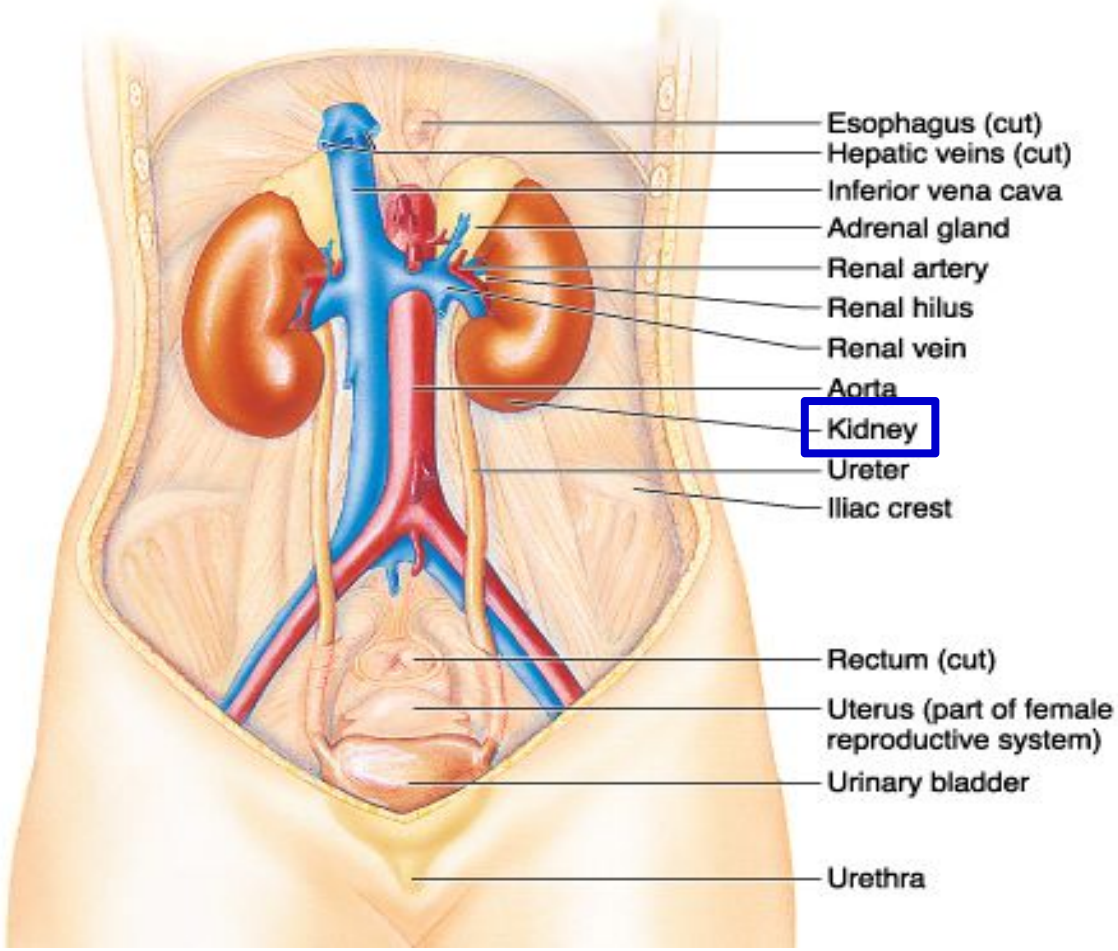
Introduction to Basic Renal Processes

Dr. Denny C.W. Ma

Urinary System

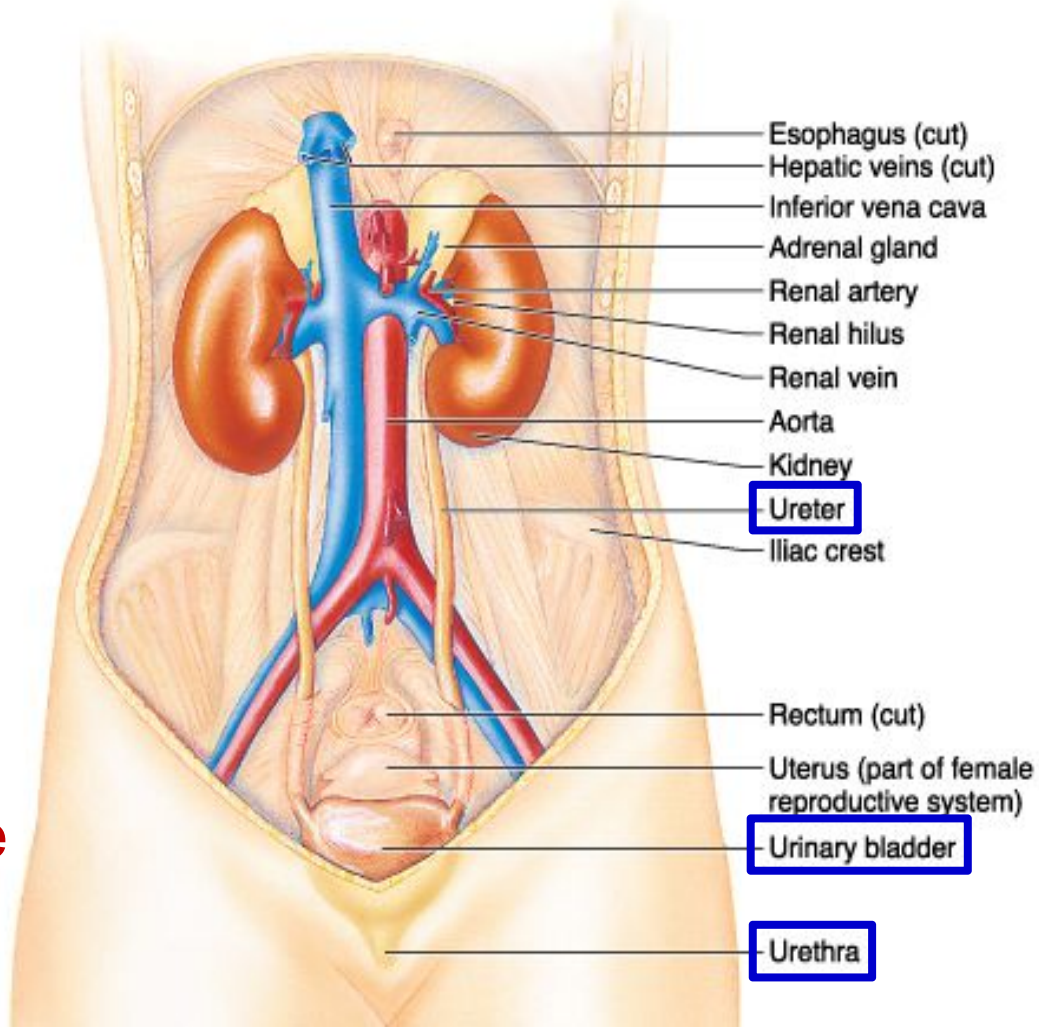
Kidneys

- Weight: ~150 g (average value in adult)
- Dimensions: 12 cm long; 6 cm wide; 3 cm thick (average value in adult)
- Bean-shaped



Urinary System

- **Paired ureters** – transports urine from kidneys to bladder
- **Urinary bladder** – provides a temporary storage reservoir for urine
- **Urethra** – transports urine from the bladder out of the body



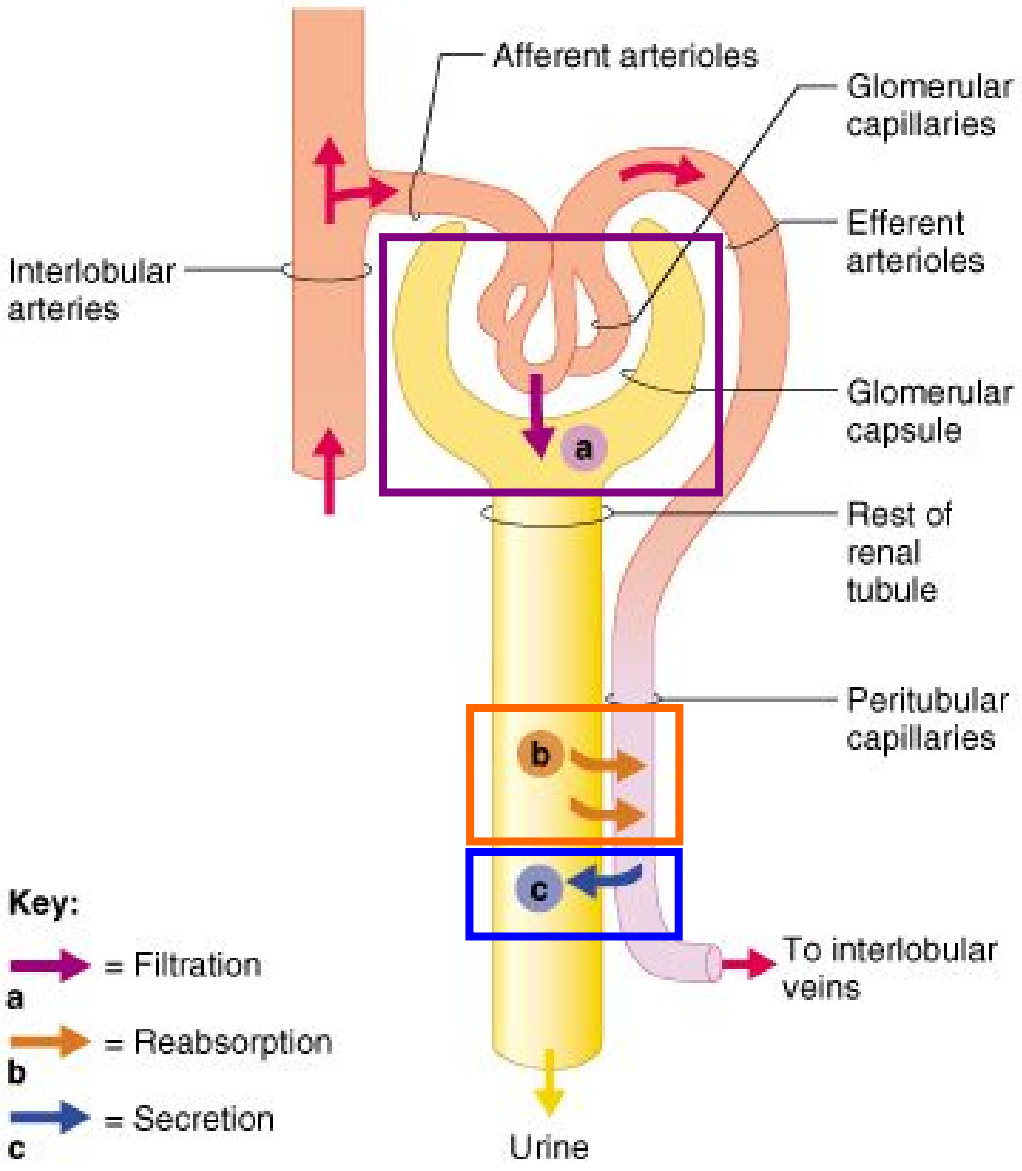
Functions of the Kidneys

- Filter 200 liters of blood daily, allowing toxins, metabolic wastes & excess ions to leave the body in **urine**
- Regulate volume & chemical makeup of blood
- Maintain the proper balance between water & salts, and acids & bases
- Produce renin to help regulate blood pressure & erythropoietin to stimulate red blood cell production

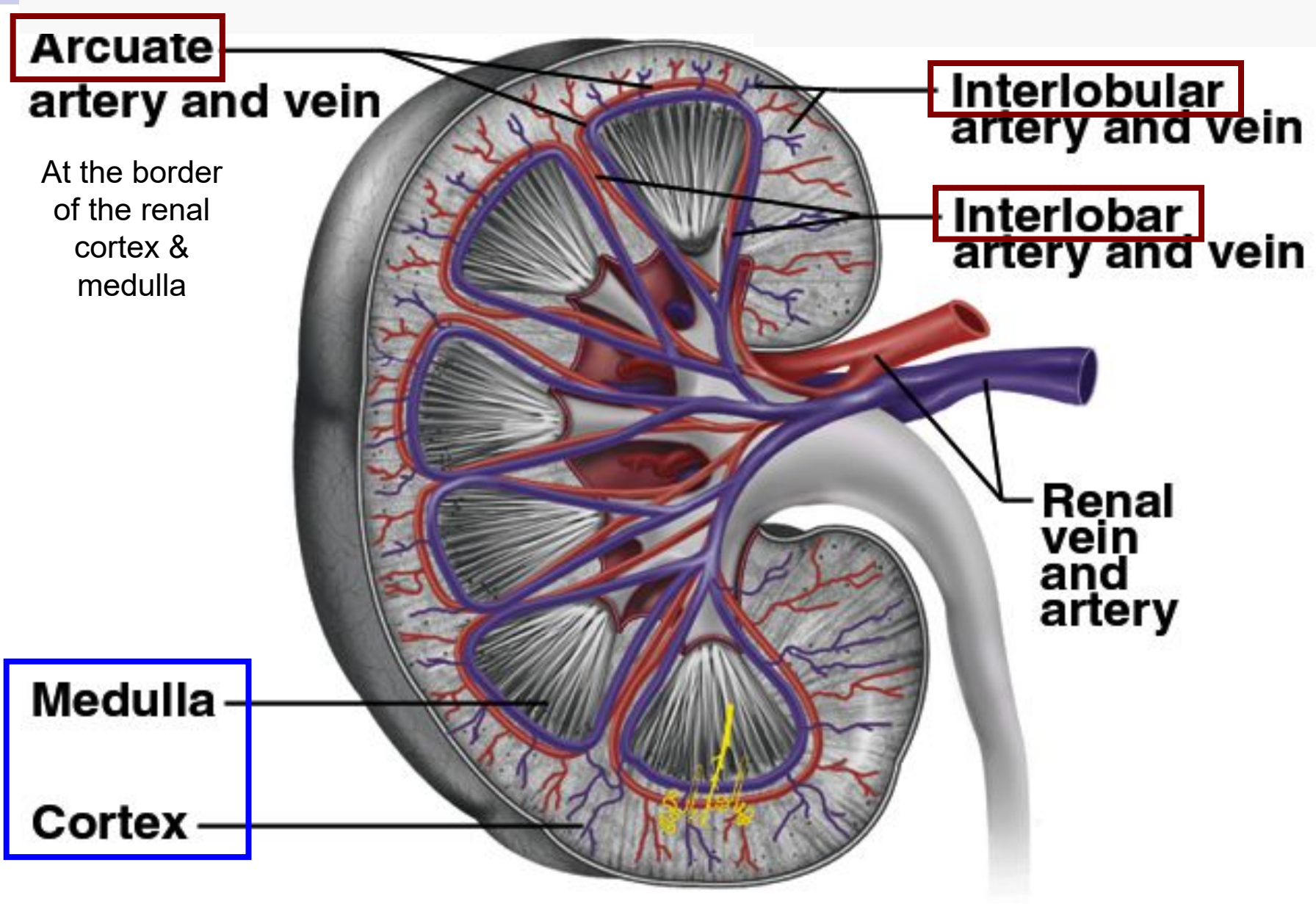
Mechanism of Urine Formation

Urine formation & adjustment of blood composition involves 3 major processes:

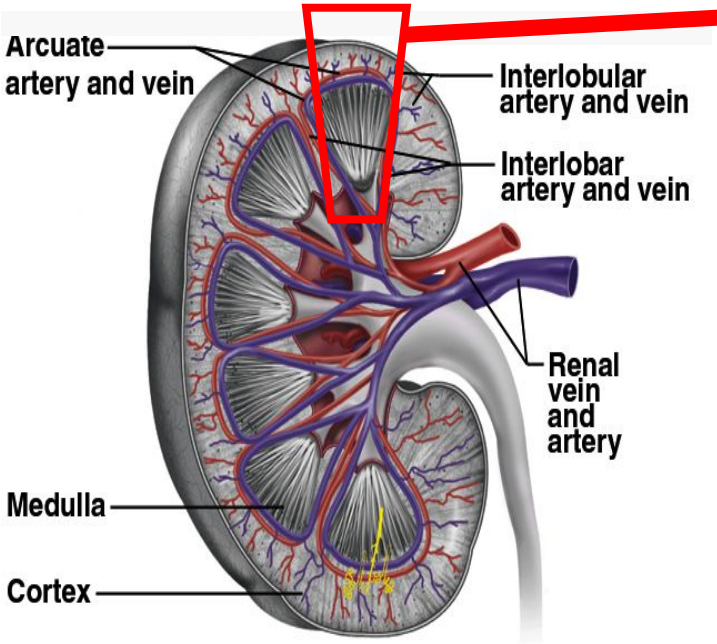
1. Glomerular filtration
2. Tubular reabsorption
3. Secretion

