The Urinary System: Introduction

The urinary system consists of the paired kidneys and ureters, the bladder, and the urethra. This system helps maintain homeostasis by a complex combination of processes that involves the following:

- Filtration of cellular wastes from blood.
- Selective reabsorption of water and solutes.
- Excretion of the wastes and excess water as urine.

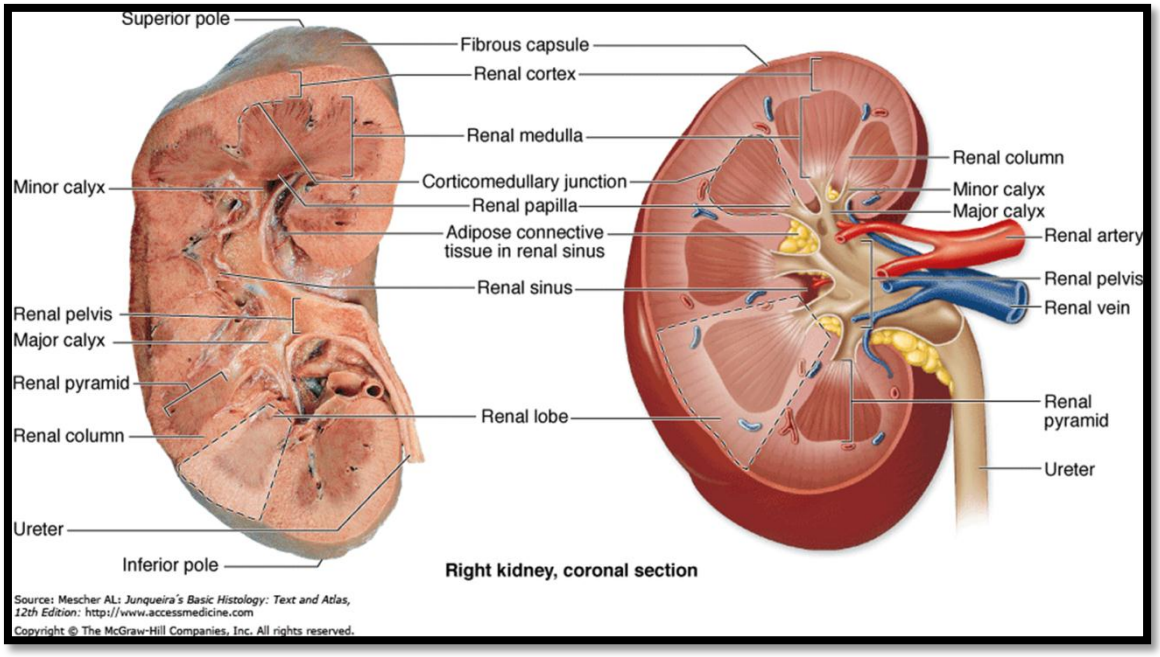
Urine produced in the kidneys passes through the ureters to the bladder for temporary storage and is then released to the exterior through the urethra. The two kidneys produce about 125 mL of filtrate per minute, of which 124 mL is reabsorbed in these organs and 1 mL is released into the ureters as urine. About 1500 mL of urine is formed every 24 hours. The kidneys also regulate the fluid and electrolyte balance of the body and are the site of production of **renin**, a protease that participates in the regulation of blood pressure by cleaving circulating angiotensinogen to angiotensin I. **Erythropoietin** , a glycoprotein that stimulates the production of erythrocytes, is also produced in the kidneys. The steroid prohormone vitamin D, initially produced in skin keratinocytes, is hydroxylated in kidneys to an active form (**1, 25-dihydroxyvitamin D3 or calcitriol**) involved in regulating calcium balance.

Kidneys

Each kidney has a concave medial border, the **hilum**—where nerves enter, the ureter exits, blood and lymph vessels enter and exit—and a convex lateral surface, both covered by a thin fibrous capsule . The expanded upper end of the ureter, called the **renal pelvis,** divides into two or three **major calyces.** Smaller branches, the **minor calyces,** arise from each major calyx. The area surrounding the calyces, called the **renal sinus**, usually contains considerable adipose tissue.

The kidney has an outer **cortex** and an inner **medulla**. In humans, the renal medulla consists of 8–15 conical structures called **renal pyramids**, which are separated by cortical

extensions called **renal columns**. Each medullary pyramid plus the cortical tissue at its base and along its sides constitutes a **renal lobe**.



