Human Renal Physiology

Urinary system

Urinary system: Organ system that produces, stores, and carries urine.

Includes: two kidney, two ureters, the urinary bladder, two sphincter muscles, the urethra.

Functions of Kidneys:

1. Regulation of blood plasma and interstitial fluid composition (homeostasis), especially inorganic ions (e.g. Na+, K+, Cl-, Ca2+) and osmolality (osmotic activity of dissolved particles)

2. Regulation of body fluid volume -- fluid balance

3. Regulation of blood plasma and interstitial fluid pH

4. Excretion of (non-volatile) metabolic end products (e.g. urea, uric acid, creatinine, NH4+) and "foreign" solutes (e.g. some drugs).

5. Endocrine organ, secreting:

a. renin, for regulation of Na+, ECF (extracellular fluid) volume, vascular resistance b. erythropoietin, for regulation of erythrocyte production c. calcitriol, related to calcium regulation

6. Metabolic functions: e.g. peptide degradation, synthesis of NH3 and H+

Kidney physiological Anatomy

1. Paired organs, located in the abdomen just below the diaphragm

2. Size: 10 cm x 5 cm x 2.5 cm; weight about 150 gm each (300 gm total)

3. Supplied with blood by renal artery; after passing through the kidney, blood is returned to the heart by the renal vein

4. Divided into cortex (outer) and medulla (inner) regions

Nephron

Functional unit: nephron (about one million per kidney); nephron divided into

a. glomerular region (renal corpuscle; about 0.2 mm diameter)

1) glomerulus 2) Bowman's capsule (Bowman's capsule and the glomerulus together are named the Malpigian corpuscle)

b. proximal convoluted and straight tubule (about 15 mm long, 0.05 mm diameter).

c. loop of Henle; dips deeply (juxtamedullary nephron) or slightly (cortical nephron) into the medulla; each has segments :1) descending limb 2) ascending limb .

d. distal convoluted and straight tubule ( the initial part of the distal tubule passes near the glomerulus of the nephron)

e. collecting tubule

Renal Microcirculation

Renal arteries ==> afferent arterioles ==> glomerular capillaries ==> efferent arterioles ==> proximal peritubular capillaries ==> vasa recta ==> distal peritubular capillaries ==> collecting duct capillaries ==> renal

venules

Renal Blood Flow (RBF) Value -- Rate and Distribution

1. Normal (resting) blood flow: 1.2 L/min (20-25% of cardiac output).

2. Normal (resting) plasma flow: 650 ml/min *.*

Note: the high blood flow is required to furnish the kidney with sufficient plasma for filtration, reabsorption, etc.

Types of nephrons:

Cortical and Juxtamedullary (15% of nephrons ) nephrons are distinguished by the cortical location of their glomeruli and the depth to which their loops of Henle penetrate into the medulla; cortical nephrons are sometimes subdivided into superficial and mid cortical.

Juxtaglomerular Apparatus

Region in each nephron where the Afferent arteriole comes in contact with the thick ascending limb (or distal tubules).

 Granular cells within Afferent arteriole secrete renin:

1. Converts angiotensinogen to angiotensin I.

2. Initiates the renin-angiotensin-aldosterone system.

 Macula densa: -Region where ascending limb is in contact with afferent arteriole. -Inhibits renin secretion when blood [Na+] in blood increases.

Cells of macula densa are taller and have more prominent nuclei than surrounding cells.

Sensitive to the concentration of sodium ions in the fluid.

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2. Range: the highest renal blood flow occurs at rest; increasing activity or stress progressively reduces renal blood flow; under extreme conditions (e.g. shock), renal blood flow can be reduced to almost zero

Blood flow in kidneys and other organs

Functions of the Nephron: Four main processes

– Filtration

– Reabsorption

– Secretion

– Excretion

Filtration:

-Glomerular filtration is the first step in the production of urine, where the kidneys filter blood to remove waste products and excess water.

-Blood enters the glomerulus under high pressure, forcing substances across the leaky endothelial-capsular membrane into the nephron.

-This membrane acts like a sieve, allowing small substances to be filtered into the nephron while large molecules such as plasma proteins remain within the blood.

The filtered fluid passes from the Bowman's Capsule into the proximal convoluted tubule

- About 20% of the plasma volume passing through the glomerulus at any given time is filtered, which amounts to approximately 180 liters of fluid per day

-The glomerular filtration rate (GFR) is the main driving force for filtration, and it is regulated by blood pressure and other factors

Reabsorption:

-Reabsorption in the kidney is the process by which water and solutes are removed from the tubular fluid (pre-urine) and returned to the circulating blood.

- This occurs as a result of the nephron's segmented structure, with different segments responsible for reabsorbing specific substances.

- The majority of reabsorption occurs in the proximal convoluted tubule, where more than 70% of the filtrate is reabsorbed, including essential solutes such as glucose, amino acids, and bicarbonate

- Reabsorption is a two-step process:

1. The first step is the passive or active movement of water and dissolved substances from the fluid inside the tubule through the epithelial cells.
2. The second step is for water and these substances to move through the capillary walls back into the bloodstream, again, either by passive or active transport

-Reabsorption allows many useful solutes to return to the circulation, maintaining the body's fluid homeostasis and preventing the loss of essential substances in the urine

Secretion:

-Secretion is the transfer of materials from the peritubular capillaries to the renal tubular lumen, and it occurs mainly in the proximal convoluted tubule and distal convoluted tubule.

- Secretion is the opposite process of reabsorption, and it deals with filtering and cleaning substances from the blood, rather than retaining them.

-The substances that are secreted include hydrogen ions, creatinine, ions, and other types of waste products, such as drugs.

- The secretion of hydrogen ions and ammonium ions from the blood into the tubular fluid is involved in blood pH regulation. The movement of these ions also helps to conserve sodium bicarbonate (NaHCO3).

- Secretion is an important process in maintaining the balance of electrolytes and acid-base homeostasis in the body

Excretion:

Loss of fluid from body in form of urine

The amount of urine excreted varies depending on factors such as fluid intake, diet, and physical activity. On average, a healthy adult excretes about 1 to 2 liters of urine per day.

-The amount of urine excreted is determined by the formula:

 Amount excreted = amount filtered - amount reabsorbed + amount secreted

The glomerulus filters approximately 180 liters of fluid per day, but only about 1% of this fluid is excreted as urine

-The remaining fluid is reabsorbed back into the bloodstream

Reference:

Hall, J. E. (2016). Guyton and Hall textbook of medical physiology (13th edition)