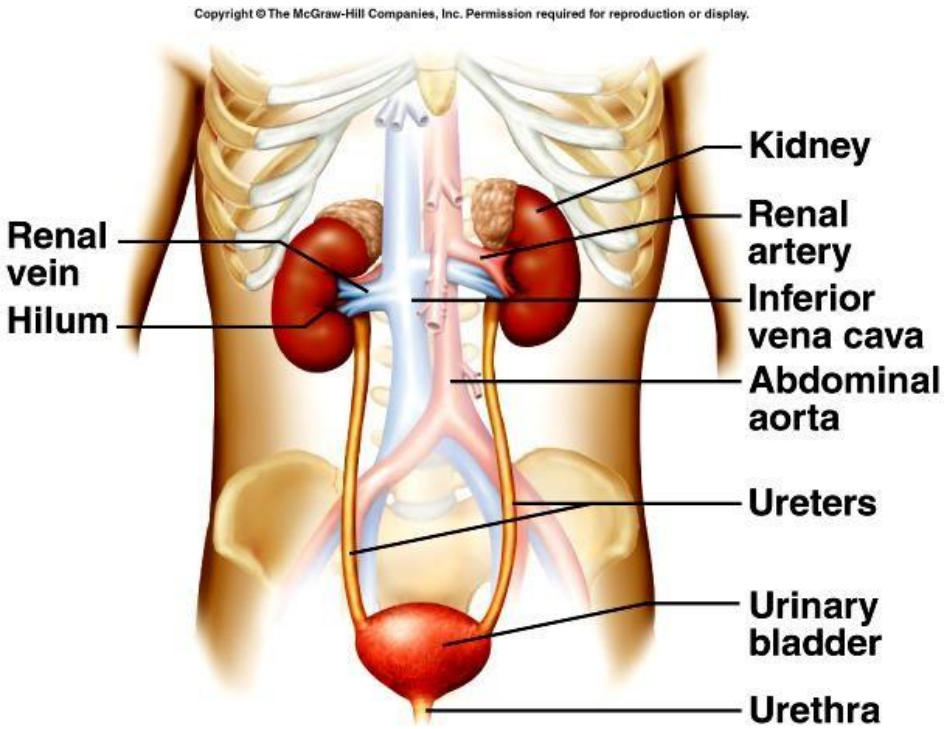
Urinary System

consists of the kidneys, ureters, urinary bladder and urethra



Prof. Zaporozhets
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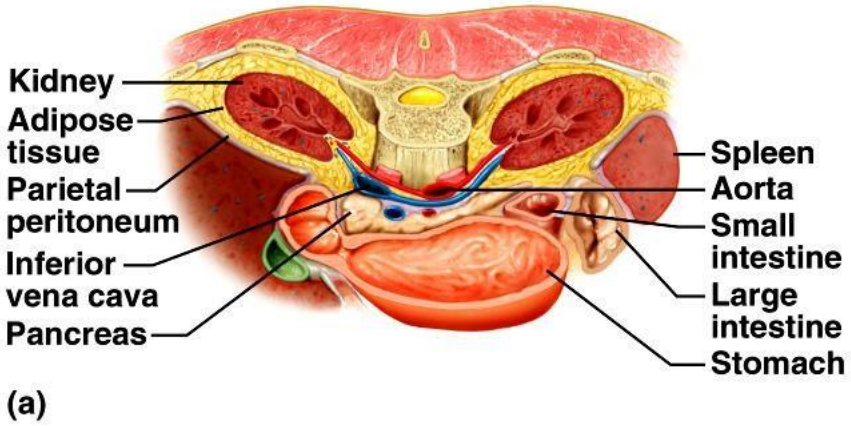
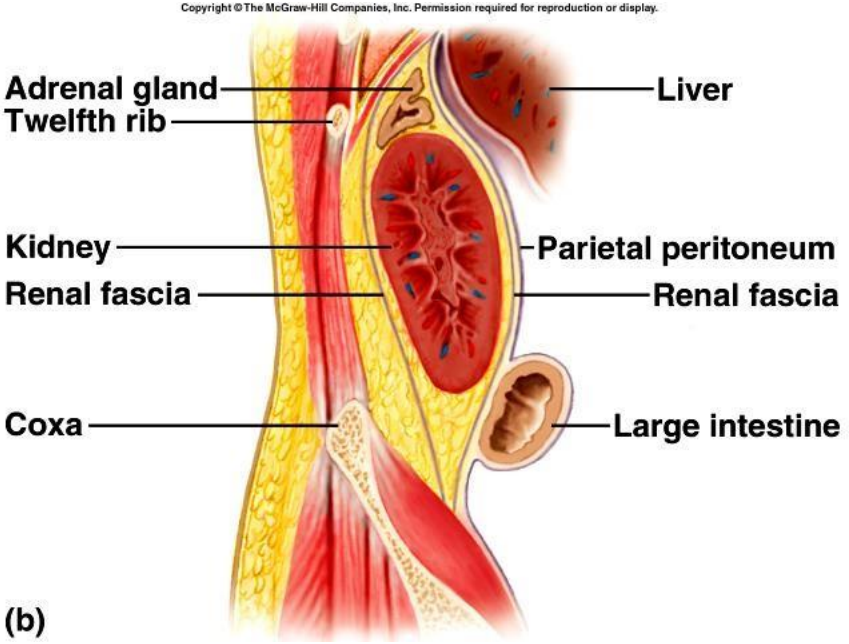
Excretory system physiology.

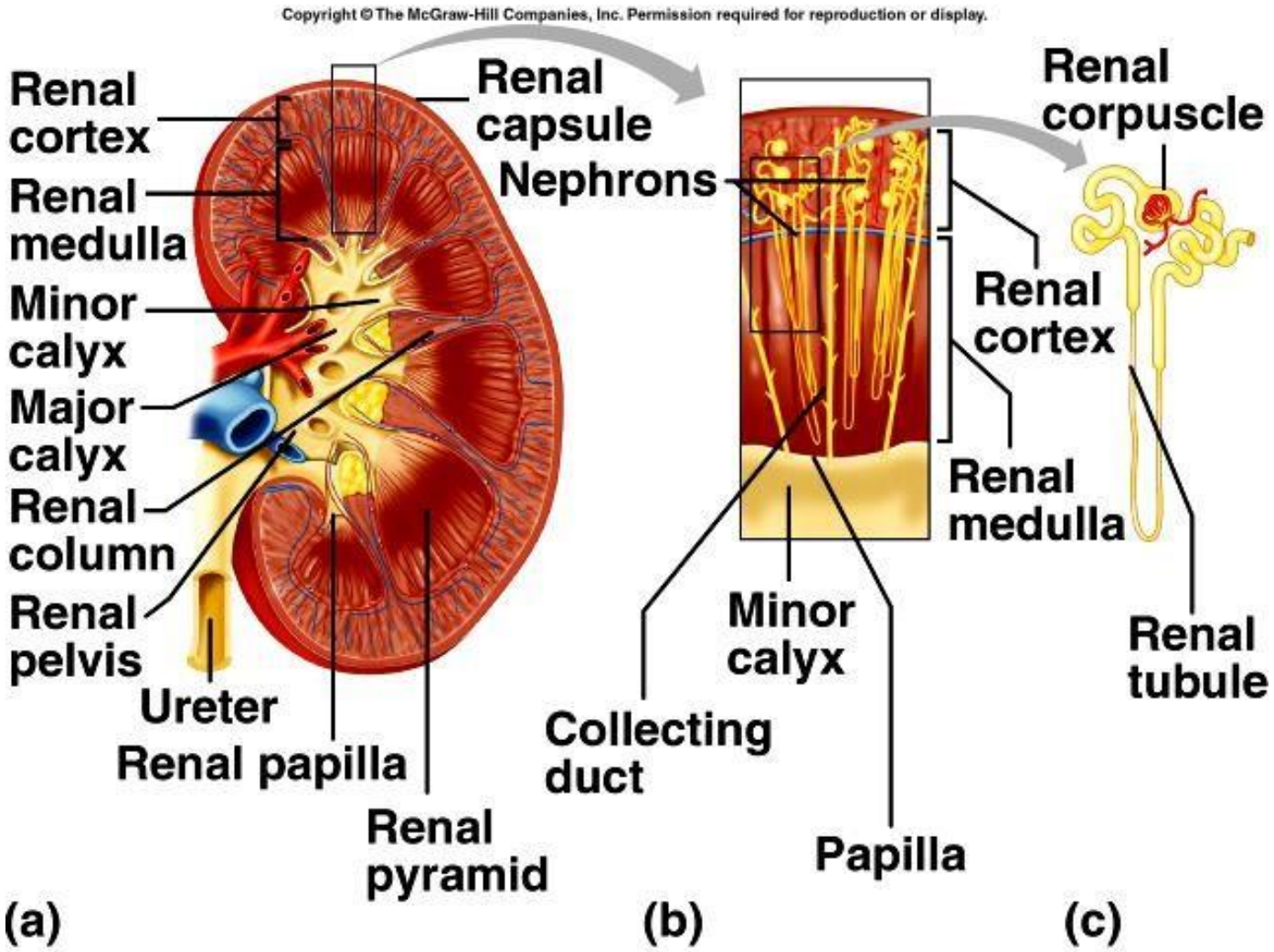
Location of Kidneys

The kidneys which are positioned retroperitoneally lie on either side of the vertebral column, high on the posterior wall of the abdominal cavity





