

Chapter 3

THE KIDNEY

Kidneys

Anatomically distinct areas:

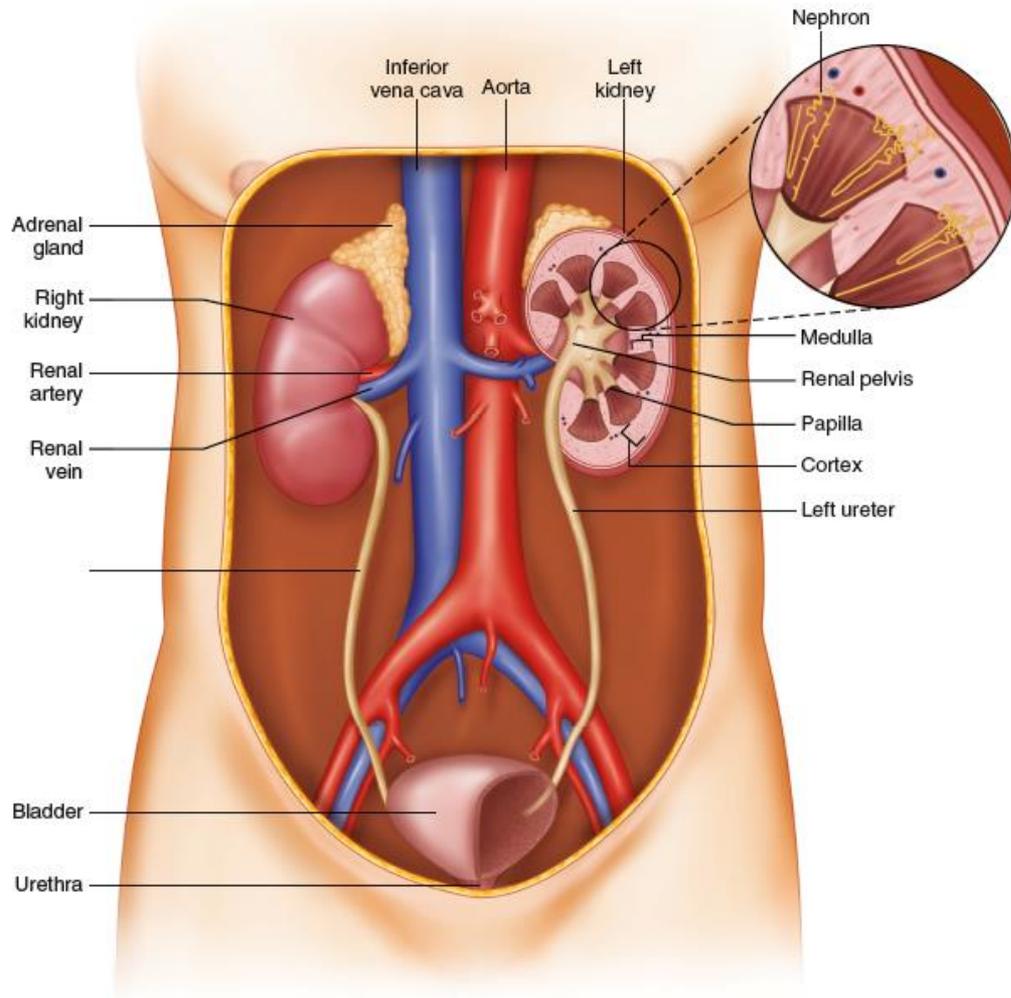
- Cortex
- Medulla

Glomeruli located in outer cortex; exclusive site of plasma filtration

Medulla consists of pyramid-shaped tissue

Each pyramid has a duct that enters a calyx

Calyces funnel urine from collecting tubules to renal pelvis



Flow of Urine

Urine from each renal pelvis enters a ureter, which is about 25 cm long

Urine passes from ureter to bladder, which serves as a holding area

When about 150 mL of urine accumulates, a nerve reflex signals an urge to urinate

