The urinary System

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Functions of the urinary system

- **Excretion** – removal of waste material from the blood plasma and the disposal of this waste in the urine.

- **Elimination** – removal of waste from other organ systems. From digestive system – undigested food, water, salt, ions, drugs. From respiratory system – CO$_2$, H$^+$, water, toxins. From skin – water, NaCl, nitrogenous wastes (urea, uric acid, ammonia, creatinine).

- **water balance** - kidney tubules regulate water reassertion and urine concentration.

- **Regulation of pH** - volume, and composition of body fluids.

- **Production of erythropoietin**: for hematopoieses, and **renin** for blood pressure regulation.
Anatomy of the urinary System

- **kidneys** – a pair of bean-shaped organs located retroperitoneally, responsible for blood filtering and urine formation.

- **Renal capsule** – a layer of fibrous connective tissue covering the kidneys.

- **Renal cortex** – outer region of the kidneys where most enthrones is located.

- **Renal medulla** – inner region of the kidneys where some enthrones is located, also where urine is collected to be excreted outward.

- **Renal calyx** – duct – like sections of renal medulla for collecting urine from nephrons and direct urine into renal pelvis.
- **Renal pyramid** – connective tissues in the renal medulla binding various structures together.

- **Renal pelvis** – central urine collecting area of renal medulla.

- **Hilum** – concave notch of kidneys where renal artery, renal vein, ureter, nerves, and lymphatic vessels converge.

- **Ureter** – a tubule that transports urine (mainly by peristalsis) from the kidney to the urinary bladder.

- **Urinary bladder** – a spherical storage organ that contains up to 400 ml of urine.

- **Urethra** – a tubule that excretes urine out of the urinary bladder to the outside, through the urethral orifice.
Urinary System Organs

- Renal pelvis
- Esophagus (cut)
- Hepatic veins (cut)
- Inferior vena cava
- Adrenal gland
- Renal artery
- Renal hilum
- Renal vein
- Aorta
- Kidney
- Ureter
- Iliac crest
- Rectum (cut)
- Uterus (part of female reproductive system)
- Urinary bladder
- Urethra

(a)
Internal Anatomy of the Kidney

- Cortical radiate vein
- Cortical radiate artery
- Arcuate vein
- Arcuate artery
- Interlobar vein
- Interlobar artery
- Segmental arteries
- Renal column
- Major calyx
- Papilla of pyramid
- Cortex
- Renal pelvis
- Minor calyx
- Renal pyramid of medulla
- Fibrous capsule
- Renal artery
- Renal vein
- Renal pelvis
- Major calyx
- Ureter
Microscopic Anatomy

- Each kidney consists of about 1 million basic functional units called nephrons where blood filtering and urine formation occur.

- Each nephron is composed of 10 parts –

  - afferent arteriole → glomerulus → bowman's capsule → efferent arteriole → proximal convoluted tubule (PCT) → descending limb of loop of henle → loop of henle ascending limb of loop of henle → distal convoluted tubule (DCT) → collecting duct (not part of the nephron).

- molecules in the blood that will be transformed to become part of urine travel through the above structures, while molecules that will be retained and reabsorbed back to the blood will come out of the bowman's capsule, and go into efferent arteriole and the peritubular capillaries.
The Nephron
Urine Formation

- urine formation involves 4 processes:
  - **Filtration** – small molecules are filtered from glomerulus's to bowman's capsule.
  - **Rebasorption** – nutrient molecules are transported from PCT and DCT to per tubular capillaries.
  - **Concentration** – water is reabsorbed from descending limb of loop of handle and from collecting duct into peritubular capillaries.
  - **Secretion** – waste or harmful substances are transported from peritubular capillaries to PCT and DCT.
Glomerular Filtration

- small molecules in blood plasma are forced from the glomerulus to Bowman's capsule, through the pores in the capillary walls of glomerulus.

- any molecules smaller than the plasma proteins will be filtered across — e.g. water, glucose, amino acids, fatty acids, vitamins, minarets, electrolytes, antibodies, enzymes, hormones, drugs, and nitrogenous wastes.
Functions of nephron components

- **Renal capsule:**
  - Glomerulus's: filtration of $\text{H}_2\text{O}$ and dissolved substances from the plasma.
  - Glomerular capsule: receives the glomerular filtrate.