Each kidney contains 1–1.4 million functional units called **nephrons** . The major divisions of each nephron are:

- **Renal corpuscle**, an initial dilated portion in the cortex
- **Proximal convoluted tubule**, located primarily in the cortex
- **Thin** and **thick limbs** of the **nephron loop** (loop of Henle), which descend into the medulla, then ascend back to the cortex
- **Distal convoluted tubule**
- **Collecting tubule**.

Collecting tubules from several nephrons converge into **collecting ducts** which carry urine to the calyces and the ureter. **Cortical nephrons** are located almost completely in the cortex while **juxtamedullary nephrons** close to the medulla have long loops in the medulla .

Renal Corpuscles & Blood Filtration

At the beginning of each nephron is a renal corpuscle, about 200 m in diameter and containing a loose knot of capillaries, the glomerulus, surrounded by a double-walled epithelial capsule called the glomerular (Bowman's) capsule. The internal layer (visceral layer) of the capsule closely envelops the glomerular capillaries . The external parietal layer forms the outer surface of the capsule.

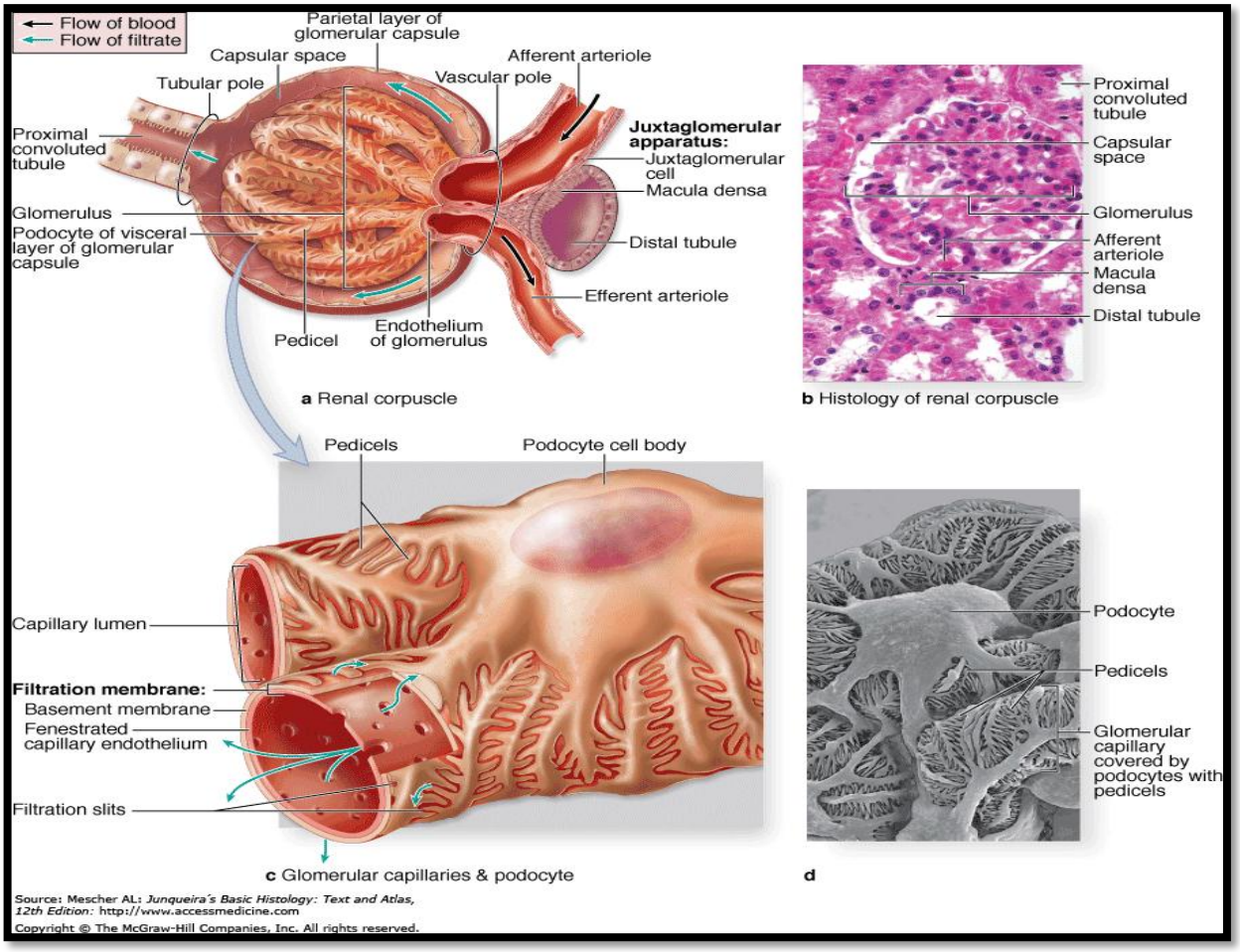
Between the two capsular layers is the urinary or capsular space, which receives the fluid filtered through the capillary wall and the visceral layer. Each renal corpuscle has a vascular pole, where the afferent arteriole enters and the efferent arteriole leaves, and a urinary or tubular pole, where the proximal convoluted tubule begins . After entering the renal corpuscle, the afferent arteriole usually divides and subdivides into the two to five capillaries of the renal glomerulus.