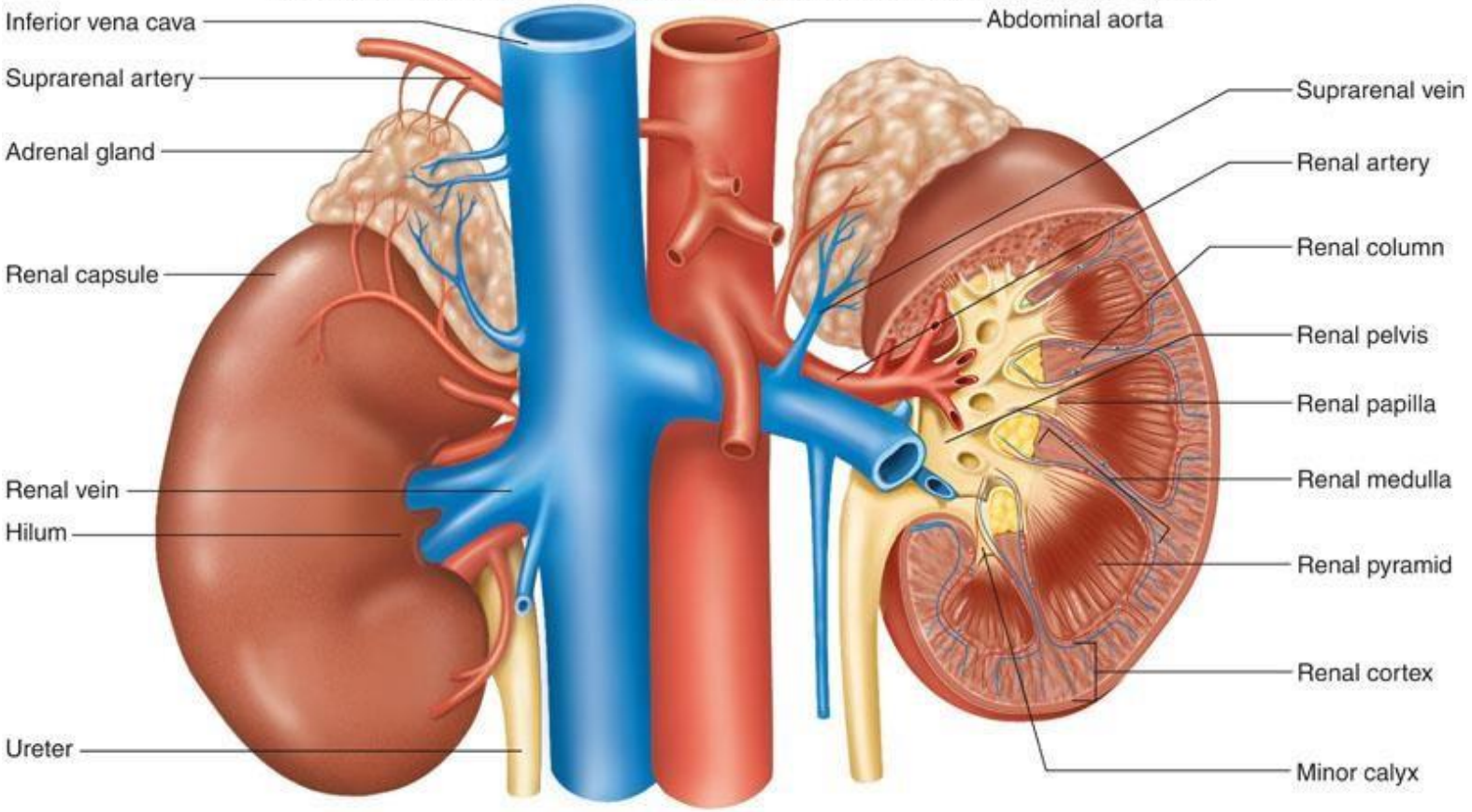
Kidney Structure



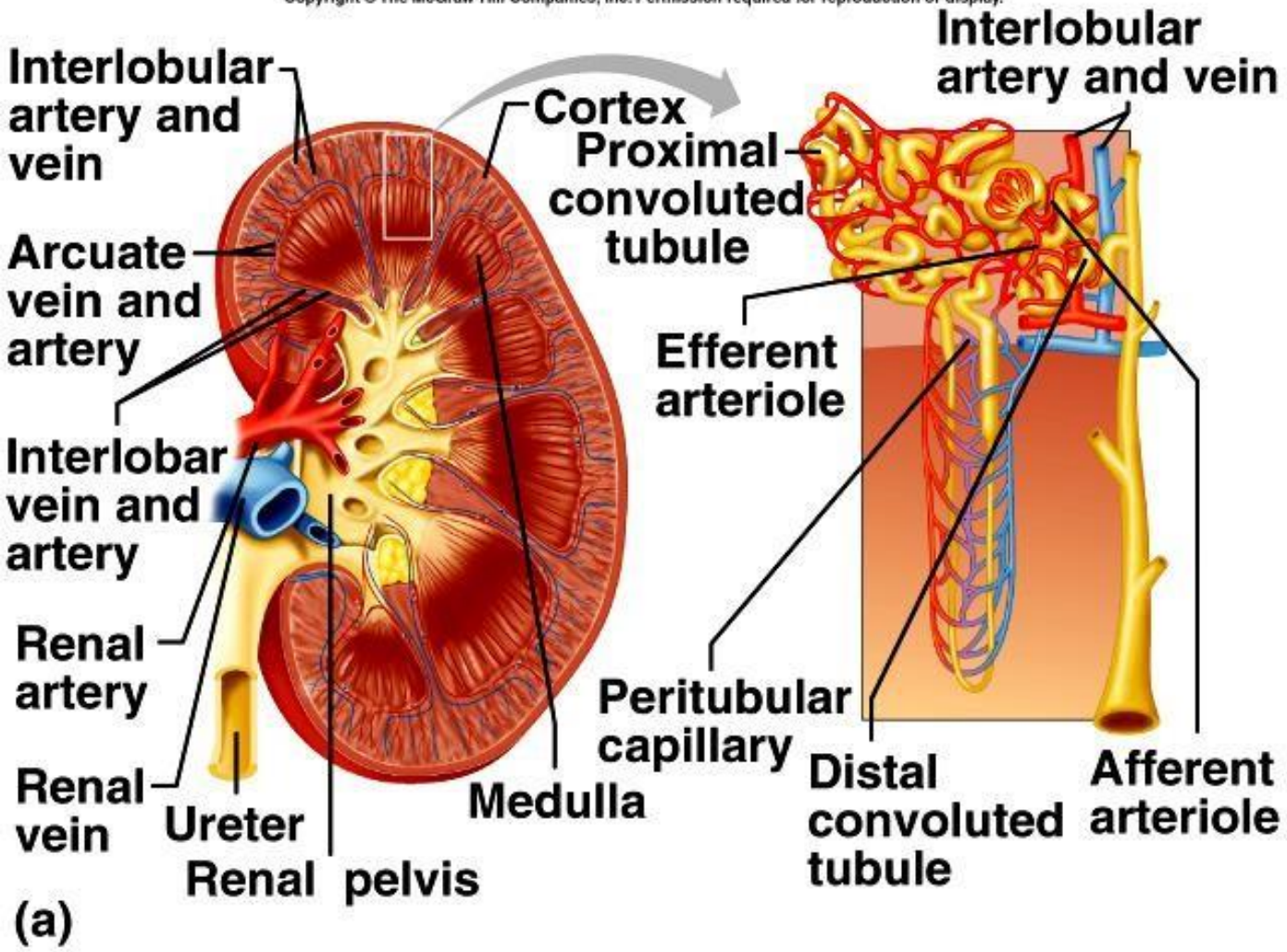
Functions of the Kidneys

- removal of metabolic wastes from the blood and excretion to the outside of the body
- regulation of red blood cell production, blood pressure, calcium ion absorption, and the volume, composition, and pH of the blood

