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Renal Physiology

Anatomy & Physiology

Functions of kidneys, glomerular filtration, tubular reabsorption, tubular secretion, urine formation, fluid and electrolyte balance and acid-base regulation.

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Functions and the urine-formation equation

The kidneys regulate extracellular volume, electrolyte composition, osmolality and acid-base balance while excreting metabolic wastes and many foreign compounds. They also release renin, produce erythropoietin and activate vitamin D. Renal regulation therefore influences blood pressure, red-cell production and calcium balance as well as urine. The nephron and collecting system modify a plasma-derived filtrate to produce the final urine.

Three processes determine the excretion of a substance: glomerular filtration, tubular reabsorption and tubular secretion. Excretion equals filtration minus reabsorption plus secretion. Filtration moves material from glomerular plasma into the capsular space. Reabsorption returns material from tubular fluid to blood. Secretion moves material from blood or tubular cells into the tubular lumen. These directions should be explicit in every examination diagram.

Glomerular filtration and its control

The filtration barrier comprises fenestrated capillary endothelium, a basement membrane and podocyte filtration slits. Water and many small solutes cross readily, whereas blood cells and most plasma proteins are retained. Filtration depends on opposing hydrostatic and oncotic pressures and the barrier's permeability and surface area. Afferent and efferent arteriolar tone influence glomerular pressures, but the effect depends on severity and the overall haemodynamic state.

Glomerular filtration rate is the volume filtered by both kidneys per unit time. A commonly taught young-adult value is around 120 mL/min, but age, body size, pregnancy and measurement method affect interpretation. Estimated GFR reported per 1.73 m2 is not identical to a directly measured unindexed volume. Myogenic autoregulation and tubuloglomerular feedback help stabilize filtration over a physiological pressure range; severe circulatory compromise can overwhelm them.

Compare nephron segment functions

Segment	Predominant function	Important qualification
Proximal tubule	Reabsorbs most filtered sodium and water and nearly all usual filtered glucose and amino acids	Transport capacity is finite; also secretes selected substances
Descending loop	Permits substantial water reabsorption into the medullary gradient	Tubular fluid becomes more concentrated
Ascending loop	Reabsorbs salt while remaining relatively impermeable to water	Helps generate the medullary osmotic gradient
Distal nephron and collecting duct	Fine-tune sodium, potassium, water and acid-base handling	Hormonal regulation alters final excretion
Peritubular capillaries and vasa recta	Recover reabsorbed material and support medullary exchange	Blood flow must preserve both delivery and the concentration gradient

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Sodium transport provides gradients that drive many other reabsorptive processes. Glucose normally returns to blood through proximal transporters, but when the filtered load exceeds transport capacity it remains in urine and promotes osmotic water loss. Filtrate volume is much greater than final urine volume because most filtered water is reclaimed; urine output and GFR are therefore different measurements.

Concentrated urine and hormonal regulation

The loop of Henle, medullary interstitium, vasa recta and urea recycling support a corticomedullary osmotic gradient. Countercurrent multiplication creates the gradient, while countercurrent exchange helps preserve it. The gradient provides the driving force for water recovery when collecting ducts become more permeable. Without a suitable gradient, increasing water-channel availability alone cannot provide normal concentrating ability.

Antidiuretic hormone increases collecting-duct water permeability through aquaporin insertion. Increased osmolality and substantial volume-related signals can stimulate its release. Aldosterone promotes distal sodium reabsorption and potassium secretion. Renin release activates the angiotensin pathway; angiotensin II supports vascular tone and aldosterone release. Atrial natriuretic peptide favours sodium excretion in response to cardiac chamber stretch. These controls coordinate water and salt balance rather than controlling urine volume independently.

Electrolyte and acid-base regulation

Sodium balance strongly influences extracellular fluid volume, whereas water balance relative to solute determines plasma sodium concentration. Potassium excretion is adjusted in the distal nephron and is affected by aldosterone, tubular flow and delivery. Calcium and phosphate handling interact with parathyroid hormone and calcitriol. Disturbances can alter neuromuscular and cardiac function, so a laboratory value must be assessed with symptoms and its rate of change.

