolytes (and water)

- Proper concentrations of various electrolytes must be present
- Regulation is primarily by hormones
- Antidiuretic hormone (ADH) prevents excessive water loss in urine
- Aldosterone regulates sodium ion content of extracellular fluid
  Triggered by the rennin-angiotensin mechanism
  (also causes vasoconstriction)
- Cells in the kidneys and hypothalamus are active monitors
*Aldosterone alone: sodium reabsorbed
*ADH alone: slight increase water reabsorption (minute by minute control)
*Aldosterone + ADH = a big increase in water reabsorption (common with blood loss)
C. pH

-Blood pH must remain between 7.35 and 7.45 to maintain homeostasis
  Alkalosis - pH above 7.45
  Acidosis - pH below 7.35

-Most ions originate as byproducts of cellular metabolism

* **Acids produced by the body**
  - Phosphoric acid, lactic acid, fatty acids
  - Carbon dioxide forms carbonic acid
  - Ammonia

-Most acid-base balance is maintained by the kidneys
  - Other acid-base controlling systems
    Blood buffers
    Respiration

1. Blood Buffers
   - Molecules react to prevent dramatic changes in hydrogen ion (H+) concentrations - BLOOD BUFFERS
     * Bind to H+ when pH drops
     * Release H+ when pH rises

-Three major chemical buffer systems
  * Bicarbonate buffer system
  * Phosphate buffer system
  * Protein buffer system
Bicarbonate Buffer System

\[ \text{H}_2\text{CO}_3 \rightarrow \text{HCO}_3^- + \text{H}^+ \]

*Mixture of carbonic acid (H$_2$CO$_3$) and sodium bicarbonate (NaHCO$_3$)*

*Bicarbonate ions (HCO$_3^-$) react with strong acids to change them to weak acids*

*Carbonic acid dissociates in the presence of a strong base to form a weak base and water*

2. Respiratory System Controls

-Carbon dioxide in the blood is converted to bicarbonate ion and transported in the plasma

-Increases in hydrogen ion concentration produces more carbonic acid

-Excess hydrogen ion can be blown off with the release of carbon dioxide from the lungs

-Respiratory rate can rise and fall depending on changing blood pH
3. Renal Mechanisms
   - Excrete bicarbonate ions if needed (we do NOT change H+ absorption/secretion very much to control pH)
   - Conserve or generate new bicarbonate ions if needed
   - Urine pH varies from 4.5 to 8.0