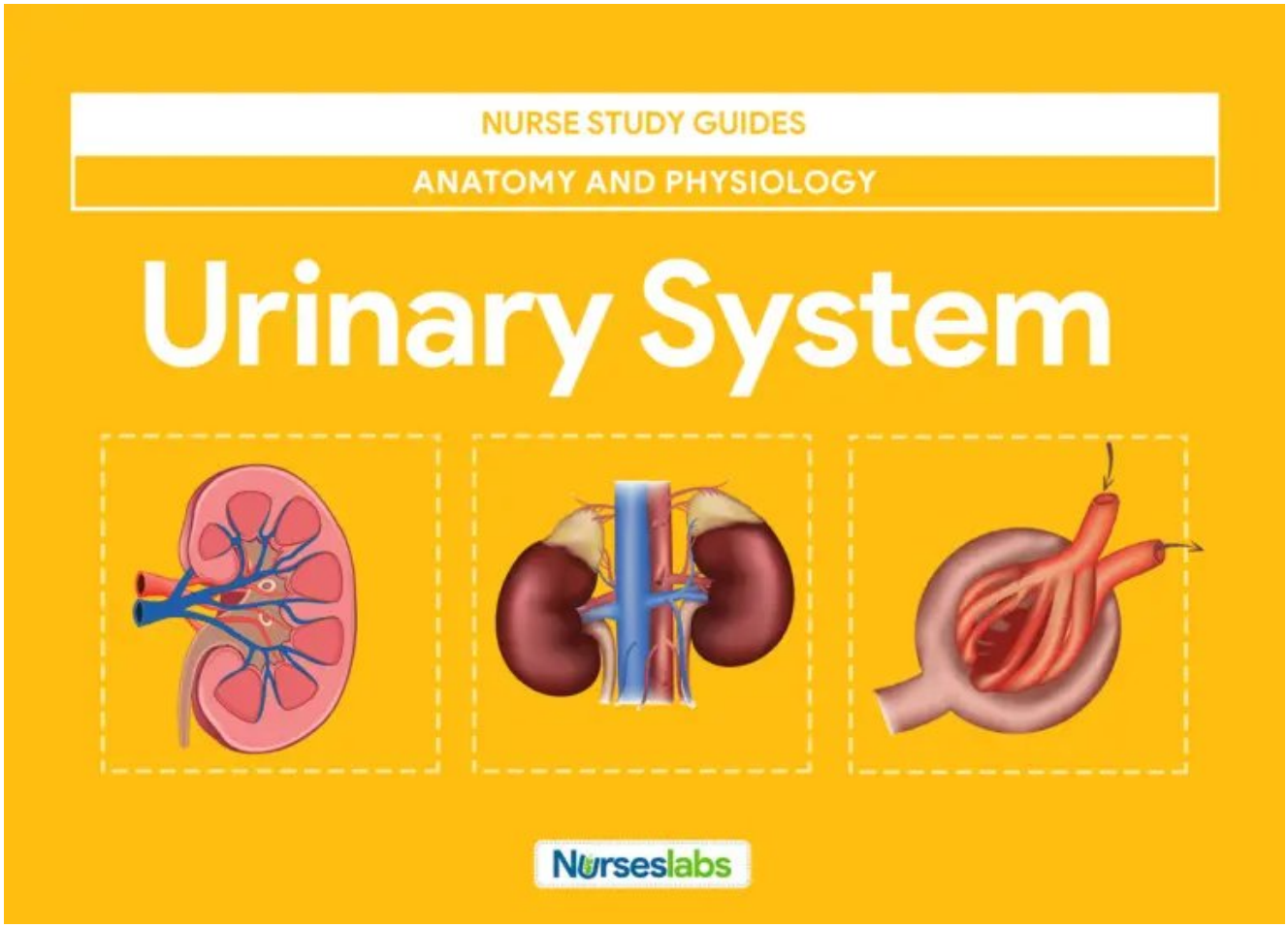
Urinary System Anatomy and Physiology

UPDATED ON FEBRUARY 11, 2021 BY MARIANNE BELLEZA, R.N.



Much like sanitation workers who keep a city's water supply drinkable and dispose of its waste, the kidneys are usually unappreciated until there is a malfunction and "internal garbage" piles up.

