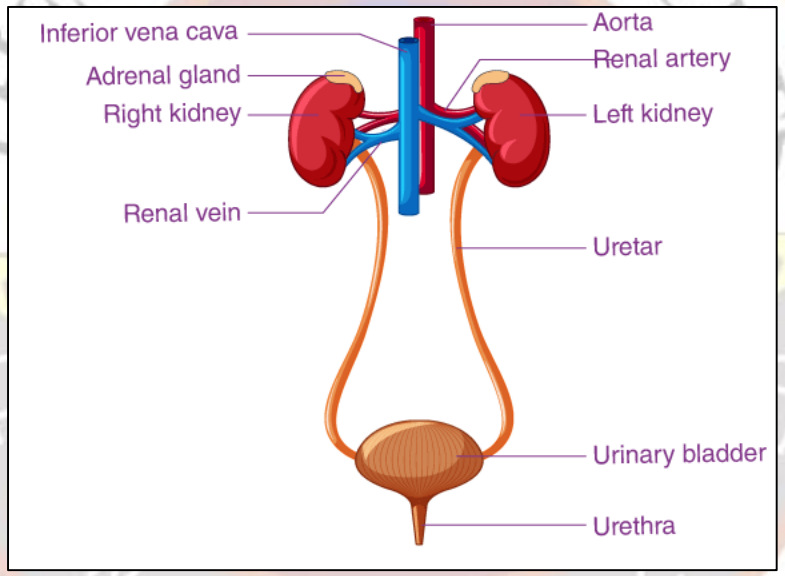
URINARY SYSTEM

- The urinary system is the **main excretory system** of the body.
- It consists of the following structures:
    1. **Two kidneys** – filter blood and excrete wastes into a fluid called urine.
    2. **Two ureters** – convey urine from the kidneys to the urinary bladder.
    3. **Urinary bladder** – collects and stores urine.
    4. **Urethra** – through which urine leaves the body.
- The **kidneys perform the major work** of the urinary system.
- Other parts act mainly as **passageways and storage areas**.
- The scientific study of the **anatomy, physiology, and pathology of the kidneys** is called **Nephrology**.
- The branch of medicine that deals with the **male and female urinary system and the male reproductive system** is called **Urology**.
- The urinary system **maintains homeostasis of water and electrolytes** within the body.



FUNCTIONS OF THE KIDNEYS

1. Formation of Urine and Excretion of Waste Products

- By forming urine, the kidneys help excrete wastes from the body.
- Wastes include:
    - Urea
    - Ammonia
    - Creatinine
    - Uric acid
    - Urobilin (nitrogenous wastes)
- Other substances excreted include drugs and environmental toxins.

2. Regulation of Blood Ionic Composition (Electrolyte Balance)

- Regulates blood levels of:
  - Na^+
  - K^+
  - Ca^{2+}
  - Cl^-
  - HPO_4^{2-} ions

3. Regulation of Blood pH (Acid–Base Balance)

- Kidneys excrete **H^+ ions** into urine.
- Kidneys conserve **HCO_3^- (bicarbonate)**.

4. Regulation of Blood Volume (Water Balance)

- Adjust blood volume by conserving or eliminating water in urine.

5. Regulation of Blood Pressure

- Kidneys secrete **renin enzyme**.
- Renin plays a role in long-term control of blood pressure.

6. Maintenance of Blood Osmolarity

- Kidneys separately regulate loss of water and solutes in urine.
- Maintain osmolarity close to **300 milliosmoles/L**.

7. Production of Hormones

- Kidneys produce two hormones:
  - **Calcitriol** – active form of vitamin D; regulates calcium homeostasis.
  - **Erythropoietin** – stimulates production of red blood cells.

