Structure of Kidney in Special Reference to Nephron

Debajyoti Bhattacharya

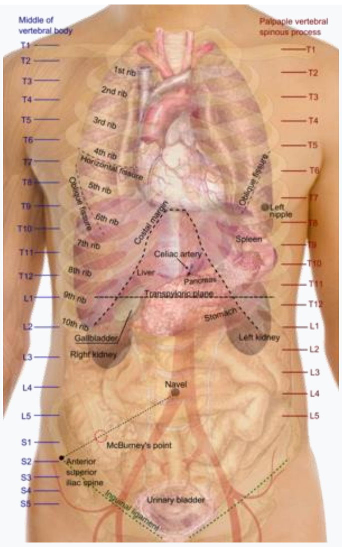
FNTA SEM II

The kidneys are two bean-shaped organs found in vertebrates. They are located on the left and right in the retroperitoneal space, and in adult humans are about 11 centimetres (4.3 in) in length. They receive blood from the paired renal arteries; blood exits into the paired renal veins. Each kidney is attached to a ureter, a tube that carries excreted urine to the bladder.

The nephron is the structural and functional unit of the kidney. Each human adult kidney contains around 1 million nephrons, while a mouse kidney contains only about 12,500 nephrons. The kidney participates in the control of the volume of various body fluid compartments, fluid osmolality, acid-base balance, various electrolyte concentrations, and removal of toxins. Filtration occurs in the glomerulus: one-fifth of the blood volume that enters the kidneys is filtered. Examples of substances reabsorbed are solute-free water, sodium, bicarbonate, glucose, and amino acids. Examples of substances secreted are hydrogen, ammonium, potassium and uric acid. The kidneys also carry out functions independent of the nephron. For example, they convert a precursor of vitamin D to its active form, calcitriol; and synthesize the hormones erythropoietin and renin.

Renal physiology is the study of kidney function. Nephrology is the medical specialty which addresses diseases of kidney *function*: these include chronic kidney disease, nephritic and nephrotic syndromes, acute kidney injury, and pyelonephritis. Urology addresses diseases of kidney (and urinary tract) *anatomy*: these include cancer, renal cysts, kidney stones and ureteral stones, and urinary tract obstruction.

Procedures used in the management of kidney disease include chemical and microscopic examination of the urine (urinalysis), measurement of kidney function by calculating the estimated glomerular filtration rate (eGFR) using the serum creatinine; and kidney biopsy and CT scan to evaluate for abnormal anatomy. Dialysis and kidney transplantation are used to treat kidney failure; one (or both sequentially) of these are almost always used when renal function drops below 15%. Nephrectomy is frequently used to cure renal cell carcinoma.



Images showing the human trunk, with positions of the organs show, and kidneys seen at the vertebral level of T12 to L3.

In humans, the kidneys are located high in the abdominal cavity, one on each side of the spine, and lie in a retroperitoneal position at a slightly oblique angle. The asymmetry within the abdominal cavity, caused by the position of the liver, typically results in the right kidney being slightly lower and smaller than the left, and being placed slightly more to the middle than the left kidney. The left kidney is approximately at the vertebral level T12 to L3, and the right is slightly lower. The right kidney sits just below the diaphragm and posterior to the liver. The left kidney sits below the diaphragm and posterior to the spleen. On top of each kidney is an adrenal gland. The upper parts of the kidneys are partially protected by the 11th and 12th ribs. Each kidney, with its adrenal gland is surrounded by two layers of fat: the perirenal fat present between renal fascia and renal capsule and pararenal fat superior to the renal fascia.

