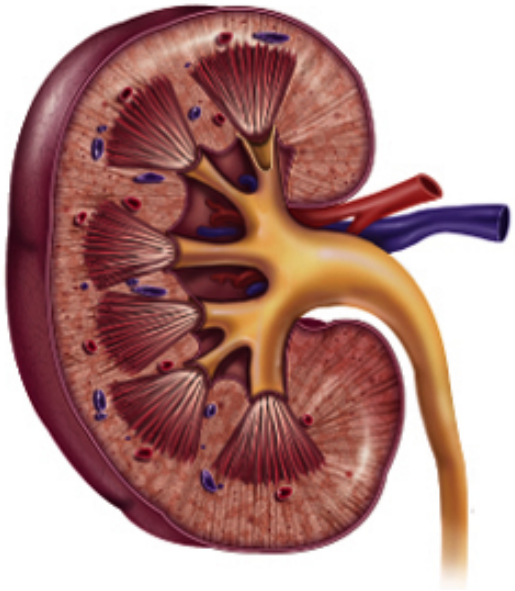
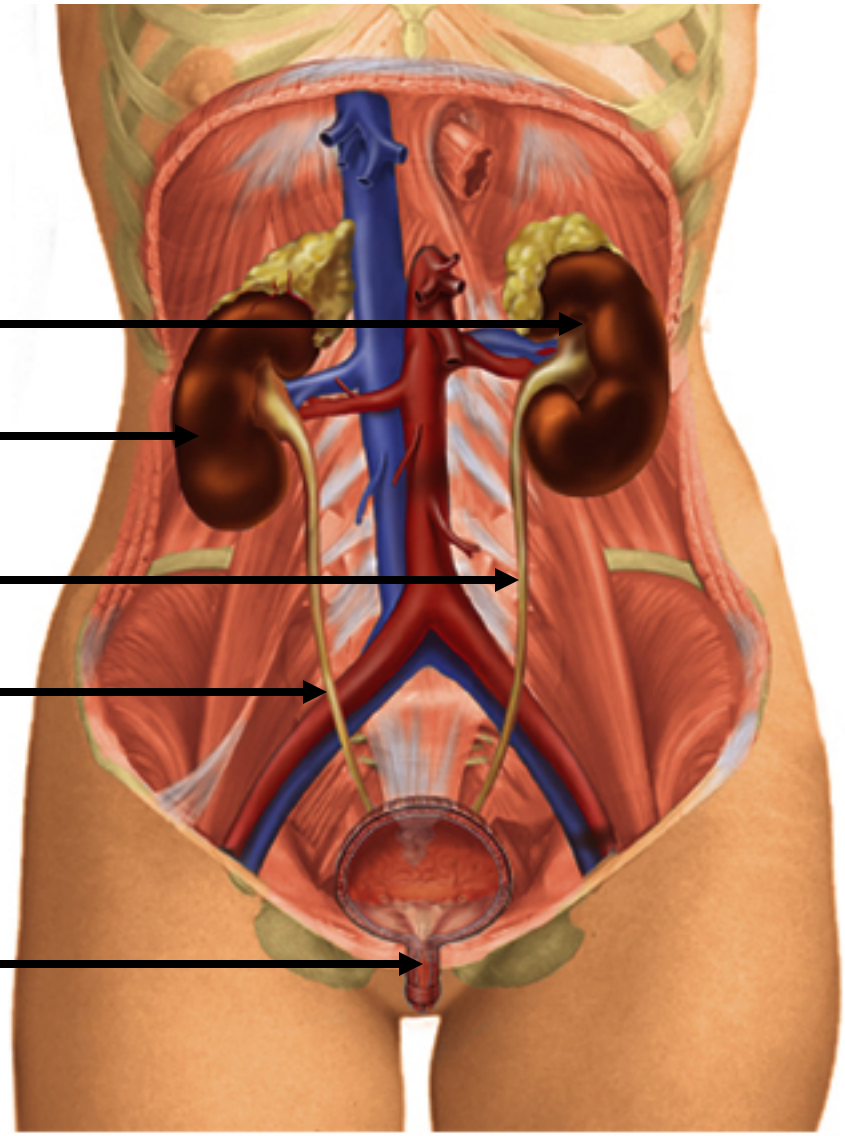
The Urinary System

- Functions of the urinary system
- Anatomy of the kidney
- Urine formation
  - glomerular filtration
  - tubular reabsorption
  - water conservation
- Urine and renal function tests
- Urine storage and elimination



Urinary System

- Two kidneys
- Two ureters
- Urethra

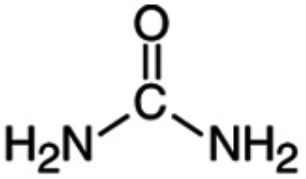


Kidney Functions

- Filters blood plasma, eliminates waste, returns useful chemicals to blood
- Regulates blood volume and pressure
- Regulates osmolarity of body fluids
- Secretes renin, activates angiotensin, aldosterone
  - controls BP, electrolyte balance
- Secretes erythropoietin, controls RBC count
- Regulates P_{CO_2} and acid base balance
- Detoxifies free radicals and drugs
- Gluconeogenesis

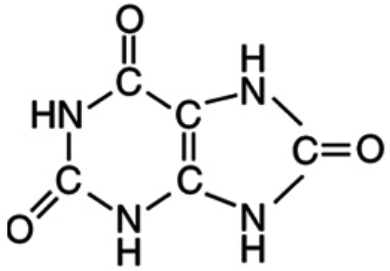
Nitrogenous Wastes

- Urea
  - proteins→amino acids →NH_2 removed →forms ammonia, liver converts to urea



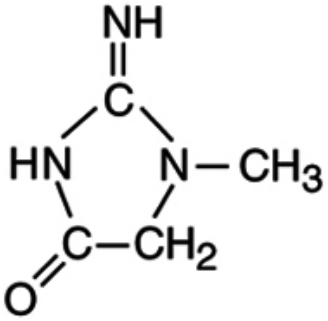
Urea

- Uric acid
  - nucleic acid catabolism



Uric acid

- Creatinine
  - creatinine phosphate catabolism



Creatinine

- Renal failure
  - azotemia: nitrogenous wastes in blood
  - uremia: toxic effects as wastes accumulate

