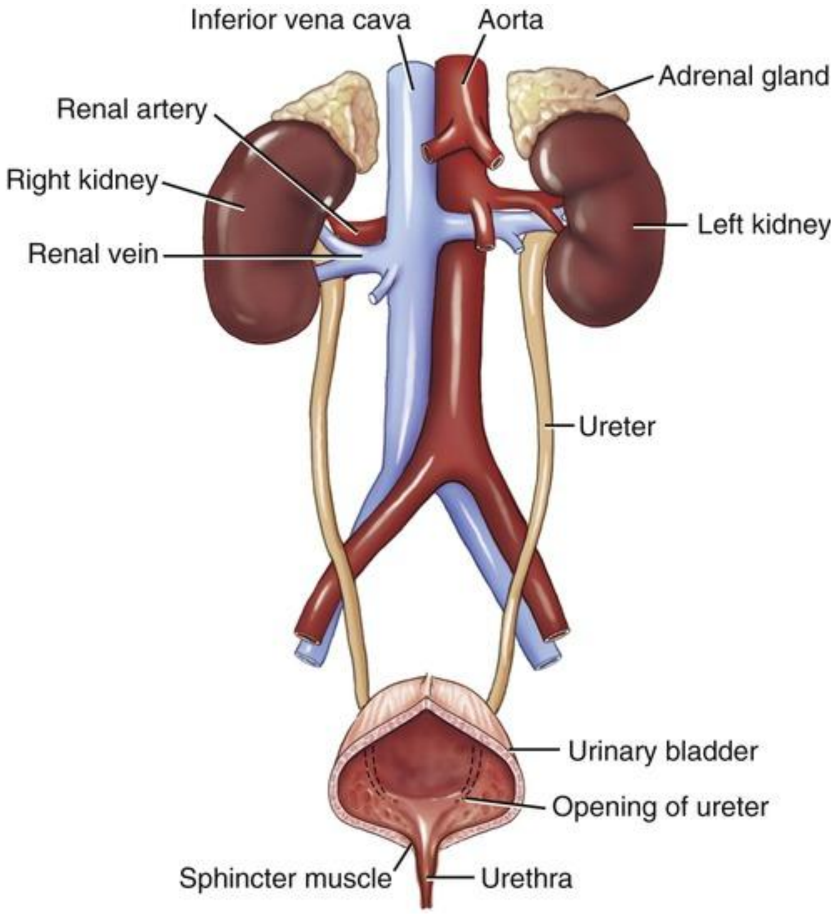
Anatomy Lecture Notes Section 6: The Renal (Urinary) System

The **urinary system** is also called the **renal system**, and, as seen in the image below, it consists of the following structures:

There are two (2) **kidneys**, both of which constantly filter, cleanse and regulate the blood and body fluids. Each kidney has a **ureter** which is a tube that leaves the kidneys and carries the urine produced by the kidneys to the urinary **bladder**, where it is stored. The **urethra** is a tube that transports the urine from the bladder for **excretion** to the external environment, or voiding of urine, a process termed **micturition**.



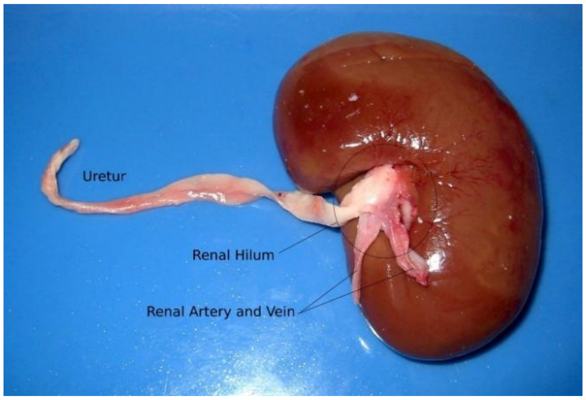
Although urine is a waste byproduct from cleansing the blood, in a healthy person it is **non-toxic** and **aseptic**, meaning it is not contaminated with harmful organisms or substances. It typically contains **95% water**, **2.5% urea** and **2.5%** of other **mineral** salt mixtures and enzymes, and possibly trace amounts of other wastes depending on the diet and activity of the person.