The parietal layer of a glomerular capsule consists of a simple squamous epithelium supported externally by a basal lamina and a thin layer of reticular fibers. At the tubular pole, this epithelium changes to the simple cuboidal epithelium characteristic of the proximal tubule . The cells of this layer, the **podocytes** , have a cell body from which arise several primary processes. Each primary process gives rise to numerous secondary (foot) processes or pedicels that embrace a portion of one glomerular capillary . The cell bodies of podocytes do not contact the basement membrane of the capillary, but each pedicel is in direct contact with this structure .

Glomerular filtration barrier :

The glomerular filtration barrier consists of three layered components : The fenestrated capillary endothelium , the glomerular basement membrane , and filtration slits between podocyte processes .

Between the highly fenestrated endothelial cells of the capillaries and the covering podocytes is the thick (~0.1 m) glomerular basement membrane . This membrane is the most substantial part of the filtration barrier separating the blood in the capillaries from the capsular space. The glomerular basement membrane (GBM) is a selective macromolecular barrier which acts as a physical filter and as a barrier against negatively charged molecules.



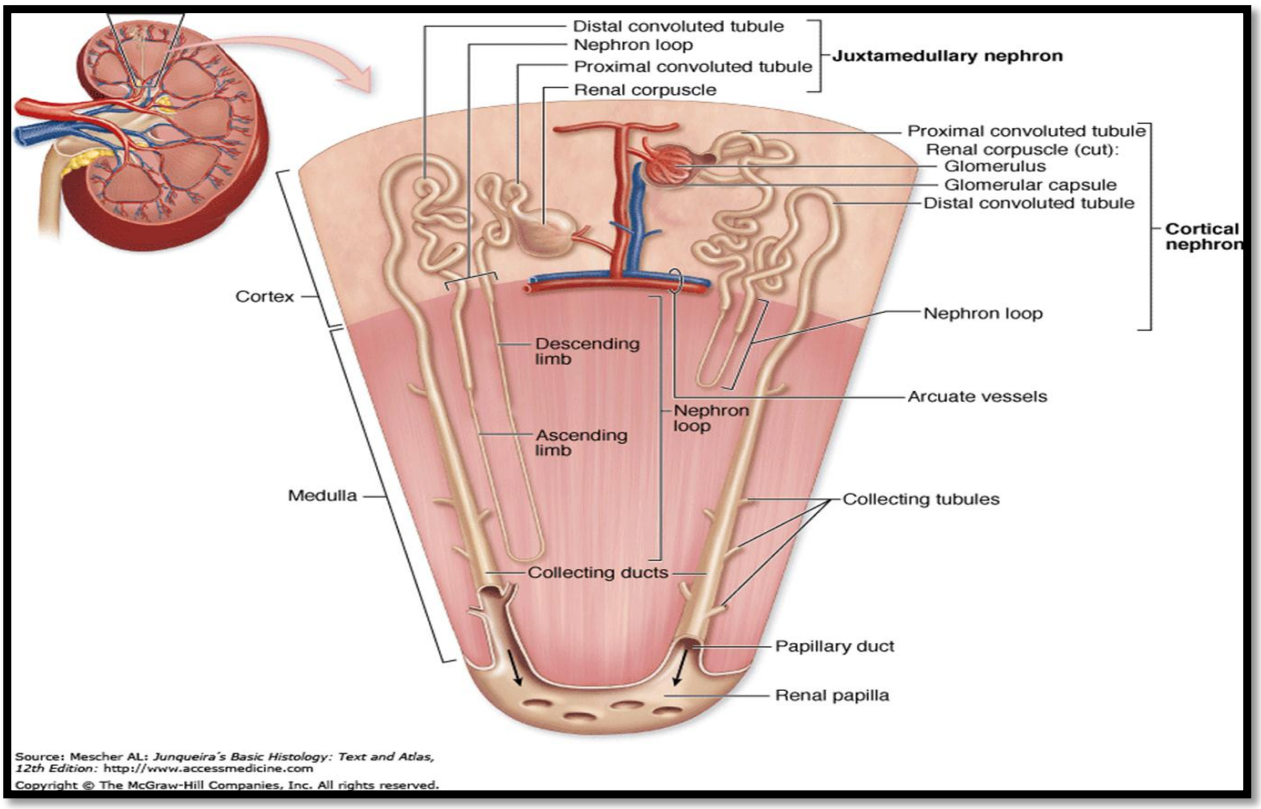
Proximal Convoluted Tubule

At the tubular pole of the renal corpuscle, the squamous epithelium of the capsule's parietal layer is continuous with the cuboidal epithelium of the proximal convoluted tubule . This very tortuous tubule is longer than the distal convoluted tubule . Cells of the proximal tubule reabsorb 60–65% of the water filtered in the renal corpuscle, along with almost all of the nutrients, ions, vitamins, and small plasma proteins. The water and its solutes are transferred directly across the tubular wall and immediately taken up by the peritubular capillaries.

The cell apex has abundant long microvilli which form a prominent brush border for reabsorption .

Nephron Loop (of Henle):

The proximal convoluted tubule continues as a much shorter proximal straight tubule which enters the medulla and becomes the nephron loop. This is a U-shaped structure with a descending limb and an ascending limb, both composed of simple epithelia, cuboidal near the cortex, but squamous deeper in the medulla . Cuboidal cells of loops thick ascending limbs actively transport sodium chloride out of the tubule against a concentration gradient . Squamous cells of the loops thin descending limbs are freely permeable to water to not salts ,While the thin ascending limbs are they permeable to NaCl but impermeable to water.



Distal Convoluted Tubule& Juxtaglomerular Apparatus

