



ANATOMY OF THE KIDNEYS

A Complete Illustrated Guide

From the whole organ to the microscopic nephron

Inside this guide

- Location, size, shape, coverings, and neighbors
- Cortex, medulla, calyces, and the blood supply
- The nephron, glomerulus, tubules, and hormones
- Ureters, bladder, urethra, development, and variations
- How structure explains disease, plus imaging and biopsy
- 17 original diagrams, 4 labeling exercises, quiz, glossary

For patients, families, students, and community members

Educational purposes only. The Liver and Kidney Hope Foundation is not a medical provider. This guide does not replace the advice of your healthcare team.

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Welcome

The kidneys do more work, with more precision, than almost any other organ their size. Each day they filter roughly 180 liters of blood plasma, return nearly all of it to the body, and turn the rest into about 1 to 2 liters of urine, while quietly regulating blood pressure, red blood cell production, bone health, and the chemistry of every cell you have. All of that depends on **structure**: how the kidneys are built, where they sit, how blood reaches them, and how each of about two million tiny filtering units is put together.

This guide from **The Liver and Kidney Hope Foundation (TLHF)** is a complete tour of kidney anatomy, from the kidneys' place in the body, to their blood supply and nerves, to the microscopic **nephron**, to the ureters, bladder, and urethra, and finally to how the anatomy explains kidney disease. It is written in plain language for patients, families, students, and community members, and it includes 17 original labeled diagrams, tables, review questions, and four fill-in labeling exercises.

How this guide is organized

Part	Chapters
Part 1: The Big Picture	1. Why kidneys matter and how to read anatomy; 2. Location, size, and shape; 3. Coverings and neighbors
Part 2: Inside the Kidney	4. Gross (visible) internal structure; 5. Blood supply; 6. Nerves and lymphatics
Part 3: The Microscopic Kidney	7. The nephron; 8. The glomerulus and filtration barrier; 9. Tubules and transport; 10. The juxtaglomerular apparatus and hormones
Part 4: The Drainage System	11. Ureters, bladder, and urethra
Part 5: Life Story and Variations	12. Development, growth, and aging; 13. Variations and birth differences; 14. Imaging the kidneys
Part 6: Anatomy and Disease	15. How structure explains disease; 16. Protecting your kidneys
Part 7: Study Tools	Labeling exercises, quiz, answer keys, glossary, anatomy by the numbers, resources

How to use it

Each chapter starts with the big idea and then adds detail. If you are new to the topic, read the boxes marked **Key point** first, then return for the tables and diagrams. Students can skip straight to the labeling exercises in Part 7 as a self-test.

Ranges, not rules

Numbers such as sizes, flows, and percentages are typical values for healthy adults. Normal ranges vary with age, sex, body size, and the lab or imaging method. If a number here differs from your own report, ask your healthcare team what is normal **for you**.

Medical disclaimer and about TLHF

This guide is provided for **educational purposes only**. The Liver and Kidney Hope Foundation is a Nevada 501(c)(3) nonprofit organization that provides liver and kidney health education, community support, and outreach. **TLHF is not a medical provider** and does not diagnose, treat, or prescribe. Nothing in this guide replaces professional medical advice, diagnosis, or treatment. Diagrams are simplified, hand-built schematics meant for learning; they are not drawn to scale and are not a substitute for a medical atlas or for images of your own kidneys.

Seek emergency care (call 911 in the U.S.)

- Severe one-sided back or flank pain with fever, chills, or vomiting
- No urine at all for 8 to 12 hours, or blood clots in the urine
- Chest pain, trouble breathing, confusion, or fainting
- Injury to the back, side, or belly followed by pain, blood in urine, or dizziness

Words used in this guide

- **Renal** means "of the kidney" (from Latin). **Nephro-** is the Greek root for the same idea. A **nephrologist** is a kidney doctor; a **urologist** is a surgeon for the urinary tract.
- **Anterior** = front, **posterior** = back, **medial** = toward the middle, **lateral** = toward the side, **superior** = upward, **inferior** = downward.
- **Cortex** = outer layer; **medulla** = inner region; **hilum** = the "doorway" where vessels and the ureter enter and leave.
- **Parenchyma** = the working tissue of the kidney (cortex plus medulla).

A word from TLHF

Understanding how your kidneys are built is the first step to understanding kidney tests, imaging, and treatment. Knowledge is not just power: it is also calming. Bring your questions to your care team, and remember that **hope is part of health**.

PART 1

The Big Picture

CHAPTER 1

Why the Kidneys Matter

Seven jobs, one small organ, and how to read anatomy

~150 g	20-25%	~180 L	~1 million
weight of one adult kidney, about the size of a fist	of the heart's output goes to the kidneys each minute	of plasma filtered per day (about 125 mL every minute)	nephrons in each kidney (varies widely)

The two kidneys together weigh less than 0.5% of your body, yet they receive about a fifth of the blood your heart pumps. That generous blood supply is what lets them clean the entire blood volume many times a day, and it explains why the kidneys are so sensitive to low blood pressure, dehydration, and blocked blood vessels.

The seven jobs of the kidneys

Job	What the kidneys do	Where in the anatomy it happens
1. Filter blood and remove waste	Clear urea, creatinine, drug breakdown products, and toxins	Glomeruli (filtering) and tubules (secretion)
2. Balance fluid	Keep total body water steady by making dilute or concentrated urine	Loop of Henle, collecting duct, and the medullary gradient
3. Balance salts and minerals	Sodium, potassium, calcium, magnesium, phosphate, chloride	Every tubule segment, each with its own transporters
4. Balance acid and base	Excrete acid; recover bicarbonate; keep blood pH near 7.4	Proximal tubule and collecting duct (intercalated cells)
5. Help control blood pressure	Release renin; adjust salt and water; tune blood flow	Juxtaglomerular apparatus; afferent and efferent arterioles
6. Support red blood cells	Make erythropoietin (EPO) when oxygen is low	Special fibroblast-like cells in the cortex interstitium
7. Support bones and vitamin D	Activate vitamin D to calcitriol; handle calcium and phosphate	Proximal tubule (1-alpha-hydroxylase enzyme)

Key point

Structure explains function. Every feature in this guide, from the fenestrated capillary to the cup-shaped calyx, exists because it solves a physical problem the kidney faces.

Follow the flow: a one-page map

Keep this "big picture" in mind while you read the details:

- 1** **Blood** arrives from the aorta through the **renal artery**, which divides many times until each tiny **afferent arteriole** delivers blood to one glomerulus.
- 2** The **glomerulus** works like a sieve. Water and small dissolved substances are pushed through into **Bowman's space**; blood cells and large proteins stay behind. This fluid is the **filtrate**.
- 3** The filtrate flows through the **tubule**: proximal tubule, loop of Henle, distal tubule, and collecting duct. Along the way, the tubule takes back what the body needs and adds what it wants to remove.
- 4** What is left is **urine**. It drips from the papilla into a **calyx**, gathers in the **renal pelvis**, and travels down the **ureter** to the **bladder**.
- 5** The **bladder** stores urine until it is released through the **urethra**.
- 6** The cleaned blood leaves through the **renal vein** and returns to the heart via the inferior vena cava.

Reading anatomy: the language of position

Term	Meaning	Kidney example
Anterior / posterior	Front / back of the body	The kidneys lie posterior (behind) to the abdominal cavity
Superior / inferior	Above / below	The adrenal gland sits superior to the kidney
Medial / lateral	Toward the midline / toward the side	The hilum faces medially; the convex border is lateral
Proximal / distal	Nearer to / farther from the starting point	In the tubule, "proximal" is nearer to the glomerulus
Superficial / deep	Nearer to / farther from the surface	The cortex is superficial; the medulla is deep
Coronal plane	Slices the body into front and back halves	The classic lengthwise kidney section (Figure 4)
Axial (transverse) plane	Slices the body into upper and lower parts	CT and MRI "cross-sections" (Figure 2)
Sagittal plane	Slices the body into left and right parts	Used for ultrasound views of the kidney

CHAPTER 2

Location, Size, and Shape

Where the kidneys sit and what they look like from outside

The kidneys are **bean-shaped**, reddish-brown, smooth-surfaced organs. They lie high on the back wall of the abdomen, one on each side of the spine, mostly protected by the lower ribs. They are **retroperitoneal**: they sit behind the peritoneum, the thin lining that wraps the intestines, stomach, and liver, so they are not floating among the bowels.

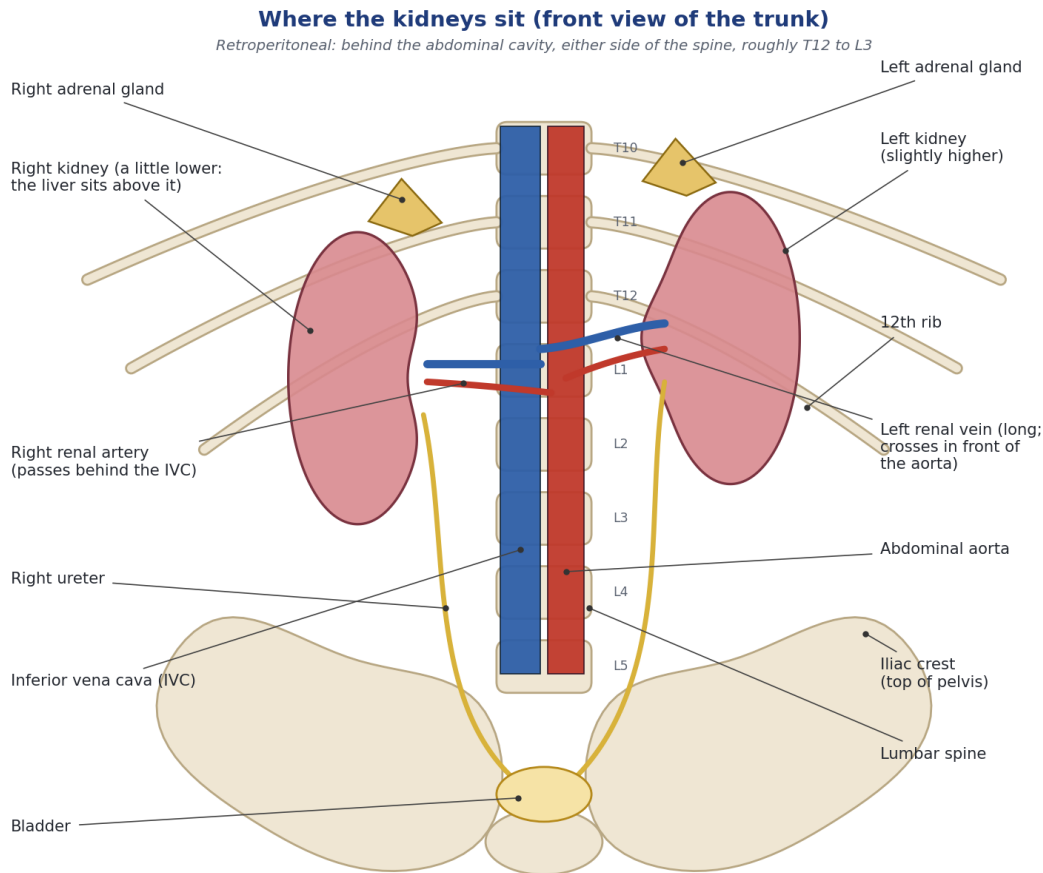


Figure 1. The kidneys, adrenal glands, great vessels, ureters, and bladder in relation to the spine, ribs, and pelvis (front view).

Where exactly?

Feature	Right kidney	Left kidney
Vertebral levels (approx.)	Upper pole about T12; lower pole about L3	Upper pole about T11 to T12; lower pole about L2 to L3
Height compared with other side	About 1 to 2 cm lower (the liver pushes it down)	Slightly higher, and often a little longer and narrower
Hilum level	About L1 to L2	About L1
Ribs in front of the back surface	12th rib crosses the upper part	11th and 12th ribs cross the upper part
Movement	Moves about 2 to 3 cm up and down with deep breathing (attached to the diaphragm-side wall)	Same

Size and weight

Measure	Typical adult	Notes
Length	10 to 12 cm (about 4 to 5 inches)	A difference of more than about 1.5 to 2 cm between the two sides deserves a look
Width	5 to 7 cm	Measured across the hilum
Thickness (front to back)	3 to 4 cm	About the thickness of a small fist
Weight	About 125 to 170 g (men); 115 to 155 g (women)	Kidneys are slightly smaller in women, in smaller people, and in older age
Volume	About 120 to 200 mL	Measured with ultrasound, CT, or MRI
Share of body weight	Less than 0.5%	Yet about 20 to 25% of cardiac output

Growing with you

Kidney length grows steadily through childhood and levels off in early adulthood. Typical lengths are about 4 to 5 cm in a newborn, about 6 cm at one year, about 8 cm at five years, about 9 to 10 cm at ten years, and 10 to 12 cm in adults. After about age 50 to 60, kidneys gradually shrink and the cortex thins.

Outside surfaces and borders

- **Two surfaces:** an **anterior** (front) surface that touches many organs, and a **posterior** (back) surface that rests on muscles.
- **Two borders:** a convex **lateral** border, and a concave **medial** border with a deep notch, the **hilum**.
- **Two poles:** a broader **upper pole** (capped by the adrenal gland) and a narrower **lower pole**.
- **Smooth surface** in adults. In babies, faint grooves show where the original lobes were fused (**fetal lobulation**). Persistent lobulation is a harmless variant.

The hilum: the kidney's doorway

The hilum is a vertical slit on the medial border, about 3 cm long, that opens into the **renal sinus**, a fat-filled cavity inside the kidney. Structures pass through the hilum in a fairly consistent order from front to back:

Order (front to back)	Structure	Direction of flow
Most anterior	Renal vein	Blood leaves the kidney
Middle	Renal artery (its branches)	Blood enters the kidney
Most posterior (and lowest)	Renal pelvis / ureter	Urine leaves the kidney

Remember it

A memory trick for the hilum from front to back: **V-A-U** (vein, artery, ureter).

Finding the kidneys from outside

Surface anatomy: the **costovertebral angle (CVA)** is the corner where the 12th rib meets the spine. The kidneys lie deep to this area, which is why doctors tap gently there to check for kidney tenderness. Normal kidneys usually cannot be felt from the outside; a lower pole may sometimes be felt in very thin people.

CHAPTER 3

Coverings and Neighbors

Capsule, fat, fascia, muscles, and the organs next door

Each kidney is wrapped in **four layers of protection** and cushioned by fat. Understanding these layers explains why kidney infections and bleeding behave as they do, and why surgeons and radiologists refer to distinct "compartments" around the kidney.

Layers from inside to outside

Layer	What it is	Why it matters
1. Renal (fibrous) capsule	A thin, tough, transparent membrane stuck to the kidney surface	Keeps shape; strips off easily in healthy kidneys but sticks when scarred. Swelling inside it causes pain
2. Perirenal (perinephric) fat	Fat cushion surrounding the kidney and adrenal gland	Shock absorber; also where infection or blood can collect
3. Renal (Gerota's) fascia	A sheet of connective tissue with an anterior and posterior layer enclosing kidney, adrenal, and perirenal fat	Forms a compartment; open below, so fluid can track downward toward the pelvis
4. Pararenal (paranephric) fat	Fat outside the fascia, mostly behind and to the side	Extra padding against the back muscles

Cross-section through the abdomen at the level of L2
Viewed from below (patient's right is on the left of the picture); back of the body is at the bottom

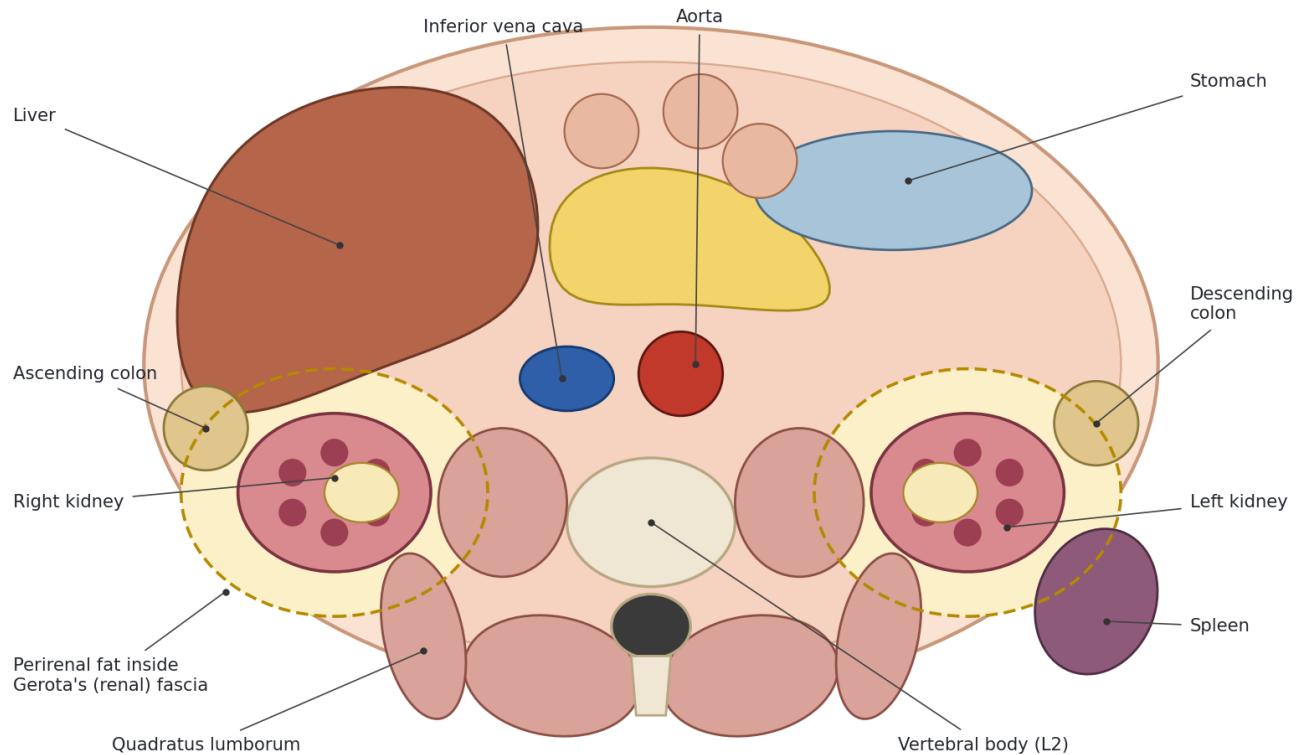


Figure 2. Schematic cross-section at the level of L2, viewed from below. The dashed gold line marks the renal fascia around each kidney and its surrounding fat.