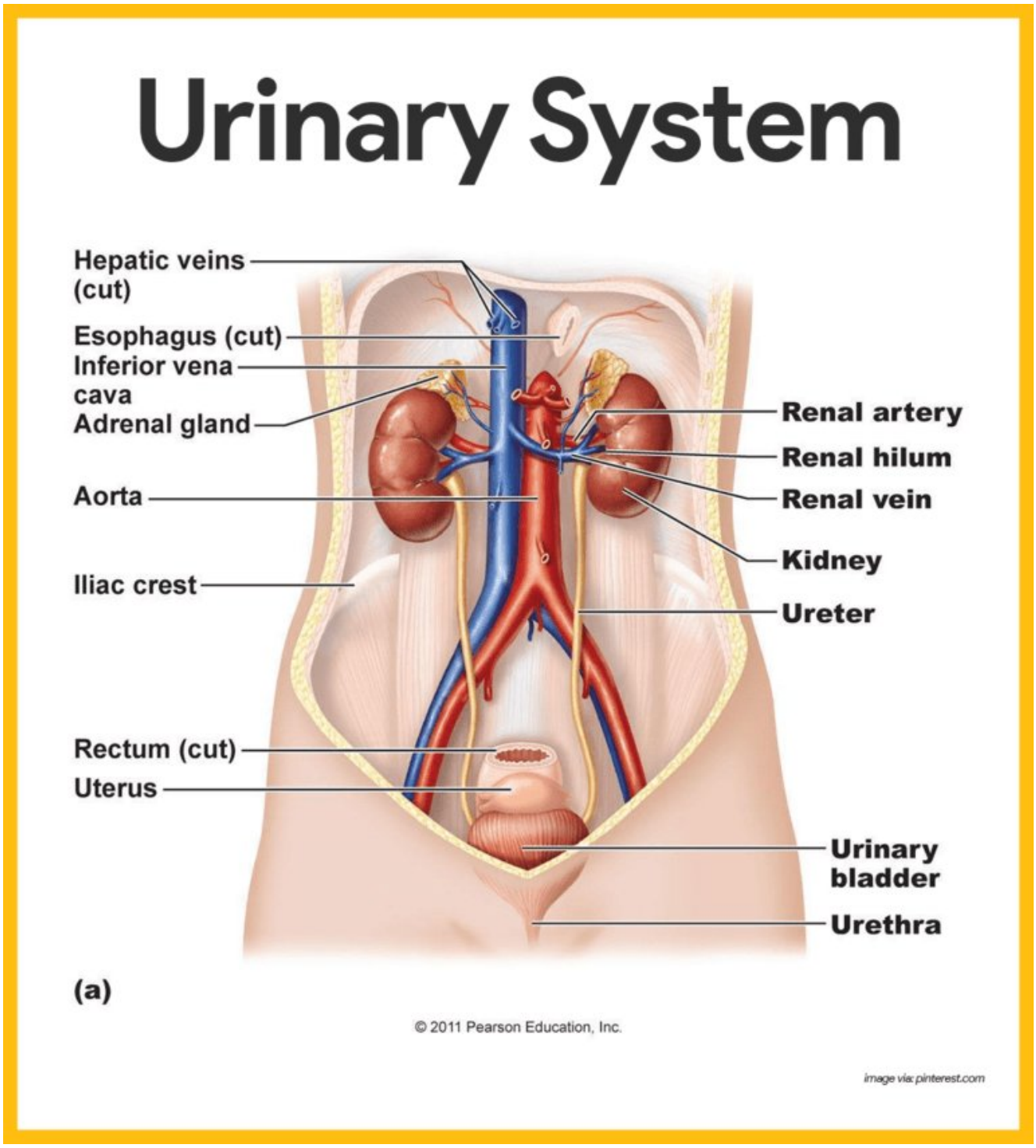
Functions of the Urinary System

The function of the kidneys are as follows:

1. **Filter.** Every day, the kidneys filter gallons of fluid from the bloodstream.
2. **Waste processing.** The kidneys then process this filtrate, allowing **wastes** and **excess ions** to leave the body in urine while returning needed substances to the blood in just the right proportions.
3. **Elimination.** Although the lungs and the skin also play roles in excretion, the kidneys bear the **major responsibility** for eliminating nitrogenous **wastes**, **toxins**, and **drugs** from the body.
4. **Regulation.** The kidneys also regulate the blood's volume and chemical makeup so that the proper balance between **water** and **salts** and between **acids** and **bases** is maintained.
5. **Other regulatory functions.** By producing the enzyme **renin**, they help regulate blood pressure, and their hormone **erythropoietin** stimulates red blood cell production in the bone marrow.
6. **Conversion.** Kidney cells also convert **vitamin D** to its active form.

Anatomy of the Urinary System

The urinary system consists of two kidneys, two ureters, a urinary bladder, and a urethra. The kidneys alone perform the functions just described and manufacture urine in the process, while the other organs of the urinary system provide temporary storage reservoirs for urine or serve as transportation channels to carry it from one body region to another.



