Chapter 26: The Urinary System

Kidney functions

- Excretion of metabolic wastes
  - Urea and other nitrogenous wastes
  - Maintenance of salt and water balance
- Maintenance of acid-base balance
  - Blood pH = 7.4
- Production of hormones
  - Calcitriol (active form of vitamin D)
  - Erythropoietin (stimulates RBC production)

The nephron: know its parts

- Renal corpuscle – filters blood plasma
  - Glomerulus – capillary network
  - Glomerular (Bowman’s) capsule – double-walled cup surrounding glomerulus
- Renal tubule – processes the filtered fluid
  1. Proximal convoluted tubule
  2. Loop of Henle
  3. Distal convoluted tubule
- Collecting duct

Urine formation: excretion of metabolic wastes

Urea – a metabolic waste

- Amino acid catabolism produces ammonia
- \( \text{NH}_3 \) is a toxic substance, and can damage the brain and cause coma.
- Usually, the ammonia is converted into urea in the liver and the urea transported through the blood to the kidneys
- Urea is excreted in the urine
Homeostasis of body fluid volume

- Fluid intake is highly variable, but total volume of fluid in the body is stable
- Kidneys regulate rate of water loss in urine
  - High fluid intake → lots of dilute urine
  - Low fluid intake → a little concentrated urine

How do kidneys produce dilute or concentrated urine?

- Kidneys can change the osmotic concentration of the urine
- Osmotic concentration of a solution = total number of dissolved particles/liter

<table>
<thead>
<tr>
<th>Solution</th>
<th>Osmolarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>plasma</td>
<td>300 mOsm</td>
</tr>
<tr>
<td>sea water</td>
<td>1000 mOsm</td>
</tr>
<tr>
<td>fresh water</td>
<td>5 mOsm</td>
</tr>
<tr>
<td>conc’d urine</td>
<td>1400 mOsm</td>
</tr>
</tbody>
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ADH controls blood (and urine) volume

- Antidiuretic hormone
- In the absence of ADH, urine is dilute (water is excreted)
- A high level of ADH stimulates reabsorption of water into the blood, producing a concentrated urine

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Forming an osmotic gradient in the medulla

- The descending and ascending limbs of the loop of Henle have different permeability characteristics
  - Descending limb: impermeable to water; active transport of NaCl out of filtrate
  - Ascending limb: permeable to water

Generating an osmotic gradient in the medulla

- The ability to concentrate urine depends on generating an osmotic gradient in the medulla.
- The loops of Henle are set up to concentrate osmolarity in the deepest part of the medulla.
- This occurs because the ascending and descending limbs have different permeabilities to salt and water.

Generating an osmotic gradient in the medulla

- In the ascending limb, Na+ and Cl- are pumped out of the filtrate into the ECF.
- This increases the osmotic concentration in the fluid around the loop of Henle.
- Result: water leaves the filtrate in the descending limb and the filtrate becomes more concentrated.
Generating an osmotic gradient in the medulla

- Countercurrent flow in the loop of Henle causes the osmolality differences to multiply as the renal tubule descends into the medulla.
- The filtrate inside the descending limb becomes progressively more concentrated.
- But in ascending limb, active reabsorption of ions causes the filtrate to become less concentrated.
- The result is that osmolality becomes trapped in the medulla.

Blood flow in the medulla maintains the osmotic gradient

- The vasa recta are capillaries that flow in parallel to the loops of Henle.
- The osmolality of the plasma inside the vasa recta increases as it descends into the medulla, and then decreases again on the ascending side.
- This allows blood to flow to the medulla, without eliminating the osmotic gradient.

How do the kidneys vary their urine concentrating ability?

- They regulate water reabsorption in the collecting ducts.
- The permeability of cell membranes to water depends upon the presence of water channels known as aquaporins.
- When ADH binds to its receptor on the collecting duct cells, it stimulates the insertion of aquaporins into the membrane.
- Increases reabsorption of water, makes urine more concentrated and increase blood volume.

Homeostasis of body fluid volume

- Aldosterone: ↑ reabsorption of water & salts; ↑ blood volume; ↓ urine volume.
- ADH: ↑ reabsorption of water; ↑ blood volume; ↓ urine volume.

Diabetes insipidus

- Defect in the ability to concentrate urine.
- Causes:
  - lack of ADH
  - genetic mutation where ADH is missing or defective
  - defect in the ability of the kidney to respond to ADH
  - defect in ADH receptors
  - defect in the gene for AQP2. This prevents the proper localization of AQP2 proteins on the apical membrane of collecting duct cells.