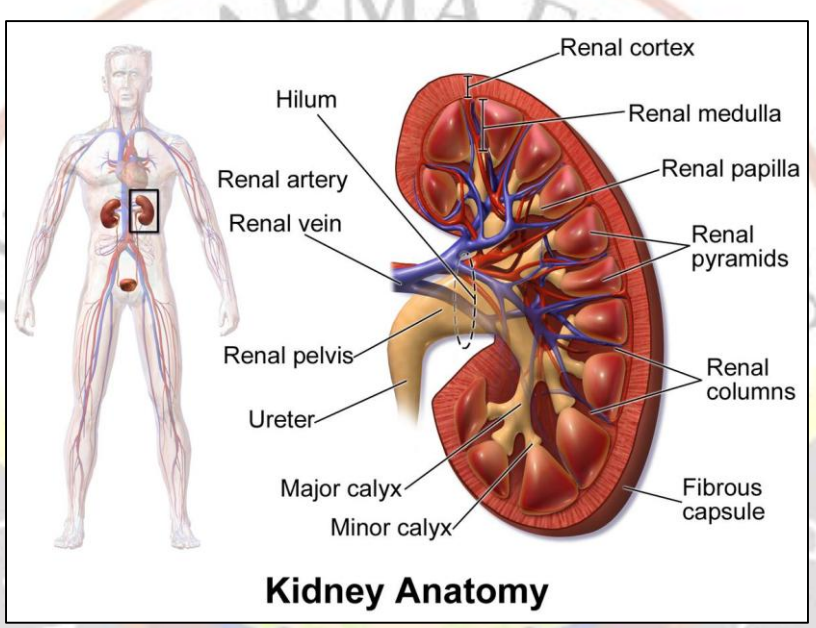
8. Regulation of Blood Glucose Level

- Kidneys use the amino acid **glutamine** in gluconeogenesis.
- Release glucose into the blood to help maintain normal blood glucose levels.

KIDNEYS

- Kidneys are **paired, reddish, bean-shaped organs**.
- Located just above the waist between the peritoneum and posterior abdominal wall.
- One kidney lies on each side of the vertebral column.

- Kidneys are **retroperitoneal organs**.
- Extend from the level of **12th thoracic vertebra to 3rd lumbar vertebra**.
- Partially protected by the **11th and 12th ribs**.
- The **right kidney is slightly lower** than the left due to the liver.
- Average size:
  - Length – 11 cm
  - Width – 6 cm
  - Thickness – 3 cm
  - Weight – 150 g
- Embedded in and held in position by a mass of fat.
- Enclosed by a fibrous connective tissue sheath called the **renal fascia**.



ORGANS ASSOCIATED WITH KIDNEYS

Right Kidney

- Superior: Right adrenal gland
- Anterior: Right lobe of liver, duodenum, hepatic flexure of colon
- Posterior: Diaphragm, muscles of posterior abdominal wall

Left Kidney

- Superior: Left adrenal gland
- Anterior: Spleen, stomach, pancreas, jejunum, splenic flexure of colon
- Posterior: Diaphragm, muscles of posterior abdominal wall

EXTERNAL ANATOMY OF KIDNEY

- Medial border of each kidney is concave and faces the vertebral column.
- **Renal hilum** is an indentation at the medial border.
- Ureter, blood vessels, lymph vessels, and nerves enter or leave at the hilum.
- Three layers surround each kidney:
    1. **Renal capsule** – smooth, transparent dense irregular connective tissue.
    2. **Adipose capsule** – mass of fatty tissue around renal capsule.
    3. **Renal fascia** – thin layer of dense irregular connective tissue.

INTERNAL ANATOMY OF KIDNEY

A longitudinal section of the kidney reveals **two distinct regions**:

1. **Superficial light red region – Renal cortex**
2. **Deep darker reddish-brown inner region – Renal medulla**

The **renal cortex** is a **smooth-textured area** extending from the **renal capsule** to the **renal pyramids** and also into the **spaces between them**.

- **Outer cortical zone**
- **Inner juxtamedullary zone**
- Portions of the renal cortex that extend between the renal pyramids are called **renal columns**.

The **renal medulla** consists of several **cone-shaped renal pyramids**.

Each renal pyramid has a **pointed end** known as the **renal papilla**.

The **renal cortex** and **renal pyramids** together form the **renal parenchyma**, which is the **functional portion of the kidney**.

• Within the parenchyma are the **functional units called nephrons**, which are **microscopic structures**, about **1 million in number**.

URINE FLOW PATHWAY

- Filtrate drains into **papillary ducts**.
- Papillary ducts drain into **minor calyces**.
- Minor calyces merge to form **major calyces**.
- Major calyces combine to form the **renal pelvis**.
- Renal pelvis funnels urine into the **ureter**.