The thick ascending limb of the nephron loop is straight as it enters the cortex, and then becomes tortuous as the distal convoluted tubule . The simple cuboidal cells of these tubules differ from those of the proximal convoluted tubules in being smaller and having no brush border . 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.

The rate of Na^+ absorption and K^+ secretion by the sodium pumps is regulated by aldosterone from the adrenal glands and is important for the body's water-salt balance. The distal tubule also secretes H^+ and NH_4^+ into tubular urine, an activity essential for maintenance of the acid-base balance in the blood.

The initial, straight part of the distal tubule makes contact with the vascular pole of the renal corpuscle of its parent nephron and forms part of a specialized structure, the juxtaglomerular apparatus (JGA). Cells of this structure establish a feedback mechanism that allows autoregulation of renal blood flow and keeps the rate of glomerular filtration relatively constant.

Collecting Tubules & Ducts

Urine passes from the distal convoluted tubules to **collecting tubules**, the last part of each nephron, which join each other to form larger, straight **collecting ducts** that run to the tips of the medullary pyramids and empty into the minor calyces . The collecting tubules are lined with cuboidal epithelium .

Along their entire extent, collecting tubules and ducts are composed mainly of weakly staining **principal cells** with few organelles and scanty microvilli.

In the medulla, collecting ducts are a major component of the urine-concentrating mechanism. Cells of collecting ducts are particularly rich in **aquaporins**, integral proteins found in most cell membranes that function as selective pores for passage of water molecules.

Ureters, Bladder, & Urethra

Urine is transported by the **ureters** to the **bladder** where it is stored until emptied during micturition via the **urethra**. The calyces, renal pelvis, ureter, and bladder have the same basic histologic structure, with the walls becoming gradually thicker closer to the bladder. The mucosa of these organs is lined by unique stratified **transitional epithelium** or urothelium . This is surrounded by a folded lamina propria and submucosa, followed by a dense sheath of interwoven smooth muscle layers and adventitia . Urine moves from the renal pelvises to the bladder by peristaltic contractions.

The urothelium is composed of the following three layers:

- a single layer of small basal cells resting on a very thin basement membrane,

- an intermediate region containing from one to several layers of more columnar cells,

- a superficial layer of very large, polyhedral or bulbous cells called **umbrella cells** which are occasionally bi- or multinucleated and are highly differentiated to protect underlying cells against the cytotoxic effects of hypertonic urine.

