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Renal System

Anatomy & Physiology

Kidneys, ureters, urinary bladder and urethra

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Renal System - B.Sc. Nursing Applied Anatomy Notes

1. Introduction

The renal system, also called the urinary system, is responsible for filtering blood, removing metabolic waste products and maintaining the body's fluid and electrolyte balance.

It consists of four main organs:

1. Two kidneys
2. Two ureters
3. One urinary bladder
4. One urethra

Main function: Formation, transportation, storage and elimination of urine.

2. Functions of the Renal System

- Removes metabolic waste products such as urea, creatinine and uric acid.
- Regulates water and electrolyte balance.
- Maintains acid-base balance.
- Helps regulate blood pressure through the renin-angiotensin-aldosterone system.
- Produces erythropoietin, which stimulates red blood cell production.
- Activates vitamin D into its active form, calcitriol.
- Maintains blood osmolarity and fluid volume.
- Helps maintain calcium and phosphate balance.

3. Kidneys

Definition

The kidneys are a pair of bean-shaped, reddish-brown organs that filter blood and produce urine.

Location

- Located on the posterior abdominal wall.
- Situated behind the peritoneum (retroperitoneal organs).
- Present on either side of the vertebral column.
- Extend approximately from T12 to L3.

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- The right kidney lies slightly lower than the left because of the liver.

Size and Weight

- Length: Approximately 10-12 cm.
- Width: Approximately 5-7 cm.
- Thickness: Approximately 3 cm.
- Weight: Approximately 120-170 g in adults, with variation.

External Structure of Kidney

Each kidney has:

- Upper pole: Upper rounded end.
- Lower pole: Lower rounded end.
- Lateral border: Convex outer border.
- Medial border: Concave inner border containing the hilum.
- Hilum: Opening through which renal vessels, nerves, lymphatics and the renal pelvis pass.

Coverings of the Kidney

From inside outward:

1. Fibrous capsule: Thin protective covering directly surrounding the kidney.
2. Perirenal fat: Fat surrounding the kidney and providing cushioning.
3. Renal fascia: Connective tissue that helps anchor the kidney.
4. Pararenal fat: Fat outside the renal fascia.

Internal Structure of Kidney

The kidney has two main regions:

A. Renal Cortex

- Outer region of the kidney.
- Contains renal corpuscles and convoluted tubules.
- Appears granular.
- Plays an important role in blood filtration and tubular processing.

B. Renal Medulla

- Inner region of the kidney.
- Contains renal pyramids.
- Renal pyramids end at renal papillae.
- Papillae drain urine into minor calyces.

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Urine Collection Pathway

Renal papilla -> Minor calyx -> Major calyx -> Renal pelvis -> Ureter -> Urinary bladder -> Urethra.

Hilum of Kidney

The renal hilum is the medial opening of the kidney.

Structures passing through it include:

- Renal vein
- Renal artery
- Renal pelvis and ureter
- Lymphatic vessels
- Nerves

A useful anterior-to-posterior arrangement is: Vein - Artery - Pelvis (VAP).

Blood Supply of Kidney

- Renal artery: Arises from the abdominal aorta.
- Renal vein: Drains into the inferior vena cava.

The kidneys receive approximately 20-25% of resting cardiac output.

Nerve Supply

- Sympathetic fibres mainly arise from thoracic and upper lumbar spinal segments.
- Parasympathetic supply is mainly through the vagus nerve.
- Autonomic nerves influence renal blood flow and renin release.

4. Nephron

Definition

The nephron is the structural and functional unit of the kidney. Each kidney contains approximately one million nephrons, although the number varies.

Parts of Nephron

A. Renal Corpuscle

It consists of:

- Glomerulus: A network of capillaries where blood filtration begins.
- Bowman's capsule: A cup-shaped structure surrounding the glomerulus that collects the filtrate.

B. Renal Tubule

It consists of:

1. Proximal convoluted tubule (PCT)

2. Loop of Henle

3. Distal convoluted tubule (DCT)

4. Connecting tubule, which drains toward the collecting duct

Collecting ducts receive fluid from multiple nephrons and carry it toward the renal papilla.

Types of Nephrons

1. Cortical nephrons: Mostly located in the outer cortex; have shorter loops of Henle.

2. Juxtamedullary nephrons: Located near the corticomedullary junction; have long loops of Henle and help concentrate urine.

