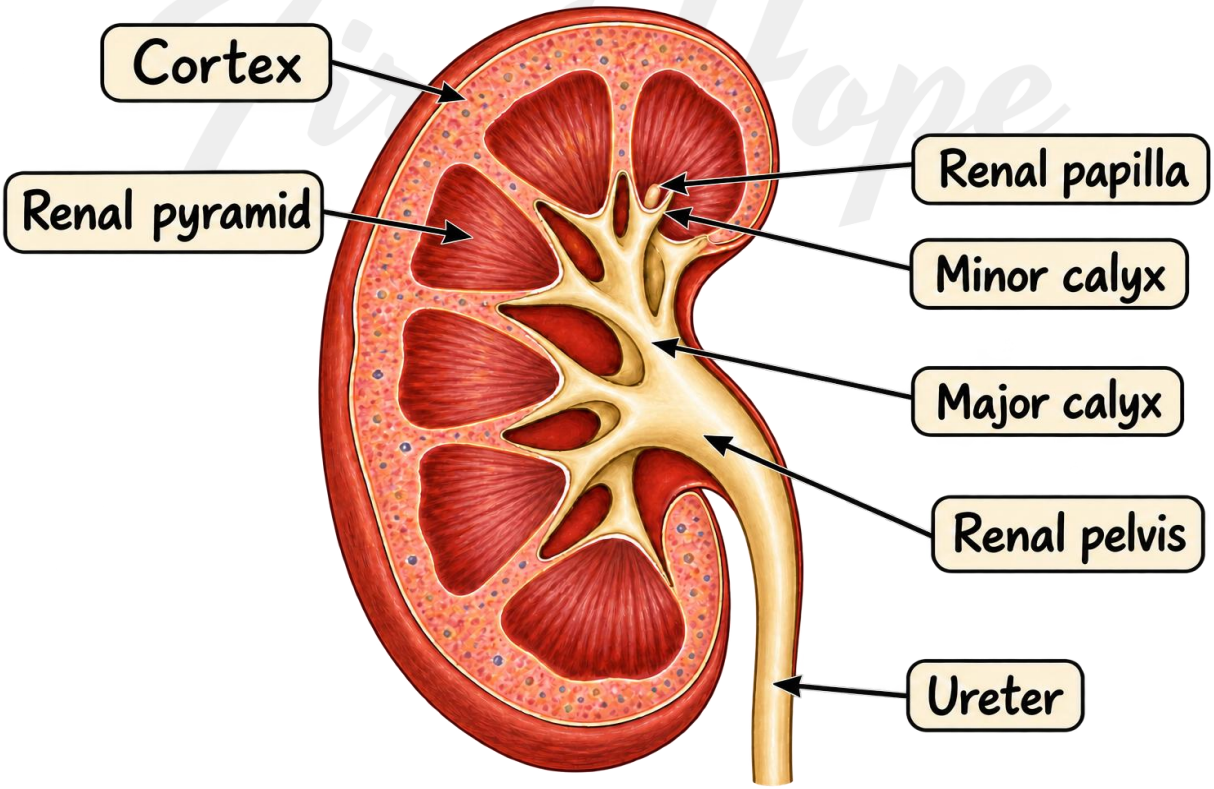
Physiology - Topic 7 - Renal Physiology

The Kidneys and Homeostasis

- **The kidneys** maintain the composition and volume of the internal environment by adjusting the excretion of water, electrolytes, acids, and metabolic waste.
- **The kidneys** achieve this regulation by filtering plasma and then selectively modifying the filtered fluid along renal tubules.
    - Urine formation is not simply the removal of unwanted material through a sieve.
    - Most filtered water and many useful solutes return to the blood, while some substances are actively added to the tubular fluid by **secretion**.
- **The kidneys** also have important endocrine and metabolic functions.
- They influence blood pressure, red-cell production, calcium balance, acid–base balance, and glucose metabolism, so renal disease can produce effects far beyond reduced urine output.

Functional Anatomy of the Kidneys

Gross organisation and blood supply



Internal structure of the kidney and the route from the renal calyces to the ureter

Kidney regions and the urine pathway

Cortex and Medulla

- The **renal cortex** contains all renal corpuscles and much of the convoluted tubular system.

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- The medulla contains loops of Henle, collecting ducts, and the specialised circulation that supports the concentration of urine.

Pathway from Collecting Duct to Ureter

- Urine passes from **collecting ducts** through papillary ducts into minor calyces, then through major calyces and the renal pelvis into the ureter.
- **Ureteric peristalsis** moves urine toward the bladder even when the person is not upright.