- **proximal convoluted tubule:**
  - Reabsorption of glucose, amino acids, creatine, lactic acid, citric, uric, and ascorbic acids; phosphate, sulfate, calcium, K, and Na by active transport.
  - Reabsorption of proteins by pinocytosis. Reabsorption of $\text{H}_2\text{O}$ by osmosis. Reabsorption of $\text{Cl}^-$ and other negatively charged ions by electrochemical attraction.
  - Active secretions of substances such as penicillin, and hydrogen ions.
- **Descending limb of nephron loop**: 
  - Reabsorption of $\text{H}_2\text{O}$ by osmosis

- **Ascending limb of nephron loop**: 
  - Reabsorption of Na, K and Cl$^-$ by active transport.

- **Distal convoluted tubule**: 
  - Reabsorption of Na by active Transport.
  - Reabsorption of $\text{H}_2\text{O}$ by osmosis.
  - Active secretion of hydrogen ions.
  - Secretion of K both actively and by electorchemical attraction (passives).

- **Collecting duct**: 
  - Reabsorption of $\text{H}_2\text{O}$ by osmosis.
The JG apparatus is located at the point of contact between the distal convoluted tubule and the afferent and efferent arterioles.

In its convolutions, the DCT comes into very close contact with the afferent arterioles.

At this point the cells in the afferent arteriols are more numerous, forming a cuff, and are called JG cells; these are mechanoreceptors that detect changes in blood pressure in the afferent arterioles, and secrete renin.

The distal convoluted tubule cells contacting these JG cells are called macula densa (chemo or osmoreceptors) that respond to changes in the solute concentration of the filtrate in the tubule.
Vasorecta: capillaries of the juxtamedullary nephrons that loops and have a hairpin configuration, forming a bundle of long straight vessels.
Glomerular Filtration

- a. urine formation begins when waste and water and dissolved materials are filtered out of the glomerular capillary.

Urinary excretion = glomerular filtration + Tubular secretion – tubular reabsorption

- b. the glomerular capillaries are much more permeable than the capillaries in other tissues.

Filtration pressure = Forces favoring filtration (Glomerular capillary hydrostatic pressure & capsular osmotic pressure) – forces opposing filtration (capsular hydrostatic pressure & Glomerular capillary osmotic pressure).

- Thus, filtration pressure is the net force acting to move material out of glomerulus and into the glomerular capsule.
Regulation of GFR

- **Neural regulation** where sympathetic nerves, upon the activation of chloride ion levels, can cause the constriction or relaxation of the afferent arteriole, resulting in a change of GFR.

- **Renal autoregulation** where the juxtaglomerular apparatus (JGA) (formed by the afferent arteriole and DCT) secretes vasoconstriction substances to either afferent arteriole, in response to GFR changes and NaCl levels.

- **Hormonal regulation** involves the JGA secreting a hormone called renin which activates an inactive hormone from the liver called angiotensinogen, resulting in an active hormone (angiotensin I) which will be converted to angiotensin II by the angiotensin converting enzyme (ACE) [released from the lungs]. Angiotensin II causes constriction of afferent arteriole & release of Aldosterone from adrenal cortex which leads to salt & water retention.
GFR

- The rate of filtration varies with filtration pressure. Filtration pressure changes with the diameters of the afferent and efferent arterioles.

- Constriction of afferent arterioles due to sympathetic stimulation decreases glomerular filtration rate.

- As the osmotic pressure in the glomerulus increases, filtration decreases.

- As the hydrostatic pressure in a glomerular capsule increases, filtration decreases.

- The kidney produce 125 ml of glomerular fluid per minute, most of which is reabsorbed.

- The volume of filtrate varies with the surface area of the glomerular capillary.
Key:

- Glomerular (blood) hydrostatic pressure (55 mm Hg)
- Blood colloid osmotic pressure (30 mm Hg)
- Capsular hydrostatic pressure (15 mm Hg)
Regulation of Filtration Rate

- a. Glomerular filtration rate remains relatively constant by may increase or decrease when needed. Increased sympathetic activity decreases GFR.

- b. when tubular fluid NaCl decreases, the macula densa causes the JG cells to release renin which leads to vasoconstriction, which affect GFR, and secretion of aldosterone, which stimulate tubular Na\(^+\) reabsorption.
Role of ADH (Antidiuretic hormone)

1. Concentration of $\text{H}_2\text{O}$ in the blood decreases.

2. Increase in the osmotic pressure of body fluids stimulates osmoreceptors in the hypothalamus.

3. Hypothalamus signals the posterior pituitary gland to release ADH.

4. Blood carries ADH to the kidneys.

5. ADH causes the distal convoluted tubules and collecting ducts to become more permeable & increase $\text{H}_2\text{O}$ reabsorption by osmosis.