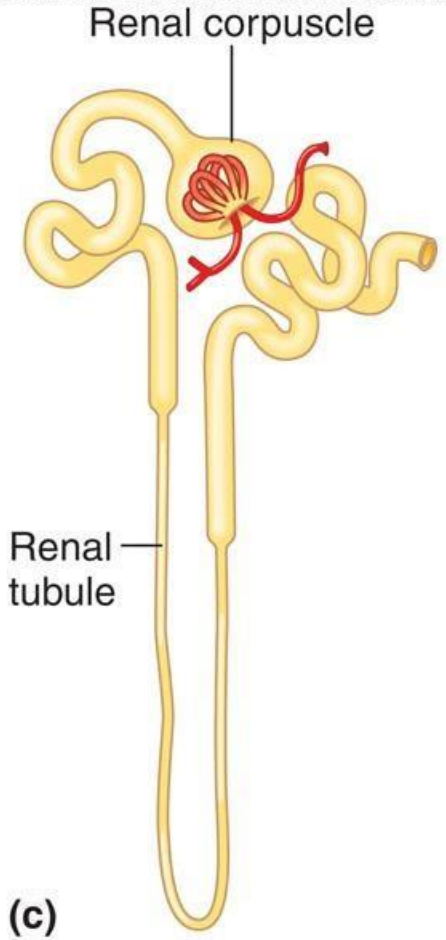
Renal Blood Vessels



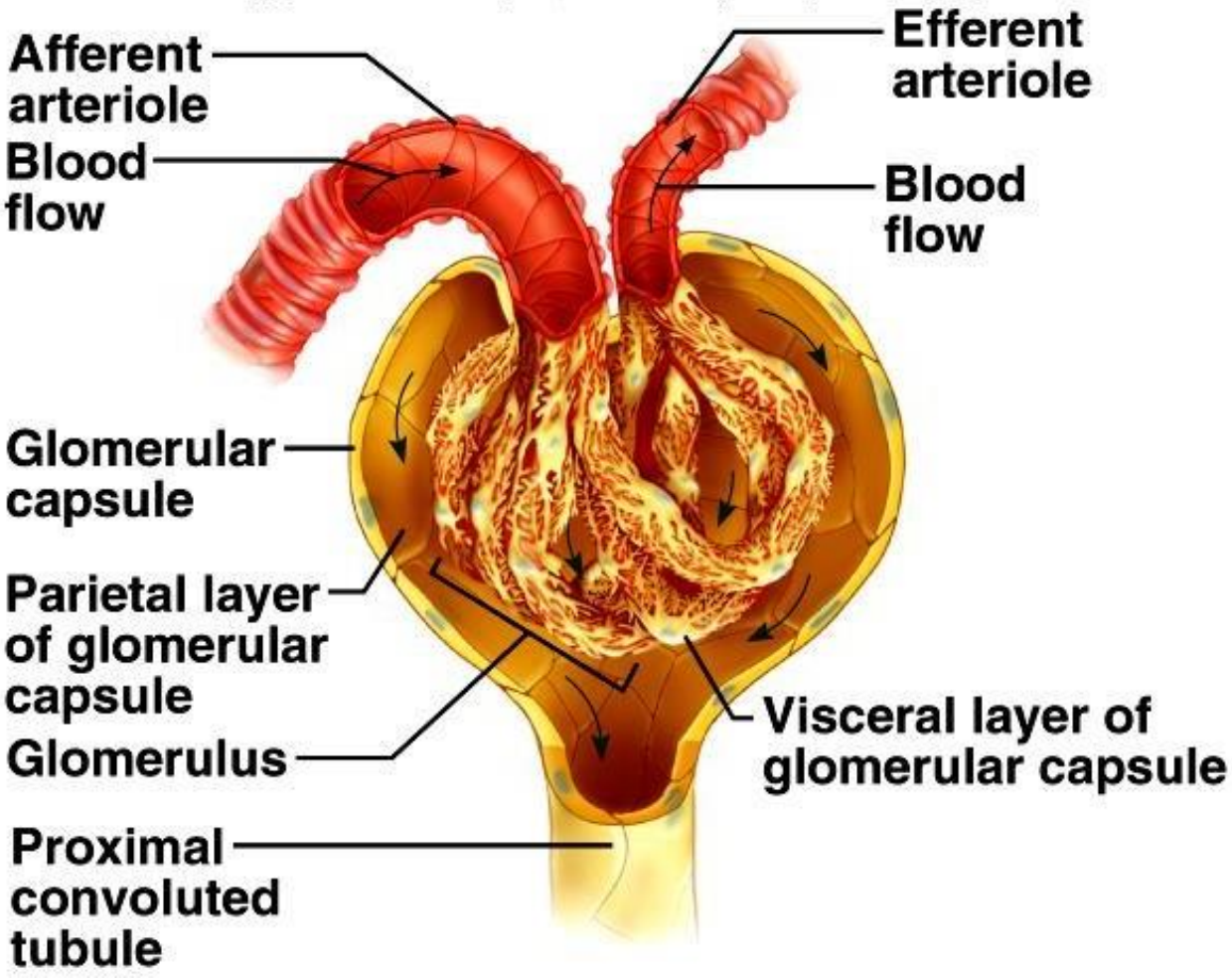
Renal Blood Vessels



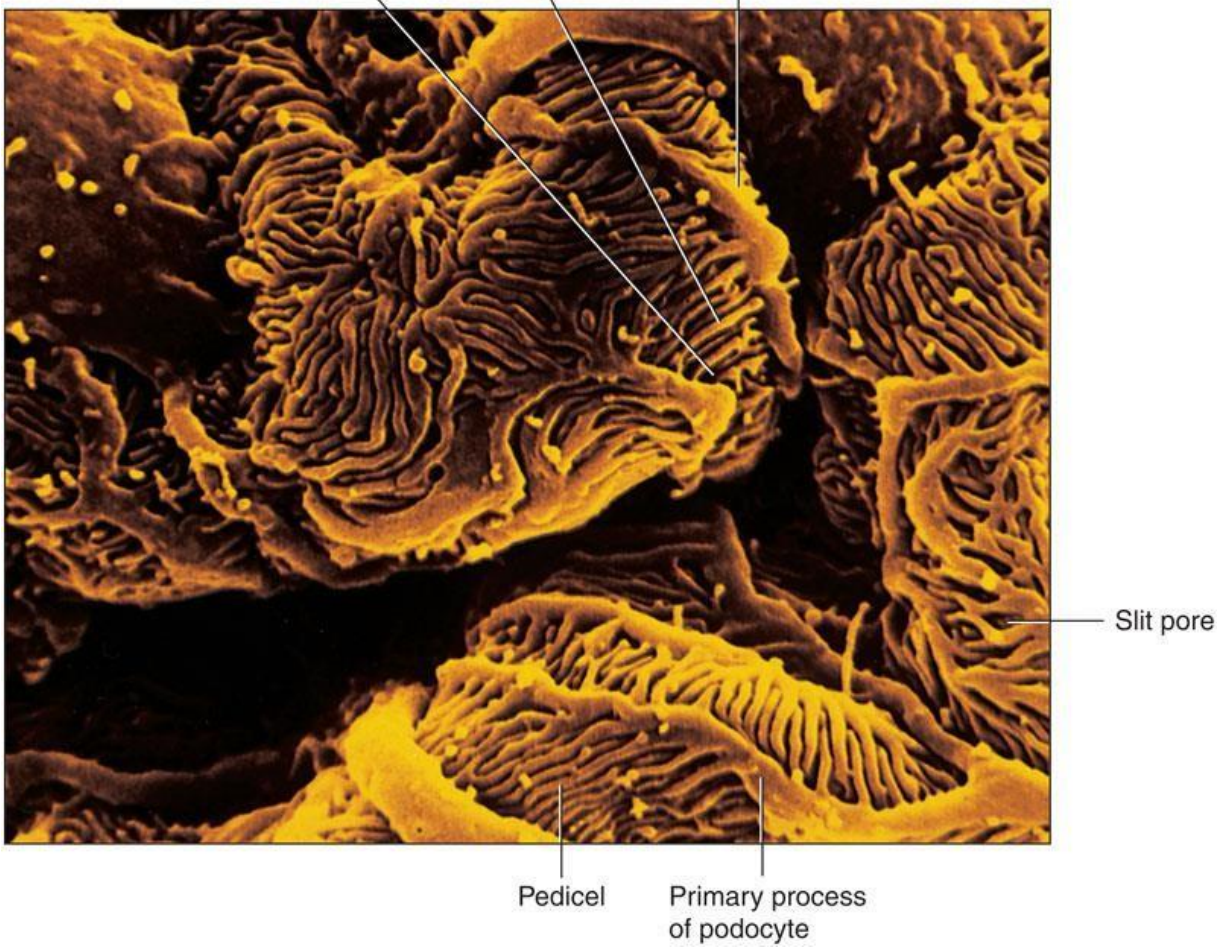
Structure of a Nephron



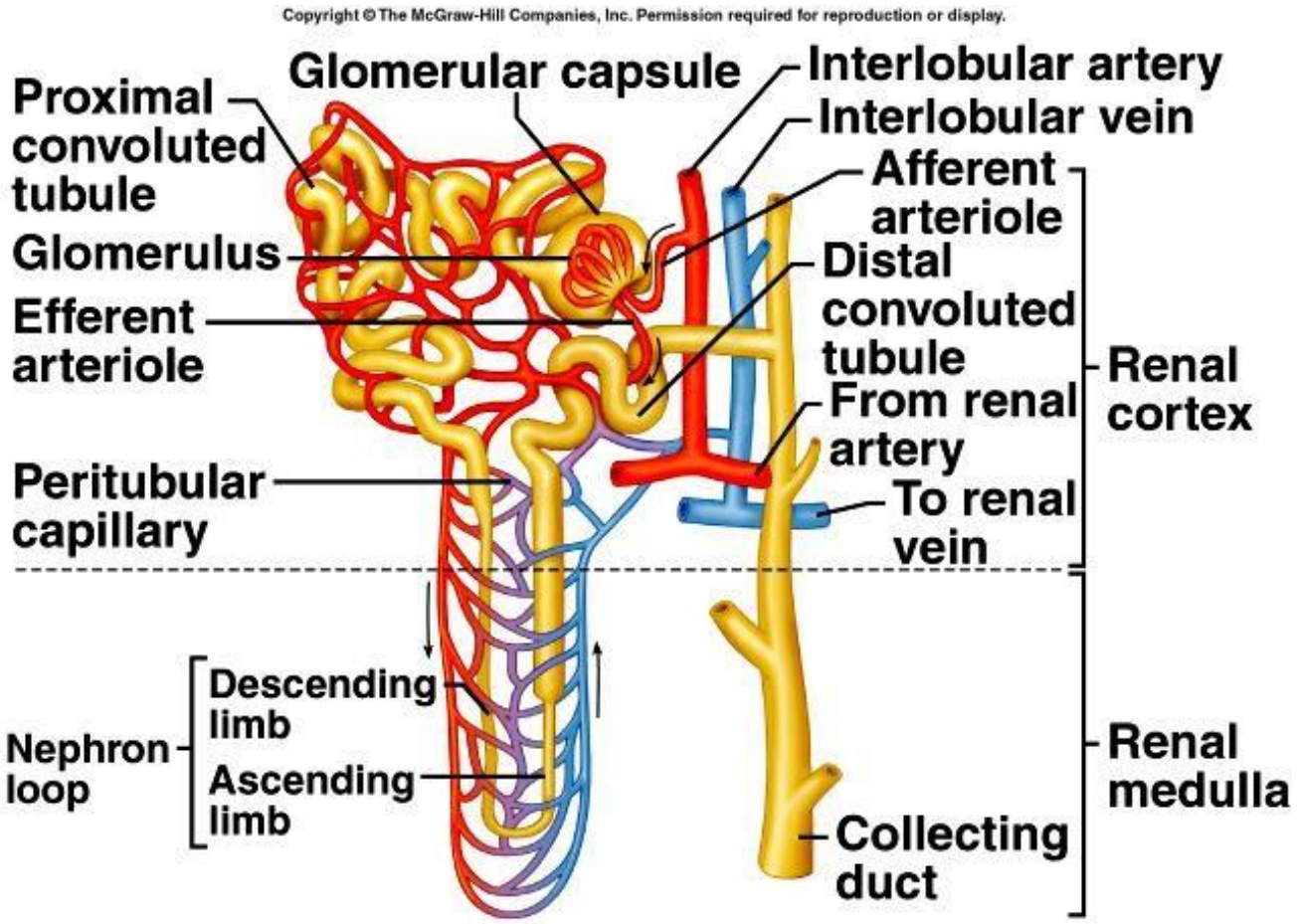
Glomerular Capsule



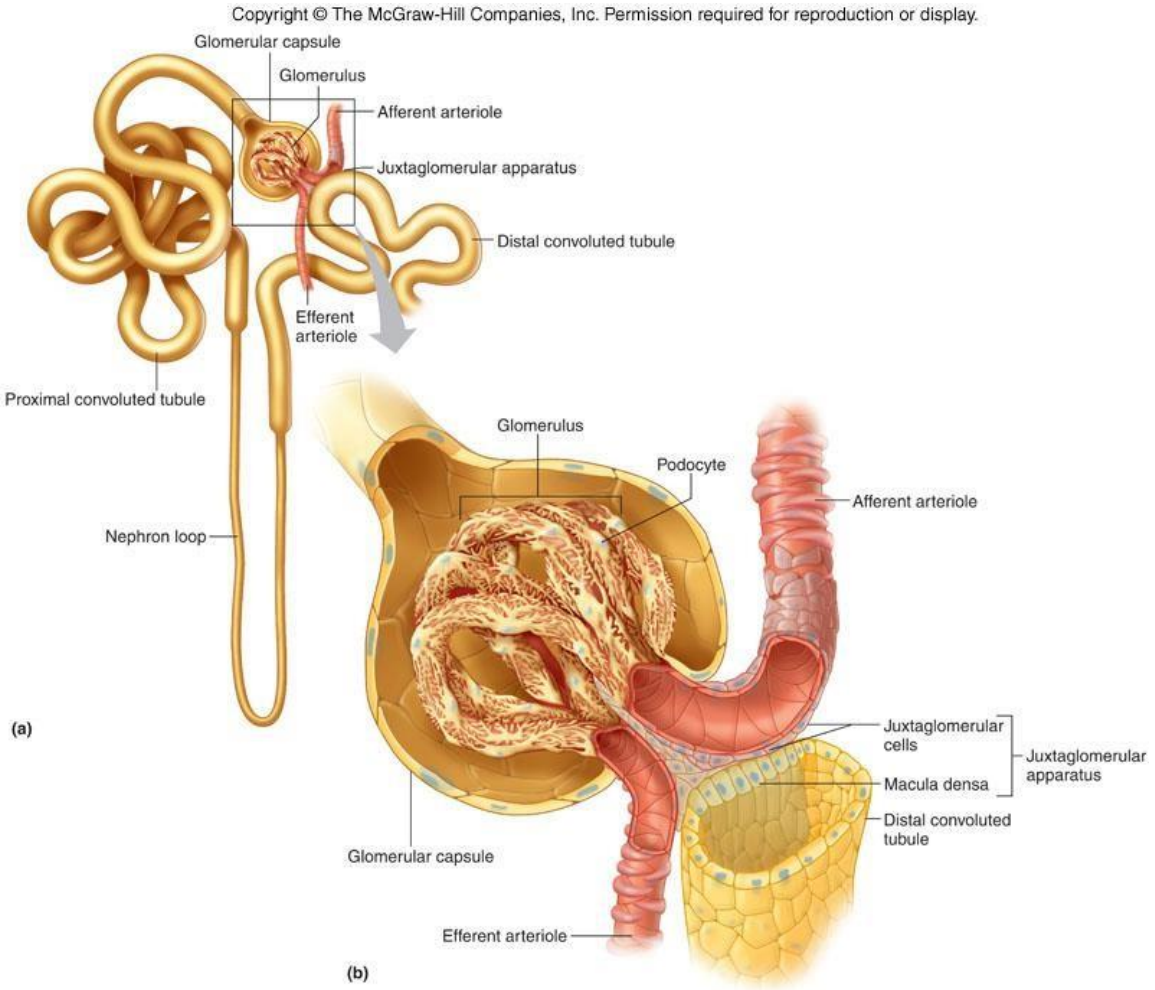
Glomerulus



Nephron and Associated Blood Vessels

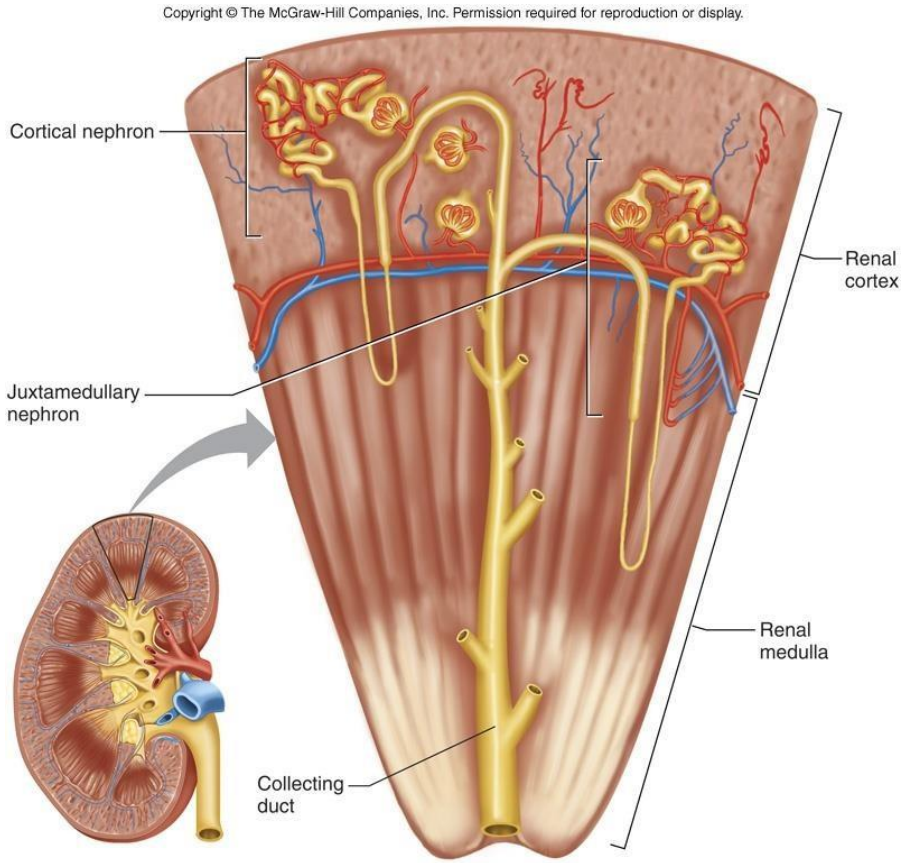


Juxtaglomerular Apparatus



Cortical and Juxtamedullary Nephrons

- cortical nephrons
  - 80% of nephrons
  - located close to the surface of the kidney
- juxtamedullary nephrons
  - regulate water balance
  - located near the renal medulla

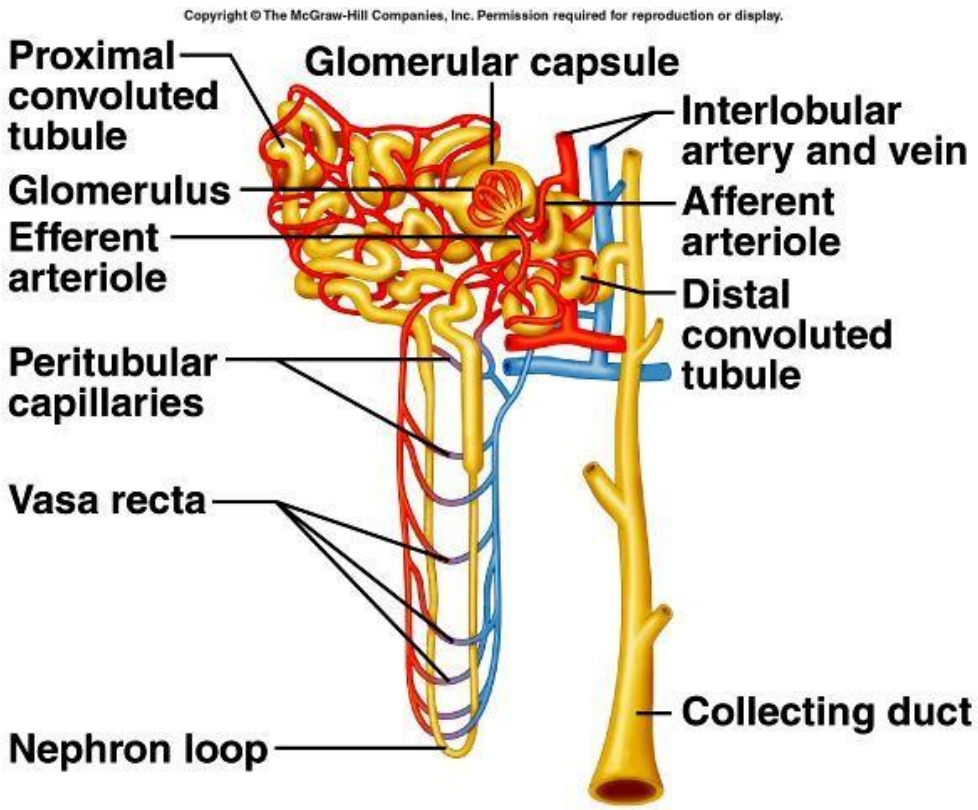


Blood Supply of Nephron

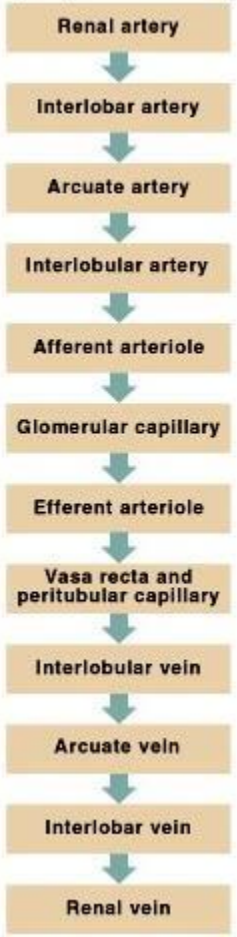
• The glomerular capillary receives blood from the afferent arteriole and passes it to the efferent arteriole

• The efferent arteriole gives rise to the peritubular system, which surrounds the tubule

• Capillary loops called vasa recta dip down into the medulla



Pathway of Blood Flow Through Kidney and Nephron



Urine Formation

- nephrons remove wastes from the blood and regulate water and electrolyte concentrations