Clinical link

Because the fascia is closed on the top, sides, and middle but **open at the bottom**, a pus collection or bleed around the kidney can extend downward along the ureter. The kidneys also slide slightly within this compartment, which is why very thin people sometimes have a "floating" (mobile) kidney.

What lies behind the kidneys (posterior relations)

- **Diaphragm** (upper third of each kidney) and the pleural sac (lung lining) above it. The pleura reaches down to the 12th rib, so back or flank incisions can risk a collapsed lung (pneumothorax).
- **Psoas major muscle** (medial), **quadratus lumborum** (middle), and **transversus abdominis** (lateral): the muscle "bed" of the kidney.
- **Nerves** running with these muscles: subcostal, iliohypogastric, and ilioinguinal. Kidney or flank surgery can irritate them, causing pain or numbness in the flank or groin.
- **12th rib** (both sides) and **11th rib** (left).

Neighbors of the kidneys (front surfaces)

Approximate areas where organs lie against each kidney. The surface of each kidney is shown as if seen from the front.

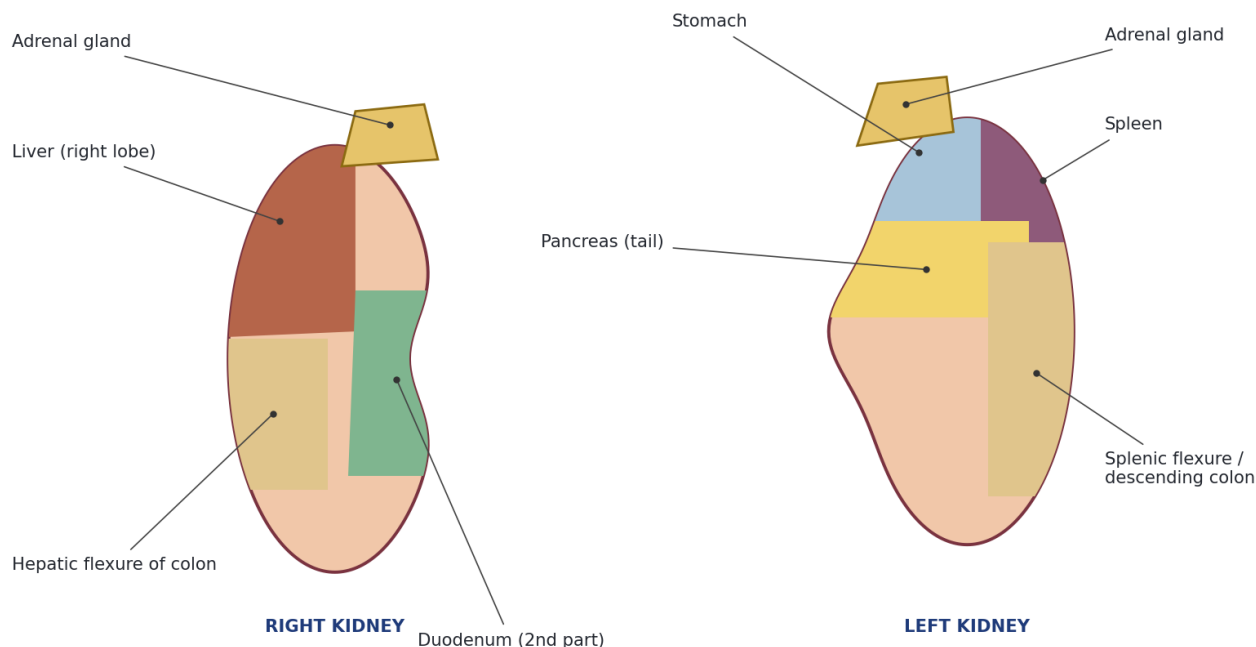


Figure 3. Approximate areas of the front (anterior) surface of each kidney that touch neighboring organs (schematic; contact areas vary from person to person).

What lies in front (anterior relations)

Right kidney	Left kidney
Adrenal gland (upper pole, on the upper front)	Adrenal gland (upper pole, medial)
Liver (right lobe, upper and lateral)	Spleen (lateral, upper)
Duodenum (second part) near the hilum	Stomach (back wall, upper)
Hepatic flexure of the colon (lateral, lower)	Pancreas (body and tail) across the middle
Small intestine (lower pole)	Splenic flexure and descending colon (lateral, lower); loops of jejunum

Trauma note

Because the spleen, liver, and colon lie against the kidneys, blunt injuries to the flank can damage more than one organ at once. Blood in the urine after any injury needs urgent medical evaluation.

The adrenal (suprarenal) glands

Each kidney wears a small triangular "hat": the adrenal gland. Although it shares the kidney's fascial envelope, it is a separate hormone gland that makes cortisol, aldosterone, and adrenaline (epinephrine). Aldosterone acts directly on the kidney's collecting ducts (Chapter 9), which is one example of how tightly the two organs cooperate.

PART 2

Inside the Kidney

CHAPTER 4

Inside the Kidney: Gross Anatomy

Cortex, medulla, pyramids, and the collecting system you can see with the naked eye

If you cut a kidney in half lengthwise, you see three visibly different zones: a pale outer **cortex**, a striped darker **medulla** made of cone-shaped **pyramids**, and a central **sinus** holding the drainage cups and vessels.

Internal anatomy of the kidney (coronal section)

Right kidney cut lengthwise, seen from the front

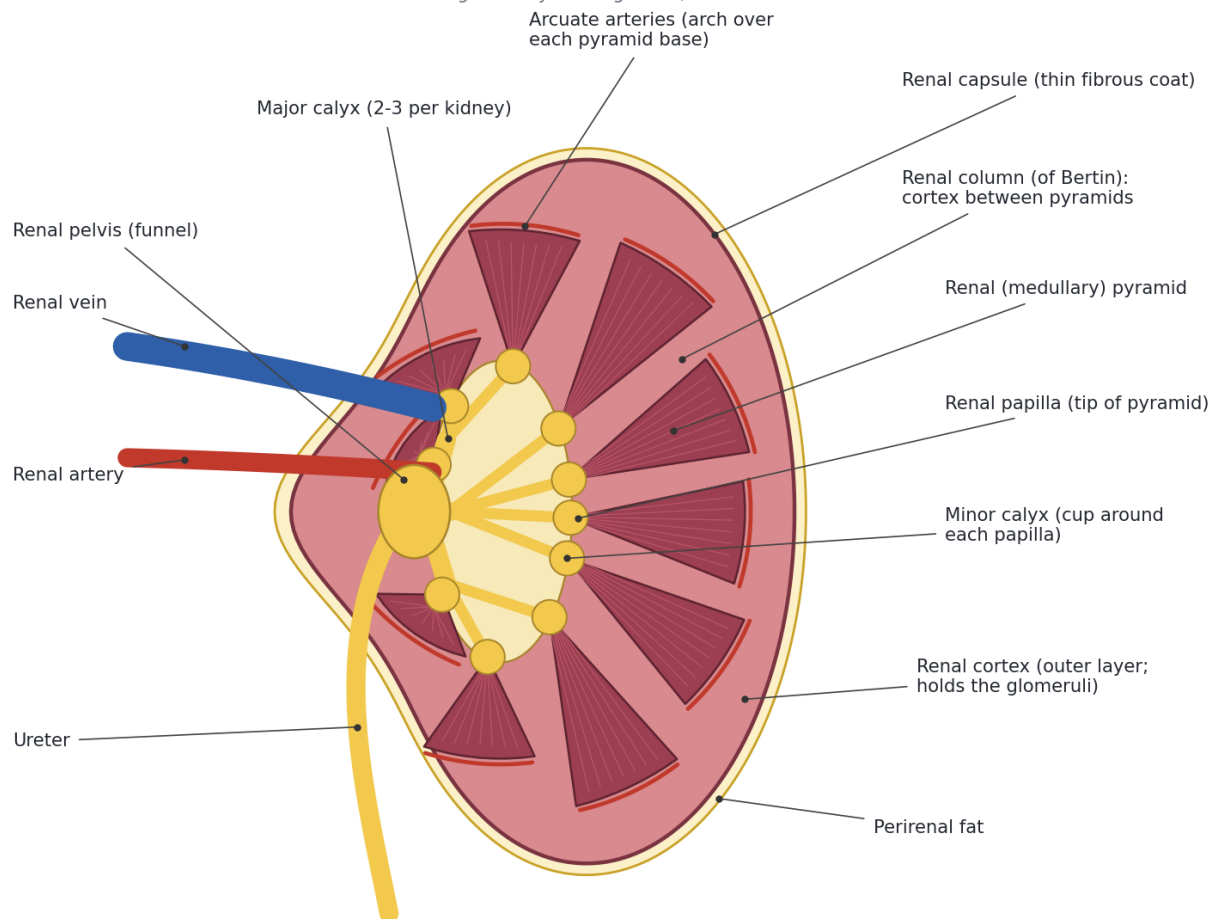


Figure 4. Coronal (lengthwise) section of a right kidney showing cortex, medulla, calyces, pelvis, and vessels.

The major regions

Region	Appearance	Contains	Main roles
Renal capsule	Thin fibrous coat	Collagen	Protection, shape
Renal cortex	Outer 1 cm or so; granular, reddish	Glomeruli, proximal and distal convoluted tubules, cortical collecting ducts, most blood vessels	Filtration and most reabsorption
Renal columns (of Bertin)	Cortex tissue that dips between pyramids	Interlobar vessels	Supports pyramids; carries blood vessels
Renal medulla	Inner region made of 8 to 18 cone-shaped pyramids (often 10 to 14)	Loops of Henle, collecting ducts, vasa recta	Concentrating and diluting urine
Renal papilla	Tip of each pyramid, pointing toward the sinus	Openings of collecting ducts (area cribrosa)	Delivers urine into a minor calyx
Renal sinus	Central fat-filled cavity opening at the hilum	Calyces, pelvis, vessels, nerves, fat	Space for the drainage system

Lobes and lobules

- A **renal lobe** is one pyramid plus the cortex around it (the part of the column beside it and the cap above). Each kidney has about 8 to 18 lobes.
- A **renal lobule** is a smaller unit: a **medullary ray** (a bundle of straight tubules and collecting ducts extending from the medulla into the cortex) plus the cortex on either side. Lobules are only visible under the microscope.
- A **medullary ray** is why the cortex has faint vertical striations in some cuts.

The collecting system: how urine leaves the kidney

Urine drips from openings at the tip of each papilla into a cup-shaped **minor calyx**. The calyces are lined with a special stretchy lining called **urothelium** and are wrapped in smooth muscle that moves urine along in small waves (peristalsis).

Structure	Number (typical)	Description
Minor calyx	7 to 14 per kidney	Small cup that catches urine from one (sometimes two or three) papillae
Major calyx	2 to 3 per kidney (upper, middle, lower)	Formed where 2 to 4 minor calyces join
Renal pelvis	1 per kidney	Funnel that gathers urine from major calyces. May lie mostly inside the sinus (intrarenal pelvis) or partly outside the kidney (extrarenal pelvis), a normal variation
Ureter	1 per kidney	Muscular tube that begins at the pelviureteric junction (PUJ) and carries urine to the bladder (Chapter 11)

Order of drainage

Follow the path of urine in order: **papilla** > **minor calyx** > **major calyx** > **renal pelvis** > **ureter** > **bladder** > **urethra**.

Compound papillae

Most pyramids end in a single, simple papilla. In some parts of the kidney, especially the poles, two or more pyramids merge into a **compound papilla**. These have wider openings that do not close as well against back-flow, which is why urine can more easily flow backward into the kidney tissue there (**intrarenal reflux**) and why scarring from infection often starts at the poles.

The avascular plane (Brodel's line)

Because the arteries divide into front (anterior) and back (posterior) sets, there is a relatively bloodless line along the lateral border where the two territories meet, called **Brodel's line**. Surgeons aim for this plane when they need to enter the kidney with the least bleeding, although its exact position varies.

Key point

The kidney is really a collection of many small "mini-kidneys" (lobes) sharing one blood supply and one drainage system. That design lets a surgeon remove a diseased segment, and lets the remaining tissue keep working.

CHAPTER 5

Blood Supply

The renal arteries, the branching tree inside the kidney, and the veins that carry blood away

The kidneys receive about **1.0 to 1.2 liters of blood per minute**, roughly 20 to 25% of the heart's output. About 90% of that blood goes to the cortex, where the glomeruli are, and only about 10% to the medulla. That imbalance matters: the deep medulla lives on a low oxygen supply, which makes it especially vulnerable when blood flow drops.

1.0-1.2 L	~90%	2 sets	End arteries
blood flow per minute (both kidneys)	of kidney blood flow goes to the cortex	of capillaries in a row: glomerular, then peritubular	no bypass: a blocked branch injures its territory

Outside the kidney: the renal arteries and veins

Vessel	Origin / course	Notes
Renal arteries	Arise from the sides of the abdominal aorta at about L1 to L2, just below the superior mesenteric artery	Right is longer and passes behind the inferior vena cava. Left is shorter
Accessory (extra) renal arteries	Additional arteries from the aorta or iliac arteries	Present in about 1 in 4 people; enter at the hilum or directly at a pole. Important to surgeons and in transplant work
Renal veins	Leave the hilum in front of the arteries and empty into the inferior vena cava	Left vein is longer (about 6 to 10 cm) and crosses in front of the aorta , below the origin of the superior mesenteric artery. Right is short (about 2 to 4 cm)
Tributaries of the left renal vein	Left adrenal (suprarenal) vein, left gonadal (ovarian or testicular) vein, sometimes a lumbar vein	The right adrenal and gonadal veins drain directly into the vena cava instead. This is why the left renal vein is preferred for donor kidney removal

Five segments

Each main renal artery divides at or near the hilum into an **anterior division** (larger, supplying about three-quarters of the kidney) and a **posterior division**. The anterior division gives four **segmental arteries** (apical, upper, middle, lower); the posterior division supplies the **posterior segment**. Each of the five segments is an "end-artery" territory with little overlap.

