

Lec. 6

The urinary system kidney nephrons, collecting tubules and ducts

The urinary system consists of the **paired kidneys** and **ureters**, the **bladder**, and the **urethra**. This system's primary role is to ensure optimal properties of the blood, which the kidneys continuously monitor.

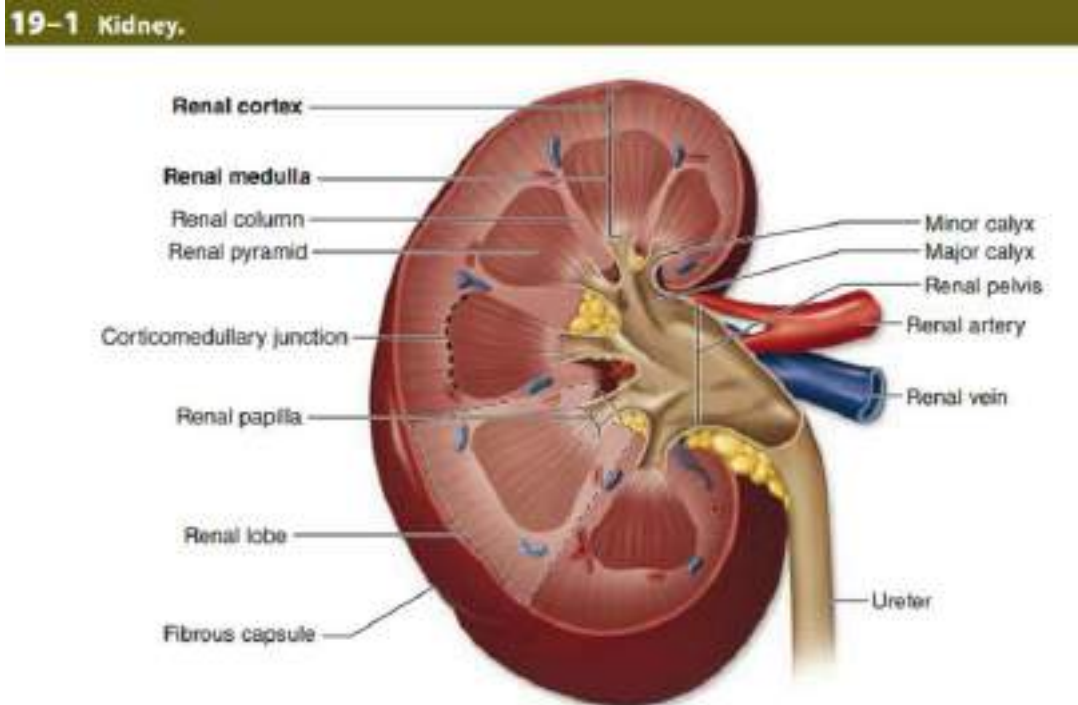
This general role of the kidneys involves a complex combination of renal functions:

1. ■ Regulation of the balance between water and electrolytes (inorganic ions) and the **acid-base balance**;
2. ■ Excretion of metabolic wastes along with excess water and electrolytes in urine, the kidneys' excretory product which passes through the ureters for temporary storage in the bladder before its release to the exterior by the urethra;
3. ■ Excretion of many **bioactive substances**, including many **drugs**;
4. ■ Secretion of renin, a protease important for regulation of blood pressure by cleaving circulating angiotensinogen to angiotensin I;
5. ■ Secretion of **erythropoietin**, a glycoprotein growth factor that stimulates **erythrocyte production** in red marrow when the blood O₂ level is low;
6. ■ Conversion of the steroid prohormone vitamin D, initially produced in the skin, to the active form (**1,25-dihydroxyvitamin D3** or **calcitriol**); and
7. ■ **Gluconeogenesis** during starvation or periods of prolonged fasting, making glucose from amino acids to supplement this process in the liver.