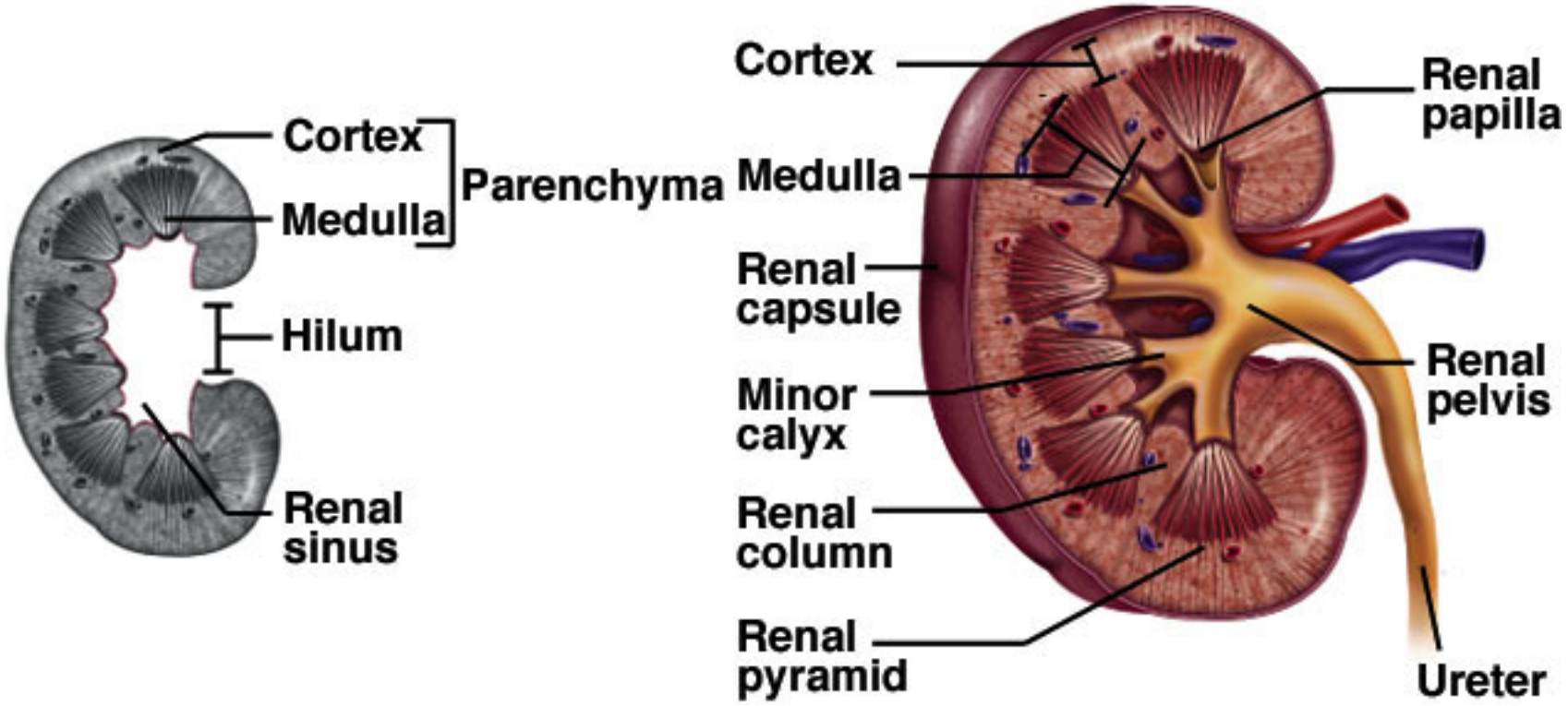
Excretion

- Separation of wastes from body fluids and eliminating them
  - **respiratory** system: CO_2
  - **integumentary** system: water, salts, lactic acid, urea
  - **digestive** system: water, salts, CO_2, lipids, bile pigments, cholesterol
  - **urinary** system: many metabolic wastes, toxins, drugs, hormones, salts, H^+ and water

Anatomy of Kidney

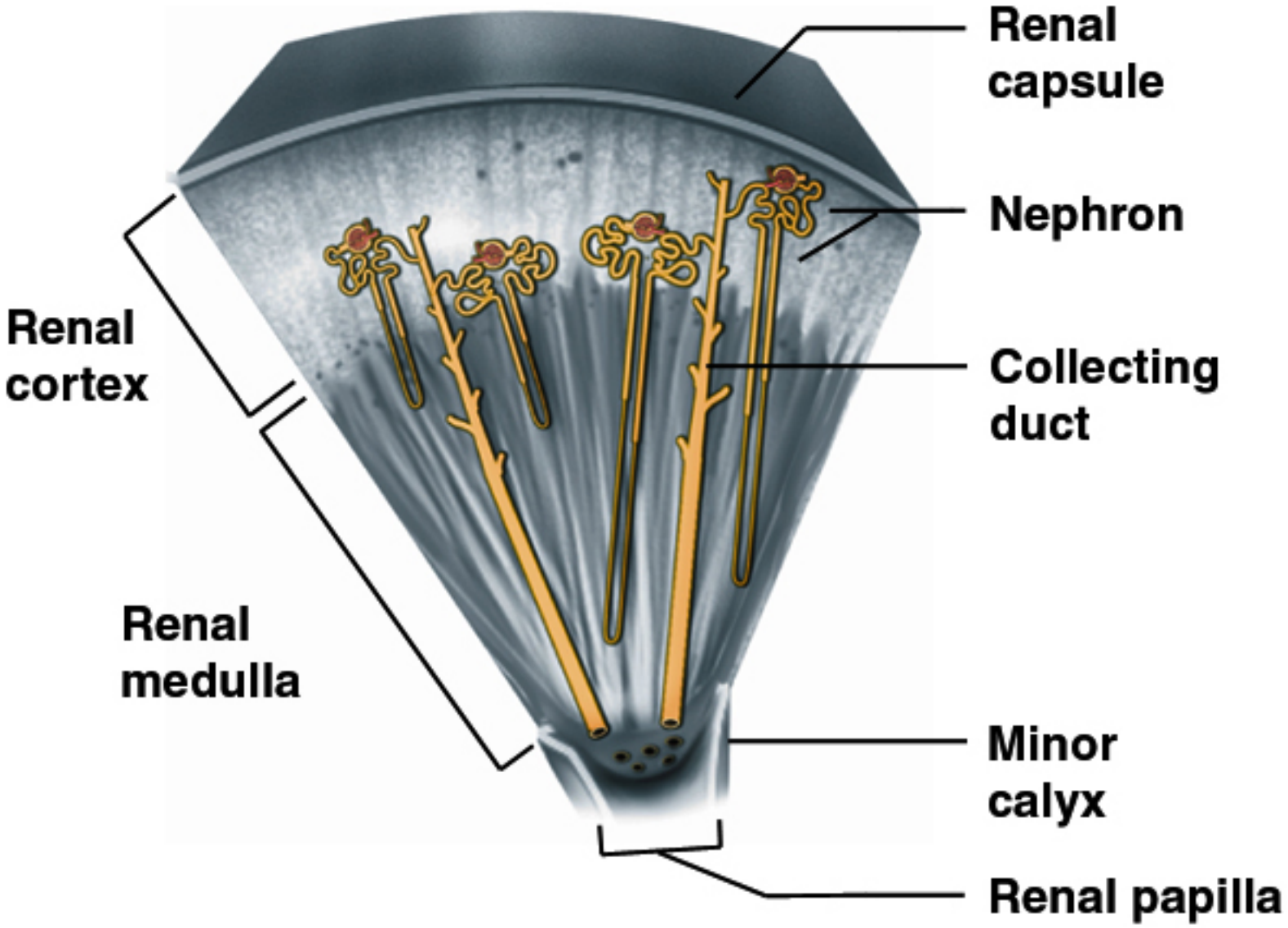
- Position, weight and size
  - retroperitoneal, level of T12 to L3
  - about 160 g each
  - about size of a bar of soap (12x6x3 cm)
- Shape
  - lateral surface - convex; medial - concave
- CT coverings
  - renal fascia: binds to abdominal wall
  - adipose capsule: cushions kidney
  - renal capsule: encloses kidney like cellophane wrap

