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Introduction

Forms of Nitrogenous Wastes

- Excretion removes metabolic wastes like ammonia, urea, uric acid, CO_2, water, and ions (Na^+, K^+, Cl^-, phosphate, sulphate).
- Major nitrogenous wastes: ammonia, urea, uric acid.
- Animals differ in waste excretion: ammonotelic (ammonia), ureotelic (urea), uricotelic (uric acid).

Memory Aids

- Ammonotelic = Ammonia excretion, aquatic animals, high water need.
- Ureotelic = Urea excretion, mammals, moderate water need.
- Uricotelic = Uric acid excretion, birds/reptiles, low water need.

Quick Checkpoints

- What are the three main nitrogenous wastes?
- Which animals are ammonotelic, ureotelic, and uricotelic?
- How does water requirement vary among these types?

Table : Different animals based on modes of excretion

Character		Type of Organisms		
		Ammonotelic	Ureotelic	Uricotelic
(i)	Excretory waste	Ammonia	Urea	Uric acid
(ii)	Requirement of water	Very large	Less than ammonia	Least
(ii)	Mechanism of excretion	By diffusion across body surface or through gill surface (in fish) as ammonium ion	Ammonia produced by metabolism is converted into urea in the liver and released into the blood which is filtered and excreted out by the kineys	In the form of pellet or paste
(iv)	Toxicity	Most toxic	Less than ammonia	Least
(v)	Examples	Many bony fishes, Aquatic insects, Aquatic amphibians	Mammals, Marine fishes, Terrestrial amphibians	Reptiles, Birds, Insects and Land snails

Excretory Organs

Types of Excretory Organs

- Protozoans: contractile vacuoles for waste removal.
- Insects: Malpighian tubules.
- Earthworms: nephridia.
- Vertebrates: kidneys.

Memory Aids

- Protozoans = Contractile vacuole.
- Insects = Malpighian tubules.
- Earthworms = Nephridia.
- Vertebrates = Kidneys.

Quick Checkpoints

- Which excretory organ is found in protozoans?
- What organ do insects use for excretion?
- What is the excretory organ in earthworms?
- Which organ do vertebrates use?

Prepzy

Table : Organs of excretion in different animals

	Organs of excretion	Animal
(i)	Contractile vacuoles and plasma membrane	Protozoans
(ii)	General body surface	Hydra and sponges
(iii)	Renette cells	Aschelminthes
(iv)	Flame cells (solenocytes and protonephriidia)	Planarians (Platyhelminth)
(v)	Nephridia and chloragogen cells	Earthworm (Annelida)
(vii)	Malpighian tubules	Insects (Arthropoda)
(viii)	Coxal glands	Spider (Arachnida, Phylum Arthropoda)
(viii)	Antennal glands or green glands	Prawn (Crustacea, Phylum Arthropoda)
(ix)	Keber's organ and organs of Bojanus	Mollusca
(x)	Kidneys	Vertebrates

Human Excretory System

Components

- Pair of kidneys, pair of ureters, urinary bladder, urethra.

Memory Aids

- Kidneys filter blood and produce urine.
- Ureters transport urine to bladder.
- Bladder stores urine.
- Urethra expels urine.

Quick Checkpoints

- What are the main parts of the human excretory system?
- What is the function of ureters?
- Where is urine stored?
- Which tube expels urine?

Kidneys

Structure and Location

- Bean-shaped, reddish brown organs located between last thoracic and third lumbar vertebrae.
- Right kidney is slightly lower than left.
- Size: 10-12 cm length, 5-7 cm width, 2-3 cm thickness; weight: 120-170 g.
- Hilum: notch on inner concave surface for ureter, blood vessels, nerves.

Memory Aids

- Hilum is the entry/exit point for vessels and ureter.
- Right kidney lower due to liver position.

Quick Checkpoints

- Where are kidneys located?
- What is the hilum?
- Which kidney is lower and why?

Prepzy

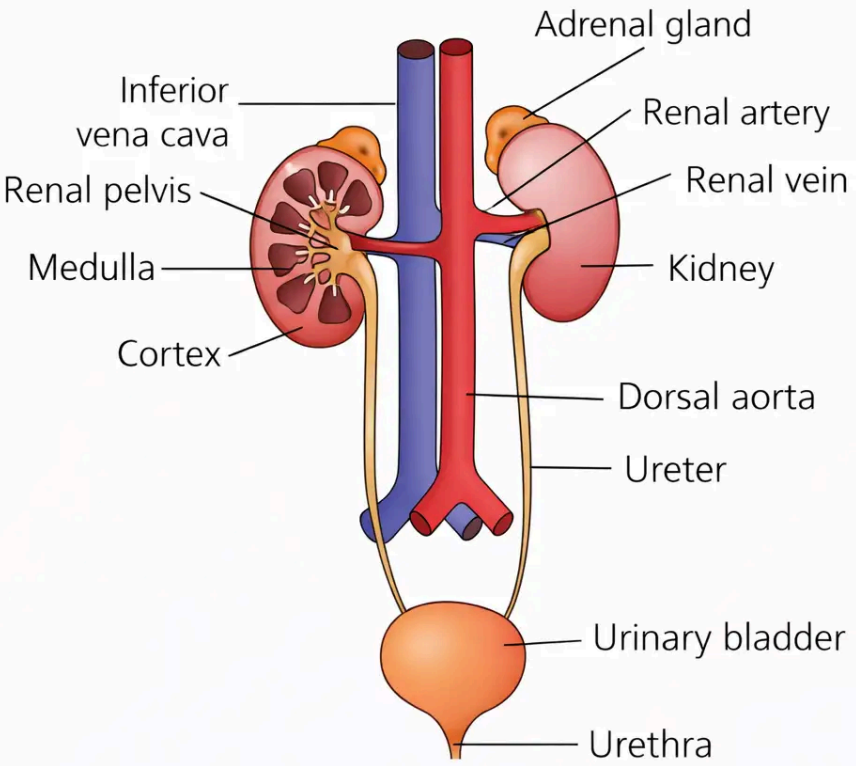


Fig.: Human urinary system

Kidney Internal Structure

Zones and Parts

- Outer tough capsule covers kidney.
- Two zones: outer cortex and inner medulla.
- Medulla has medullary pyramids projecting into calyces.
- Cortex extends between pyramids as renal columns (columns of Bertin).
- Major calyces open into renal pelvis leading to ureter.

Memory Aids

- Medullary pyramids collect urine.
- Columns of Bertin separate pyramids.
- Renal pelvis funnels urine to ureter.