› KIDNEYS

Approximately 12-cm long, 6-cm wide, and 2.5-cm thick in adults, each kidney has a concave medial border, the **hilum**— where nerves enter, the ureter exits, and blood and lymph vessels enter and exit—and a convex lateral surface, both covered by a thin **fibrous capsule** (Figure 19–1). Within the hilum the upper end of the ureter expands as the **renal pelvis** and divides into two or three **major calyces**. Smaller branches, the **minor calyces**, arise from each major calyx. The area surrounding the renal pelvis and calyces contains **adipose tissue**. The parenchyma of each kidney has an outer **renal cortex**, a darker stained region with many round corpuscles and tubule cross sections, and an inner **renal medulla** consisting mostly of aligned linear tubules and ducts (Figure 19–1). The renal medulla in humans consists of 8-15 conical structures called **renal pyramids**, all with their bases meeting the cortex (at the **corticomedullary junction**) and separated from each other by extensions of the cortex called **renal columns**. Each pyramid plus the cortical tissue at its base and extending along its sides constitutes **a renal lobe**. Parallel ducts and

tubules extending from the medulla into the cortex comprise the **medullary rays**; these plus their associated cortical tissue are considered **renal lobules**. The tip of each pyramid, called the **renal papilla**, projects into a minor calyx that collects urine formed by **tubules** in one **renal lobe** (Figure 19–1).



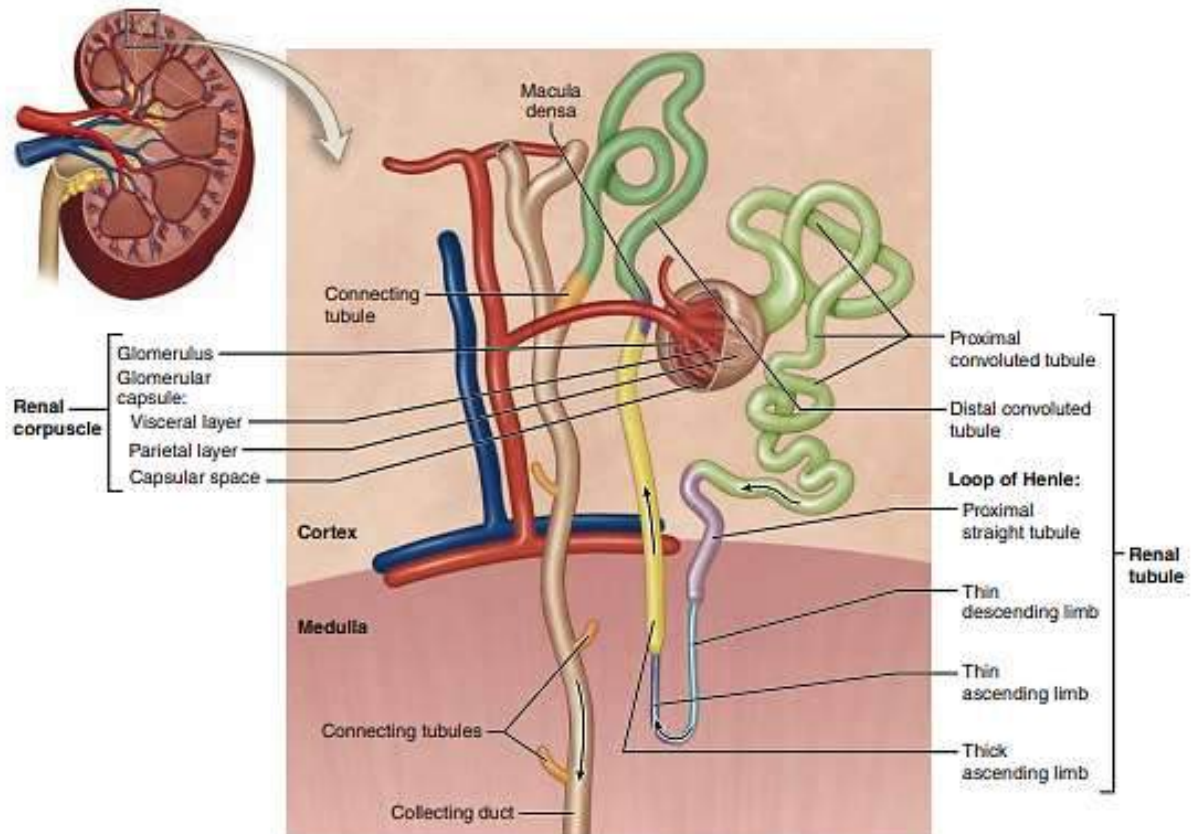
Kidneys each contain 1-4 million functional units called **nephrons** (Figure 19–2), each consisting of a corpuscle and a long, simple epithelial renal tubule with three main parts along its length.