Anatomy of Kidney

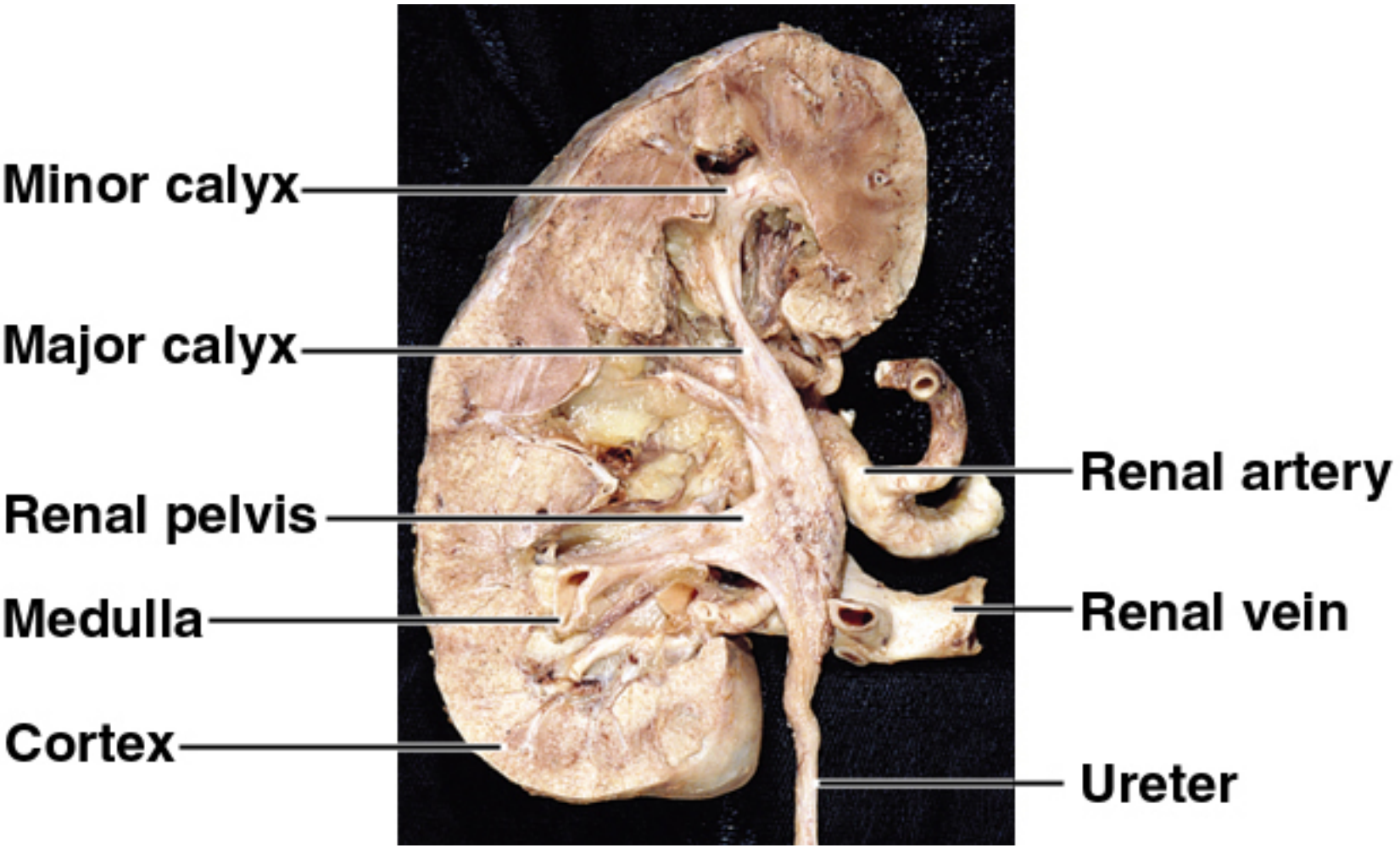


- Renal cortex: outer 1 cm
- Renal medulla: renal columns, pyramids - papilla
- Lobe of kidney: pyramid and it's overlying cortex