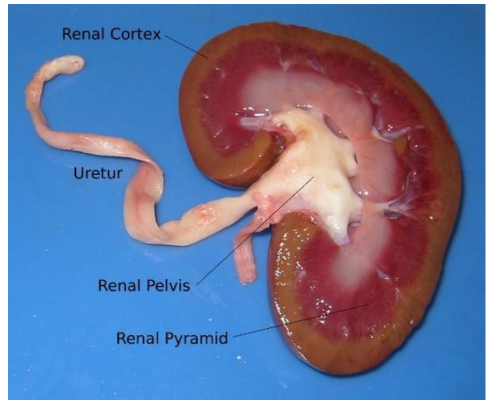
The Kidneys

The **kidneys** are considered the major **excretory organs** of the body and are part of the **urinary system**. In the simplest terms, the primary function of the kidneys is to continuously filter and cleanse the blood of waste and maintain the homeostasis of blood and all body fluids.

Location in the Body

The location of the kidneys is termed **retroperitoneal**, which means they are behind the peritoneal cavity. They are sealed onto the posterior wall of the abdominal cavity by an adipose capsule. This is vital for keeping the kidneys in the correct anatomical alignment, so that urine may flow un-obstructed through the ureters to the bladder. As part of the urinary system, the bladder temporarily stores this waste product, called **urine**, and eliminates it from the body by voiding it. In its role of regulating the blood, the kidneys also have many other very important functions. It is worth noting that there are several other organs that are involved in excreting wastes from the body, including the livers, lungs, and the skin.





Basic Functions of the Urinary System

1. Regulation of Blood and Extracellular Fluid Volume

The total blood volume for a typical male is 5.0 L of blood. The kidneys are central to the regulation and maintenance of blood total volume, therefore this is also related to Mean Arterial Pressure (MAP) of the body. If blood volume is too high, then more filtrate is created, and therefore more urine is excreted; if body fluids are too low, then fluid is conserved by the body, filtration at the kidneys is decreased, and the excretion of urine (and thus water) is decreased in volume.

2. Regulation of Osmolarity

Think of the osmolarity of blood plasma as the '*saltiness*" of it. Its osmolarity is controlled by changing the amount of water that is excreted in the urine. Normally plasma osmolarity sits in a range of **295 to 310 mOsM**. If excessive water intake caused a decrease in plasma osmolarity below about 280 mOsM, the kidneys remove the excess water by producing more dilute urine (it looks more pale). If plasma osmolarity goes up beyond 320 mOsM (that is, becomes very salty), the kidneys conserve water by producing more concentrated urine (looks darker!), in order to maintain the normal homeostatic range for plasma.

3. Maintenance of Ion Balance in Blood

Having the appropriate levels of **essential ions** and **minerals** in the body is crucial for optimum health. Ions are charged particles in solution, and they have a significant impact on every system in the body, especially the excitable tissues in the body that send electrical signals, such as the nervous, cardiac and skeletal muscle systems. These are the most abundant and necessary ions: Na^+, K^+, Cl^-, Ca^{2+}, H^+, Mg^{2+}, PO_4, but the list is very long, as trace minerals are also essential for good health.

4. Homeostatic Regulation of pH in Body Fluids

The selective secretion of H^+ (hydrogen ions) is an effective way to regulate any acidic conditions, and the secretion of HCO_3^- (bicarbonate ions) is very effective for regulation of any basic or alkaline conditions that may occur. The secretion of these ions for the control of the pH of body fluids most significantly occurs in the *distal convoluted tubule* of the nephron, this is how the kidney contributes to the maintenance a stable pH of blood and other body fluids.

5. Filters Wastes and Metabolic Products from Blood and Excretes them from the Body

The urinary system removes normal metabolic waste products that are always being generated by natural processes in the body and would accumulate to dangerous levels if not continuously removed. Substances like ***urea*** (a product of protein breakdown or catabolism), ***uric acid*** (a product of nucleic acid catabolism) are constantly excreted in the urine. Interestingly, when amino acids are broken down by a process called 'de-animation' it generates ammonia as a byproduct – which is toxic. It is the liver that converts ammonia to the less toxic urea, and the kidneys that then excrete urea in the urine. Finally, ***creatinine*** (a waste product from muscle breakdown of a creatine) ais also continuously excreted in urine.