The major divisions of each nephron are:

1. ■ **Renal corpuscle**, an initial dilated part enclosing a tuft of capillary loops and the site of blood filtration, always located in the cortex;
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; and
5. ■ **Connecting tubule**, a short minor part linking the nephron to collecting ducts.

Connecting tubules from several nephrons merge to form **collecting tubules** that then merge as larger **collecting ducts**. These converge in the **renal papilla**, where they deliver urine to a **minor calyx**. **Cortical nephrons** are located almost completely in the cortex while **juxtamedullary nephrons** (about one-seventh of the total) lie close to the medulla and have long loops of Henle.

FIGURE 19–2 A nephron and its parts.



Each kidney contains 1-4 million functional units called **nephrons**. Each nephron originates in the cortex, at the **renal corpuscle** surrounding a small tuft of glomerular capillaries. Extending from the corpuscle is the long **proximal convoluted tubule** which leads to the short **proximal straight tubule** that enters the outer medulla. This tubule continues as the **thin descending limb** and the **thin ascending limb** of the nephron's loop of Henle in the medulla. The loop of Henle ends with a **thick ascending limb**,

a straight tubule that reenters the cortex and ends at its thickened **macula densa** area where it contacts the arterioles entering the glomerulus. Beyond the macula densa this tubule is the **distal convoluted tubule**, the end of which is the short **connecting tubule**. Connecting tubules from many nephrons merge into cortical collecting tubules and a **collecting duct** that transports urine to the calyx.