BLOOD SUPPLY OF KIDNEY

- The kidneys receive blood through the **right and left renal arteries**, which undergo repeated divisions within the kidneys and finally form **afferent arterioles**.
- Each nephron receives **one afferent arteriole**, which divides into a **ball-shaped capillary network called the glomerulus**. These capillaries reunite to form an **efferent arteriole**.
- The **efferent arterioles** further divide to form **peritubular capillaries**, which surround the **tubular parts of the nephron in the renal cortex**.
- From some efferent arterioles arise **long, loop-shaped capillaries called vasa recta**, which supply the **tubular portions of the nephron in the renal medulla**.
- The **peritubular capillaries** eventually reunite and finally form a **single renal vein**, which exits the kidney at the **hilum**.

NEPHRON

- Kidney contains **1–2 million nephrons**.
- Nephron is a tubule closed at one end and opens into a collecting duct.
- Two parts:
    1. **Renal corpuscle**
        - Glomerulus
        - Bowman's capsule
    2. **Renal tubule**
        - Proximal convoluted tubule (PCT)
        - Loop of Henle
        - Distal convoluted tubule (DCT)
- 80–85% are **cortical nephrons**.
- 15–20% are **juxtamedullary nephrons**.

GLOMERULAR CAPSULE

- Double-walled epithelial cup.
- **Visceral layer** – podocytes.
- **Parietal layer** – simple squamous epithelium.
- Filtrate enters the **capsular space**.

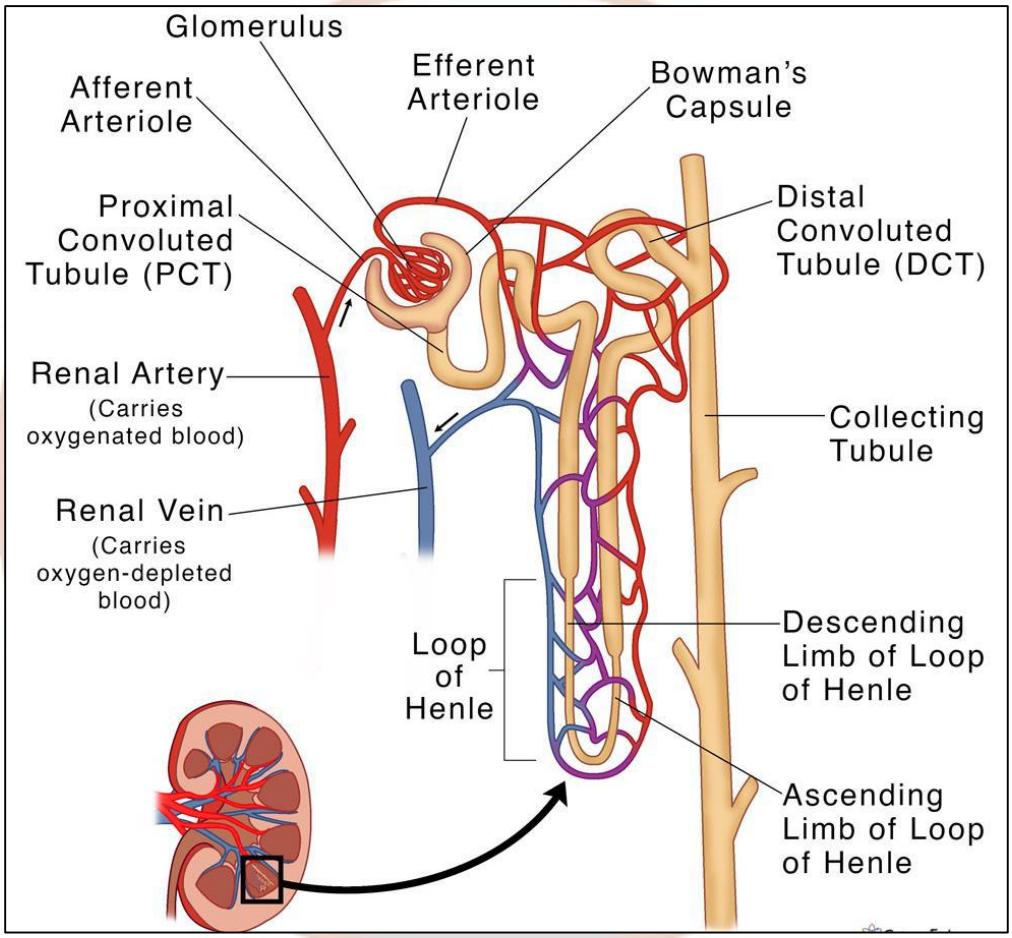
RENAL TUBULE HISTOLOGY

- PCT: Simple cuboidal epithelium with brush border.
- Descending limb: Simple squamous epithelium.
- Ascending limb: Simple cuboidal to low columnar epithelium.