6. Urine becomes more concentrated, and urine volume decreases.
Mechanism of forming dilute & concentrated urine

Key:
- Red: Active transport
- Blue: Passive transport

(a) Absence of ADH
- Cortex: 300 mOsm
- Outer medulla: 600 mOsm
- Inner medulla: 900 mOsm
- Descending limb of loop of Henle: 1200 mOsm
- Collecting duct: 300 mOsm
- Osmolarity of interstitial fluid (mOsm)

(b) Presence of ADH
- Cortex: 300 mOsm
- Outer medulla: 600 mOsm
- Inner medulla: 900 mOsm
- Descending limb of loop of Henle: 1200 mOsm
- Collecting duct: 300 mOsm
- Osmolarity of interstitial fluid (mOsm)
Mechanisms of Urine Formation

- Urine formation and adjustment of blood composition involves three major processes
  - Glomerular filtration
  - Tubular reabsorption
  - Secretion
Tubular Reabsorption

- The kidney must have mechanisms for reabsorption of the many solutes (Na, K, glucose, chloride) and $\text{H}_2\text{O}$ that it filters each day or in a matter of minutes we would by depleted of all these substances.
- Substances are selectively reabsorbed from the glomerular filtrate.
- The preteritubular capillary is adapted for reabsorption. It carries low pressure blood & is very permeable. Most reabsorption (70%), occurs in the proximal tubule.
- Different modes of transport reabsorbs various substances in particular segments of renal tubule.
- Glucose and amino acids by active transport. $\text{H}_2\text{O}$ is reabsorbed by osmosis. Proteins are reabsorbed by pinocytosis.
Water Reabsorption (Proximal Tubule)

- Na+ and K+ ions are reabsorbed by active transport.
- Negatively charged ions are attracted to positively charged ions (passive transport).
- As the concentration of ions (solute) increases in plasma, osmotic pressure increases.
- Water (70%) moves from renal tubule to capillary by osmosis (passive transport).
Countercurrent Mechanism

- The fluid entering the loop of Henle has an osmolarity of 300mosm/l.

- 2) Thus, a small horizontal gradient of 200 is established between the ascending and descending limbs.

- 3) This occurs because of the characteristics of each portion of the loop:
  - The descending limb is very permeable to H$_2$O (out) and to Na$^+$ and Cl$^-$ in). [Cl$^-$ follows Na$^+$ because of electrical attraction].
  - No Active transport of ions occurs here.
  - The Ascending limb is impermeable to H$_2$O but actively transports Cl$^-$ out of the tubular fluid into interstitial fluid, with Na$^+$ ion following passively.
Thus this small horizontal osmolar gradient is due to active pumping of salt out of a H$_2$O impermeable ascending limb into both the ISF and the descending limb, and H$_2$O movement out of the descending limb.
Summary of events in the loop of Henle

- A. Fluid enters the descending limb of the loop. At each horizontal level Cl⁻ is actively transported out of the ascending limb into the ISF. Na⁺ follows & diffuses out of the ascending limb into the ISF. H₂O can not leave the ascending limb. Thus, the osmolarity of fluid in the ascending limb decreases as you go up and within the ISF. It increases as you go deeper in the medulla.
The descending limb is permeable to H₂O. Water moves passively out of the descending limb into the ISF.

This causes the conc. of NaCl in the descending limb to increase, and this fluid also increases in osmolarity.

The net overall result is that an osmolar gradient is established in the ISF as one progresses from the beginning to the end in the loop of Henle.
Thus, more fluid has been reabsorbed from the original volume of glomerular filtrate.

The loop has actually placed more solute than H₂O into the medullary interstitial space and so as fluid leaves the loop and enter the DCT it is hypoosmotic to plasma.
The distal convoluted tubule and collecting duct are **impermeable** to $\text{H}_2\text{O}$, so water may be excreted as dilute urine.

- If ADH is present, these segments become permeable, and water is reabsorbed by osmosis into the hypertonic medullary interstitial fluid.

- ADH stimulates $\text{H}_2\text{O}$ reabsorption and the production of concentrated urine which contains soluble waste and other substances in a minimum of $\text{H}_2\text{O}$, thus minimizing the loss of body $\text{H}_2\text{O}$ when dehydration is a threat. If the body fluids contain excess $\text{H}_2\text{O}$, ADH secretion is decreased and the DCT and CD becomes less permeable to $\text{H}_2\text{O}$.