- urine is the final product of the processes of:
  - glomerular filtration
  - tubular reabsorption
  - tubular secretion

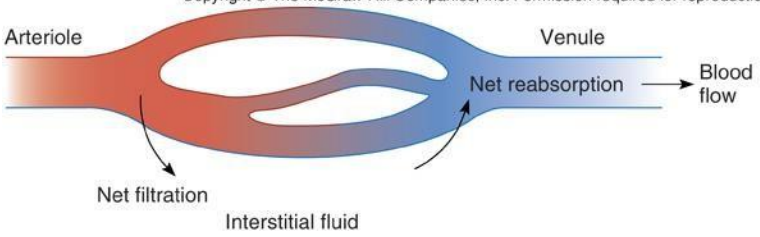
Urine Formation

- Glomerular Filtration
  - substances move from blood to glomerular capsule

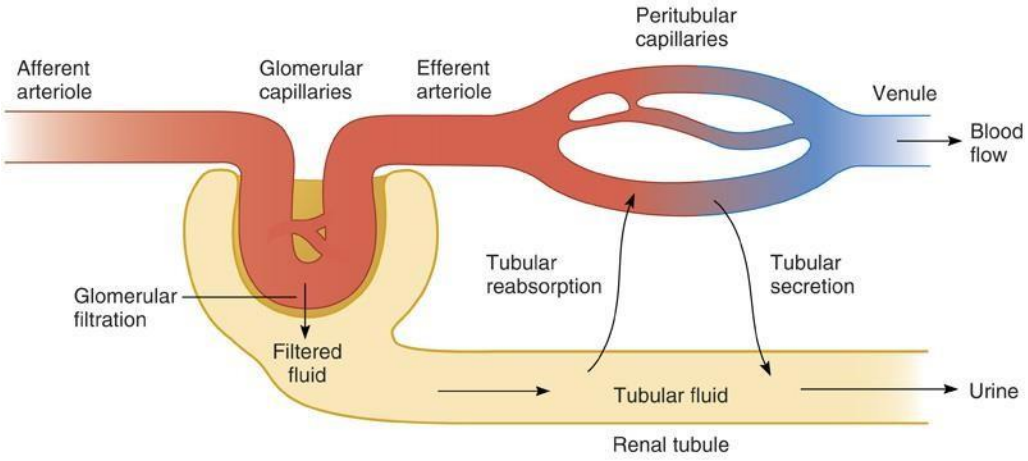
- Tubular Reabsorption
  - substances move from renal tubules into blood of peritubular capillaries
  - glucose, water, urea, proteins, creatine
  - amino, lactic, citric, and uric acids
  - phosphate, sulfate, calcium, potassium, and sodium ions

- Tubular Secretion
  - substances move from blood of peritubular capillaries into renal tubules
  - drugs and ions

Glomerular Filtration



(a) In most systemic capillaries, filtration predominates at the arteriolar end and osmotic reabsorption predominates at the venular end.

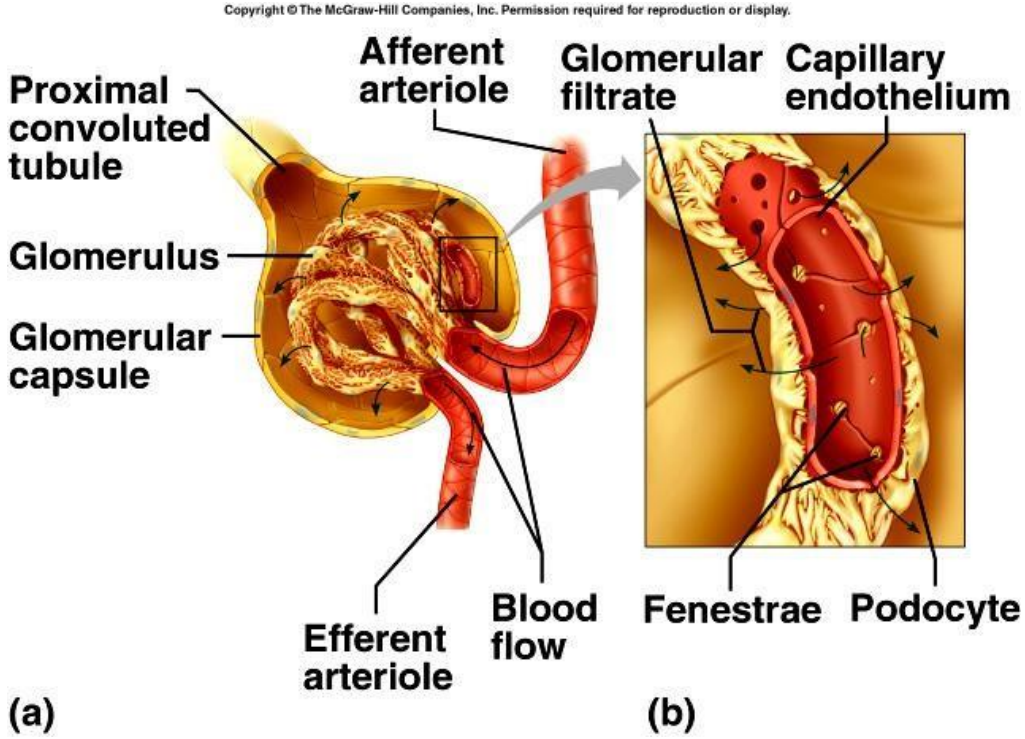


(b) In the kidneys, the glomerular capillaries are specialized for filtration. The renal tubule is specialized to control movements of substances back into the blood of the peritubular capillaries (tubular reabsorption) or from the blood into the renal tubule (tubular secretion).

