# The Urinary System

The urinary system consists of the paired kidneys and ureters and the unpaired bladder and urethra. This system contributes to the maintenance of homeostasis by a complex process that involves **filtration, active absorption, passive absorption,** and **secretion**. The result is the production of urine, in which various metabolic waste products are eliminated. Urine produced in the kidneys passes through the ureters to the bladder, where it is temporarily stored and then released to the exterior through the urethra. About 1500mL of urine formed every 24 hours. The kidneys also regulate the fluid and electrolyte balance of the body and are the site of production of renin that participates in the regulation of blood pressure, and erythropoietin that stimulates the production of erythrocytes (the kidneys have an endocrine function).

## Overview of Kidney Structure

Each kidney is bean-shaped, with a concave **hilum** where the nerves enter, the ureter exits, and blood and lymph vessels enter and exit. The **renal pelvis**, the expanded upper end of the ureter, is divided into 2 or 3 **major calyces**. Several small branches, the **minor calyces**, arise from each major calyx. The kidney can be divided into an outer **cortex** and an inner **medulla**. In humans, the renal medulla consists of 8-12 conical or pyramidal structures called **renal** or **medullary pyramids**, which are separated by extensions from the cortex called **renal columns**. Each pyramid plus the cortical tissue at its base and along its sides constitutes a **renal lobe**. Striations extending from the medulla into the cortex are called **medullary rays**; these plus the attached cortical tissue are considered lobules. The tip of each pyramid, called the **renal papilla**, projects into a minor calyx that collects urine formed by tubules in the pyramid. The cortex and hilum are covered with a fibrous capsule (**Figures 1** and **2**).

Each kidney contains around 1 million functional units called **nephrons**. Each nephron consists of (**Figure 3**):

**1. Renal Corpuscle,** an initial dilated part enclosing a tuft of capillary loops and the site of blood filtration, always located in the cortex and consists of:

**A. Glomerulus. B. Bowman's capsule.**

**2. Proximal Tubule,** a long convoluted part, located entirely in the cortex, with a shorter straight part that enters the medulla.

**3. Loop of Henle** (or nephron loop), in the medulla, with a **thin descending** and a **thin ascending** limb.

**4. Distal Tubule,** consisting of a thick straight part ascending from the loop of Henle back into the cortex and a convoluted part completely in the cortex.

- **Connecting Tubule,** a short final part linking the nephron to **collecting ducts**.