Quick Checkpoints

- What are the two main zones of the kidney?
- What are medullary pyramids?
- What is the function of renal pelvis?

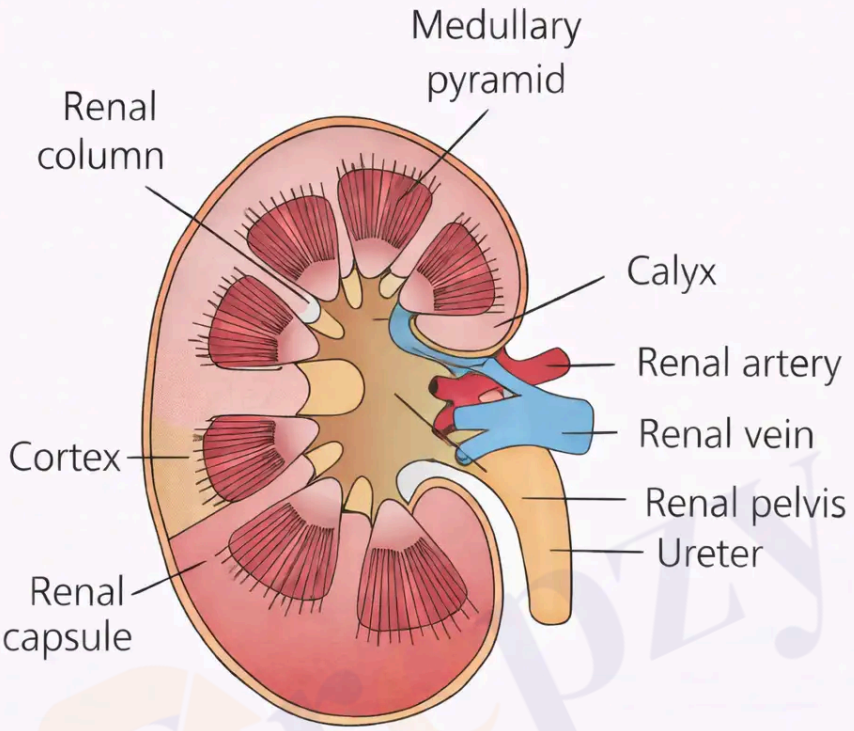


Fig.: Longitudinal section (Diagrammatic) of kidney

Structure of Nephron

Components

- Nephrons are functional units; ~1 million per kidney.
- Two parts: glomerulus (capillary tuft) and renal tubule.
- Renal tubule starts with Bowman's capsule enclosing glomerulus (Malpighian body).
- Renal tubule segments: proximal convoluted tubule (PCT), Henle's loop (descending and ascending limbs), distal convoluted tubule (DCT), collecting ducts.
- Collecting ducts converge into renal pelvis via medullary pyramids.

Memory Aids

- Malpighian body = glomerulus + Bowman's capsule.
- Henle's loop has descending (thin, water permeable) and ascending (thicker, cuboidal cells) limbs.
- Collecting ducts collect urine from many nephrons.

Quick Checkpoints

- What are the two main parts of a nephron?
- What is the Malpighian body?
- Describe the segments of the renal tubule.
- Where does urine collect before entering the renal pelvis?

Prepzy

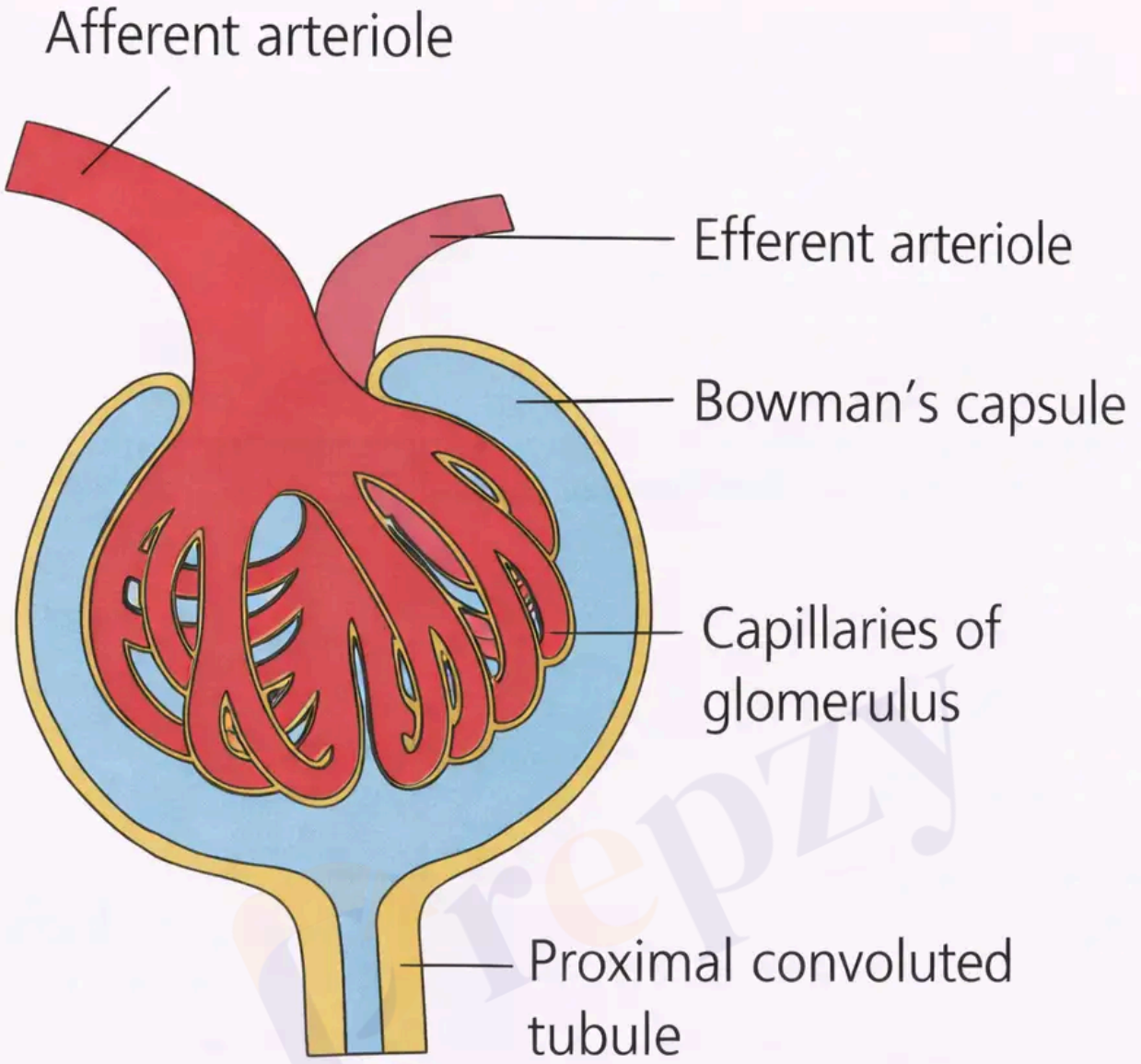


Fig.: Malpighian body (renal corpuscle)