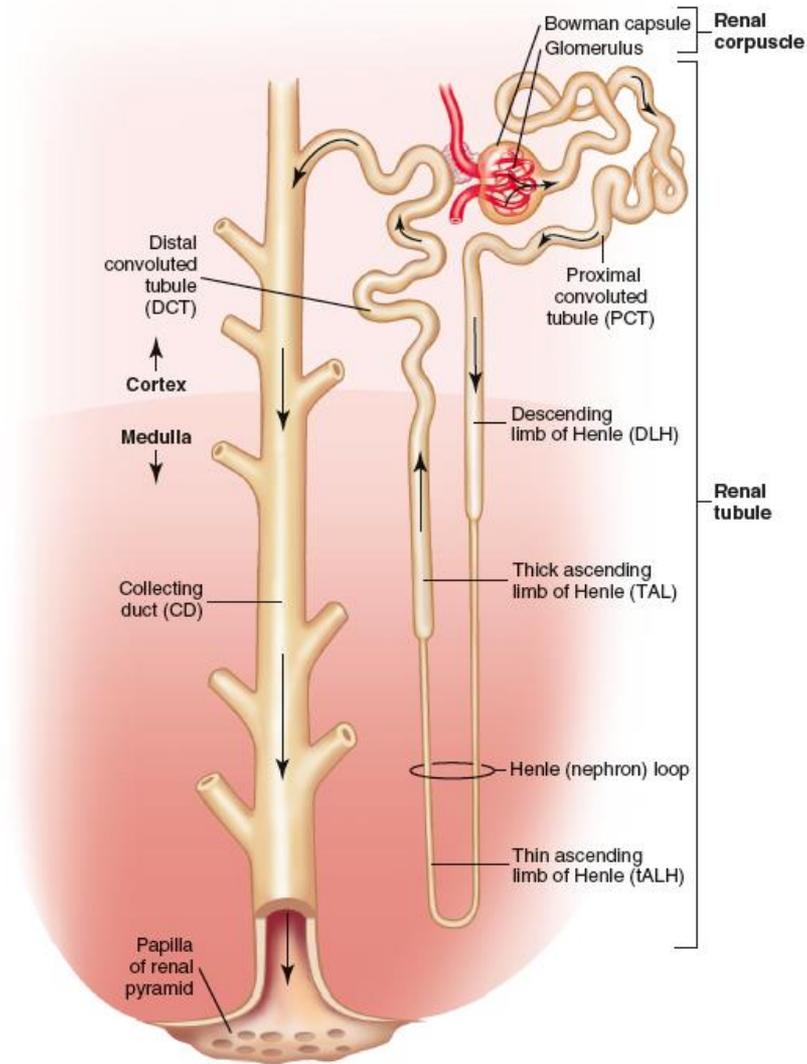
Contraction of bladder and relaxation of urinary sphincter push urine into urethra (4 cm long in women, 24 cm in men) leading to outside of the body

Nephron: The Functional Unit

1.3 million nephrons in a kidney

Five distinct areas:

- Glomerulus
 - Capillary tuft surrounded by Bowman's capsule, where filtration occurs
- Proximal convoluted tubule
- Loop of Henle
- Distal convoluted tubule
 - Reabsorption and secretion of small molecules take place in the tubules, also reabsorption of water to concentrate the urine
- Collecting tubule



Modified from Patton KT, Thibodeau GA: Anatomy and physiology, ed 9, St Louis, 2016, Mosby.

The Glomerulus

An afferent arteriole supplies blood individually to the glomerulus of each nephron