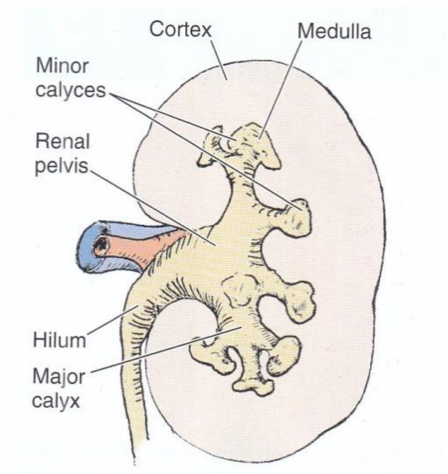


**Figure 1.**

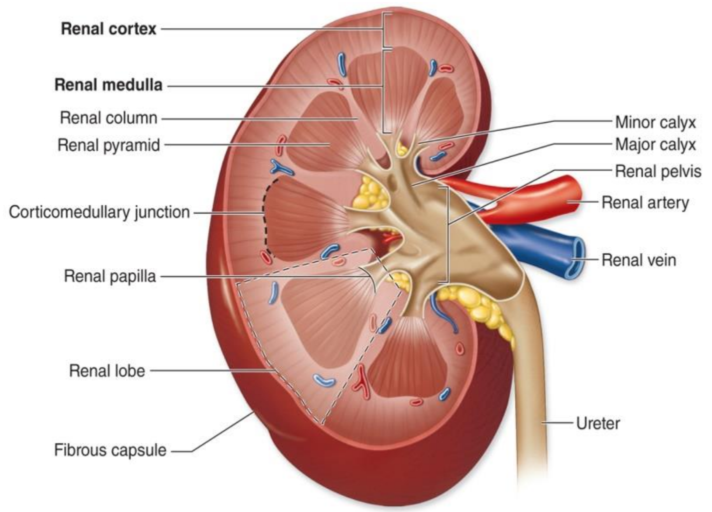


**Figure 2.**

**Figures 1 and 2. General organization of the kidney.**

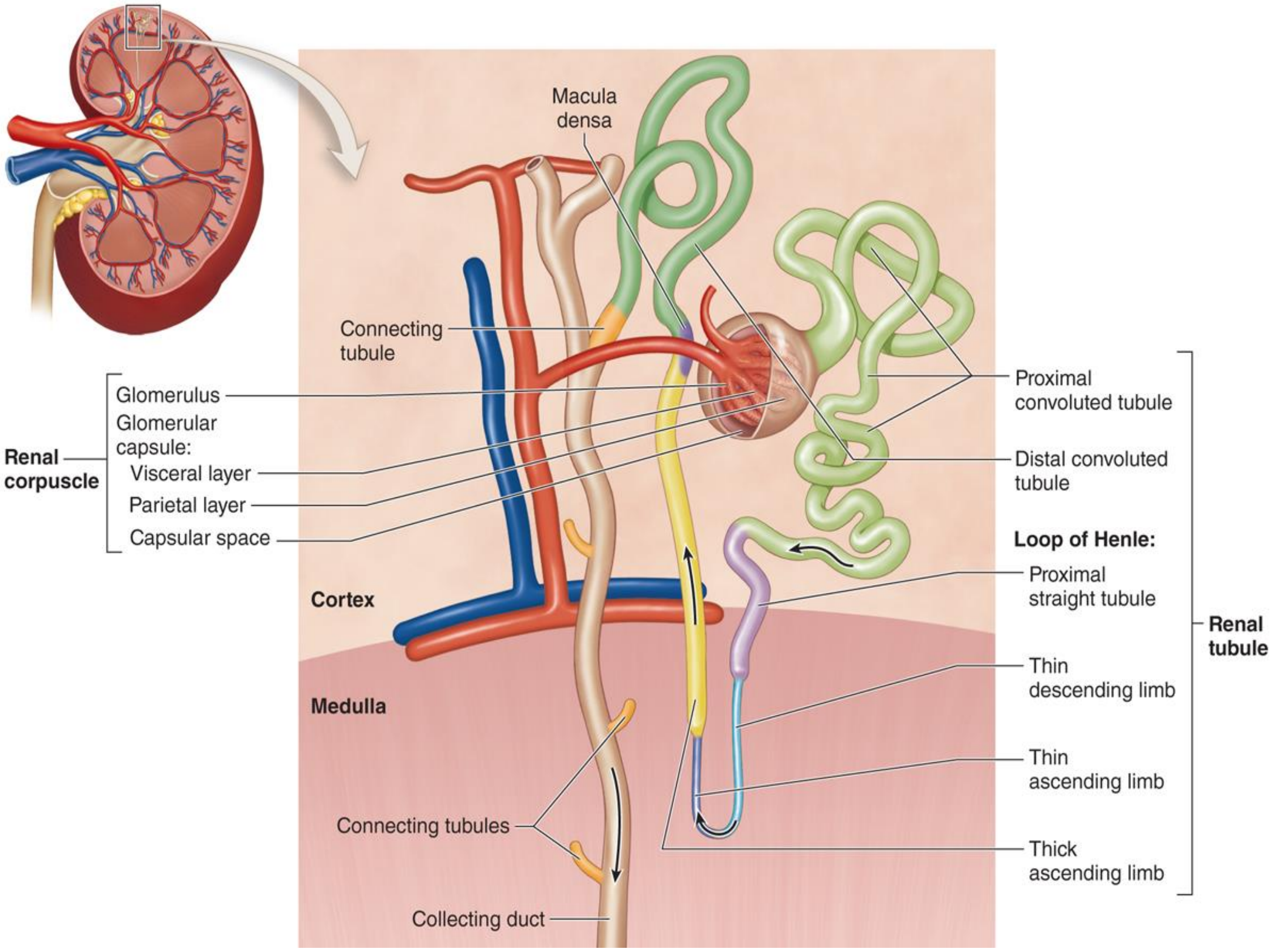


**Figure 3. Nephrons.**

## 1. Renal Corpuscle

Each renal corpuscle is about 200µm in diameter and consists of a tuft of capillaries, the **glomerulus,** surrounded by a double-walled epithelial capsule called **glomerular (Bowman's) capsule.** Each renal corpuscle has a **vascular pole,** where the **afferent arteriole** enters, and the efferent arteriole leaves, and a **urinary pole,** where the proximal convoluted tubule begins (**Figure 4**). After entering the renal corpuscle, the afferent arteriole usually divides into 2 to 5 primary branches, each subdividing into capillaries and forming the renal glomerulus.

## A. Glomerulus

The glomerulus is formed as several tufts of anastomosing capillaries that arise from branches of the afferent glomerular arteriole. There are specialized cells in the glomerulus called **mesangial cells** (**Figure 5**). These cells are also attached to the capillaries and perform several important functions. Mesangial cells synthesize the extracellular matrix and provide structural support for the glomerular capillaries. Mesangial cells function as **macrophages** in the intraglomerular regions and phagocytose antigen–antibody complexes and the material that accumulate on the glomerular filter, thus preventing its clogging with filtered matter and keeping the glomerular filter free of debris. These cells also appear to be contractile and can regulate glomerular blood flow as a result of the presence of receptors for vasoactive substances. Some of the mesangial cells are also located outside the renal corpuscle in the vascular pole region, between the afferent and efferent arterioles. Here, they are called the **extraglomerular mesangial cells**, also called lacis cells, and form part of the juxtaglomerular apparatus.