Lobe of Kidney



Kidney: Frontal Section

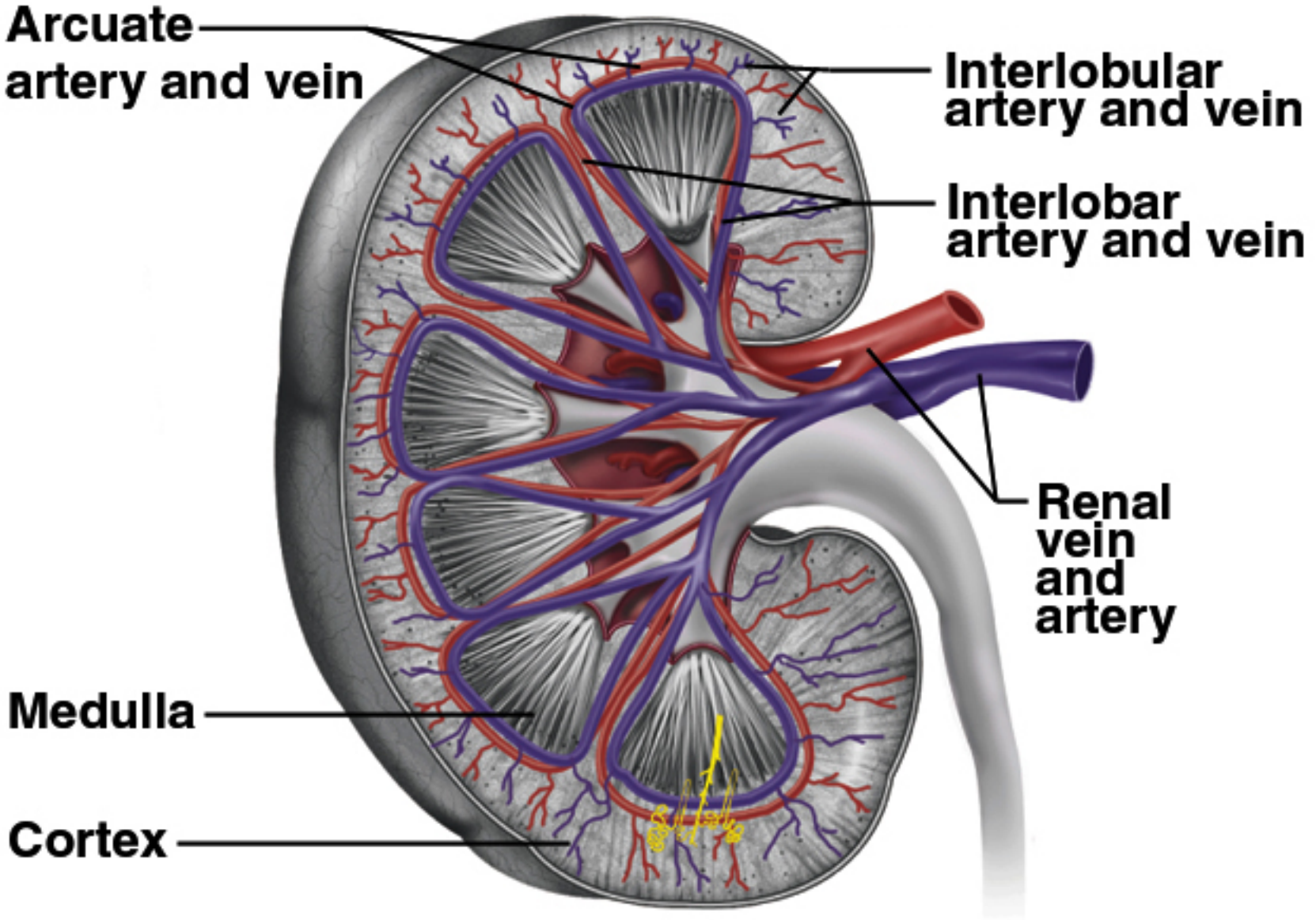


- Minor calyx: cup over papilla collects urine

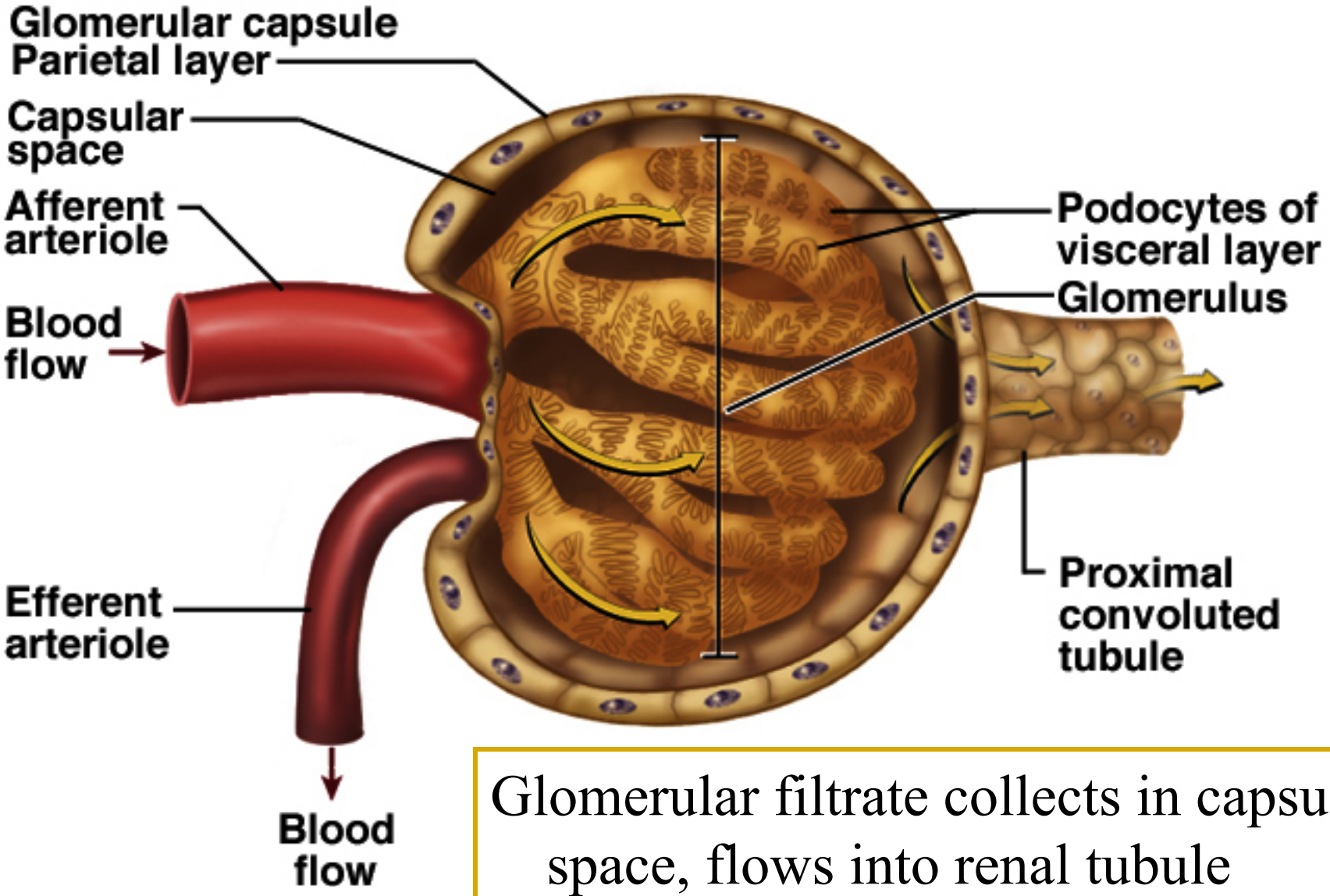
Path of Blood Through Kidney

- Renal artery
  → interlobar arteries **(up renal columns, between lobes)**
  → arcuate arteries (over pyramids)
  → interlobular arteries (up into cortex)
  → afferent arterioles
  → glomerulus (cluster of capillaries)
  → efferent arterioles (near medulla → vasa recta)
  → peritubular capillaries
  → interlobular veins → arcuate veins → interlobar veins
- Renal vein

Blood Supply Diagram



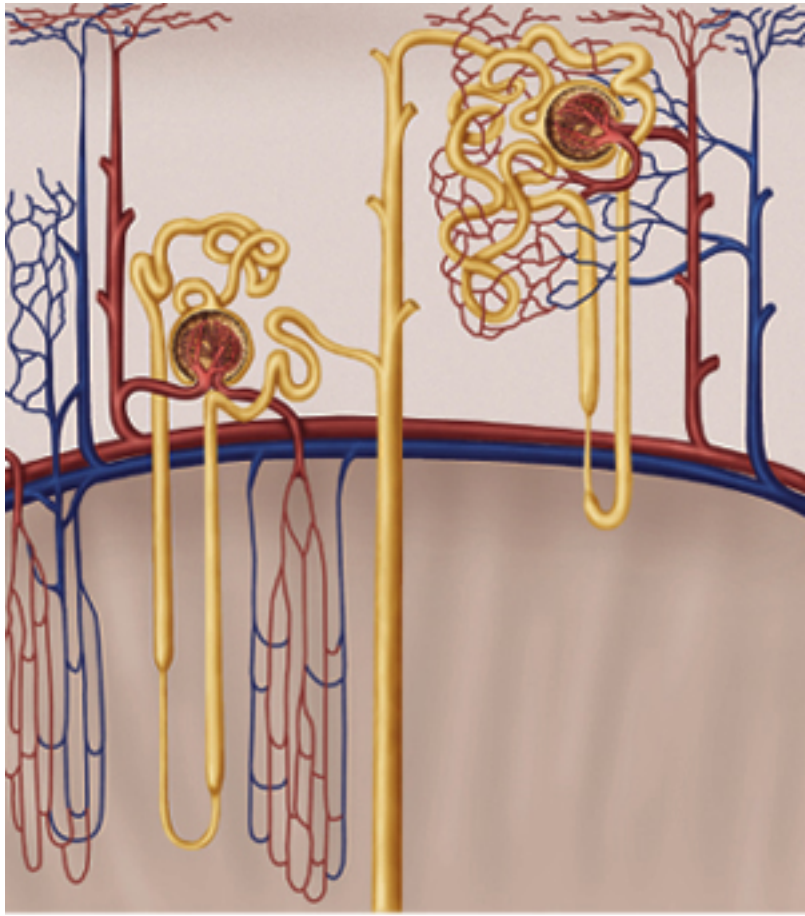
Renal Corpuscle



Glomerular filtrate collects in capsular space, flows into renal tubule

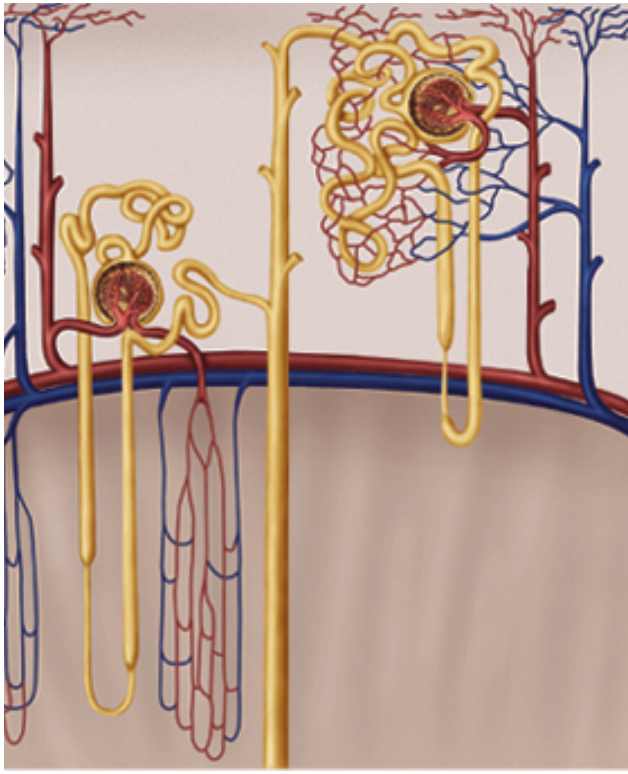
Renal (Uriniferous) Tubule

- Proximal convoluted tubule (PCT)
  - longest, most coiled, simple cuboidal with brush border
- Nephron loop - U shaped; descending + ascending limbs
  - **thick segment** (simple cuboidal) initial part of descending limb and part or all of ascending limb, active transport of salts
  - **thin segment** (simple squamous) very water permeable
- Distal convoluted tubule (DCT)
  - cuboidal, minimal microvilli