Renal blood supply

Arteriolar and Capillary Arrangement

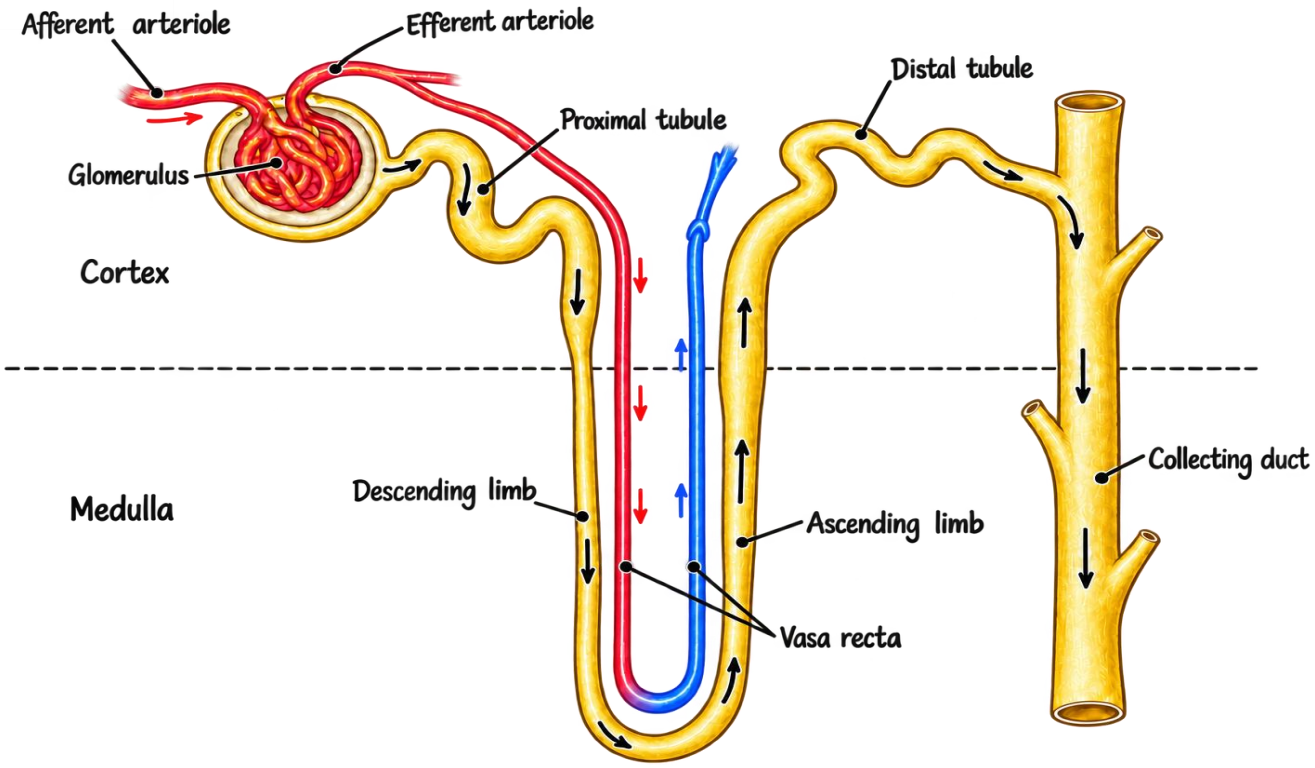
- The renal artery branches into progressively smaller arteries and then **afferent arterioles**, which supply glomerular capillaries.
- Blood leaves each glomerulus through an efferent arteriole before entering peritubular capillaries or the vasa recta.
- The arrangement of two capillary beds in series allows high-pressure filtration in the glomerulus and lower-pressure exchange around the tubules.
- Changes in afferent and efferent arteriolar tone can therefore influence both filtration and subsequent **reabsorption**.

Distribution and Purpose of Renal Blood Flow

- **The kidneys** receive roughly one-fifth of resting cardiac output, often around 1.0–1.2 L/min in a healthy adult.
- **High renal blood flow** supports filtration and homeostasis and is large relative to the metabolic needs of the kidney tissue itself.
- Most **renal blood flow** supplies the cortex, while medullary flow is much lower.
- A relatively low medullary flow helps preserve the concentration gradient but also makes some medullary regions vulnerable to oxygen shortage during illness.

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The nephron and collecting system



Schematic long-loop nephron, collecting duct, and vasa recta; tubular fluid and blood follow separate pathways

Nephron Components and Functional Organisation

Renal Corpuscle and Tubule

- The nephron begins with a **renal corpuscle**, consisting of a glomerular capillary tuft enclosed by Bowman's capsule.
- **Filtrate** enters the proximal tubule, passes through the loop of Henle and distal tubule, and then enters connecting tubules and collecting ducts.

