Excretory system: Nephron

Introduction

The nephron is the microscopic structural and functional unit of the kidney. It is composed of a renal corpuscle and a renal tubule. The renal corpuscle consists of a tuft of capillaries called a glomerulus and an encompassing Bowman's capsule. The renal tubule extends from the capsule. The capsule and tubule are connected and are composed of epithelial cells with a lumen. A healthy adult has 0.8 to 1.5 million nephrons in each kidney. Blood is filtered as it passes through three layers: the endothelial cells of the capillary wall, its basement membrane, and between the foot processes of the podocytes of the lining of the capsule. The tubule has adjacent peritubular capillaries that run between the descending and ascending portions of the tubule. As the fluid from the capsule flows down into the tubule, it is processed by the epithelial cells lining the tubule: water is reabsorbed and substances are exchanged (some are added, others are removed); first with the interstitial fluid outside the tubules, and then into the plasma in the adjacent peritubular capillaries through the endothelial cells lining that capillary. This process regulates the volume of body fluid as well as levels of many body substances. At the end of the tubule, the remaining fluid—urine—exits: it is composed of water, metabolic waste, and toxins.

Types of Nephrons

1. Cortical nephrons (the majority of nephrons) start high in the cortex and have a short loop of Henle which does not penetrate deeply into the medulla. Cortical nephrons can be subdivided into *superficial cortical nephrons* and *midcortical nephrons*.
2. Juxtamedullary nephrons start low in the cortex near the medulla and have a long loop of Henle which penetrates deeply into the renal medulla: only they have their loop of Henle surrounded by the vasa recta. These long loops of Henle and their associated vasa recta create a hyperosmolar gradient that allows for the generation of a concentratedurine. Also the hairpin bend penetrates up to the inner zone of medulla.

Structure of nephron

The nephron is the functional unit of the kidney. Each nephron is composed of a renal corpuscle, the initial filtering component; and a renal tubule that processes and carries away the filtered fluid.

Renal corpuscle: The renal corpuscle is the site of the filtration of blood plasma. The renal corpuscle consists of the glomerulus, and the glomerular capsule or Bowman's capsule. The renal corpuscle has two poles – a vascular pole and a urinary pole. The arterioles from the renal circulation enter and leave the glomerulus at the vascular pole. The glomerular filtrate leaves the Bowman's capsule at the renal tubule at the urinary pole.

Glomerulus: The glomerulus is the network known as a *tuft*, of filtering capillaries located at the vascular pole of the renal corpuscle in Bowman's capsule. Each glomerulus receives its blood supply from an afferent arteriole of the renal circulation. The glomerular blood

pressure provides the driving force for water and solutes to be filtered out of the blood plasma, and into the interior of Bowman's capsule, called Bowman's space.