Glomerular Filtration

• The first step in urine formation is filtration of substances out of the glomerular capillaries into the glomerular capsule

• Glomerular filtrate passes through the fenestrae of the capillary endothelium



Glomerular Filtrate and Urine Composition

TABLE 20.1 Relative Concentrations of Plasma, Glomerular Filtrate, and Urine Components

Substance	Concentrations (mEq/L) Plasma	Glomerular Filtrate	Urine
Sodium (Na^+)	142	142	128
Potassium (K^+)	5	5	60
Calcium (Ca^{+2})	4	4	5
Magnesium (Mg^{+2})	3	3	15
Chloride (Cl^-)	103	103	134
Bicarbonate (HCO_3^-)	27	27	14
Sulfate (SO_4^{-2})	1	1	33
Phosphate (PO_4^{-3})	2	2	40

(mEq/L (milliequivalents per liter) is a commonly used measure of concentration based on how many charges an ion carries. For a substance with a charge of 1, such as Cl^-, a mEq is equal to a millimole.)

Substance	Concentrations (mg/100 mL) Plasma	Glomerular Filtrate	Urine
Glucose	100	100	0
Urea	26	26	1,820
Uric acid	4	4	53
Creatinine	1	1	196

Filtration Pressure and Rate

Net Filtration Pressure = force favoring filtration – forces opposing filtration

(glomerular capillary hydrostatic pressure)

(capsular hydrostatic pressure and glomerular capillary osmotic pressure)

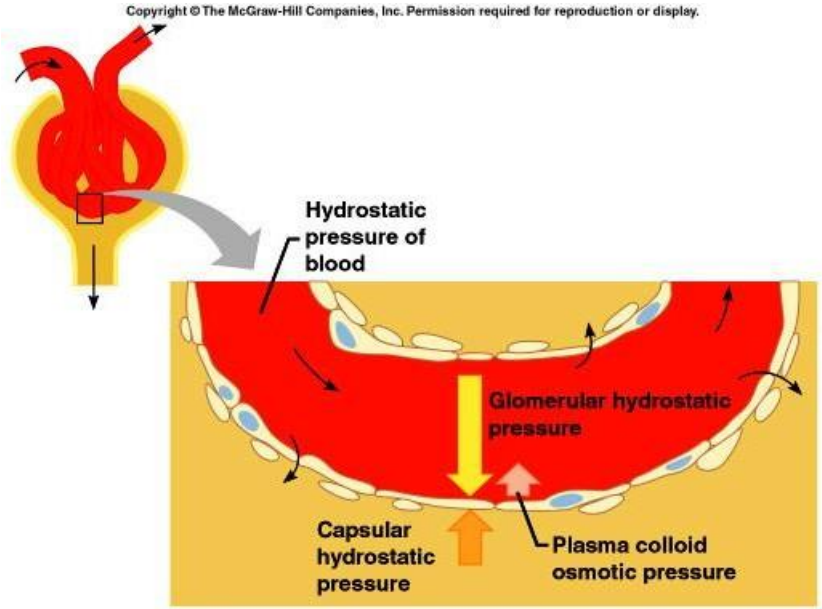
Glomerular Filtration Rate

- directly proportional to the net filtration pressure

Filtration Pressure and Rate

• normally the glomerular net filtration pressure is positive causing filtration

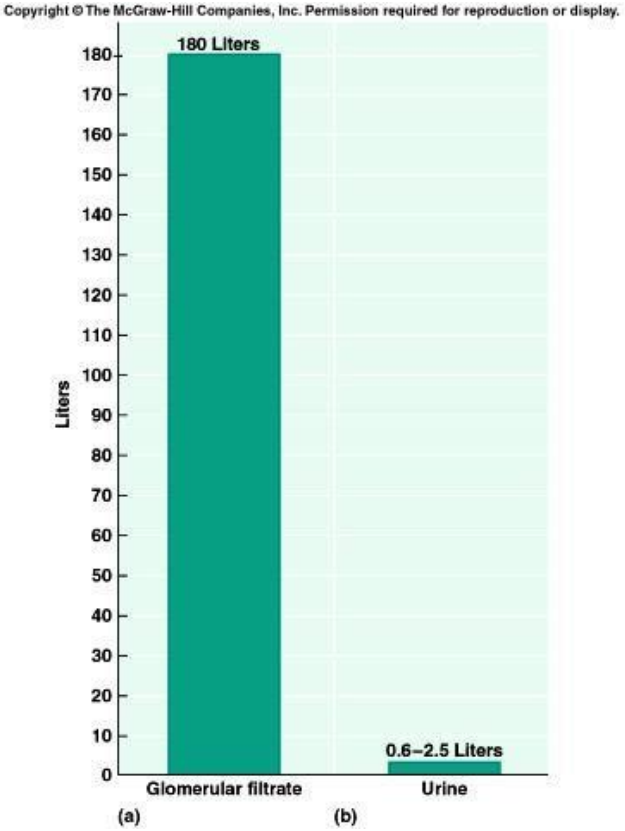
• the forces responsible include hydrostatic pressure and osmotic pressure of plasma and the hydrostatic pressure of the fluid in the glomerular capsule



Net Outward Pressure		
Outward force, glomerular hydrostatic pressure	=	+60 mm
Inward force of plasma colloid osmotic pressure	=	−32 mm
Inward force of capsular hydrostatic pressure	=	−18 mm
Net outward pressure	=	+10 mm

Amounts of Glomerular Filtrate and Urine

average amounts over a 24 hour period



Control of Filtration Rate

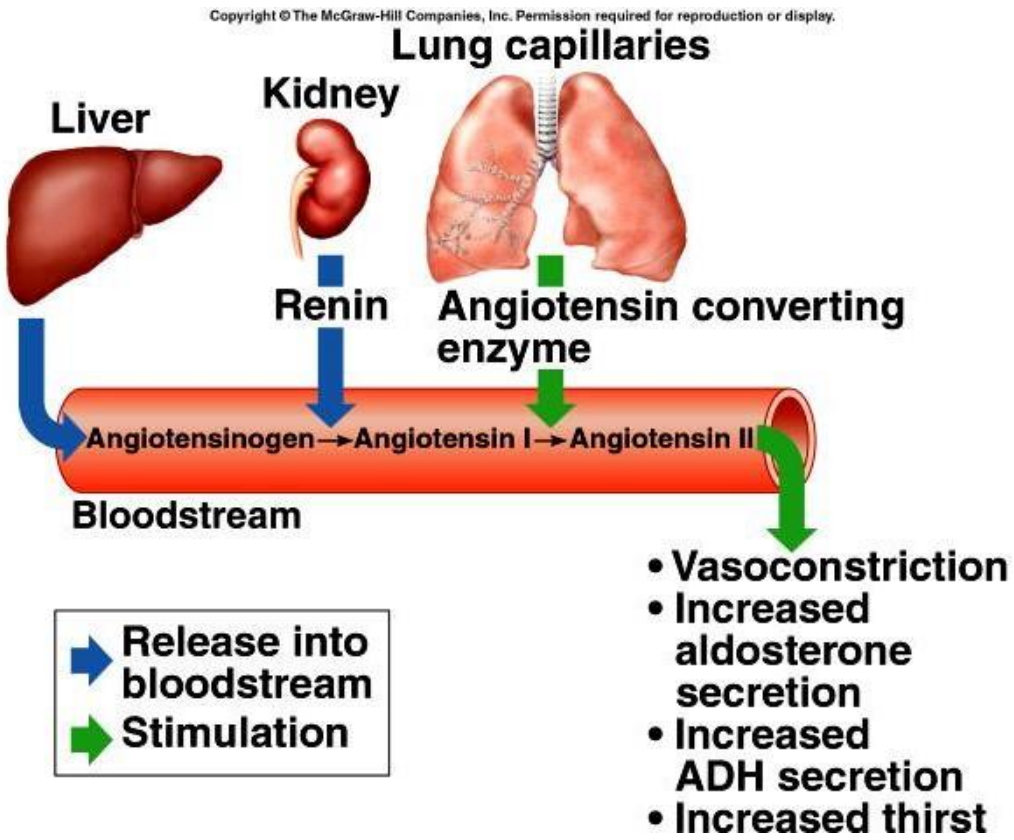
- Primarily three mechanisms are responsible for keeping the GFR constant

  - Increased sympathetic impulses decrease GFR by causing afferent arterioles to constrict

  - Renin-angiotensin system

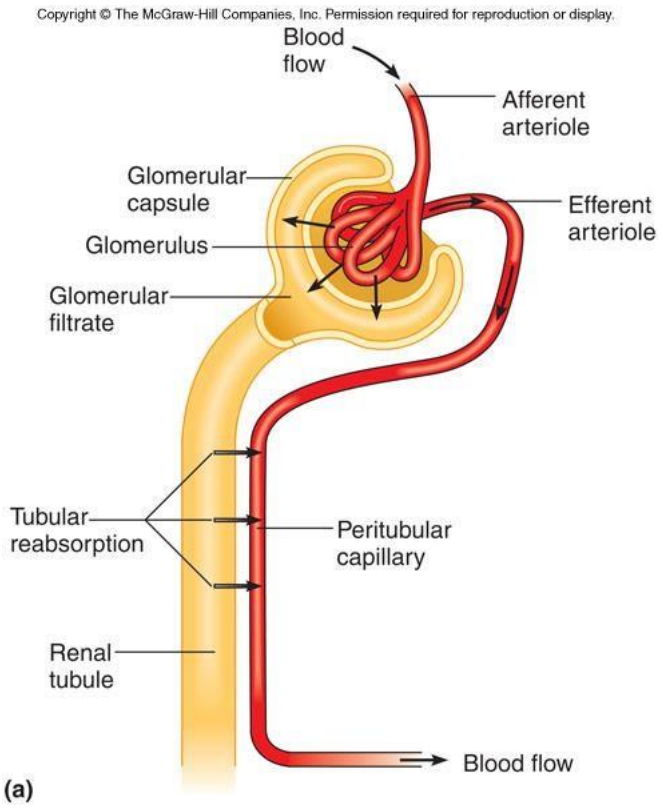
  - Autoregulation

Renin-Angiotensin system



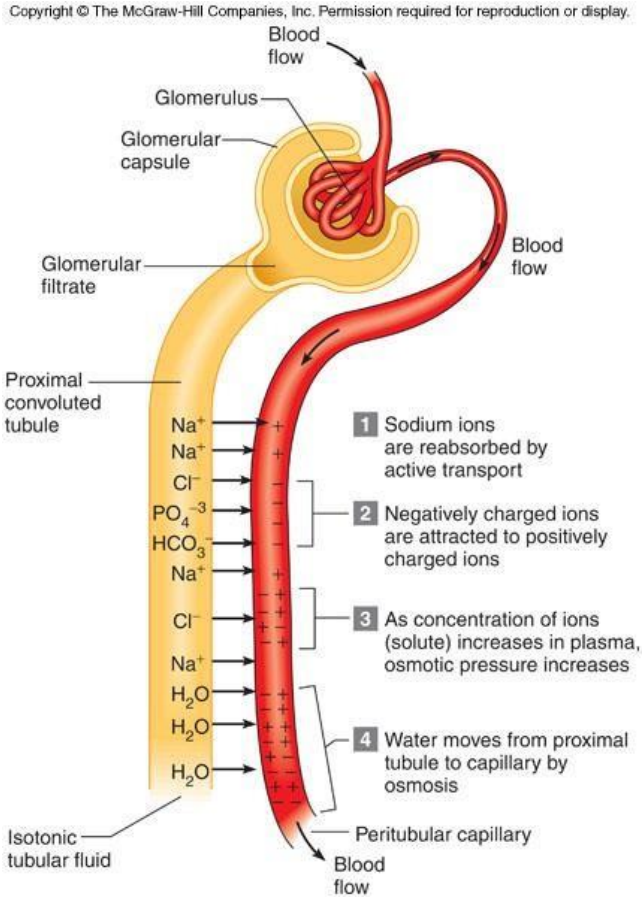
Tubular Reabsorption

• transports substances from the glomerular filtrate into the blood within the peritubular capillary