Types of Kidneys

Classification

- Archinephric kidney: basic ancestral form, in larvae of cyclostomes (*Myxine*).
- Pronephric kidney: primitive, embryonic stage in some vertebrates.
- Mesonephric kidney: main excretory organ in aquatic vertebrates, temporary in higher vertebrates.

- Metanephric kidney: advanced type with loop of Henle, functional in reptiles, birds, mammals.

Memory Aids

- Archinephric = ancestral.
- Pronephric = embryonic.
- Mesonephric = middle, temporary.
- Metanephric = mature, advanced.

Quick Checkpoints

- What is the ancestral kidney type?
- Which kidney is embryonic?
- Which kidney is temporary in higher vertebrates?
- Which kidney has loop of Henle?

Nephron Zones

Location of Parts

- Malpighian corpuscle, PCT, DCT in renal cortex.
- Loop of Henle, collecting duct, duct of Bellini in renal medulla.
- PCT cells have brush border microvilli for surface area.
- Descending limb: thin, squamous epithelium, permeable to water.
- Ascending limb: thicker, cuboidal epithelium, impermeable to water.
- Efferent arteriole forms peritubular capillaries and vasa recta around tubules.

Memory Aids

- PCT: microvilli increase absorption.
- Descending limb: water permeable.
- Ascending limb: water impermeable.
- Vasa recta supports medullary function.

Quick Checkpoints

- Where are Malpighian corpuscle and PCT located?
- What epithelium lines the descending limb?
- What is the role of vasa recta?

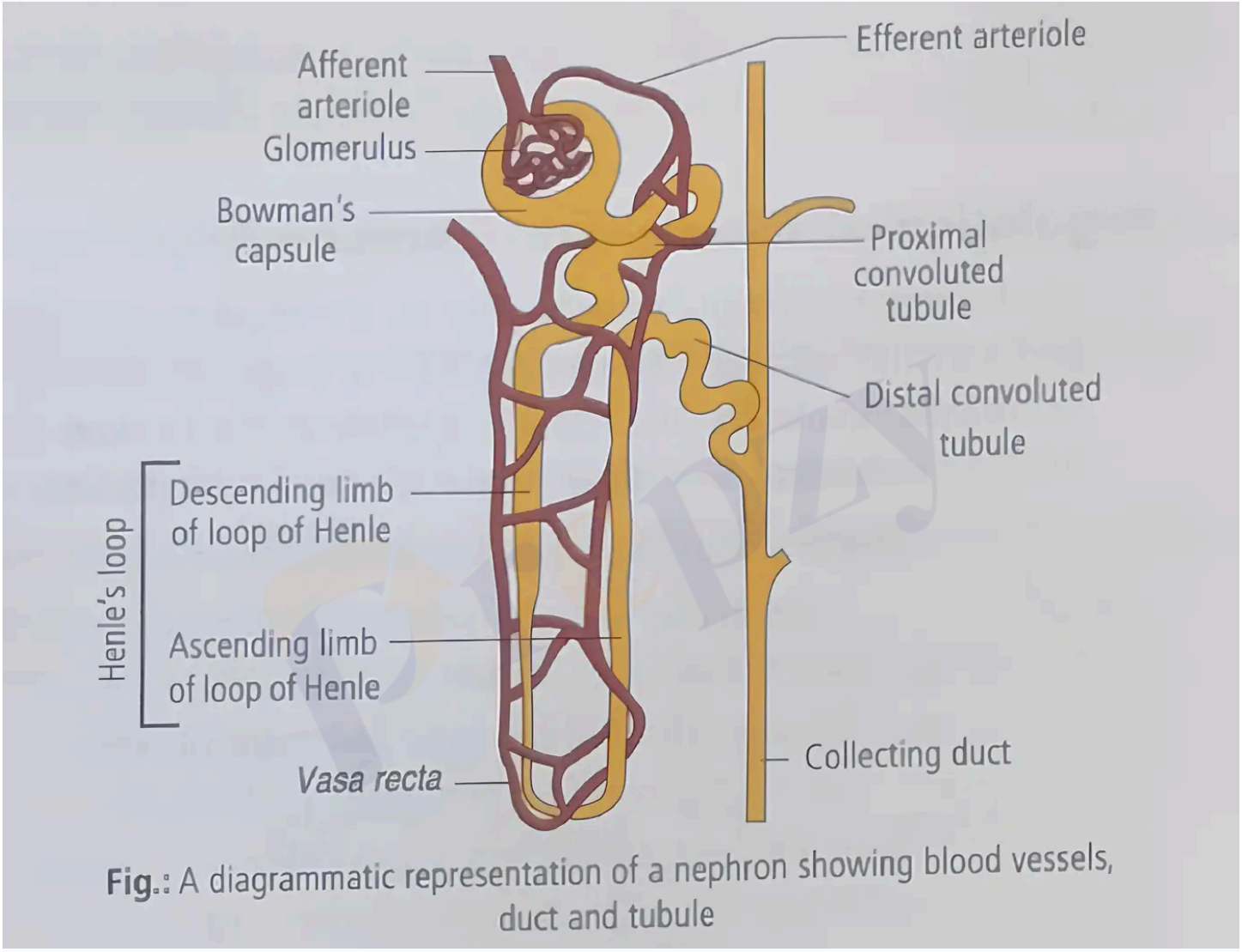


Fig.: A diagrammatic representation of a nephron showing blood vessels, duct and tubule