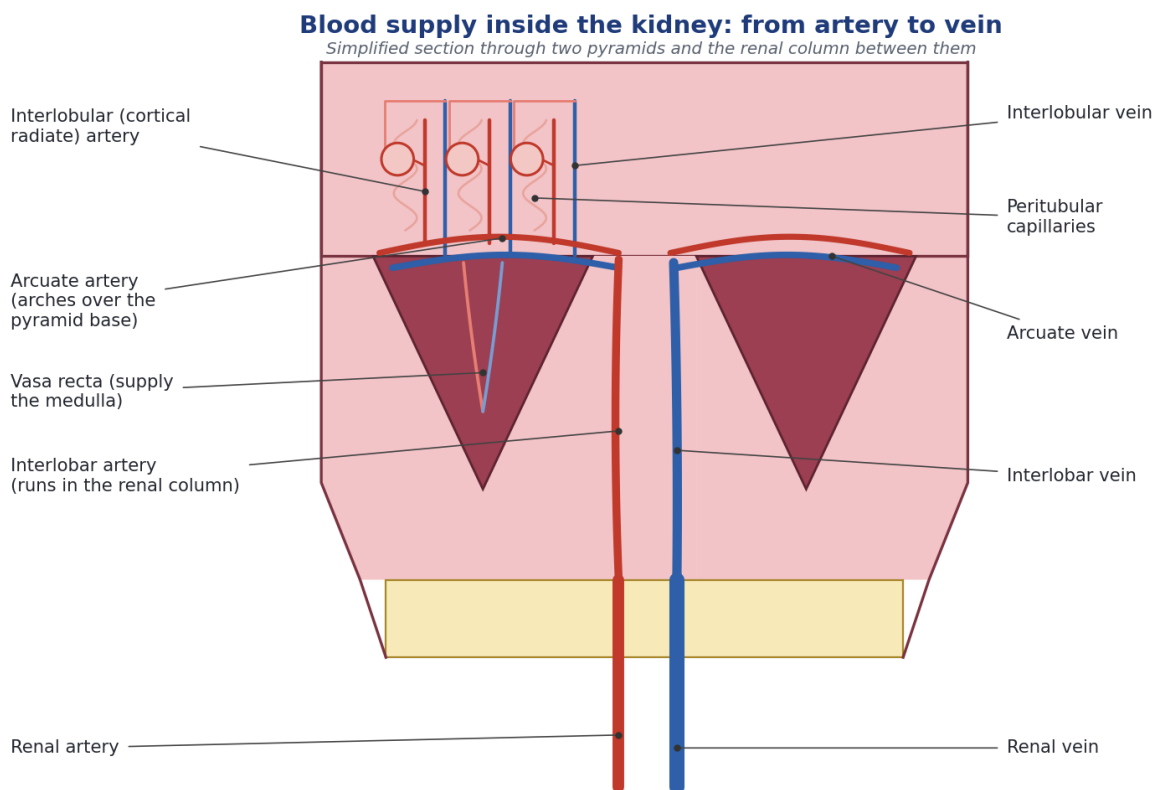


Figure 5. Blood supply inside the kidney, from the renal artery (red) to the renal vein (blue). The interlobar vessels run in the renal columns; arcuate vessels arch over the pyramid bases.

Inside the kidney: the branching tree

Step	Vessel	Location	Key features
1	Renal artery	At the hilum	Divides into anterior and posterior divisions
2	Segmental arteries	In the renal sinus	Five per kidney; each supplies a wedge (segment)
3	Interlobar arteries	Run in the renal columns, between pyramids	Head toward the outer cortex
4	Arcuate arteries	Arch over the base of each pyramid (cortico-medullary junction)	Do not connect to each other (true end arteries)
5	Interlobular (cortical radiate) arteries	Ascend through the cortex	Give off afferent arterioles at regular intervals
6	Afferent arterioles	Cortex	Thick-walled, muscular; deliver blood to one glomerulus each
7	Glomerular capillaries	Inside Bowman's capsule	First capillary bed: filtration under high pressure (about 45 to 60 mmHg)
8	Efferent arterioles	Leave the glomerulus	Blood leaves the glomerulus through an arteriole , not a venule: an unusual arrangement that lets the kidney control pressure in the glomerulus
9	Peritubular capillaries (cortex) and vasa recta (medulla)	Around tubules	Second capillary bed: low pressure, reabsorbs water and solutes; vasa recta preserve the salt gradient
10	Interlobular, arcuate, interlobar veins	Run alongside the arteries	Collect blood back toward the hilum; veins do connect with each other, so vein blockage is better tolerated
11	Renal vein	Leaves at the hilum	Empties into the inferior vena cava

The kidney's two capillary beds

Most organs have one capillary bed between an artery and a vein. The kidney has **two in series**, separated by the efferent arteriole. The first (**glomerular**) is a high-pressure bed built for filtering. The second (**peritubular**) is a low-pressure bed built for taking back water and dissolved substances from the tubule. The efferent arteriole between them works like an adjustable tap that helps keep glomerular pressure steady.

Two kinds of nephron circulation

	Cortical nephrons (about 85%)	Juxtamedullary nephrons (about 15%)
Glomerulus location	Outer and mid cortex	Deep cortex, near the medulla
Loop of Henle	Short; barely reaches the outer medulla	Long; reaches deep into the inner medulla
Capillaries after the glomerulus	Peritubular capillary network	Peritubular network plus long vasa recta hairpins
Main job	Filtration and reabsorption	Building and using the concentrating gradient

Regulating blood flow: autoregulation

Even when blood pressure changes (within roughly 80 to 180 mmHg), healthy kidneys keep glomerular blood flow and filtration remarkably constant. Two mechanisms work together at the afferent arteriole:

- **Myogenic response:** when arterial pressure rises, the arteriole wall is stretched and its muscle automatically contracts, protecting the glomerulus.
- **Tubuloglomerular feedback:** the macula densa senses salt in the tubule fluid and signals the afferent arteriole to tighten or relax (Chapter 10).

Why medicines can matter

Some common medicines (such as NSAID pain relievers like ibuprofen) block the prostaglandins that keep the afferent arteriole open, while others (ACE inhibitors and ARBs) relax the efferent arteriole. In dehydration, heart failure, or narrowed renal arteries, these effects can sharply lower filtration. Ask your healthcare team before starting or stopping any of these medicines.

Blood vessels and disease: anatomy clues

Condition	Anatomy involved	What happens
Renal artery stenosis	Main renal artery	Narrowing lowers blood flow, activating renin and raising blood pressure
Renal infarct	A segmental or smaller artery	A blocked end artery causes a wedge of dead tissue
Renal vein thrombosis	Renal vein	A clot backs up blood; more common in some protein-losing kidney diseases
Nutcracker syndrome	Left renal vein between aorta and superior mesenteric artery	Compression can cause blood in the urine or flank pain in some people
Fibromuscular dysplasia	Renal artery wall	Bead-like narrowing, most often in younger women; causes high blood pressure
Atherosclerosis	Origin of the renal artery	Plaque narrows the artery, especially in older adults

CHAPTER 6

Nerves and Lymphatics

How the kidneys feel, respond, and drain

Nerve supply

The kidneys are wired with nerves that mainly follow the arteries. Their main jobs are to adjust blood flow, renin release, and salt handling, and to sense stretch and injury (pain).

Nerve type	Source	Job
Sympathetic (motor)	Spinal levels T10 to L1; pass through the celiac and aorticorenal ganglia and form the renal plexus around the renal artery	Narrow the arterioles, trigger renin release, and increase sodium reabsorption when the body is under stress or the blood pressure is low
Parasympathetic	Vagus nerve (minor contribution)	Function in the kidney is small and not well established
Sensory (pain)	Afferent fibers back to T10 to L1	Carry pain from capsule stretch, ureter spasm, or inflammation

Interesting fact

Kidney nerves do not run the kidney. A transplanted kidney has no nerve connection at all, yet it works well, because the kidney's local controls (autoregulation, hormones, tubuloglomerular feedback) do most of the work. This is also why a transplanted kidney is usually painless, except when the capsule is stretched.

Why kidney pain shows up where it does

Kidney and ureter pain is carried by nerves that enter the spinal cord at T10 to L1, the same levels that supply the skin of the flank, lower belly, groin, and genitals. The brain reads these signals as coming from the skin, a phenomenon called **referred pain**.

Where it hurts	Likely source	Typical description
Flank or back, below the ribs	Kidney (stretch of capsule from infection, blockage, or bleeding)	Dull, constant ache
Flank spreading toward the groin	Ureter (stone or clot moving down)	Sharp, comes in waves (renal colic); may cause nausea
Groin, testicle or labia, inner thigh	Lower ureter near the bladder	Often mistaken for a hernia or testicular problem
Lower belly, urgency, burning	Bladder or urethra	Pressure, stinging

Lymphatic drainage

Lymph is the clear fluid that drains tissue spaces. In the kidney, lymph vessels follow the blood vessels out through the hilum and drain to the **lateral aortic (para-aortic) lymph nodes** beside the aorta and vena cava at the L1 to L2 level. These nodes are important in kidney cancer and infection because that is where disease may first spread.

Key point

The kidney's nerves and lymph channels follow its blood vessels through the hilum. If you can picture the hilum as a doorway for vessels, nerves, lymph, and the ureter, you can picture almost everything that reaches or leaves the kidney.

PART 3

The Microscopic Kidney

CHAPTER 7

The Nephron

The microscopic filtering unit that does the kidney's work

Each kidney contains about **1 million nephrons** (the range in healthy adults is very wide, from about 200,000 to over 2 million). A nephron is a filter plus a long processing tube, and its parts are matched to different jobs. A nephron consists of the **renal corpuscle** (glomerulus plus Bowman's capsule) and the **renal tubule**. Many nephrons empty into a shared **collecting duct**.

A nephron by the numbers

Item	Typical value	Note
Glomerulus diameter	About 200 micrometers (0.2 mm)	Just visible as a dot on a fresh kidney section
Total tubule length (one nephron)	About 30 to 55 mm	If stretched out, the tubules of both kidneys total many tens of kilometers
Filtered per day (both kidneys)	About 180 liters (roughly 125 mL/min)	The whole plasma volume is filtered about 60 times a day
Urine made per day	About 1 to 2 liters	More than 99% of filtered water is reabsorbed
Nephron number at birth	Set by about 34 to 36 weeks of pregnancy	No new nephrons form after birth; those lost to injury or aging do not regrow

Key point

Because new nephrons cannot be made after birth, the surviving nephrons work harder (**hyperfiltration**) when others are lost. This helps for a while, but over years it can damage the remaining glomeruli. It is one reason early detection and protection of kidney function matter so much.

Parts of the nephron in order

Segment	Location	Lining cells	Main jobs
Renal corpuscle (glomerulus + Bowman's capsule)	Cortex	Fenestrated capillary endothelium; podocytes; parietal epithelium	Filter the blood
Proximal convoluted tubule (PCT)	Cortex; about 14 mm long	Tall cuboidal cells with a dense brush border and many mitochondria	Reabsorb about 65% of filtered sodium and water, nearly all glucose and amino acids, most bicarbonate and phosphate; secrete drugs and acids
Proximal straight tubule (pars recta)	Medullary ray to outer medulla	Similar to PCT	Continue reabsorption; secrete organic anions and some drugs
Thin descending limb	Medulla	Flat (squamous) cells	Very water-permeable; water leaves, filtrate becomes more concentrated
Thin ascending limb (long loops only)	Inner medulla	Flat cells	Permeable to salt but not water; salt leaves passively
Thick ascending limb (TAL)	Outer medulla to cortex	Cuboidal cells with many mitochondria	Pump out about 25% of filtered sodium (NKCC2); watertight; dilutes the filtrate; reabsorbs calcium and magnesium
Macula densa	End of the TAL, touching its own glomerulus	Tall, tightly packed cells	Sense salt delivery; control filtration (Chapter 10)
Distal convoluted tubule (DCT)	Cortex	Cuboidal cells, many mitochondria, no brush border	Reabsorb sodium and chloride (thiazide site), fine-tune calcium (PTH effect) and magnesium
Connecting tubule	Cortex	Mixed cells	Joins the nephron to the collecting duct; sodium, potassium, calcium handling
Collecting duct	Cortex, medulla, ending at the papilla	Principal cells and intercalated cells	Final water, sodium, potassium, and acid-base adjustments under hormonal control (aldosterone, ADH)

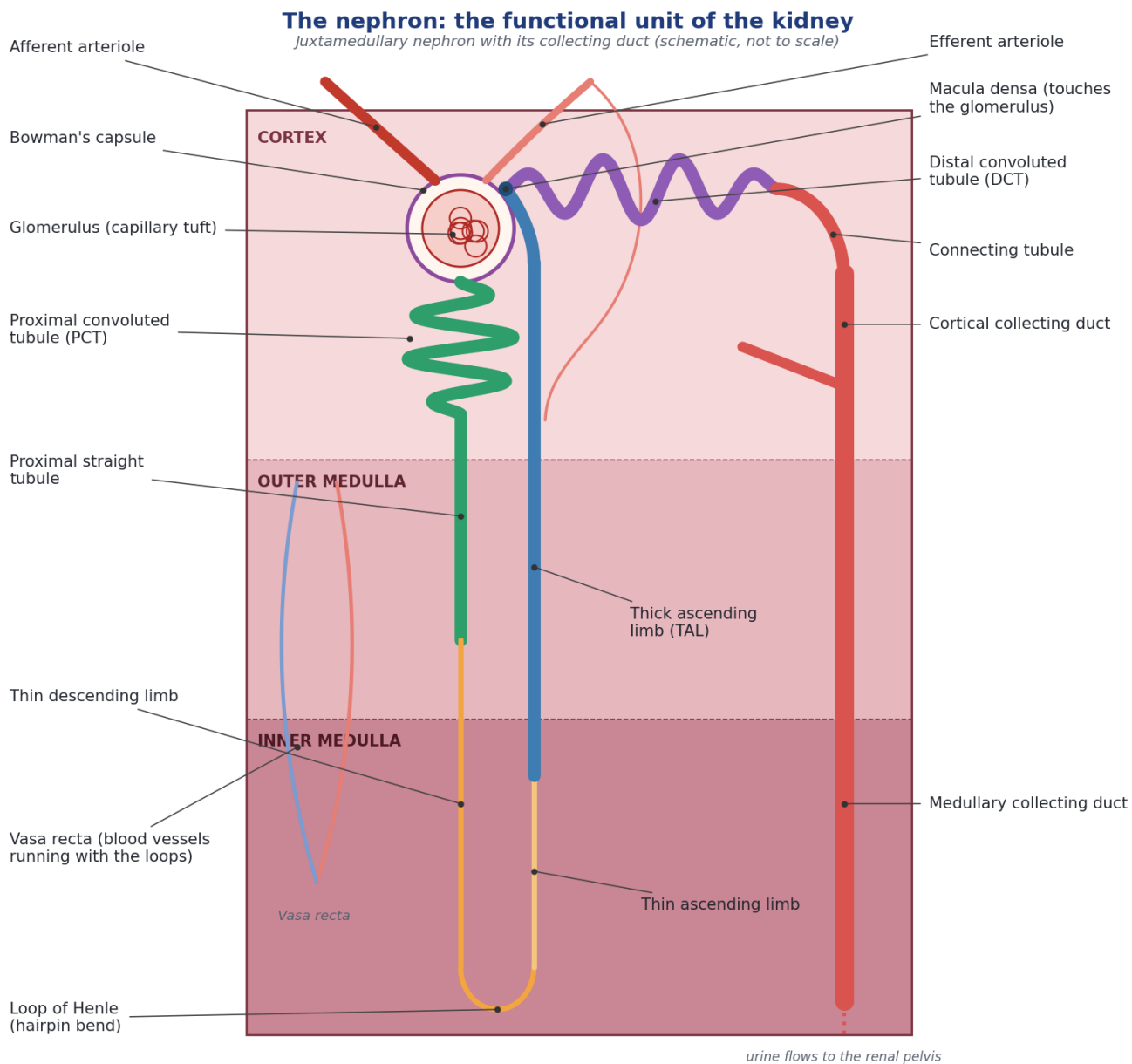


Figure 6. A juxtamedullary nephron and its collecting duct (schematic). Colors match the tubule segments described in the table above.

Cortical vs juxtamedullary nephrons

Feature	Cortical (about 85%)	Juxtamedullary (about 15%)
Glomerulus	Smaller; outer and mid cortex	Larger; deep cortex
Loop of Henle	Short; usually no thin ascending limb	Long; reaches inner medulla
Efferent arteriole leads to	Peritubular capillaries	Peritubular capillaries and vasa recta
Role	Bulk filtration and reabsorption	Concentrating the urine

CHAPTER 8

The Glomerulus and Filtration Barrier

The tiny sieve that turns blood into filtrate

The **glomerulus** is a knot of about 30 to 50 looping capillaries nestled inside the cup-shaped **Bowman's capsule**. Blood enters through the **afferent arteriole** and leaves through the **efferent arteriole**, at a spot called the **vascular pole**. Filtrate leaves through the **urinary pole**, where the proximal tubule begins.