Sodium and Water Reabsorption

- osmosis reabsorbs water in response to active transport reabsorbing sodium and other solutes in the proximal portion of the renal tubule



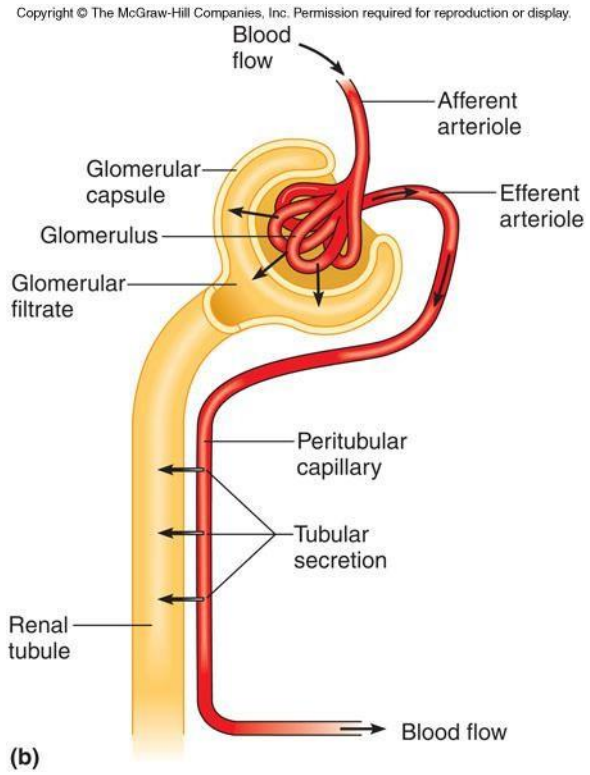
Sodium and Water Filtration, Reabsorption, and Excretion

TABLE 20.2 Average Values for Sodium and Water Filtration, Reabsorption, and Excretion

	Amount Filtered per Day	Amount Reabsorbed per Day (%)	Amount Excreted per Day
Water (L)	180	178.2 (99%)	1.8 (1%)
Na^+ (g)	630	626.8 (99.5%)	3.2 (0.5%)

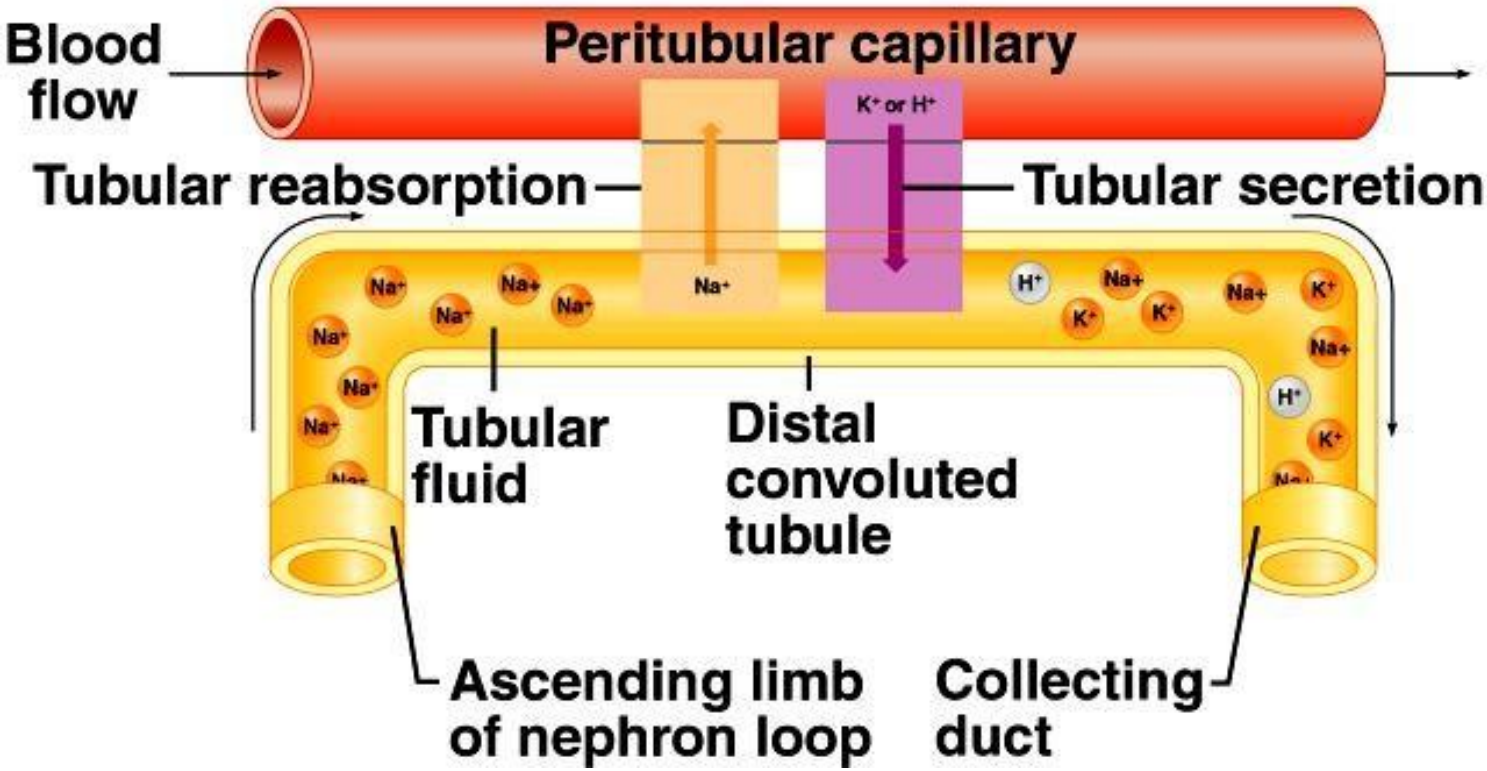
Tubular Secretion

• transports substances from the blood within the peritubular capillary into the renal tubule



Tubular Secretion

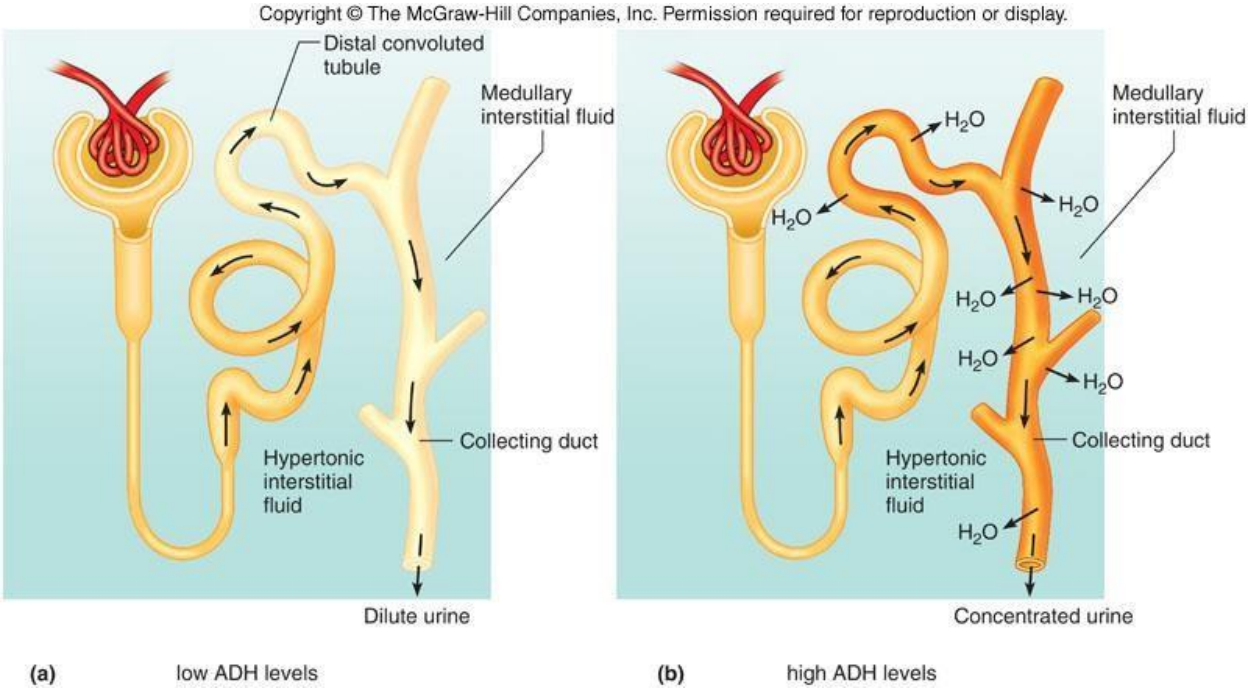
In distal convoluted tubules, potassium ions or hydrogen ions may be passively secreted in response to active reabsorption of sodium ions



Regulation of Urine Concentration and Volume

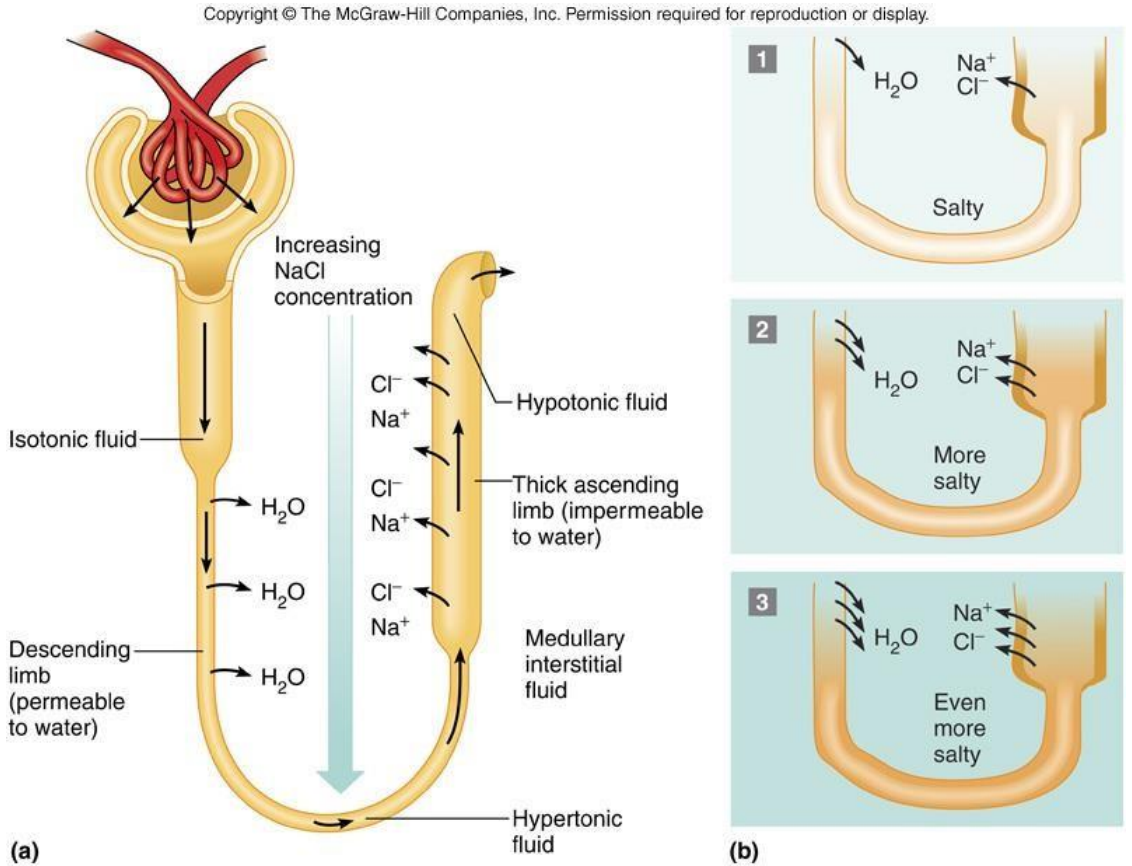
• the distal convoluted tubule and collecting duct are impermeable to water, so water may be excreted as dilute urine