Types of Nephrons

Characteristics

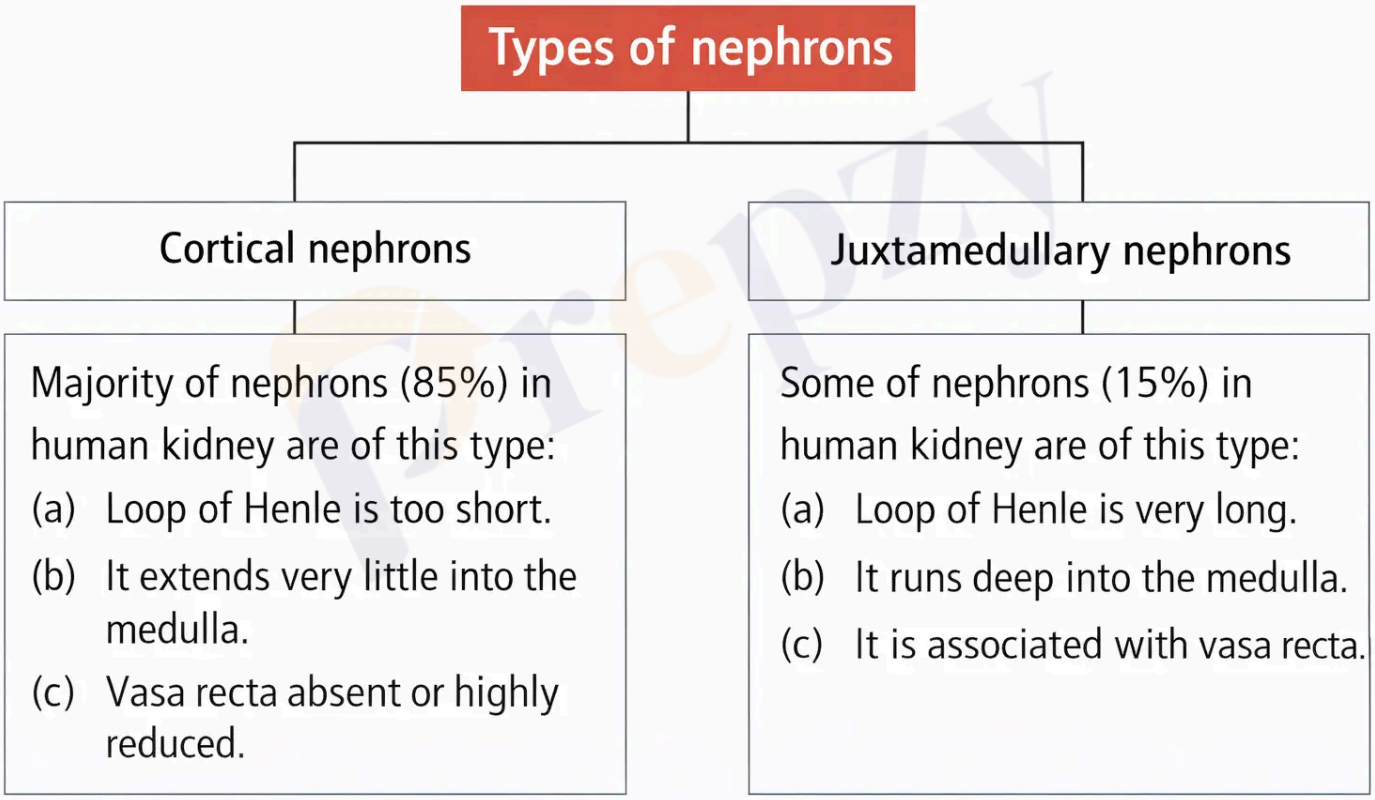
- Cortical nephrons (85%): short loop of Henle, extend little into medulla, few/no vasa recta.
- Juxtamedullary nephrons (15%): long loop of Henle, extend deep into medulla, associated with vasa recta.

Memory Aids

- Cortical = short loop, mostly cortex.
- Juxtamedullary = long loop, deep medulla.

Quick Checkpoints

- What percentage of nephrons are cortical?
- Which nephron type has a long loop of Henle?
- Which nephron type is associated with vasa recta?



Urine Formation

Processes

- Glomerular filtration (ultrafiltration) of blood plasma by glomeruli.

- Tubular reabsorption of useful substances back to blood.
- Tubular secretion of wastes and excess ions into filtrate.

Memory Aids

- Filtration: blood plasma filtered in glomerulus.
- Reabsorption: nutrients and water reabsorbed.
- Secretion: wastes secreted into tubule.

Quick Checkpoints

- What are the three main steps in urine formation?
- Where does filtration occur?
- What is reabsorbed during tubular reabsorption?
- What substances are secreted during tubular secretion?

Glomerular Filtration

Mechanism

- Blood filtered by glomerulus through endothelium, basement membrane, and Bowman's capsule epithelium.
- Podocytes form filtration slits allowing plasma except proteins to pass.
- Filtrate formed is called ultrafiltrate.
- Glomerular filtration rate (GFR) ~125 mL/min (180 L/day).
- Filtration driven by blood hydrostatic pressure; no energy required.

Memory Aids

- Filtration layers: endothelium, basement membrane, podocytes.
- Filtrate excludes proteins.
- GFR is a measure of kidney filtration efficiency.

Quick Checkpoints

- What are the three layers involved in filtration?
- What cells form filtration slits?
- What is the normal GFR value?

Regulation of Glomerular Filtration Rate

Mechanism

- Juxtaglomerular apparatus (JGA) regulates GFR.
- JGA formed by distal convoluted tubule and afferent arteriole contact.
- Drop in GFR triggers renin release from JG cells.
- Renin increases glomerular blood flow, restoring GFR.

Memory Aids

- JGA senses GFR changes.
- Renin release adjusts filtration rate.

Quick Checkpoints

- What is the role of JGA?
- How does renin affect GFR?

Effective Filtration Pressure

Components

- Glomerular blood hydrostatic pressure (GBHP): ~60 mmHg, promotes filtration.
- Blood colloidal osmotic pressure (BCOP): ~32 mmHg, opposes filtration.
- Capsular hydrostatic pressure (CHP): ~18 mmHg, opposes filtration.

- Effective filtration pressure (EFP) = GBHP - (BCOP + CHP) = 10 mmHg.
- EFP drives plasma filtration into Bowman's capsule.
- Renal plasma flow (RPF): 650-700 mL/min out of 1100-1200 mL blood/min.

Memory Aids

- EFP is net pressure for filtration.
- GBHP is main driving force.
- BCOP and CHP resist filtration.

Quick Checkpoints

- What pressures oppose filtration?
- How is EFP calculated?
- What is the typical value of EFP?

Tubular Reabsorption

Process

- Filtrate substances reabsorbed into blood via peritubular capillaries.
- About 99% of filtrate reabsorbed.
- Active reabsorption: glucose, amino acids, Na^+.
- Passive reabsorption: nitrogenous wastes, water.