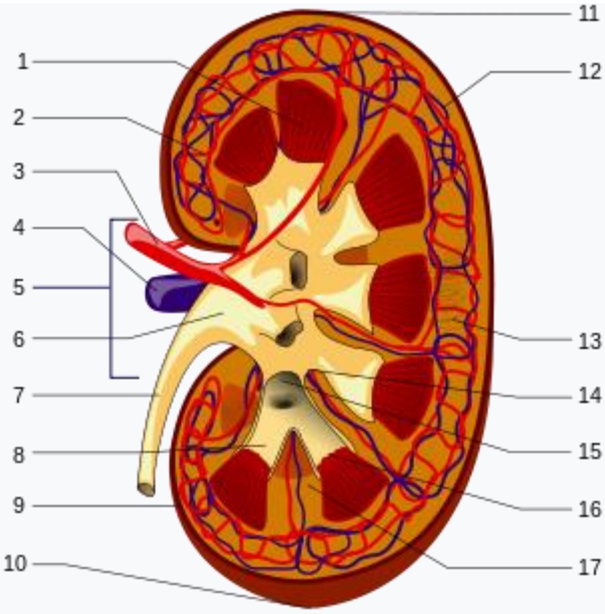
The kidney is a bean-shaped structure with a convex and a concave border. A recessed area on the concave border is the renal hilum, where the renal artery enters the kidney and the renal vein and ureter leave. The kidney is surrounded by tough fibrous tissue, the renal capsule, which is itself surrounded by perirenal fat, renal fascia, and pararenal fat. The anterior (front) surface of these tissues is the peritoneum, while the posterior (rear) surface is the transversalis fascia.

The superior pole of the right kidney is adjacent to the liver. For the left kidney, it is next to the spleen. Both, therefore, move down upon inhalation.

.

Sex	Weight, standard reference range	
	Right kidney	Left kidney
Men	80–160 g (2.8–5.6 oz)	80–175 g (2.8–6.2 oz)
Women	40–175 g (1.4–6.2 oz)	35–190 g (1.2–6.7 oz)

Gross anatomy



1. Renal pyramid • 2. Interlobular artery • 3. Renal artery • 4. Renal vein 5. Renal hilum • 6. Renal pelvis • 7. Ureter • 8. Minor calyx • 9. Renal capsule • 10. Inferior renal capsule • 11. Superior renal capsule • 12. Interlobular vein • 13. Nephron • 14. Renal sinus • 15. Major calyx • 16. Renal papilla • 17. Renal column

The functional substance, or parenchyma, of the kidney is divided into two major structures: the outer renal cortex and the inner renal medulla. Grossly, these structures take the shape of eight to 18 cone-shaped renal lobes, each containing renal cortex surrounding a portion of medulla called a renal pyramid. Between the renal pyramids are projections of cortex called renal columns. Nephrons, the urine-producing functional structures of the kidney, span the cortex and medulla. The initial filtering portion of a nephron is the renal corpuscle, which is located in the cortex. This is followed by a renal tubule that passes from the cortex deep into the medullary pyramids. Part of the renal cortex, a medullary ray is a collection of renal tubules that drain into a single collecting duct.

The tip, or papilla, of each pyramid empties urine into a minor calyx; minor calyces empty into major calyces, and major calyces empty into the renal pelvis. This becomes the ureter. At the hilum, the ureter and renal vein exit the kidney and the renal artery enters. Hilar fat and lymphatic tissue with lymph nodes surround these structures. The hilar fat is contiguous with a fat-filled cavity called the renal sinus. The renal sinus collectively contains the renal pelvis and calyces and separates these structures from the renal medullary tissue. The kidneys possess no overtly moving structures.

Blood supply

The kidneys receive blood from the renal arteries, left and right, which branch directly from the abdominal aorta. Despite their relatively small size, the kidneys receive approximately 20% of the cardiac output. Each renal artery branches into segmental arteries, dividing further into interlobar arteries, which penetrate the renal capsule and extend through the renal columns between the renal pyramids. The interlobar arteries then supply blood to the arcuate arteries that run through the boundary of the cortex and the medulla. Each arcuate artery supplies several interlobular arteries that feed into the afferent arterioles that supply the glomeruli.

Blood drains from the kidneys, ultimately into the inferior vena cava. After filtration occurs, the blood moves through a small network of small veins (venules) that converge into interlobular veins. As with the arteriole distribution, the veins follow the same pattern: the interlobular provide blood to the arcuate veins then back to the interlobar veins, which come to form the renal veins which exiting the kidney .