Functions of Nephron

- Filters blood.
- Reabsorbs useful substances.
- Secretes certain substances into tubular fluid.
- Helps regulate water, electrolytes and acid-base balance.
- Forms urine.

Juxtaglomerular Apparatus (JGA)

The JGA is a specialised structure near the glomerulus.

It includes:

- Juxtaglomerular cells
- Macula densa
- Extraglomerular mesangial cells

Functions:

- Helps regulate blood pressure.
- Controls renin release.
- Helps regulate glomerular filtration.

5. Formation of Urine

Urine formation occurs through three major processes:

1. Glomerular Filtration

- Occurs in the renal corpuscle.
- Water and small dissolved substances pass from blood into Bowman's capsule.
- Blood cells and most plasma proteins normally remain in the bloodstream.

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2. Tubular Reabsorption

- Occurs along the renal tubules.
- Useful substances return from tubular fluid to the blood.
- Includes glucose, amino acids, water and electrolytes.

3. Tubular Secretion

- Certain substances move from blood into the renal tubules.
- Examples include hydrogen ions, potassium ions and some drugs.
- Helps maintain electrolyte and acid-base balance.

Normal urine output: Approximately 800-2,000 mL per day in many adults, depending on fluid intake and other factors. A commonly used minimum clinical threshold is around 0.5 mL/kg/hour.

Normal Characteristics of Urine

Characteristic

Normal finding

Colour

Pale yellow to amber

Appearance

Clear

pH

Usually around 4.5-8

Specific gravity

Approximately 1.005-1.030

Protein

Absent or trace

Glucose

Normally absent

Blood

Normally absent

Daily volume

Commonly 800-2,000 mL

6. Ureters

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Definition

Ureters are two narrow muscular tubes that transport urine from the renal pelvis to the urinary bladder.

Location and Length

- One ureter arises from each kidney.
- They are retroperitoneal structures.
- Each ureter is approximately 25-30 cm long in adults.
- They enter the urinary bladder obliquely.

Structure of Ureter

The ureter has three main layers:

1. Mucosa: Inner lining, mainly transitional epithelium (urothelium).
2. Muscular layer: Smooth muscle that produces peristaltic contractions.
3. Adventitia: Outer connective tissue layer containing blood vessels and nerves.

Functions of Ureter

- Transports urine from kidneys to the bladder.
- Uses peristaltic contractions to move urine.
- The oblique entry into the bladder helps prevent backflow of urine.

Narrowings of Ureter

Three common anatomical narrowings are clinically important because stones may become lodged there:

1. Pelviureteric junction (PUJ).
2. Crossing of the pelvic brim near the iliac vessels.
3. Ureterovesical junction (UVJ).

Blood Supply

The ureter receives blood from several sources along its length, including branches from:

- Renal artery
- Gonadal arteries
- Common and internal iliac artery branches
- Vesical arteries

7. Urinary Bladder

Definition

The urinary bladder is a hollow, muscular organ that temporarily stores urine before its elimination through the urethra.

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Location

- Situated in the pelvic cavity.
- Lies behind the pubic symphysis.
- When empty, it remains mainly within the pelvis.
- When distended, it expands upward into the lower abdomen.

Shape and Capacity

- Empty bladder: Usually pyramidal or tetrahedral in shape.
- Full bladder: Becomes rounded or oval.
- Typical functional adult capacity: Approximately 400-600 mL, with individual variation.

Parts of Urinary Bladder

1. Apex: Anterior end directed toward the umbilicus.
2. Body: Main central portion.
3. Fundus or base: Posterior surface.
4. Neck: Lowest part that continues into the urethra.

Layers of Urinary Bladder

1. Mucosa: Lined by transitional epithelium (urothelium).
2. Submucosa: Connective tissue layer, where distinguishable.
3. Muscular layer: Detrusor muscle, composed of interlacing smooth muscle bundles.
4. Outer covering: Adventitia, with serosa covering the superior surface.

Trigone of Urinary Bladder

The trigone is a smooth triangular area on the internal base of the bladder.

It is formed by three openings:

- Two ureteric openings.
- One internal urethral opening.

Functions of Urinary Bladder

- Temporarily stores urine.
- Expels urine during micturition.
- Maintains continence between urination episodes.

Blood Supply

- Mainly supplied by superior and inferior vesical arteries.
- In females, vaginal artery branches may also contribute.