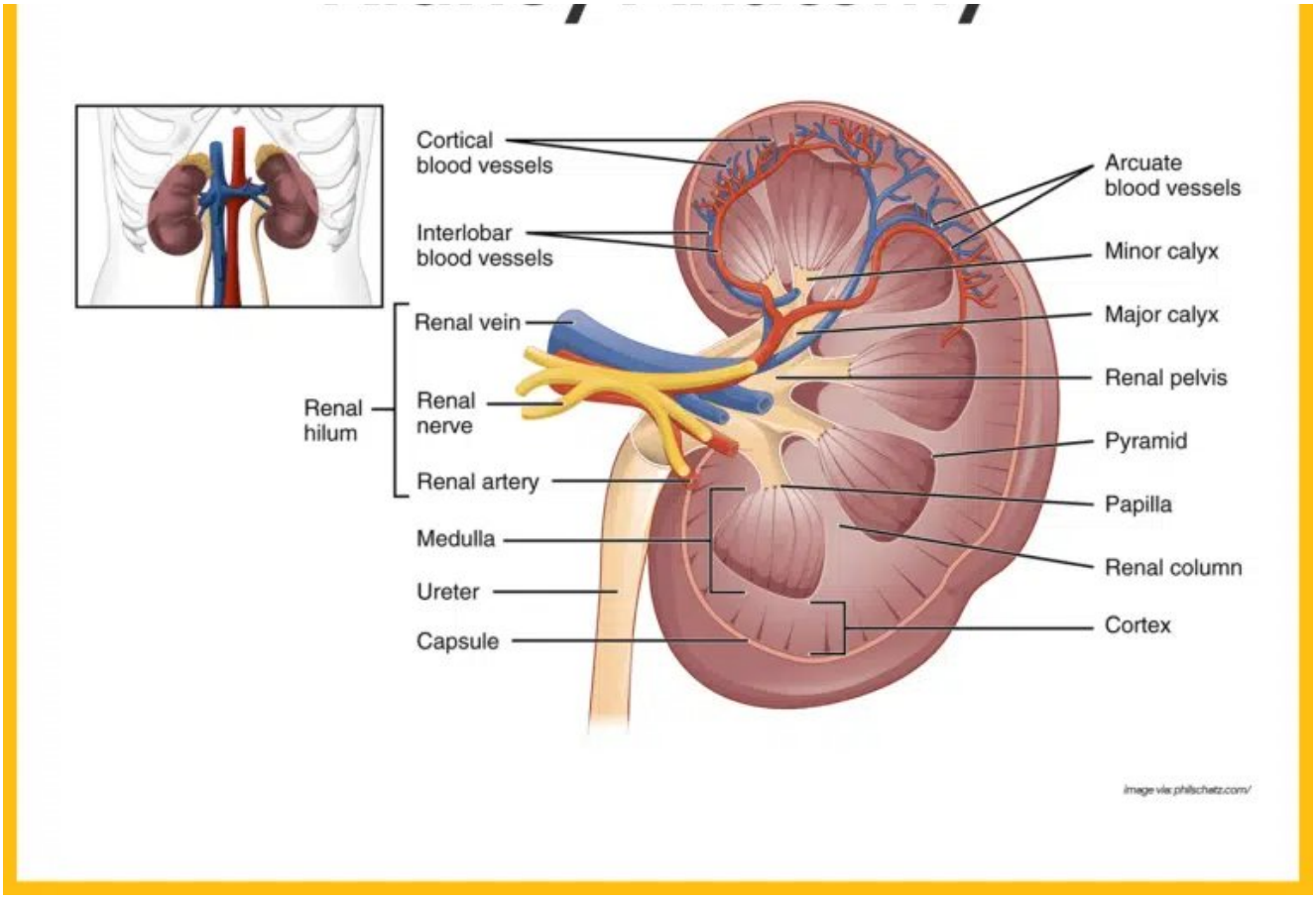
The Kidneys

The kidneys, which maintain the purity and constancy of our internal fluids, are perfect examples of homeostatic organs.

- **Location.** These small, dark red organs with a kidney-bean shape lie against the

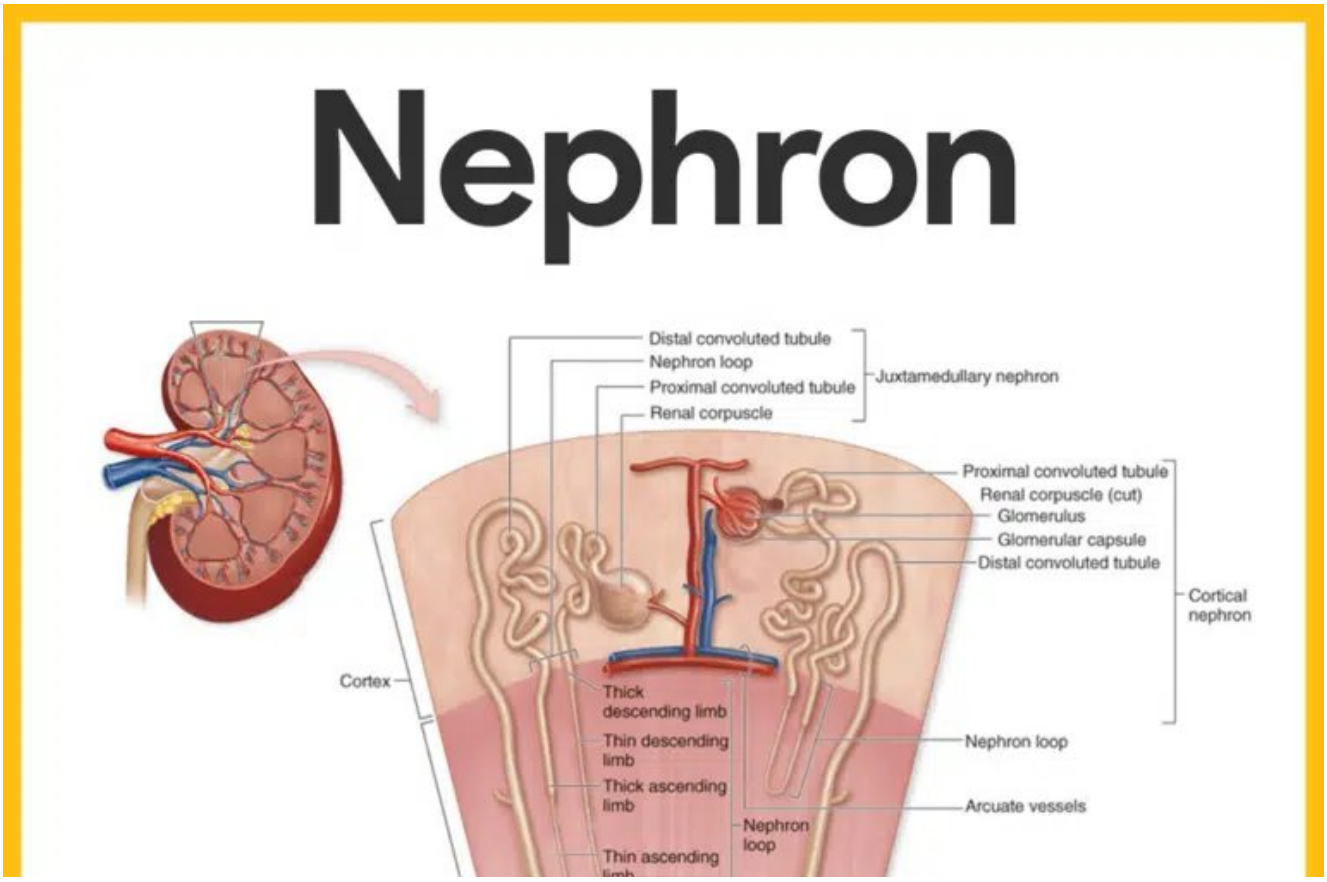
dorsal body wall in a retroperitoneal position (beneath the parietal peritoneum) in the **superior lumbar region**; they extend from the T12 to the L3 vertebra, thus they receive protection from the lower part of the rib cage.