• if ADH is present, these segments become permeable, and water is reabsorbed by osmosis into the hypertonic medullary interstitial fluid



The Countercurrent Multiplier

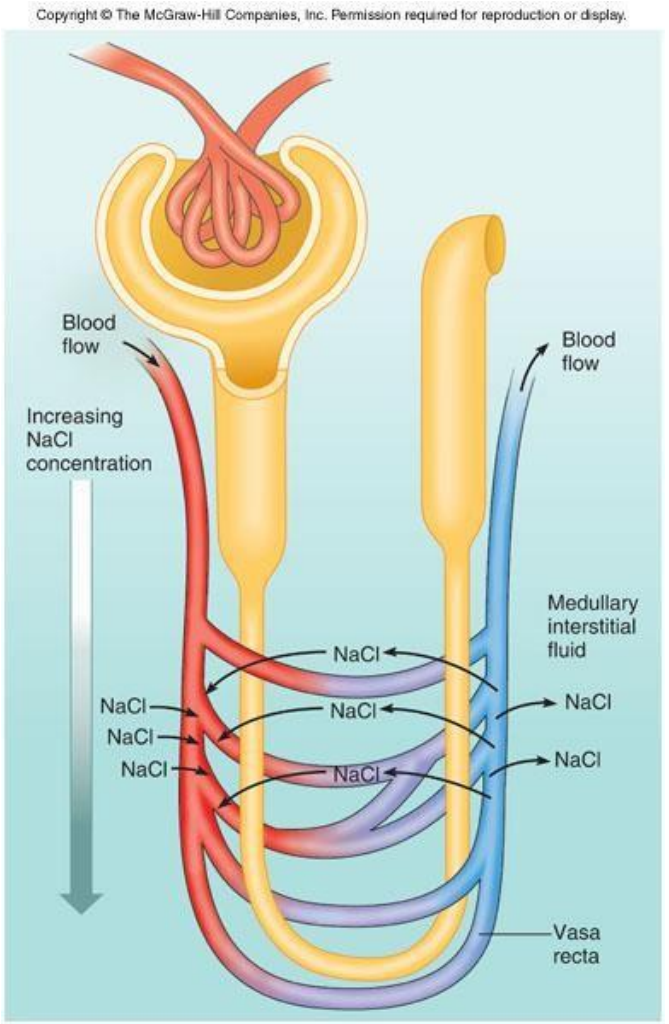
• helps maintain the NaCl concentration gradient in the medullary interstitial fluid



Countercurrent Mechanism of Vasa Recta

•fluid in ascending limb becomes hypotonic as solute is reabsorbed

• fluid in descending limb becomes hypertonic as it loses water by osmosis



Role of ADH in Regulating Urine Concentration and Volume

TABLE 20.3 Role of ADH in Regulating Urine Concentration and Volume

1. Concentration of water in the blood decreases.
2. Increase in the osmotic pressure of body fluids stimulates osmoreceptors in the hypothalamus.
3. Hypothalamus signals the posterior pituitary gland to release ADH.
4. Blood carries ADH to the kidneys.
5. ADH causes the distal convoluted tubules and collecting ducts to increase water reabsorption by osmosis.
6. Urine becomes more concentrated, and urine volume decreases.

Functions of Nephron Components

TABLE 20.4 Functions of Nephron Components

Part	Function
Renal Corpuscle	
Glomerulus	Filtration of water and dissolved substances from the plasma
Glomerular capsule	Receives the glomerular filtrate
Renal Tubule	
Proximal convoluted tubule	Reabsorption of glucose; amino acids; creatine; lactic, citric, uric, and ascorbic acids; phosphate, sulfate, calcium, potassium, and sodium ions by active transport
	Reabsorption of proteins by endocytosis
	Reabsorption of water by osmosis
	Reabsorption of chloride ions and other negatively charged ions by electrochemical attraction
	Active secretion of substances such as penicillin, histamine, creatinine, and hydrogen ions
Descending limb of nephron loop	Reabsorption of water by osmosis
Ascending limb of nephron loop	Reabsorption of sodium, potassium, and chloride ions by active transport
Distal convoluted tubule	Reabsorption of sodium ions by active transport
	Reabsorption of water by osmosis
	Active secretion of hydrogen ions
	Secretion of potassium ions both actively and by electrochemical attraction
Collecting Duct	Reabsorption of water by osmosis

(Note: Although the collecting duct is not anatomically part of the nephron, it is functionally connected.)

Urea and Uric Acid Excretion

Urea

- by-product of amino acid catabolism
- plasma concentration reflects the amount or protein in diet
- enters renal tubules through glomerular filtration
- contributes to the reabsorption of water from the collecting duct

Uric Acid

- product of nucleic acid metabolism
- enters renal tubules through glomerular filtration
- most reabsorption occurs by active transport
- ~10% secreted and excreted

Urine Composition

- about 95% water
- usually contains urea, uric acid, and creatinine
- may contain trace amounts of amino acids and varying amounts of electrolytes
- volume varies with fluid intake and environmental factors

Renal Clearance

- the rate at which a chemical is removed from the plasma

- tests of renal clearance
  - inulin clearance test
  - creatinine clearance test
  - para-aminohippuric acid (PAH) test

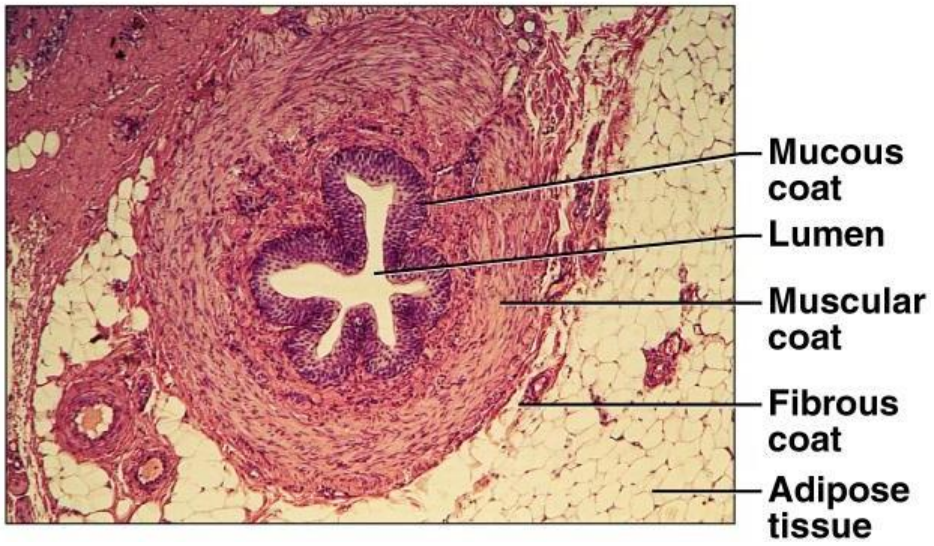
- tests of renal clearance used to calculate glomerular filtration rate

Elimination of Urine

- nephrons
- collecting ducts
- renal papillae
- minor and major calyces
- renal pelvis
- ureters
- urinary bladder
- urethra
- outside

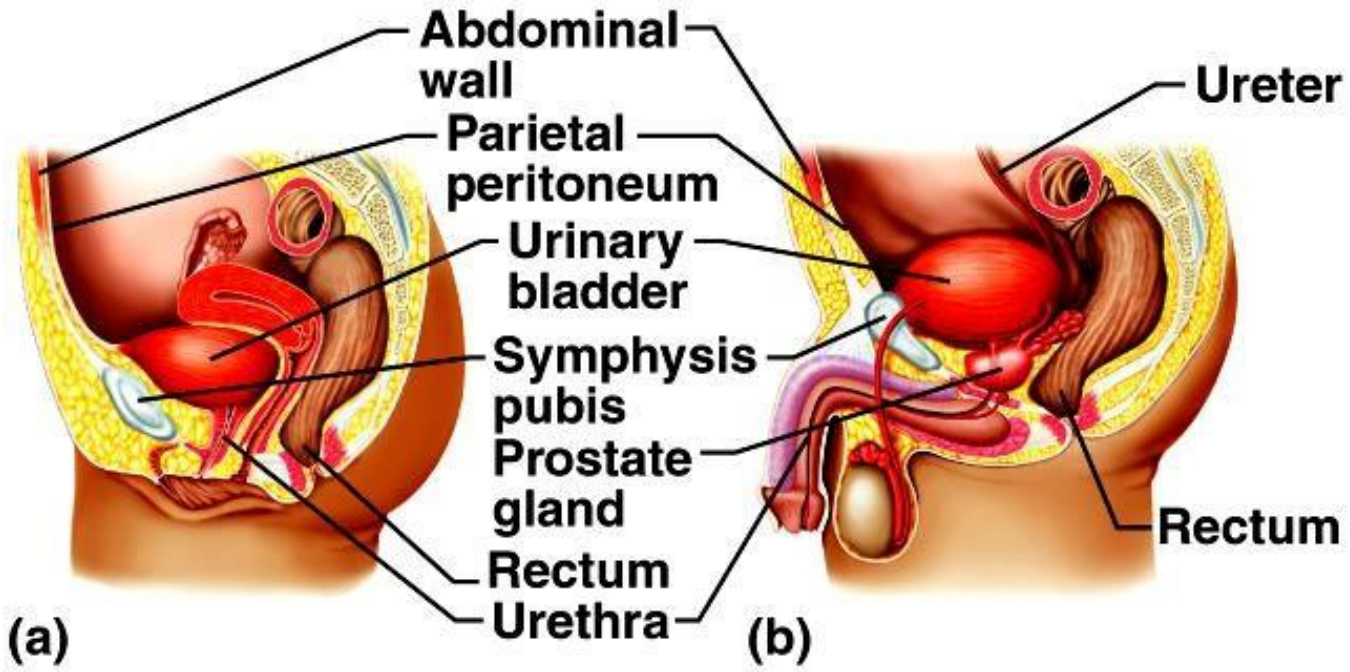
Ureters

- 25 cm long
- extend downward posterior to the parietal peritoneum
- parallel to vertebral column
- in pelvic cavity, join urinary bladder
- wall of ureter
    - mucous coat
    - muscular coat
    - fibrous coat