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Nerve Supply

- Parasympathetic: Pelvic splanchnic nerves (S2-S4); stimulate detrusor contraction and promote voiding.
- Sympathetic: Mainly T11-L2 through hypogastric pathways; supports storage.
- Somatic: Pudendal nerve (S2-S4); controls the external urethral sphincter.

8. Urethra

Definition

The urethra is a muscular tube that carries urine from the urinary bladder to the outside of the body.

Functions

- Carries urine out of the body.
- Helps maintain urinary continence through sphincter mechanisms.
- In males, also serves as a passage for semen.

Female Urethra

- Approximately 3-4 cm long.
- Short and relatively straight.
- Opens into the vestibule of the vulva, anterior to the vaginal opening.
- Carries urine only.

Clinical importance: The short female urethra contributes to the increased risk of urinary tract infections.

Male Urethra

- Approximately 18-20 cm long.
- Longer than the female urethra.
- Carries both urine and semen, at different times.

Parts of Male Urethra

1. Pre-prostatic (intramural) part: Short segment at the bladder neck.
2. Prostatic urethra: Passes through the prostate gland.
3. Membranous urethra: Passes through the external urethral sphincter and perineal membrane.
4. Spongy (penile) urethra: Passes through the corpus spongiosum of the penis.

Comparison: Male and Female Urethra

Feature

Male urethra

Female urethra

Length

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Approximately 18-20 cm

Approximately 3-4 cm

Function

Urine and semen passage

Urine passage

Course

Longer and curved

Short and relatively straight

Parts

Four commonly described parts

Not divided into comparable named parts

UTI risk

Lower anatomical risk

Higher anatomical risk

Sphincters of Urethra

1. Internal urethral sphincter: Smooth muscle at the bladder neck; involuntary control is particularly important in males.
2. External urethral sphincter: Skeletal muscle; under voluntary control through the pudendal nerve.

9. Micturition (Urination)

Definition

Micturition is the process of emptying urine from the urinary bladder through the urethra.

Mechanism of Micturition

1. Urine gradually fills the bladder.
2. Stretch receptors in the bladder wall detect distension.
3. Sensory impulses travel mainly through pelvic nerves to the sacral spinal cord.
4. Parasympathetic activity causes detrusor muscle contraction.
5. The bladder outlet and urethral sphincters relax in coordination.
6. Urine passes through the urethra.

Voluntary control of the external urethral sphincter helps determine when urination occurs.

Nervous Control

- Parasympathetic (S2-S4): Promotes bladder emptying.
- Sympathetic (T11-L2): Supports urine storage.

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- Somatic (S2-S4): Controls the external urethral sphincter.

10. Common Renal and Urinary Disorders

Disorder

Description

Urinary tract infection (UTI)

Infection affecting the urinary tract

Cystitis

Inflammation or infection of the urinary bladder

Urethritis

Inflammation of the urethra

Pyelonephritis

Infection involving the kidney and renal pelvis

Glomerulonephritis

Inflammation of the glomeruli

Renal calculi

Formation of stones in the kidney

Hydronephrosis

Dilatation of the renal collecting system due to impaired urine drainage

Acute kidney injury (AKI)

Sudden reduction in kidney function

Chronic kidney disease (CKD)

Abnormal kidney structure or function persisting for at least three months

Urinary incontinence

Involuntary leakage of urine

Urinary retention

Inability to empty the bladder completely

Benign prostatic hyperplasia (BPH)

Enlargement of the prostate that may obstruct urine flow

Clinical Importance

- Kidney stones can obstruct urine flow and cause severe flank pain.
- UTIs may spread upward and cause pyelonephritis.
- Glomerular damage can cause proteinuria and haematuria.
- Severe renal impairment can lead to fluid overload and electrolyte imbalance.

- BPH may cause urinary hesitancy, weak stream and retention.
- Reduced renal erythropoietin production can contribute to anaemia in CKD.

11. Nursing Importance of the Renal System

Nurses should understand renal anatomy and physiology to provide safe and effective patient care.

Assessment

- Monitor intake and output (I&O).
- Measure urine volume, colour, clarity and odour.
- Assess for pain, dysuria, frequency, urgency and haematuria.
- Monitor blood pressure, oedema and daily body weight.
- Assess for bladder distension and urinary retention.