6. Excretion of Foreign Substances from the Blood

Normal metabolic waste products (such as the substances listed above) are not the only type of toxins that can build up in blood; there can also be many unnatural and harmful substances that need have come to be in the body that need to be removed from the body via the kidneys. The elimination of drugs or 'medications' in the urine is an example.

Other harmful chemicals such as pesticides, preservatives, artificial flavors, artificial colors, and genetically modified food substances would all be seen by the body as '**foreign' or novel** substances and can cause harm to the body. Therefore, the kidney and the liver act as very effective detoxifiers (liver) and eliminators (kidney) of these harmful substances from the body in order to protect us. These substances can often generate an allergic response from the body, something that would be very beneficial to avoid. The kidneys are also responsible for the removal of unwanted microbes from the body.

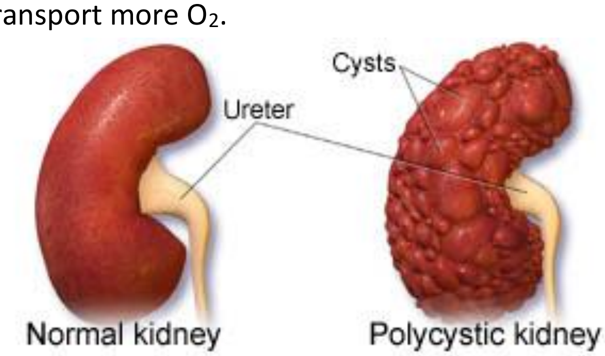
7. Production of Hormones

The kidneys function as a ***secondary endocrine organ***. The primary role of the kidneys is to filter blood; however, they also produce two very powerful hormones which are released into the bloodstream and have a significant impact on many other structures in the body. The 2 hormones are:

1) ***Renin*** – this is actually an enzyme and a hormone. It is released from the **juxtaglomerular cells** in the afferent arteriole of the renal corpuscle in response to increased blood osmolarity – this condition indicates there is not enough water in the blood. The release of renin into the blood stream triggers a series of reactions in the body and the overall response of multiple systems is to ***conserve water***, especially the retention water and salts by the kidneys.

2) ***Erythropoietin*** – this word tells the function of the molecule; erythro = red, as in red blood cells (RBCs); and poietin = potentiate, generator, as in maker. This hormone, which is also released from the **juxtaglomerular cells** of the nephron, is triggered when oxygen (O_2) levels in the blood are low. It stimulates the hemocytoblasts (stem cells in red bone marrow) to increase red blood cell formation. Having more RBCs allows the blood to transport more O_2.

Your kidneys are very important, take care of them forever. If you ingest too many toxins your kidneys and your liver have to work much harder than they already do in order to protect the rest of your body.

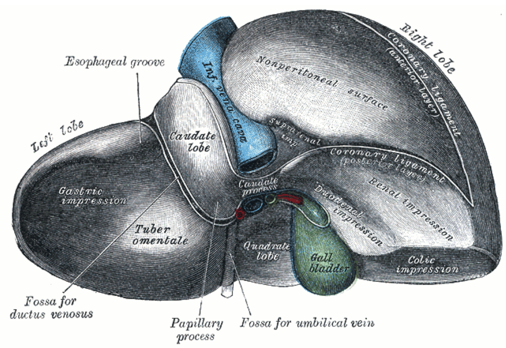


The Anatomy of the Kidneys

The kidneys are located in the **retroperitoneal** cavity, that is, they are located behind the parietal peritoneum and are tethered to the posterior abdominal wall from about T_{11} to L_3. So, although they are in the abdominal cavity, they are not in the peritoneal cavity.

The kidneys are small organs, each one being about 5 inches in length, about 2-3 inches wide and 1½ inches thick. They each weigh from 140 to 160 grams, which is about 1/3 of a pound. Despite their small size they receive from 20 to 25% of the total cardiac output, which is very large. This makes sense when we understand that the kidneys constantly filter and cleanse the blood.

The right kidney is slightly lower than the left kidney because another very important organ of cleansing and detoxification, the liver, occupies much of that upper right quadrant and tends to push the right kidney down somewhat. That's OK because we adore the liver. By the way, drink beet juice if you want to help your two favorite and most hard-working internal organs, your liver and your kidneys.