- Aldosterone secreted by adrenal cortex causes more sodium reabsorption at DCT, and the positive charges of these ions attract water molecules to be reabsorbed also at DCT.
Tubular secretion

- Unwanted substances such as wastes and excessive salts are secreted by the peritubular capillaries to the renal tubules (mainly PCT and DCT), so that it can be disposed in the urine.

- Most substances are secreted by active transport.

- Substances secreted include excessive Na\(^+\), Cl\(^-\), H\(^+\), K\(^+\), histamine, cretonne, ammonia, uric acid, vitamins and excessive drugs.
Major events of micturition

- Urinary bladder distends as it fills with urine.
- Stretch receptors in the bladder wall are stimulated and signal the micturition center in the sacral spinal cord.
- Parasympathetic nerve impulses travel to the detrusor muscle, which respond by contracting rhythmically.
- The need to urinate is sensed as urgent.
- Voluntary contraction of the external urethral sphincter and inhibition of the micturition reflex by impulses from the brain stem and the cerebral cortex prevent urination.
- Following the decision to urinate, the external urethral sphincter is relaxed, the impulses from the pons and hypothalamus facilitate the micturation reflex.
- The detrusor muscle contracts and urine is expelled through the urethra.
- Neurons of the micturition reflex center fatigue, the detrusor muscle relaxes, and the bladder begins to fill with urine again.
Physical properties of urine

- **Transparency** is clear, indicating the lack of large solutes such as plasma proteins or blood cells. [can be influenced by bacterial metabolism in older urine samples].

- **Color** is from light yellow to amber, due to urochrome pigments as byproduct of bile metabolism [can be influenced by food, menstrual bleeding, and minor metabolic products].

- **Odor** is from aromatic to slightly ammonia-like, due to the nitrogenous wastes in urine. [can be influenced by disorders such as glycosuria where urine shows a sweet odor, or by food such as garlic, or by drug].

- **pH** is from 4.6 to 8.0 with an average of 6.0, due to H\(^+\) in the urine [strongly influenced by diet where protein cause acidic urine, and vegetables and wheat cause alkaline urine].
- **Specific gravity** (a measurement of dissolved solutes in a solution) is from 1.001 to 1.035, due to the 5% solute composition in normal urine.

- **Volume** is 1-2 liters per day (about 1% of filtration input). [can be influenced by body activities, water intake, hormonal regulation, or disorders such as diabetes insipidus].
Abnormal Constituents Of Urine

- **Albumin** – a large plasma protein that should not be filtered out of glomerulus; when it is present, it is called **albuminuria** which may be due to kidney infection called glomerulonephritis.

- **Glucose** – a nutrient molecules that should have been reabsorbed (in the case of high carbohydrate diets, trace amount of glucose may be found in urine); when is present, it is called **glycosuria** which may be due to insulin–related problems in a disease called diabetes mellitus.

- **blood or erythrocytes** – any blood cell should not be filtered out of glomerulus or be present in the urine (except in menstruation–related bleeding); when it is present, it is called **Hematuria** which may be caused by glomerulonephritis, hemolytic anemia, or urinary tract in infections.
- **Hemoglobin** – pigment protein that normally should be enclosed in erythrocytes and not filtered out of glomerulus; when present, it is called **hemoglobinuria** which may indicated hemolytic anemia.

- **Leukocytes** – large white blood cells that should not be present in urine (except in UTI where leukocytes are present to fight the infection); when it is present, it is called **Pyuria** which may be caused by glomerulus's nephritis, UTI, or even strenuous exercise.

- **Ketones** – by product of metabolism that may occur in trace amounts, but not large quantities in the urine; when it is present, it is called **Kentonuria** which may indicate certain infections in the urinary system.

- **Bilirubin** – a bile pigment that is normally recycled in lipid metabolism; when it is present, it is called **bilirubinuria** which may be due to abnormal lipid metabolism, or certain infections in the urinary system.
Clinical Terms

- Bacteriuria: Bacteria in urine.
- Diuresis: increased production of urine.
- Diuretic: substances that increase urine production.
- Dysuria: painful or difficult urination.
- Hematuria: Blood in urine.
- Polyuria: excess urine.
- Uremia: urine in blood.
- Glomerulonephritis: Inflammation of glomeruli, damaging the filtration membrane, increasing its permeability (may be due to streptococcal bacteria).
- Urinalysis: Analysis of urine to diagnose health or disease.