Investigations

Important investigations include:

- Urine routine and microscopy.
- Urine culture and sensitivity.
- Blood urea and serum creatinine.
- Estimated glomerular filtration rate (eGFR).
- Serum electrolytes.
- Ultrasound of kidneys, ureters and bladder.
- Other imaging when clinically indicated.

Nursing Responsibilities

- Maintain accurate intake and output records.
- Encourage appropriate fluid intake when not contraindicated.
- Maintain aseptic technique during urinary catheterisation.
- Provide catheter care and monitor urine drainage.
- Observe for signs of UTI and report abnormalities.
- Monitor renal function and electrolyte results.
- Administer prescribed medicines safely, considering renal function.
- Educate patients about hydration, personal hygiene and medication adherence.
- Report reduced urine output, sudden anuria, blood in urine or signs of fluid overload promptly.

Important: In adults, urine output persistently below approximately 0.5 mL/kg/hour for six hours requires clinical assessment for possible oliguria or acute kidney injury.

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12. Important Differences for Examination

Kidney vs Ureter vs Urinary Bladder vs Urethra

Organ

Main function

Kidney

Filters blood and forms urine

Ureter

Transports urine to the bladder

Urinary bladder

Stores urine

Urethra

Carries urine outside the body

Filtration vs Reabsorption vs Secretion

Process

Direction

Main purpose

Filtration

Blood to Bowman's capsule

Forms filtrate

Reabsorption

Tubule to blood

Returns useful substances

Secretion

Blood to tubule

Removes additional substances

13. Important Questions for Nursing Examinations

Long Answer Questions

1. Describe the anatomy of the kidney with a labelled diagram.
2. Explain the structure and functions of the nephron.
3. Describe the mechanism of urine formation.
4. Explain the anatomy of the urinary bladder and urethra.
5. Describe the mechanism and nervous control of micturition.

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Short Answer Questions

1. Write the functions of the kidney.
2. Explain the coverings of the kidney.
3. What is a nephron?
4. Write the parts of the ureter.
5. Describe the trigone of the urinary bladder.
6. Differentiate between male and female urethra.
7. Write the functions of the urinary bladder.
8. What is the juxtaglomerular apparatus?
9. Define micturition.
10. Write the three processes of urine formation.

Very Short Answer Questions

1. What is the functional unit of the kidney? Answer: Nephron.
2. How many kidneys are normally present? Answer: Two.
3. Where are the kidneys located? Answer: Retroperitoneally on the posterior abdominal wall.
4. Which hormone stimulates red blood cell production? Answer: Erythropoietin.
5. Which muscle forms the main muscular wall of the urinary bladder? Answer: Detrusor muscle.
6. What is the approximate length of the female urethra? Answer: 3-4 cm.
7. What is the approximate length of the male urethra? Answer: 18-20 cm.
8. Which nerve controls the external urethral sphincter? Answer: Pudendal nerve.
9. Which artery supplies the kidney? Answer: Renal artery.
10. What is the normal route of urine from the kidney to the outside? Answer: Kidney -> Ureter -> Urinary bladder -> Urethra.