The glomerulus and the filtration barrier

Left: whole glomerulus in its capsule. Right: enlarged view of the three-layer filter (not to scale)

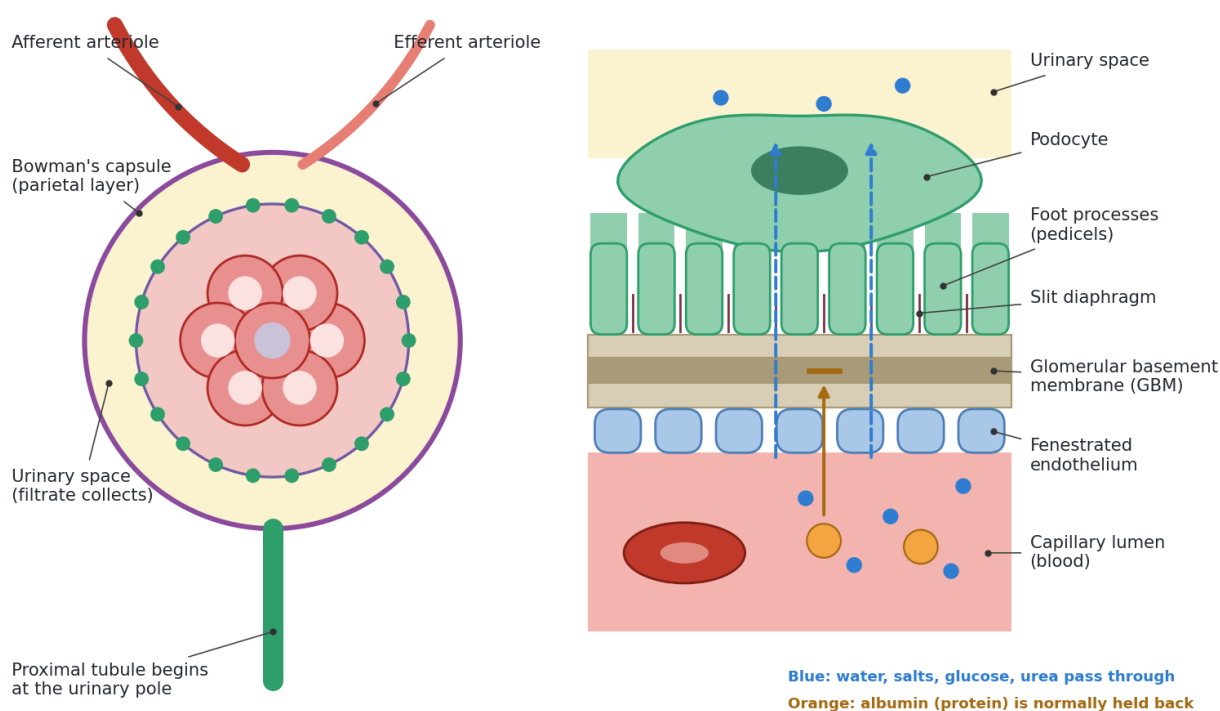


Figure 7. Left: the glomerulus inside Bowman's capsule. Right: an enlarged, simplified view of the three-layer filtration barrier.

The three-layer filtration barrier

Everything that leaves the blood to become filtrate must cross three layers in series. Each layer contributes to size and charge selectivity:

Layer	What it is	How it filters
1. Fenestrated endothelium	Capillary lining with oval pores (fenestrae) about 70 to 100 nm wide, coated with a sugar-rich glycocalyx	Holds back blood cells and platelets; the negatively charged coat repels some proteins

Layer	What it is	How it filters
2. Glomerular basement membrane (GBM)	A dense gel of type IV collagen, laminin, nidogen, and heparan sulfate, about 300 to 350 nm thick in adults	Main size barrier; negative charges repel negatively charged proteins such as albumin
3. Podocytes and slit diaphragms	Octopus-like epithelial cells whose interlocking foot processes (pedicels) leave narrow slits (about 30 to 40 nm) bridged by a slit diaphragm made of nephrin, podocin, and related proteins	Final size sieve; podocytes also anchor the capillary wall and resist pressure

Other cells of the glomerulus

- **Mesangial cells:** support the capillary loops, clear trapped debris, and can contract to alter filtration surface area. They sit in a matrix between the capillaries.
- **Parietal epithelial cells:** the flat cells that form the outer wall of Bowman's capsule.
- **Endothelial cells:** the fenestrated lining described above.

What gets through and what does not

Substance	Size	Filtered?
Water, sodium, potassium, chloride	Tiny	Freely
Glucose, amino acids, urea, creatinine	Small	Freely (glucose and amino acids are later reabsorbed)
Small proteins (for example, some hormones, light chains)	About 3 to 6 nm (up to about 30 kDa)	Mostly filtered, then reabsorbed and broken down by the proximal tubule
Albumin	About 3.5 nm radius, 67 kDa, negatively charged	Very little: only trace amounts; that small amount is reabsorbed
Larger proteins (globulins), fibrinogen	Greater than about 4 nm	Essentially none
Red blood cells, white cells, platelets	Micrometers wide	Not in a healthy kidney

What drives filtration: the balance of pressures

Filtration is pushed by blood pressure in the glomerular capillary and opposed by the pressure of fluid already in Bowman's space and by the protein-related (**oncotic**) pull of blood plasma. In round numbers:

Force	Approximate value	Effect
Glomerular capillary hydrostatic pressure	About 45 to 60 mmHg	Pushes fluid out (favors filtration)
Bowman's space hydrostatic pressure	About 10 to 15 mmHg	Opposes filtration
Capillary oncotic (protein) pressure	About 25 to 30 mmHg	Opposes filtration (rises along the capillary as fluid leaves)

Force	Approximate value	Effect
Net filtration pressure	About 10 mmHg	Small but effective because the surface area is huge and the membrane is very permeable

GFR in one box

The **glomerular filtration rate (GFR)** is the volume of filtrate made per minute by all nephrons. Healthy young adults have a GFR around 90 to 120 mL/min/1.73 m². Doctors **estimate** it (eGFR) from a blood creatinine test with a formula. The **filtration fraction** (the share of plasma that is filtered) is about 20%.

When the filter is damaged

Damage	Typical finding	Example conditions
Podocyte injury (slit diaphragm)	Large amounts of protein in the urine (nephrotic pattern)	Minimal change disease, FSGS
GBM thickening or splitting	Protein and/or blood in the urine	Membranous nephropathy, Alport syndrome, diabetic kidney disease
Inflammation of the glomerulus	Blood and protein in urine, reduced GFR (nephritic pattern)	IgA nephropathy, lupus nephritis, post-infectious GN, ANCA vasculitis, anti-GBM disease
Scarring (glomerulosclerosis)	Progressive loss of GFR	Long-standing diabetes or high blood pressure

CHAPTER 9

Tubules and Transport

How the filtrate is refined into urine, one segment at a time

Of the roughly 180 liters of filtrate produced each day, more than 99% is returned to the blood. The tubule does this by moving substances across its lining cells. Each segment has its own set of **transport proteins** (pumps, channels, and carriers) placed on the **apical** membrane (facing the urine) or the **basolateral** membrane (facing the blood). Nearly everything depends on one workhorse: the **sodium-potassium ATPase pump** on the blood side, which keeps sodium low inside the cell so that sodium can flow in from the urine and drag other substances with it.

How each tubule segment moves salt and water (key transporters)

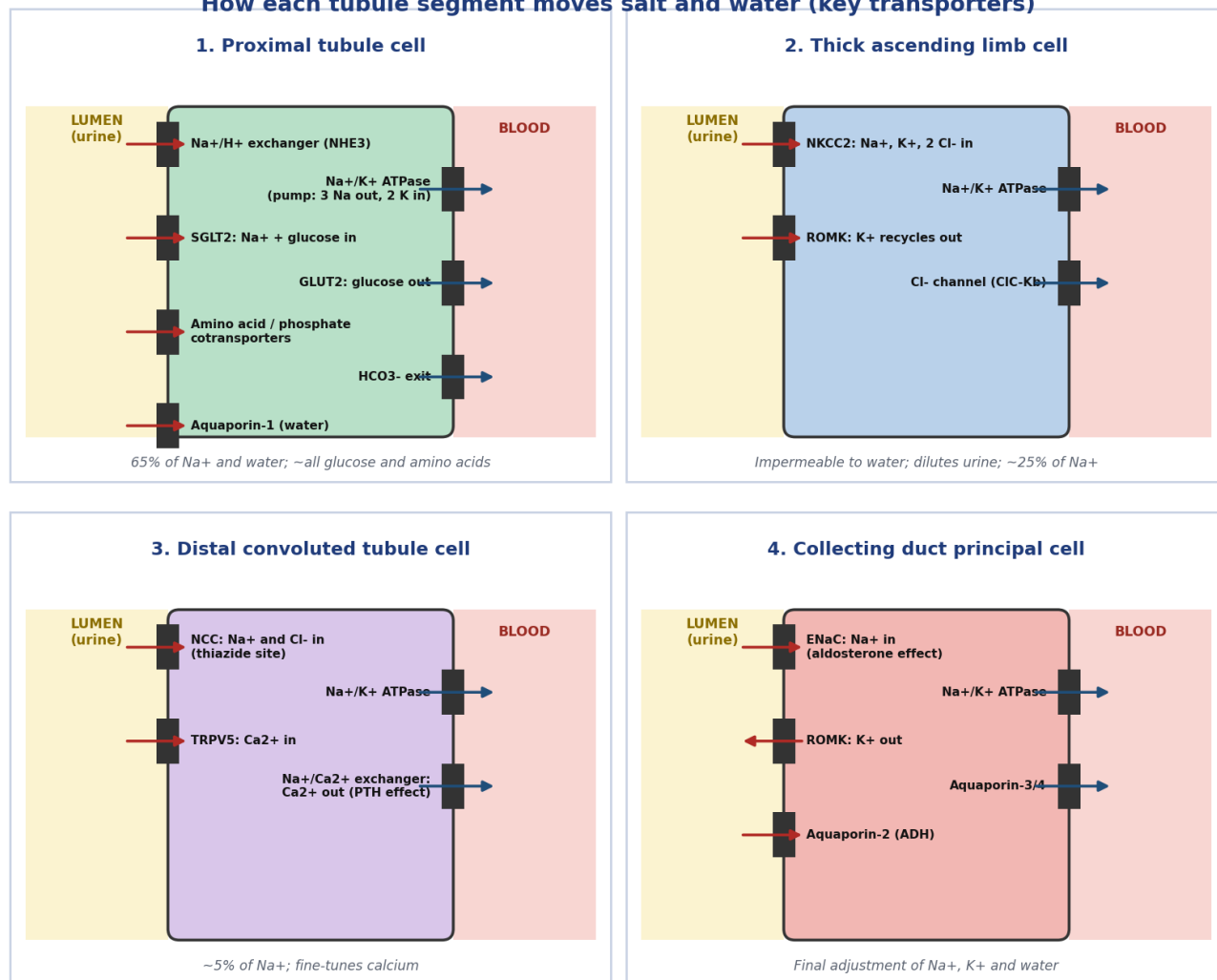


Figure 8. Key transporters in four tubule cell types. Red arrows: movement across the apical membrane (from urine into the cell or the reverse). Blue arrows: movement across the basolateral membrane (between the cell and the blood).

Segment by segment: what is reabsorbed

Segment	Share of filtered sodium and water	Also handles	Diuretic or drug that acts here
Proximal tubule	About 65%	Nearly all glucose and amino acids; 80 to 90% of bicarbonate; about 80% of phosphate; small proteins; secretes many drugs and organic acids	Acetazolamide (carbonic anhydrase); SGLT2 inhibitors (glucose-sodium carrier)
Thin descending limb	Water only (about 15 to 20% of filtered water)	Water leaves through aquaporin-1	None commonly used
Thick ascending limb	About 25% of sodium; no water	Potassium, chloride, calcium, magnesium	Loop diuretics (furosemide, bumetanide, torsemide) block NKCC2
Distal convoluted tubule	About 5%	Calcium (PTH-controlled), magnesium	Thiazide diuretics (hydrochlorothiazide, chlorthalidone) block NCC
Connecting tubule and collecting duct	About 3 to 5% of sodium; water depends on ADH	Potassium secretion; acid secretion (intercalated cells); urea	Potassium-sparing diuretics: amiloride/triamterene (ENaC), spironolactone/eplerenone (aldosterone receptor)

The proximal tubule: the bulk processor

- **Brush border** of microvilli multiplies surface area by roughly 20 to 40 times.
- **Glucose** is reabsorbed by SGLT2 (early) and SGLT1 (late) coupled to sodium; when blood sugar is high enough to exceed the carrier capacity (about 180 mg/dL, the "renal threshold"), glucose spills into the urine.
- **Bicarbonate** is recovered using carbonic anhydrase; the tubule also makes new bicarbonate from ammonia.
- **Proteins** that slip through the filter are taken up by endocytosis (megalin and cubilin receptors).
- **Secretion:** drugs (penicillin, diuretics), uric acid, and toxins enter the tubule from the blood via organic anion and cation transporters.

Loop of Henle and the countercurrent system

The loop of Henle builds the salty environment of the inner medulla, which is what lets the kidney make concentrated urine. Three ideas make it work:

- 1 The **descending limb** is permeable to water but not salt. As it dives into the increasingly salty medulla, water leaves and the fluid inside becomes more concentrated.
- 2 The **thick ascending limb** pumps out sodium, potassium, and chloride but is **waterproof**. Salt is added to the medulla while the tubule fluid becomes **dilute** (down to about 100 mOsm/kg by the time it reaches the distal tubule).
- 3 The **vasa recta** capillaries run in a hairpin alongside the loops and exchange water and salt in a way that removes water without washing out the gradient.

Making concentrated urine: the countercurrent system

Numbers are typical osmolality values in mOsm/kg (a measure of how concentrated a fluid is)

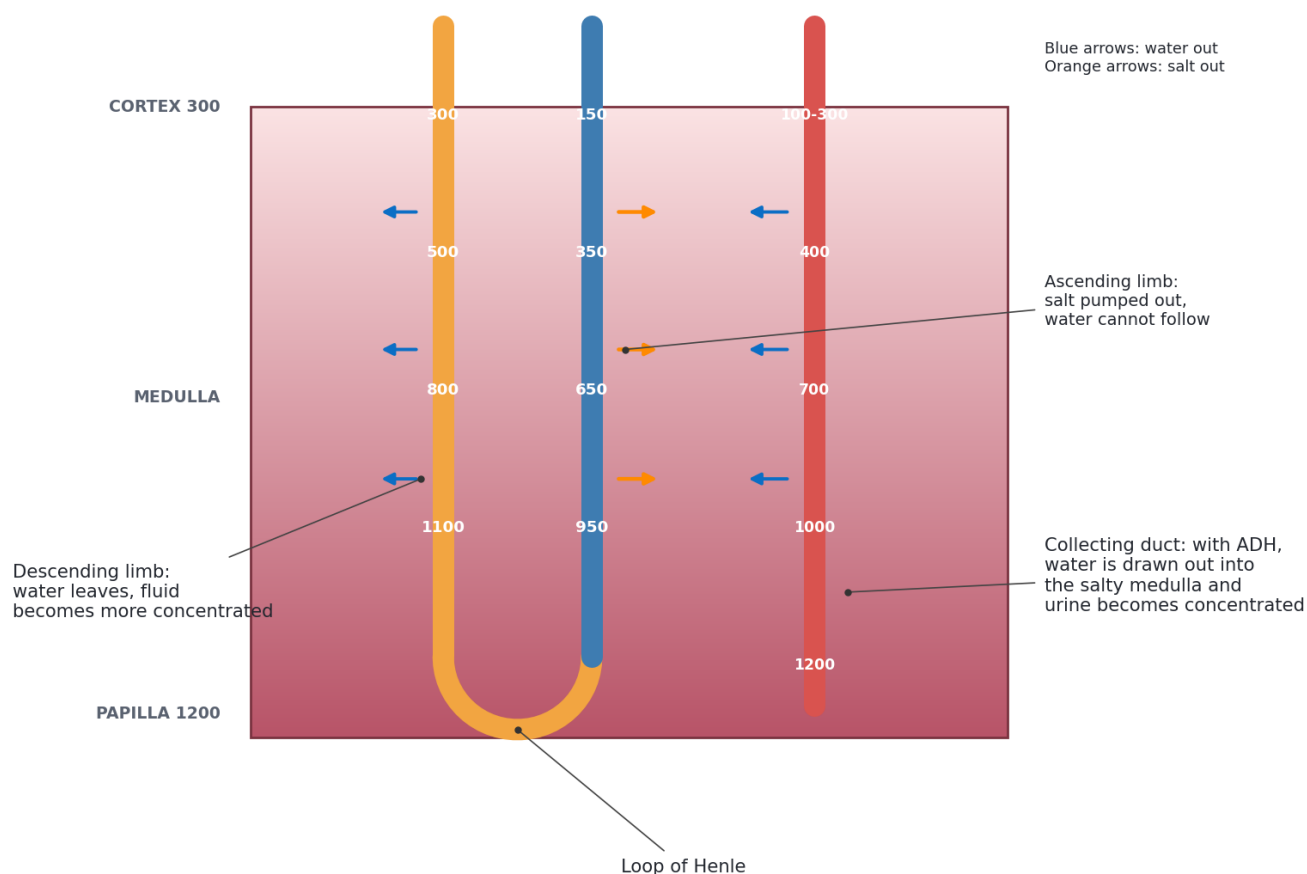


Figure 9. The countercurrent system. Values are typical osmolality figures (mOsm/kg). The salty inner medulla draws water out of the collecting duct when ADH is present.