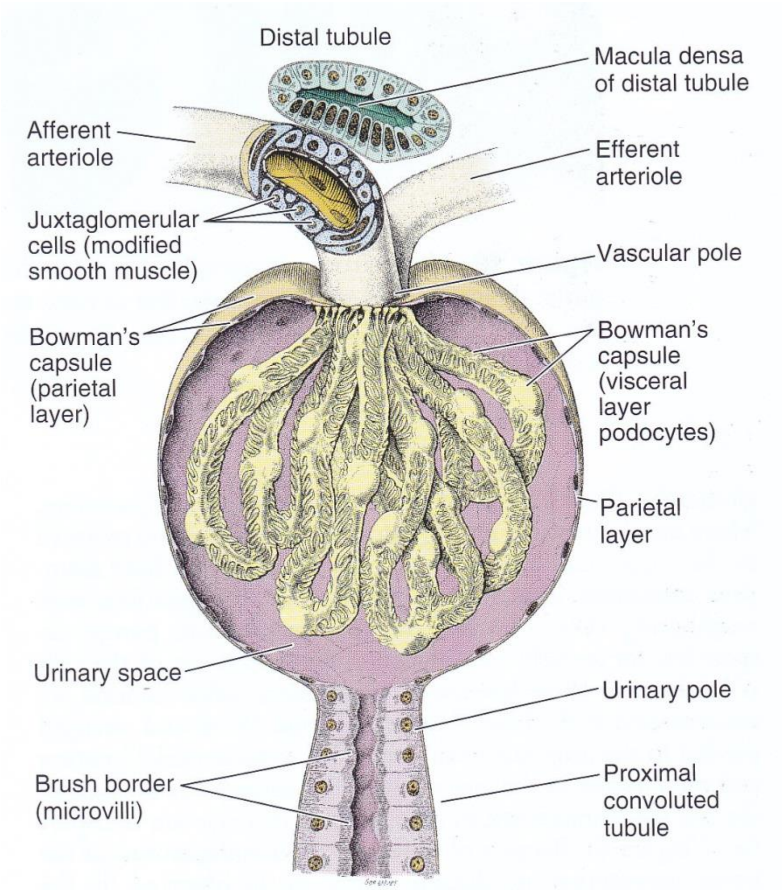

**Figure 4. The renal corpuscle. The upper part of the drawing shows the vascular pole, with afferent and efferent arterioles and the macula densa. Note the juxtaglomerular cells in the wall of the afferent arteriole. Podocyte processes cover the outer surfaces of the glomerular capillaries; the part of the podocyte containing the nucleus protrudes into the urinary space. Note the flattened cells of the parietal layer of Bowman's capsule. The lower part of the drawing shows the urinary pole and the proximal convoluted tubule.**

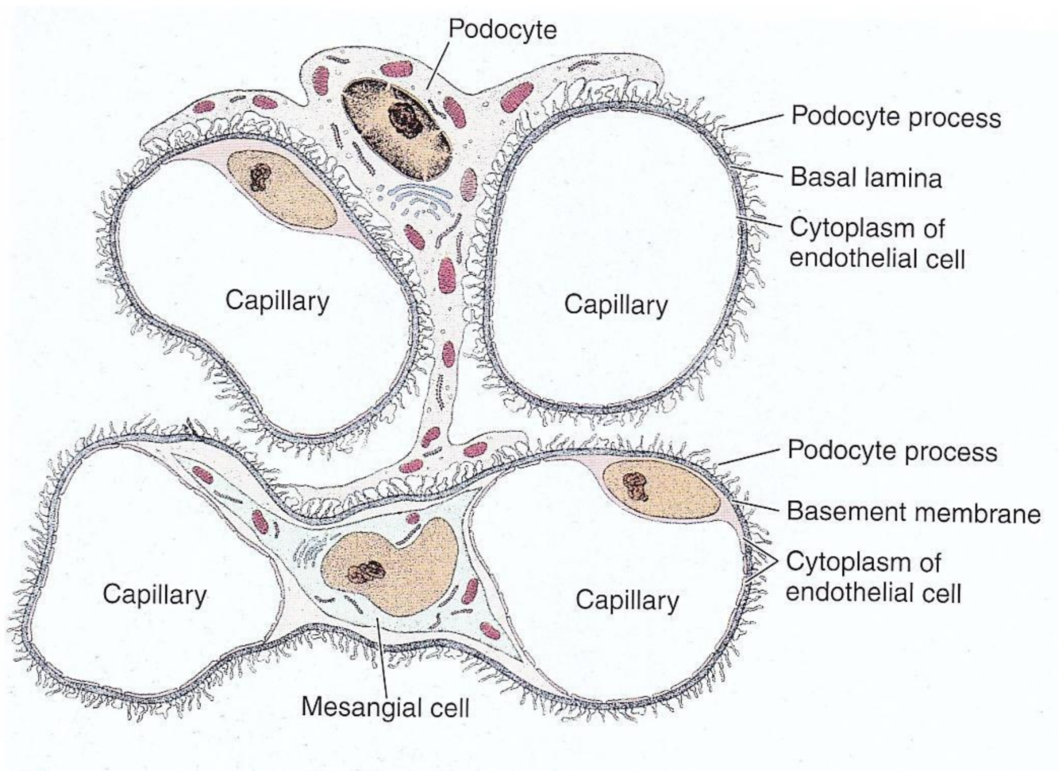


**Figure 5. Mesangial cell located between capillaries enveloped by the basement membrane.**

## B. Bowman’s Capsule

Glomerular (Bowman's) capsule consists of the internal layer called the **visceral layer** of the capsule that closely envelops the capillaries of the glomerulus. The external layer forms the surface of the renal corpuscle and is called the **parietal layer** of Bowman’s capsule (see Figure 4). Between the two layers of Bowman’s capsule is the **urinary space**, which receives the fluid filtered through the capillary wall and the visceral layer. The outer parietal layer of Bowman’s capsule consists of a **simple squamous epithelium** supported by a basal lamina and a thin layer of reticular fibers. At the urinary pole, the epithelium changes to the **simple cuboidal epithelium** that continues and forms the proximal convoluted tubule (see Figure 4).