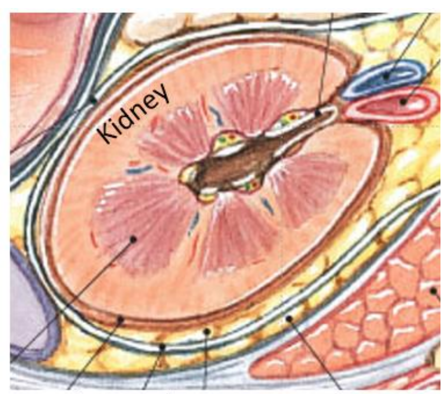
External Gross Anatomy

Each kidney is surrounded by 3 distinct capsules or layers which act to bind, support, protect and hold the kidneys in place. These are 3 capsules/ coverings help to hold the kidney in is **retroperitoneal** location, and also protect and insulate these organs. From deepest (innermost) to superficial (outermost) they are:

1. **The Renal Capsule** - This is a thin, tough coat of dense irregular and reticular connective tissue that encloses the kidney and lies directly on the kidney's surface. It maintains the kidney's shape and protects from trauma and infections.

2. **The Adipose Capsule** – the Fat capsule. External to the renal capsule is the adipose capsule. This cushions, and holds the kidneys in place to keep them from slumping. Also insulates the kidney.

3. **Renal Fascia -** External to the adipose capsule is the renal fascia. This is dense irregular connective tissue deep to the parietal peritoneum. Binds the kidneys to the posterior abdominal wall and the peritoneum.

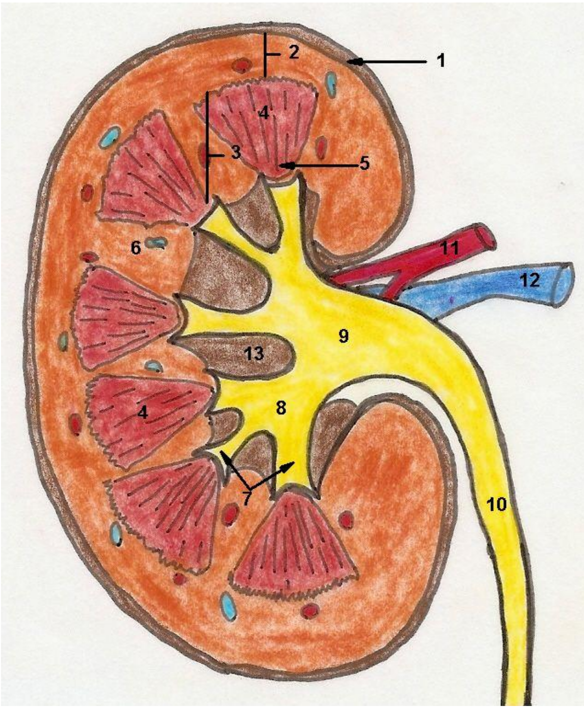


Renal capsule Renal fascia Fat capsule

Note: The **para-renal fat** is located externally and posterior to the renal fascia is the pararenal fat made of adipose tissues and functions as additional padding for protection against the outside wall.

Regions of the Kidney

When the kidney is cut in a frontal cut you can immediately see two major layers, the renal cortex and the renal medulla (see figure below). Superscript number indicates the structure in the figure.



Renal Capsule[1] - This dark brown fibro-connective tissue is the outermost surface of the kidney and represents the outer protective portion of this organ. It binds and encapsulates the kidney and is only breached at the renal hilus, where the renal artery and vein, ureter and nerves enter and exit each kidney.

Renal Cortex[2] - This is the layer immediately under the renal capsule. It is the outer region and is lighter in color. It contains renal corpuscles and extends inwards as renal columns.

Renal Medulla[3] - The medulla is below the cortex and is divided into pyramid-shaped structures called renal pyramids. The apex or point of the pyramid points internally.

Renal Pyramids[4] - The renal pyramids are made up of hundreds of collecting ducts that are all arranged in parallel and are heading toward the renal papilla and minor calyx. The renal pyramids are located in the renal medulla.

Renal Papillae[5] – These are actually the tips of the renal pyramid, deep in the renal medulla. The renal papillae are the structures that are immediately proximal to the minor calyx and represent the transitional point where filtrate becomes urine as it moves from the renal papilla to the minor calyx.

Renal Columns[6] - The renal columns are situated in between each of the renal pyramids in the medulla. For the most part it allows many blood vessels to pass and serves to anchor the renal cortex to the medulla.