14. Quick Revision

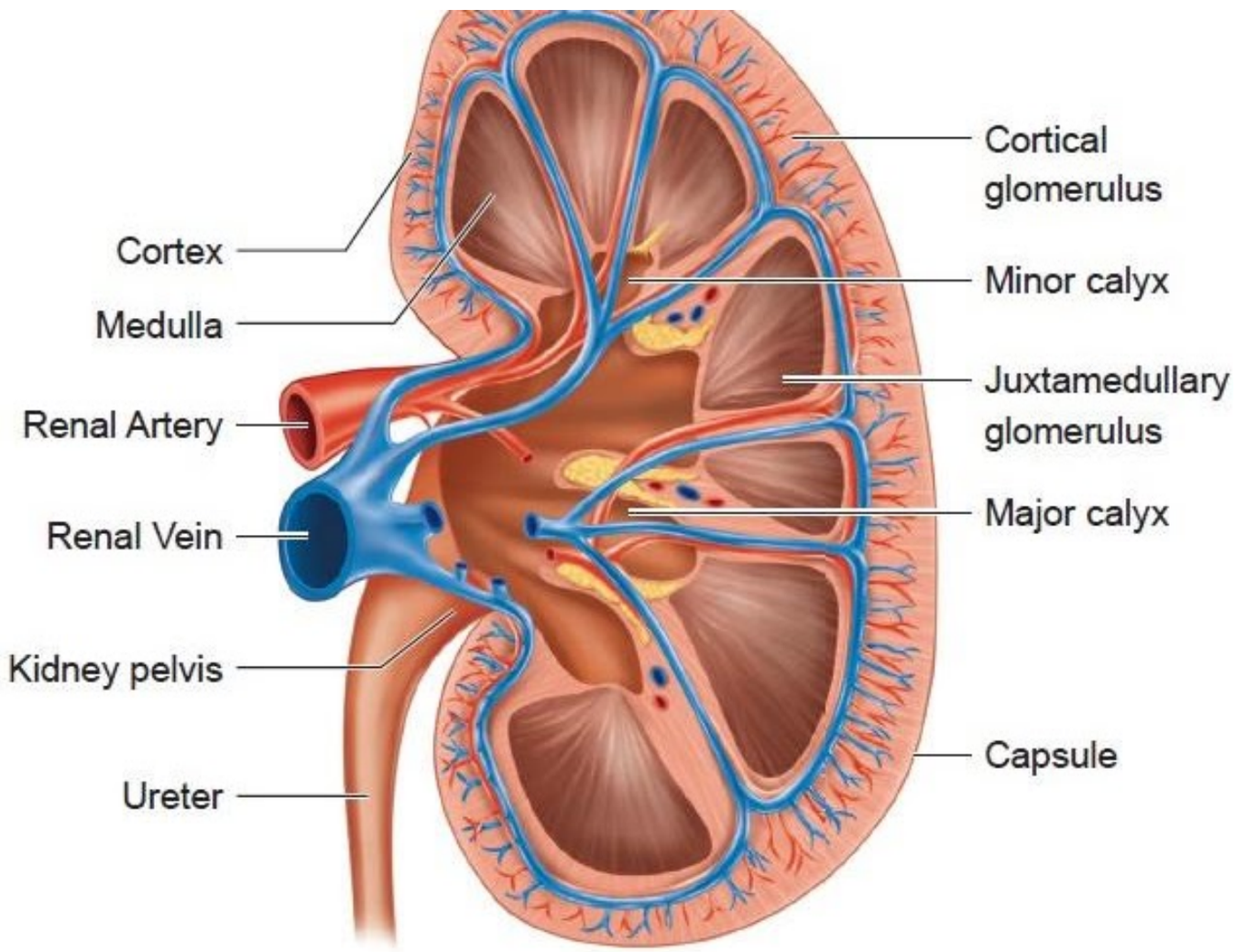
- The renal system consists of two kidneys, two ureters, one urinary bladder and one urethra.
- Kidneys are retroperitoneal organs.
- The right kidney lies slightly lower than the left.
- Nephron is the structural and functional unit of the kidney.
- The renal corpuscle consists of the glomerulus and Bowman's capsule.
- Urine formation involves filtration, reabsorption and secretion.
- Ureters transport urine through peristalsis.
- The urinary bladder stores urine.
- Detrusor muscle forms the main muscular wall of the bladder.

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- The trigone is a triangular area at the base of the bladder.
- The female urethra is shorter than the male urethra.
- The male urethra carries urine and semen.
- Micturition is the process of passing urine.
- Erythropoietin stimulates red blood cell production.
- The kidneys help regulate blood pressure, fluid balance and acid-base balance.