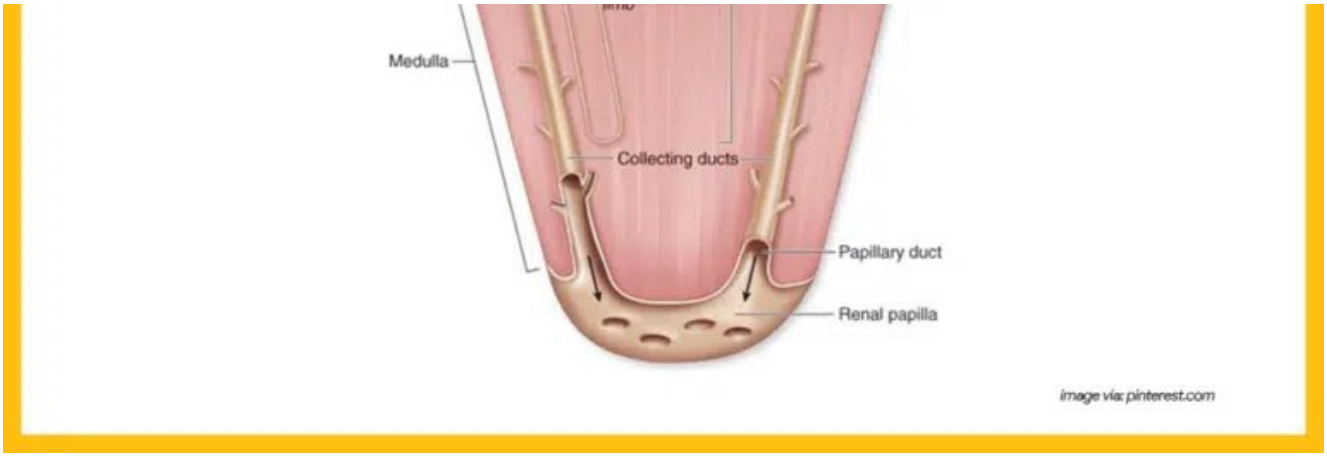
- **Positioning.** Because it is crowded by the liver, the **right kidney** is positioned slightly **lower** than the left.
- **Size.** An adult kidney is about **12 cm (5 inches) long**, **6 cm (2.5 inches) wide**, and **3 cm (1 inch) thick**, about the size of a large bar of soap.
- **Adrenal gland.** Atop each kidney is an adrenal gland, which is part of the endocrine system is a distinctly separate organ functionally.
- **Fibrous capsule.** A transparent fibrous capsule encloses each kidney and gives a fresh kidney a **glistening appearance**.
- **Perirenal fat capsule.** A fatty mass, the perirenal fat capsule, surrounds each kidney and acts to **cushion** it against blows.
- **Renal fascia.** The renal fascia, the **outermost** capsule, **anchors** the kidney and helps hold it in place against the muscles of the trunk wall.
- **Renal cortex.** The **outer region**, which is light in color, is the renal cortex.
- **Renal medulla.** Deep to the cortex is a darker, reddish-brown area, the renal medulla.
- **Renal pyramids.** The medulla has many basically triangular regions with a striped appearance, the renal, or medullary pyramids; the broader base of each pyramid faces toward the cortex while its tip, the apex, points toward the inner region of the kidney.
- **Renal columns.** The pyramids are separated by extensions of cortex-like tissue, the renal columns.
- **Renal pelvis.** Medial to the hilum is a flat, basinlike cavity, the renal pelvis, which is continuous with the ureter leaving the hilum.
- **Calyces.** Extensions of the pelvis, calyces, form cup-shaped areas that enclose the tips of the pyramid and collect urine, which continuously drains from the tips of the pyramids into the renal pelvis.
- **Renal artery.** The arterial supply of each kidney is the renal artery, which divides into **segmental arteries** as it approaches the hilum, and each segmental artery gives off several branches called **interlobar arteries**.
- **Arcuate arteries.** At the cortex-medulla junction, interlobar arteries give off arcuate arteries, which curve over the medullary pyramids.
- **Cortical radiate arteries.** Small cortical radiate arteries then branch off the arcuate arteries and run outward to supply the cortical tissue.