Memory Aids

- Most filtrate is reabsorbed to prevent loss.
- Active transport for nutrients and ions.
- Water reabsorbed passively.

Quick Checkpoints

- What percentage of filtrate is reabsorbed?
- Which substances are actively reabsorbed?
- How is water reabsorbed?

Tubular Secretion

Process

- Tubular cells secrete H^+, K^+, ammonia into filtrate.
- Maintains ionic and acid-base balance.
- Removes substances not filtered by glomerulus.
- Secretion via active and passive transport from peritubular capillaries.
- If filtration stops due to low pressure, urine forms by secretion only.

Memory Aids

- Secretion removes excess ions and wastes.
- Important for acid-base balance.

Quick Checkpoints

- Which ions are secreted into filtrate?
- Why is tubular secretion important?
- What happens when filtration stops?

Function of the Tubules

Proximal Convoluted Tubule (PCT)

- PCT lined by simple cuboidal brush border epithelium to increase surface area for reabsorption.
- Reabsorbs nearly all essential nutrients and 70-80% of electrolytes and water.
- Maintains pH and ionic balance by secreting H^+, NH_3, K^+ into filtrate and absorbing HCO_3^-.
- Glucose and amino acids reabsorbed by active transport; water by osmosis.
- Maximum reabsorption occurs in PCT.

Memory Aids

- PCT = "Primary Catch Tubule" for nutrients and water.
- Brush border = More surface, more absorption.
- Secretes acids and bases to balance pH.

Quick Checkpoints

- What epithelium lines the PCT?
- Which substances are actively reabsorbed in PCT?
- How does PCT maintain pH?

Henle's Loop

- Ascending limb has minimal reabsorption; maintains high osmolarity in medulla.
- Descending limb permeable to water, impermeable to electrolytes; concentrates filtrate.
- Ascending limb impermeable to water; actively/passively transports electrolytes out.
- Filtrate dilutes as electrolytes leave ascending limb to medullary fluid.

Memory Aids

- Descending limb = "Water leaves, salts stay".

- Ascending limb = "Salts leave, water stays".
- Loop creates medullary osmotic gradient.

Quick Checkpoints

- Which limb is permeable to water?
- What happens to filtrate concentration in descending limb?
- How does ascending limb affect filtrate?

Distal Convoluted Tubule (DCT)

Functions

- Conditional reabsorption of Na^+ and water.
- Reabsorbs HCO_3^- and selectively secretes H^+, K^+, and NH_3 to maintain pH and ionic balance.

Memory Aids

- DCT = "Dynamic Control Tubule" for ions and pH.
- Selective secretion keeps blood balanced.

Quick Checkpoints

- What ions are reabsorbed in DCT?
- Which ions are secreted to maintain pH?

Collecting Duct

Functions

- Extends from cortex to medulla; reabsorbs large amounts of water to concentrate urine.
- Allows small amounts of urea to pass into medullary interstitium to maintain osmolarity.
- Maintains pH and ionic balance by selective secretion of H^+ and K^+.

Memory Aids

- Collecting duct = "Final water adjustment".
- Urea recycling helps osmolarity.
- Secretion controls blood pH and ions.

Quick Checkpoints

- What is the main function of the collecting duct?
- How does urea contribute to urine concentration?
- Which ions are secreted here?

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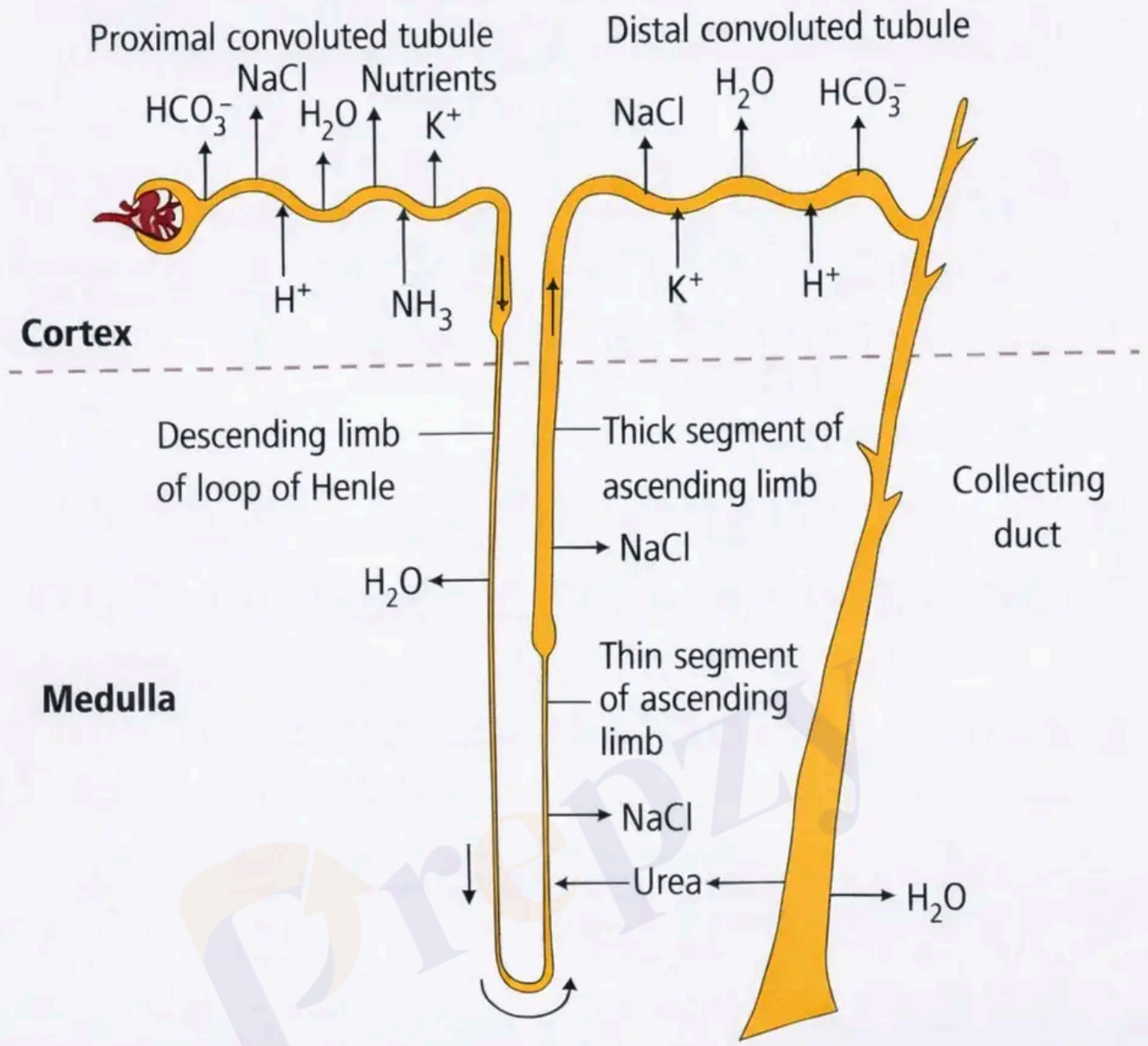

Fig.: Reabsorption and secretion of major substances at different parts of the nephron (Arrows indicate direction of movement of materials.)