Minor Calyx[7] (calyx = cup) A calyx* is a short, cup-shaped tube that receives what is now urine from the collecting ducts. Each renal papilla projects into the space called the minor calyx. There is one for each pyramid. *Singular is calyx and the plural of calyx is calicies.

Major Calyx[8] – The several minor calicies merge to form larger spaces called a major calyx. Each kidney has about 2-3 major calicies. A minor calyx collects urine from one renal papilla. A major calyx collects urine from several minor calicies and empties the urine into the renal pelvis. From the pelvis the urine goes to the ureter and then bladder and then urethra for excretion.

Renal Pelvis[9] (pelvis = basin) - This is a flat, funnel-shaped tube and is the expanded superior part of the ureter. The renal pelvis is formed by the junction of all major calyces. Once urine exits the kidneys at the renal hilus, the renal pelvis delivers urine to the ureter.

Renal Ureter[10] (ureter = urine farrier) - Once the renal pelvis leaves the kidneys it becomes the ureter. One ureter from each kidney carries the waste product urine from the kidneys to the urinary bladder which is the storage facility for urine until it can be eliminated (or excreted) from the body by the urine voiding reflex called the **micturition reflex**.

The Renal Artery[11] **and Vein**[12] – These two blood vessels travel through the renal hilus and deliver and return (respectively) from 20 to 25% of the total cardiac output to the kidneys for cleansing and immediate return to the body.

The Renal Sinus[13] is a compartment inside the kidney containing some fat to cushion and stabilize the position of other elements, such as the renal pelvis, lymphatic channels, calyces and the renal artery. The renal sinus contains is not empty, but the renal vessels, nerves, renal pelvis, and the calices. The adipose tissue fat pads here act to protects these structures.

The Renal Hilus – is that dimpled space in the medial part of the kidney which opens the kidney to the exterior. This region is like a port of access, the indentation in the medial part of kidney is where the ureter, renal blood vessels, lymphatics and nerves, enter or exit the kidney.

The Renal System has 4 main Processes:
1. Filtration - Water, solutes smaller than proteins, and most wastes passively pass out of the glomerulus capillaries into a cupped region called the Bowman's capsule. This fluid is called filtrate. Proteins and blood cells cannot pass through and so are not part of the filtrate.

2. Reabsorption - The filtrate moves into tubules that recover most of the nutrients, water, and essential ions from the filtrate and return it to the blood of capillaries in surrounding connective tissue. What is left becomes "urine" and is eventually excreted out. Conserves Valuable Nutrients - At the same time, the urinary system makes sure that glucose, amino acids and other valuable nutrients are not lost from the urine.

3. Secretion - This process takes any waste that is still in the capillaries that now surround the renal tubules (nay waste that was not filtered by the glomerulus) and adds or secretes them to the filtrate that is destined to soon become urine. This occurs most prominently in the Distal Convoluted Tubule (DCT).

4. Excretion – This is the elimination of the waste product urine from the body. Urine is an acidic (pH of 4 to 5) solution that is temporarily stored in the bladder. It is voided by the bladder by what is called the micturition reflex. Urine is normally **aseptic** - meaning it is not contaminated with any microbes.

The Nephron

The smallest structure that performs the function of the whole organ is called the "Functional Unit" of that organ. The nephrons filter blood and remove waste, therefore, the functional unit of the kidneys is the nephron! The kidneys filter out waste and excess ions, which leave the body in the urine, and before leaving the kidneys, the nephrons give 99% of what was filtered back to the body – just cleaner than when it took it. All of the essentially needed substances are back in the blood fast. In 1 day, the kidneys filter over 140 liters of blood (the body's entire volume of blood is filtered every 40 minutes).

Each Nephron is composed of **2** main parts: The **Renal Corpuscle** and the **Renal Tubules**.