The internal lining of the capsule is composed of complex epithelial cells called **podocytes**. From the cell body of each podocyte, several **primary processes** extend and curve around a length of glomerular capillary. Each primary process gives rise to many parallel, interdigitating secondary processes or **pedicels**. The pedicels cover much of the capillary surface, in direct contact with the basal lamina. Between the interdigilating pedicels are elongated spaces called **filtration slits**, 25 to 30 nm wide. **(Figure 6)**. Podocytes have bundles of actin microfilaments in their cytoplasm that give them a contractile capacity. The glomerular filtration barrier consists of three layered components: the fenestrated **capillary endothelium**, the **glomerular basement membrane (GBN)**, and **filtration slit** diaphragms between pedicels.

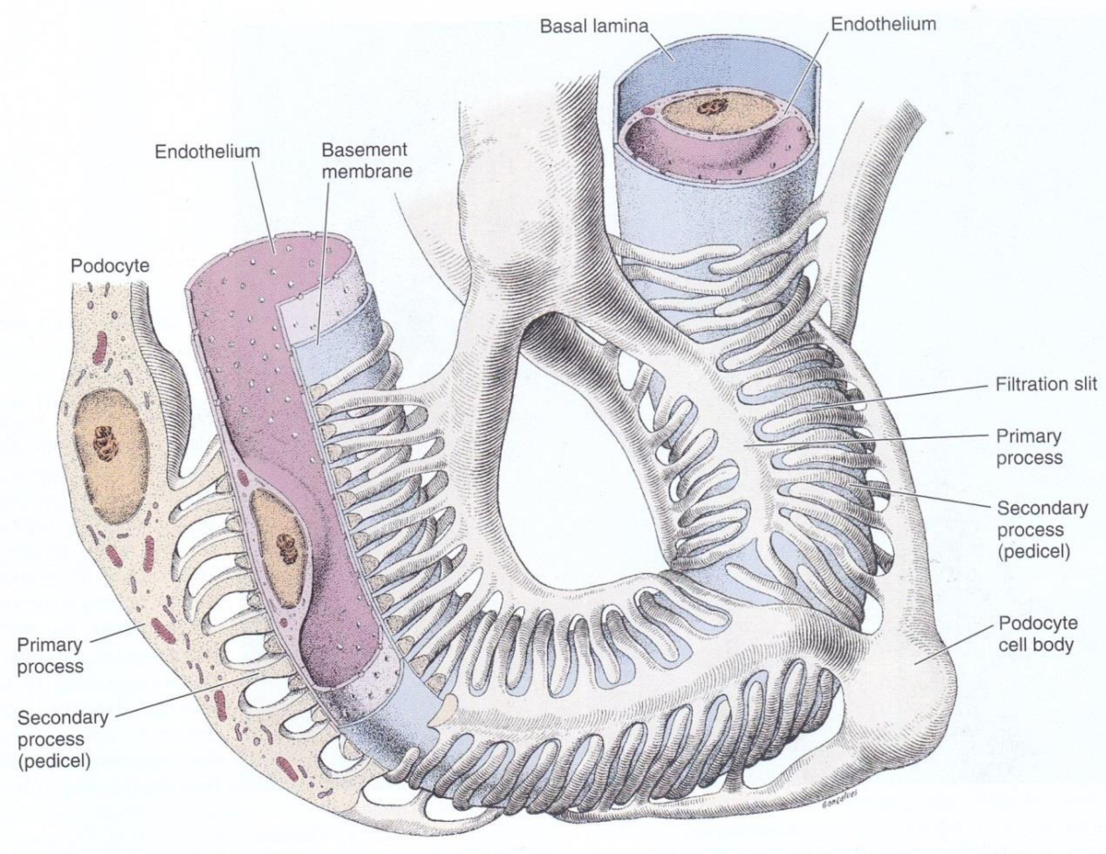


**Figure 6. Schematic representation of a glomerular capillary with the visceral layer of Bowman's capsule (formed of podocytes). In this capillary, endothelial cells are fenestrated, but the basal lamina on which they rest is continuous. At left is a podocyte shown in partial section. As viewed from the outside, the part of the podocyte that contains the nucleus protrudes into the urinary space. Each podocyte has many primary processes, from which arise an even greater number of secondary processes or pedicels that are in contact with the basal lamina.**

## 2. Proximal Convoluted Tubule

At the urinary pole of the renal corpuscle, the squamous epithelium of the parietal layer of Bowman's capsule is continuous with the simple cuboidal epithelium of the proximal convoluted tubule (see Figures 3 and 4).