PHYSIOLOGY OF URINE FORMATION

Three Processes

1. Glomerular filtration
2. Tubular reabsorption
3. Tubular secretion



GLOMERULAR FILTRATION

- Occurs through semipermeable walls.
- Filtered substances:
  - Water
  - Glucose
  - Amino acids
  - Electrolytes
  - Urea, uric acid, creatinine
- Not filtered:

    - Blood cells
    - Plasma proteins
- GFR = **125 mL/min (180 L/day)**.
- Net filtration pressure = **10 mm Hg**.

TUBULAR REABSORPTION

- 99% of water reabsorbed.
- PCT reabsorbs water, electrolytes, glucose, amino acids.
- Loop of Henle reabsorbs water and Na^+.
- DCT reabsorbs electrolytes.
- Collecting duct regulates water based on body needs.

HORMONAL CONTROL

- ADH – increases water reabsorption.
- Aldosterone – increases Na^+ reabsorption.
- ANP – decreases Na^+ and water reabsorption.
- PTH – increases calcium reabsorption.

TUBULAR SECRETION

- Secretion of H^+, drugs, toxins.
- Maintains blood pH.

COMPOSITION OF URINE

- Clear, amber colored.
- pH: 4.5–8
- Volume: 1000–1500 mL/day
- Constituents:
    - Water – 96%
    - Urea – 2%
    - Others – 2%

URETERS

- Two muscular tubes, 25–30 cm long.
- Retroperitoneal.
- Peristalsis propels urine.
- No valves.

URINARY BLADDER

- Hollow muscular reservoir.
- Capacity: 700–800 mL.
- Located behind pubic symphysis.
- Lined with transitional epithelium.
- Detrusor muscle present.
- Trigone formed by three openings.

URETHRA

Male

- 20 cm long.
- Prostatic, membranous, spongy parts.

Female

- 4 cm long.
- Voluntary control via external sphincter.

MICTURITION

Discharge of urine from the urinary bladder is called Micturition

•Also known as **Urination or Voiding**

•It occurs via a combination of involuntary and voluntary muscle contractions

•When the volume of urine in the bladder exceeds200-400 mL, pressure within the bladder increases considerably

•Stretchreceptorsinitswalltransmitnerveimpulsesintothespinalcord

•Impulses propagate to the micturition center in sacral spinal cord segments S2andS3–trigger a spinal reflex called the Micturition Reflex

•In this reflex arc, parasympathetic impulses from the micturition center propagate to urinary bladder wall and internal urethral sphincter

NEURAL CONTROL OF MICTURITION

Nerve impulses cause **contraction of the detrusor muscle** and **relaxation of the internal urethral sphincter muscle**.

Simultaneously, the **micturition center inhibits somatic motor neurons** that innervate the **skeletal muscle of the external urethral sphincter**.

When the **urinary bladder walls contracts** and the **urethral sphincters relax**, **urination takes place**.

Filling of the urinary bladder produces a **sensation of fullness**, which initiates a **conscious desire to urinate** even before the micturition reflex actually occurs.

Although **emptying of the urinary bladder is a reflex action**, during **early childhood it is learned** how to **initiate and stop it voluntarily**.

Through **learned control of the external urethral sphincter muscle** and **certain muscles of the pelvic floor**, the **cerebral cortex** can **initiate micturition** or **delay its occurrence for a limited period**.