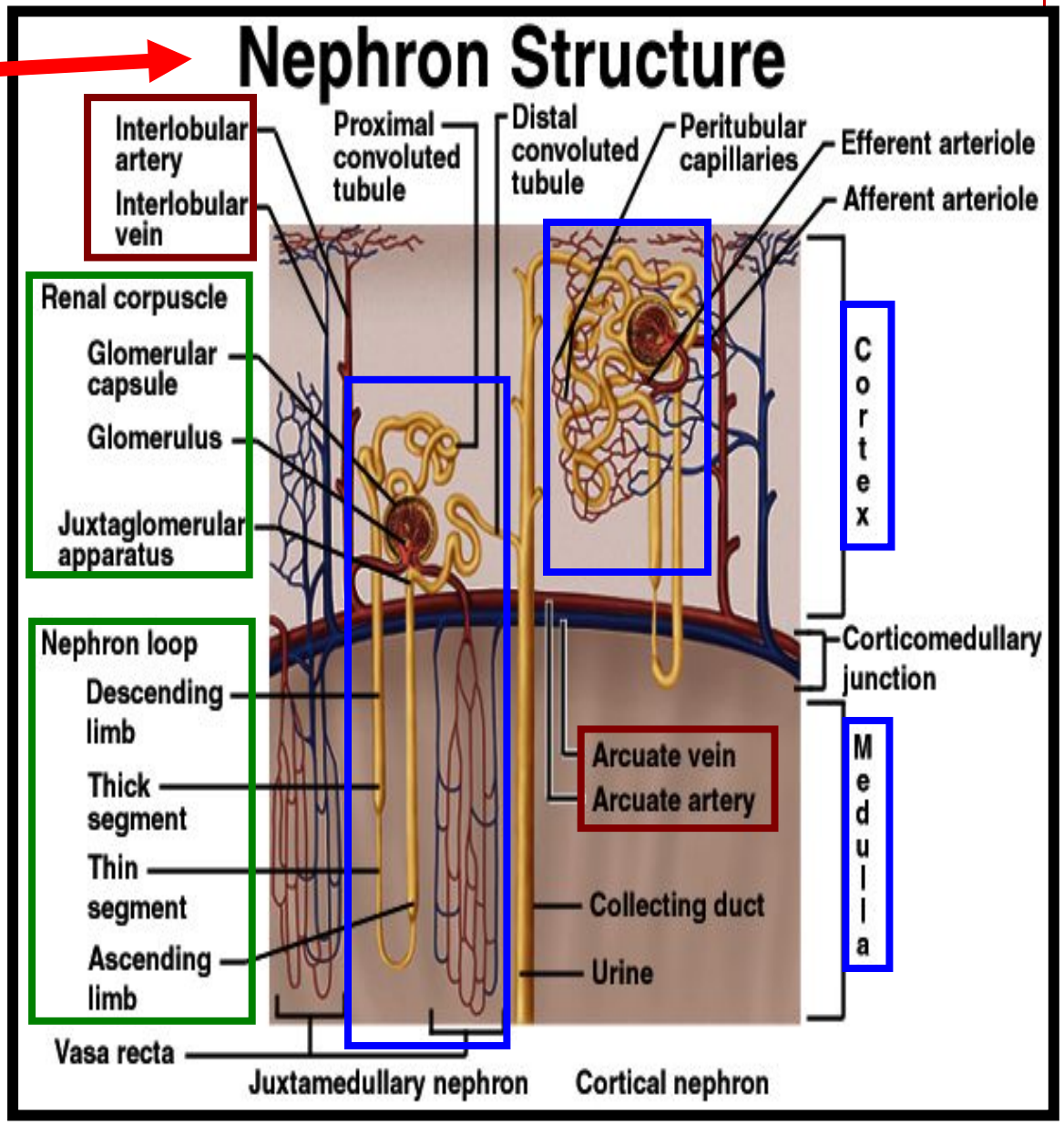


Renal Circulation



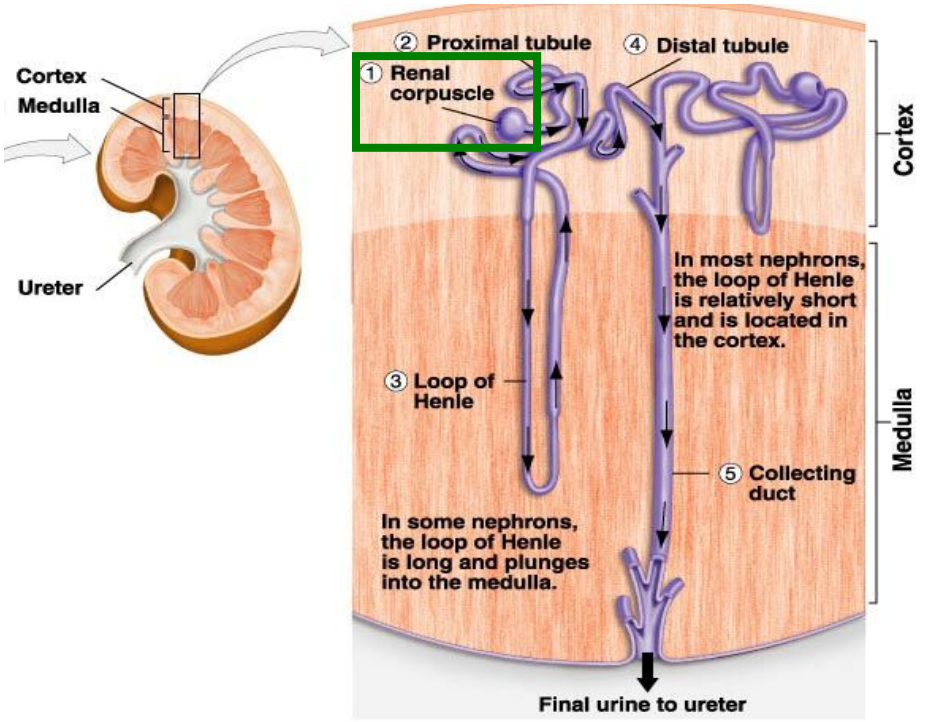
Renal Circulation





Nephron

- Each kidney contains over 1 million tiny blood processing unit is called **nephrons**, which carry out the processes that form urine



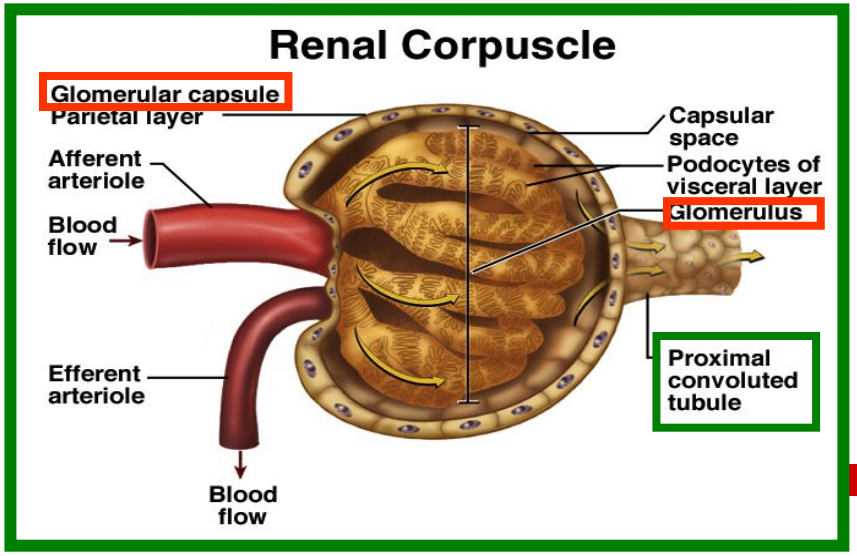
- Each nephron consists of:

1. Renal corpuscle

– Glomerulus & Bowman's capsule

- **Glomerulus** – a clump of capillaries associated with a renal tubule
- **Bowman's capsule** – cup-shaped end of a renal tubule that completely surrounds the glomerulus

2. Renal tubule



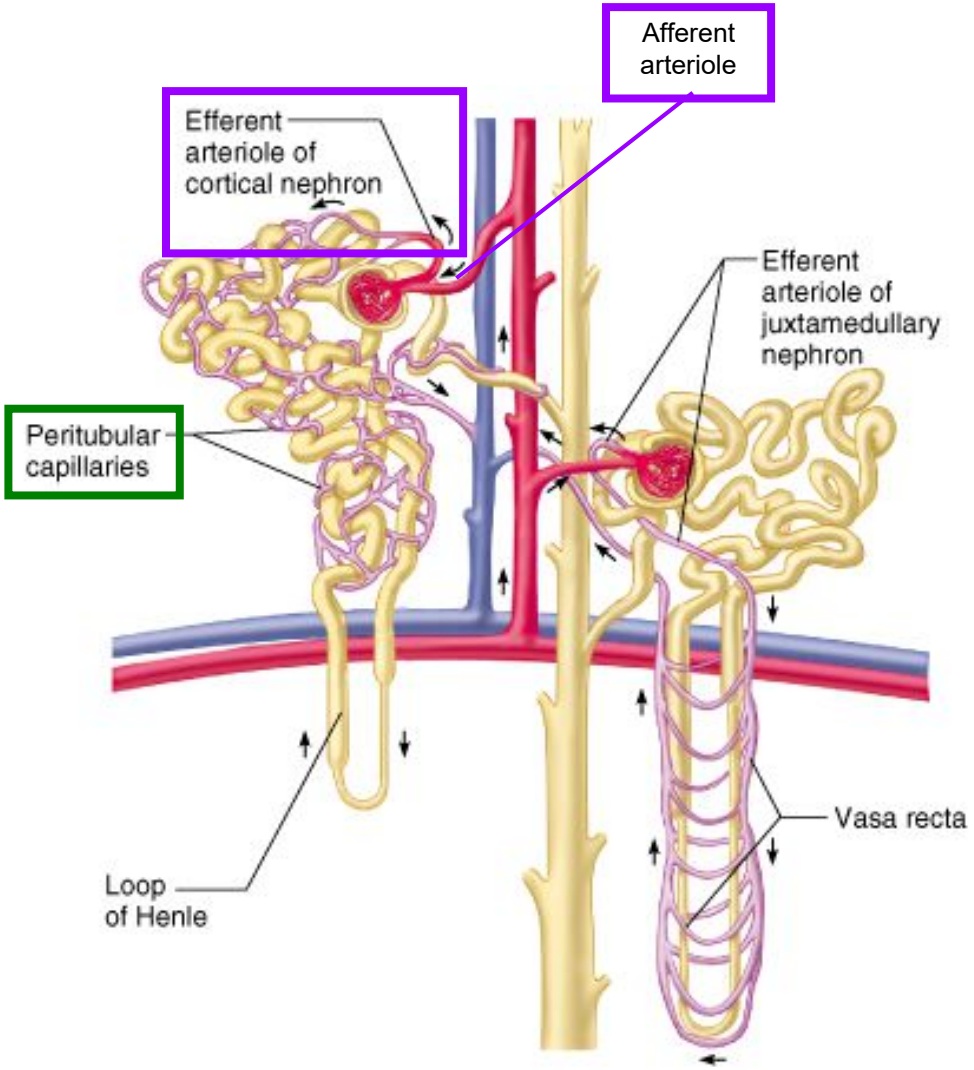
Capillary Beds of the Nephron

Each nephron has **2 capillary beds:**

1. **Glomerulus**
2. **Peritubular capillaries**

Each glomerulus is:

- Fed by an **afferent arteriole**
- Drained by an **efferent arteriole**

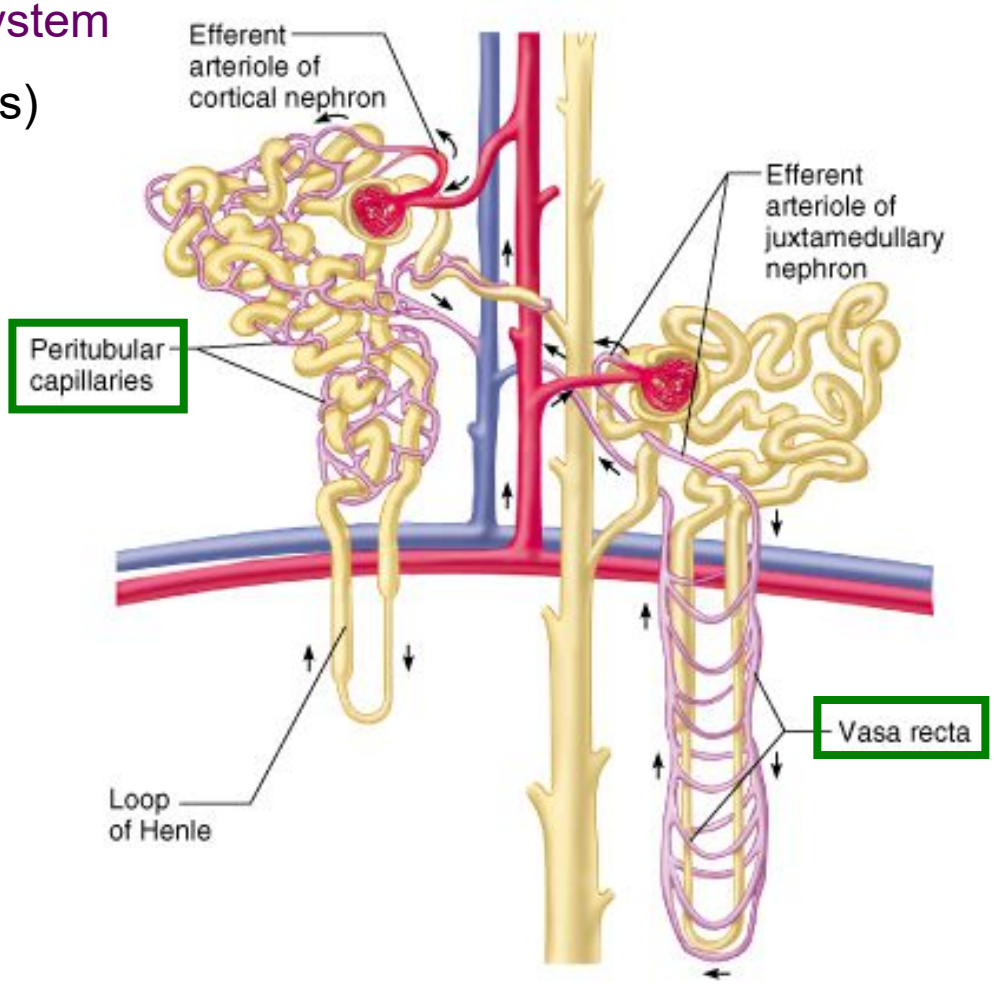


Peritubular Capillaries

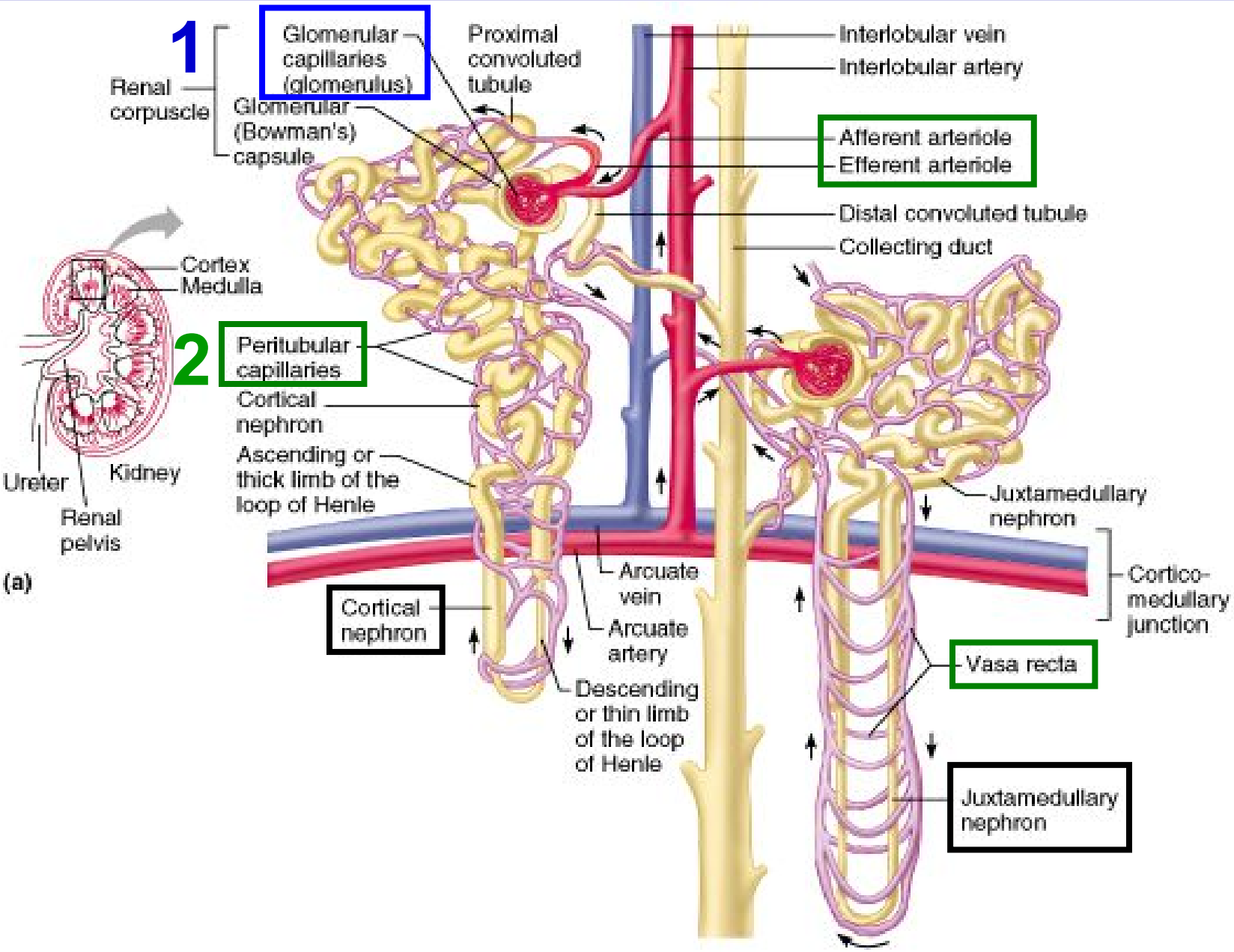
Low-pressure, porous capillaries adapted for **absorption**