① **The Renal Corpuscle**: This is where filtration of the blood occurs! It has 3 main components or structures:

1. Glomerulus.
2. Bowman's Capsule or Glomerular Capsule.
3. Bowman's Space or Glomerular Space.

1. The **Glomerulus** is a fenestrated capillary bed. (glomer = ball; ulus = little).The glomerulus is like a ball or 'knot' of capillaries. The endothelium of the glomerulus has fenestrations or pores and therefore these capillaries are very 'leaky' and allow large quantities of fluid and small molecules to pass from the blood in the capillary into the hollow interior of the Bowman's capsule. The fluid that is made here at the glomerulus is a filtrate of blood (from the fluid component of blood) and is called **filtrate**. More than 99% of this filtrate is reabsorbed by the renal tubules before it even leaves the kidneys. Any filtrate that is not reabsorbed will become urine and be eliminated from the body as urine.

Only about **20%** of blood that passes through the glomerulus will leave the capillaries as filtrate; about **80%** remains in the capillaries.

2. The Bowman's capsule (glomerular capsule). This is an enlarged, cup-shaped closed end of the renal tubule that completely surrounds the glomerulus. The capsule is double-walled and contains a parietal and visceral layer.

3. Bowman's Space (glomerular space) – this can also be referred to as the parietal layer. This is the outer wall of the capsule. It is made of simple squamous epithelium. The visceral layer is the inner wall of the capsule. This portion does not form filtrate but rather provides a place to catch the filtrate and funnel it into the waiting renal tubules.

a) Podocytes - The visceral layer is made of branching epithelial cells called podocytes (pod = foot; cyte = cell). The branches of the podocytes end in small structures called pedicles (little feet). The pedicles interdigitate with one another as they surround the glomerular capillaries; by changing the size of the gap in between the pedicles, this can change the glomerular filtration rate (GFR).

b) Filtration Slits - The filtrate passes into the capsular space through thin clefts between the foot processes called filtration slits (created by the pedicles). Filtration slits prevent filtration of large proteins and also regulate the overall flow of filtrate into the Bowman's space.

The Juxtaglomerular Apparatus

The homeostatic regulation of the body by the kidneys is amazing, complex and involves regulation of renal function by the kidneys themselves – this is called **autoregulation**. The autoregulation of the renal system is achieved by the **juxtaglomerular apparatus** – which is composed basically of two structures: **1)** the **juxtaglomerular cells** that surround the afferent arteriole and **2)** the **macula densa**, which is a specialized region of the DCT located in between afferent and efferent arteriole of the glomerulus

② **The Renal Tubules** – the 2nd part of the Nephron. This is responsible for reabsorption of the filtrate (**99%** of filtrate is reabsorbed!!) and for the process of secretion.

The Renal Tubules have **3** Regions:

1. **Proximal Convoluted Tubule** (PCT). This is the coiled portions of the renal tubules that are immediately proximal to the Bowman's capsule. They are the most active in reabsorption and secretion. The walls of the tubule are made of cuboidal epithelial cells with dense microvilli – called 'brush border' epithelium. This anatomical feature greatly increases the surface area for reabsorbing water, ions, and solutes from the filtrate.

2. **Loop of Henle**. This is a U-shaped loop found mostly in the medulla. Its primary function is to maintain a salty medulla and is a key site for the conservation of water. It has a descending and ascending portion, as well as thick and thin segments. It is lined with simple squamous or simple cuboidal epithelium.

3. **Distal Convoluted Tubule** (DCT). The last portion of the renal tubules is also convoluted and coiled. Close to the very end of the nephron, the DCT loops back to the renal corpuscle and travels right in between the afferent and efferent arteriole of the glomerulus! The **macula densa** is a specialized region of the DCT that is in close proximity to the **juxtaglomerular cells** of the afferent arteriole. These two groups of cells, the macula densa and the juxtaglomerular cells, comprise the **Juxtaglomerular Apparatus** - which is the primary auto-regulator of the kidneys, that is, these are the structures that enable the kidneys to regulate themselves. The DCT is lined with simple cuboidal epithelium but without many microvilli. The DCT is the end of the nephron, and it fuses into collecting ducts.

Two Types of Nephrons

The main functional filtration unit of the kidney is the nephron (a urine-forming structure). Each kidney has approximately 1.25 million nephrons, for a total of over 2.5 nephrons in the entire renal system.

Cortical Nephrons - **85%** of nephrons in humans are this type. In these nephrons the renal corpuscle is located high in the renal cortex and they have shorter loops of Henle. They are called *cortical* nephrons because of their location higher in the renal cortex.