Common Signs and Symptoms of Disorders of the Urinary System

Urinary sys

- **Oliguria** – urine output of less than 400 mL/day
- **Haematuria** – presence of blood in the urine
- **Proteinuria** – presence of protein in the urine
- **Anuria** – absence of urine
- **Dysuria** – pain on passing urine, often described as a burning sensation
- **Glycosuria** – presence of sugar (glucose) in the urine; occurs in diabetes mellitus
- **Ketonuria** – presence of ketones in the urine; abnormal and occurs in starvation and diabetes mellitus
- **Nocturia** – passing urine during the night
- **Polyuria** – passing unusually large amounts of urine
- **Frequency of micturition** – need to pass urine frequently, often in small amounts
- **Incontinence** – involuntary loss of urine

DISEASES OF URINARY SYSTEM

- Glomerulonephritis
- Nephrotic syndrome

- Diabetic nephropathy
- Hypertension
- Pyelonephritis
- Acute kidney injury
- Chronic kidney disease
- Renal calculi
- Congenital anomalies
- Tumors
- Urinary tract infections
- Incontinence

Glomerulonephritis

- Inflammatory condition of the glomerulus
- Mostly has an autoimmune component; immune complexes lodge in glomerular capillaries
- Leads to inflammation and impairment of glomerular filtration
- Types include:
    - Diffuse proliferative
    - Focal proliferative
    - Membranous
    - Minimal-change
- Effects include:
    - Haematuria
    - Asymptomatic proteinuria
    - Acute nephritis
    - Nephrotic syndrome
    - Chronic kidney disease (CKD)

Nephrotic Syndrome

- Not a disease but an important feature of several kidney diseases
- Main characteristics include:
    - Marked proteinuria
    - Hypoalbuminaemia
    - Generalised edema
    - Hyperlipidemia
- Occurs due to damage to the glomerulus resulting in significant loss of albumin
- Seen in a number of renal diseases

Diabetic Nephropathy

- A complication of diabetes mellitus
- Diabetes damages both large and small blood vessels throughout the body

- In the kidneys, diabetic nephropathy causes:
    1. Progressive damage of glomeruli, proteinuria and nephrotic syndrome
    2. Ascending infection leading to acute pyelonephritis
    3. Arteriosclerosis of renal arteries and their branches, leading to renal ischaemia and hypertension
    4. Development of chronic kidney disease

Hypertension and the Kidneys

- Hypertension may be either a cause or a result of renal disease
- Disrupts renal function when renal blood vessel damage causes ischaemia
- Reduced renal blood flow stimulates the RAAS system
- RAAS activation further increases blood pressure
- Leads to gradual and progressive damage to glomeruli
- Results in chronic kidney disease or malignant hypertension

Acute Pyelonephritis

- Acute bacterial infection of the renal pelvis and calyces
- Infection spreads into the kidney causing small abscesses
- Bacteria usually reach the kidney by ascending the urinary tract
- Occasionally infection is blood-borne
- Accompanied by:
    - Fever
    - Malaise
    - Loin pain
- Bacterial infection causes suppuration and destruction of nephrons

Reflux Nephropathy

- Previously called chronic pyelonephritis
- Almost always associated with reflux of urine from the bladder to the ureter
- Infection spreads upwards towards the kidneys
- Progressive damage to renal papillae and collecting ducts
- May lead to:
    - Chronic kidney disease
    - Concurrent hypertension

Acute Kidney Injury (Acute Renal Failure)

- Occurs as a complication of many conditions
- Causes classified as:
    - Prerenal
    - Renal
    - Postrenal
- Characterized by sudden and severe reduction in GFR and kidney function

- Condition is reversible if treated early
- Features include:
  - Oliguria or anuria
  - Metabolic acidosis due to retention of H^+ ions
  - Electrolyte imbalance
  - Accumulation of nitrogenous wastes
- **Acute tubular necrosis (ATN)**:
  - Most common cause of acute renal failure
  - Due to severe damage to tubular epithelial cells
  - Caused by ischaemia or nephrotoxic substances

Chronic Kidney Disease (Chronic Renal Failure)

- Present when GFR has fallen to around 20% of normal
- Onset is slow and often asymptomatic
- Progresses irreversibly over several years
- Main causes include:
  - Diabetes mellitus
  - Glomerulonephritis
  - Hypertension
- GFR and filtrate volumes are greatly reduced
- Reabsorption of water is seriously impaired
- Can result in production of up to 10 L of urine per day
- Accumulation of waste substances in blood causes:
  - Raised blood urea levels (uraemia)
- Signs and symptoms include:
  - Nausea
  - Vomiting
  - Gastrointestinal bleeding
  - Pruritis (itching)
  - Polyuria
  - Acidosis
  - Electrolyte imbalance
  - Anaemia
  - Hypertension
- **End-stage renal disease**:
  - Death likely without renal replacement therapy
  - Treatment options include haemodialysis and kidney transplantation