- Arise from efferent arterioles
- Cling to adjacent renal tubules
- Empty into the renal venous system

Vasa recta (of juxtamedullary nephrons)

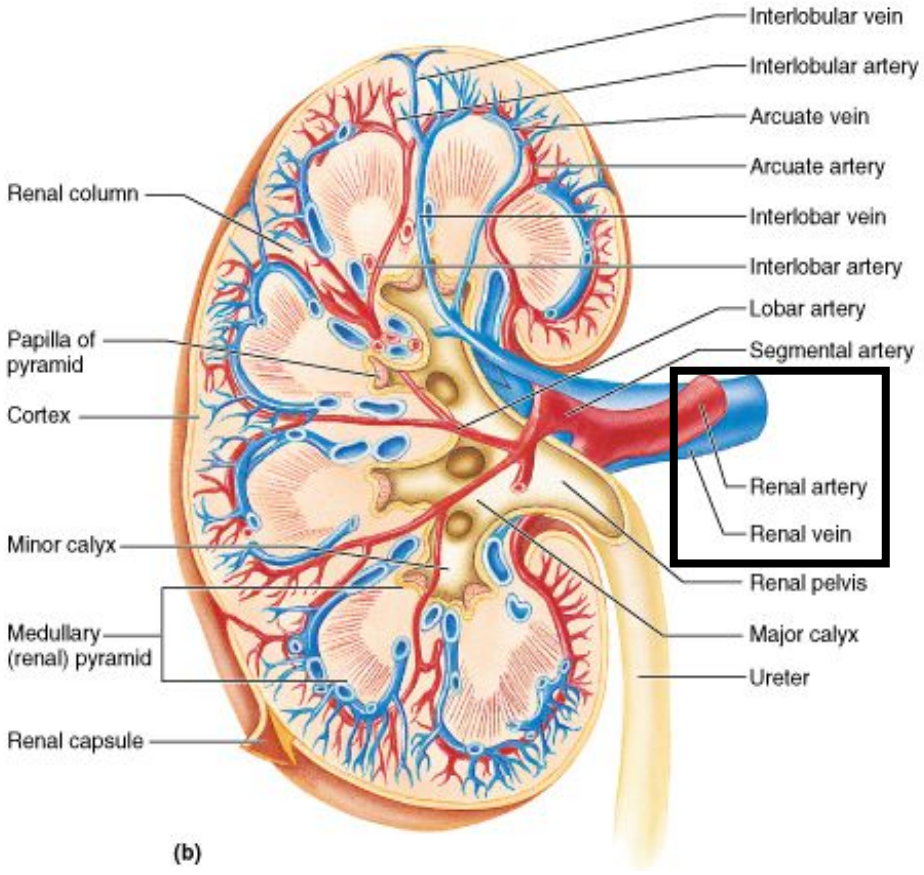


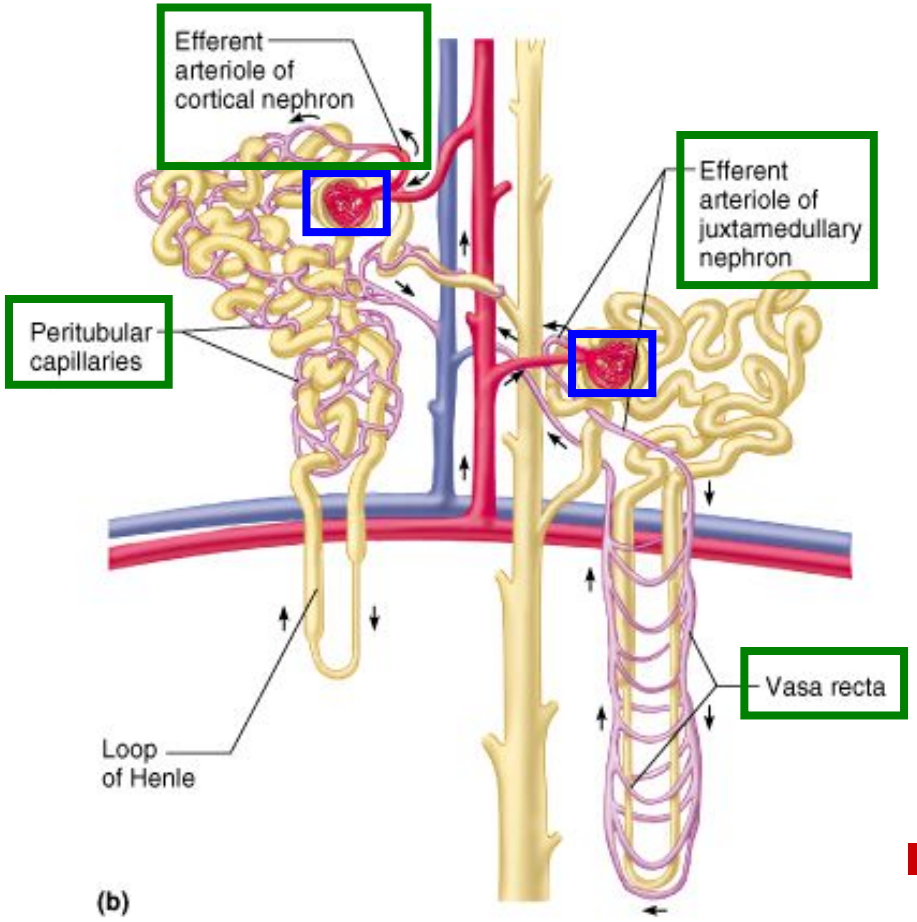
Capillary Beds of the Nephron



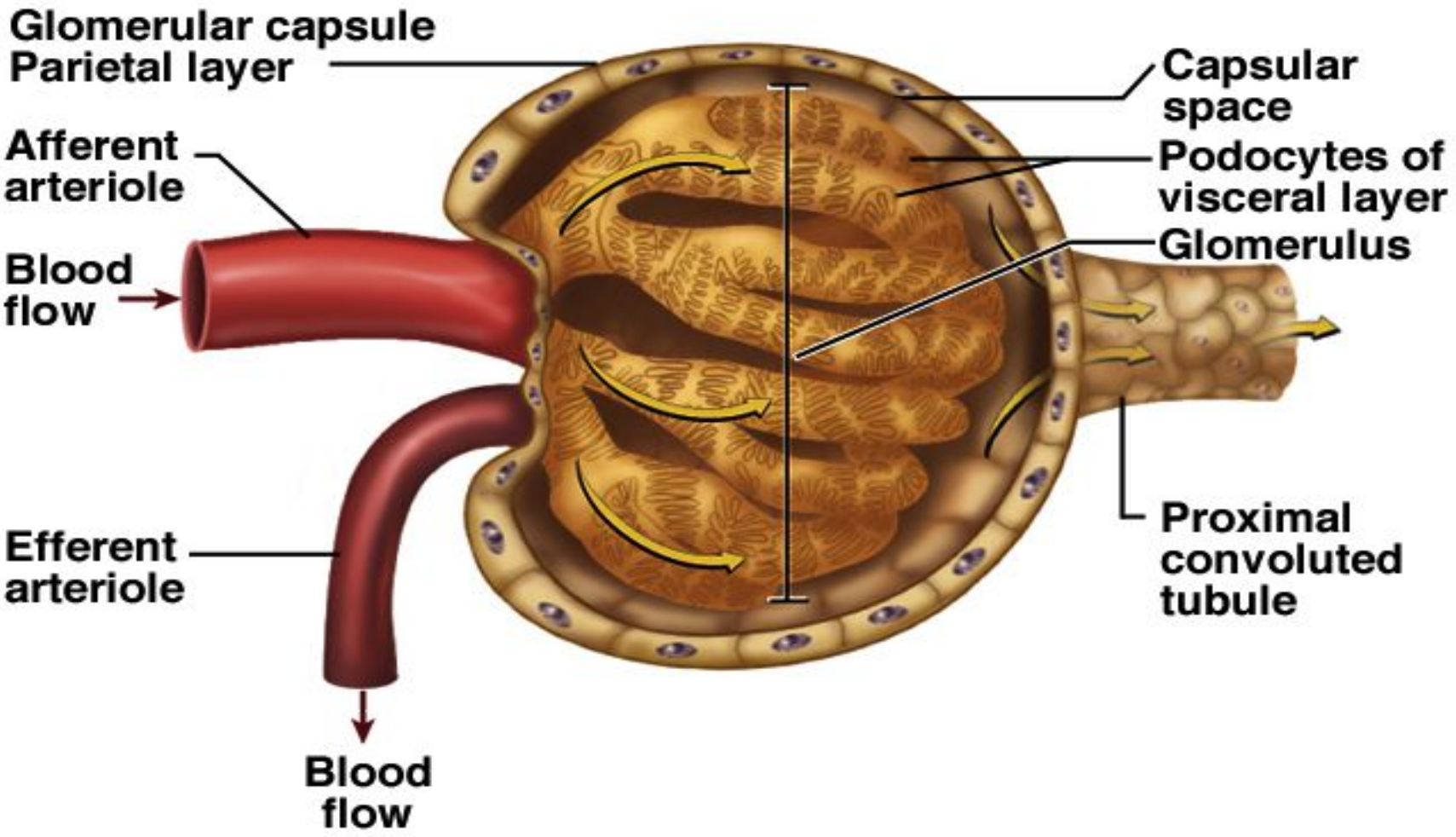
Pathway of Renal Blood Flow

- Aorta → Renal artery →
- Afferent arteriole → Glomerular capillaries → Efferent arteriole → Peritubular capillaries & vasa recta →
- Renal vein → Inferior vena cava