The distal tubule and collecting duct: hormonal fine-tuning

Hormone	Made by	Kidney target	Action
Antidiuretic hormone (ADH, vasopressin)	Hypothalamus, released by the pituitary	Principal cells of the collecting duct	Inserts aquaporin-2 water channels so water is reabsorbed: concentrated, low-volume urine
Aldosterone	Adrenal cortex	Principal cells, late DCT	Increases ENaC and Na/K pumps: more sodium retained, more potassium lost
Parathyroid hormone (PTH)	Parathyroid glands	DCT and proximal tubule	More calcium reabsorbed; phosphate excreted
Atrial natriuretic peptide (ANP)	Heart atria	Collecting duct, glomerulus	More sodium and water excreted
Angiotensin II	Made from renin-driven cascade	Proximal tubule and efferent arteriole	Sodium retention; efferent arteriole constriction

Acid-base balance: the intercalated cells

The collecting duct's **alpha-intercalated cells** pump hydrogen ions into the urine with a proton pump (H^+ -ATPase) and return bicarbonate to the blood. When the body has too much base, **beta-intercalated cells** do the opposite. Together with the proximal tubule's bicarbonate recovery, this keeps the blood pH between 7.35 and 7.45. Failure of these cells causes **renal tubular acidosis**.

Key point

The kidney's tubule is not a passive pipe. It is a set of chemical "factories in a row." Diuretics, diabetes drugs (SGLT2 inhibitors), and many kidney diseases make more sense once you can point to the segment where the action is.

Where things go wrong: tubular and interstitial disease

Segment affected	What may happen	Examples
Proximal tubule	Spilling of glucose, amino acids, phosphate, bicarbonate (Fanconi syndrome); vulnerable to toxins and low oxygen	Acute tubular injury, some medicines and heavy metals, some inherited disorders
Thick ascending limb	Salt, calcium, magnesium loss	Bartter syndrome; loop diuretic effect
Distal tubule	Salt loss with low potassium and magnesium	Gitelman syndrome; thiazide effect
Collecting duct	Water and acid-base or potassium problems	Nephrogenic diabetes insipidus (no ADH response); renal tubular acidosis; Liddle syndrome
Interstitial (tissue between tubules)	Inflammation and scarring	Acute interstitial nephritis (often from medicines), chronic pyelonephritis, analgesic nephropathy



CHAPTER 10

The Juxtaglomerular Apparatus and Kidney Hormones

How the nephron communicates with itself and with the rest of the body

At the point where the thick ascending limb returns to touch its own glomerulus, three cell types cluster to form the **juxtaglomerular apparatus (JGA)**. It works like a local thermostat: it senses how much salt reaches the distal tubule and adjusts the glomerulus and the body's blood pressure controls accordingly.

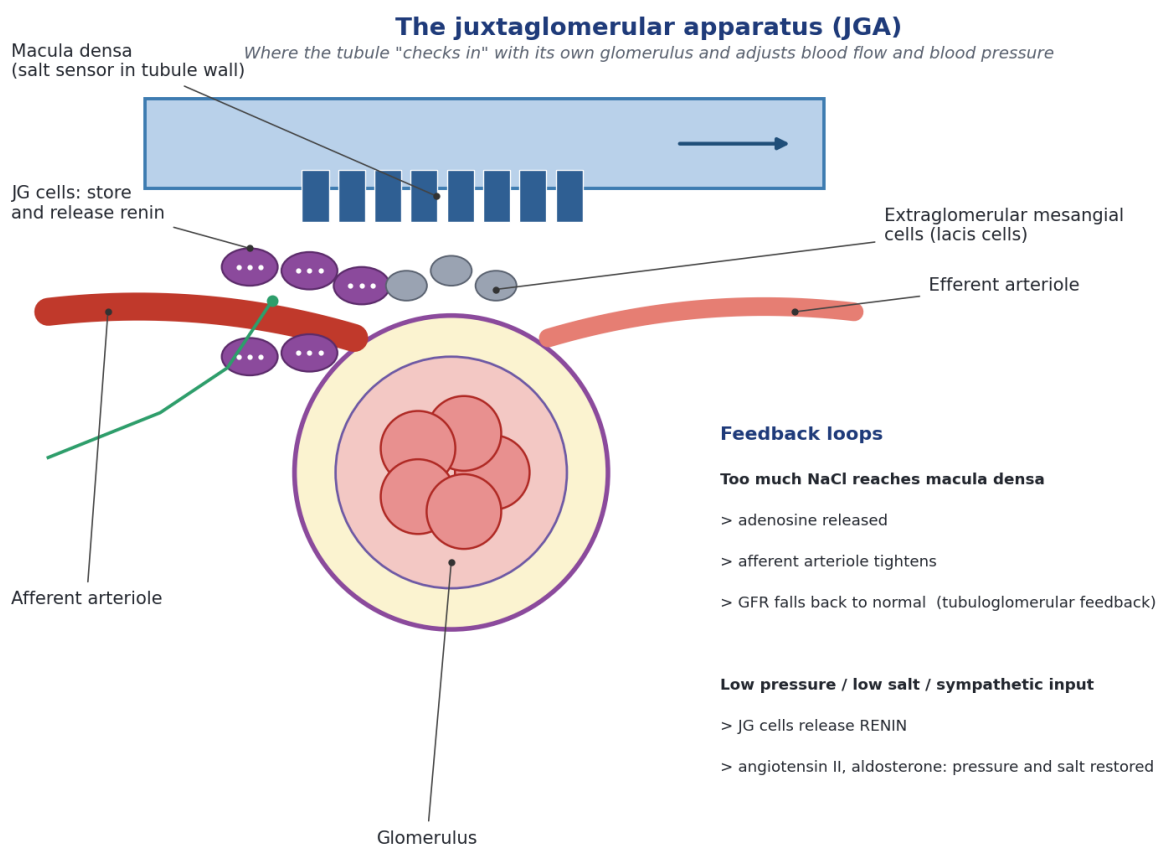


Figure 10. The juxtaglomerular apparatus and its two feedback pathways (schematic).

Component	Location	Function
Macula densa	Specialized cells in the wall of the tubule (end of the thick ascending limb) where it touches the glomerulus	Senses sodium chloride delivery to the distal tubule
Juxtaglomerular (JG, granular) cells	Modified smooth muscle cells in the wall of the afferent arteriole (a few in the efferent)	Store and release renin ; sense arteriole stretch (pressure)

Component	Location	Function
Extraglomerular mesangial (laci) cells	In the triangle between the arterioles and macula densa	Relay signals between macula densa and JG cells

Tubuloglomerular feedback (fast, local)

When too much salt reaches the macula densa (filtration is running too high), the cells release adenosine, which tightens the afferent arteriole and reduces filtration back to the set point. If salt delivery is too low, the opposite happens and renin is released. This keeps the nephron's filtration and salt delivery in balance from minute to minute.

The renin-angiotensin-aldosterone system (RAAS) (slower, body-wide)

Step	What happens
1. Trigger	Low blood pressure, low sodium, or sympathetic activation is sensed by the JG cells and macula densa
2. Renin	JG cells release renin , an enzyme, into the blood
3. Angiotensin I	Renin converts liver-made angiotensinogen into angiotensin I
4. Angiotensin II	ACE (mostly in the lungs) converts angiotensin I to angiotensin II
5. Actions	Angiotensin II narrows blood vessels (especially the efferent arteriole), increases sodium retention in the proximal tubule, stimulates thirst, and causes the adrenal gland to release aldosterone
6. Result	Blood pressure and blood volume rise, and the trigger switches off (negative feedback)

Medicines that target the RAAS

Common blood pressure medicines work on this pathway: **ACE inhibitors** (block step 4), **ARBs** (block angiotensin II receptors), and **mineralocorticoid receptor antagonists** (block aldosterone). Because the efferent arteriole relaxes, these medicines can slightly lower GFR at first; that is expected and is checked with blood tests.

The kidney as an endocrine organ

Hormone or factor	Made where	What it does	What happens in kidney failure
Erythropoietin (EPO)	Peritubular interstitial cells of the cortex, in response to low oxygen	Stimulates bone marrow to make red blood cells	Anemia (treated with EPO-type medicines and iron)
Calcitriol (active vitamin D)	Proximal tubule (1-alpha-hydroxylase)	Raises calcium and phosphate absorption from the gut; supports bone	Low calcitriol, high PTH, bone disease (CKD-mineral and bone disorder)
Renin	JG cells	Starts the RAAS	May be too high or too low; contributes to high blood pressure
Prostaglandins, kallikrein-kinin	Cortex and medulla	Dilate vessels, protect kidney blood flow	NSAIDs block prostaglandins and can lower GFR in vulnerable people

Key point

The kidney is both a **target** of hormones (ADH, aldosterone, PTH) and a **producer** of hormones (EPO, calcitriol, renin). That two-way conversation explains why kidney disease affects blood, bones, and blood pressure, not only urine.

PART 4

The Drainage System

CHAPTER 11

Ureters, Bladder, and Urethra

The drainage system that carries urine out of the body

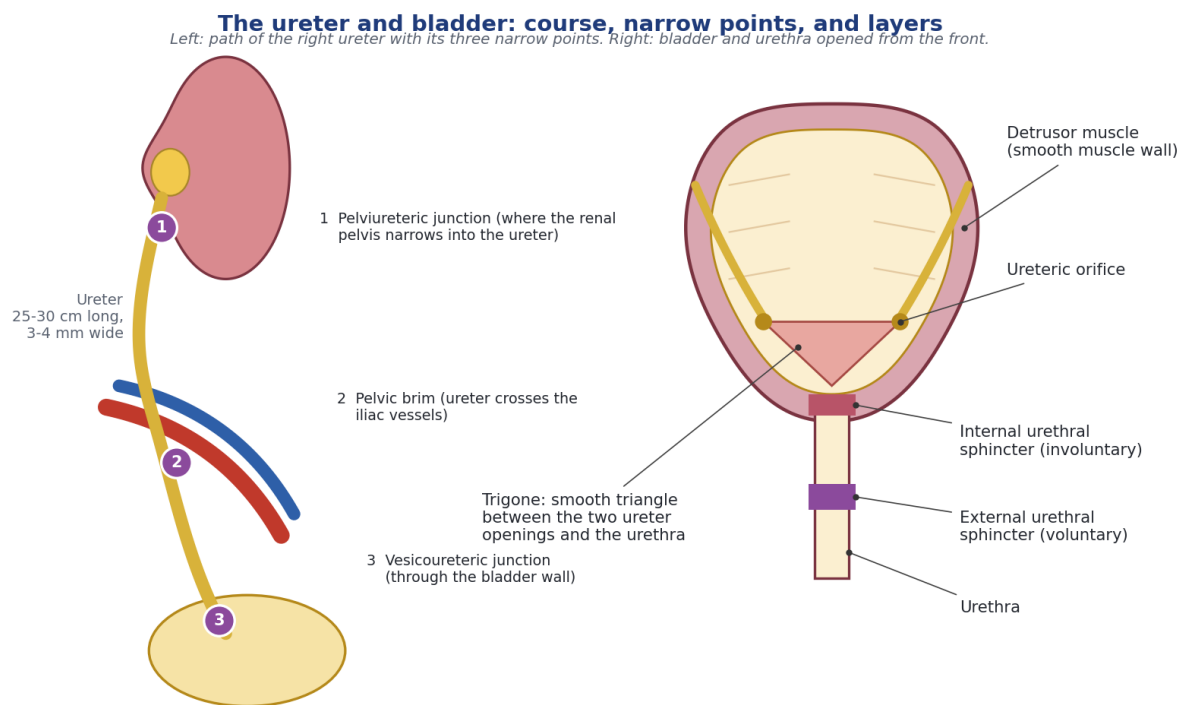


Figure 11. Left: the right ureter with its three narrow points. Right: bladder, trigone, and urethral sphincters seen in a front cut section.

The ureters

Feature	Details
Length and width	About 25 to 30 cm long, 3 to 4 mm wide (a soft drinking straw is wider)
Course	Begins at the renal pelvis, runs down on the front of the psoas muscle, crosses in front of the iliac vessels at the pelvic brim, dips into the pelvis, and enters the bladder from behind and to the side
Wall layers	Urothelium (lining), lamina propria (connective tissue), muscularis (inner longitudinal and outer circular smooth muscle; a third layer near the bladder), adventitia (outer covering)
Movement	Peristalsis : waves of muscle contraction roughly every 10 to 30 seconds push urine downward; gravity is not enough
Blood supply	Comes from several nearby arteries (renal, gonadal, common iliac, and bladder arteries), forming a chain along the ureter
One-way valve	The ureter tunnels obliquely through the bladder wall; as the bladder fills and squeezes, the tunnel is compressed, preventing urine from flowing back up (vesicoureteric reflux if this fails)

Three narrow points (where stones tend to stop)

Site	Where	Why it is narrow
1. Pelviureteric junction (PUJ)	Where the renal pelvis narrows into the ureter	Sudden change from a wide funnel to a thin tube
2. Pelvic brim	Where the ureter crosses the iliac vessels	The ureter is angled and compressed by the vessels
3. Vesicoureteric junction (VUJ)	Where the ureter passes through the bladder wall	The narrowest point (about 1 to 3 mm at the orifice)

Stone size (very approximate)

Most kidney stones smaller than about 5 mm pass on their own; stones larger than about 10 mm usually need treatment. Stone size, location, and symptoms guide the choice. Talk with your healthcare team; do not rely on these rules of thumb for your own care.

The bladder

The bladder is a hollow, stretchy muscular bag in the pelvis, behind the pubic bones. When empty it is about the size of a small pear and sits low; when full it rises into the lower abdomen.

Part or feature	Description
Detrusor muscle	Thick smooth muscle wall; contracts to expel urine
Urothelium (transitional epithelium)	Stretchy, waterproof lining that changes shape as the bladder fills and protects tissues from urine's acidity and waste
Trigone	Smooth triangle at the base between the two ureteric openings and the exit to the urethra (no rugae)

Part or feature	Description
Capacity	About 400 to 600 mL; the first urge is usually felt at about 150 to 300 mL
Nerves	Parasympathetic (S2 to S4, pelvic nerves) contract the detrusor; sympathetic (T10 to L2) helps storage; somatic (pudendal nerve) controls the external sphincter

The urethra and sphincters

	Female	Male
Length	About 3 to 4 cm; opens in front of the vagina	About 18 to 20 cm; passes through the prostate, then the penis
Sections	Single short tube	Prostatic, membranous, and spongy (penile) parts
Internal sphincter (involuntary)	Weaker; at the bladder neck	Stronger; also prevents semen flowing backward
External sphincter (voluntary)	Around the mid-urethra	Around the membranous urethra
Infection risk	Shorter urethra: urinary tract infections are more common	Enlarged prostate can block flow in older men

How urination works (micturition)

- 1 As the bladder fills, stretch receptors send signals to the spinal cord and brain. The brain normally **holds off** the urge by keeping the external sphincter closed and the detrusor relaxed.
- 2 When it is time to void, the brain's **pontine micturition center** switches the system: the detrusor contracts, the internal sphincter and bladder neck open, and the external sphincter relaxes.
- 3 Urine flows out through the urethra until the bladder is empty, and the system resets to storage mode.

When the plumbing and wiring disagree

Nerve damage (for example from spinal cord injury, diabetes, or multiple sclerosis) can disrupt this coordination and cause leakage or trouble emptying. Incomplete emptying raises infection risk and can back pressure up toward the kidneys; a nephrologist and urologist often work together on such cases.