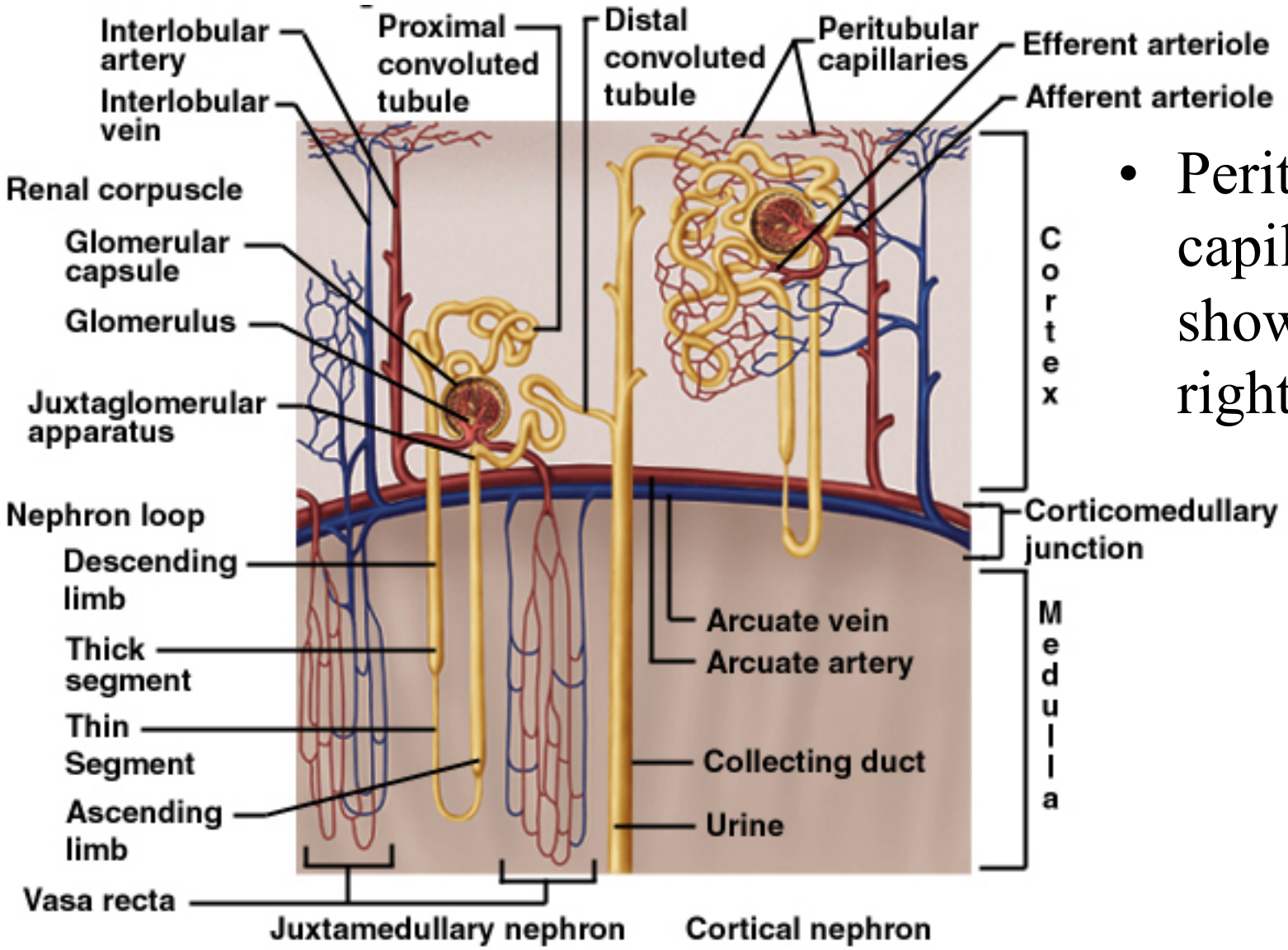


Renal (Uriniferous) Tubule 2

- Juxtaglomerular apparatus: DCT, afferent, efferent arterioles
- Collecting duct: several DCT's join
- Flow of glomerular filtrate:
  - glomerular capsule → PCT → nephron loop → DCT → collecting duct → papillary duct → minor calyx → major calyx → renal pelvis → ureter → urinary bladder → urethra

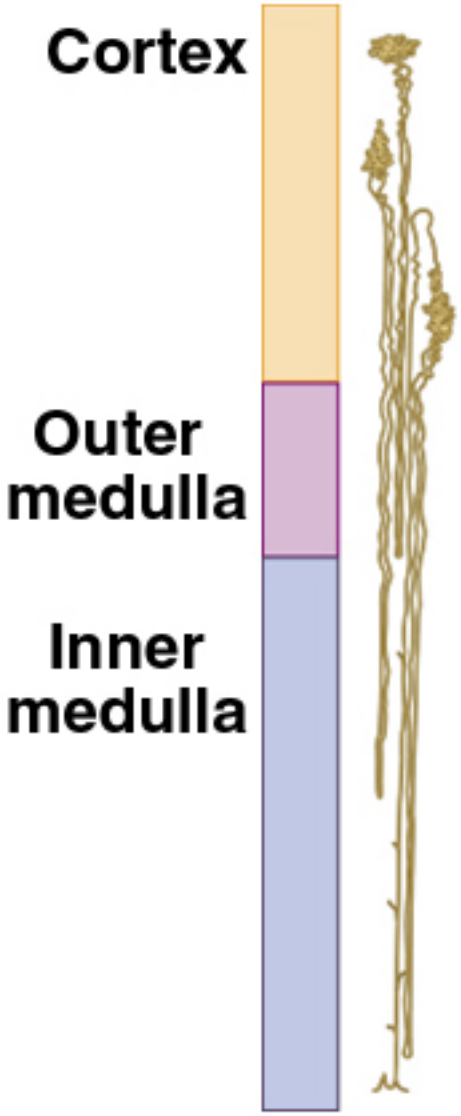


Nephron Diagram



- Peritubular capillaries shown only on right

Nephrons



- True proportions of nephron loops to convoluted tubules shown
- Cortical nephrons (85%)
  - short nephron loops
  - efferent arterioles branch off peritubular capillaries
- Juxtamedullary nephrons (15%)
  - very long nephron loops, maintain salt gradient, helps conserve water
  - efferent arterioles branch off vasa recta, blood supply for medulla