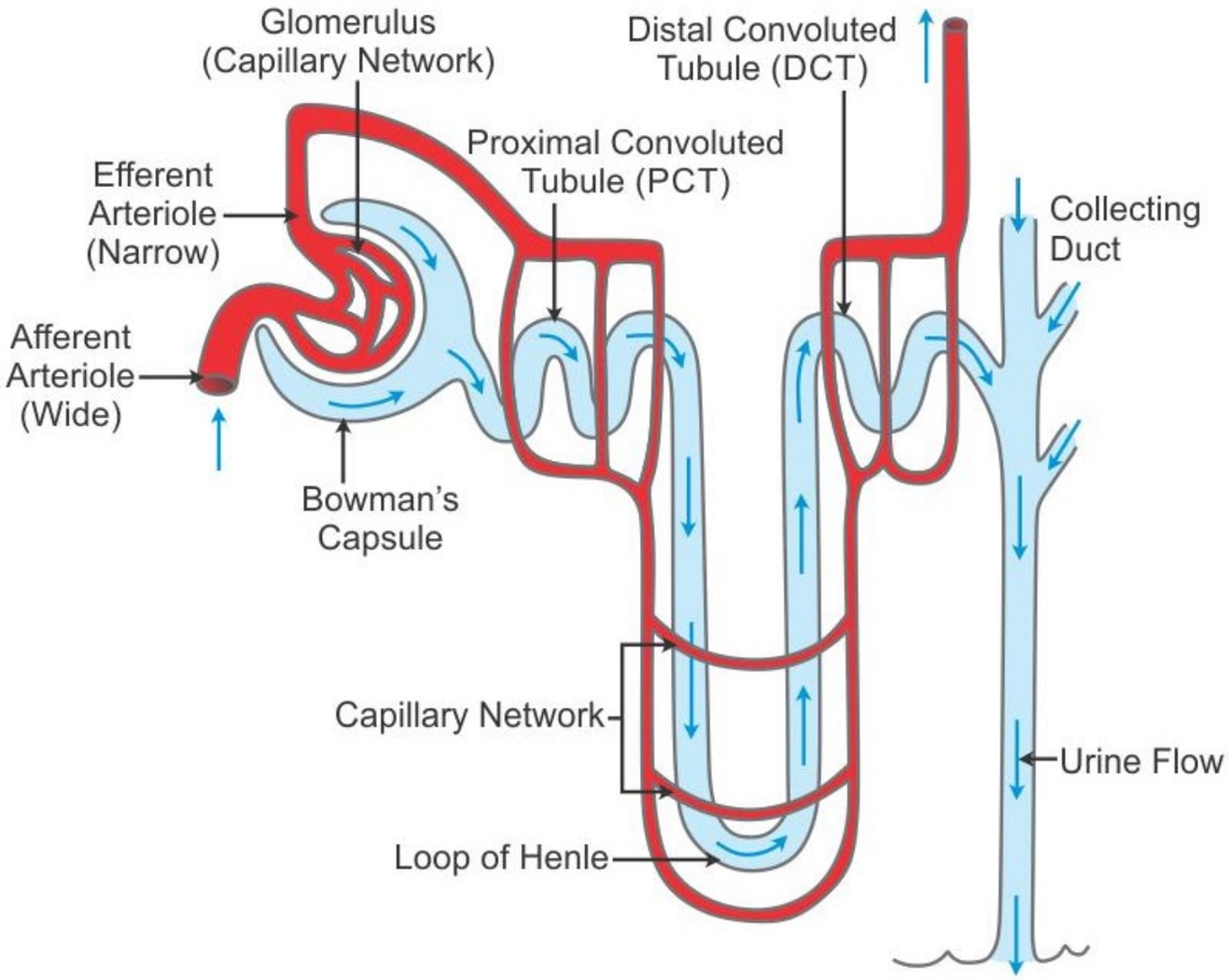
Conclusion

The renal system maintains internal body balance by filtering blood, forming urine, regulating fluids and electrolytes, and eliminating waste products. Knowledge of kidney, ureter, bladder and urethral anatomy is essential for nursing assessment, urinary catheterisation, fluid monitoring and the care of patients with renal and urinary disorders.