Renal Calculi

- Calculi (stones) form in kidneys and bladder due to precipitation of urinary constituents such as oxalate and phosphate salts
- More common in males and after 30 years of age
- Originate in collecting tubules
- Pass into renal pelvis and increase in size

- May become too large to pass through ureter
- Obstruct outflow of urine causing kidney damage
- Some pass to bladder and are excreted or enlarge further to obstruct urethra
- Predisposing factors include:
    - Dehydration
    - Raised urine pH
    - Infection
    - Hyperparathyroidism
    - Gout

Small Calculi

- May pass through or become impacted in the ureter
- Damage epithelium and cause haematuria
- Obstruction causes spasmodic contractions
- Leads to acute intermittent ischaemic pain

Large Calculi (Staghorn Calculus)

- Single large stone develops over many years
- Fills renal pelvis and calyces
- Causes stagnation of urine
- Leads to infection, hydronephrosis and chronic kidney disease

Congenital Abnormalities

Misplaced (Ectopic) Kidney

- One or both kidneys develop in abnormally low positions
- Kidneys function normally if blood supply is adequate
- May cause problems during pregnancy
- Increased risk of infection
- Increased tendency for reflux
- Difficulties during childbirth

Polycystic Kidney Disease

Autosomal Recessive Polycystic Kidney Disease (ARPKD)

- Also called infantile polycystic kidney disease
- Abnormal development of kidneys and liver
- High risk of organ failure

Autosomal Dominant Polycystic Kidney Disease (ADPKD)

- Both kidneys affected

- Cysts form at junctions of DCT and collecting ducts
- Cysts enlarge slowly
- Pressure causes ischaemia and destruction of nephrons
- Death may occur due to:
    - Chronic kidney disease
    - Cardiac failure
    - Subarachnoid haemorrhage

Tumors of the Kidney

Malignant Tumors

Renal Adenocarcinoma

- Tumor of tubular epithelium
- More common after 50 years of age and in males
- Features include:
    - Haematuria
    - Back or loin pain
    - Anaemia
    - Weight loss
    - Fever
- Increased incidence in cigarette smokers

Nephroblastoma (Wilm's Tumor)

- Most common malignant tumor in children under 10 years
- Features include:
    - Haematuria
    - Hypertension
    - Abdominal pain
    - Occasionally intestinal obstruction
- Usually unilateral
- Grows rapidly and invades renal blood vessels
- Early blood spread to lungs

Obstruction to the Outflow of Urine

Hydronephrosis

- Dilation of renal pelvis and calyces
- Due to accumulation of urine above an obstruction
- Leads to destruction of nephrons
- Causes fibrosis and atrophy of kidney
- Obstruction above bladder more common
- Usually affects only one kidney

- Causes include:
  - Large calculus
  - Tumor causing complete sustained obstruction
  - Calculi in ureter
  - Constriction of ureter
  - Enlarged prostate gland in males causing partial or intermittent obstruction

Spinal Lesions

- Interrupt nerve supply to the bladder
- Micturition does not occur
- Bladder fills causing rise in pressure
- Leads to overflow incontinence
- Back pressure into ureters causes hydronephrosis

Urinary Tract Infections

- Infection of any part of urinary tract due to bacteria or trauma
- May spread upwards causing acute pyelonephritis
- Leads to:
  - Ureteritis
  - Cystitis
  - Urethritis

Tumors of the Urinary Tract

- Predisposing factors include:
  - Cigarette smoking
  - Certain analgesics
  - Occupational exposure

Transitional Cell Carcinoma

- Also known as papillomas
- Arise from transitional epithelium
- Often benign

Solid Tumors

- All are malignant to some degree

Urinary Incontinence

- Normal micturition is affected

- Involuntary loss of urine occurs
- Causes include:
  - Spinal cord injury
  - Multiple sclerosis
- Types include:
  - Stress incontinence
  - Urge incontinence
  - Overflow incontinence