Kidneys reclaim filtered bicarbonate, secrete hydrogen ions and generate new bicarbonate through net acid excretion, including ammonium and titratable acid. Buffers act rapidly and lungs adjust carbon dioxide, whereas renal compensation develops more slowly. The often-used adult arterial pH interval of 7.35-7.45 applies to arterial blood and must be interpreted with carbon dioxide and bicarbonate. Urine pH alone cannot establish the type or severity of a systemic acid-base disturbance.

Nursing applications and exam organization

Use intake and output records, weight trends, blood pressure, oedema, mental state and laboratory findings to assess renal function in context. Unexpected reduction in output requires review of measurement accuracy, drainage-system patency when present, perfusion and the clinical picture. Persistent decline or associated deterioration warrants escalation. Normal-looking urine volume does not exclude impaired clearance, and concentrated urine does not by itself prove adequate renal function.

For exams, start with kidney functions, then trace filtrate through the nephron using arrows for filtration, reabsorption and secretion. Add a segment table and a separate hormone table. In a case answer, connect reduced filtration with waste retention, altered electrolyte handling and fluid effects. Distinguish the kidney's excretory, regulatory and endocrine roles, and explain why assessment uses several observations rather than urine volume alone.

Quick Revision

- Kidneys have excretory, regulatory and endocrine functions.
- Excretion equals filtration minus reabsorption plus secretion.
- Glomerular filtration usually retains blood cells and most plasma proteins.

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- Nephron segments perform different bulk and fine-control functions.
- ADH regulates water permeability; aldosterone affects distal sodium and potassium handling.
- Kidneys contribute to acid-base balance through bicarbonate and net acid handling.

Important Examination Questions

1. Explain the filtration barrier and determinants of glomerular filtration.
2. Compare filtration, reabsorption and secretion with directional diagrams.
3. Describe the countercurrent mechanism and concentrated urine formation.
4. Discuss ADH, aldosterone, renin-angiotensin and natriuretic peptide effects.
5. Explain renal contributions to electrolyte and acid-base regulation and relevant nursing observations.

References and further reading

Newly written physiology study notes. Read the supporting textbook sections for diagrams, mechanisms and further explanation.

- OpenStax Anatomy and Physiology 2e: Physiology of Urine Formation (https://openstax.org/books/anatomy-and-physiology-2e/pages/25-5-physiology-of-urine-formation)
- OpenStax Anatomy and Physiology 2e: Tubular Reabsorption (https://openstax.org/books/anatomy-and-physiology-2e/pages/25-6-tubular-reabsorption)
- OpenStax Anatomy and Physiology 2e: Regulation of Renal Blood Flow (https://openstax.org/books/anatomy-and-physiology-2e/pages/25-7-regulation-of-renal-blood-flow)
- OpenStax Anatomy and Physiology 2e: Endocrine Regulation of Kidney Function (https://openstax.org/books/anatomy-and-physiology-2e/pages/25-8-endocrine-regulation-of-kidney-function)
- OpenStax Anatomy and Physiology 2e: Regulation of Fluid Volume and Composition (https://openstax.org/books/anatomy-and-physiology-2e/pages/25-9-regulation-of-fluid-volume-and-composition)
- OpenStax Anatomy and Physiology 2e: Acid-Base Balance (https://openstax.org/books/anatomy-and-physiology-2e/pages/26-4-acid-base-balance)

Practice questions

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

1. Which equation describes excretion of a substance?

A. Filtration + reabsorption - secretion
B. Filtration - reabsorption + secretion
C. Reabsorption - filtration
D. GFR x heart rate

2. Which hormone increases collecting-duct water permeability?

A. Erythropoietin
B. Thyroxine
C. Antidiuretic hormone

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D. Gastrin

3. Which part of the loop reabsorbs salt but is relatively impermeable to water?

A. Ascending loop

B. Descending loop

C. Renal pelvis

D. Ureter

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Answer key and explanations

1. B - Filtration - reabsorption + secretion

Filtered material contributes to excretion, reabsorbed material is removed from it, and secreted material is added.

2. C - Antidiuretic hormone

ADH increases water-channel availability so water can follow the medullary osmotic gradient.

3. A - Ascending loop

Salt transport without accompanying water helps create the medullary gradient.

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