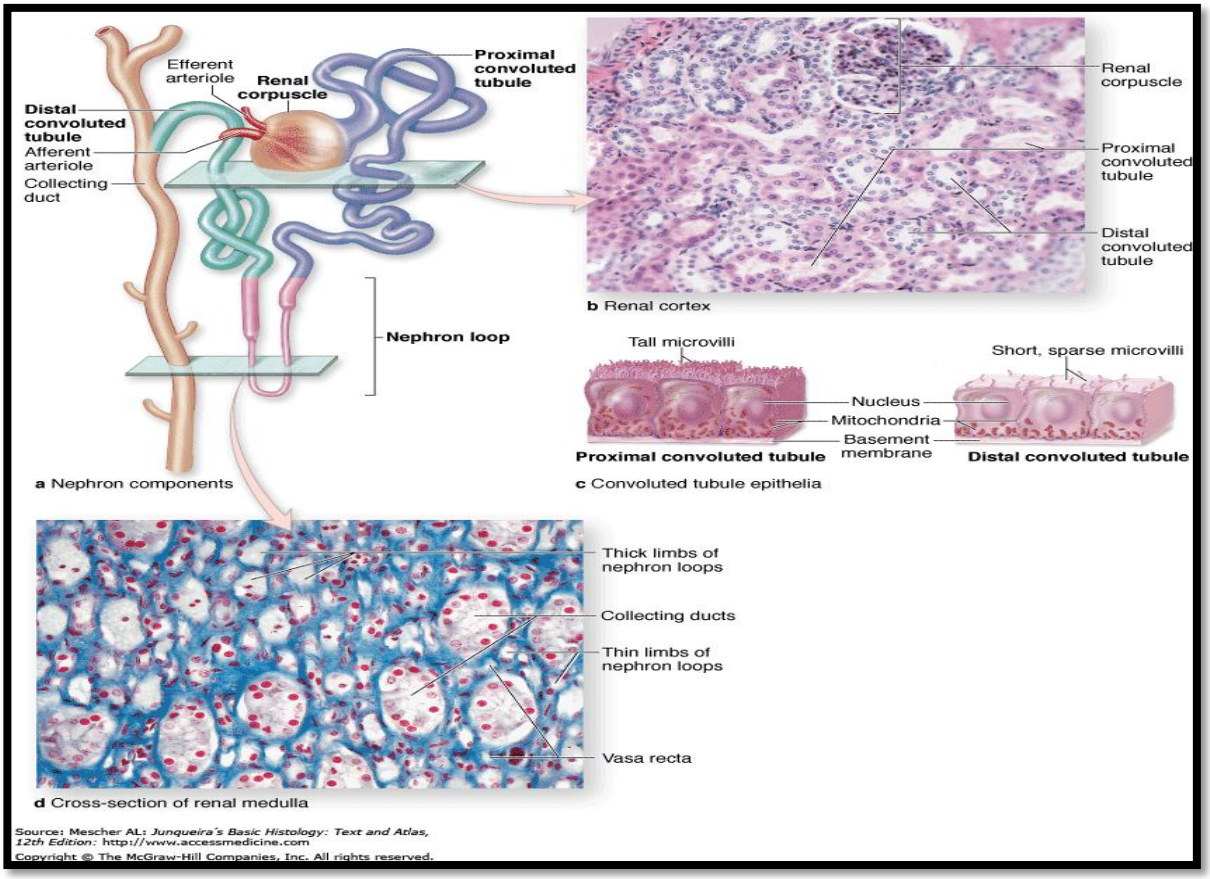
The bladder's lamina propria and dense irregular connective tissue of the submucosa are highly vascularized. The muscularis consists of three poorly delineated layers, collectively called the detrusor muscle, which contract to empty the bladder . Three muscular layers are seen most distinctly at the neck of the bladder near the urethra . The ureters pass through the wall of the bladder obliquely, forming a valve that prevents the backflow of urine into the ureters. All the urinary passages are covered externally by an adventitial layer, except for the upper part of the bladder which is covered by serous peritoneum.

The **urethra** is a tube that carries the urine from the bladder to the exterior. The urethral mucosa has large longitudinal folds, giving it a distinctive appearance in cross section. The male urethra consists of three segments:

- The **prostatic urethra**, 3–4 cm long, extends through the prostate gland and is lined by urothelium

- The **membranous urethra**, a short segment, is lined by stratified columnar and pseudostratified epithelium

- The **spongy urethra**, 15 cm in length, is lined by stratified columnar and pseudostratified columnar epithelium , with stratified squamous distally.


Efferent arteriole
Renal corpuscle
Proximal convoluted tubule
Distal convoluted tubule
Afferent arteriole
Collecting duct
Nephron loop
a Nephron components
Renal corpuscle
Proximal convoluted tubule
Distal convoluted tubule
b Renal cortex
Tall microvilli
Short, sparse microvilli
Nucleus
Mitochondria
Basement membrane
Proximal convoluted tubule
Distal convoluted tubule
c Convoluted tubule epithelia
Thick limbs of nephron loops
Collecting ducts
Thin limbs of nephron loops
Vasa recta
d Cross-section of renal medulla
Source: Mescher AL: Junqueira's Basic Histology: Text and Atlas, 12th Edition: http://www.accessmedicine.com
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