This tubule is longer than the distal convoluted tubule and is therefore more frequently seen near renal corpuscles in the renal cortex. The cells of this cuboidal epithelium have an acidophilic cytoplasm, because of the presence of numerous elongated mitochondria. The cell apex has abundant microvilli about 1μm in length, which form a **brush border** (**Figures7** and **8**).

The proximal convoluted tubule absorbs all the glucose and amino acids and about 85% of the sodium chloride and water contained in the filtrate, in addition to phosphate and calcium. When the amount of glucose in the filtrate exceeds the absorbing capacity of the proximal tubule, urine becomes more abundant and contains glucose. The proximal convoluted tubule secretes creatinine and substances foreign to the organism, such as para-aminohippuric acid and penicillin, from the interstitial plasma into the filtrate. This is an active process referred to as tubular secretion. Study of the rates of secretion of these substances is useful in the clinical evaluation of kidney function.

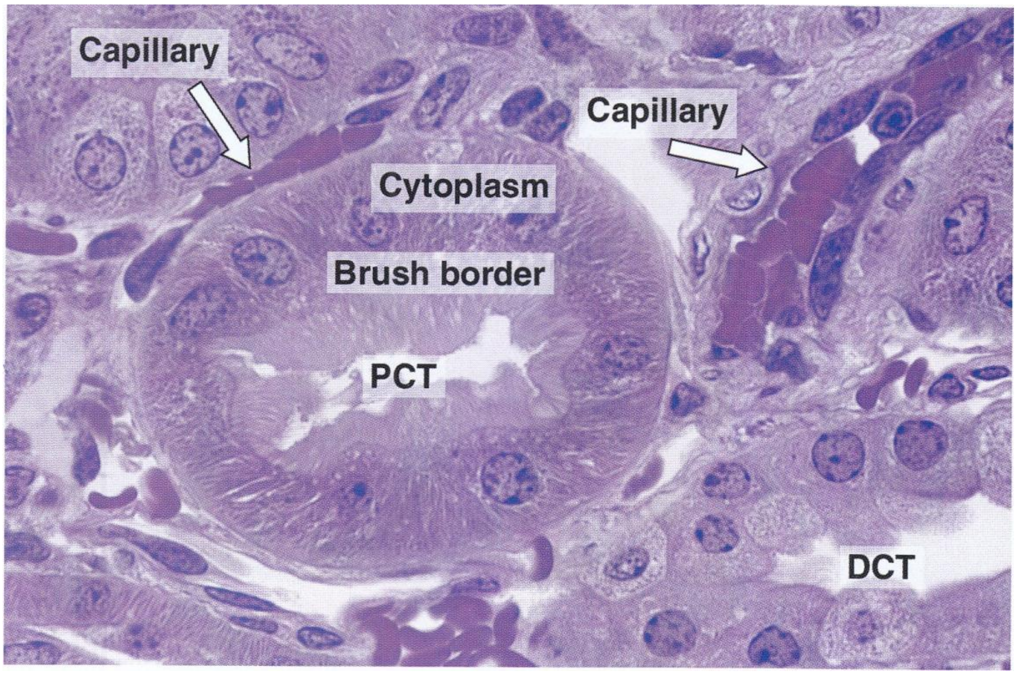

**Figure 7. Renal cortex section showing a proximal convoluted tubule (PCT) with its large cuboidal cells presenting a brush border formed by numerous microvilli. Distal convoluted tubules (DCT) are also present.**