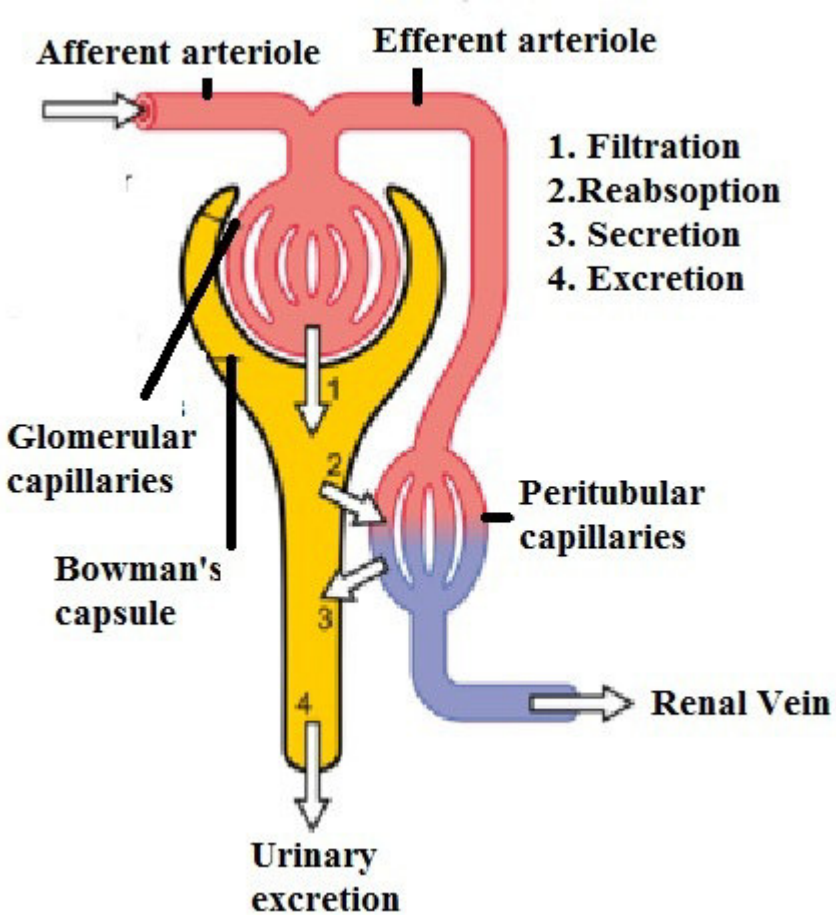

Figure 1. Schematic of the glomerular filtration barrier (GFB). A. The endothelial cells of the glomerulus; 1. endothelial pore (fenestra).

Only about a fifth of the plasma is filtered in the glomerulus. The rest passes into an efferent arteriole. The diameter of the efferent arteriole is smaller than that of the afferent, and this difference increases the hydrostatic pressure in the glomerulus.

Bowman's capsule: The Bowman's capsule, also called the glomerular capsule, surrounds the glomerulus. It is composed of a visceral inner layer formed by specialized cells called podocytes, and a parietal outer layer composed of simple squamous epithelium. Fluids from blood in the glomerulus are filtered through the visceral layer of podocytes, resulting in the glomerular filtrate. The glomerular filtrate next moves to the renal tubule, where it is further processed to form urine. The different stages of this fluid are collectively known as the tubular fluid.

Renal tubule: The renal tubule is the portion of the nephron containing the tubular fluid filtered through the glomerulus. After passing through the renal tubule, the filtrate continues to the collecting duct system.

The components of the renal tubule are:

- Proximal convoluted tubule (lies in cortex and lined by simple cuboidal epithelium with brush borders which help to increase the area of absorption greatly.)
- Loop of Henle (hair-pin like, i.e. U-shaped, and lies in medulla)
    - ✓ Descending limb of loop of Henle
    - ✓ Ascending limb of loop of Henle
        - ❖ The ascending limb of loop of Henle is divided into 2 segments: Lower end of ascending limb is very thin and is lined by simple squamous epithelium. The distal portion of ascending limb is thick and is lined by simple cuboidal epithelium.
        - ❖ Thin ascending limb of loop of Henle
        - ❖ Thick ascending limb of loop of Henle (enters cortex and becomes - distal convoluted tubule.)
- Distal convoluted tubule
- Connecting tubule

Blood from the efferent arteriole, containing everything that was not filtered out in the glomerulus, moves into the peritubular capillaries, tiny blood vessels that surround the loop of Henle and the proximal and distal tubules, where the tubular fluid flows. Substances then reabsorb from the latter back to the blood stream. The peritubular capillaries then recombine to form an efferent venule, which combines with efferent venules from other nephrons into the renal vein, and rejoins the main bloodstream.

Proximal convoluted tubule: The proximal tubule as a part of the nephron can be divided into an initial convoluted portion and a following straight (descending) portion. Fluid in the filtrate entering the proximal convoluted tubule is reabsorbed into the peritubular capillaries, including approximately two-thirds of the filtered salt and water and all filtered organic solutes (primarily glucose and amino acids).

Loop of Henle: The loop of Henle is a U-shaped tube that extends from the proximal tubule. It consists of a descending limb and an ascending limb. It begins in the cortex, receiving filtrate from the proximal convoluted tubule, extends into the medulla as the descending limb, and then returns to the cortex as the ascending limb to empty into the distal convoluted tubule. The primary role of the loop of Henle is to concentrate the salt in the interstitium, the tissue surrounding the loop.

Distal convoluted tubule: The distal convoluted tubule has a different structure and function to that of the proximal convoluted tubule. Cells lining the tubule have numerous mitochondria to produce enough energy (ATP) for active transport to take place. Much of the ion transport taking place in the distal convoluted tubule is regulated by the endocrine system. In the presence of

parathyroid hormone, the distal convoluted tubule reabsorbs more calcium and secretes more phosphate. When aldosterone is present, more sodium is reabsorbed and more potassium secreted. Atrial natriuretic peptide causes the distal convoluted tubule to secrete more sodium.

Collecting duct system: Each distal convoluted tubule delivers its filtrate to a system of collecting ducts, the first segment of which is the connecting tubule. The collecting duct system begins in the renal cortex and extends deep into the medulla. As the urine travels down the collecting duct system, it passes by the medullary interstitium which has a high sodium concentration as a result of the loop of Henle's countercurrent multiplier system.

Because it has a different origin during the development of the urinary and reproductive organs than the rest of the nephron, the collecting duct is sometimes not considered a part of the nephron. Instead of originating from the metanephrogenic blastema, the collecting duct originates from the ureteric bud.