Diuretics

- Substances that slow renal reabsorption of water → increases urine volume
- This in turn reduces blood volume
- Diuretic drugs are prescribed to treat hypertension
- Lowering blood volume usually reduces blood pressure.
Diuretics

Natural diuretics
- Caffeine – inhibits Na\(^+\) reabsorption
  (water follows Na\(^+\))
- Alcohol – inhibits secretion of ADH

Diuretic drugs
- Most act by promoting loss of NaCl in the urine
  - Inhibit transport proteins responsible for Na\(^+\) reabsorption

Urine transport, storage and elimination
- Urine drains into the renal pelvis
- Ureters transport urine to the bladder
  - Primarily by peristalsis
  - Hydrostatic pressure and gravity contribute
  - No anatomical valve at the opening of the ureter into bladder – when bladder fills it compresses the opening and prevents backflow

Urinary bladder
- Hollow, muscular organ
- Capacity 700-800 mL
- In the floor of the urinary bladder is a small, smooth triangular area, the trigone.
- The ureters enter the urinary bladder near two posterior points in the triangle; the urethra drains the urinary bladder from the anterior point of the triangle
- Two sphincters
  - external urethral sphincter is composed of skeletal (voluntary) muscle

Micturition reflex
- Micturition = urination
- discharge of urine from bladder
- Combination of voluntary and involuntary muscle contractions
- When urine volume increases, stretch receptors in the urinary bladder wall transmit impulses that initiate a spinal micturition reflex
- In early childhood we learn to initiate and stop it voluntarily

Urethra
- The urethra is a tube leading from the floor of the urinary bladder to the exterior
- The function of the urethra is to discharge urine from the body
- The male urethra serves as a duct for semen as well as urine

Urinary incontinence
- A lack of voluntary control over urination
- In children under 2-3 years old
  - Incontinence is normal
  - Neurons to the external urethral sphincter muscle are not completely developed
  - Voiding occurs when the bladder is sufficiently distended to stimulate the micturition reflex
Incontinence in adults

- **Overflow incontinence**
  - If the urethra is blocked, the bladder overfills and the pressure causes small amounts of urine to leak out.

- **Stress incontinence**
  - Due to weak muscles of pelvic floor.
  - Coughing and other stresses that increase abdominal pressure cause urine leakage.

- **Urge incontinence**
  - Common in older people.
  - Abrupt urge to urinate.
  - Causes: irritation of bladder by infection, neurologic disorders.

Evaluation of kidney function

- **Urinalysis**
  - Analysis of the volume and physical, chemical and microscopic properties of urine.
  - Water accounts for 95% of total urine volume.
  - Typical solutes in urine:
    - Electrolytes that are not reabsorbed
    - Urea (from breakdown of protein)
    - Creatinine (from breakdown of creatine phosphate in muscle)
    - Uric acid (from breakdown of nucleic acids)
  - Normal urine is protein-free.
  - If disease alters metabolism or kidney function, traces of substances normally not present or normal constituents in abnormal amounts may appear.

- **Blood tests**
  - **Blood urea nitrogen (BUN)** — measures blood nitrogen that is part of the urea.
    - High BUN indicates abnormally low GFR.
    - May indicate renal disease or obstruction of urinary tract.
  - **Plasma creatinine** — results from catabolism of creatine phosphate in skeletal muscle.
    - An elevated creatinine level indicates poor renal function.

- **Renal plasma clearance**
  - Measures how effectively the kidneys remove (clear) a substance from blood plasma.
  - More useful in diagnosis of kidney problems than above.
  - The clearance of inulin gives the glomerular filtration rate.
    - Inulin is filtered but not reabsorbed or secreted.
  - The clearance of PAH (para-aminohippuric acid) measures renal plasma flow.
    - PAH is filtered and secreted in a single pass through the kidneys.

Disorders of urinary tract

- **Urinary tract infection (UTI)**
  - An infection of a part of the urinary system or the presence of large numbers of microbes in urine.
  - More common in females due to shorter length of the urethra.
  - UTIs include:
    - Urethritis (inflammation of the urethra)
    - Cystitis (inflammation of the urinary bladder)
    - Pyelonephritis (inflammation of the kidneys).

Renal failure

- **Kidney failure** can be caused by injury, illness, or many other factors.
- **Chronic renal failure** — a progressive and generally irreversible decline in glomerular filtration rate.
  - Stage 1: Many nephrons are destroyed, but no symptoms.
  - Stage 2: Renal insufficiency: 75% of nephrons are lost, decreased GFR, increase in BUN.
  - Stage 3: End-stage renal failure: 90% of nephrons are lost, further increase in plasma urea and creatinine.
  - Patient needs dialysis therapy or kidney transplant.
Dialysis

- Artificial cleansing of the blood
  - **Hemodialysis** directly filters the patient’s blood by removing wastes and excess electrolytes and returning the cleansed blood to the patient

Figure 21.18