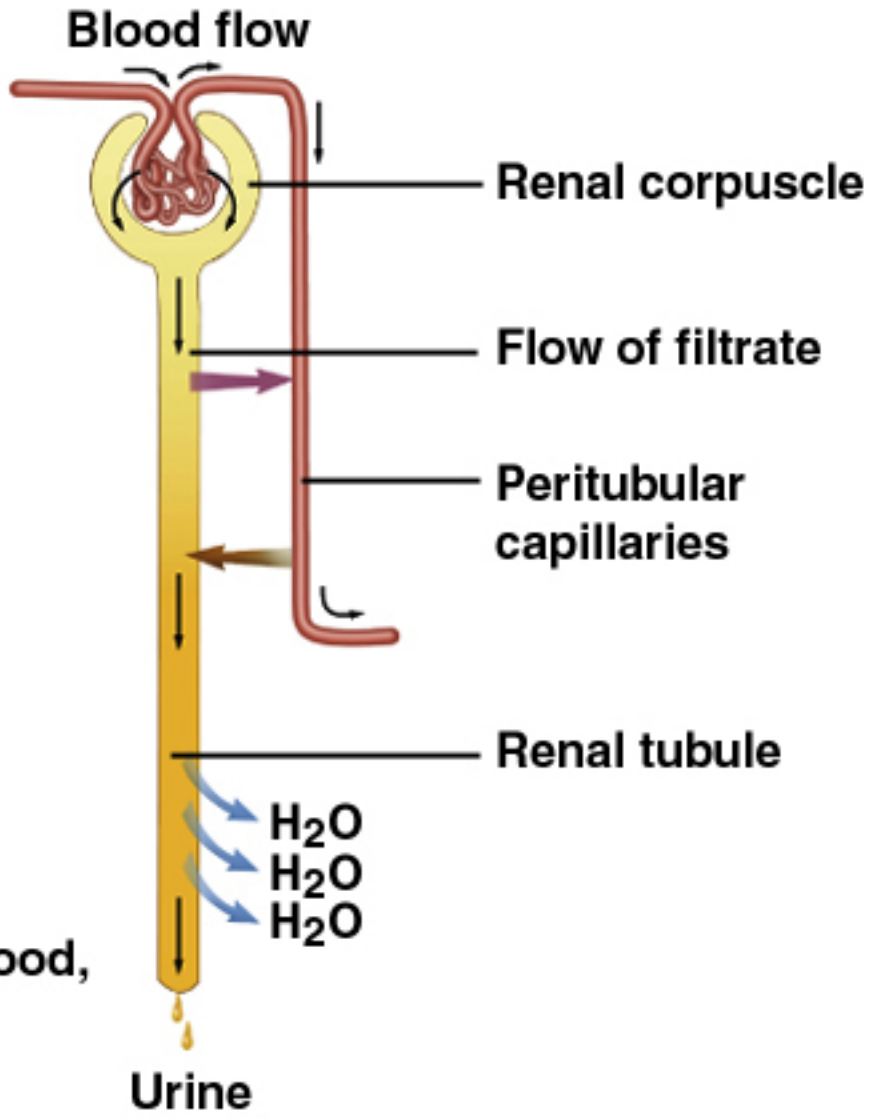
Urine Formation Preview

① **Glomerular filtration**
Creates a plasmalike filtrate of the blood

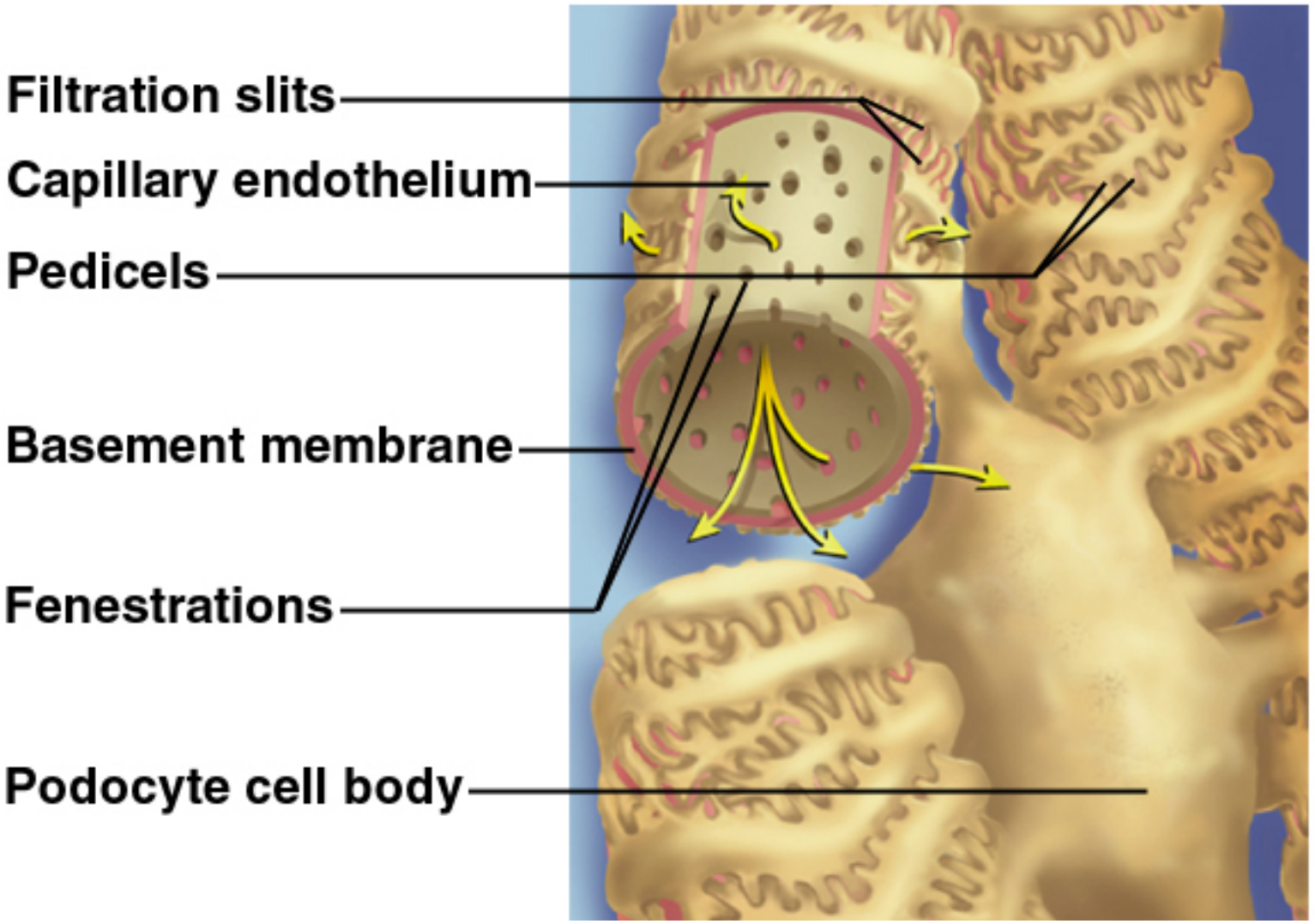
② **Tubular reabsorption**
Removes useful solutes from the filtrate, returns them to the blood

③ **Tubular secretion**
Removes additional wastes from the blood, adds them to the filtrate

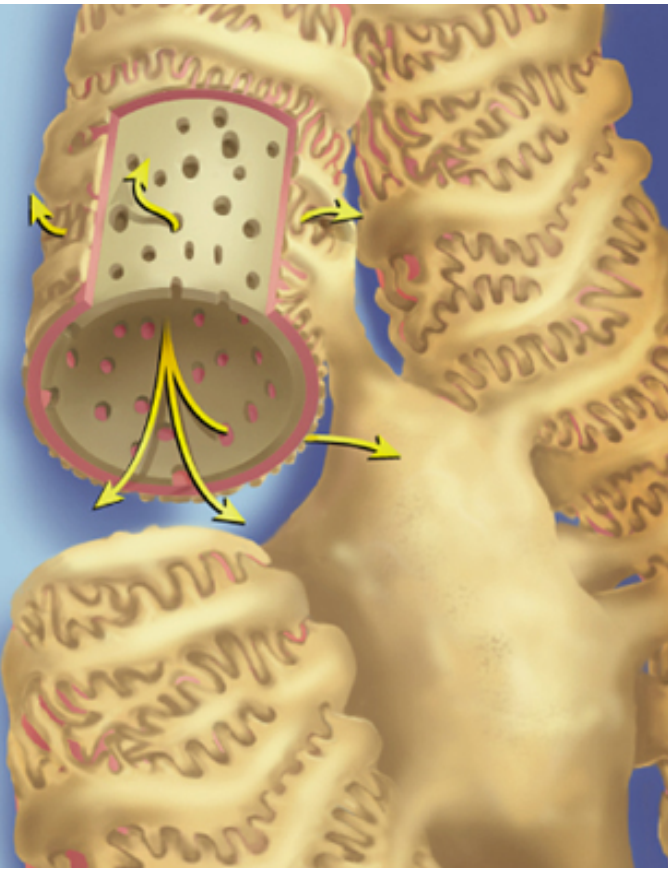
④ **Water conservation**
Removes water from the urine and returns it to blood, concentrates wastes