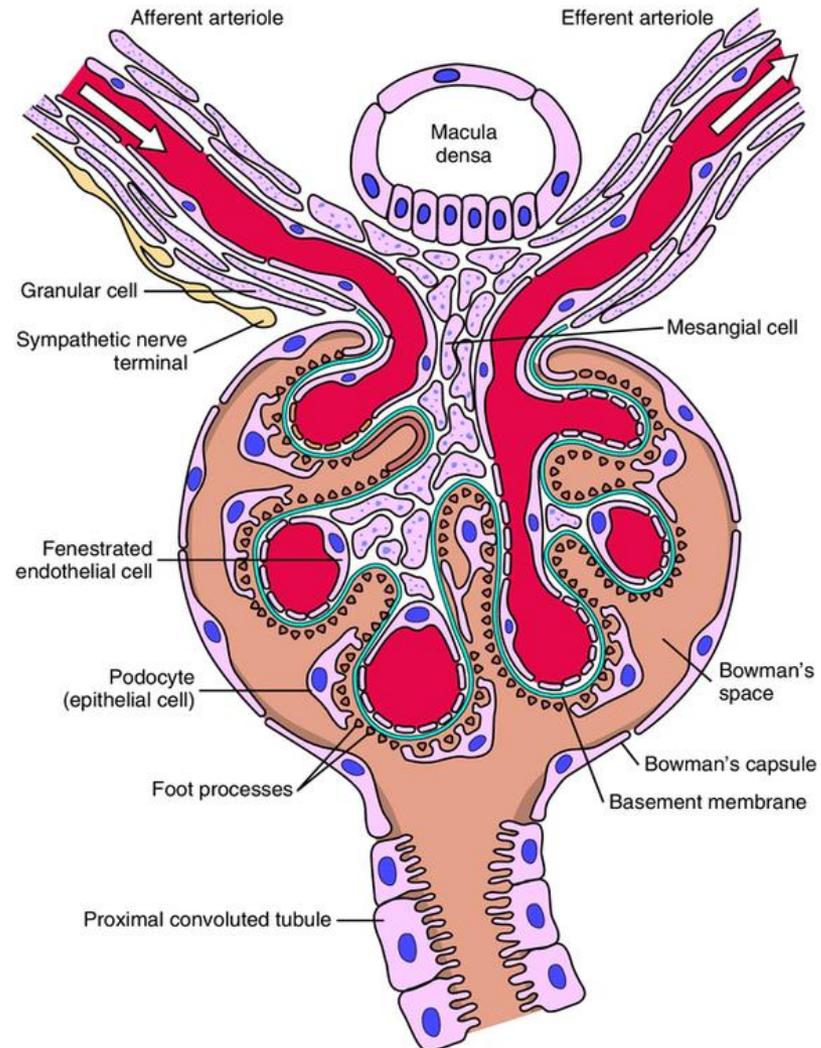
Branches into a capillary tuft on entering

Capillaries come back together to form efferent arteriole on exiting

Efferent arteriole branches a second time into a capillary plexus

High hydrostatic pressure of afferent arteriole is driving force behind glomerular filtration

Figure 3-4. A schematic overview of a glomerulus. The afferent arteriole enters the glomerulus and the efferent arteriole exits the glomerulus at the vascular pole. Also at the vascular pole, a portion of the thick ascending limb of the distal tubule, the macula densa, is in contact with the glomerular mesangium. Bowman's space is formed from specialized epithelial cells (Bowman's capsule) at the end of a renal tubule. At the urinary pole, Bowman's space becomes the tubular lumen of the proximal tubule. Podocytes are the epithelial cells that cover the glomerular capillaries and derive their name from their characteristic footlike processes. The glomerular capillaries are lined with fenestrated endothelial cells (i.e., epithelium with pores). The basement membrane, which separates the capillary endothelium and the podocytes (the epithelium of Bowman's space), is continuous throughout the glomerulus. The basement membrane is absent between the capillary endothelium and the mesangium. The mesangial cells of the glomerular tuft form the structural core of the glomerulus and are continuous with the extraglomerular mesangial cells located at the vascular pole between the afferent and efferent arterioles. The secretory granules of the granular cells contain large amounts of renin. The afferent arteriole is innervated by sympathetic nerves.



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Renin

Large amounts of secretory granules containing enzyme renin are present in afferent arteriole of juxtaglomerular apparatus

Renin is released in response to:

- Decreased arterial blood pressure or volume
- Decreased sodium (Na) or increased potassium (K)
- Vascular hemorrhage

Renin causes angiotensin formation and aldosterone secretion

Aldosterone causes kidneys to retain sodium and water

- Blood pressure will rise as a result

Urine Formation

180,000 mL of plasma is filtered each day producing a final urine volume of 600 to 1800 mL

Urine formation consists of:

- Plasma filtration at glomeruli
- Reabsorption and selective secretion by renal tubules

Kidneys play important roles in:

- Removal of metabolic wastes
- Regulation of water and electrolytes
- Maintenance of body's acid-base equilibrium