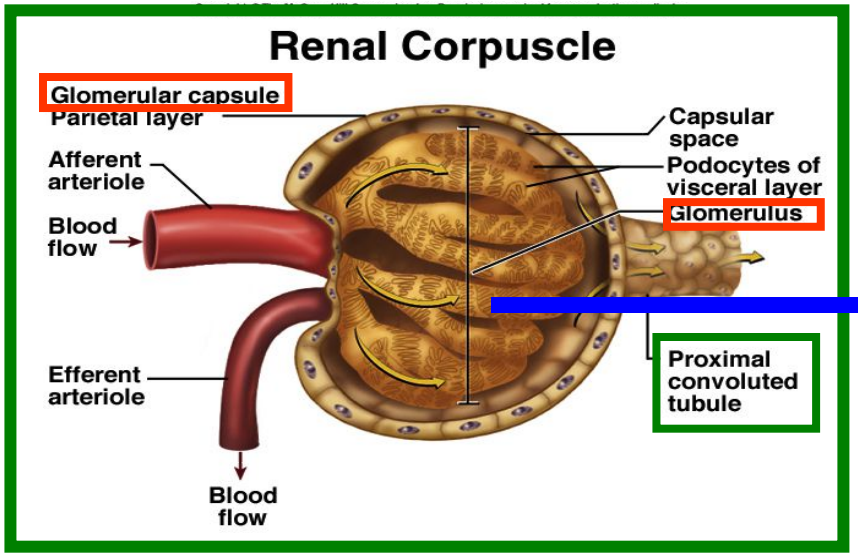


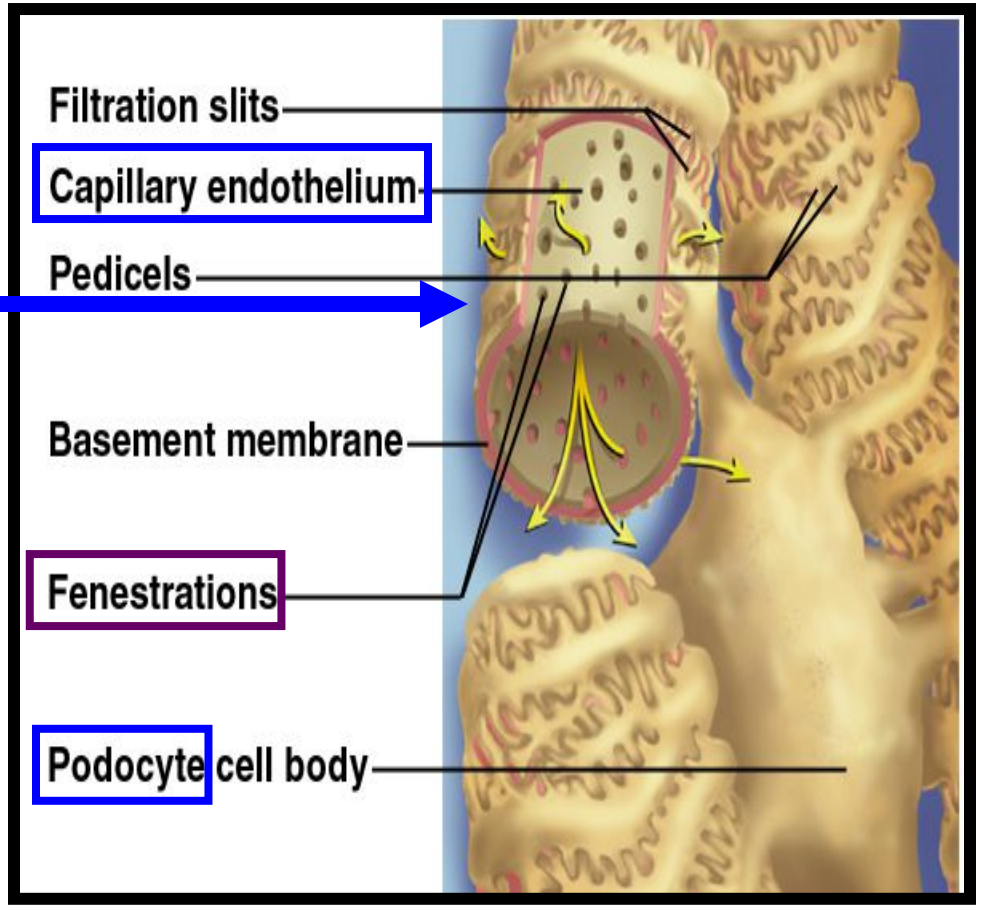


Glomerular Filtration

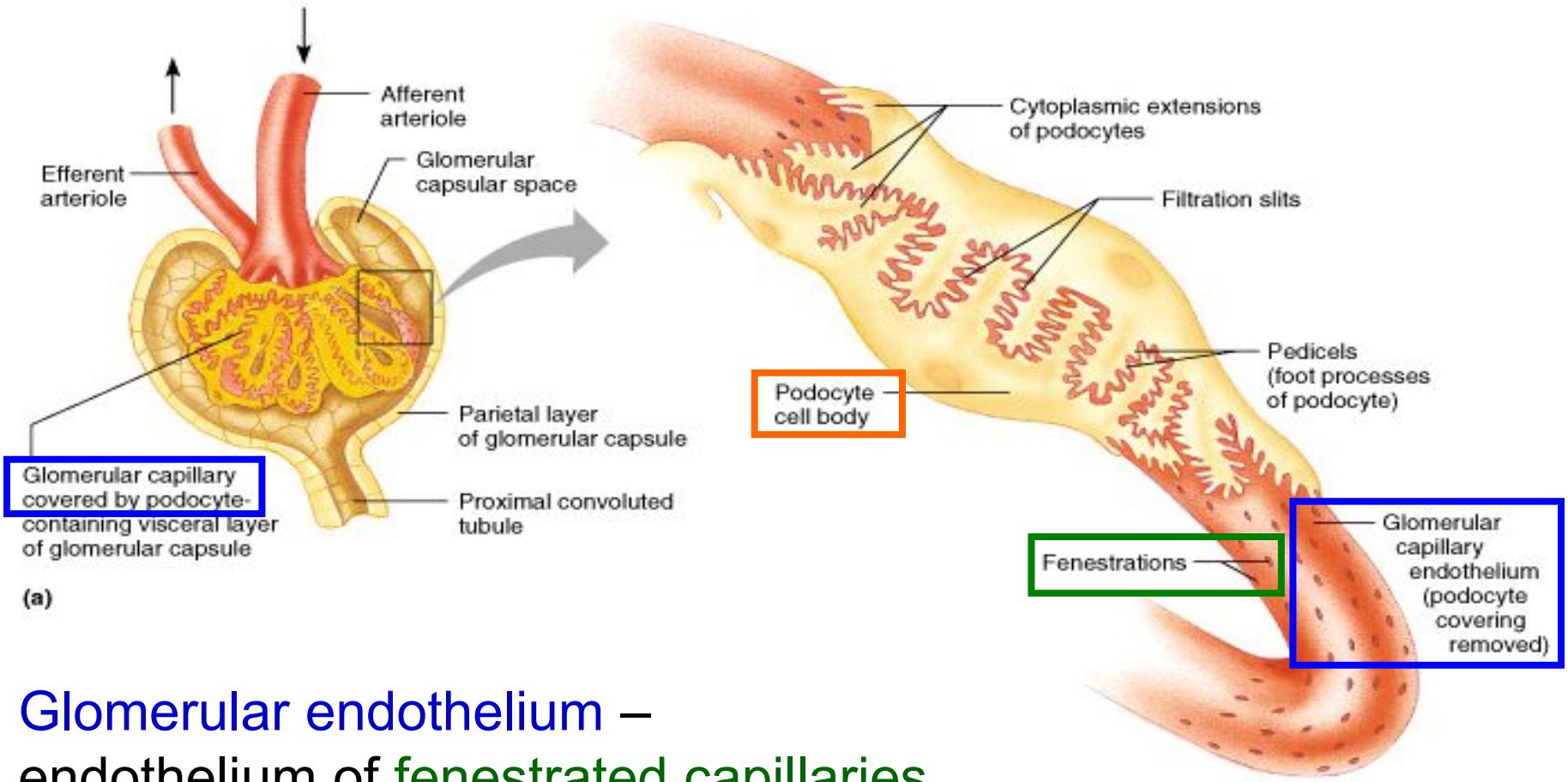


Filtration Membrane





Filtration Membrane



Glomerular endothelium – endothelium of fenestrated capillaries that allows solute-rich, virtually protein-free filtrate to pass from blood into glomerular capsule

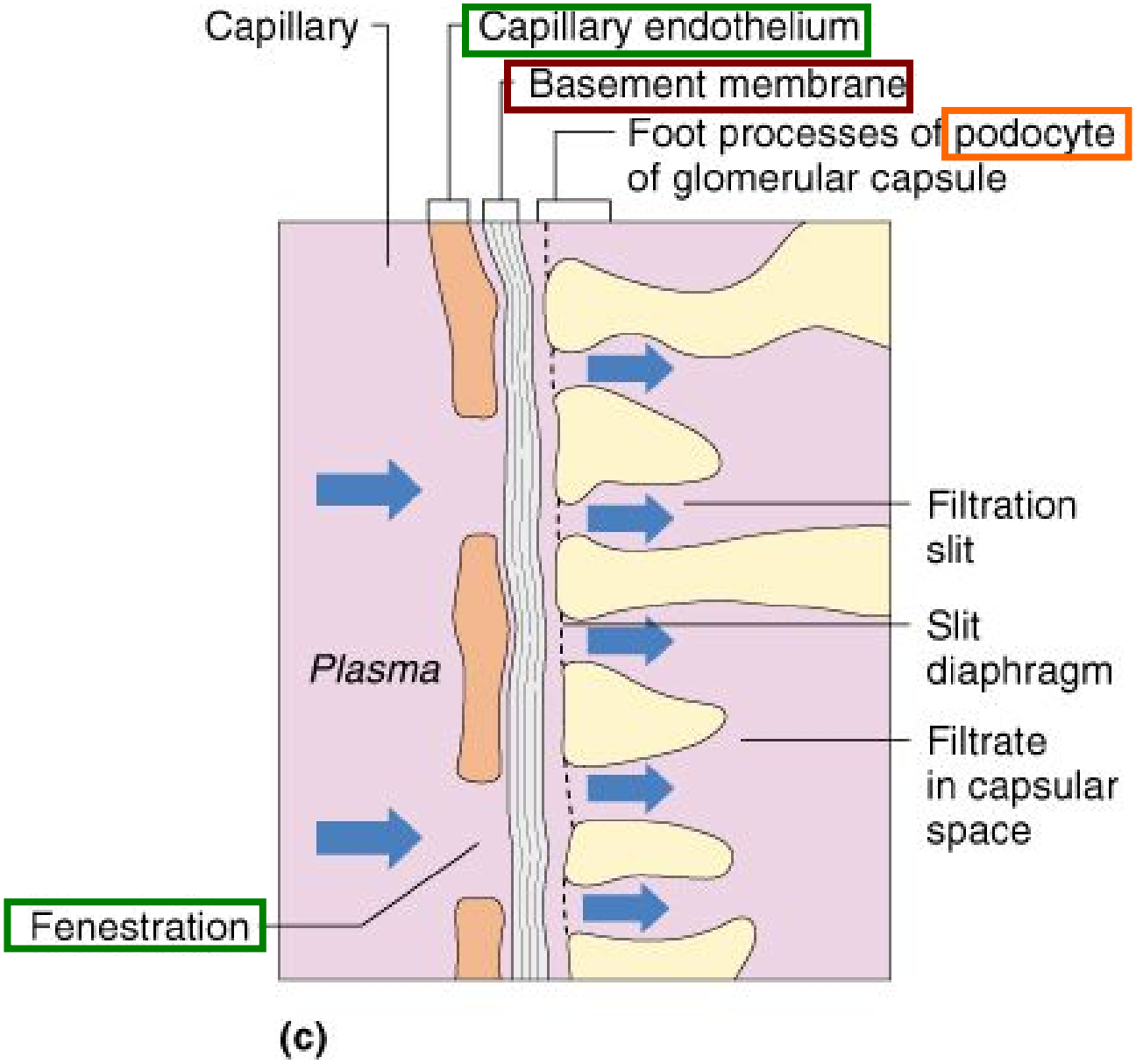
Filtration Membrane

Filter that lies between blood & interior of glomerular capsule

Composed of 3 layers:

- Endothelium of fenestrated capillaries
- Visceral membrane of glomerular capsule (podocytes)
- Basement membrane composed of fused basal laminas of other layers

Filtration Membrane



Glomerular Filtration

- Glomerulus is more efficient than other capillary beds because:
  - Filtration membrane has fenestrated capillaries

    → significantly more permeable
  - Glomerular blood pressure is higher (55 mmHg)

    → higher filtration pressure

- Filtration membrane allows molecules smaller than ~5 nm to pass from blood into renal tubule (e.g. water, glucose, amino acids & wastes)
  - Larger molecules (e.g. protein) cannot pass the membrane into the tubule

Glomerular Filtration

- Kidneys filter the body's entire plasma volume 60 times each day

- Filtrate contains all plasma components except protein

  →Loses water, nutrients & essential ions to become urine

- Urine contains metabolic wastes & unneeded substances

Glomerular Filtration Rate (GFR)

Total amount of filtrate formed per minute by the kidneys

Factors governing filtration rate at capillary bed are:

- Total surface area available for filtration [constant]
- Filtration membrane permeability [constant]
- Net filtration pressure [variable]

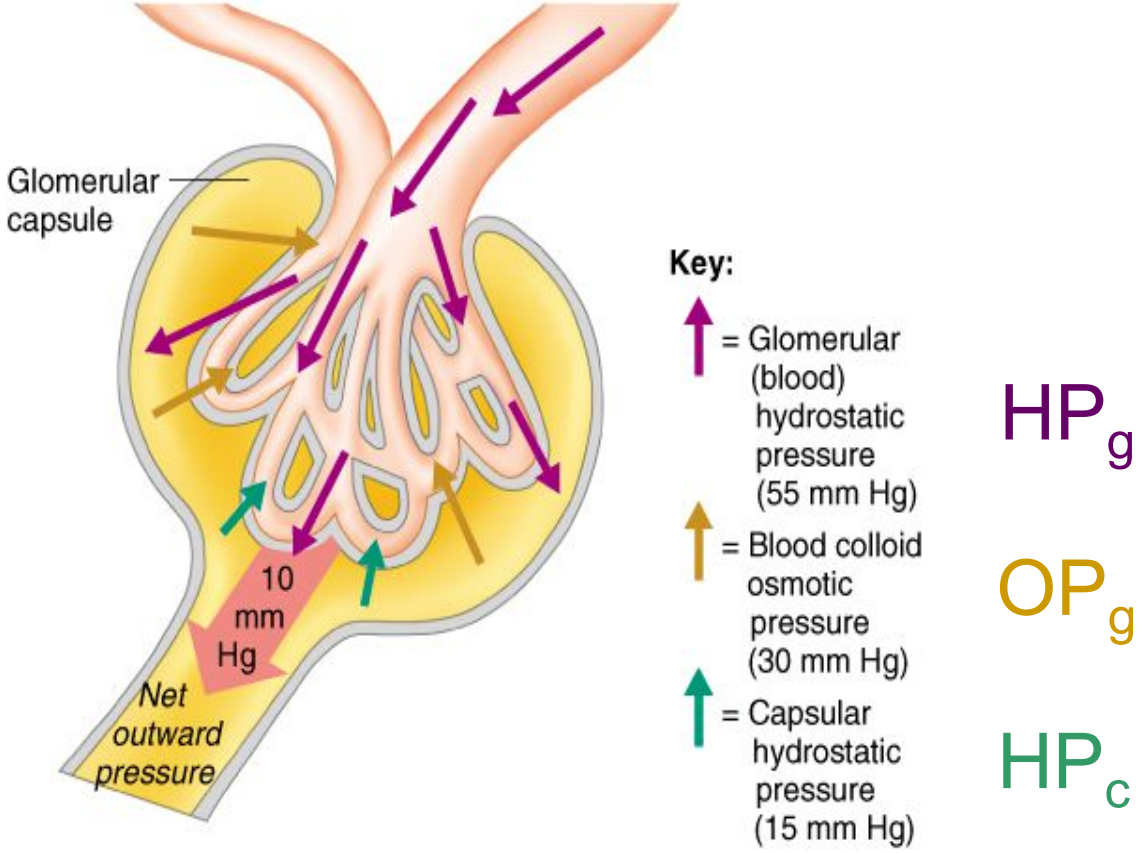
Changes in GFR normally result from changes in glomerular blood pressure

Net Filtration Pressure (NFP)

NFP: Pressure responsible for filtrate formation

Glomerular hydrostatic (blood) pressure is the major factor forcing fluids & solutes out of the blood

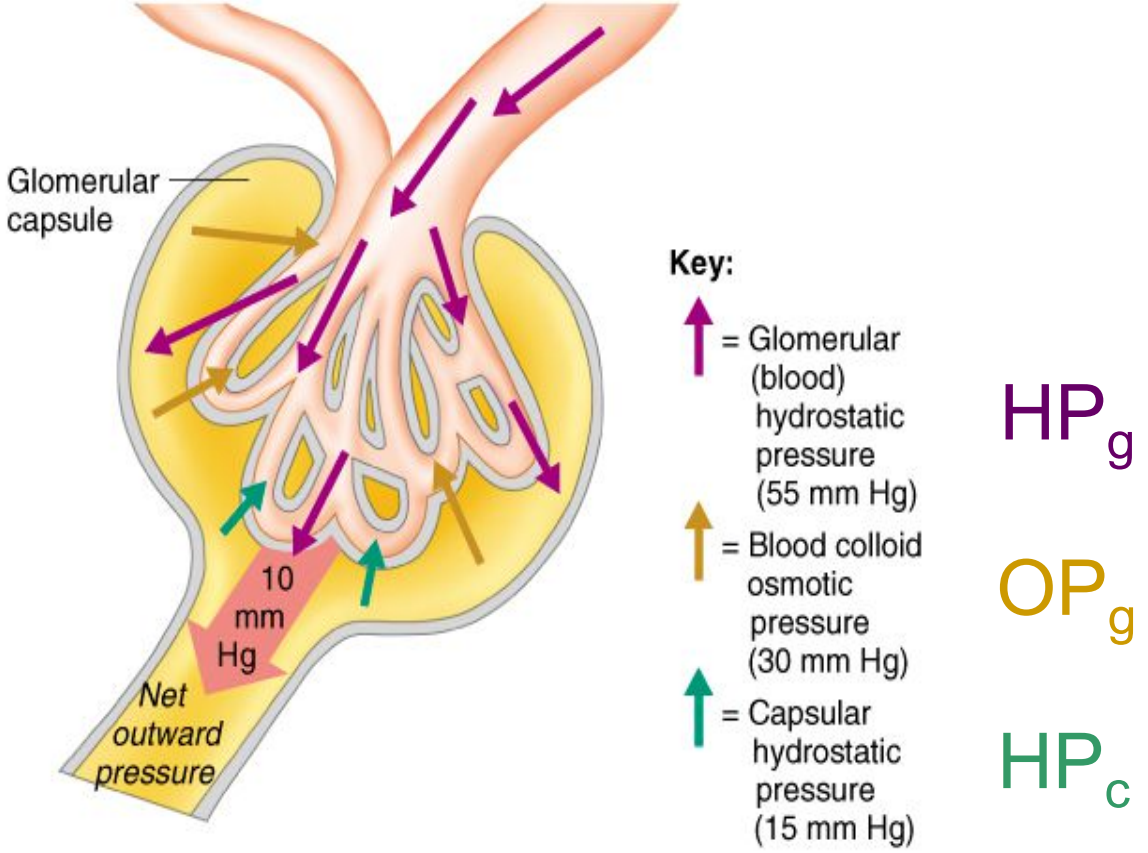
This is opposed by colloid osmotic pressure of blood & hydrostatic pressure within glomerular capsule



Net Filtration Pressure (NFP)

NFP: Pressure responsible for filtrate formation

$$NFP = HP_g - (OP_g + HP_c)$$
$$= 55 - (30 + 15)$$
$$= 10 \text{ mm Hg}$$



Glomerular Filtration Rate (GFR)