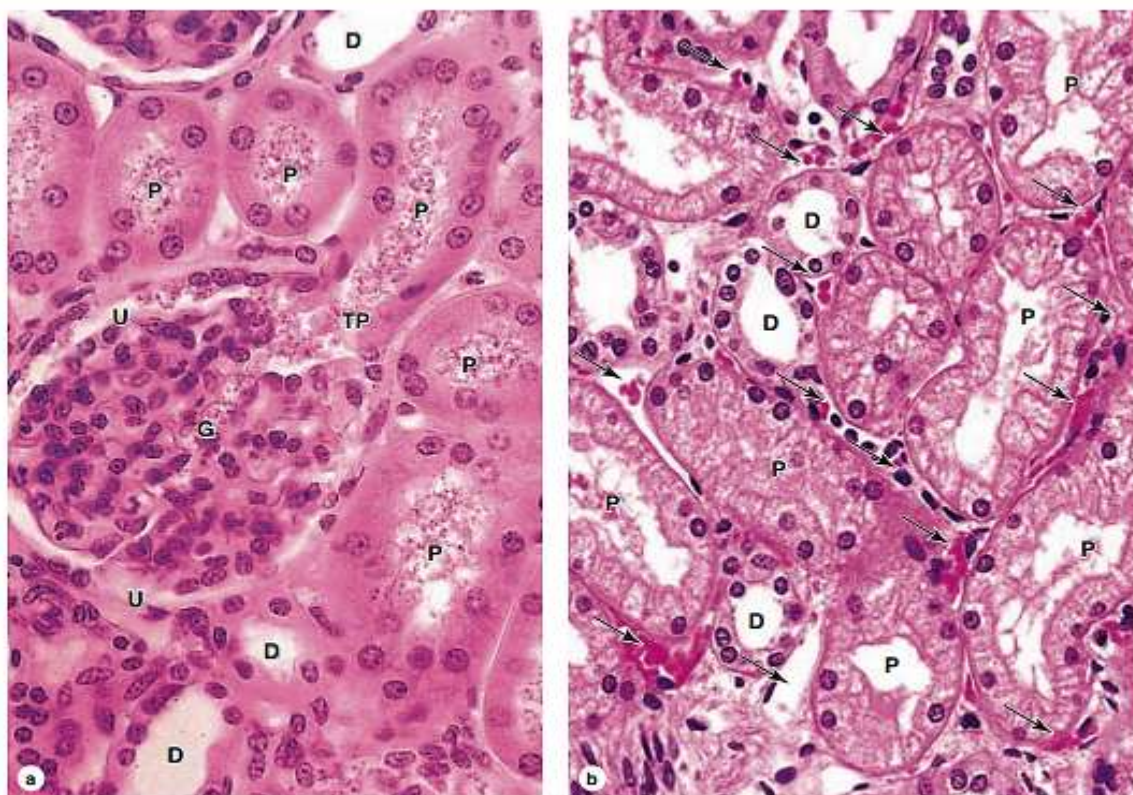
Proximal Convoluted Tubule

Cells in many parts of the nephron tubule and collecting system **reabsorb** water and electrolytes, but other activities are restricted mainly to specific tubular regions. Table 19–1 summarizes major functions of parts within nephrons and collecting ducts, along with the histologic features involved in these activities. At the tubular pole of the **renal corpuscle**, the **simple squamous epithelium** of the capsule's parietal layer is continuous with the **simple cuboidal epithelium** of the **proximal convoluted tubule (PCT)** (Figures 19–8 and 19–9). These long, tortuous tubules fill most of the cortex. PCT cells are specialized for both **reabsorption** and **secretion**. Over half of the water and electrolytes, and all of the organic nutrients (glucose, amino acids, vitamins, etc), filtered from plasma in the renal corpuscle are normally reabsorbed in the PCT. These molecules are transferred directly across the tubular wall for immediate uptake again into the plasma of the **peritubular capillaries**.

| TABLE 19-1 Histologic features and major functions of regions within renal tubules. | | | |
|---|--|----------------------------|--|
| Region of Tubule | Histological Features | Locations | Major Functions |
| PCT | Simple cuboidal epithelium; cells well-stained, with numerous mitochondria, prominent basal folds and lateral interdigitations; long microvilli, lumens often occluded | Cortex | Reabsorption of all organic nutrients, all proteins, most water and electrolytes; secretion of organic anions and cations, H ⁺ , and NH ₄ ⁺ |
| Loop of Henle | | | |
| Thin limbs | Simple squamous epithelium; few mitochondria | Medulla | Passive reabsorption of Na ⁺ and Cl ⁻ |
| TAL | Simple cuboidal epithelium; no microvilli, but many mitochondria | Medulla and medullary rays | Active reabsorption of various electrolytes |
| DCT | Simple cuboidal epithelium; cells smaller than in PCT, short microvilli and basolateral folds, more empty lumens | Cortex | Reabsorption of electrolytes |
| Collecting system | | | |
| Principal cells | Most abundant, cuboidal to columnar; pale-staining, distinct cell membranes | Medullary rays and medulla | Regulated reabsorption of water & electrolytes; regulated secretion of K ⁺ |
| Intercalated cells | Few and scattered; slightly darker staining | Medullary rays | Reabsorption of K ⁺ (low-K ⁺ diet); help maintain acid-base balance |

DCT, distal convoluted tubule; PCT, proximal convoluted tubule; TAL, thick ascending limb.

FIGURE 19-8 Renal cortex: proximal and distal convoluted tubules.