Image Explanation

- Nephron filters blood and removes waste.
- PCT reabsorbs nutrients, water, NaCl, and HCO_3^-.
- H^+ and NH_3 secreted into tubule.
- Descending limb reabsorbs water, concentrating filtrate.
- Ascending limb reabsorbs NaCl, diluting filtrate.
- DCT selectively reabsorbs and secretes ions.
- Collecting duct reabsorbs water and urea to concentrate urine.

- Process maintains water, salt, and acid-base balance.

Mechanism of Concentration of the Filtrate

Counter Current System in Kidney

- Mammalian kidneys produce concentrated urine via loop of Henle and vasa recta in the medulla.
- Filtrate flows in opposite directions in the two limbs of loop of Henle, forming a counter current.
- Blood flow in the two limbs of vasa recta is also opposite, creating a counter current pattern.
- This arrangement maintains an osmolarity gradient from cortex (300 mOsmol/L) to inner medulla (1200 mOsmol/L).
- NaCl is actively transported by the ascending limb of Henle's loop and exchanged with descending vasa recta.
- NaCl returns to medullary interstitium via ascending vasa recta.
- Urea enters thin ascending limb and is recycled via collecting tubule, aiding concentration.
- Counter current mechanism conserves water and concentrates urine up to four times the initial filtrate.
- Longer loop of Henle in mammals correlates with higher urine concentration due to more water reabsorption.

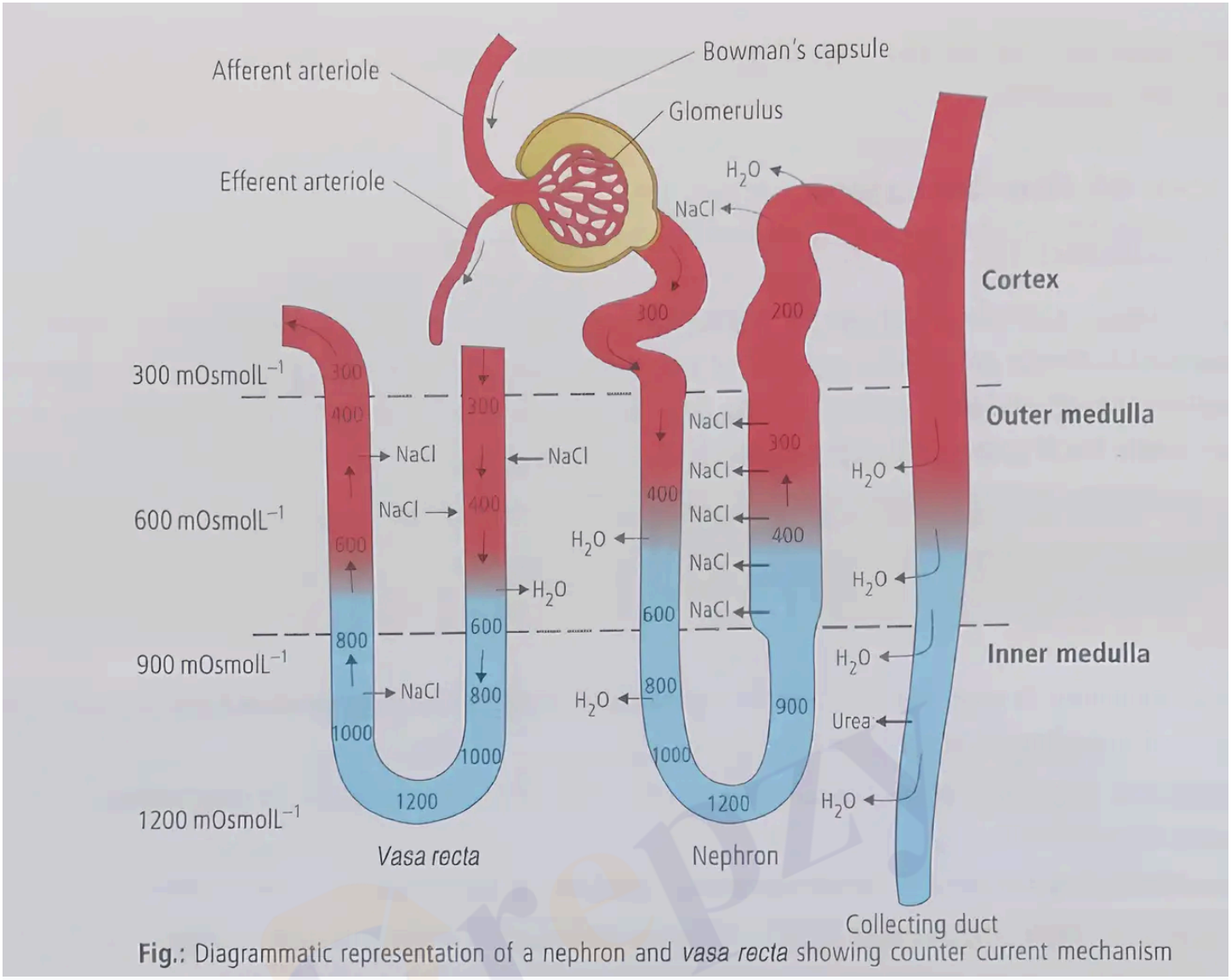

Fig.: Diagrammatic representation of a nephron and *vasa recta* showing counter current mechanism

Memory Aids

- Counter current = Opposite flows in loop of Henle and vasa recta.
- Osmolarity gradient: Cortex 300 → Inner medulla 1200 mOsmol/L.
- NaCl pumped up ascending limb; water moves down descending limb.
- Urea recycling enhances medullary concentration.
- Longer loop = More water conserved = More concentrated urine.