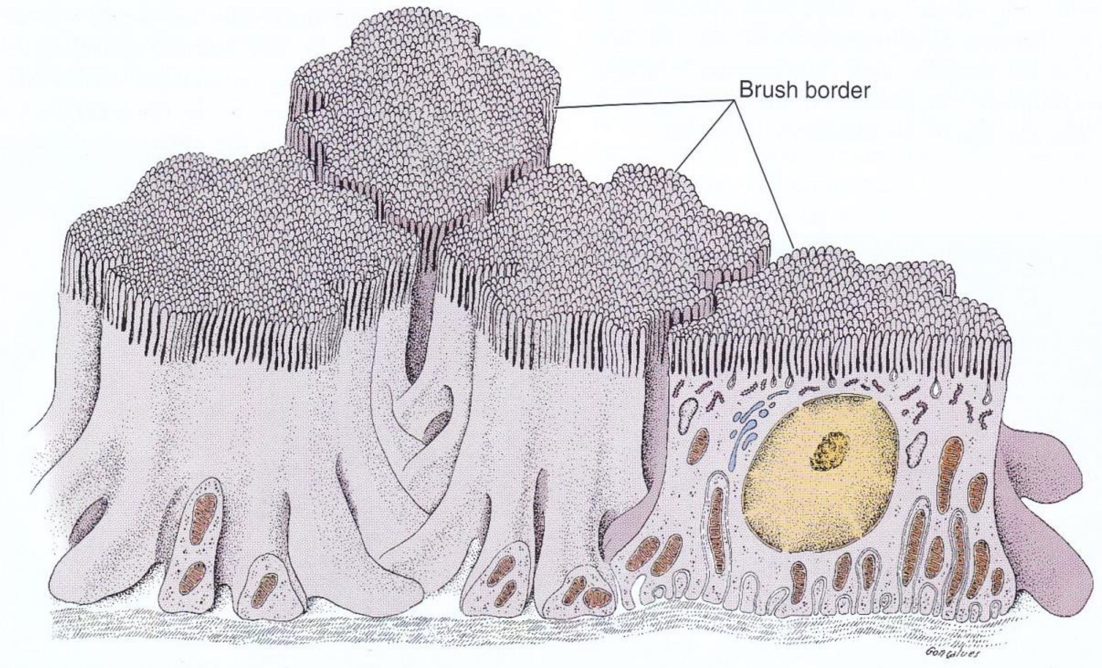


**Figure 8. Schematic drawing of proximal convoluted tubule cells. The apical surfaces of these cuboidal cells have abundant microvilli constituting a brush border. Note the distribution of mitochondria and associated basilar infoldings of the cell membrane. The latter processes are longer than the former and penetrate deeply among the neighboring cells.**

**3. Loop of Henle**

This is a U-shaped structure with a **thin descending limb** and a **thin ascending limb**, both composed of **simple squamous epithelia** (**Figures 9** and **10**). The wall of the thin segments consists only of squamous cells with few organelles (indicating a primarily passive role in transport) and the luman is prominent (see Figure10).The thin ascending limb of the loop becomes the **thick ascending limb** (**TAL**), with **simple cuboidal epithelium** and extends as far as the macula densa near the nephron's glomerulus and becomes continued with distal convoluted tubule (see Figure 3).

The loops of Henle and surrounding interstitial connective tissue are involved in further adjusting the salt content of the filtrate. Cuboidal cells of the loops' TALs actively transport sodium and chloride ions out of the tubule against a concentration gradient into renal interstitium. This causes water to be withdrawn passively from the thin descending part of the loop (permeable to water), thus concentrating the filtrate. The thin ascending limbs reabsorb sodium chloride (NaCl) but are impermeable to water. The countercurrent flow of the filtrate (descending, then immediately ascending) in the two parallel thin limbs.