Nerve supply

The kidney and nervous system communicate via the renal plexus, whose fibers course along the renal arteries to reach each kidney. Input from the sympathetic nervous system triggers vasoconstriction in the kidney, thereby reducing renal blood flow. The kidney also receives input from the parasympathetic nervous system, by way of the renal branches of the vagus nerve; the function of this is yet unclear. Sensory input from the kidney travels to the T10-11 levels of the spinal cord and is sensed in the corresponding dermatome. Thus, pain in the flank region may be referred from corresponding kidney.

Microanatomy

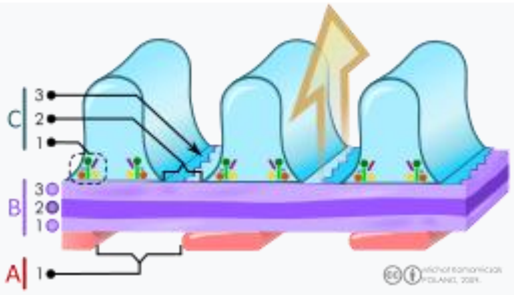
Renal histology is the study of the microscopic structure of the kidney. Distinct cell types include:

- Kidney glomerulus parietal cell
- Kidney glomerulus podocyte
- Kidney proximal tubule brush border cell
- Loop of Henle thin segment cell
- Thick ascending limb cell
- Kidney distal tubule cell
- Collecting duct principal cell
- Collecting duct intercalated cell
- Interstitial kidney cells

Structure of Nephron

The nephron is the functional unit of the kidney. Each nephron is composed of a renal corpuscle, the initial filtering component; and a renal tubule that processes and carries away the filtered fluid.

Renal corpuscle



Schematic of the glomerular filtration barrier (GFB). A. The endothelial cells of the glomerulus; 1. endothelial pore (fenestra).
B. Glomerular basement membrane: 1. lamina rara interna 2. lamina densa 3. lamina rara externa
C. Podocytes: 1. enzymatic and structural proteins 2. filtration slit 3. diaphragm

The renal corpuscle is the site of the filtration of blood plasma. The renal corpuscle consists of the glomerulus, and the glomerular capsule or Bowman's capsule. The renal corpuscle has two poles – a vascular pole and a urinary pole.

The arterioles from the renal circulation enter and leave the glomerulus at the vascular pole. The glomerular filtrate leaves the Bowman's capsule at the renal tubule at the urinary pole.

The glomerulus is the network known as a *tuft*, of filtering capillaries located at the vascular pole of the renal corpuscle in Bowman's capsule. Each glomerulus receives its blood supply from an afferent arteriole of the renal circulation. The glomerular blood pressure provides the driving force for water and solutes to be filtered out of the blood plasma, and into the interior of Bowman's capsule, called Bowman's space.

Only about a fifth of the plasma is filtered in the glomerulus. The rest passes into an efferent arteriole. The diameter of the efferent arteriole is smaller than that of the afferent, and this difference increases the hydrostatic pressure in the glomerulus.

Bowman's capsule

The Bowman's capsule, also called the glomerular capsule, surrounds the glomerulus. It is composed of a visceral inner layer formed by specialized cells called podocytes, and a parietal outer layer composed of simple squamous epithelium. Fluids from blood in the glomerulus are filtered through the visceral layer of podocytes, resulting in the glomerular filtrate.

The glomerular filtrate next moves to the renal tubule, where it is further processed to form urine. The different stages of this fluid are collectively known as the tubular fluid.

Renal tubule

The renal tubule is the portion of the nephron containing the tubular fluid filtered through the glomerulus. After passing through the renal tubule, the filtrate continues to the collecting duct system.