Filtration Membrane Diagram

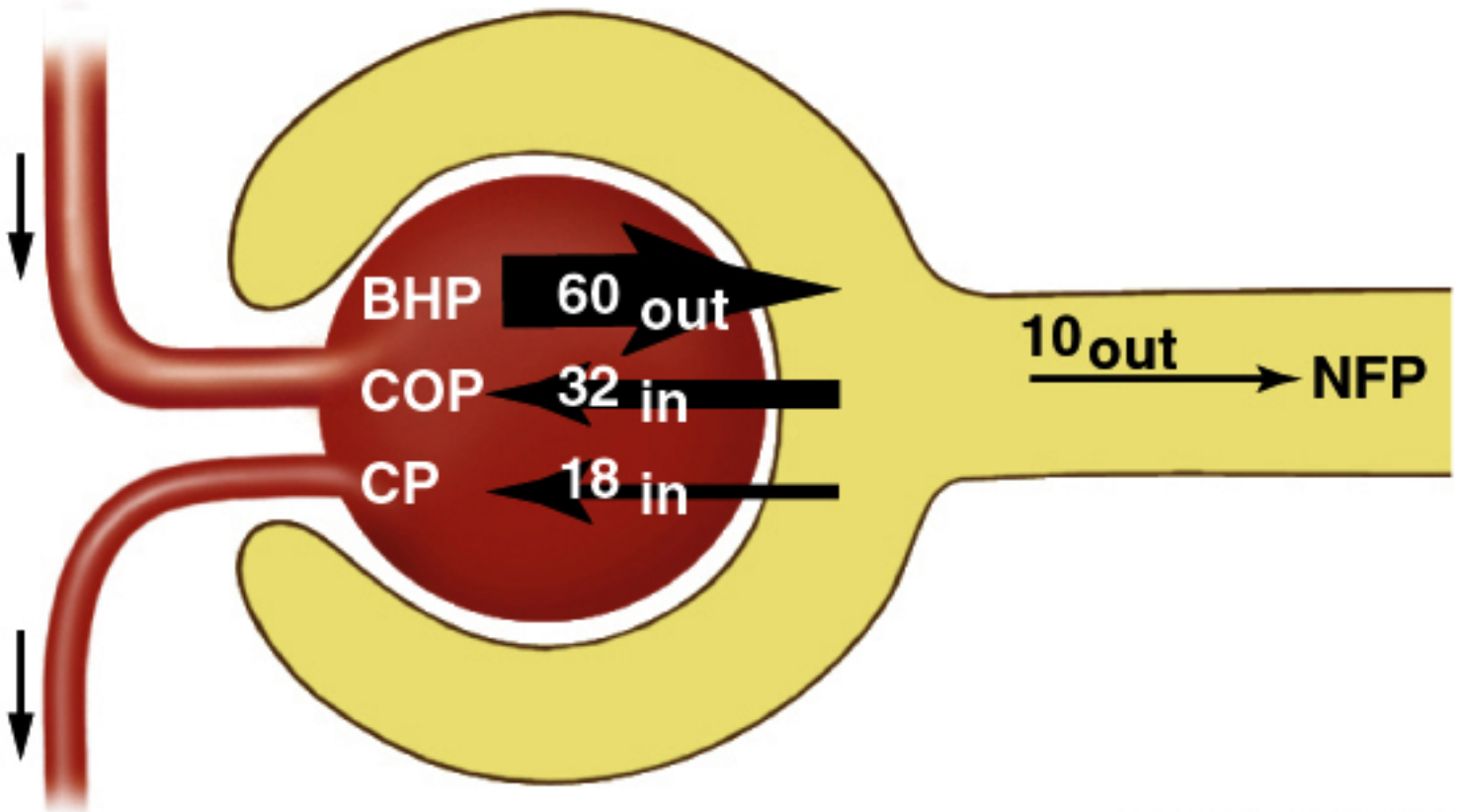


Filtration Membrane



- Fenestrated endothelium
  - 70-90nm pores exclude blood cells
- Basement membrane
  - proteoglycan gel, negative charge excludes molecules > 8nm
  - blood plasma 7% protein, glomerular filtrate 0.03%
- Filtration slits
  - podocyte arms have pedicels with negatively charged filtration slits, allow particles < 3nm to pass

Filtration Pressure



Blood hydrostatic pressure (BHP)	60 mmHg out
Colloid osmotic pressure (COP)	–32 mmHg in
Capsular pressure (CP)	–18 mmHg in
Net filtration pressure (NFP)	10 mmHg ou

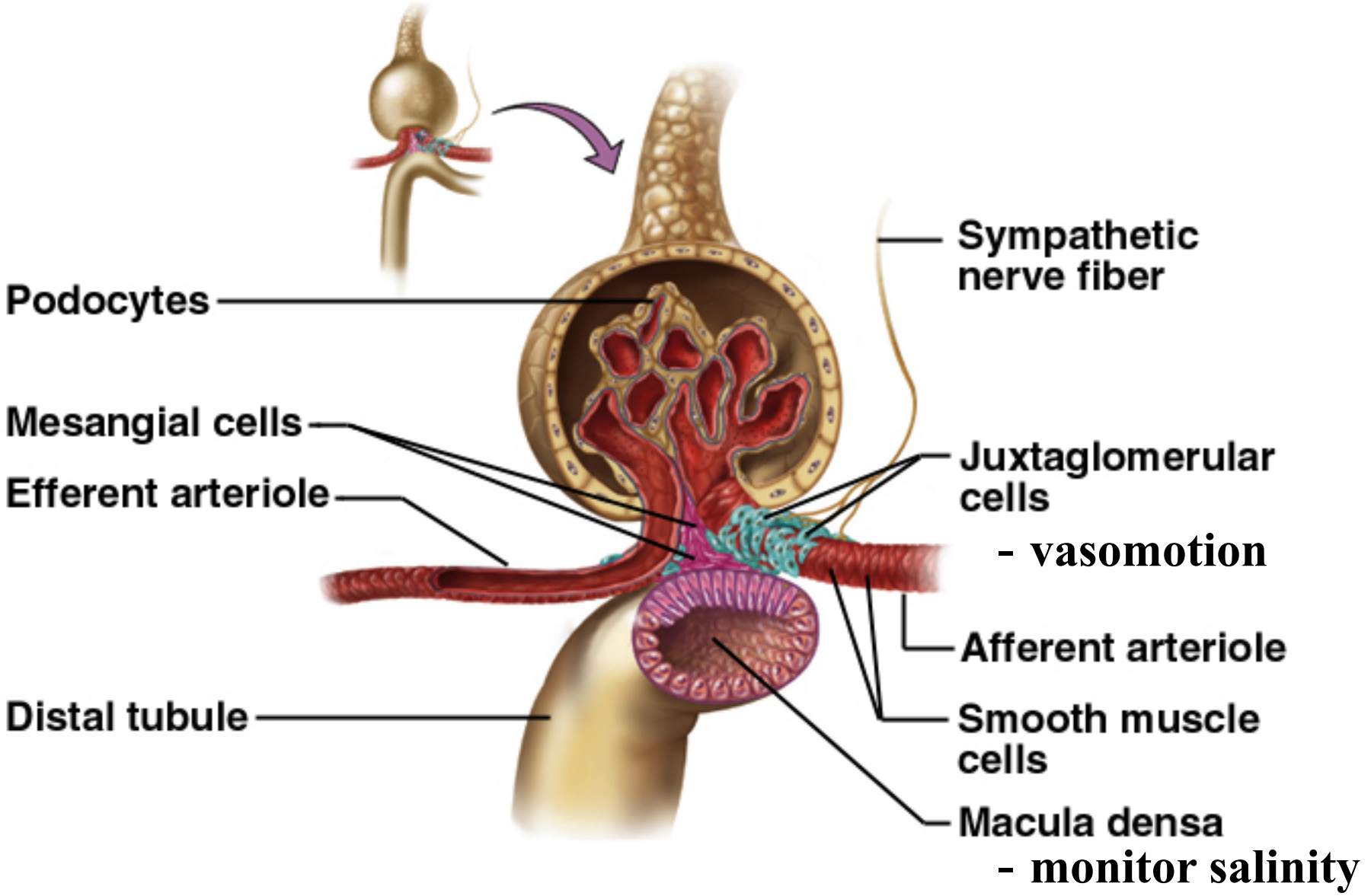
Glomerular Filtration Rate (GFR)

- Filtrate formed per minute
- Filtration coefficient (K_f) depends on permeability and surface area of filtration barrier
- GFR = NFP x K_f $\approx$ 125 ml/min or 180 L/day
- 99% of filtrate reabsorbed, 1 to 2 L urine excreted

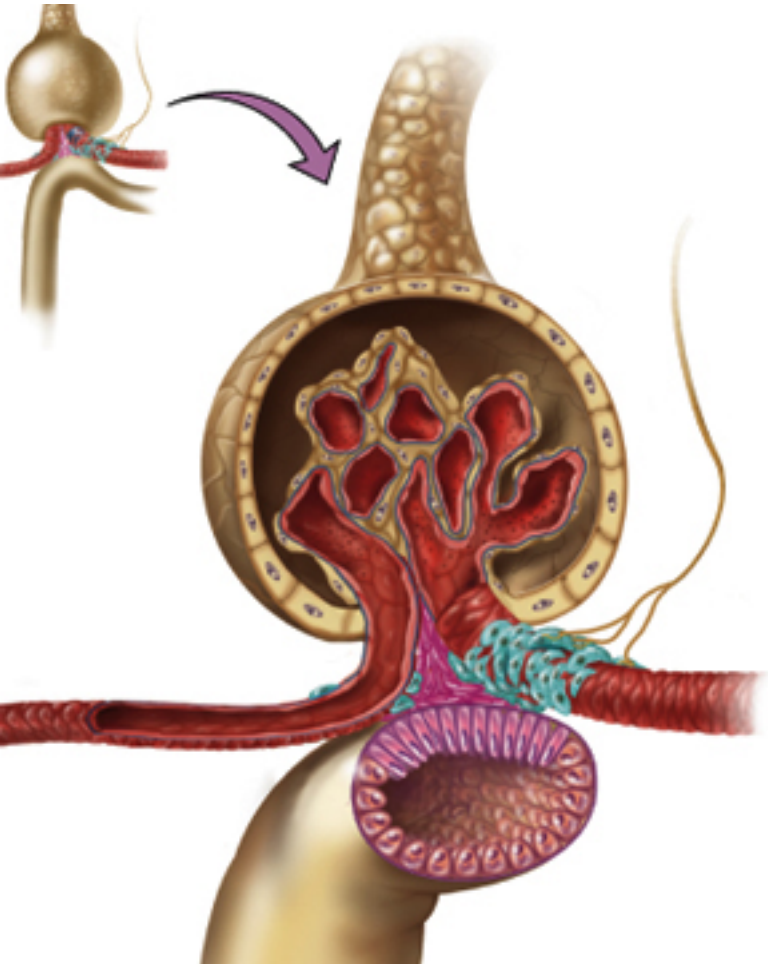
Effects of GFR Abnormalities

- ↑GFR, urine output rises → dehydration, electrolyte depletion
- ↓GFR → wastes reabsorbed (azotemia possible)
- GFR controlled by adjusting glomerular blood pressure
  - autoregulation
  - sympathetic control
  - hormonal mechanism: renin and angiotensin