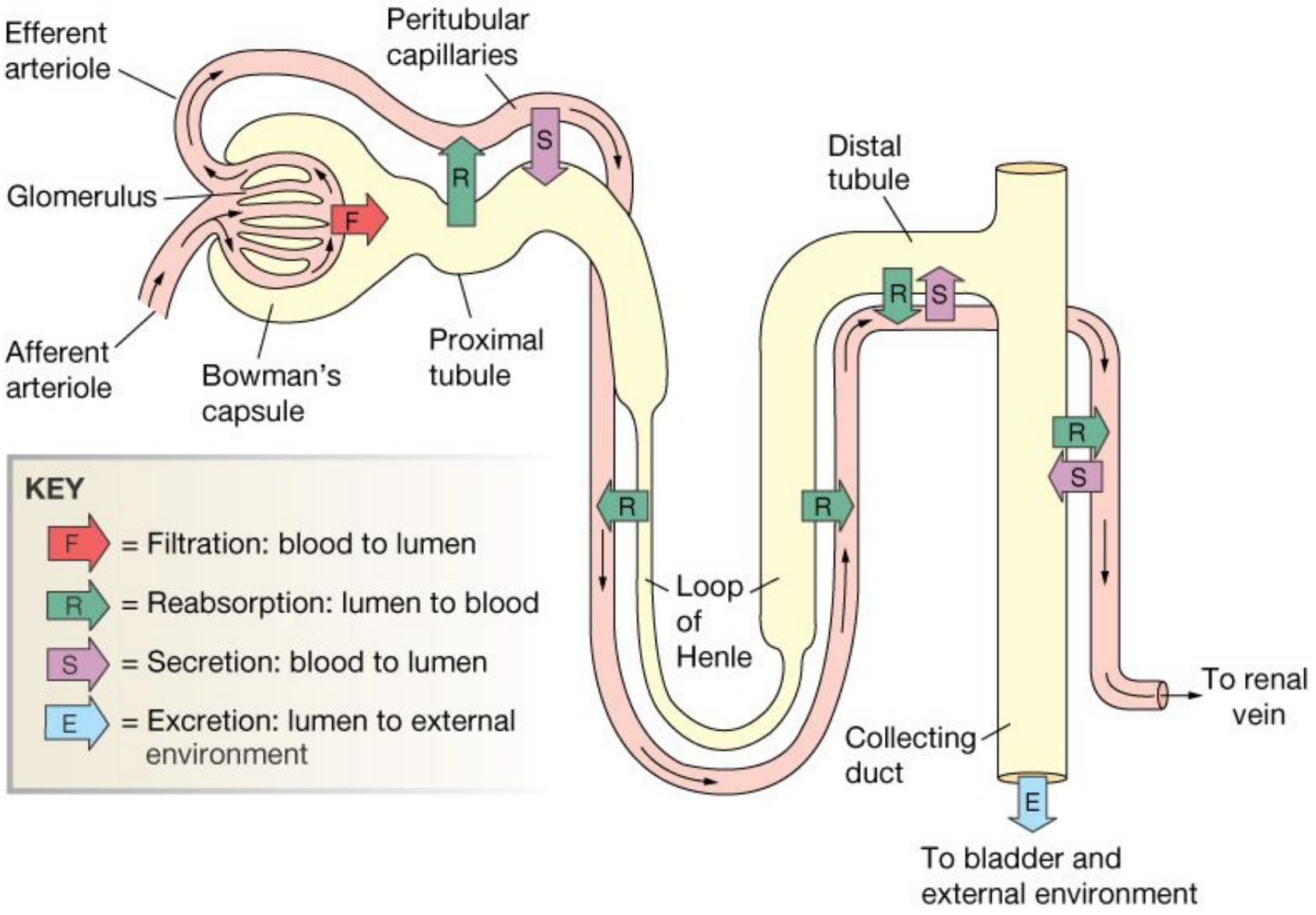
Female:

115 mL/min = 160 litres/day

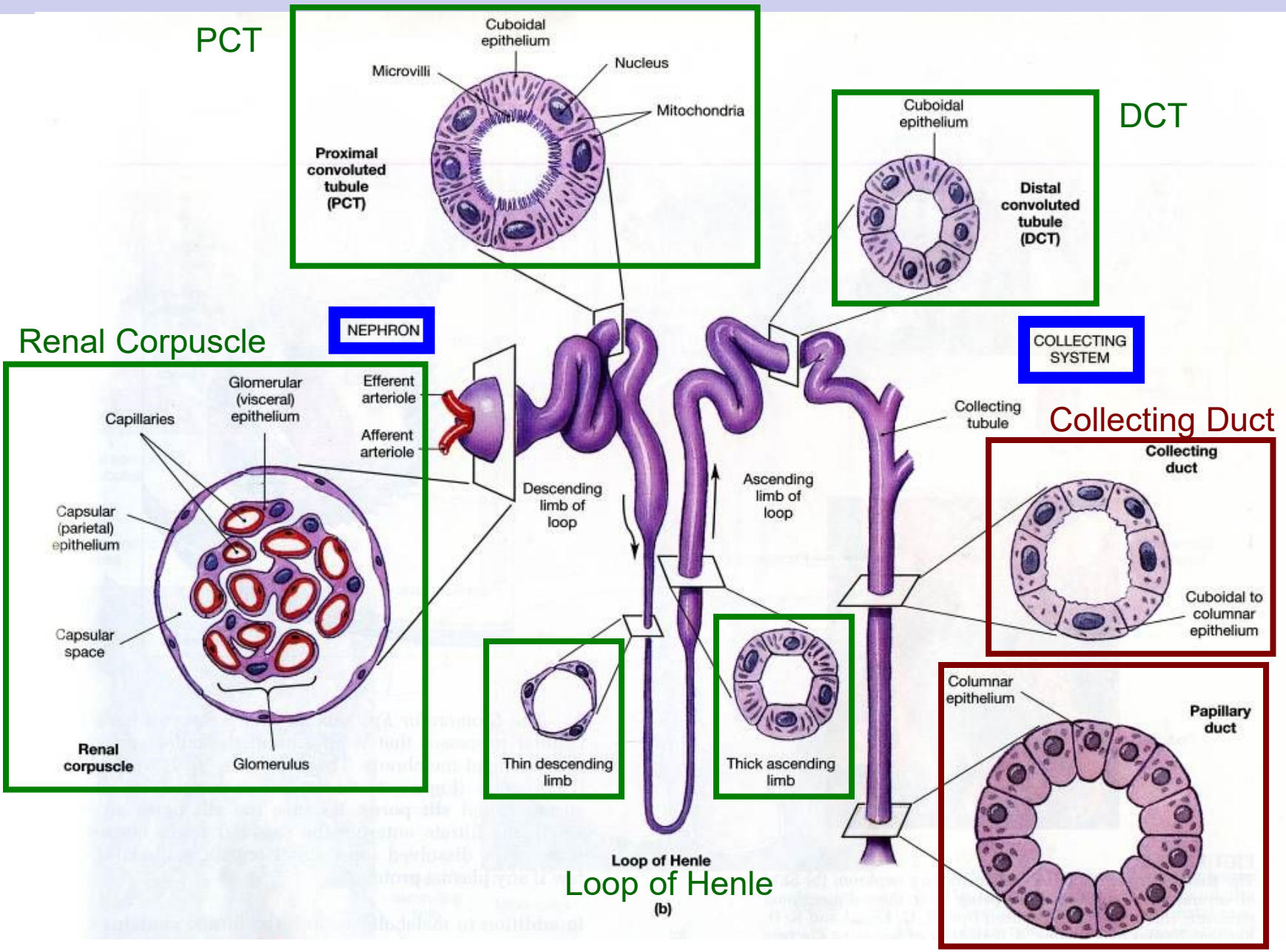
Male:

125 mL/min = 180 litres/day

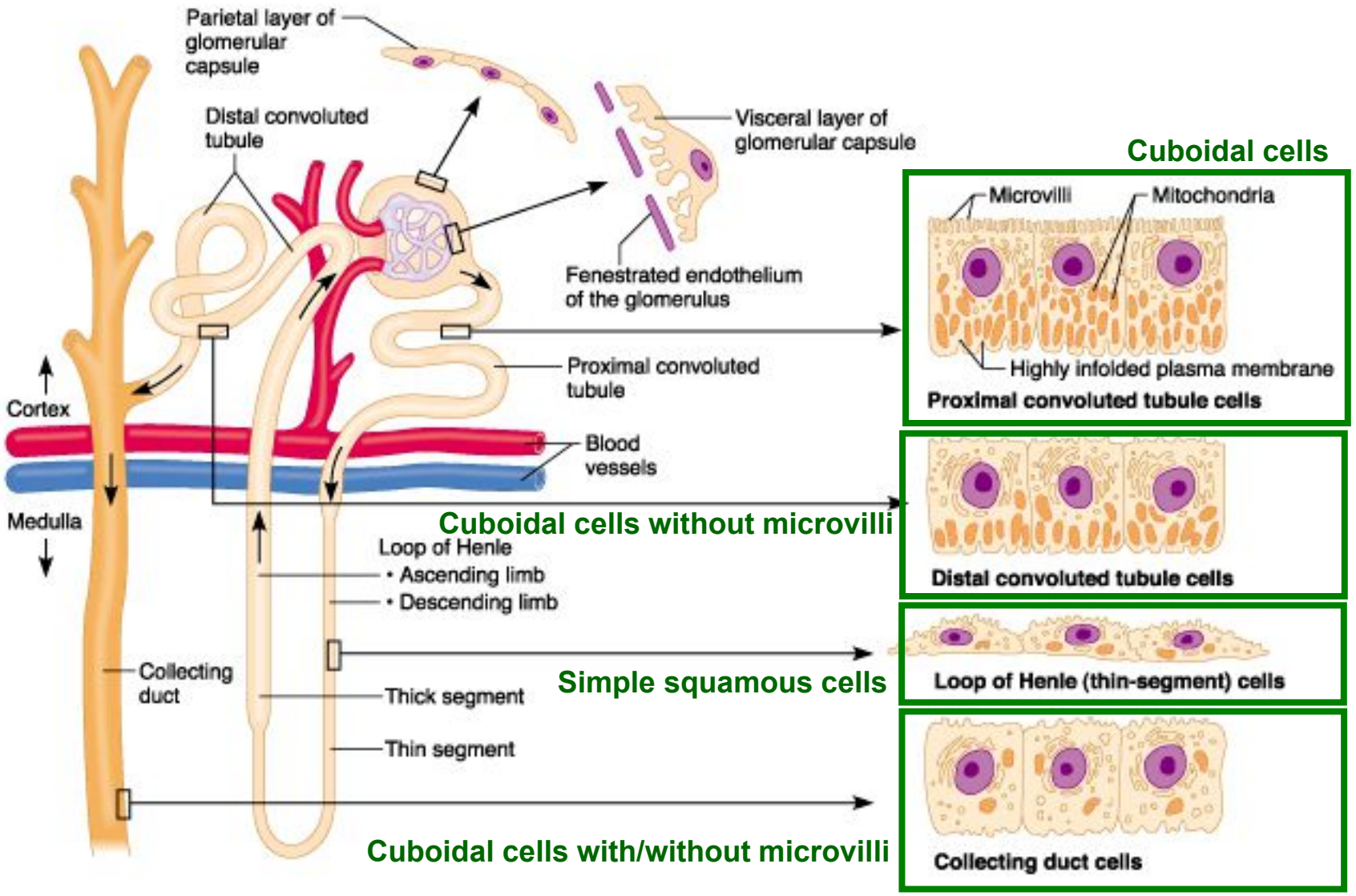
Renal Tubular Transport



Renal Tubular Transport

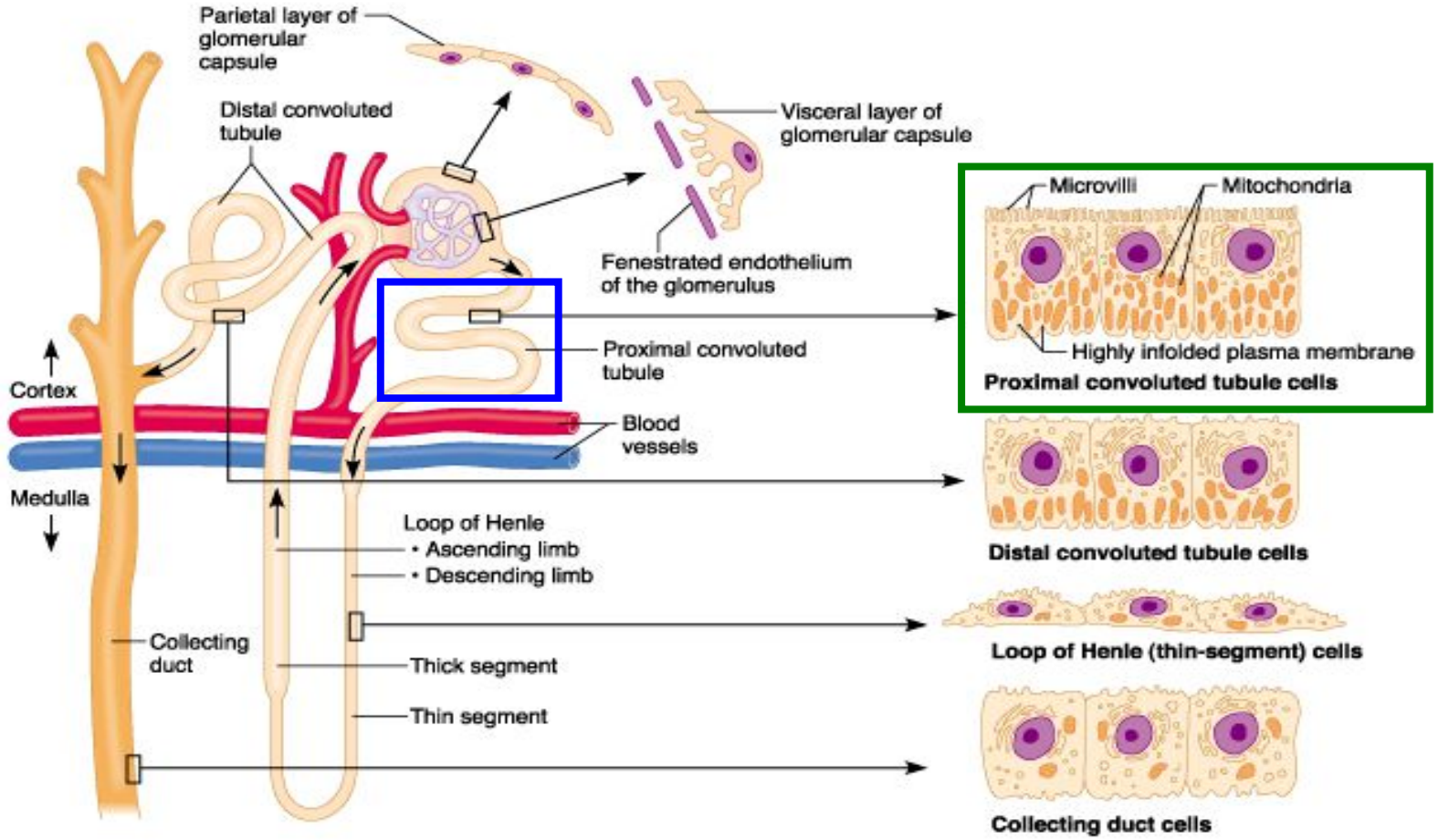


Nephron


Parietal layer of glomerular capsule
Distal convoluted tubule
Visceral layer of glomerular capsule
Fenestrated endothelium of the glomerulus
Proximal convoluted tubule
Cortex
Blood vessels
Medulla
Loop of Henle
• Ascending limb
• Descending limb
Collecting duct
Thick segment
Thin segment
Cuboidal cells
Microvilli
Mitochondria
Highly infolded plasma membrane
Proximal convoluted tubule cells
Cuboidal cells without microvilli
Distal convoluted tubule cells
Simple squamous cells
Loop of Henle (thin-segment) cells
Cuboidal cells with/without microvilli
Collecting duct cells