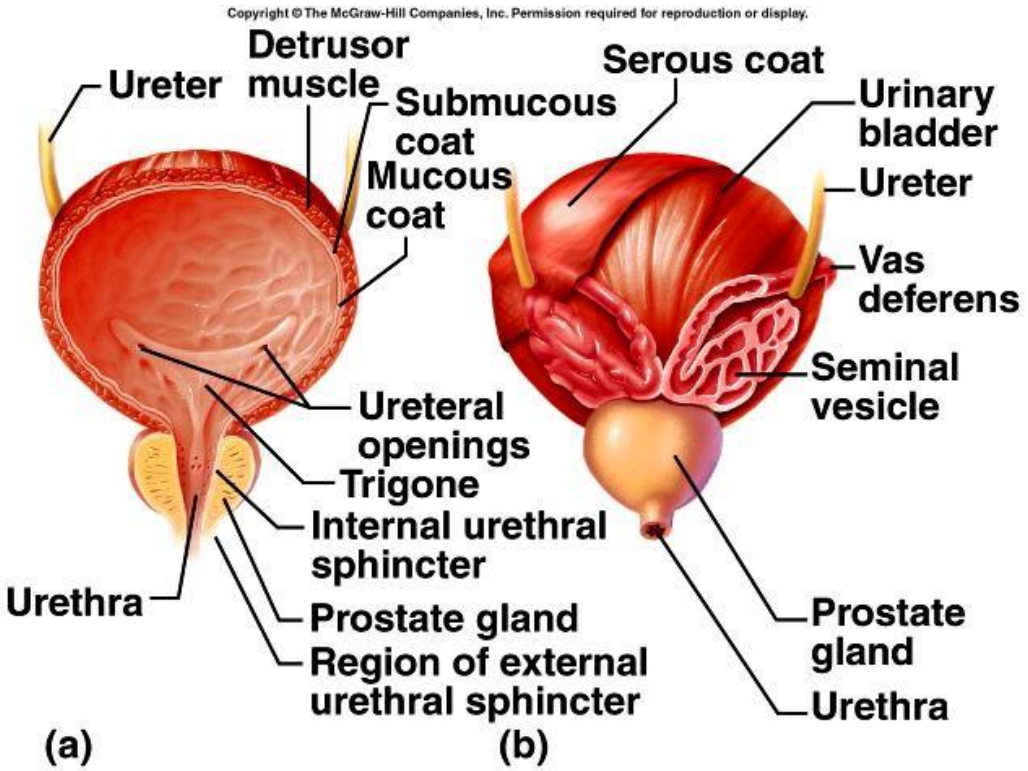
Urinary Bladder

• hollow, distensible, muscular organ located within the pelvic cavity, posterior to the symphysis pubis and inferior to the parietal peritoneum

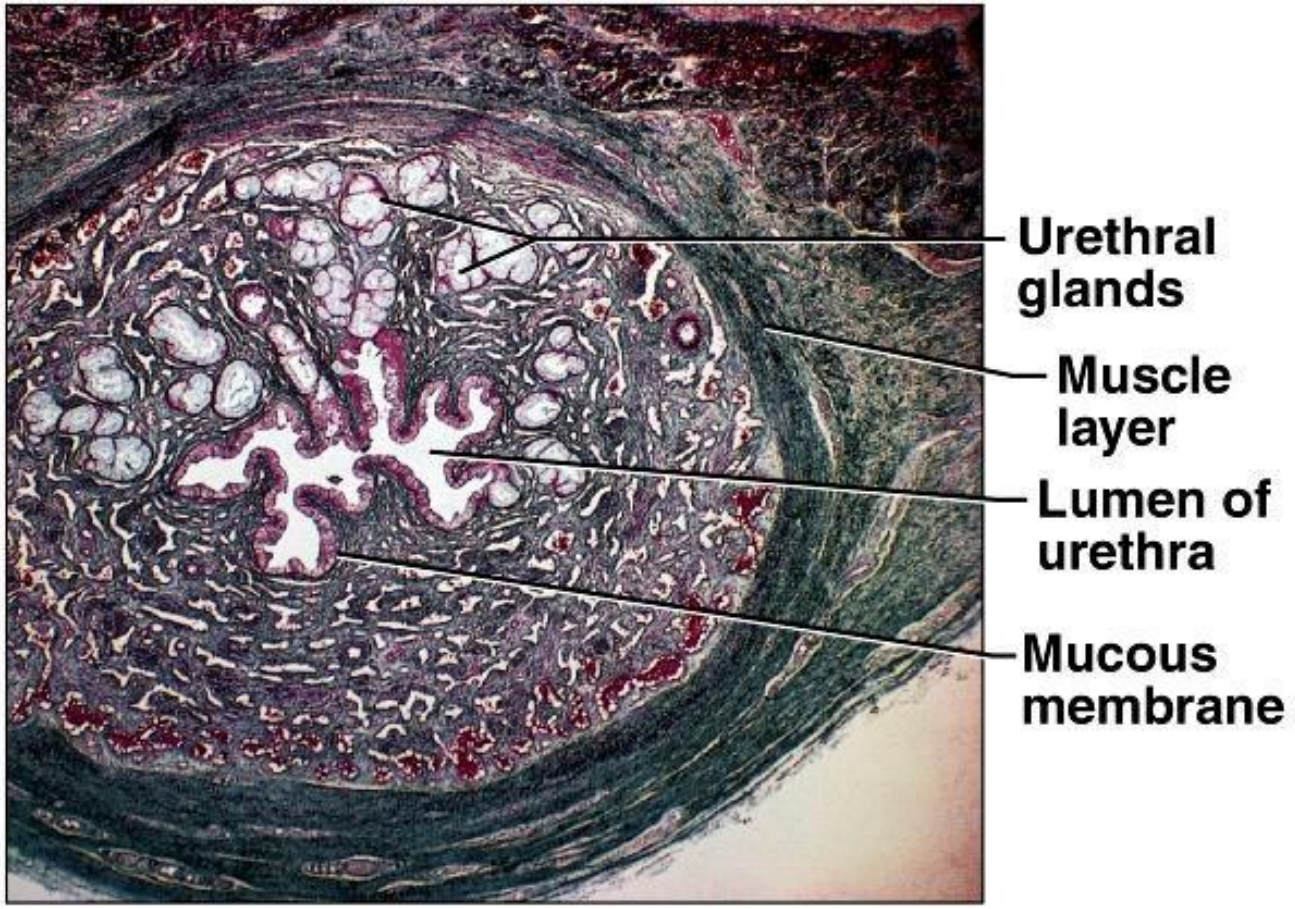


Urinary Bladder

• the internal floor of the bladder includes a triangular area called the trigone which has an opening at each of three angles

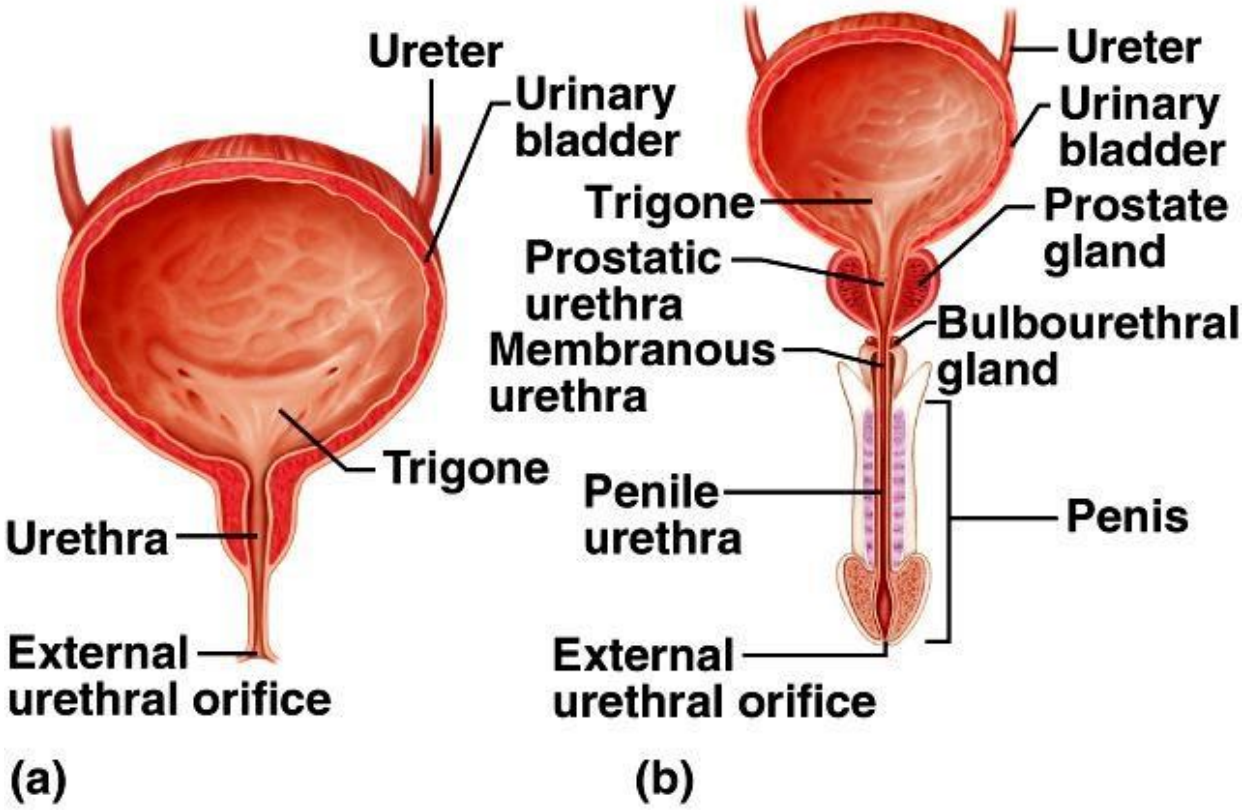


Cross Section of Urethra



Urethra

• tube that conveys urine from the urinary bladder to the outside of the body



Micturition

TABLE 20.5 Major Events of Micturition

1. Urinary bladder distends as it fills with urine.
2. Stretch receptors in the bladder wall are stimulated, and they signal the micturition center in the sacral spinal cord.
3. Parasympathetic nerve impulses travel to the detrusor muscle, which responds by contracting rhythmically.
4. The need to urinate is urgent.
5. Voluntary contraction of the external urethral sphincter and inhibition of the micturition reflex by impulses from the brainstem and the cerebral cortex prevent urination.
6. Following the decision to urinate, the external urethral sphincter is relaxed, and impulses from the pons and the hypothalamus facilitate the micturition reflex.
7. The detrusor muscle contracts, and urine is expelled through the urethra.
8. Neurons of the micturition reflex center fatigue, the detrusor muscle relaxes, and the bladder begins to fill with urine again.

Life-Span Changes

- kidneys appear scarred and grainy
- kidney cells die
- by age 80, kidneys have lost a third of their mass
- kidney shrinkage due to loss of glomeruli
- proteinuria may develop
- renal tubules thicken
- harder for kidneys to clear certain substances
- bladder, ureters, and urethra lose elasticity
- bladder holds less urine

Clinical Application

Glomerulonephritis

- inflammation of glomeruli
- may be acute or chronic
- acute glomerulonephritis usually occurs as an immune reaction to a *Streptococcus* infection
- antigen-antibody complexes deposited in glomeruli and cause inflammation
- most patients recover from acute glomerulonephritis
- chronic glomerulonephritis is a progressive disease and often involves diseases other than that caused by *Streptococcus*
- renal failure may result from chronic glomerulonephritis