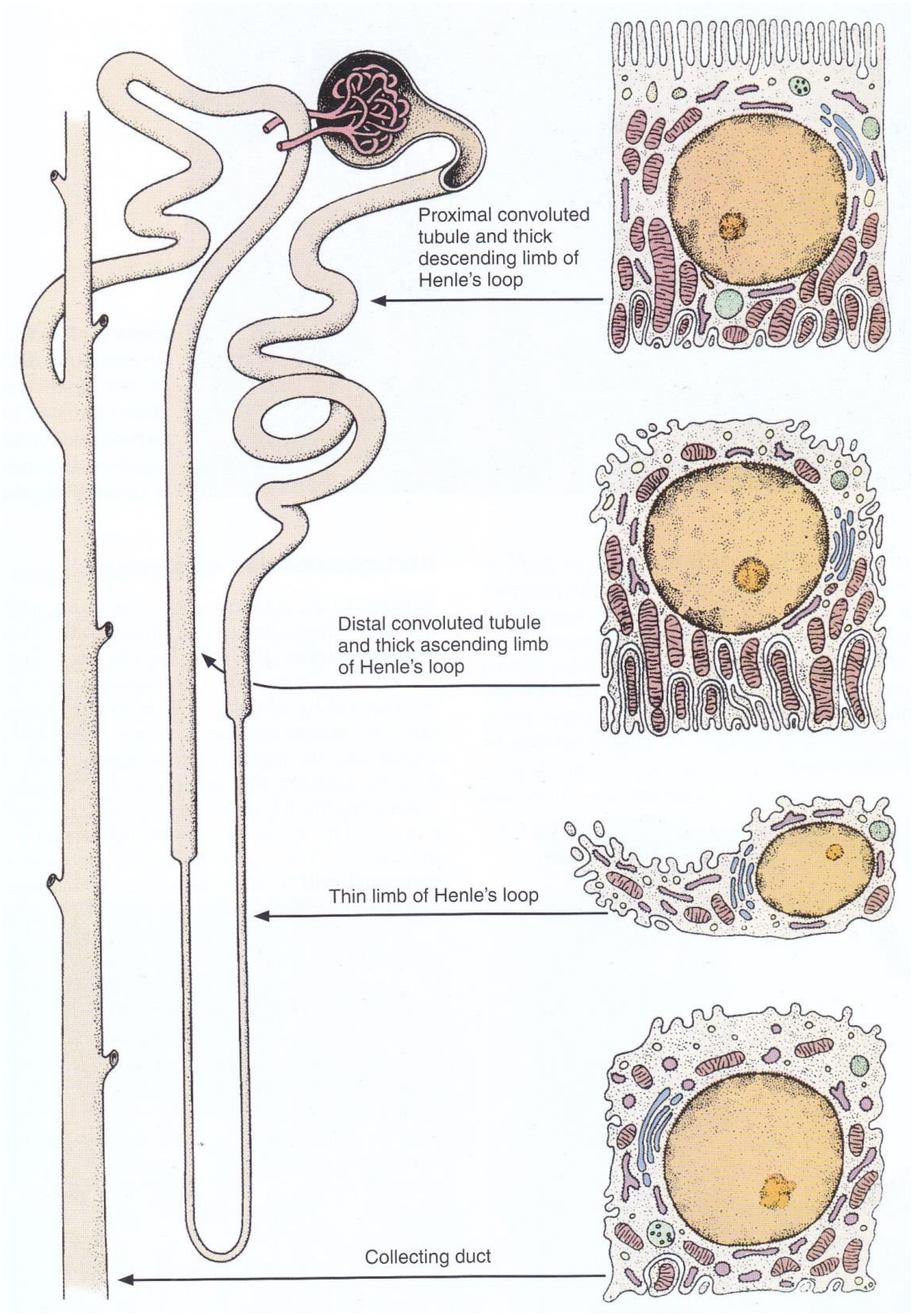


**Figure 9. Cellular ultrastructure of the nephron, represented schematically. Cells of the thick ascending limb of Henle's loop and the distal tubule are different in their ultrastructures and functions.**

## 4. Distal Convoluted Tubule

The thick ascending limb **(TAL)** of Henle's loop penetrates the cortex (forms the macula densa); after describing a certain trajectory, it becomes tortuous and is called the distal convoluted tubule. This tubule, like the ascending limb, is lined with simple cuboidal epithelium (see Figures 9 and 10).The distal convoluted tubules differ from the proximal convoluted tubules (both found in the cortex) because they have no brush border, no apical canaliculi, and smaller cells. Because distal tubule cells are flatter and smaller than those of the proximal tubule, more nuclei are seen in the distal tubule than in the proximal tubule. Cells of the distal convoluted tubule have fewer mitochondria than cells of proximal tubules, making them less acidophilic (see Figure 10). The distal convoluted tubule establishes contact with the vascular pole of the renal corpuscle of its patent nephron. At this point of close contact, the distal tubule is modified, as is the afferent arteriole. In this juxtaglomerular region, cells of the distal convoluted tubule usually become columnar, and their nuclei are closely packed together. Most of the cells have Golgi complex in the basal region. This modified segment of the wall of the distal tubule which appears darker in microscopic preparations because of the close proximity of its nuclei is called the **macula densa** (see Figure 4), (**Figure 11**). The cells of the macula densa are sensitive to the ionic content and water volume of the tubular fluid producing molecular signals that promote the liberation of the enzyme renin in the circulation.

In the distal convoluted tubule, the rate of $Na^+$ absorption here is regulated by aldosterone from the adrenal glands. This mechanism influences the total salt and water content of the body. The distal tubule also secretes hydrogen and ammonium ions into tubular urine. This activity is essential for maintenance of the acid-base balance in the blood.

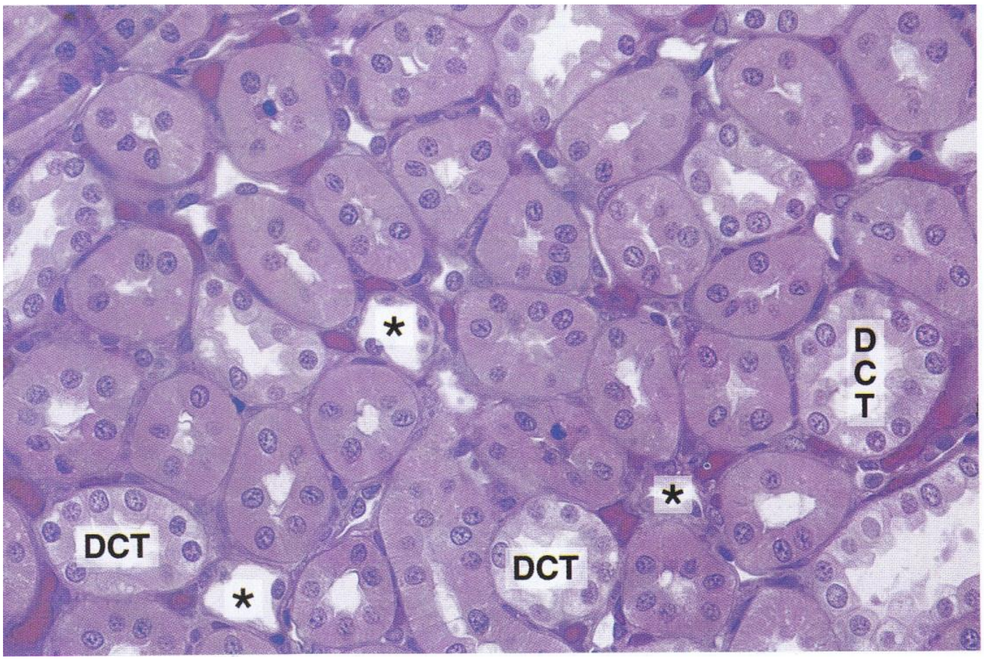


**Figure 10. Region of the kidney consisting mainly of distal convoluted tubules (DCT) and thin segments of Henle's loop (asterisks). Capillaries filled with blood appear in red.**