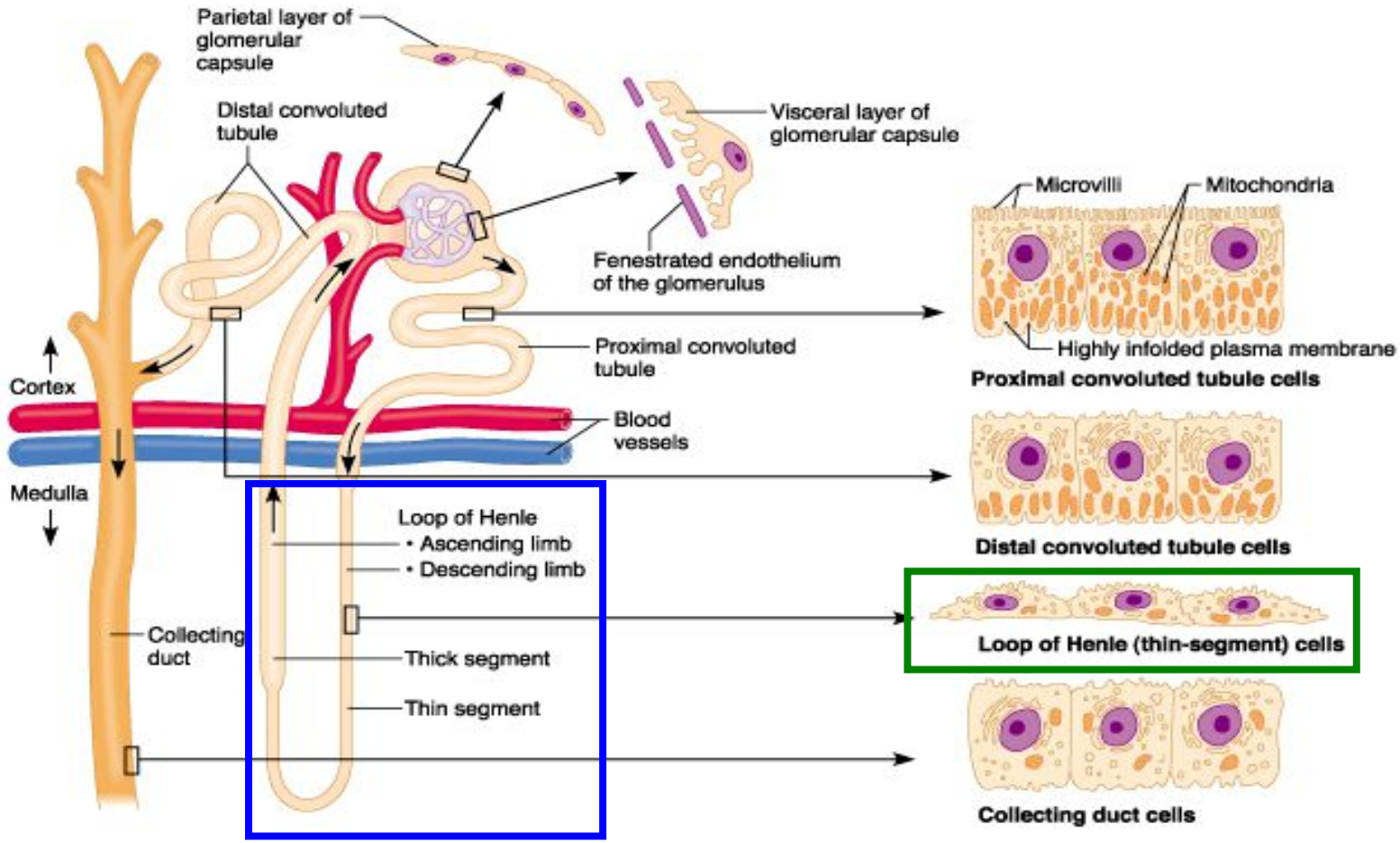
Renal Tubule

- **Proximal convoluted tubule (PCT)**
  - Cuboidal cells with numerous microvilli & mitochondria
  - Reabsorbs water & solutes from filtrate into blood
    (> secretes substances from blood into filtrate)



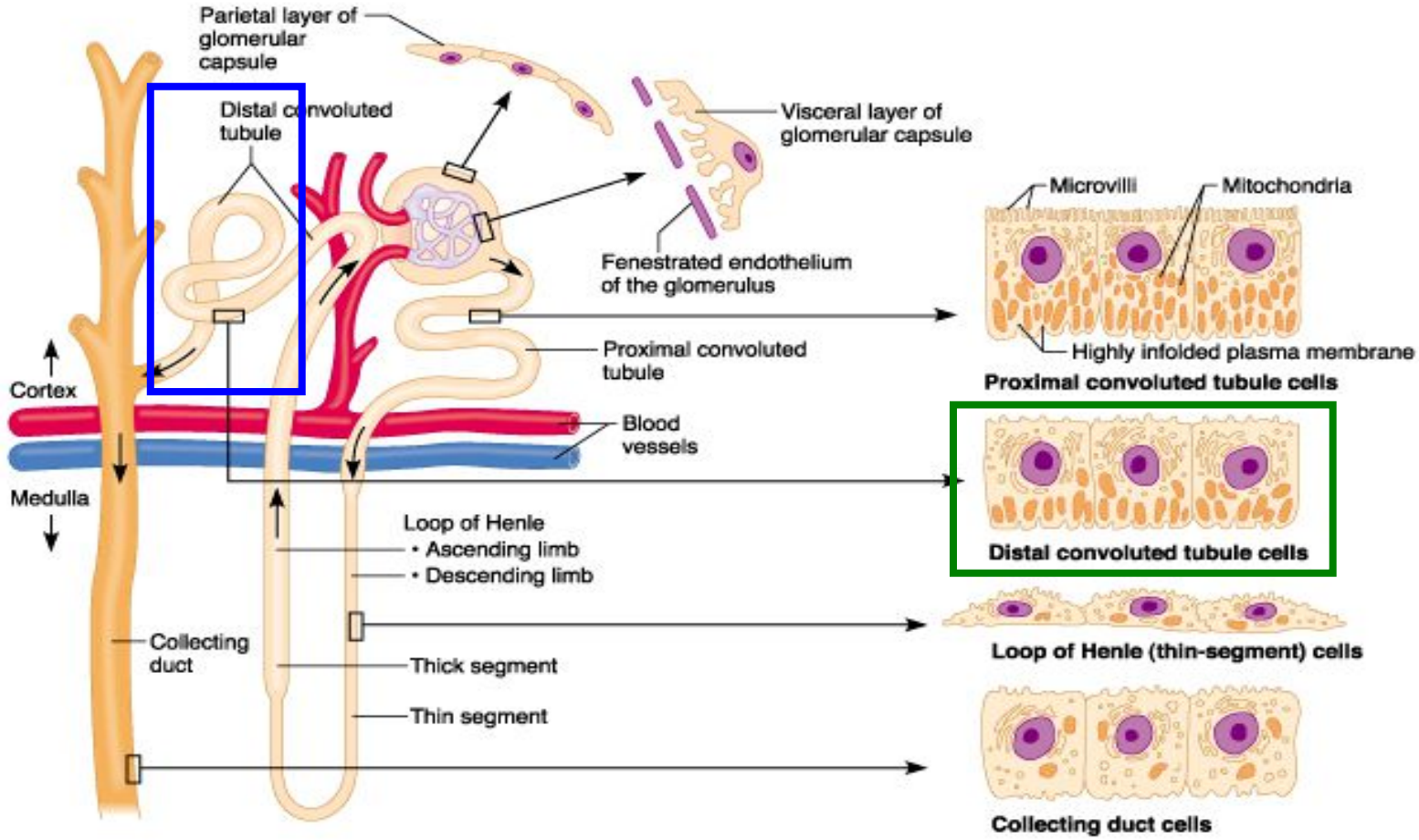
Renal Tubule

- **Loop of Henle** (hairpin-shaped)
  - Consists of descending (thin) & ascending (think) segments
  - Water & salt conservation



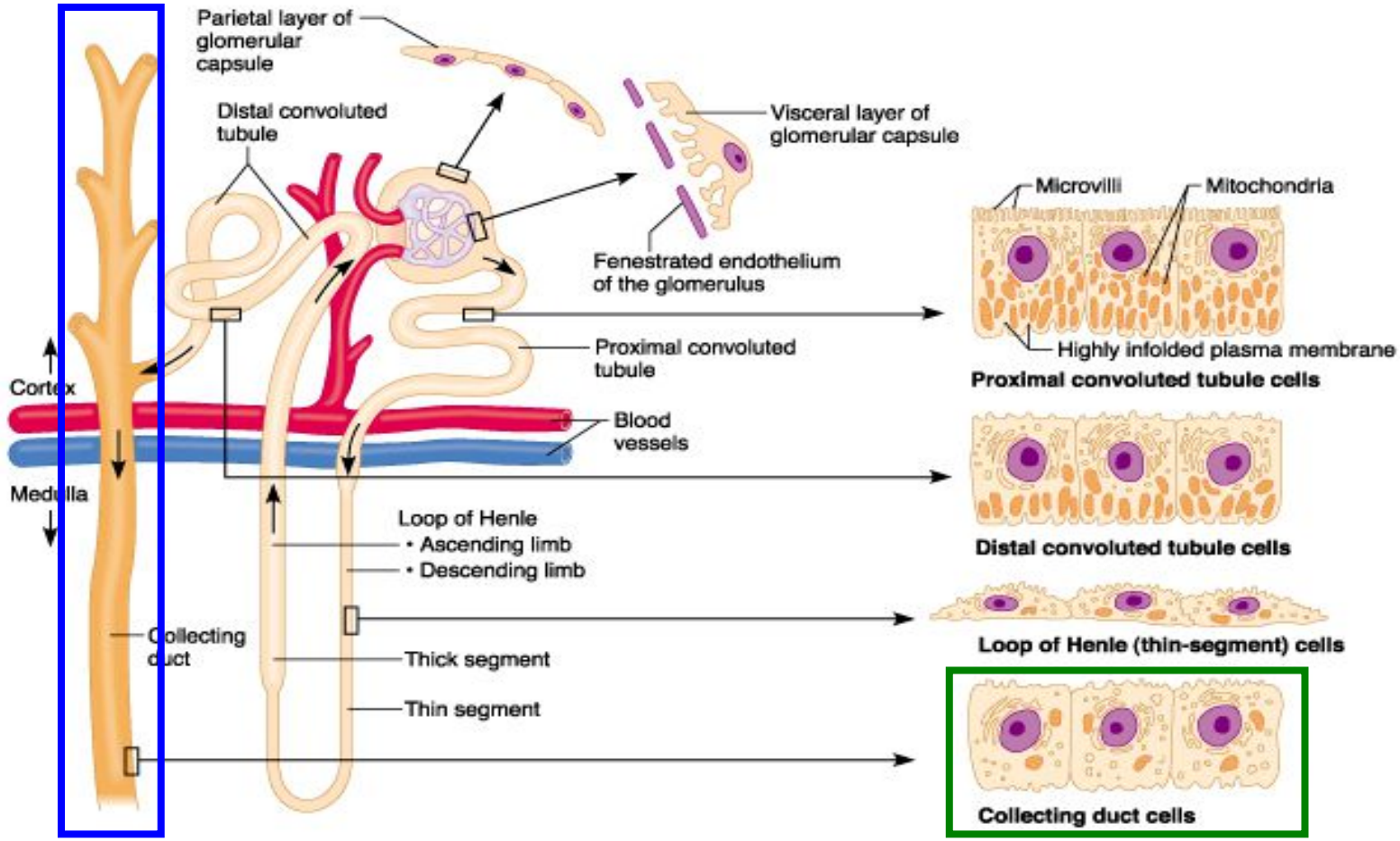
Renal Tubule

- **Distal convoluted tubule (DCT)**
  - Cuboidal cells without microvilli
  - Secretion > Reabsorption

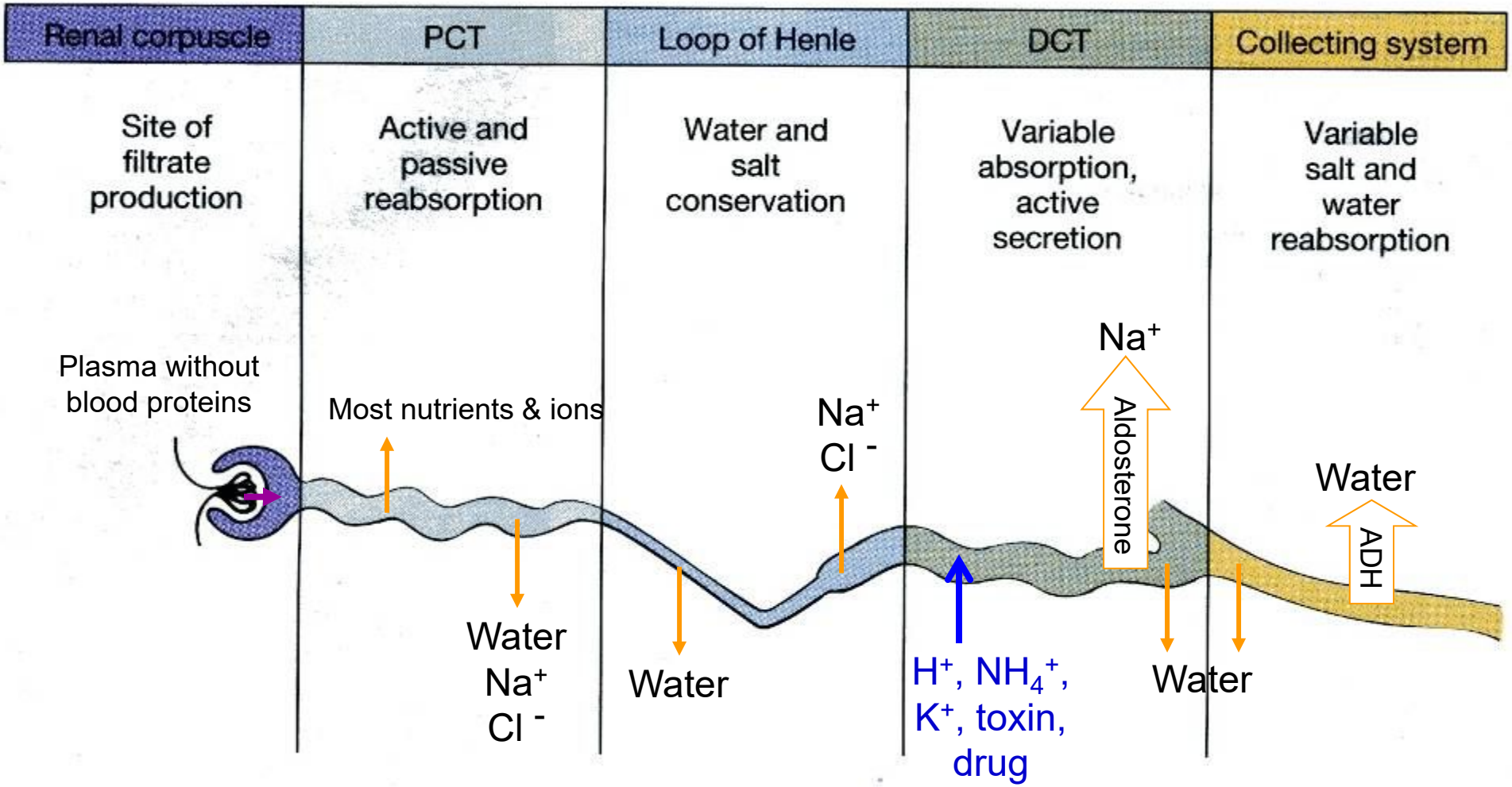


Collecting Tubules

- **Collecting duct**
  - Cuboidal cells with microvilli (for acid-base balance)
  - Cuboidal cells without microvilli (for water & salt balance)