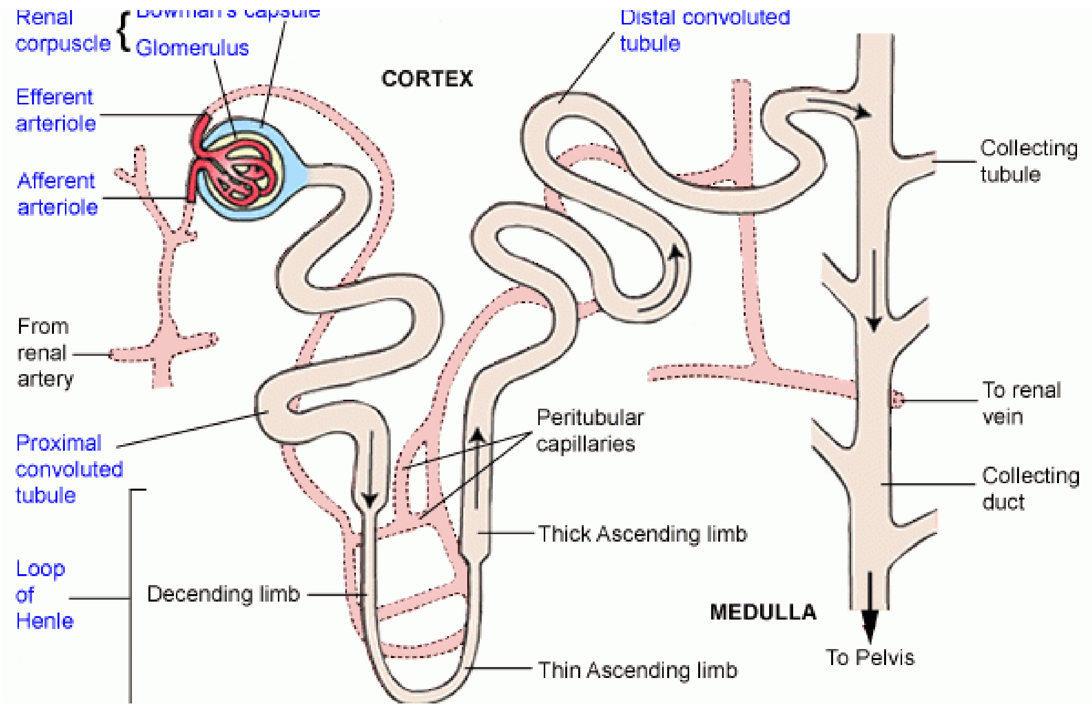
The components of the renal tubule are:

- Proximal convoluted tubule (lies in cortex and lined by simple cuboidal epithelium with brush borders which help to increase the area of absorption greatly.)

- Loop of Henle (hair-pin like, i.e. U-shaped, and lies in medulla)
    - Descending limb of loop of Henle
    - Ascending limb of loop of Henle
        - The ascending limb of loop of Henle is divided into 2 segments: Lower end of ascending limb is very thin and is lined by simple squamous epithelium. The distal portion of ascending limb is thick and is lined by simple cuboidal epithelium.
        - Thin ascending limb of loop of Henle
        - Thick ascending limb of loop of Henle (enters cortex and becomes - distal convoluted tubule.)
- Distal convoluted tubule
- Connecting tubule

Blood from the efferent arteriole, containing everything that was not filtered out in the glomerulus, moves into the peritubular capillaries, tiny blood vessels that surround the loop of Henle and the proximal and distal tubules, where the tubular fluid flows. Substances then reabsorb from the latter back to the blood stream.

The peritubular capillaries then recombine to form an efferent venule, which combines with efferent venules from other nephrons into the renal vein, and rejoins the main bloodstream.



Structure of nephron

Length difference

Cortical nephrons (the majority of nephrons) start high in the cortex and have a short loop of Henle which does not penetrate deeply into the medulla. Cortical nephrons can be subdivided into *superficial cortical nephrons* and *midcortical nephrons*.

Juxtamedullary nephrons start low in the cortex near the medulla and have a long loop of Henle which penetrates deeply into the renal medulla: only they have their loop of Henle surrounded by the vasa recta. These long loops of Henle and their associated vasa recta create a hyperosmolar gradient that allows for the generation of a concentrated urine. Also the hairpin bend penetrates up to the inner zone of medulla.