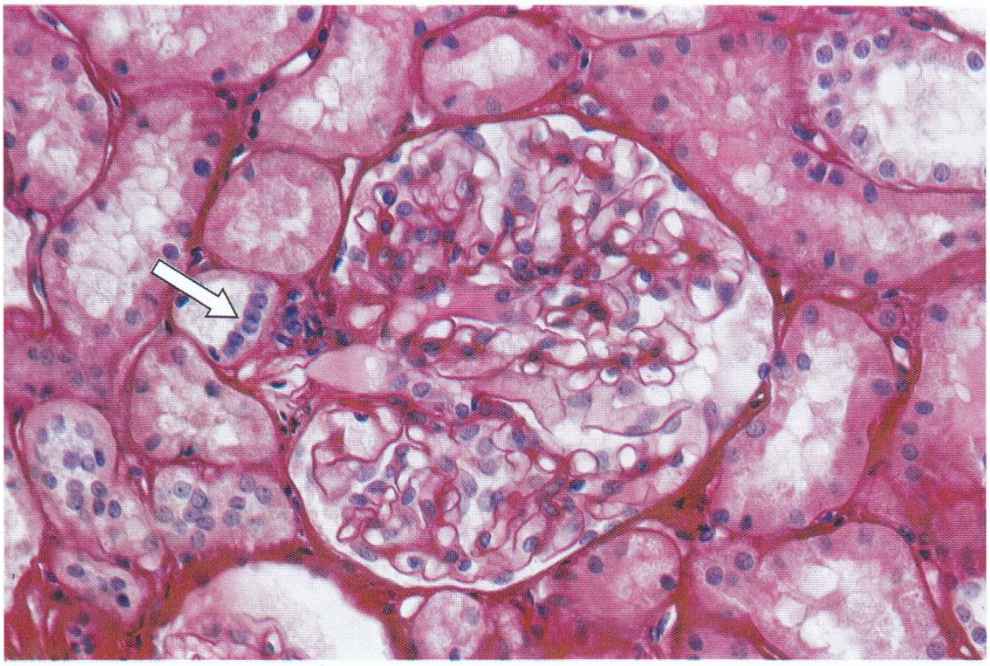

**Figure 11. Photomicrograph of renal cortex. A macula densa is clearly seen (arrow) at the vascular pole of a renal corpuscle.**

## Juxtaglomerular Apparatus

Adjacent to the renal corpuscle, the tunica media of the afferent arteriole has modified smooth muscle cells. These cells are called **juxtaglomerular (JG) cells** (**Figure 12**) and have a cytoplasm full of secretory granules. Secretions of JG cells play a role in the maintenance of blood pressure (JG cells produce the enzyme **renin**). The macula densa of the distal convoluted tubule is usually located near the region of the afferent arteriole that contains the JG cells; together, this portion of the arteriole and the macula densa form the JG apparatus (see Figure 4). Also a part of the JG apparatus, at the vascular pole are **lacis cells**, which are **extraglomerular mesangial cells** that have many of the same supportive , contractile , and defensive functions as these cells inside the glomerulus. Basic functions of the JGA in the autoregulation of the glomerular filtration rate (GFR) and in controlling blood pressure.

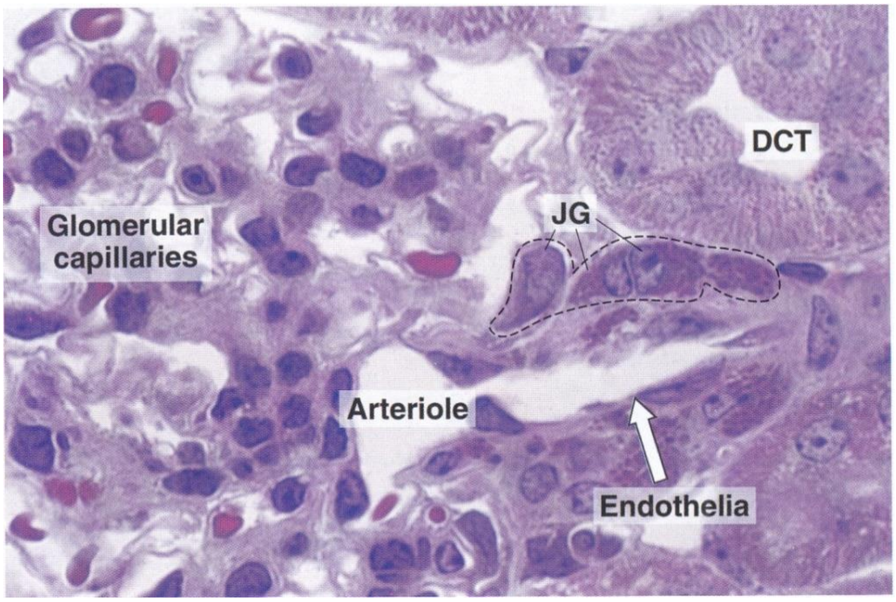


**Figure 12. Photomicrograph of an afferent arteriole entering a renal corpuscle. The wall of this arteriole shows the renin-producing juxraglomerular (JG) cells (broken line). At the upper right is a distal convoluted tubule (DCT) with many elongated mitochondria.**