Urine formation

The four mechanisms used to create and process the filtrate (the result of which is to convert blood to urine) are:

- Filtration
- Reabsorption
- Secretion
- Excretion.

Filtration occurs in the glomerulus and is largely passive: it is dependent on the intracapillary blood pressure. About one-fifth of the plasma is filtered as the blood passes through the glomerular capillaries; four-fifths continues into the peritubular capillaries. Normally the only components of the blood that are not filtered into Bowman's capsule are blood proteins, red blood cells, white blood cells and platelets. Over 150 liters of fluid enter the glomeruli of an adult every day: 99% of the water in that filtrate is reabsorbed. Reabsorption occurs in the renal tubules and is either passive, due to diffusion, or active, due to pumping against a concentration gradient. Secretion also occurs in the tubules and is active. Substances reabsorbed include: water, sodium chloride, glucose, amino acids, lactate, magnesium, calcium phosphate, uric acid, and bicarbonate. Substances secreted include urea, creatinine, potassium, hydrogen, and uric acid. Some of the hormones which signal the tubules to alter the reabsorption or secretion rate, and thereby maintain homeostasis, include (along with the substance affected) antidiuretic hormone (water), aldosterone (sodium, potassium), parathyroid hormone (calcium, phosphate), atrial natriuretic peptide (sodium) and brain natriuretic peptide (sodium). A countercurrent system in the renal medulla provides the mechanism for generating a hypertonic interstitium, which allows the recovery of solute-free water from within the nephron and returning it to the venous vasculature when appropriate.

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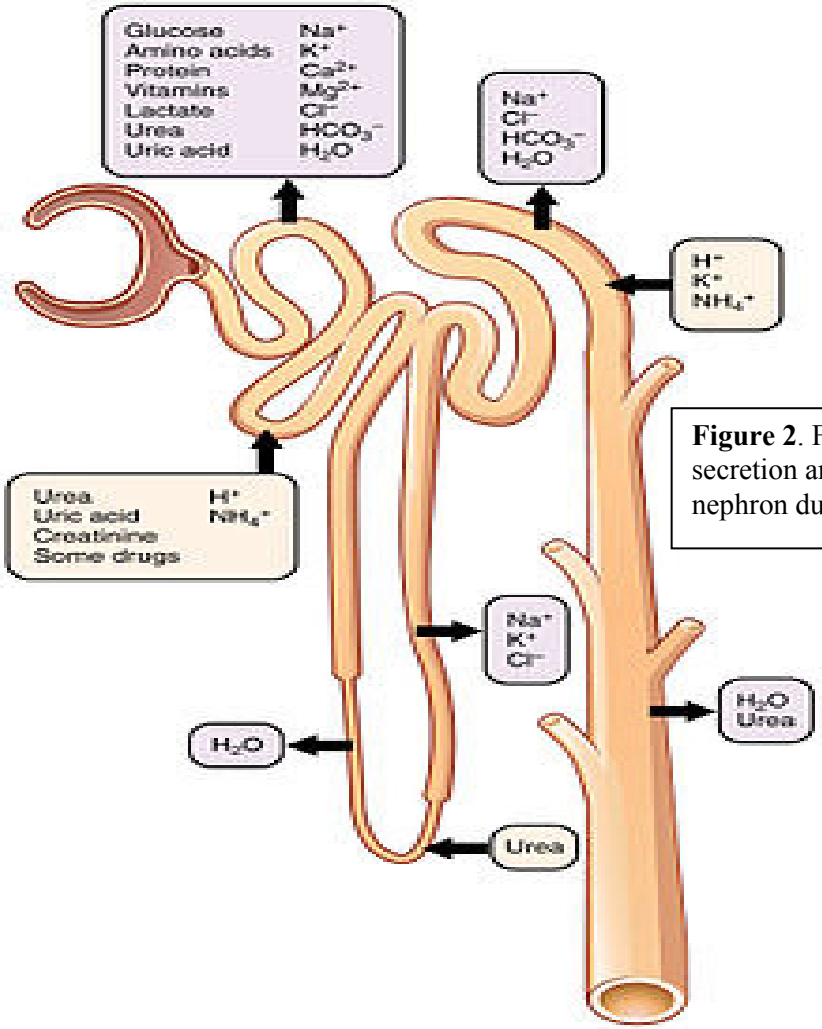

Figure 2. Filtration, Reabsorption, secretion and excretion process in the nephron during urine formation

Notes prepared by:
Dr. Asheesh Shivam Mishra
Asst. Professor & Head,
Department of Zoology,
Nehru Gram Bharti (Deemed to be University)
Prayagraj, U.P.