Cortical and Juxtamedullary Nephrons

- Cortical nephrons have relatively short loops, whereas **juxtamedullary nephrons** have long loops that extend deeply into the medulla.
- The long loops and associated vasa recta are particularly important for generating and preserving concentrated urine.

Collecting System and Segmental Specialisation

- The **collecting system** receives fluid from many nephrons and makes final hormone-dependent adjustments in water, sodium, potassium, and acid excretion.
- A **collecting duct** is therefore functionally essential even though its embryological origin differs from that of the nephron proper.
- Proximal tubular cells have a **brush border** and many mitochondria, supporting extensive reabsorption.
- Different later segments contain different transporters and water permeabilities, so the function of a segment cannot be predicted from tubular fluid composition alone.

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Reabsorption and Secretion

- Tubular fluid and peritubular blood remain separate compartments divided by epithelial cells, basement membranes, interstitium, and capillary walls.
- **Reabsorption** moves material from lumen toward blood, while secretion moves material from blood or tubular cells toward the lumen.

Non-Excretory Functions of the Kidneys

Endocrine and Metabolic Functions

- The kidneys release **renin**, which initiates a hormonal cascade that helps regulate sodium balance and arterial pressure.
- Renin release responds to renal perfusion, tubular sodium-chloride delivery, and sympathetic activity.
- Renal interstitial cells produce **erythropoietin** in response to reduced local oxygen availability.
- Erythropoietin supports red-cell production in the bone marrow, explaining why chronic renal disease can contribute to anaemia.
- Proximal tubular cells convert 25-hydroxyvitamin D to the active hormone **calcitriol** through 1-alpha-hydroxylase.
- Calcitriol supports intestinal calcium and phosphate absorption and participates in the coordinated regulation of mineral balance.
- The kidney metabolises several hormones and contributes to **gluconeogenesis**, especially during fasting and acid–base stress.
- These functions show that it is a metabolically active organ rather than only an excretory filter.
- Local **prostaglandins** and other mediators modify renal vascular tone and tubular handling.
- Their importance increases in states where powerful vasoconstrictor influences threaten renal perfusion.

Glomerular Filtration

The filtration barrier

Structure and Selectivity of the Filtration Barrier

Layers of the Barrier

- The glomerular **filtration barrier** includes fenestrated capillary endothelium, the glomerular basement membrane, and podocyte filtration slits with their slit diaphragms.

Retention of Cells and Large Proteins

- Together these layers permit filtration of water and small solutes while strongly restricting cells and most large plasma proteins.

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- Molecular size, shape, charge interactions, and the condition of the barrier influence passage.
- Protein restriction cannot be attributed to only one layer, and damage to podocytes or other barrier components can increase urinary protein loss.
- Normal **filtrate** is nearly cell-free and contains very little albumin compared with plasma.
- Small freely filtered solutes such as sodium, glucose, and urea initially have concentrations close to those in plasma water before tubular modification.

Filterability and Protein Binding

- The **protein-bound fraction** of a substance is not freely available for filtration while it remains bound.
- Drug filtration therefore depends on the unbound concentration as well as the glomerular filtration rate.

Filtration pressures and filtration rate

GFR and body-size indexing

Typical Filtration Rate and Daily Volume

- **Glomerular filtration rate**, or GFR, is the volume of plasma ultrafiltrate formed by all functioning glomeruli each minute.
- A frequently used healthy young-adult teaching value is about 125 mL/min, which corresponds to approximately 180 L/day.

Body-Size Indexing and Interpretation

- **GFR** varies with age, body size, pregnancy, and physiological conditions, and clinical reports often index it to a body surface area of 1.73 m^2.
- An indexed value should not be confused with an unadjusted clearance in mL/min when interpreting drug elimination or calculations.

Filtration forces

Filtration Coefficient

- The filtration rate equals the **filtration coefficient** multiplied by net filtration pressure.
- The filtration coefficient depends on the surface area and hydraulic permeability of the glomerular barrier.

Net Filtration Pressure

- A useful expression is **GFR = Kf[(PGC − PBS) − (πGC − πBS)]**.
- PGC and PBS are glomerular capillary and Bowman's-space hydrostatic pressures, while πGC and πBS are their oncotic pressures.
- Glomerular capillary hydrostatic pressure favours filtration, whereas Bowman's-space hydrostatic pressure and glomerular capillary **oncotic pressure** oppose it.

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