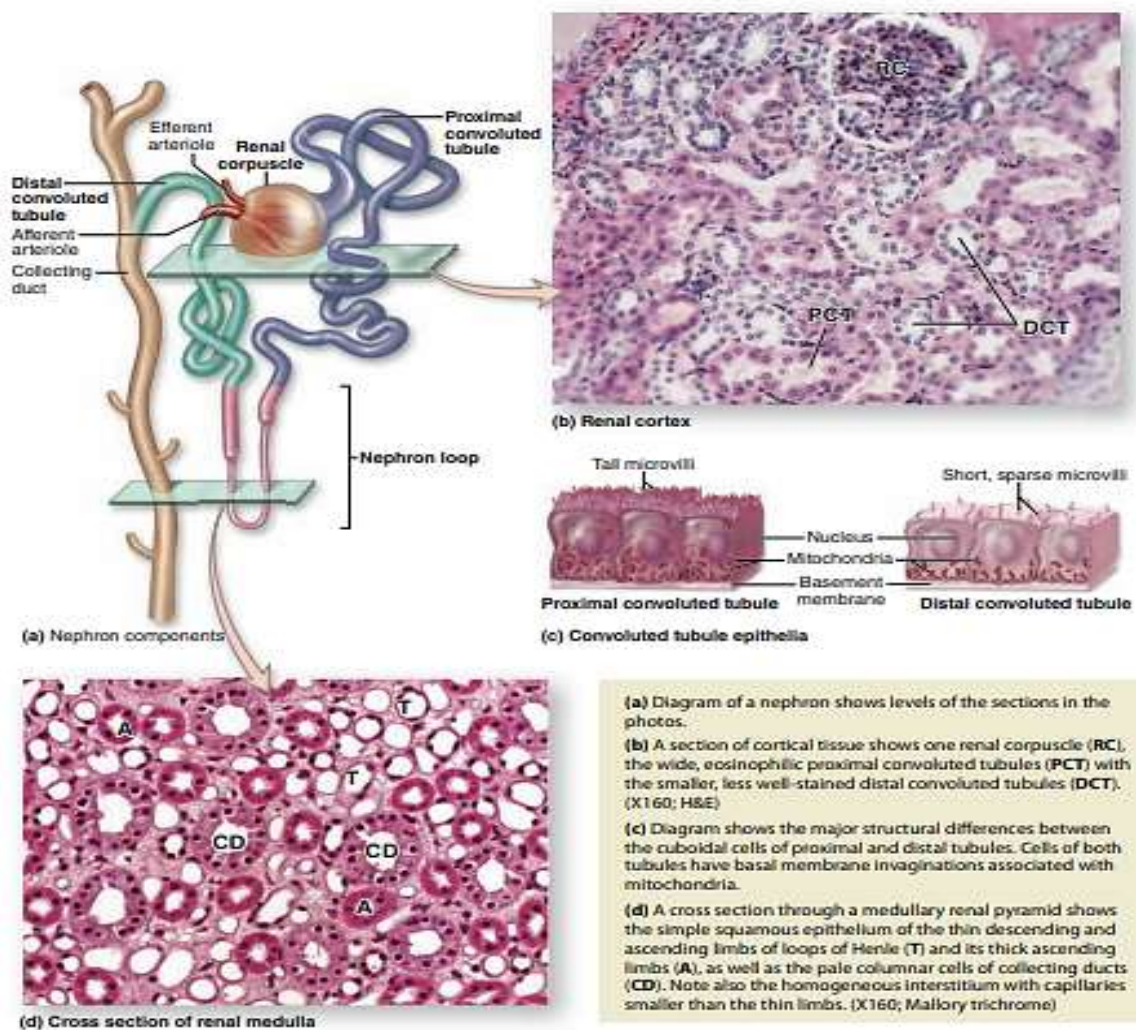
(a) The micrograph shows the continuity at a renal corpuscle's tubular pole (TP) between the simple cuboidal epithelium of a proximal convoluted tubule (P) and the simple squamous epithelium of the capsule's parietal layer. The urinary space (U) between the parietal layer and the glomerulus (G) drains into the lumen of the proximal tubule. The lumens of the proximal tubules appear filled, because of the long microvilli of the brush border