PART 5

Life Story and Variations

CHAPTER 12

Development, Growth, and Aging

From a few cells to two million nephrons, and what happens over a lifetime

How the kidney forms and moves up

Top: the kidney rises from the pelvis to the loin. Bottom: how one nephron is built (steps not to scale)

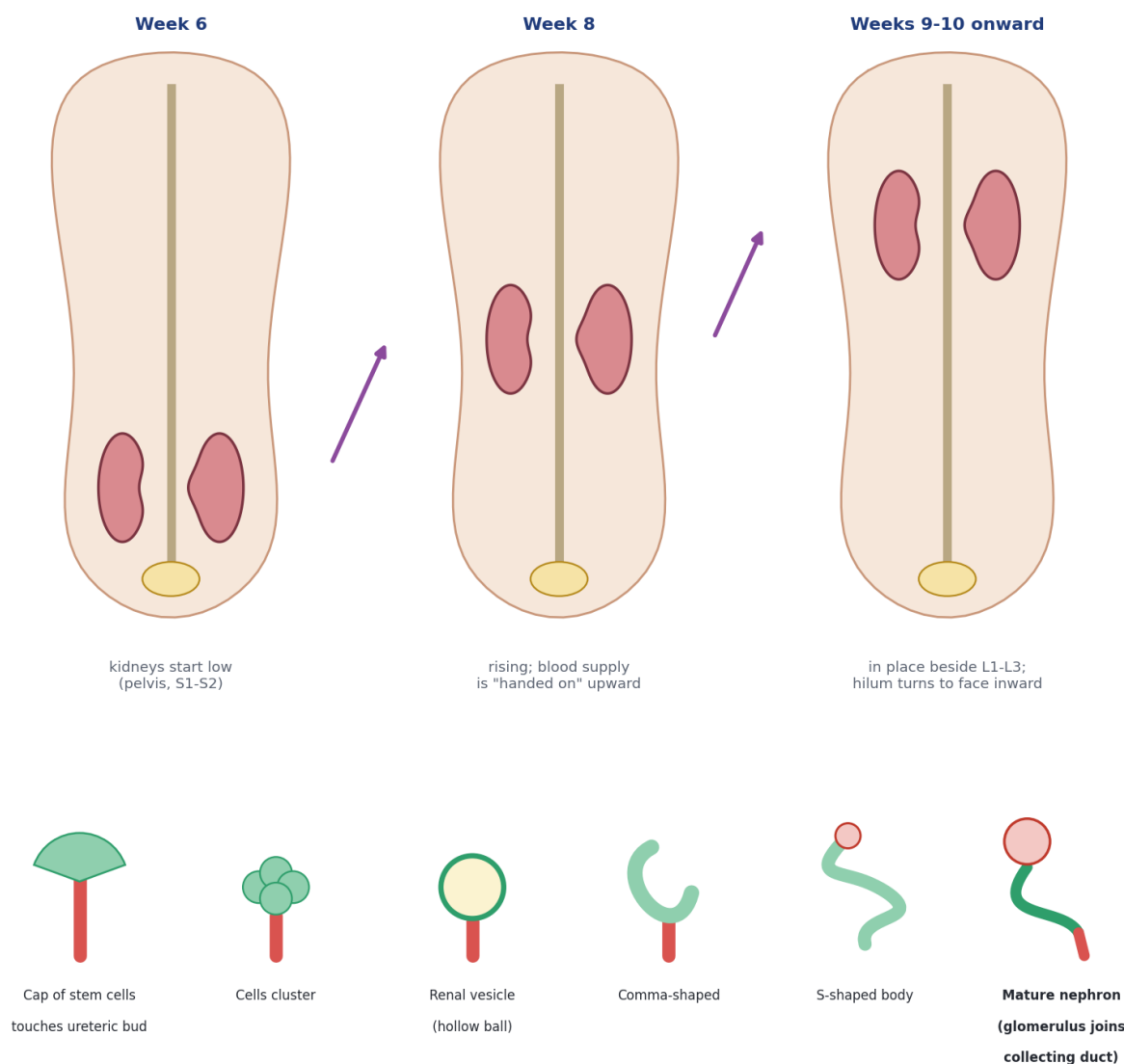


Figure 12. Top: the kidneys rise from the pelvis to the loin during weeks 6 to 10. Bottom: how a new nephron forms from stem cells and joins a collecting duct (schematic).

The kidney develops in three overlapping stages, each built from the intermediate mesoderm, a strip of embryonic tissue along the back.

Stage	When	What happens
Pronephros	About week 4	A temporary, non-working structure in the neck region; it disappears
Mesonephros	Weeks 4 to 8	A temporary filter; its duct persists and helps form parts of the male reproductive tract
Metanephros	From about week 5	The permanent kidney: a ureteric bud grows from the mesonephric duct and meets a cluster of stem cells (the metanephric mesenchyme). Signals pass both ways, so the bud branches into the collecting system and the stem cells build nephrons

Key steps and timeline

When	Event
About week 5	Ureteric bud meets the metanephric mesenchyme
Weeks 6 to 9	The bud branches repeatedly, forming the ureter, pelvis, calyces, and collecting ducts; the young kidney rises from the pelvis (S1 to S2) toward the loin (L1 to L3) and rotates so the hilum faces inward
About week 10	The kidneys begin making urine
Weeks 10 to 34	Nephron formation (nephrogenesis) continues; the fetal kidney's urine becomes the main source of amniotic fluid in the second half of pregnancy
About weeks 34 to 36	Nephron formation is complete; premature babies may have fewer nephrons
Infancy to adulthood	Kidneys grow by enlargement of existing nephrons, not by making new ones

Before birth

The kidney is not the fetus's waste filter; the placenta does that. Fetal urine mainly makes amniotic fluid, which the lungs need to develop. This is why severe kidney malformations before birth can affect lung development.

Nephron number and long-term risk

The number of nephrons a person is born with varies more than tenfold. Factors that can reduce the number include premature birth, low birth weight, poor maternal nutrition, and some maternal medicines or illnesses. People born with fewer nephrons may be at higher lifetime risk of high blood pressure and chronic kidney disease, especially with extra stress such as diabetes or obesity. This is a risk factor, not a certainty.

The kidney across the lifespan

Life stage	Changes
Newborn	Kidneys are lobulated; GFR is low (about 20 to 40 mL/min/1.73 m ² in term babies) and matures over the first 1 to 2 years; the newborn cannot concentrate urine as well as an adult
Childhood and adolescence	Kidney length and weight increase steadily; GFR reaches adult values by age 2; growth spurts adjust size
Young adulthood	Peak function; GFR about 100 to 125 mL/min/1.73 m ²
Pregnancy	Kidneys enlarge slightly (about 1 cm longer); renal pelvis and ureters widen; GFR rises by about 40 to 50% in the first half of pregnancy
After about age 30 to 40	GFR falls on average by about 0.5 to 1 mL/min/1.73 m ² per year; some nephrons scar (nephrosclerosis)
Older age	Cortex thins, kidney volume shrinks, more cysts; less able to concentrate urine and handle salt or water loads; more sensitive to dehydration and to some medicines

Aging vs disease

A lower eGFR in older age is common, but a rapid fall or a large amount of protein in the urine is **not** normal aging. Ask your healthcare team what your numbers mean for you.

CHAPTER 13

Variations and Birth Differences

When the plan for building the kidney changes

About 1 in 500 babies is born with a difference in the kidneys or urinary tract, making these among the most common birth differences. Many cause no symptoms and are found by chance on imaging; others need follow-up. The numbers below are approximate and vary among studies.

Common variations in the kidneys and their drainage tubes

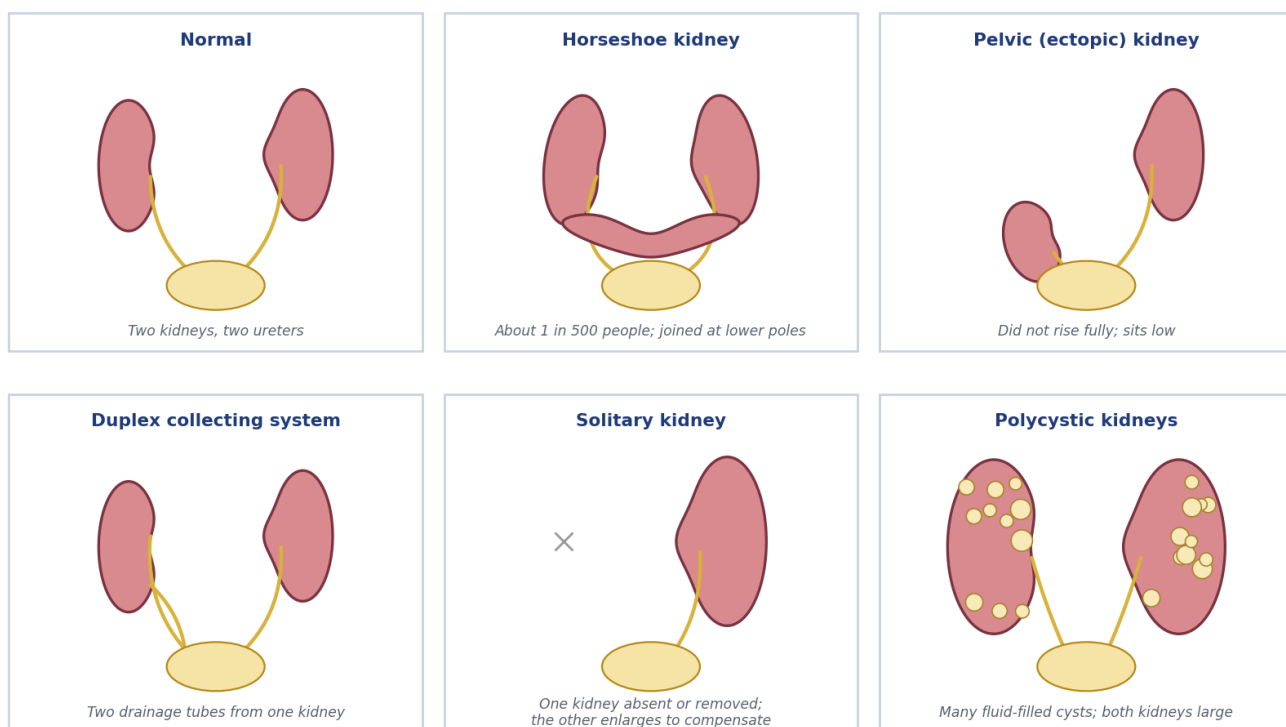


Figure 13. Common variations in kidney number, position, shape, and drainage (schematic).

Common variations and anomalies

Condition	Approximate frequency	What it is	Why it matters
Unilateral renal agenesis (one kidney)	About 1 in 1,000 to 2,000	One kidney never forms; the other enlarges to compensate	Usually normal function; protect the healthy kidney; may have other urinary tract differences
Horseshoe kidney	About 1 in 500	Kidneys fused at the lower poles by an isthmus that stays low and crosses in front of the aorta	More prone to blockage, stones, infection; important for surgery planning
Ectopic (pelvic) kidney	About 1 in 2,000 to 3,000	Kidney fails to rise; sits in the pelvis	May have unusual blood supply; can be confused with a mass
Crossed fused ectopia	Rare (about 1 in 7,000)	One kidney lies on the opposite side and is fused to its partner	Often found by chance
Duplex (double) collecting system	About 0.5 to 2%	Two pelvises and ureters from one kidney; may join (partial) or stay separate (complete)	The upper ureter can drain abnormally (ureterocele or ectopic insertion), and the lower one can reflux
Accessory renal arteries	About 20 to 30%	Extra arteries from the aorta	Surgical planning; can cause a blockage in rare cases
Malrotation	Uncommon	Kidney fails to turn so the hilum faces forward	Usually harmless; can look unusual on imaging
Pelviureteric junction (PUJ) obstruction	About 1 in 1,500	Narrowing where the pelvis meets the ureter	Backs urine into the pelvis (hydronephrosis); found on prenatal ultrasound or later with pain or infection
Vesicoureteric reflux (VUR)	About 1% of children	Urine flows backward from the bladder toward the kidney	Linked to urinary infections and scarring; often improves with growth
Multicystic dysplastic kidney (MCDK)	About 1 in 4,000	A non-working kidney replaced by cysts	Often shrinks over time; the other kidney must be watched
Polycystic kidney disease (PKD)	ADPKD about 1 in 400 to 1,000 (gene carriers); ARPKD about 1 in 20,000	Inherited cyst-forming diseases	Enlarged kidneys, high blood pressure, and often kidney failure later in life (see the TLHF PKD guide)
Posterior urethral valves	About 1 in 5,000 to 8,000 boys	A membrane in the male urethra blocks urine outflow	Needs early treatment; can damage the bladder and kidneys before birth

Living well with one kidney

If you have one kidney (from birth or surgery), general advice is the same as for anyone: keep blood pressure controlled, stay hydrated, avoid unnecessary NSAIDs, protect from contact injury with padding when playing sports, and have regular checkups of blood pressure, urine protein, and eGFR.

Before birth: how differences are found

Many differences are first spotted on **prenatal ultrasound**: a fluid-filled pelvis (**hydronephrosis**), a missing kidney, extra-bright kidneys, or too little amniotic fluid. Most mild cases resolve, and follow-up ultrasound after birth confirms the finding. Persistent or severe findings lead to further tests, sometimes including a bladder x-ray study (VCUG) or nuclear scans, and referral to pediatric nephrology or urology.

CHAPTER 14

Seeing the Kidneys: Imaging and Biopsy

What each test shows about anatomy

Different imaging tests highlight different parts of kidney anatomy. Radiologists interpret the pictures in three standard planes (coronal, axial, and sagittal; see Chapter 1). Images of your own kidneys are available from your care team; this chapter explains how to read the anatomy on them.

Test	How it works	What it shows well	Considerations
Ultrasound	High-frequency sound waves; no radiation	Size, shape, cortex thickness, cysts, stones (larger ones), hydronephrosis, blood flow with Doppler	Safe in pregnancy and children; quality depends on body size and gas in the bowel
X-ray (KUB)	Simple x-ray of kidneys, ureters, bladder	Calcified stones, gas patterns	Limited detail; small or non-calcified stones can be missed
CT scan	X-ray slices; contrast dye can highlight vessels and function	Stones (best test in emergencies), masses, injuries, vessels (CT angiography), abscess	Uses radiation; iodine contrast requires attention to kidney function and hydration
MRI	Magnets and radio waves; no radiation	Soft tissue detail, masses, blood vessels, cysts	Gadolinium contrast is avoided or limited in severe kidney failure
Nuclear scans (DMSA, MAG3)	Small amount of radioactive tracer	Split function (how much each kidney works), scarring, blockage, transplant function	Low radiation; tests function more than fine anatomy
Voiding cystourethrogram (VCUG)	X-ray during bladder filling and voiding	Bladder shape, urethra, reflux	Common in children with infections or prenatal findings
Angiography	Contrast injected into arteries	Renal artery narrowing, aneurysm, bleeding	Invasive; usually reserved for treatment or complex cases
Kidney biopsy	A thin needle takes tiny tissue samples, guided by ultrasound	Microscopic structure (glomeruli, tubules, interstitium, vessels), immunofluorescence, electron microscopy	Usually taken from the lower pole of the kidney where the cortex is thick and large vessels are fewer; needs bleeding-risk checks

What a normal ultrasound looks like

- **Size:** about 10 to 12 cm long in adults. The two kidneys should be within about 1.5 to 2 cm of each other in length.

- **Cortex:** smooth outline; echo brightness (echogenicity) equal to or lower than the nearby liver or spleen. Bright cortex suggests medical kidney disease.
- **Pyramids:** darker (hypoechoic) triangles arranged like a ring around the sinus.
- **Sinus:** bright central fat and collecting system. A dark central area within the bright sinus suggests a widened pelvis or calyces (hydronephrosis).
- **Parenchymal thickness:** cortex plus medulla roughly 1.5 to 2.5 cm; thinning suggests chronic scarring.
- **Doppler:** color and waveform shows blood flow in the main and segmental arteries and veins.

What a normal CT or MRI cross-section shows

- Both kidneys as rounded structures beside the spine (see Figure 2).
- Bright cortex and darker medulla in the early contrast phase; then uniform brightness, and later bright urine in the collecting system.
- Renal veins running toward the inferior vena cava; the left vein crossing in front of the aorta.
- Perirenal fat (dark on CT) outlining the fascia.
- Ureters as small dots along the psoas muscles.

Reading a report

When you receive a radiology report, look for these words and ask your healthcare team what they mean for you: **echogenicity**, **hydronephrosis**, **cortical thickness**, **simple cyst** (usually harmless) versus **complex cyst** (needs follow-up), **calculus** (stone), and **atrophy** (shrinkage).

Normal variants

Common, harmless findings include simple cysts (present in about half of people over 50), persistent fetal lobulation, a "dromedary hump" (a bulge on the left kidney from the spleen), and a prominent column of Bertin (which can mimic a mass). Radiologists are used to these, but new findings should always be reviewed by your doctor.

PART 6

Anatomy and Disease

CHAPTER 15

How Structure Explains Disease

Using anatomy to understand symptoms, tests, and treatments

Every kidney disease affects one or more parts of the anatomy you have just learned. Knowing **which part** is affected helps explain which tests are ordered and why treatments differ. This chapter connects structure to disease. It is an overview for understanding, not a diagnostic guide.