Juxtamedullary Nephrons - **15%** of nephrons have long loops of Henle that dip deep into the renal medulla. Also, the renal corpuscles of these nephrons are located closer to cortex-medulla junction. The term juxta = next to, is in reference to the renal corpuscle being closer to, but not in the renal medulla.

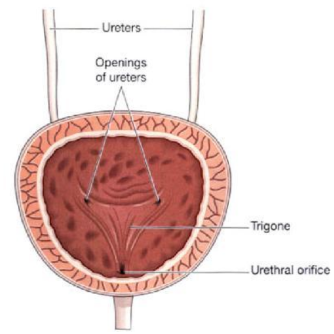
The **Collecting Ducts** emerge for the collecting tubules, and collect filtrate from the DCT's of many nephrons. These structures travel from the top all the way down deep into the renal medulla and are a key site involved in the conservation of water and the concentrating of filtrate.

Once the filtrate passed from the ends of the collecting ducts (which are located in the renal papillae) into the minor calicies, the fluid can no longer be modified and is now considered "urine" – a waste product, destined for elimination from the storage facility the urinary bladder.

Below is a summary of the flow of fluid from where filtrate is made – at the glomerular - to the point where urine leaves the body: Glomerular capsule -> proximal convoluted tubule -> loop of Henle -> distal convoluted tubule -> collecting duct -> renal papilla -> minor calyx* (fluid is now urine) -> major calyx -> renal pelvis -> ureter -> bladder -> urethra -> out of body.

Ureters
These are paired tubes about 10 inches (25 cm) long. These structures are responsible for the transport urine from the kidney to the urinary bladder by peristalsis and some help from gravity.

The Urinary Bladder
The urinary bladder is posterior to public symphysis and anterior to the vagina and uterus (females) and rectum (males). The interior surface has openings for the 2 ureters and the urethra. The smooth triangular region of the base is outlined by these 3 openings. This triangular area is called the **trigone** (trī-gōn) (tri = three; gon = angle). Many bladder infections persist in this region. The role of the bladder is to store and expel urine. The bladder can hold about 500 mL of urine.



When about 300 mL of urine collect, stretch receptors initiate a reflex called the **micturition reflex** (voiding or urinating). It produces a series of contractions of the urinary bladder, and also relaxes the involuntary **internal urethral sphincter** (smooth muscle). When the **external urinary sphincter** (skeletal muscle) is consciously relaxed, urine is released from the urinary bladder when the pressure there is great enough to force urine to flow out of the urethra.

Urethra
This is a tube that transports urine from the bladder to the outside of the body. The tunica mucosa in males is transitional epithelium near the urinary bladder and then this changes to stratified squamous epithelium near the orifice. In females it is all stratified squamous epithelium. The tunica muscularis is the smooth muscle layer that helps propel the urine to the outside of the body.

Male vs. Female Urethra
The female urethra is 3-4 cm long and the opening is anterior to the vaginal opening. The male urethra is about 18 cm long and has 3 regions:

1. Prostatic urethra (inside prostate gland just inferior to urinary bladder)
2. Membranous urethra (just inside the urogenital diaphragm)
3. Penile urethra (inside the corpus spongiosum of the penis).