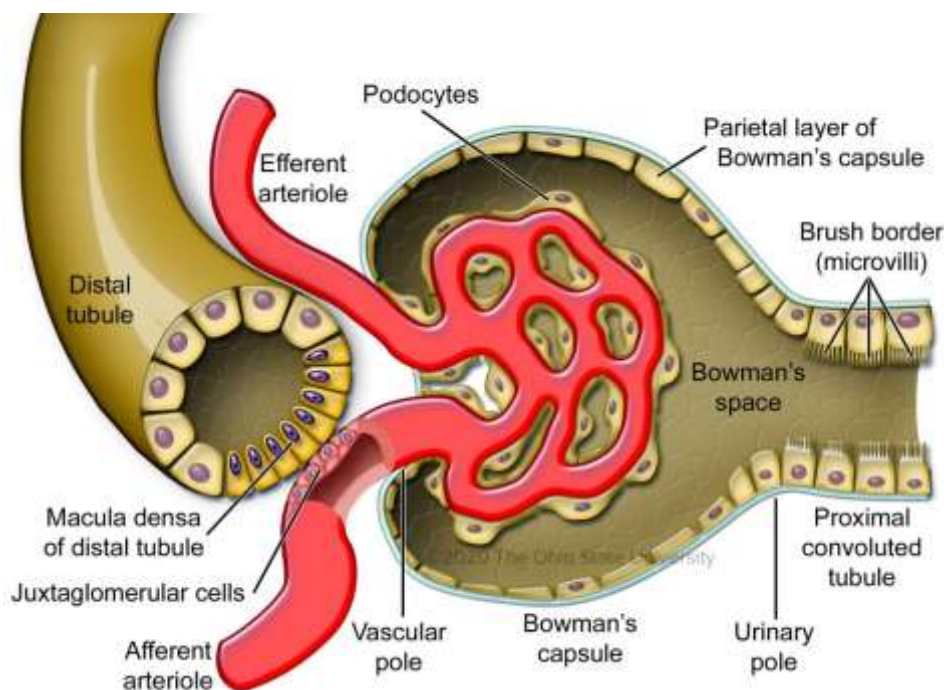
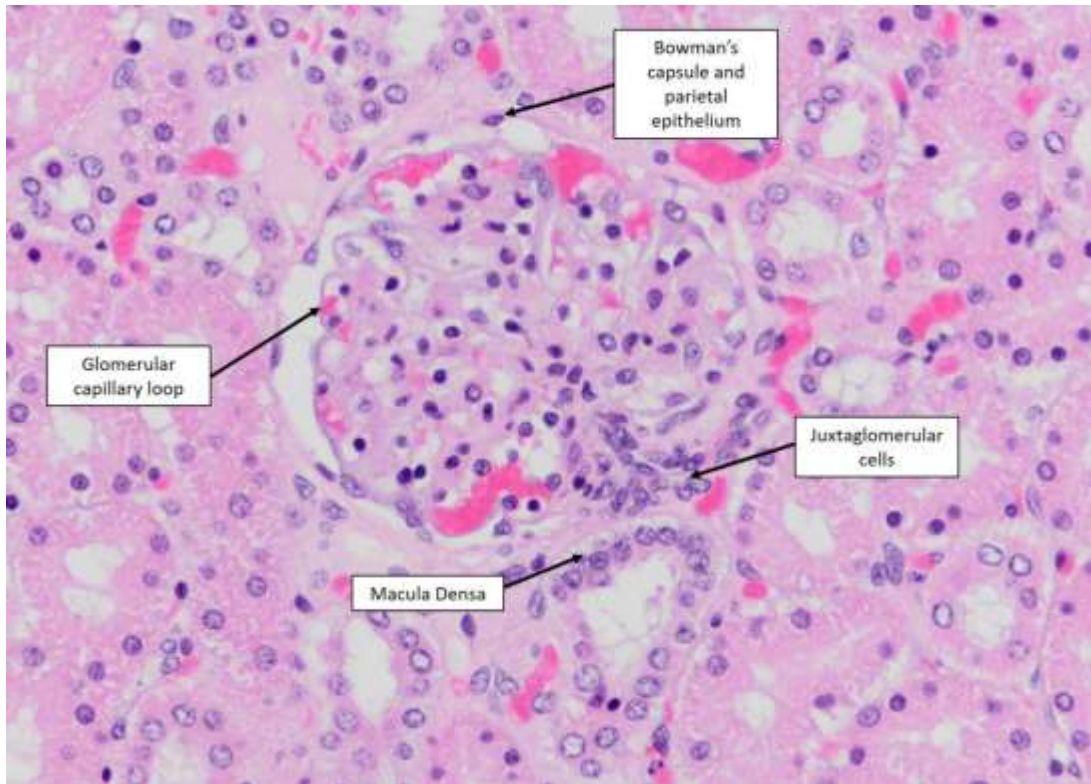
and aggregates of small plasma proteins bound to this structure. By contrast, the lumens of distal convoluted tubules (D) appear empty, lacking a brush border and protein. (b) Here the abundant peritubular capillaries and draining venules (arrows) that surround the proximal (P) and distal (D) convoluted tubules are clearly seen. (Both X400; H&E)

Loop of Henle

The PCT continues with the much shorter **proximal straight tubule** that enters the medulla and continues as the nephron's loop of Henle (Figure 19–2). This is a U-shaped structure with a **thin descending limb** and a **thin ascending limb**, both composed of **simple squamous epithelia**. The straight part of the proximal tubule has an outer diameter of about 60 μm , but it narrows abruptly to about 30 μm in the thin limbs of the loop. The wall of the thin segments consists only of squamous cells with few organelles (indicating a primarily passive role in transport) and the lumen is prominent (Figures 19–9 and 19–11). The thin ascending limb of the loop becomes the thick ascending limb (TAL), with **simple cuboidal epithelium** and many mitochondria again, in the outer medulla and extends as far as the macula densa near the nephron's glomerulus. **The loops of Henle** and surrounding interstitial **connective tissue** are involved in further adjusting the salt content of the filtrate.

FIGURE 19–9 Convoluted tubules, nephron loops, and collecting ducts.