Glomerular Filtration

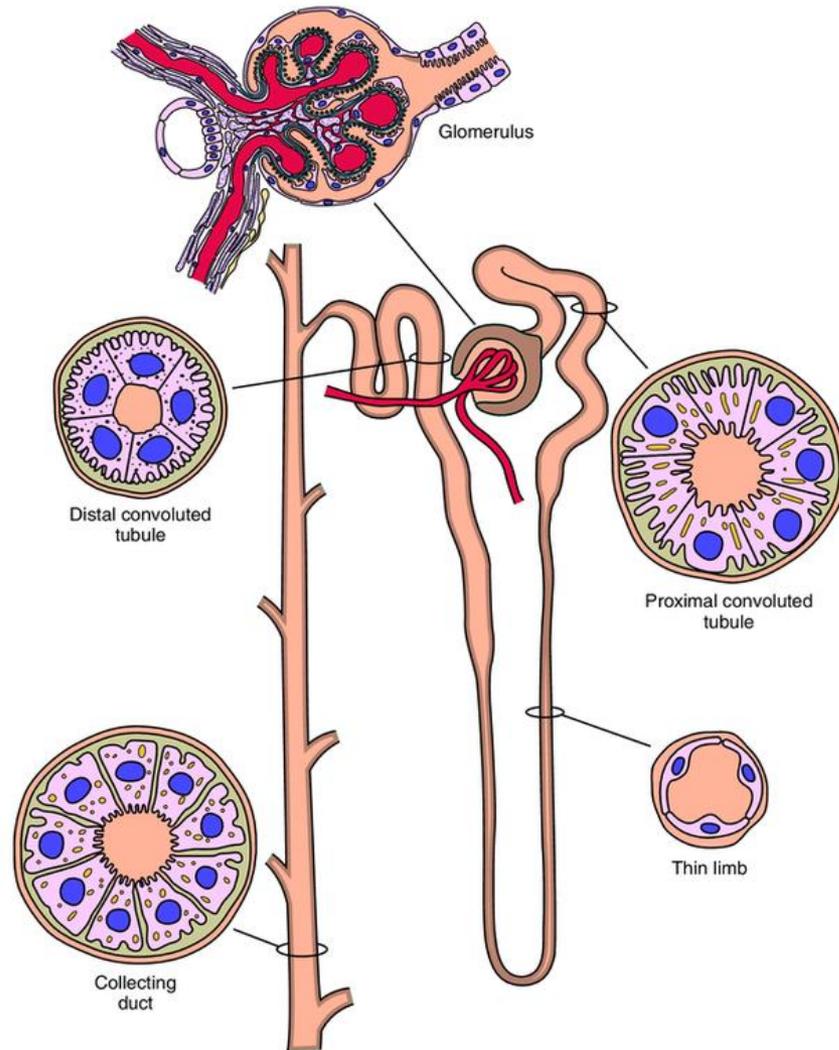
Three structures of glomerular filtration barrier:

- Capillary endothelium with its large open pores
- Trilayer basement membrane
- Filtration diaphragms located between podocytes of Bowman's space

Selectivity of barrier based on molecular size and charge, allowing water and small molecules to pass rapidly

Endothelium has a negative charge that large molecules have to overcome to pass

Figure 3-8. The general histologic characteristics of the renal tubular epithelium. Representative cross-sections of the various tubular segments roughly indicate their cellular morphology and the relative size of the cells, the tubules, and the tubular lumens.



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Tubular Transport

Reabsorption and secretion mechanisms are same, differing only in direction of movement:

- Reabsorption—back to blood
- Secretion—to the urine

Tubular transport mechanisms are active or passive

- Active—moves against a gradient, requires energy
- Passive—movement from a higher concentration to an area of lower concentration

Each solute has a specific transport system that may differ by area of tubule where it occurs

Reabsorption and Secretion

Tubules selectively reabsorb substances necessary for body homeostasis and function, such as water, amino acids, salts, and glucose

Does not reabsorb waste products such as creatinine

Secretion occurs to:

- Eliminate wastes and substances not normally present in plasma
- Adjust acid-base status of body

Most substances secreted (other than hydrogen [H], ammonia [NH₃], and potassium [K]) are weak acids or bases from metabolic or exogenous sources

TABLE 3.3 Summary of Tubular Reabsorption of Ultrafiltrate Components

Location	Mode of Reabsorption	Substance
Proximal tubule (convoluted and straight portions)	Passive	H ₂ O, Cl ⁻ , K ⁺ , urea
	Active	Na ⁺ , HCO ₃ ⁻ , glucose, amino acids, proteins, phosphate, sulfate, Mg ²⁺ , Ca ²⁺ , uric acid
<i>Loop of Henle</i>		
Thin descending limb	Passive	H ₂ O, urea
U-turn and thin ascending limb	Passive	Na ⁺ , Cl ⁻ , urea
Thick ascending limb (medullary and cortical)	Passive	Urea
Distal tubule (convoluted portion)	Active	Na ⁺ , Cl ⁻
	Active	*Na ⁺ , Cl ⁻ , sulfate, uric acid
	Passive	†H ₂ O
<i>Collecting Tubules</i>		
Cortical	Passive	†H ₂ O, Cl ⁻
	Active	*Na ⁺
Medullary	Passive	H ₂ O, urea