Nephrons

Nephrons are the structural and functional units of the kidneys.





- **Nephrons.** Each kidney contains over a million tiny structures called nephrons, and they are responsible for forming urine.
- **Glomerulus.** One of the main structures of a nephron, a glomerulus is a knot of capillaries.
- **Renal tubule.** Another one of the main structures in a nephron is the renal tubule.
- **Bowman's capsule.** The closed end of the renal tubule is enlarged and cup-shaped and completely surrounds the glomerulus, and it is called the **glomerular** or Bowman's capsule.
- **Podocytes.** The inner layer of the capsule is made up of highly modified **octopus-like** cells called podocytes.
- **Foot processes.** Podocytes have long branching processes called **foot processes** that intertwine with one another and cling to the glomerulus.
- **Collecting duct.** As the tubule extends from the glomerular capsule, it coils and twists before forming a hairpin loop and then again becomes coiled and twisted before entering a collecting tubule called the collecting duct, which receives urine from many nephrons.
- **Proximal convoluted tubule.** This is the part of the tubule that is **near** to the glomerular capsule.
- **Loop of Henle.** The loop of Henle is the **hairpin loop** following the proximal convoluted tubule.
- **Distal convoluted tubule.** After the loop of Henle, the tubule continues to coil and twist before the collecting duct, and this part is called the distal convoluted tubule.
- **Cortical nephrons.** Most nephrons are called cortical nephrons because they are located almost entirely within the cortex.
- **Juxtamedullary nephrons.** In a few cases, the nephrons are called juxtamedullary nephrons because they are situated next to the cortex-medullary junction, and their loops of Henle dip deep into the medulla.
- **Afferent arteriole.** The afferent arteriole, which arises from a cortical radiate

artery, is the **“feeder vessel”**.

- **Efferent arteriole.** The efferent arteriole receives blood that has passed through the glomerulus.
- **Peritubular capillaries.** They arise from the efferent arteriole that drains the glomerulus.

Ureters

The ureters do play an active role in urine transport.

- **Size.** The ureters are two slender tubes each **25 to 30 cm** (10 to 12 inches) long and **6 mm** (1/4 inch) in diameter.
- **Location.** Each ureter runs behind the peritoneum from the renal hilum to the posterior aspect of the bladder, which it enters at a slight angle.
- **Function.** Essentially, the ureters are passageways that carry urine from the kidneys to the bladder through contraction of the smooth muscle layers in their walls that propel urine into the bladder by peristalsis and is prevented from flowing back by small valve-like folds of bladder mucosa that flap over the ureter openings.

Urinary Bladder

The urinary bladder is a smooth, collapsible, muscular sac that stores urine temporarily.

- **Location.** It is located retroperitoneally in the pelvis just posterior to the symphysis pubis.
- **Function.** The detrusor muscles and the transitional epithelium both make the bladder uniquely suited for its function of urine storage.
- **Trigone.** The smooth triangular region of the bladder base outlined by these three openings is called the trigone, where infections tend to persist.
- **Detrusor muscles.** The bladder wall contains three layers of smooth muscle, collectively called the detrusor muscle, and its mucosa is a special type of epithelium, **transitional epithelium**.

Urethra

The urethra is a thin-walled tube that carries urine by peristalsis from the bladder to the outside of the body.

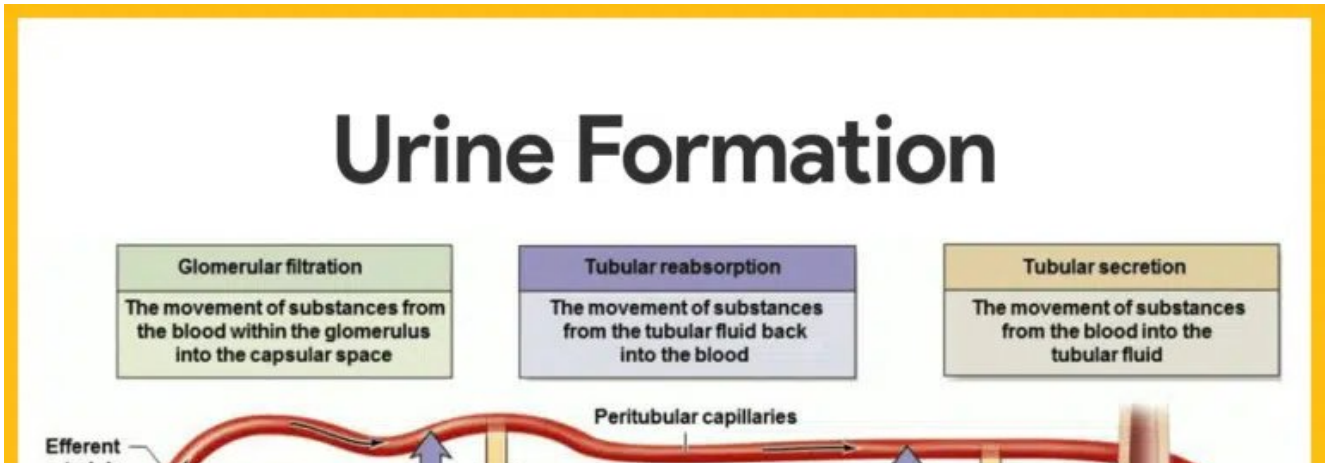
- **Internal urethral sphincter.** At the bladder-urethral junction, a thickening of the smooth muscle forms the internal urethral sphincter, an **involuntary** sphincter that keeps the urethra closed when the urine is not being passed.
- **External urethral sphincter.** A second sphincter, the external urethral sphincter, is fashioned by skeletal muscle as the urethra passes through the pelvic floor and is **voluntarily** controlled.
- **Female urethra.** The female urethra is about **3 to 4 cm** (1 1/2 inches) long, and its external orifice, or opening, lies anteriorly to the vaginal opening.
- **Male urethra.** In me, the urethra is approximately **20 cm** (8 inches) long and has three named regions: the **prostatic**, **membranous**, and **spongy (penile)** urethrae; it opens at the tip of the penis after traveling down its length.