Quick Checkpoints

- What creates the counter current in the nephron?
- How does NaCl contribute to osmolarity gradient?
- Role of vasa recta in concentration mechanism?
- How does urea aid urine concentration?

- Effect of loop of Henle length on urine concentration?

Regulation of Kidney Function

Hormonal Feedback Mechanism

- Kidney function is regulated by hormones via feedback loops.
- Key regulators: Hypothalamus (ADH), Juxtaglomerular Apparatus (JGA), Heart (ANF).

Memory Aids

- ADH from hypothalamus controls water balance.
- JGA controls blood pressure via renin.
- ANF from heart opposes renin effects.

Quick Checkpoints

- Which hormones regulate kidney function?
- What triggers ADH release?
- How does JGA affect blood pressure?
- Role of ANF in kidney regulation?

Antidiuretic Hormone (ADH)

Function and Regulation

- Osmoreceptors detect changes in blood and body fluid volume and ionic concentration.
- Fluid loss activates osmoreceptors, stimulating hypothalamus to release ADH (vasopressin) from neurohypophysis.
- ADH promotes water reabsorption in distal kidney tubules, reducing urine output (prevents diuresis).
- Increased body fluid volume inhibits ADH release, completing feedback.

- ADH also constricts blood vessels, raising blood pressure and glomerular filtration rate (GFR).
- Diuretics increase urine production, preventing water retention and edema.
- Alcohol inhibits ADH release; caffeine blocks ADH action and sodium reabsorption, increasing urine loss.
- ADH deficiency causes diabetes insipidus with excessive urine output (20-25 L/day).

Memory Aids

- ADH = Anti-Diuresis Hormone.
- Osmoreceptors trigger ADH release on fluid loss.
- Alcohol and caffeine increase urine by affecting ADH.
- Diabetes insipidus = ADH deficiency disease.

Quick Checkpoints

- What activates osmoreceptors?
- How does ADH affect kidney tubules?
- Effect of alcohol and caffeine on ADH?
- What causes diabetes insipidus?

Juxtaglomerular Apparatus (JGA)

Renin-Angiotensin Mechanism

- Decrease in glomerular blood flow/pressure/GFR activates JG cells to release renin.
- Renin converts angiotensinogen to angiotensin I, then to angiotensin II.
- Angiotensin II effects:
  - Powerful vasoconstrictor, raises glomerular blood pressure and GFR.
  - Stimulates adrenal cortex to release aldosterone.
  - Aldosterone promotes sodium and water reabsorption in distal tubules, increasing blood pressure and GFR.
- This is the Renin-Angiotensin mechanism controlling blood pressure and kidney function.

Memory Aids

- Renin released when blood flow drops.
- Angiotensin II = vasoconstrictor + aldosterone stimulator.
- Aldosterone = sodium & water reabsorption.
- Renin-Angiotensin system regulates blood pressure.

Quick Checkpoints

- What triggers renin release?
- Role of angiotensin II?
- How does aldosterone affect kidneys?
- What is the Renin-Angiotensin mechanism?

Atrial Natriuretic Factor (ANF)

Function and Regulation

- Increased blood flow to heart atria triggers ANF release.
- ANF causes vasodilation, lowering blood pressure.
- ANF inhibits renin release from JGA, opposing the renin-angiotensin mechanism.

Memory Aids

- ANF released by atria on high blood flow.
- ANF dilates vessels, reduces blood pressure.
- ANF blocks renin to balance blood pressure.

Quick Checkpoints

- What triggers ANF release?
- How does ANF affect blood vessels?
- What is ANF's role in renin regulation?

Micturition

Mechanism and Process

- Expulsion of urine from the urinary bladder is called micturition.
- Neural control of this process is the micturition reflex.
- Urine formed by nephrons is stored in the urinary bladder.
- Stretching of bladder walls by urine activates stretch receptors.
- Stretch receptors send signals to the central nervous system (CNS).
- CNS sends motor signals to contract bladder smooth muscles.
- Simultaneously, urethral sphincter relaxes to release urine.
- Average urine output in adults is 1 to 1.5 litres per day.

Urine Characteristics

- Urine is light yellow, watery, and slightly acidic (pH ~6.0).
- Colour is due to pigment urochrome from haemoglobin breakdown.
- About 25-30 g of urea is excreted daily.
- Standing urine develops ammonia smell due to bacterial urea breakdown.
- Urine analysis aids diagnosis of metabolic and kidney disorders.
- Glucose (glycosuria) and ketone bodies (ketonuria) indicate diabetes mellitus.
- Albumin presence is albuminuria; WBCs or pus presence is pyuria.

Memory Aids

- Micturition reflex = bladder stretch → CNS signal → muscle contract + sphincter relax.
- Urochrome = urine yellow pigment from RBC breakdown.
- Glycosuria and ketonuria = diabetes markers in urine.
- Albuminuria = albumin in urine; Pyuria = pus/WBCs in urine.

Quick Checkpoints

- What triggers the micturition reflex?
- Which muscles contract and relax during urination?

- What causes the yellow colour of urine?
- How does urine pH and smell change over time?
- What do glycosuria and ketonuria indicate?
- Define albuminuria and pyuria.

Role of Other Organs in Excretion

Lungs

- Remove large amounts of CO_2 (200 mL/min).
- Eliminate significant water daily through respiration.

Liver

- Secretes bile containing bilirubin, biliverdin, cholesterol, degraded steroid hormones, vitamins, and drugs.
- These substances exit the body with digestive wastes.

Skin

- Sweat glands produce watery fluid with NaCl, small urea, lactic acid.
- Sweat cools body surface and removes some wastes.
- **Sebaceous glands** secrete sterols, hydrocarbons, waxes via sebum.
- Sebum protects skin with oily covering.
- Small nitrogenous wastes also eliminated via saliva.

Memory Aids

- Lungs: "CO_2 and water out" through breathing.
- Liver: "Bile removes waste pigments and toxins."
- Skin: "Sweat cools and clears; sebum protects."
- Saliva: Minor nitrogenous waste exit.

Quick Checkpoints

- What wastes do lungs primarily remove?
- Which substances does liver secrete in bile?
- What is the main function of sweat besides waste removal?
- What wastes are eliminated by sebaceous glands?
- Can saliva remove nitrogenous wastes?