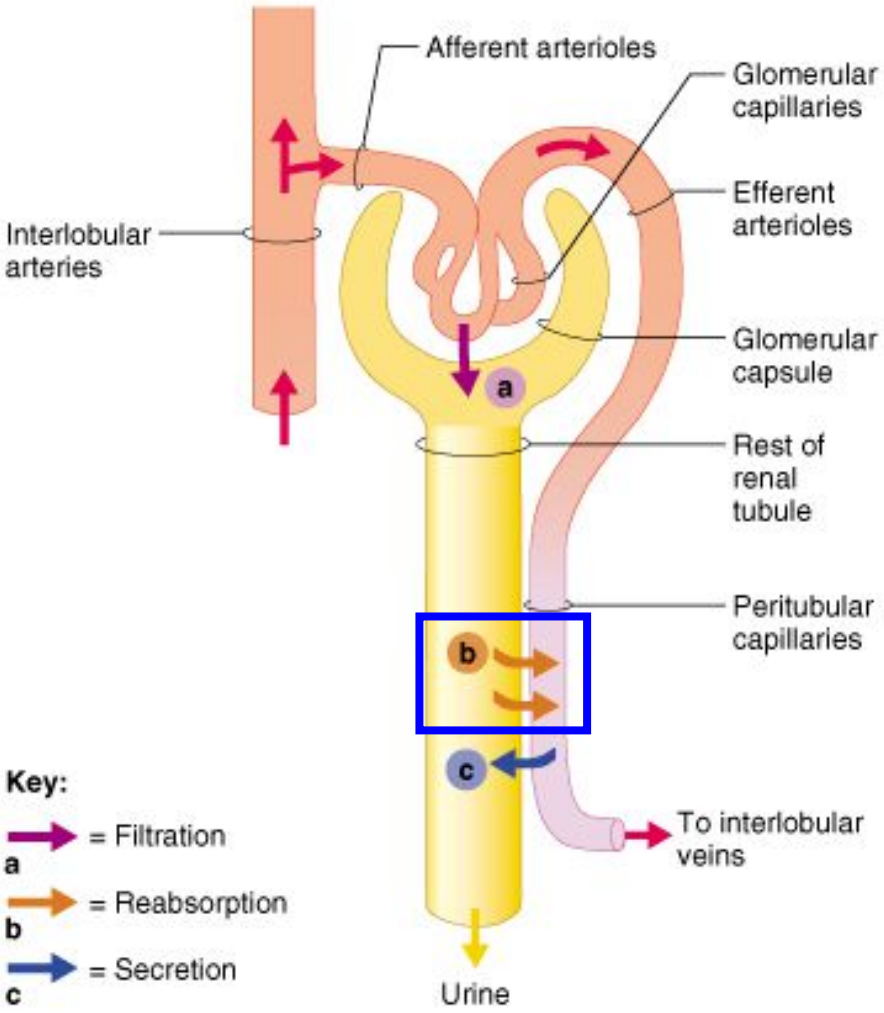


Renal Tubular Transport



Tubular Reabsorption

Substances move from the tubule lumen into peritubular capillaries

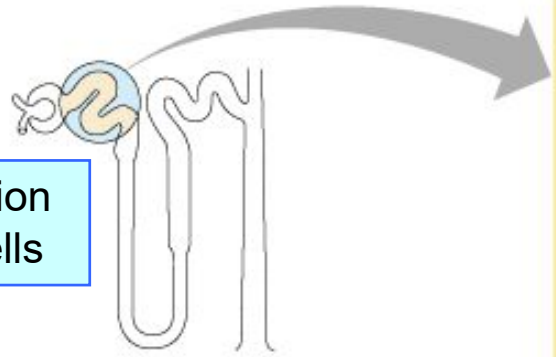


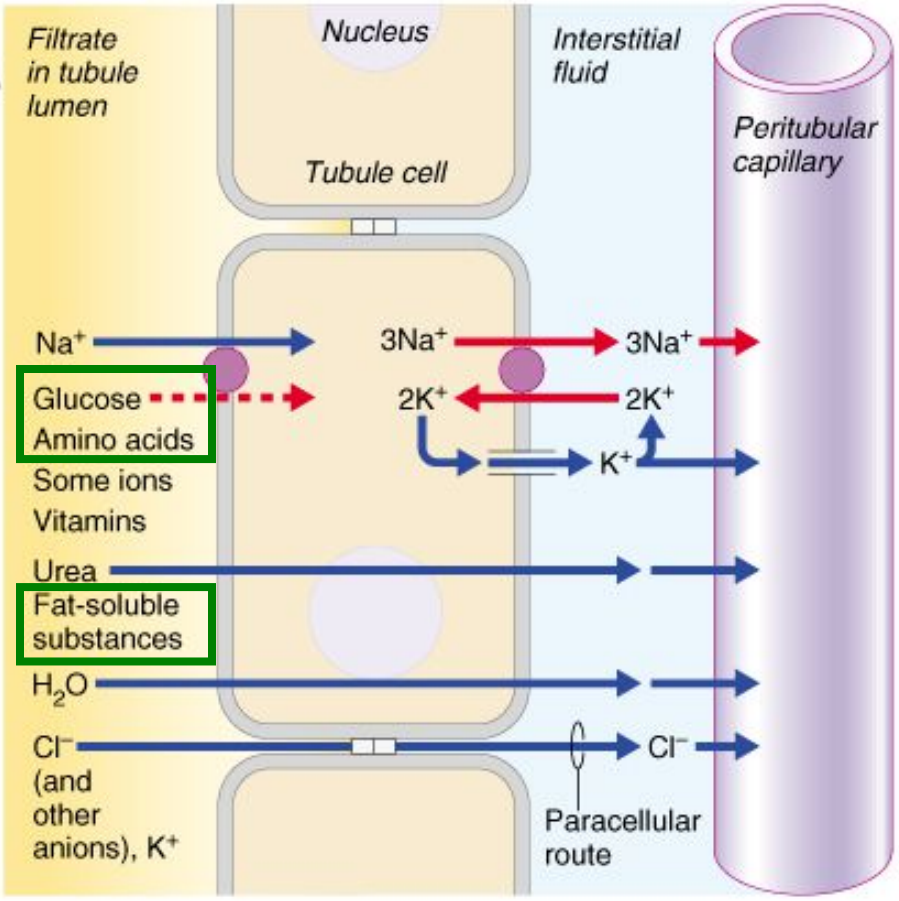
Tubular Reabsorption

Substances move from the tubule lumen into peritubular capillaries

- All organic nutrients are reabsorbed
- Water & ion reabsorption is hormonally controlled (ADH & aldosterone)

Reabsorption by PCT cells



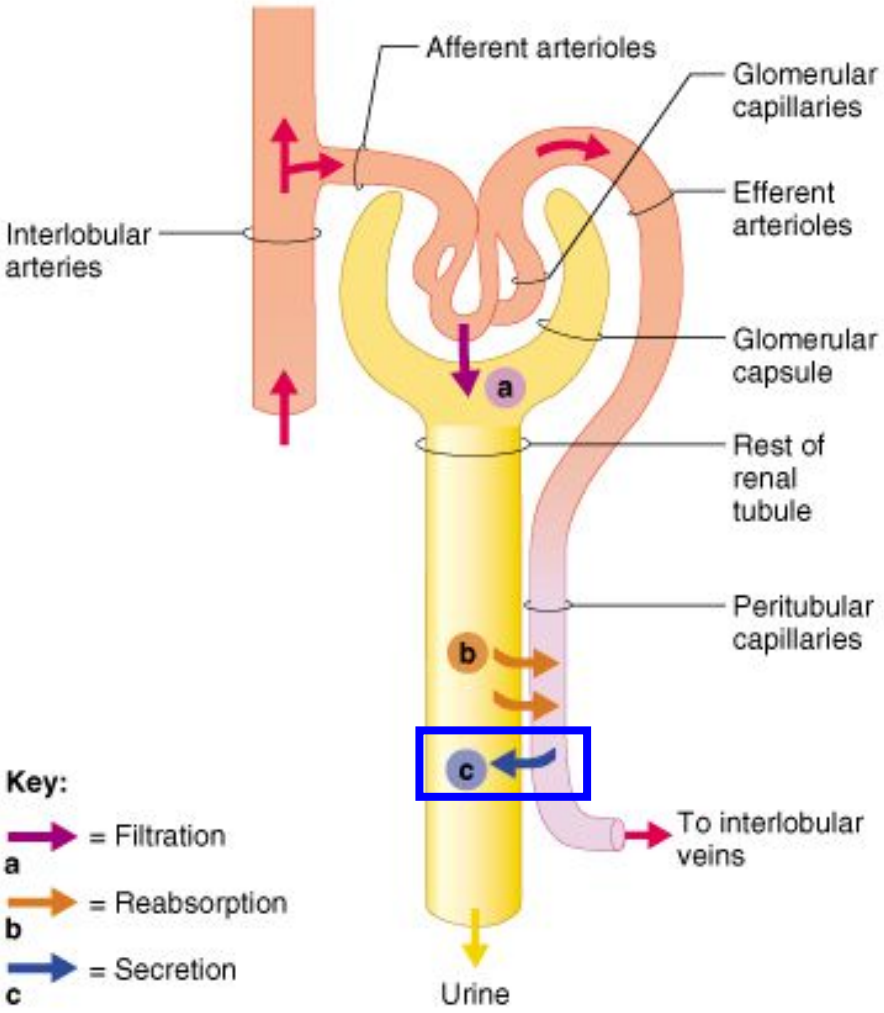


Key:

- = Primary active transport
- = Secondary active transport
- = Passive transport (diffusion)
- = Protein carrier
- = Ion channel

Tubular Secretion

- Substances move from peritubular capillaries (or tubule cells) into filtrate



Tubular Secretion

- Substances move from peritubular capillaries (or tubule cells) into filtrate
- Active transport

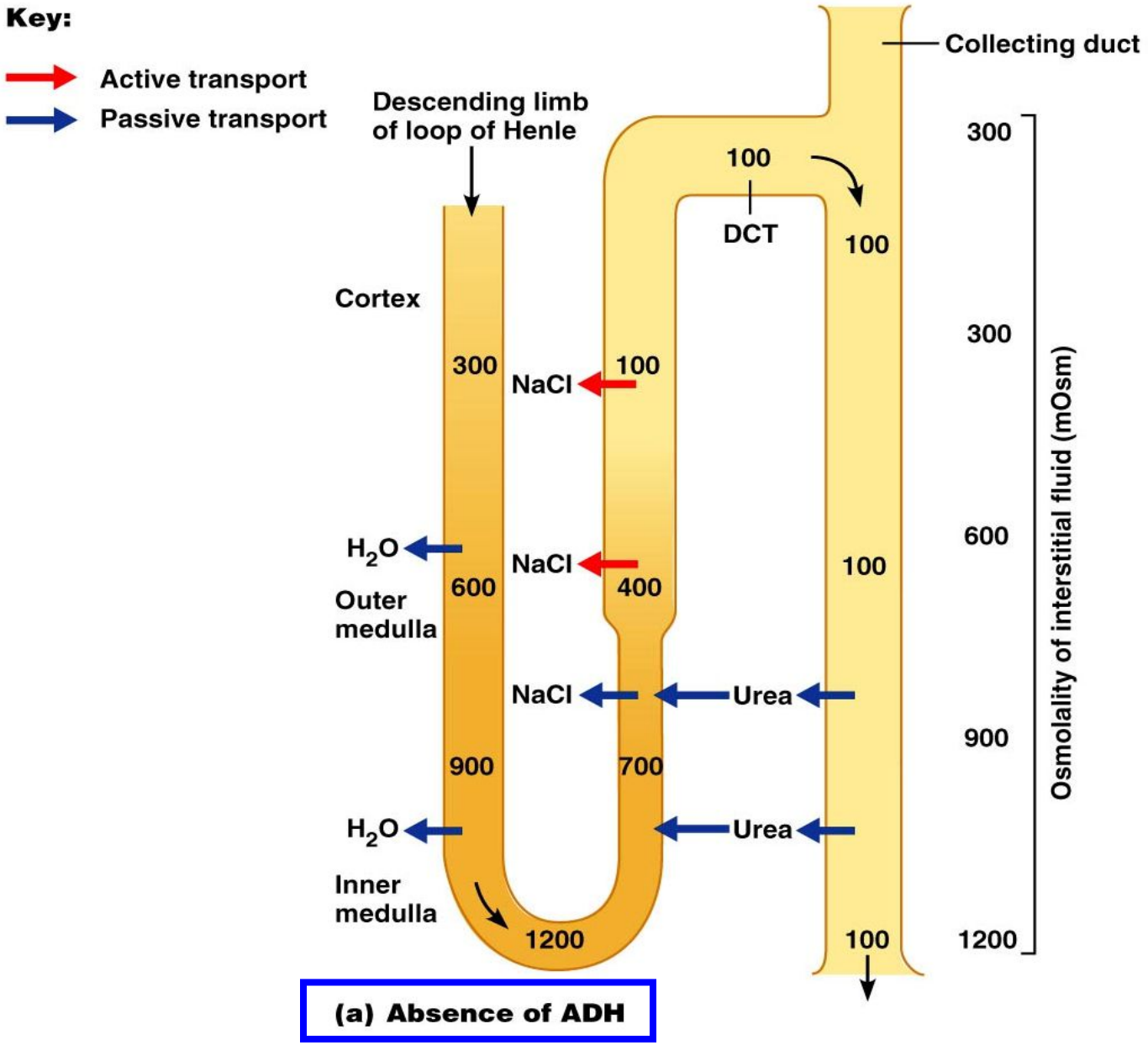
- Important for:
  - Disposing of substances not already in filtrate
  - Eliminating undesirable substances such as urea
  - Removing H^+ ion to control blood pH
  - Ridding the body of excess K^+ ions (mainly at collecting duct)

Urine Concentration

- Filtrate is diluted in ascending loop of Henle
- **Dilute urine is created** if antidiuretic hormone (ADH) is not being secreted
- Without ADH, collecting ducts (in deep medullary regions) remain impermeable to water