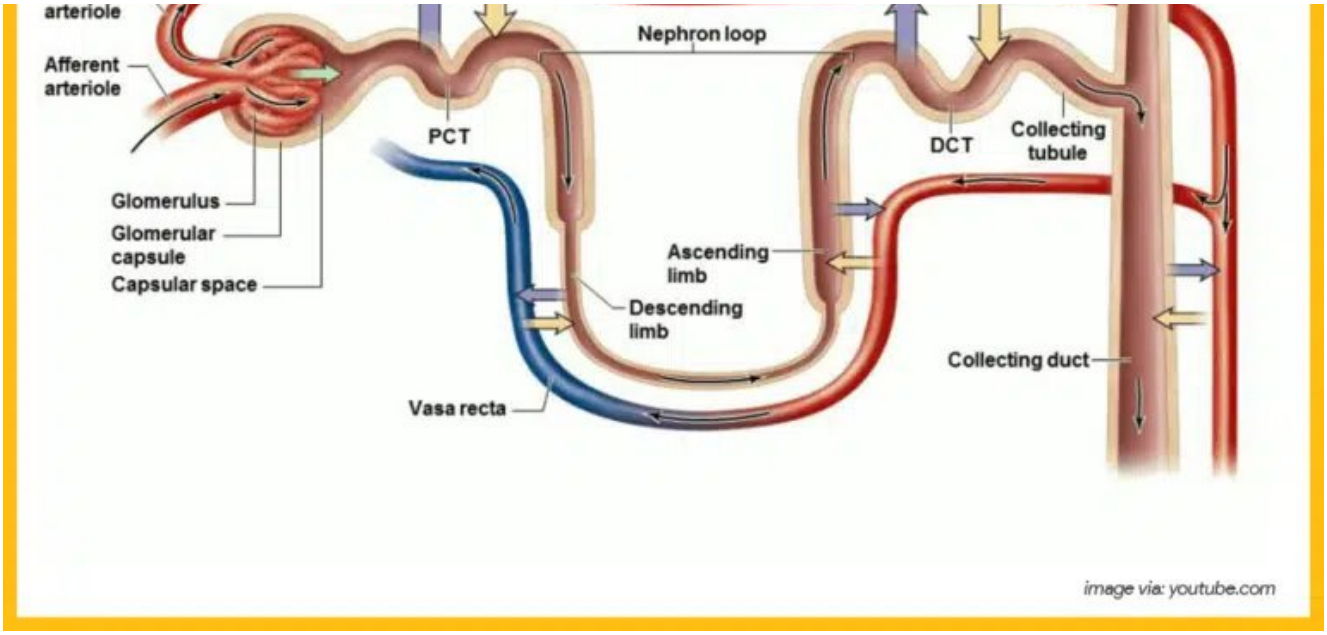
Physiology of the Urinary System

Every day, the kidneys filter gallons of fluid from the bloodstream. The normal physiology that takes place in the urinary system are as follows:

Urine Formation

Urine formation is a result of three processes:





- **Glomerular filtration.** Water and solutes smaller than proteins are forced through the capillary walls and pores of the glomerular capsule into the renal tubule.
- **Tubular reabsorption.** Water, glucose, amino acids, and needed ions are transported out of the filtrate into the tubule cells and then enter the capillary blood.
- **Tubular secretion.** Hydrogen, potassium, creatinine, and drugs are removed from the peritubular blood and secreted by the tubule cells into the filtrate.

Characteristics of Urine

In 24 hours, the marvelously complex kidneys filter some 150 to 180 liters of blood plasma through their glomeruli into the tubules.

- **Daily volume.** In 24 hours, only about **1.0 to 1.8 liters** of urine are produced.
- **Components.** Urine contains nitrogenous wastes and unneeded substances.
- **Color.** Freshly voided urine is generally **clear** and **pale to deep yellow**.
- **Odor.** When formed, urine is **sterile** and **slightly aromatic**, but if allowed to stand, it takes on an **ammonia odor** caused by the action of bacteria on the urine solutes.
- **pH.** Urine pH is usually slightly acidic (**around 6**), but changes in body metabolism and certain foods may cause it to be much more acidic or basic.
- **Specific gravity.** Whereas the specific gravity of pure water is 1.0, the specific gravity of urine usually ranges from **1.001 to 1.035**.

- **Solutes.** Solutes normally found in urine include sodium and potassium ions, urea, uric acid, creatinine, ammonia, bicarbonate ions, and various other ions.

Micturition

Micturition or voiding is the act of emptying the bladder.