Uremia

Explanation

- Malfunction of kidneys causes urea accumulation in blood.
- Leads to kidney failure if untreated.
- Hemodialysis removes urea from blood externally.
- Blood is taken from artery, anticoagulant (heparin) added.
- Blood passes through cellophane tube in dialysing fluid without nitrogenous wastes.
- Urea and wastes diffuse out by concentration gradient.
- Cleaned blood returned to body with anti-heparin added.

Memory Aids

- Hemodialysis = "Blood cleaning outside body"
- Heparin prevents clotting during dialysis.

Quick Checkpoints

- What causes uremia?
- How does hemodialysis work?
- Why is dialysing fluid free of nitrogenous wastes?

Kidney Transplantation

Explanation

- Used to treat acute renal failure.
- Transplant functioning kidney from compatible donor.
- Close relatives preferred to reduce rejection risk.
- Immune system may reject incompatible kidneys.

Memory Aids

- Transplant = "Replace failed kidney"
- Compatibility reduces rejection.

Quick Checkpoints

- When is kidney transplantation used?
- Why choose a close relative as donor?
- What causes rejection?

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Renal Calculi

Explanation

- Stones formed by crystallized salts (oxalates) in kidney.
- Caused by dehydration, excess uric acid, high milk intake.
- Also due to metabolic imbalance, infection, hormonal issues.

Memory Aids

- Calculi = "Kidney stones"
- Dehydration and diet affect stone formation.

Quick Checkpoints

- What are renal calculi made of?
- List causes of renal calculi.
- How does dehydration contribute?

Glomerulonephritis

Explanation

- Inflammation of kidney's glomerulus.
- Impairs filtration function.

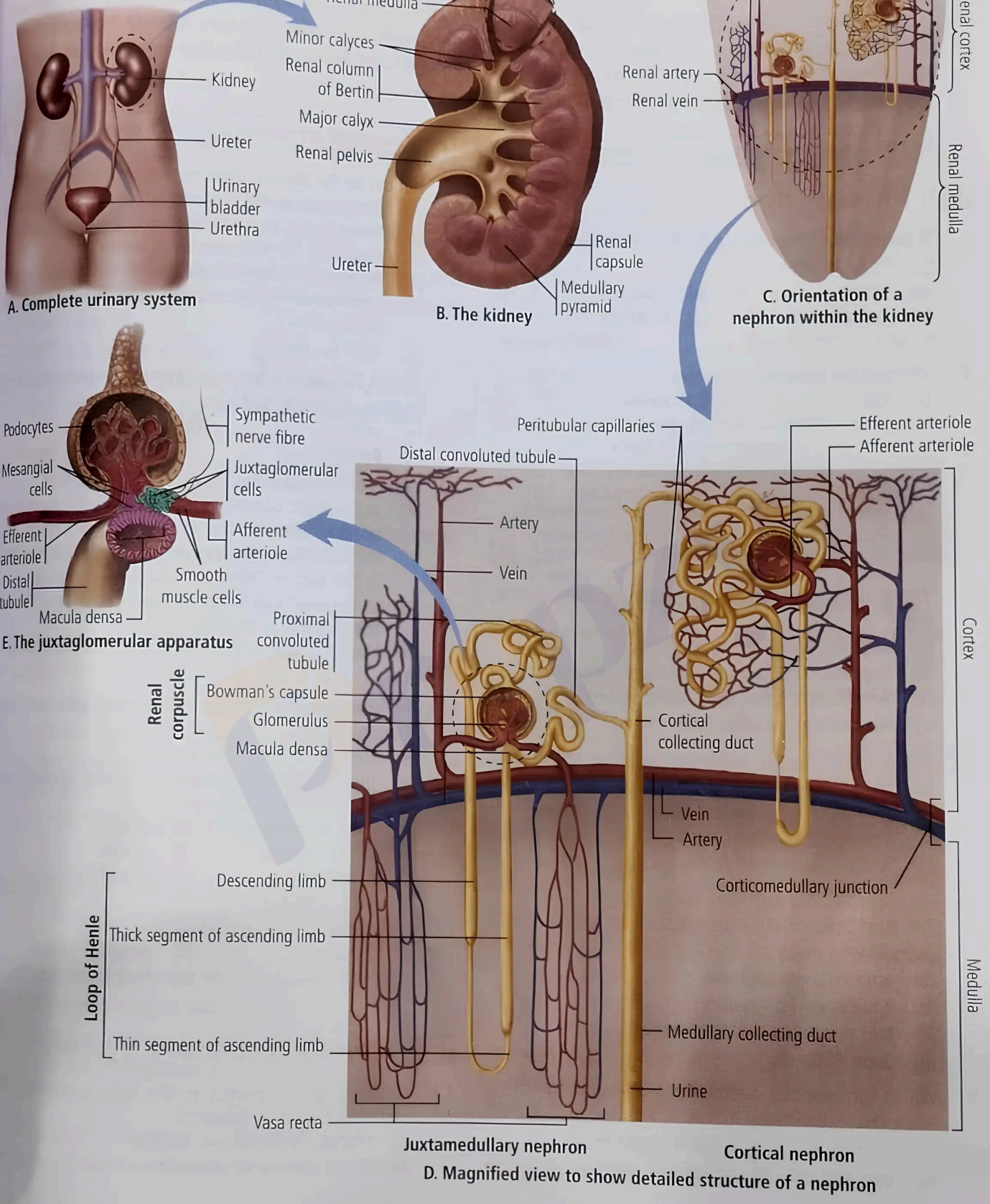
Memory Aids

- Glomerulonephritis = "Glomerulus inflammation"

Quick Checkpoints

- What part of kidney is inflamed?
- How does inflammation affect kidney function?

Human Excretory System



Human Excretory System

Explanation

- Includes kidneys, ureters, bladder, and urethra.
- Kidney has outer renal cortex and inner renal medulla.
- Contains renal pelvis and calyces for urine collection.
- Nephrons are filtering units in cortex and medulla.
- Nephron parts: Bowman's capsule, glomerulus, tubules, collecting ducts.
- Blood enters nephron via arterioles, filtered in glomerulus.
- Filtrate passes tubules; useful substances reabsorbed.
- Waste and excess fluid form urine, collected in ducts to renal pelvis.
- Urine flows through ureters to bladder, exits via urethra.

Memory Aids

- Nephron = "Kidney's filtering unit"
- Flow: Blood → Glomerulus → Tubules → Urine

Quick Checkpoints

- What are the main parts of the excretory system?
- Where are nephrons located?
- What is the function of Bowman's capsule?
- How is urine formed and transported?