TABLE 3.4 Summary of Tubular Secretion of Important Ultrafiltrate Components

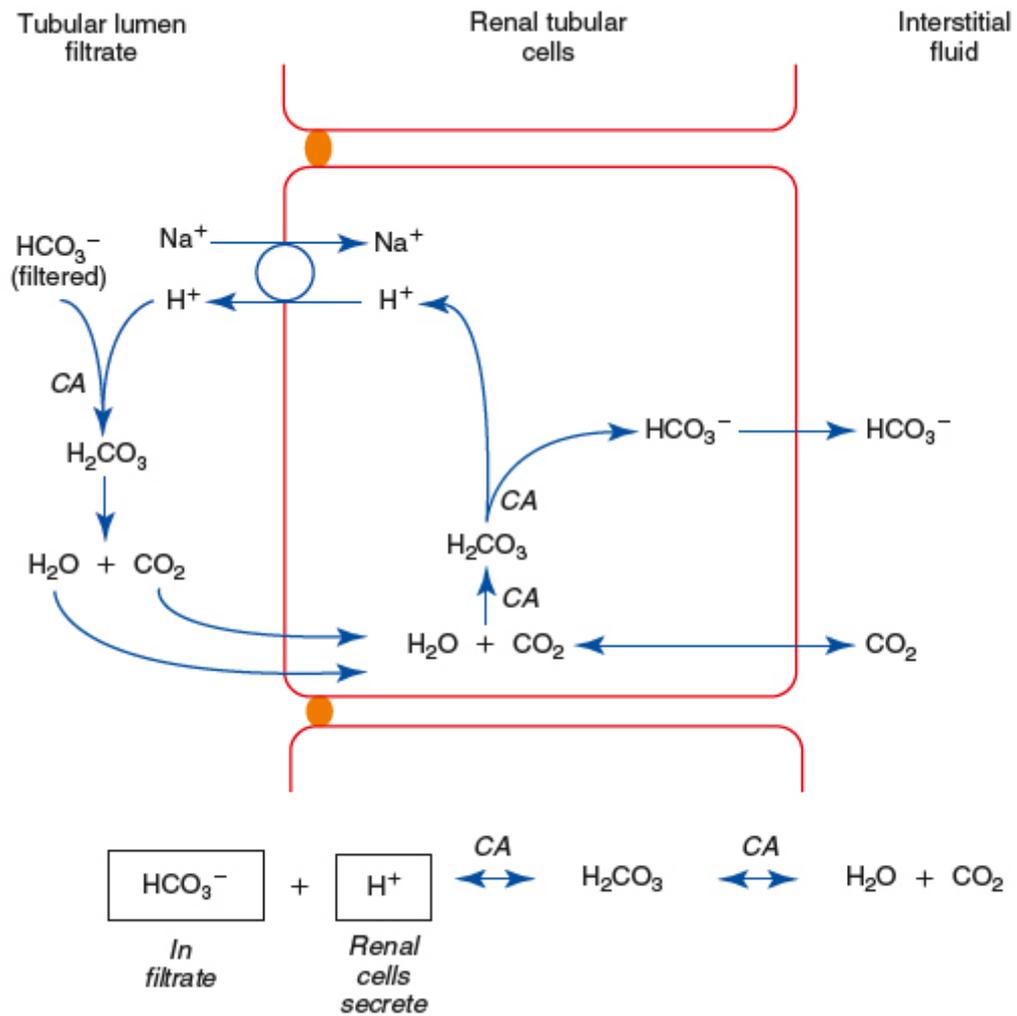
Location	Substance
Proximal tubule	H ⁺ , NH ₃ , weak acids and bases
Loop of Henle	Urea
Distal tubule	H ⁺ , NH ₃ , K ⁺ , uric acid (some drugs)
Collecting tubule	H ⁺ , NH ₃ , K ⁺ (some drugs)

Regulation of Blood pH

Normal range 7.35 to 7.45

Three body systems involved in maintenance of pH:

- Blood bicarbonate buffer system
 - Buffers prevent pH from changing
- Pulmonary system
 - Lungs can exhale or retain carbon dioxide (an acid)
- Renal system
 - Increases or decreases excretion of hydrogen (H) ions
 - Increases or decreases formation of ammonia
 - Increases or decreases reabsorption of bicarbonate