- **Accumulation.** Ordinarily, the bladder continues to collect urine until about 200 ml have accumulated.
- **Activation.** At about this point, stretching of the bladder wall activates stretch receptors.
- **Transmission.** Impulses transmitted to the sacral region of the spinal cord and then back to the bladder via the pelvic splanchnic nerves cause the bladder to go into reflex contractions.
- **Passage.** As the contractions become stronger, stored urine is forced past the internal urethral sphincter into the upper part of the urethra.
- **External sphincter.** Because the lower external sphincter is skeletal muscle and voluntarily controlled, we can choose to keep it closed or it can be relaxed so that urine is flushed from the body.

Practice Quiz: Urinary System Anatomy and Physiology

Here's a 10-item quiz about the study guide. Please visit our **nursing test bank page** for more **NCLEX practice questions**.

1. The following are considered functions of the Urinary System EXCEPT: (Select all that apply).

A. Vitamin D synthesis
B. Regulation of red blood cell synthesis
C. Excretion
D. Absorption of digested molecules
E. Regulation of blood volume and pressure

1. Answer: D. Absorption of digested molecules

- **D:** This is a function of the Digestive System. The small molecules that result from digestion are absorbed through the walls of the intestine for use in the body.
- **A:** This is a function of the Urinary System. The kidneys play an important role in controlling blood levels of Ca^{2+} by regulating the synthesis of vitamin D.
- **B:** This is a function of the Urinary System. The kidneys secrete a hormone, erythropoietin, which regulates the synthesis of red blood cells in bone marrow.
- **C:** This is a function of the Urinary System. The kidneys are the major excretory organs of the body. They remove waste products, many of which are toxic, from the blood.
- **E:** This is a function of the Urinary System. The kidneys play a major role in controlling the extracellular fluid volume in the body by producing either a large volume of dilute urine or a small volume of concentrated urine.

2. What organs compose the Urinary System?

A. Two kidneys, two urethrae, a ureter, and a urinary bladder
B. Two kidneys, a ureter, a urinary bladder, and a urethra
C. Two kidneys, two ureters, a urinary bladder, and a urethra
D. Two kidneys, two ureters, two urethrae, and a urinary bladder

2. Answer: C. Two kidneys, two ureters, a urinary bladder, and a urethra

- **C:** The urinary system consists of two kidneys, two ureters, a urinary bladder, and a urethra. The kidneys are bean-shaped organs which help the body produce urine to get rid of unwanted waste substances. When urine is formed, tubes called ureters transport it to the urinary bladder, where it is stored and excreted via the urethra. The kidneys are also important in controlling our blood pressure and producing red blood cells.

3. The connective tissue that surrounds the kidneys is the:

A. Hilum
B. Renal capsule
C. Calyx
D. Renal pyramid

3. Answer: B. renal capsule

- **B:** A connective tissue ***renal capsule*** surrounds each kidney.
- **A:** On the medial side of the kidney is the ***hilum***, where the renal artery and nerves enter and where the renal vein and ureter exit the kidney.
- **C:** A funnel-shaped ***calyx*** surrounds the tip of each renal pyramid.
- **D: *Renal pyramid***, any of the triangular sections of tissue that constitute the medulla, or inner substance, of the kidney.

4. It is the hormone made by the kidneys, needed for absorption of calcium phosphate, the active form of vitamin D.

A. Erythropoietin
B. Calcitriol
C. Creatinine
D. Calcium

4. Answer: B. Calcitriol

- **B: *Calcitriol***, also called 1,25-dihydroxycholecalciferol or 1,25-dihydroxyvitamin D3, is the hormonally active metabolite of vitamin D with three hydroxyl groups. Calcitriol increases the level of calcium (Ca^{2+}) in the blood by increasing the uptake of calcium from the gut into the blood, increasing reabsorption of calcium by the kidneys, and possibly increasing the release of calcium into the blood from bone.
- **A: *Erythropoietin***, also known as EPO, hematopoietin, or hemopoietin, is a glycoprotein hormone that controls erythropoiesis, or red blood cell production. It is produced by interstitial fibroblasts in the kidney in close association with peritubular capillary and proximal convoluted tubule.
- **C: *Creatinine*** is a chemical waste product in the blood that passes through the kidneys to be filtered and eliminated in urine
- **D:** Healthy kidneys turn vitamin D into an active hormone (calcitriol), which helps increase ***calcium*** absorption from the intestines into the blood.

5. The functional units of the kidneys are:

A. Renal papilla
B. Nephrons
C. Minor calyx
D. Major calyx

5. Answer: B. Nephrons

- **B: *Nephron*** (meaning "kidney") is the basic structural and functional unit of the kidney. Its chief function is to regulate the concentration of water and soluble substances like sodium salts by filtering the blood, reabsorbing what is needed and excreting the rest as urine.
- **A:** The ***renal papilla*** is the location where the renal pyramids in the medulla empty urine into the minor calyx in the kidney. Histologically it is marked by medullary collecting ducts converging to form a papillary duct to channel the fluid.
- **C: *Minor calyx*** is a cup-shaped cavity at the base of the renal papilla, which drains urine from the renal papillae into the major calyx.
- **D: *Major calyx*** is the cavity formed by the convergence of several minor calyces, which drain urine from the minor calyxes into the renal pelvis then through the ureter.

6. Which of the following statements is/are TRUE? Select all that apply.

A. Filtration is the movement of materials across the wall of the nephron into Bowman's capsule to form a filtrate.
B. In reabsorption, the solutes are reabsorbed across the filtration membrane into the interstitial fluid by transport processes, such as active transport and cotransport.
C. In secretion, solutes are secreted across the wall of the nephron into the filtrate.
D. All statements need further evaluation.