Juxtamedullary nephrons are found only in birds and mammals, and have a specific location: *medullary* refers to the renal medulla, while *juxta* (Latin: near) refers to the relative position of the renal corpuscle of this nephron - *near the medulla*, but still in the cortex. In other words, a *juxtamedullary nephron* is a nephron whose renal corpuscle is near the medulla, and whose proximal convoluted tubule and its associated loop of Henle occur deeper in the medulla than the other type of nephron, the cortical nephron.

The juxtamedullary nephron comprises only 20–30% of the nephrons in the human kidney. However, it is this type of nephron which is most often depicted in illustrations of nephrons.

- The nephron is the microscopic structural and functional unit of the kidney. It is composed of a renal corpuscle and a renal tubule. The renal corpuscle consists of a tuft of capillaries called a glomerulus and an encompassing Bowman's capsule. The renal tubule extends from the capsule. The capsule and tubule are connected and are composed of epithelial cells with a lumen. A healthy adult has 0.8 to 1.5 million nephrons in each kidney. Blood is filtered as it passes through three layers: the endothelial cells of the capillary wall, its basement membrane, and between the foot processes of the podocytes of the lining of the capsule. The tubule has adjacent peritubular capillaries that run between the descending and ascending portions of the tubule. As the fluid from the capsule flows down into the tubule, it is processed by the epithelial cells lining the tubule: water is reabsorbed and substances are exchanged (some are added, others are removed); first with the interstitial fluid outside the tubules, and then into the plasma in the adjacent peritubular capillaries through the endothelial cells lining that capillary. This process regulates the volume of body fluid as well as levels of many body substances. At the end of the tubule, the remaining fluid—urine—exits: it is composed of water, metabolic waste, and toxins.
- The interior of Bowman's capsule, called Bowman's space, collects the filtrate from the filtering capillaries of the glomerular tuft, which also contains mesangial cells supporting these capillaries. These components function as the filtration unit and make up the renal corpuscle. The filtering structure (glomerular filtration barrier) has three layers composed of endothelial cells, a basement membrane, and podocytes (foot processes). The tubule has five anatomically and functionally different parts: the proximal tubule, which has a convoluted section the proximal convoluted tubule followed by a straight section (proximal straight tubule); the loop of Henle, which has two parts, the descending loop of Henle ("descending loop") and the ascending loop of Henle ("ascending loop"); the distal convoluted tubule ("distal loop"); the connecting tubule, and the collecting ducts. Nephrons have two lengths with different urine concentrating capacities: long juxtamedullary nephrons and short cortical nephrons.
- The four mechanisms used to create and process the filtrate (the result of which is to convert blood to urine) are filtration, reabsorption, secretion and excretion. Filtration occurs in the glomerulus and is largely passive: it is dependent on the intracapillary

blood pressure. About one-fifth of the plasma is filtered as the blood passes through the glomerular capillaries; four-fifths continues into the peritubular capillaries. Normally the only components of the blood that are not filtered into Bowman's capsule are blood proteins, red blood cells, white blood cells and platelets. Over 150 liters of fluid enter the glomeruli of an adult every day: 99% of the water in that filtrate is reabsorbed. Reabsorption occurs in the renal tubules and is either passive, due to diffusion, or active, due to pumping against a concentration gradient. Secretion also occurs in the tubules and is active. Substances reabsorbed include: water, sodium chloride, glucose, amino acids, lactate, magnesium, calcium phosphate, uric acid, and bicarbonate. Substances secreted include urea, creatinine, potassium, hydrogen, and uric acid. Some of the hormones which signal the tubules to alter the reabsorption or secretion rate, and thereby maintain homeostasis, include (along with the substance affected) antidiuretic hormone (water), aldosterone (sodium, potassium), parathyroid hormone (calcium, phosphate), atrial natriuretic peptide (sodium) and brain natriuretic peptide (sodium). A countercurrent system in the renal medulla provides the mechanism for generating a hypertonic interstitium, which allows the recovery of solute-free water from within the nephron and returning it to the venous vasculature when appropriate.

- Some diseases of the nephron predominantly affect either the glomeruli or the tubules. Glomerular diseases include diabetic nephropathy, glomerulonephritis and IgA nephropathy; renal tubular diseases include acute tubular necrosis and polycystic kidney disease.