Disease by location in the kidney

Anatomic level	Problem examples	Typical clues
Before the kidney (prerenal): blood flow	Dehydration, heart failure, bleeding, narrowed renal artery, some medicines	Low urine output, high BUN-to-creatinine ratio; often reversible if treated early
Glomerulus	IgA nephropathy, lupus nephritis, minimal change disease, FSGS, membranous nephropathy, diabetic kidney disease	Protein or blood in urine, foamy urine, swelling, high blood pressure
Tubules and interstitium	Acute tubular injury (ATN), acute interstitial nephritis, chronic interstitial nephritis, Fanconi syndrome	Rising creatinine, casts in urine, electrolyte and acid-base problems
Blood vessels	Hypertensive nephrosclerosis, renal artery stenosis, vasculitis, thrombotic microangiopathy	High blood pressure, sudden or gradual decline in function
Cystic and inherited	Polycystic kidney disease, Alport syndrome, medullary sponge kidney	Family history, enlarged kidneys, hearing or eye findings (Alport)
Collecting system and ureter (postrenal)	Stones, strictures, tumors, retroperitoneal fibrosis, PUJ obstruction	Colicky flank pain, hydronephrosis on ultrasound, infection
Bladder and urethra	Enlarged prostate, urethral stricture, neurogenic bladder, bladder outlet obstruction, urinary tract infection	Weak stream, retention, urgency, back-pressure on both kidneys

Matching tests to anatomy

Test	Which part of the anatomy it reflects	What it tells you
Serum creatinine and eGFR	Total filtration by the glomeruli	How well the kidneys are filtering; trends matter more than single results
Blood urea nitrogen (BUN)	Filtration plus tubular handling, hydration, and protein intake	A rough measure; rises with dehydration and bleeding
Urine albumin-to-creatinine ratio (ACR) or protein	Integrity of the glomerular barrier (and proximal tubule uptake)	Early sign of kidney damage; used to stage chronic kidney disease
Urinalysis: blood, casts, cells	Glomerulus (red cell casts, dysmorphic red cells), tubule (granular casts), lower tract (whole red cells, white cells)	Localizes inflammation or bleeding
Urine specific gravity or osmolality	Concentrating ability: loop, collecting duct, medullary gradient, ADH	How well the kidney concentrates or dilutes urine
Blood potassium, bicarbonate, calcium, phosphate	Tubular transport and endocrine functions	Electrolyte and acid-base balance; mineral and bone health
Hemoglobin	EPO-producing cells in the cortex	Anemia is common in advanced kidney disease
Imaging and biopsy	Gross anatomy; microscopic anatomy	Structural cause of disease and its type

Obstruction: what the anatomy predicts

Urine flows one way. When it cannot drain, pressure backs up through the ureter, pelvis, and calyces, a condition called **hydronephrosis** ("water in the kidney"). The location of the blockage tells you what to expect:

Blocked at	What swells	Notes
PUJ (pelviureteric junction)	Renal pelvis and calyces only; ureter normal	Often congenital narrowing, or a crossing vessel
Mid-ureter or pelvic brim	Pelvis, calyces, and upper ureter	Classically kidney stones
Vesicoureteric junction	Whole ureter, pelvis, and calyces	Stones or strictures near the bladder
Bladder outlet or urethra	Both kidneys and ureters, and a full bladder	Enlarged prostate or urethral valves; can be silent for a long time

Do not wait

Blockage combined with infection is an emergency. A blocked, infected kidney can quickly lead to blood infection (sepsis). Fever, chills, severe flank pain, or vomiting with known stones needs urgent care.

Why urinary tract infections travel

Bacteria usually enter through the urethra, climb into the bladder, and, if not treated, may ascend the ureter to the kidney (**pyelonephritis**). Anatomy shapes the risk: the female urethra is shorter, which raises the frequency of bladder infections; reflux of urine up the ureter or any blockage makes upper-tract infection more likely; and the medullary papillae and poles are areas that scar most easily. Repeated infection scars the parenchyma, which is why prompt treatment in children is important.

Kidney stones and the collecting system

Stones form from crystals in concentrated urine, often starting on the tip of a papilla (a **Randall's plaque**). They matter for anatomy because they tend to lodge at the three narrow points (Chapter 11), and because stones in the lower calyx can be harder to clear. Drinking enough fluid to make pale urine is the most reliable prevention, along with dietary advice tailored to the stone type.

Kidney tumors

Tumor	Arises from	Notes
Renal cell carcinoma	Cells of the renal tubules (mostly proximal tubule)	The most common adult kidney cancer; often found by chance on imaging
Urothelial carcinoma	Urothelium lining the pelvis, ureter, or bladder	Blood in the urine is the classic sign; smoking is a major risk factor
Angiomyolipoma	Blood vessels, muscle, and fat	Usually benign; can bleed
Wilms tumor	Immature nephron precursor cells	The main kidney cancer of young children

Anatomy and kidney transplant

Understanding the anatomy makes transplant surgery easier to picture. The donor kidney is usually placed in the **iliac fossa**, in the lower abdomen on one side, outside the peritoneal cavity. The surgeon connects:

Donor structure	Connected to	Why there
Renal artery	Recipient's external (or common) iliac artery	A large, easy-to-reach artery near the surface
Renal vein	Recipient's external iliac vein	Large vein alongside the artery
Ureter	Recipient's bladder (through a short tunnel to prevent reflux)	Short path; avoids needing a long ureter

Usually the recipient's own kidneys are left in place. For living donors, the **left kidney** is often chosen for donation because its vein is longer, which makes it easier to connect. For more, see the TLHF guide *Kidney Transplant: The Complete Patient & Family Guide*.

Kidney injury (trauma): which anatomy is at risk

Injury	Anatomy involved	Comments
Bruise (contusion) or small tear of the cortex	Cortex and capsule	Most kidney injuries; often managed with rest and monitoring
Deeper tear into the medulla or collecting system	Pyramids, calyces, pelvis	Urine leakage (urinoma) possible
Injury to the pedicle (renal artery or vein)	Hilum	Life-threatening bleeding or loss of blood flow; needs emergency care
Shattered kidney	Multiple segments	Severe; may need surgery

Key point

The kidneys are the "quiet guardians" of the body. When you understand where each disease strikes, tests stop feeling like random numbers and start to feel like a map of a place you know.

CHAPTER 16

Protecting Your Kidneys

What the anatomy tells us about staying healthy

Because nephrons cannot regrow, protecting the ones you have is the best strategy. Kidney damage is often **silent** until much later; the best defense is prevention and early detection. Here are the main ideas, linked to the anatomy behind them.

Habit	Anatomy behind it	What it does
Keep blood pressure controlled	High pressure damages glomerular capillaries and arterioles	Slows scarring; ask your team for your personal target
Manage blood sugar	High glucose thickens the GBM and damages podocytes; also stresses the proximal tubule	Lowers the risk of diabetic kidney disease
Do not smoke	Narrows renal arteries; raises kidney and bladder cancer risk	Protects blood flow and urothelium
Drink enough fluid	Keeps urine dilute, helps the concentrating system, and reduces stone-forming crystals	Fewer stones and infections; amount depends on your health
Watch salt	Salt increases glomerular pressure and blood pressure	Protects the filter
Use pain relievers wisely	NSAIDs constrict the afferent arteriole and can injure tubules and the interstitium	Ask before regular use of ibuprofen, naproxen, or high-dose aspirin
Check medicines and supplements	Many drugs are cleared by the kidney; some herbs and supplements are harmful to nephrons	Bring all products to appointments
Stay active and keep a healthy weight	Extra weight increases filtration pressure and blood pressure	Lowers risk of chronic kidney disease
Treat urinary infections early; do not hold urine for long periods	The ascending route from bladder to kidney	Prevents scarring
Protect your flanks	Kidneys lie against the back wall with only partial rib cover	Wear padding in contact sports; use seat belts
Get screened if at risk	Damage is silent until late	Blood test (eGFR) and urine test (ACR) at least yearly if you have diabetes, high blood pressure, heart disease, family history, or are over 60

Five questions for your next visit

Ask your healthcare team: What is my eGFR? What is my urine albumin? What is my blood pressure goal? Are any of my medicines a concern for my kidneys? How often should I be checked?

From TLHF

Kidney health is a team effort, and every step helps. Even small changes matter.

Health. Awareness. Hope.

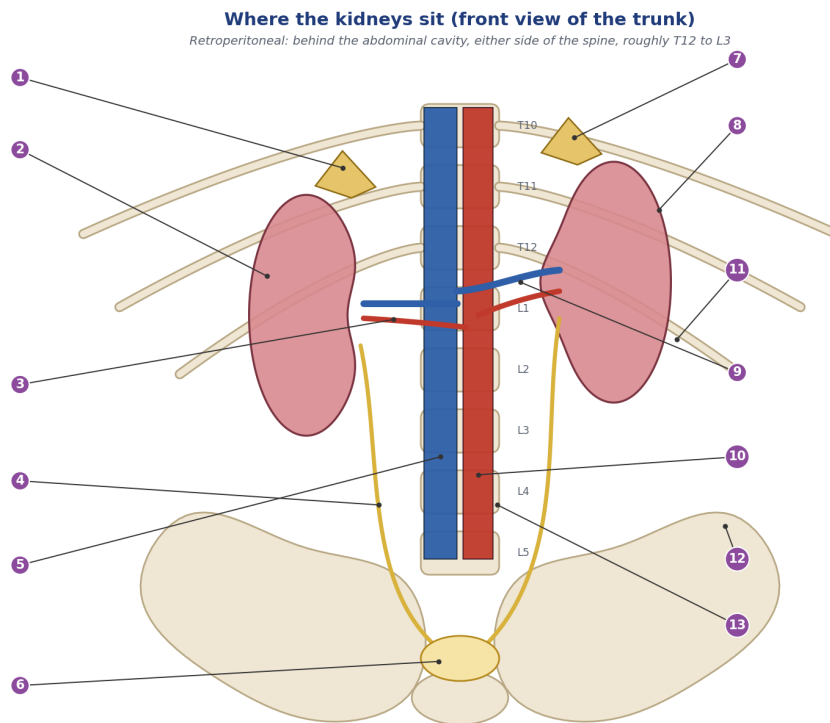
PART 7

Study Tools

LABELING EXERCISE L1

Label the diagram: where the kidneys sit

Write the name of each numbered structure. Check your work with the answer key in the next section.
(Numbers count from top left.)

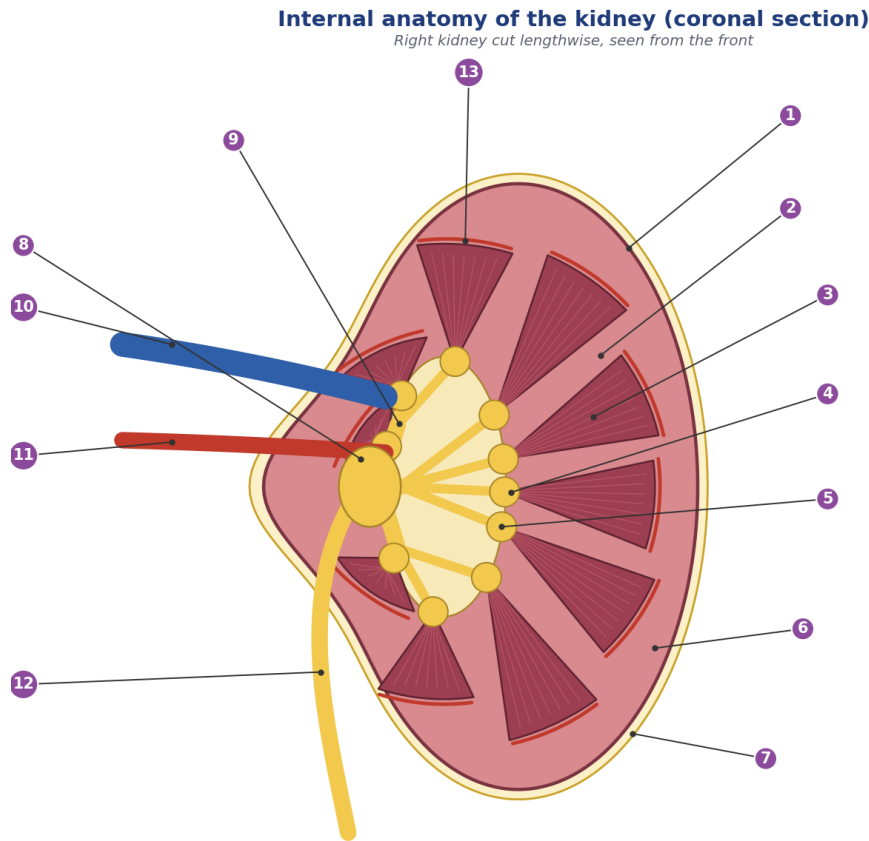


#	Your answer	#	Your answer
1		8	
2		9	
3		10	
4		11	
5		12	
6		13	
7			

LABELING EXERCISE L2

Label the diagram: inside the kidney

Name each numbered part of this lengthwise section of a kidney.

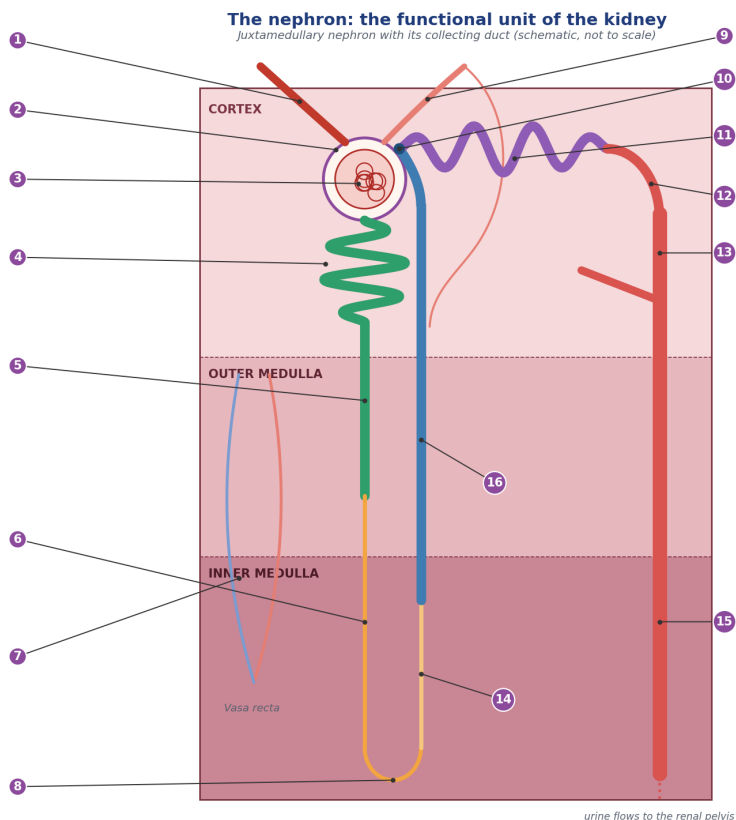


#	Your answer	#	Your answer
1		8	
2		9	
3		10	
4		11	
5		12	
6		13	
7			

LABELING EXERCISE L3

Label the diagram: the nephron

Name each numbered part of the nephron and its blood vessels.



#	Your answer	#	Your answer
1		9	
2		10	
3		11	
4		12	
5		13	
6		14	
7		15	
8		16	

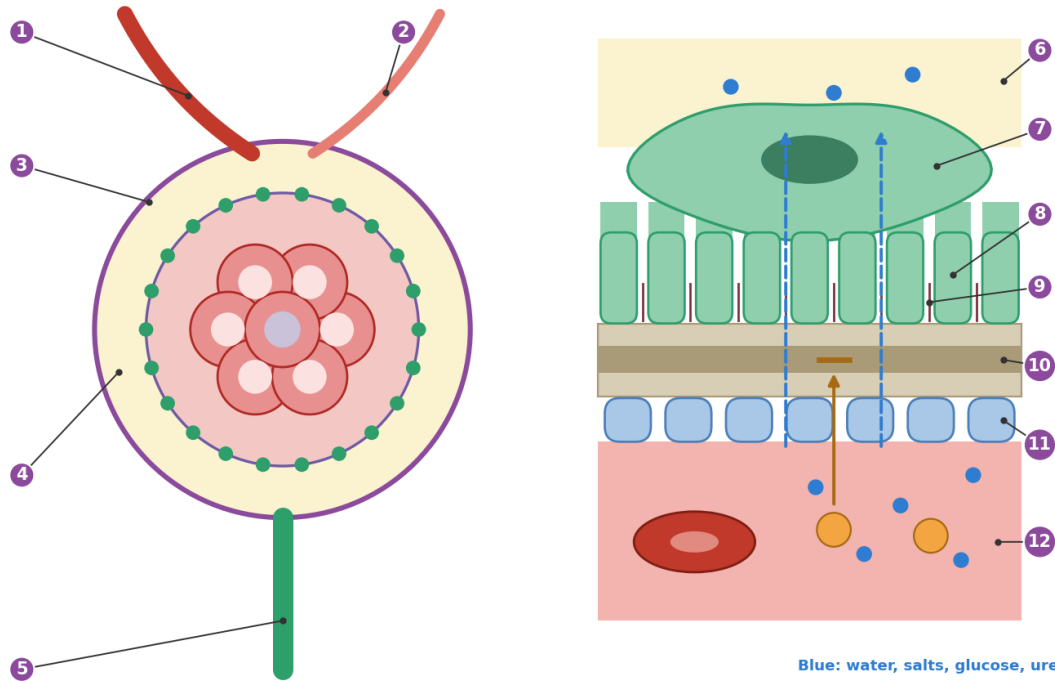
LABELING EXERCISE L4

Label the diagram: glomerulus and filtration barrier

Name each numbered structure of the glomerulus and its filtration barrier.