Distal Convoluted Tubule & Juxtaglomerular Apparatus

The ascending limb of the nephron is straight as it enters the cortex and forms the macula densa, and then becomes tortuous as the distal convoluted tubule (DCT) (Figure 19–2). Much less tubular reabsorption occurs here than in the proximal tubule. The **simple cuboidal cells** of the distal tubules differ from those of the proximal tubules in being smaller and having **no brush border** and more empty lumens (Figure 19–9). Because distal tubule cells are flatter and smaller than those of

the proximal tubule, more nuclei are typically seen in sections of distal tubules than in those of proximal tubules (Figure 19–8). Cells of the DCT also have fewer mitochondria than cells of proximal tubules, making them less acidophilic (Figure 19–9). The rate of Na⁺ absorption here is regulated by **aldosterone** from the **adrenal glands**. Where the initial, straight part of the distal tubule contacts the arterioles at the vascular pole of the renal corpuscle of its parent nephron, its cells become more columnar and closely packed, forming the **macula densa**. This is part of a specialized **sensory structure, the juxtaglomerular apparatus** (JGA) that utilizes feedback mechanisms to regulate glomerular blood flow and keep the rate of glomerular filtration relatively constant.

Collecting Ducts

The last part of each nephron, the connecting tubule, carries the filtrate into a collecting system that transports it to a **minor calyx** and in which more water is reabsorbed if needed by the body. As shown in Figures 19–13, a connecting tubule extends from each nephron and several join together in the cortical medullary rays to form collecting ducts of **simple cuboidal epithelium**. In the medulla these merge further, forming larger and straighter collecting ducts with increasingly columnar cells (Figures 19–11 and 19–14). Approaching the apex of each renal pyramid, several medullary collecting ducts merge again to form each papillary duct (or duct of Bellini), which deliver urine directly into the **minor calyx** (Figure 19–13). Running parallel with the descending and ascending limbs of the loops of Henle and vasa recta, **medullary collecting ducts lie** in the area with very high interstitial osmolarity (Figures 19–2 and 19–11). Collecting tubules and ducts are composed mainly of pale staining principal cells with few organelles, sparse microvilli, and unusually distinct cell boundaries (Figure 19–14). Ultrastructurally the principal cells can be seen to have basal membrane infoldings, consistent with their role in ion transport, and a primary cilium among the microvilli. The medullary collecting ducts are the final site of water reabsorption from the filtrate. Principal cells are particularly rich in **aquaporins**, the integral membrane pore proteins that function as specific channels for water molecules, but here most aquaporins are sequestered in membranous cytoplasmic vesicles. **Antidiuretic hormone (ADH)**, released from the **posterior pituitary gland** as the body becomes dehydrated, makes collecting ducts more permeable to water and increases the rate at which water molecules are pulled osmotically from the filtrate.

FIGURE 19-13 Fluid transport in the urinary system.

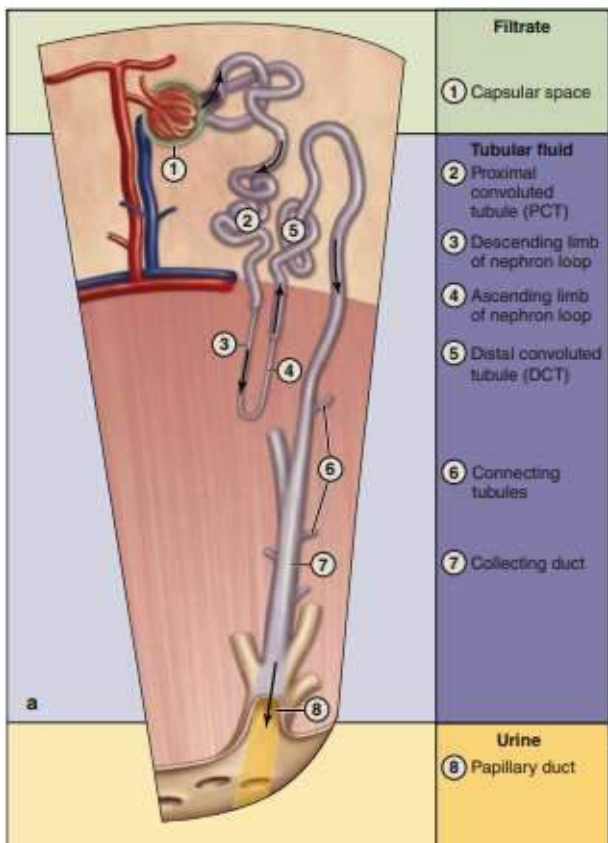


FIGURE 19-14 Collecting ducts.