  → No further water reabsorption occurs

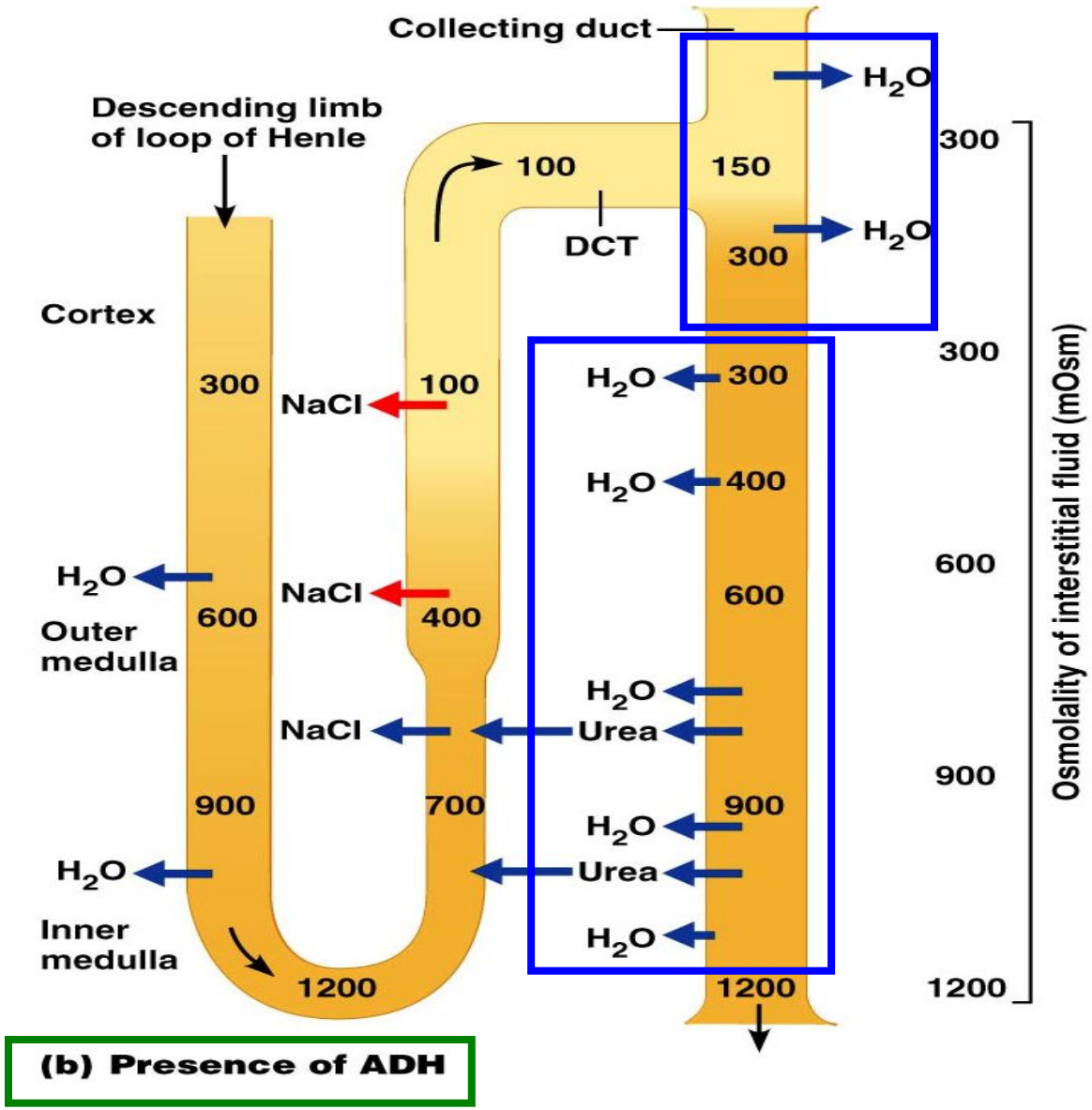
Urine Concentration



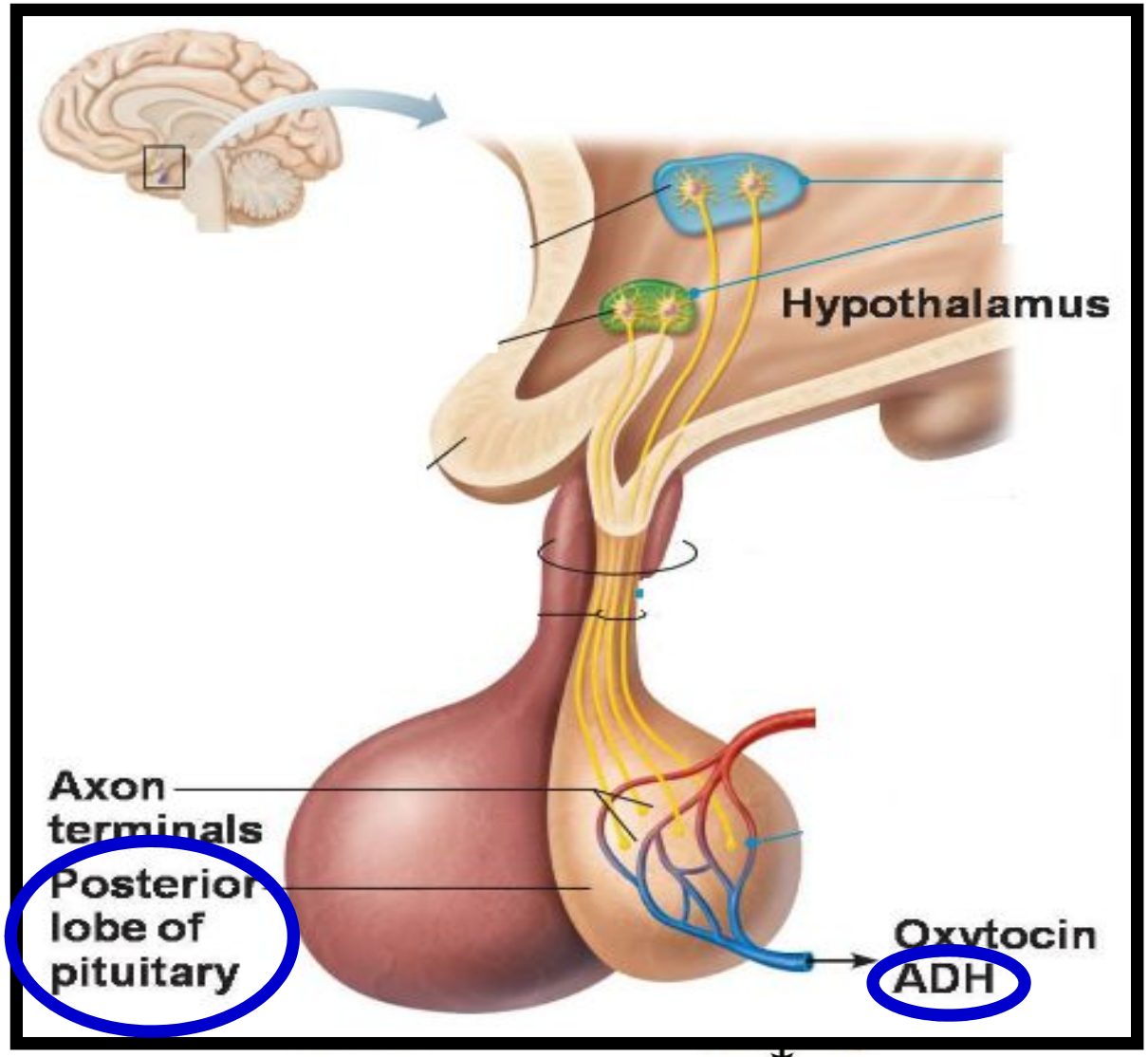
Urine Concentration

- Antidiuretic hormone (ADH) inhibits urine output
- ADH is the signal to **produce concentrated urine**
- ADH increases no. of water-filled channels of collecting ducts, so that water passes easily into interstitial space

Urine Concentration



Urine Concentration



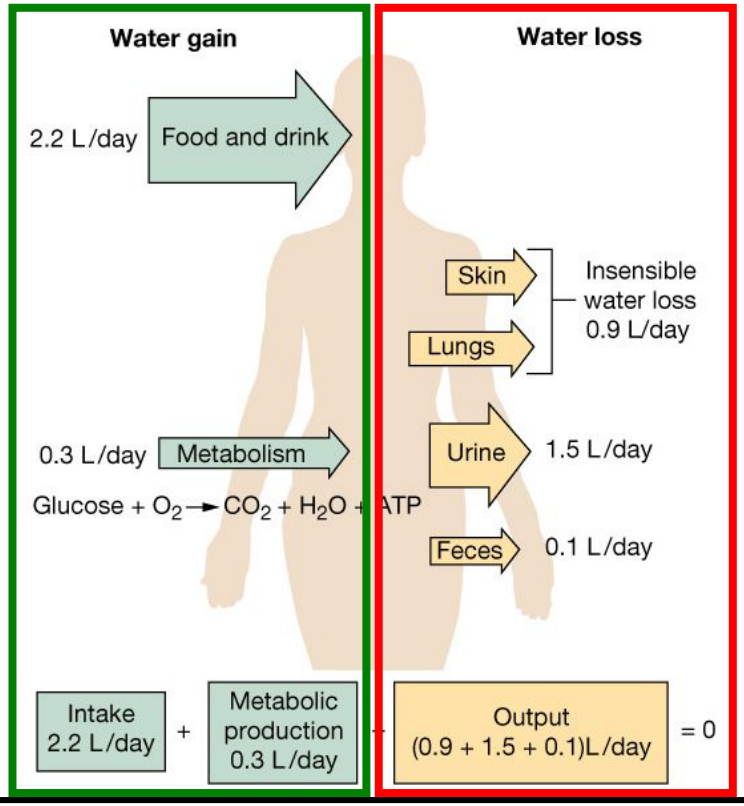
(b) Presence of ADH

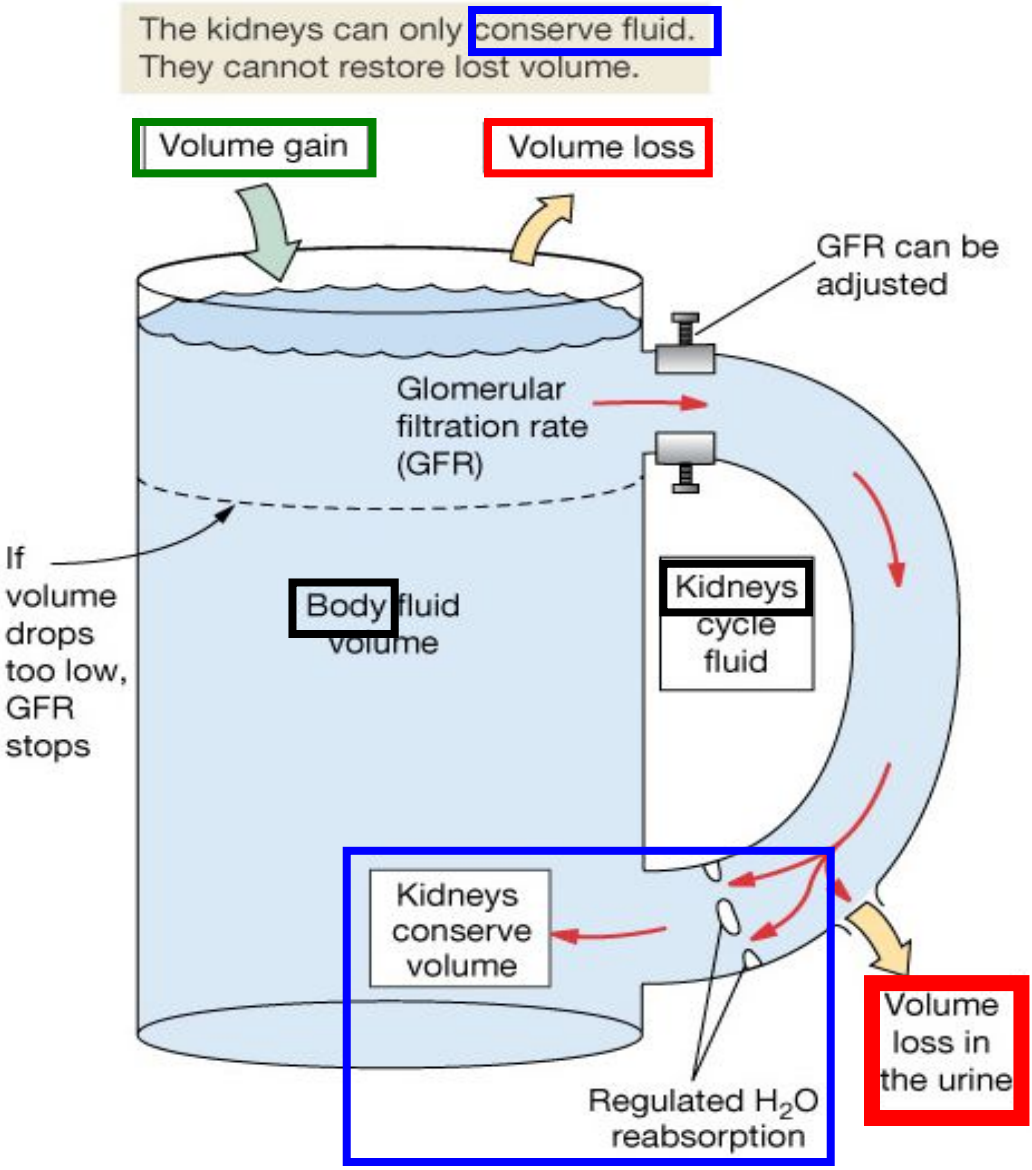
Water Balance in the Body

Water intake: drinking & eating

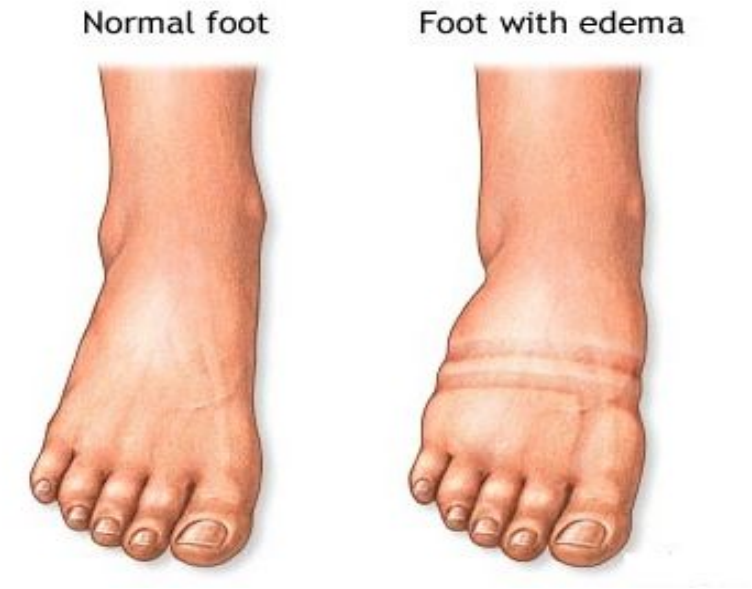
Water loss: urine, feces, sweat, expiration

Kidney conserves water, such that gain = loss





Water Balance in the Body



The kidneys can only conserve fluid.
They cannot restore lost volume.

Volume gain

Volume loss

GFR can be adjusted

Glomerular filtration rate (GFR)

If volume drops too low, GFR stops

Body fluid volume

Kidneys cycle fluid

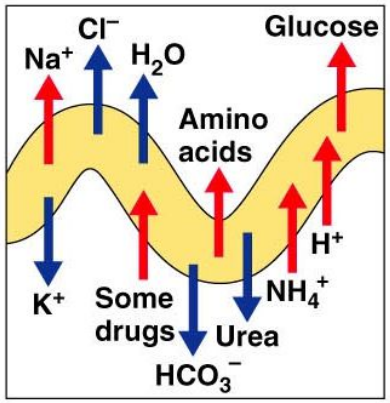
Renal Failure

Kidneys conserve volume

Volume loss in the urine

Regulated H_2O reabsorption

Summary of Nephron Function



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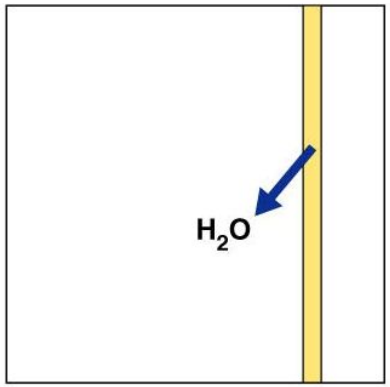

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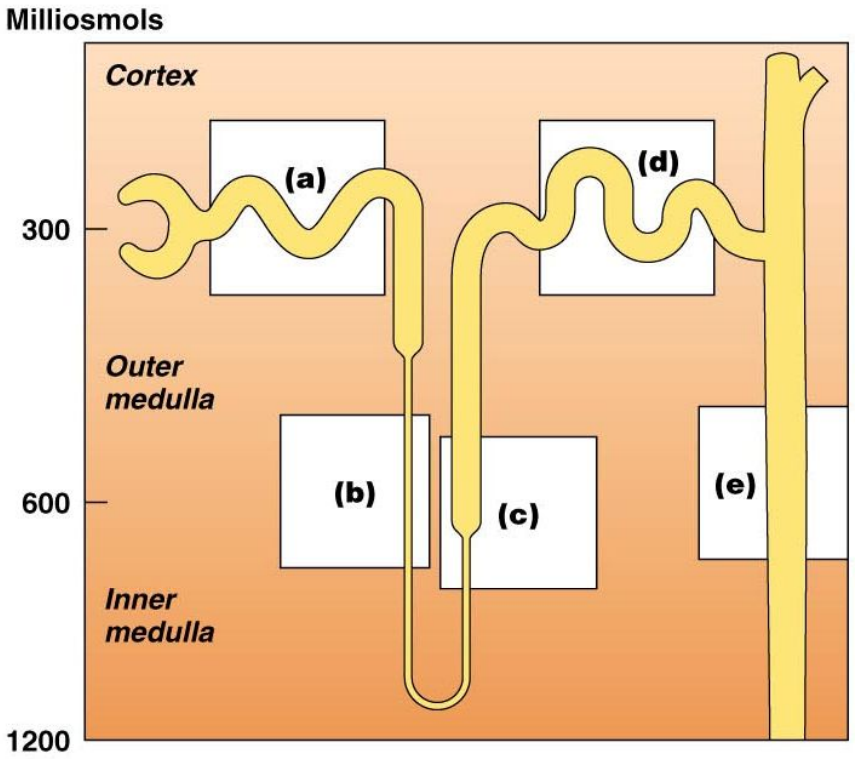

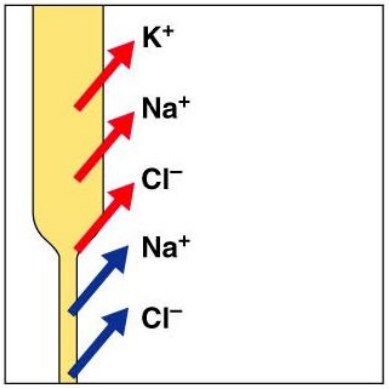

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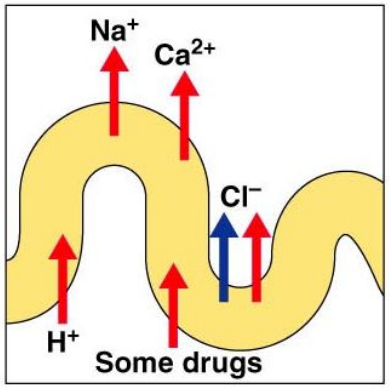

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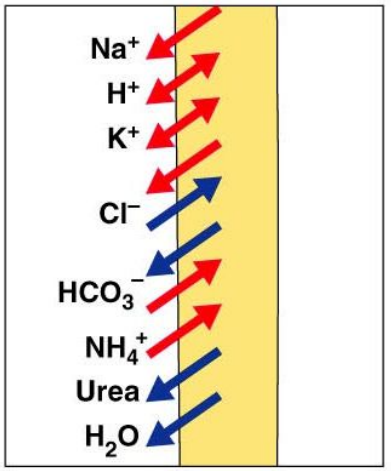

(e)

Key:

= Active transport (primary or secondary)

= Passive transport

Key Points

Functions of the Kidneys

Nephron

- Renal corpuscle
  - Glomerulus
  - Bowman's capsule
- Renal tubule
- Capillary beds of nephron

Mechanism of Urine Formation

- Glomerular filtration
  - Filtration membrane
  - Glomerular filtration rate (GFR)
- Tubular reabsorption
- Tubular secretion