The glomerulus and the filtration barrier

Left: whole glomerulus in its capsule. Right: enlarged view of the three-layer filter (not to scale)



Blue: water, salts, glucose, urea pass through
Orange: albumin (protein) is normally held back

#	Your answer	#	Your answer
1		7	
2		8	
3		9	
4		10	
5		11	
6		12	

Answer keys: labeling exercises

Compare with the labeled diagrams earlier in the guide (Figures 1, 4, 6, and 7).

L1: Where the kidneys sit

1	Right adrenal gland	8	Left kidney (slightly higher)
2	Right kidney (a little lower: the liver sits above it)	9	Left renal vein (long; crosses in front of the aorta)
3	Right renal artery (passes behind the IVC)	10	Abdominal aorta
4	Right ureter	11	12th rib
5	Inferior vena cava (IVC)	12	Iliac crest (top of pelvis)
6	Bladder	13	Lumbar spine
7	Left adrenal gland		

L2: Inside the kidney

1	Renal capsule (thin fibrous coat)	8	Renal pelvis (funnel)
2	Renal column (of Bertin): cortex between pyramids	9	Major calyx (2-3 per kidney)
3	Renal (medullary) pyramid	10	Renal vein
4	Renal papilla (tip of pyramid)	11	Renal artery
5	Minor calyx (cup around each papilla)	12	Ureter
6	Renal cortex (outer layer; holds the glomeruli)	13	Arcuate arteries (arch over each pyramid base)
7	Perirenal fat		

L3: The nephron

1	Afferent arteriole	9	Efferent arteriole
2	Bowman's capsule	10	Macula densa (touches the glomerulus)
3	Glomerulus (capillary tuft)	11	Distal convoluted tubule (DCT)
4	Proximal convoluted tubule (PCT)	12	Connecting tubule
5	Proximal straight tubule	13	Cortical collecting duct
6	Thin descending limb	14	Thin ascending limb
7	Vasa recta (blood vessels running with the loops)	15	Medullary collecting duct
8	Loop of Henle (hairpin bend)	16	Thick ascending limb (TAL)

L4: Glomerulus and filtration barrier

1	Afferent arteriole	7	Podocyte
2	Efferent arteriole	8	Foot processes (pedicels)
3	Bowman's capsule (parietal layer)	9	Slit diaphragm
4	Urinary space (filtrate collects)	10	Glomerular basement membrane (GBM)
5	Proximal tubule begins at the urinary pole	11	Fenestrated endothelium
6	Urinary space	12	Capillary lumen (blood)

Review quiz: 25 questions

Circle the best answer for each question. The answer key follows the quiz. Score yourself: 22 to 25 = excellent; 17 to 21 = good; below 17 = review the chapters and try again.

1. Which layer of tissue directly surrounds the kidney and is stuck to its surface?
A. Renal (Gerota's) fascia **B.** Renal capsule **C.** Perirenal fat **D.** Peritoneum
2. The kidneys are described as retroperitoneal. This means they lie:
A. Inside the peritoneal cavity **B.** Behind the peritoneum **C.** In front of the peritoneum **D.** Inside the pelvis
3. Which kidney usually sits slightly lower, and why?
A. Left, because of the stomach **B.** Right, because of the liver **C.** Left, because of the spleen **D.** Both are always level
4. Going from front to back, the structures at the hilum are:
A. Artery, vein, ureter **B.** Vein, artery, ureter **C.** Ureter, vein, artery **D.** Vein, ureter, artery
5. Which structure is the cortex tissue that extends between renal pyramids?
A. Renal papilla **B.** Medullary ray **C.** Renal column (of Bertin) **D.** Renal sinus
6. Urine drips from the papilla directly into the:
A. Major calyx **B.** Renal pelvis **C.** Minor calyx **D.** Ureter
7. Which arteries arch over the base of each pyramid?
A. Interlobar **B.** Arcuate **C.** Interlobular **D.** Segmental
8. The blood vessel that leaves the glomerulus is the:
A. Afferent arteriole **B.** Efferent arteriole **C.** Venule **D.** Vasa recta
9. Which statement about the renal veins is correct?
A. The right is longer than the left **B.** The left crosses in front of the aorta **C.** Both empty into the aorta **D.** They enter behind the arteries at the hilum
10. Kidney pain is often felt in the flank and groin because sensory nerves enter the spinal cord at about:
A. C3 to C5 **B.** T10 to L1 **C.** L5 to S1 **D.** S2 to S4
11. Approximately what share of the filtered sodium and water is reabsorbed in the proximal tubule?
A. About 5% **B.** About 25% **C.** About 65% **D.** About 95%
12. The brush border is found on cells of the:
A. Proximal tubule **B.** Thin descending limb **C.** Distal tubule **D.** Collecting duct
13. Which segment is waterproof and pumps out salt to dilute the tubular fluid?
A. Thin descending limb **B.** Thick ascending limb **C.** Proximal tubule **D.** Bowman's capsule
14. Loop diuretics such as furosemide block which transporter?
A. NCC **B.** ENaC **C.** NKCC2 **D.** SGLT2
15. Which cell type forms the outer layer of the filtration barrier with foot processes?
A. Mesangial cells **B.** Podocytes **C.** Endothelial cells **D.** Macula densa cells
16. Which hormone inserts aquaporin-2 water channels into the collecting duct?
A. Aldosterone **B.** ADH (vasopressin) **C.** PTH **D.** Renin

- 17.** The macula densa is best described as:
A. A group of podocytes **B.** Salt-sensing cells in the tubule wall next to the glomerulus **C.** A muscle layer of the ureter **D.** A part of the loop of Henle's bend
- 18.** Which cells release renin?
A. Macula densa cells **B.** Podocytes **C.** Juxtaglomerular (granular) cells **D.** Intercalated cells
- 19.** The cells that produce erythropoietin (EPO) are located in the:
A. Cortical interstitium **B.** Collecting duct **C.** Urethra **D.** Bladder trigone
- 20.** Which of these is NOT one of the three narrow points of the ureter?
A. Pelviureteric junction **B.** Pelvic brim **C.** Vesicoureteric junction **D.** Trigone of the urethra
- 21.** Nephron formation is essentially complete by about:
A. Week 10 of pregnancy **B.** Weeks 34 to 36 of pregnancy **C.** Age 2 **D.** Adolescence
- 22.** A horseshoe kidney is joined at the:
A. Upper poles **B.** Lower poles **C.** Hila **D.** Ureters
- 23.** Which imaging test measures how much each kidney contributes to total function?
A. KUB x-ray **B.** Nuclear scan (DMSA or MAG3) **C.** Standard ultrasound **D.** Plain MRI
- 24.** Kidney biopsy is usually taken from the lower pole because:
A. It is closest to the skin in every person **B.** The cortex is thick and large vessels are fewer **C.** There are no glomeruli elsewhere **D.** The medulla is easiest to sample
- 25.** In a kidney transplant, the donor kidney is usually placed in the:
A. Original kidney position, after removing the diseased kidney **B.** Iliac fossa in the lower abdomen **C.** Upper abdomen under the liver **D.** Chest

Quiz answer key with short explanations

1	B	The capsule is the thin fibrous layer stuck to the surface; fascia and fat lie outside it.
2	B	Retroperitoneal means behind the peritoneum.
3	B	The liver pushes the right kidney down about 1 to 2 cm.
4	B	Vein in front, then artery, then ureter (V-A-U).
5	C	Renal columns of Bertin are cortex tissue between pyramids.
6	C	Papillae drain into minor calyces first.
7	B	Arcuate arteries arch over the pyramid bases.
8	B	Blood leaves through the efferent arteriole, which keeps pressure adjustable.
9	B	The left renal vein is longer and passes in front of the aorta.
10	B	Kidney and ureter pain is carried to T10 to L1.
11	C	The proximal tubule reabsorbs about 65%.
12	A	The proximal tubule has the brush border.
13	B	The thick ascending limb pumps out salt but is watertight.
14	C	Loop diuretics block NKCC2 in the thick ascending limb.
15	B	Podocytes form the outer layer with foot processes.
16	B	ADH inserts aquaporin-2.
17	B	Macula densa cells are salt sensors in the tubule wall.
18	C	JG cells in the afferent arteriole release renin.
19	A	EPO is made by cortical interstitial cells.
20	D	The three narrow points are PUJ, pelvic brim, and VUJ; the trigone is in the bladder.
21	B	Nephron formation is complete by about 34 to 36 weeks.
22	B	Horseshoe kidneys are fused at the lower poles.
23	B	Nuclear scans (DMSA/MAG3) give split function.
24	B	The lower pole has thick cortex and fewer large vessels.
25	B	The donor kidney is placed in the iliac fossa.

Anatomy by the numbers: quick reference

Item	Typical adult value
Kidney length x width x thickness	10 to 12 cm x 5 to 7 cm x 3 to 4 cm
Kidney weight	125 to 170 g (men); 115 to 155 g (women)
Vertebral level	About T12 to L3; hilum about L1 to L2
Blood flow to both kidneys	About 1.0 to 1.2 L/min (20 to 25% of cardiac output)
Cortex share of blood flow	About 90%
Number of nephrons per kidney	About 1 million (range about 200,000 to 2 million+)
Cortical : juxtamedullary nephrons	About 85 : 15
Renal pyramids per kidney	8 to 18 (often 10 to 14)
Minor / major calyces	7 to 14 / 2 to 3
Glomerular filtration rate (GFR)	About 90 to 120 mL/min/1.73 m ² in young adults (about 125 mL/min overall)
Filtrate per day	About 180 L
Urine per day	About 1 to 2 L
Filtration fraction	About 20%
Filtration barrier (fenestrae, GBM, slit)	About 70 to 100 nm, 300 to 350 nm, 30 to 40 nm
Proximal tubule reabsorption of Na and water	About 65%
Thick ascending limb	About 25% of Na; no water
DCT, collecting duct	About 5%, about 3 to 5%
Urine concentration limits	About 50 to 1200 mOsm/kg
Ureter length / width	25 to 30 cm / 3 to 4 mm
Bladder capacity	About 400 to 600 mL
Urethra length	About 3 to 4 cm (female); about 18 to 20 cm (male)
Left renal vein / right renal vein	About 6 to 10 cm / 2 to 4 cm
Accessory renal arteries	About 1 in 4 people

Values are typical ranges from standard anatomy and physiology references and vary between individuals and studies. A medical reviewer should verify all figures before wide distribution.

Glossary

Afferent arteriole	Small artery that brings blood into a glomerulus.
Aldosterone	Adrenal hormone that increases sodium reabsorption and potassium loss in the distal nephron.
Angiotensin II	Hormone made through the renin system; narrows vessels and raises blood pressure.
Aquaporin	A water channel protein in cell membranes (AQP1 in proximal tubule, AQP2 in collecting duct).
Arcuate artery	Artery that arches over the base of a pyramid at the cortico-medullary junction.
Bowman's capsule	The cup-shaped structure around the glomerulus that collects filtrate.
Brush border	Dense microvilli on proximal tubule cells that increase absorption area.
Calyx (plural calyces)	Cup-shaped channel that collects urine from a papilla (minor) or several minor calyces (major).
Collecting duct	Tube that joins many nephrons and carries urine through the medulla to the papilla.
Cortex	Outer layer of the kidney containing the glomeruli.
Countercurrent system	Arrangement of the loop of Henle and vasa recta that builds a salt gradient in the medulla.
Creatinine	Waste product from muscle; its blood level is used to estimate GFR.
Detrusor	The smooth muscle of the bladder wall.
Distal convoluted tubule (DCT)	Coiled tubule segment after the loop of Henle; fine-tunes sodium, calcium, and magnesium.
Efferent arteriole	Small artery that carries blood away from the glomerulus.
eGFR	Estimated glomerular filtration rate calculated from creatinine (and sometimes cystatin C).
Erythropoietin (EPO)	Kidney-made hormone that stimulates red blood cell production.
Fascia	Sheet of connective tissue; renal fascia (Gerota's) surrounds the kidney and adrenal.
Fenestrae	Small pores in glomerular capillary endothelium.
Filtrate	Fluid that passes the filtration barrier into Bowman's space.
Glomerular basement membrane (GBM)	Gel-like layer between endothelium and podocytes; main size and charge barrier.
Glomerulus	Tuft of capillaries where blood is filtered.
Hilum	Notch on the medial border where vessels and ureter enter or leave the kidney.
Hydronephrosis	Swelling of the renal pelvis and calyces from urine that cannot drain.
Intercalated cell	Collecting duct cell that regulates acid-base balance.
Interlobar artery	Artery running in a renal column between pyramids.
Interlobular artery	Artery ascending through the cortex, giving afferent arterioles.
Juxtaglomerular apparatus	Cluster of macula densa, JG cells, and mesangial cells that senses salt and pressure.
Loop of Henle	Hairpin segment of the nephron (descending limb, bend, ascending limb) that builds the medullary gradient.

Macula densa	Salt-sensing cells in the tubule wall next to the glomerulus.
Medulla	Inner region of the kidney made of pyramids.
Mesangial cell	Supportive cell between glomerular capillaries.
Micturition	The act of urination.
Nephron	The functional unit of the kidney: glomerulus, Bowman's capsule, and tubule.
Nephrotic / nephritic	Patterns of glomerular disease: mainly protein loss (nephrotic) or inflammation with blood (nephritic).
Oncotic pressure	Pull exerted by plasma proteins that holds fluid in blood vessels.
Osmolality	Concentration of dissolved particles in a fluid (mOsm/kg).
Papilla	Tip of a renal pyramid that drains urine into a minor calyx.
Parenchyma	Functional tissue of the kidney (cortex and medulla).
Pelvis (renal)	Funnel-shaped space that collects urine from the calyces.
Peristalsis	Waves of muscle contraction that move urine along the ureter.
Peritubular capillaries	Low-pressure capillaries surrounding cortical tubules.
Podocyte	Glomerular epithelial cell with foot processes forming the slit diaphragm.
Principal cell	Collecting duct cell that handles sodium, potassium, and water under hormone control.
Proximal convoluted tubule (PCT)	First coiled segment of the tubule; reabsorbs most filtered solutes and water.
Pyelonephritis	Infection of the kidney and renal pelvis.
Pyramid (renal)	Cone-shaped part of the medulla.
Renal column (of Bertin)	Cortex tissue extending between pyramids.
Renal corpuscle	The glomerulus together with Bowman's capsule.
Renin	Enzyme released by JG cells that starts the RAAS.
Retroperitoneal	Located behind the peritoneum.
Sinus (renal)	Central fat-filled space within the kidney holding calyces and vessels.
Slit diaphragm	Protein bridge between podocyte foot processes forming the final filter.
Trigone	Smooth triangle at the base of the bladder.
Tubuloglomerular feedback	Local loop in which macula densa signals adjust glomerular filtration.
Ureter	Muscular tube carrying urine from the renal pelvis to the bladder.
Urethra	Tube carrying urine from the bladder to the outside.
Urothelium	Stretchy lining of the renal pelvis, ureter, and bladder.
Vasa recta	Hairpin capillaries that supply the medulla and preserve its salt gradient.

Resources and next steps

These organizations offer reliable, patient-friendly information about kidney anatomy and kidney health. Please confirm website addresses and phone numbers before sharing this guide, as they can change.

Organization	What it offers	Website
National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK)	Kidney basics, chronic kidney disease, kidney stones, tests and treatments	niddk.nih.gov
National Kidney Foundation (NKF)	Patient education, kidney disease information, support programs	kidney.org
American Kidney Fund (AKF)	Education and financial assistance programs for kidney patients	kidneyfund.org
PKD Foundation	Information and support for polycystic kidney disease	pkdcure.org
Urology Care Foundation	Urinary tract, bladder, ureter, and stone information	urologyhealth.org
MedlinePlus (U.S. National Library of Medicine)	Plain-language health topics and medical tests	medlineplus.gov

Where to go from here

- Bring this guide, your lab results, and your imaging reports to your next appointment and ask your care team to point out the structures on your own images.
- Use the labeling exercises to teach a family member; teaching is the best way to learn.
- Ask TLHF about companion education guides on kidney disease, dialysis, transplant, and healthy living.

Thank you for learning with TLHF

You now know more about how the kidneys are built than most people ever learn. Knowledge is the beginning of good questions, and good questions are the beginning of good care. **Health. Awareness. Hope.**