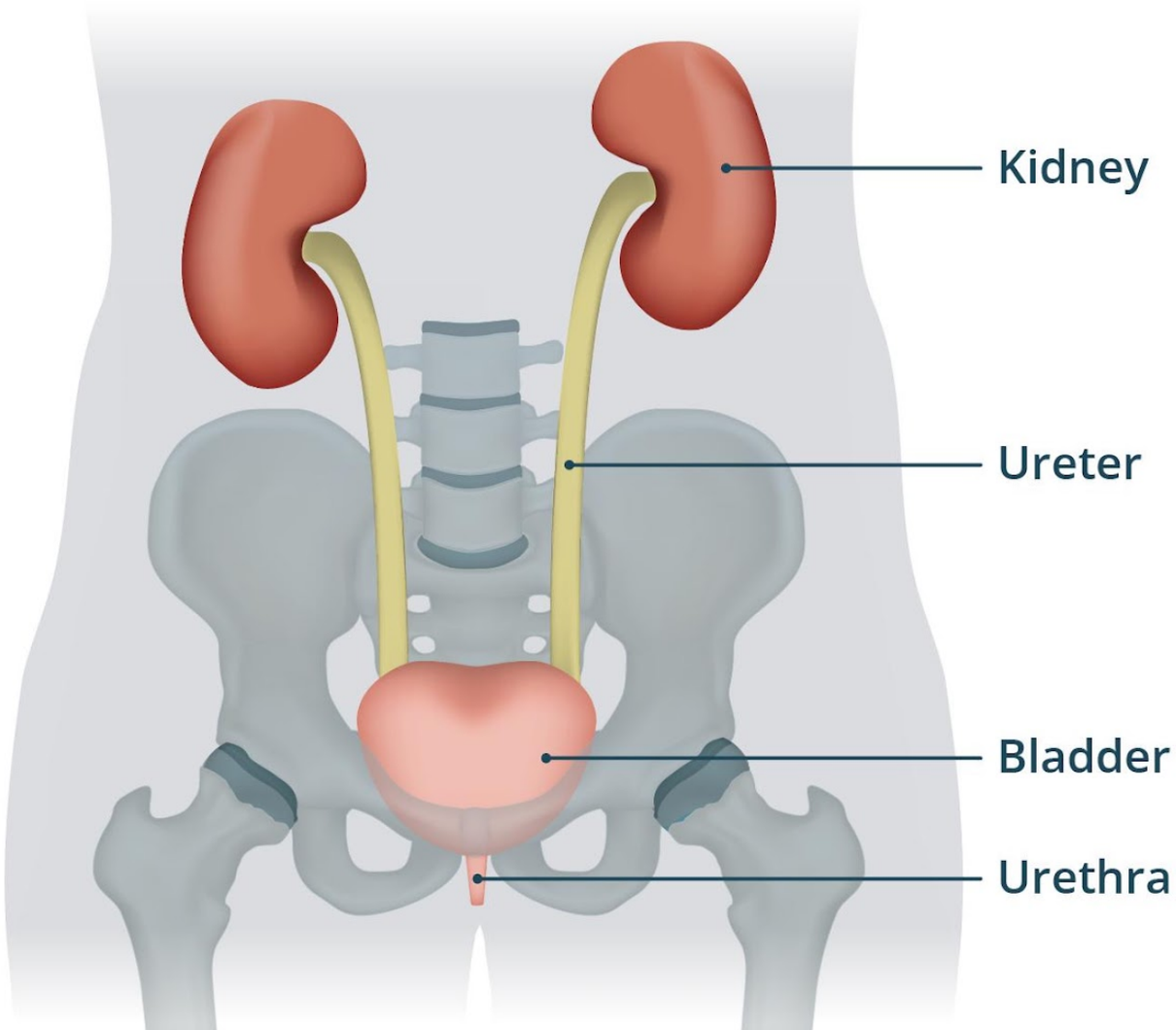
Renal System - illustration 1

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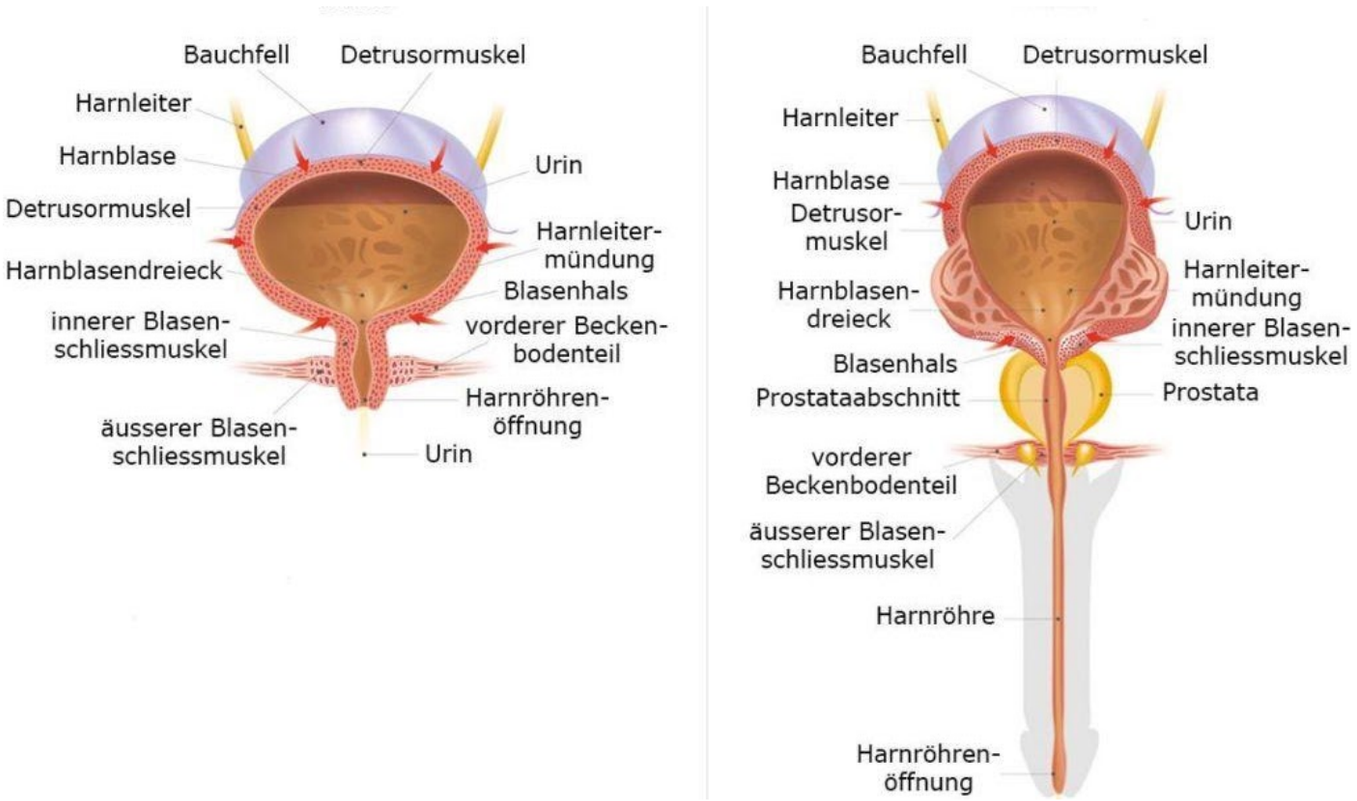
Renal System - illustration 2

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Renal System - illustration 3

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Renal System - illustration 4

Quick Revision

- Kidneys: position & structure: The kidneys are retroperitoneal on the posterior abdominal wall, approximately T12-L3; the right usually lies lower. A capsule covers each kidney. The cortex surrounds medullary pyramids whose papillae project toward minor calyces.

- Nephron & blood supply: The nephron comprises a renal corpuscle (glomerulus and glomerular/Bowman capsule) and renal tubule: proximal tubule, nephron loop and distal tubule. Tubules drain into collecting ducts.

- Ureters & urinary bladder: Ureters are muscular tubes that propel urine to the bladder. Narrowings commonly occur near the renal pelvis, pelvic brim and bladder entry. The bladder is a distensible pelvic organ with detrusor muscle.

- Urethra: Lengths vary between individuals. Distinguish the ureter (kidney to bladder) from the urethra (bladder to exterior).

Examination questions

1. Differentiate cortex and medulla.

2. List nephron segments in sequence.

3. Locate the bladder trigone.

Practice questions

Choose one best answer. The answer key and explanations follow the questions.

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1. Kidneys are located:

A. Intraperitoneally
B. Retroperitoneally
C. In the mediastinum
D. Inside the bladder

2. Which vessel enters a glomerulus?

A. Efferent arteriole
B. Renal vein
C. Afferent arteriole
D. Ureter

3. Which tube connects a kidney to the bladder?

A. Urethra
B. Ureter
C. Collecting duct
D. Renal artery

4. A ureteric stone blocks the passage between the renal pelvis and bladder. Which finding is most directly explained by this obstruction?

A. Bile accumulates in the gallbladder
B. Air collects in the pleural cavity
C. Urine backs up toward the affected kidney
D. Faeces accumulate in the rectum

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Answer key and explanations

1. B - Retroperitoneally

They lie behind the parietal peritoneum.

2. C - Afferent arteriole

The afferent arteriole brings blood to the glomerular capillaries.

3. B - Ureter

Each ureter carries urine from renal pelvis to bladder.

4. C - Urine backs up toward the affected kidney

The ureter carries urine from the renal pelvis to the urinary bladder. Obstruction can cause upstream dilation and pressure.

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