Antidiuretic Hormone (ADH)

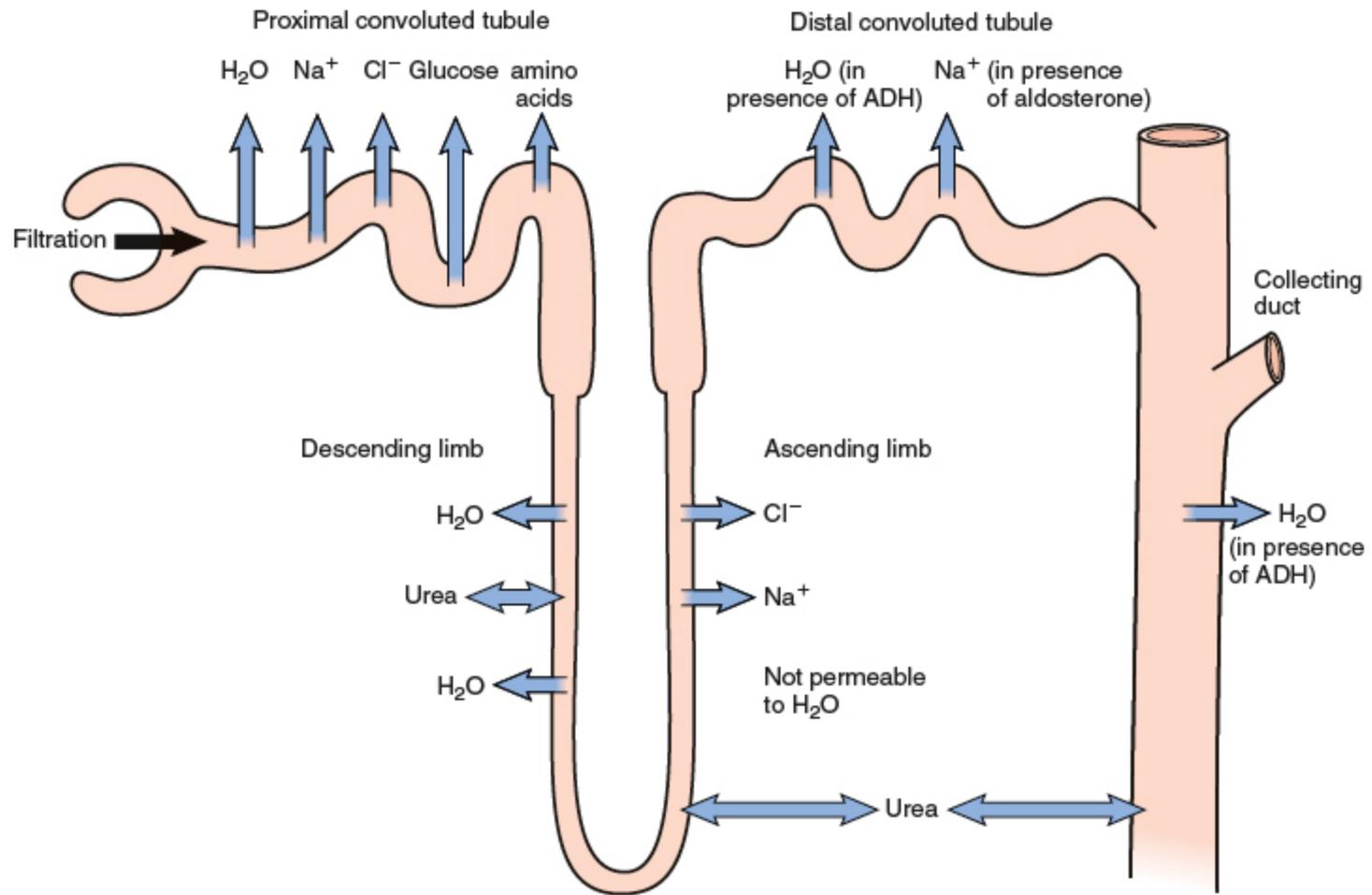
Also known as vasopressin

Controls water reabsorption in collecting tubules

ADH is produced in hypothalamus but released into blood from posterior pituitary gland

Causes a change in tubule epithelium, and increased water reabsorption occurs

Release of ADH controlled by negative feedback with arterial blood pressure and positive feedback with plasma osmolality



From Applegate E: The anatomy and physiology learning system, ed 4, Philadelphia, 2011, Saunders.