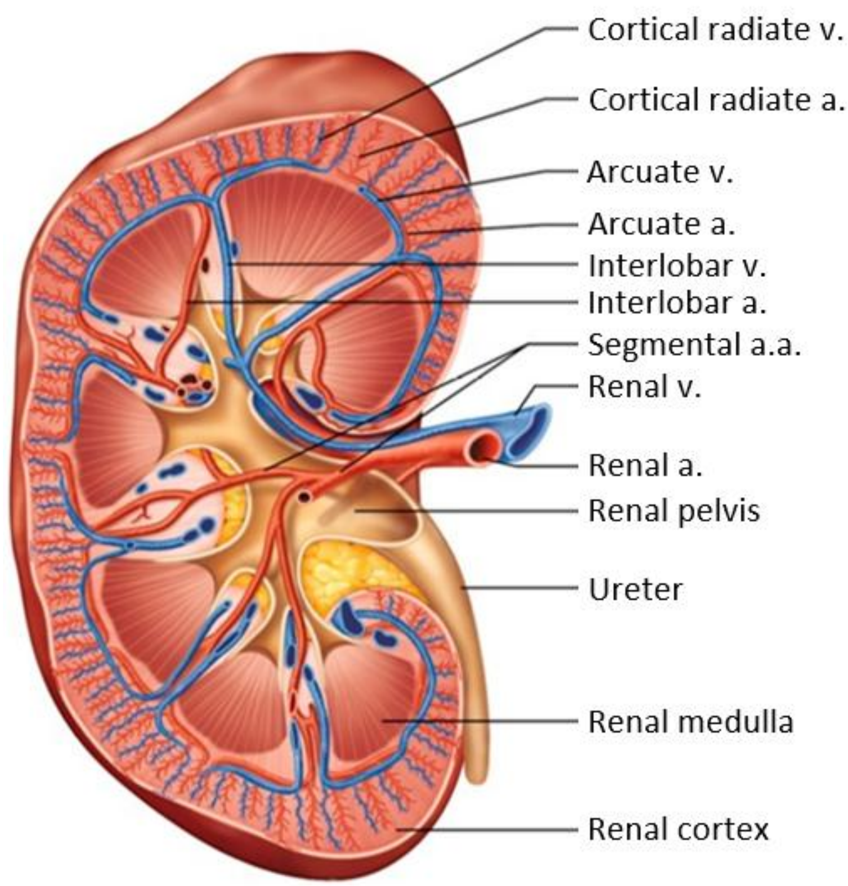
The opening is at the end of the penis and is shared by urinary and reproductive systems.

Blood Flow through the Kidney
The two kidneys receive from **20** to **25%** of **cardiac output** at any one time. This is an enormous amount of blood flow for such tiny little things. Consider that your entire brain usually only gets about 20% of cardiac output. The kidneys only weigh about 150 grams each, that is, less than ½ a pound.

Specific Bloods Vessels for the renal circulation: **Artery** = a.

In the drawing below, we can see renal vessels starting from the incoming renal artery (artery is abbreviated a. and arteries a.a. on the image), and the outgoing renal vein. As we trance the incoming blood supply to the kidneys, it proceeds in the order shown below. In the image below, we can only see as far down as the cortical radiate artery, though from there it branches into the afferent (incoming) arteriole, to the glomerulus (a capillary bed) and then the efferent (outgoing) arteriole.

- **Abdominal Aorta** - Oxygenated blood pumped from the left ventricle of the heart to the aorta.
- **Renal a.** - From the abdominal aorta the blood goes to the renal arteries.
- **Segmental a.** - As each renal artery approaches a kidney it divides into five segmental arteries that enter the renal hilus.
- **Interlobar a.** - The segmental arteries then divide into interlobar arteries which lie in the renal columns between the medullary pyramids.
- **Arcuate a.** - At the medulla-cortex junction, the interlobar arteries branch into arcuate arteries. As their name implies, these create an arc over the bases of the renal pyramids.
- **Cortical radiate a.** - The arcuate arteries radiate outward up into the renal cortex, so this relatively new name very accurately describes its anatomy.
- **Afferent arteriole** – The cortical radiate arteries branch into the afferent arterioles. These blood vessels transport incoming blood to the glomerulus.
- **Glomerulus** (fenestrated capillaries). These capillaries produce the **filtrate** that moves through the renal tubules, a small fraction of which (1%) ultimately becomes urine. This capillary bed is both supplied and drained by arterioles (the afferent and efferent arterioles) in what is a called a **Portal System**.



- **Efferent arteriole** - receives blood from the glomerulus.
    - Peritubular Capillaries - mostly associated with the cortical nephrons.
    - Vasa Recta Capillaries- mostly associated with the juxtamedullary nephrons.

The **peritubular capillaries** arise from the efferent arterioles draining the cortical glomeruli. They thread around the renal tubules. Most predominantly of the cortical nephrons. They absorb solutes and water from the tubule cells after these substances become the filtrate.

The **vasa recta capillaries** arise from the efferent arterioles draining the juxtamedullary glomeruli. (vas = vessel; recta = straight). The vasa recta are part of the kidney's urine-concentrating mechanism. These vasa recta are exclusively associated with the juxtamedullary nephrons.

The Veins (vein = v.; veins = v.v.) drain the blood in reverse of the arteries.

- **Interlobular** veins
- **Arcuate** veins
- **Interlobar** veins (goes from cortex, medulla to hilus)
- **Renal** veins (*there are no lobar or segmental veins)
- **Inferior vena cava**