6. Answer: C. In secretion, solutes are secreted across the wall of the nephron into the filtrate.

- **C:** In ***secretion***, solutes are secreted across the wall of the nephron into the filtrate.
- **A: *Filtration*** is the movement of materials across the filtration membrane into Bowman's capsule to form a filtrate.
- **B:** In ***reabsorption***, the solutes are reabsorbed across the wall of the nephron into the interstitial fluid by transport processes, such as active transport and cotransport.

7. The ascending limb of the loop of Henle functions to:

A. dilute the filtrate by removing solutes.
B. remove water and additional solutes.

C. help regulate aldosterone secretion.
D. increase the rate of active transport of Na^+ in the distal tubules and collecting ducts.

7. Answer: A. dilute the filtrate by removing solutes.

- **A:** The ascending limb of the loop of Henle functions to dilute the filtrate by removing solutes. The thin segment of the ascending limb is not permeable to water, but it is permeable to solutes.
- **B:** The cuboidal cells of the distal tubule and collecting duct function to remove water and additional solutes.
- **C:** Renin and angiotensin help regulate aldosterone secretion. Renin is secreted by cells of the juxtaglomerular apparati in the kidneys. It is an enzyme that acts on a protein produced by the liver called angiotensinogen.
- **D:** Aldosterone increases the rate of active transport of Na^+ in the distal tubules and collecting ducts. In the absence of aldosterone, large amounts of Na^+ remain in the nephron and become part of the urine.

8. Approximately _____ L of filtrate enters the nephrons each day; of that volume _____% is reabsorbed in the proximal tubule.

A. 80 L and 35%
B. 180 L and 65%
C. 240 L and 85%
D. 280 L and 99%

8. Answer: B. 180 L and 65%

- **B:** Approximately 180 L of filtrate enters the nephrons each day; of that volume, 65% is reabsorbed in the proximal tubule. In the proximal tubule, solute molecules move by active transport and cotransport from the lumen of the tubule into the interstitial fluid. Water moves by osmosis because the cells of the tubule wall are permeable to water.

9. Antidiuretic hormone (ADH), secreted by the posterior pituitary gland, passes through the circulatory system to the kidneys. ADH regulates the amount of water reabsorbed by the distal tubules and collecting ducts. When ADH levels increase, the permeability of the distal tubules and collecting ducts to water decreases, and less water is reabsorbed from the filtrate. This statement is:

A. True

B. False
C. Partially true
D. partially false

9. Answer: B. False

- **B:** When ADH levels increase, the permeability of the distal tubules and collecting ducts to water increases, and more water is reabsorbed from the filtrate. An increase in ADH results in the production of a small volume of concentrated urine. On the other hand, when ADH levels decrease, the distal tubules and collecting ducts become less permeable to water. As a result, less water is reabsorbed, and a large volume of dilute urine is produced.

10. (1) Renin is an enzyme that acts on a protein produced by the liver called (2) angiotensinogen. Amino acids are removed from, leaving (3) angiotensin I. Angiotensin I is rapidly converted to a smaller peptide called (4) angiotensin II by (5) angiotensin-converting enzyme (ACE). Angiotensin II acts on the (6) adrenal cortex, causing it to secrete aldosterone. (Correct this statement)

A. The statement is correct
B. (1) should be angiotensinogen, and (2) is renin
C. (3) should be angiotensin II, and (4) is angiotensin I
D. (6) should be adrenal medulla

10. Answer: A. The statement is correct

- **A:** Renin is an enzyme that acts on a protein produced by the liver called angiotensinogen. Amino acids are removed from, leaving angiotensin I. Angiotensin I is rapidly converted to a smaller peptide called angiotensin II by angiotensin-converting enzyme (ACE). Angiotensin II acts on the adrenal cortex, causing it to secrete aldosterone.

[sc name="Anatomy and Physiology"]

Anatomy & Physiology

Afferent Arterioles, Antidiuretic Hormone (ADH), Arcuate Arteries, Bowman's Capsule, Calyx, Capsular Pressure, Collecting Duct, Colloid Osmotic Pressure, Cortex, Cortical Nephrons, Diabetes Insipidus, Distal Tubule, Efferent Arterioles, erythropoietin, Excretion, Filtrate, Filtration Membrane, Filtration Pressure, Glomerular Capillary Pressure, Glomerulus, Hilum, Interlobar Arteries, Juxtamedullary Nephrons, Kidneys, Loop of Henle, Medulla, Nephron, Papillary Duct, Peritubular Capillaries, Podocytes, Proximal Tubule, Reabsorption, Renal Arteries, Renal Capsule, Renal Corpuscle, Renal Pelvis, Renal Pyramids, Renal Sinus, Secretion, Tubular Reabsorption, Tubular Secretion, Ureters, Urethra, Urinary Bladder, Urinary System

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Marianne Belleza, R.N.

Marianne is a staff nurse during the day and a Nurseslabs writer at night. She is a registered nurse since 2015 and is currently working in a regional tertiary hospital and is finishing her Master's in Nursing this June. As an outpatient department nurse, she is a seasoned nurse in providing health teachings to her patients making her also an excellent study guide writer for student nurses. Marianne is also a mom of a toddler going through the terrible twos and her free time is spent on reading books!