Juxtaglomerular Apparatus

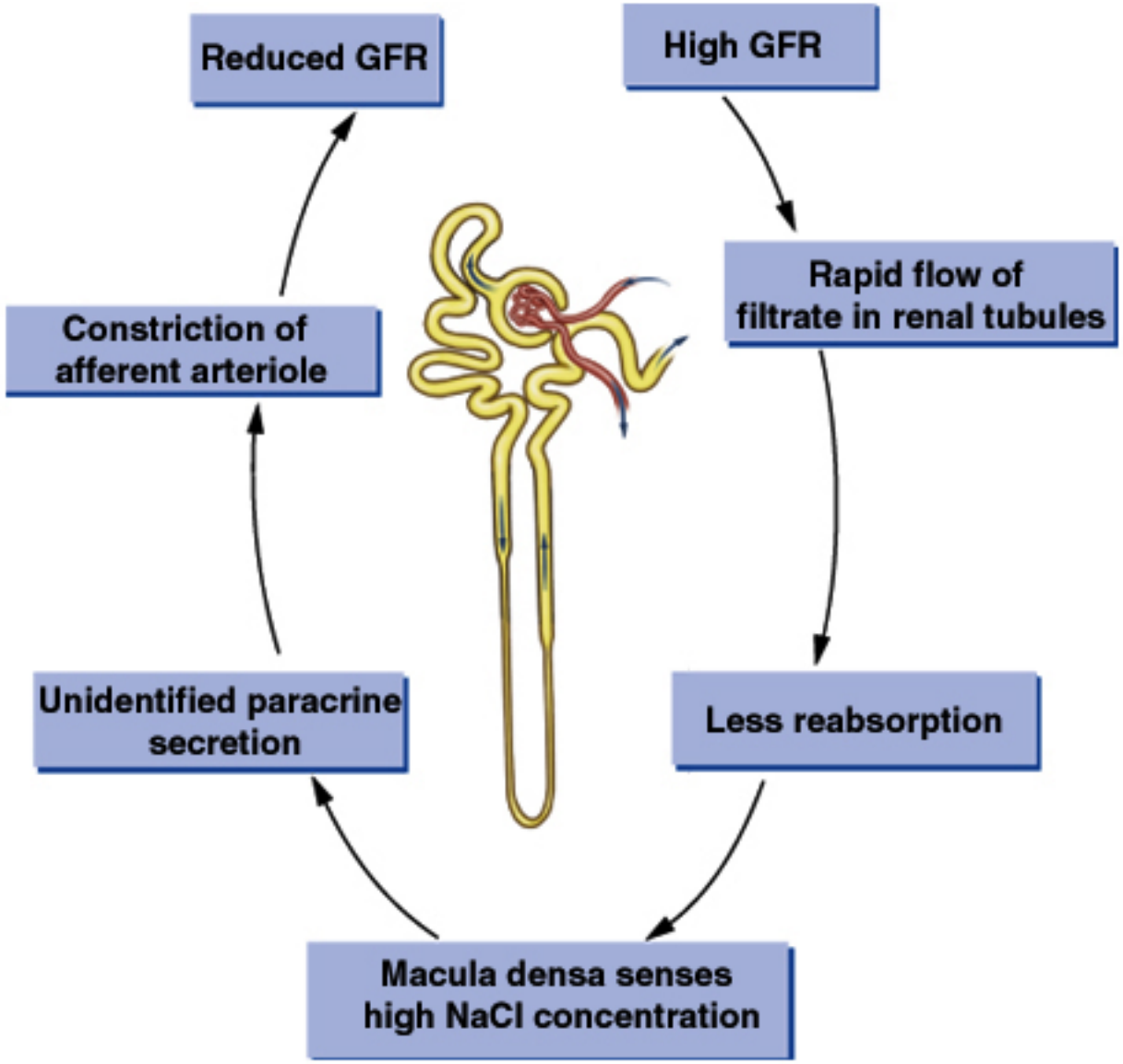


Renal Autoregulation of GFR



- ↑ BP → constrict afferent arteriole, dilate efferent
- ↓ BP → dilate afferent arteriole, constrict efferent
- Stable for BP range of 80 to 170 mmHg (systolic)
- Cannot compensate for extreme BP

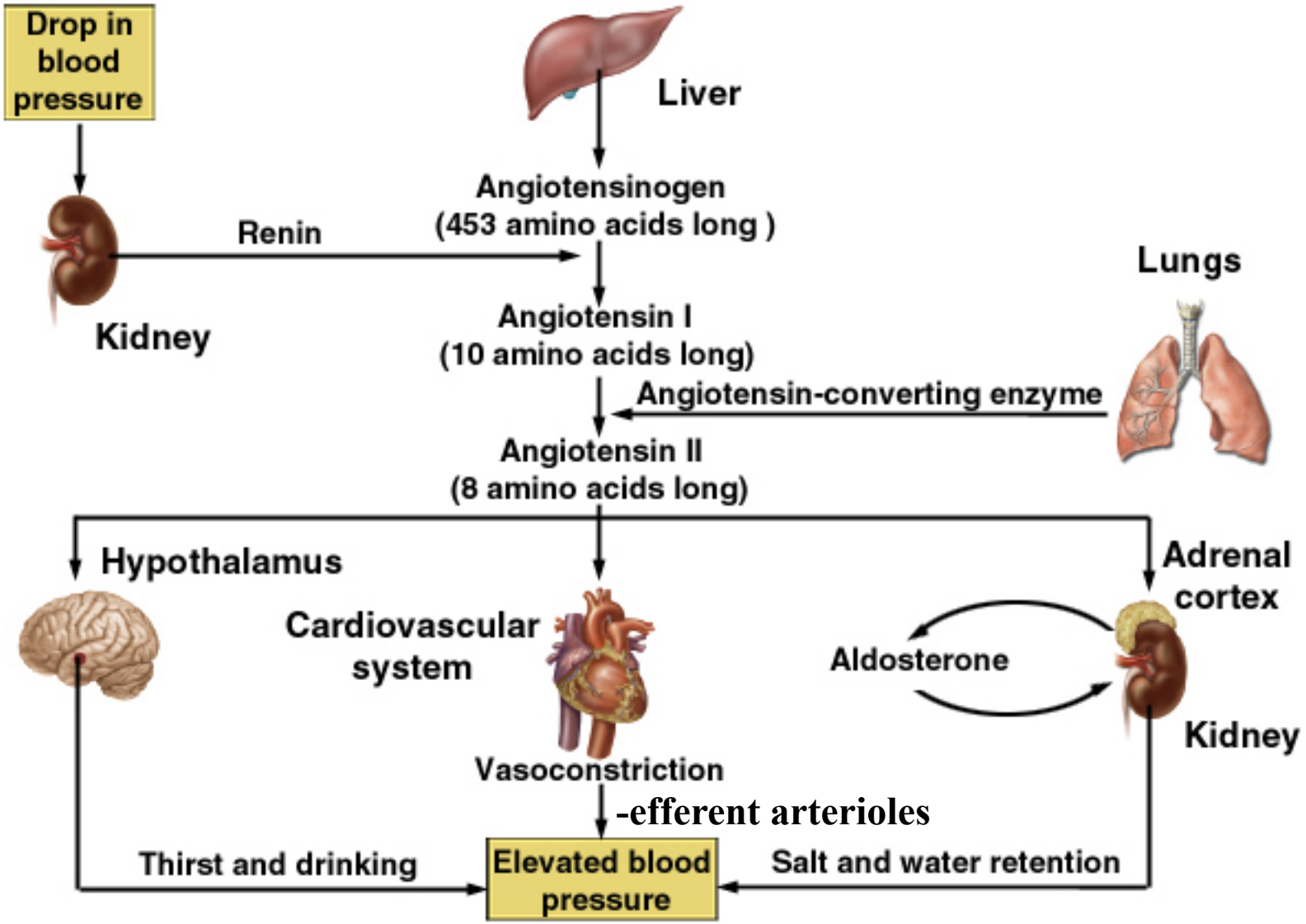
Negative Feedback Control of GFR



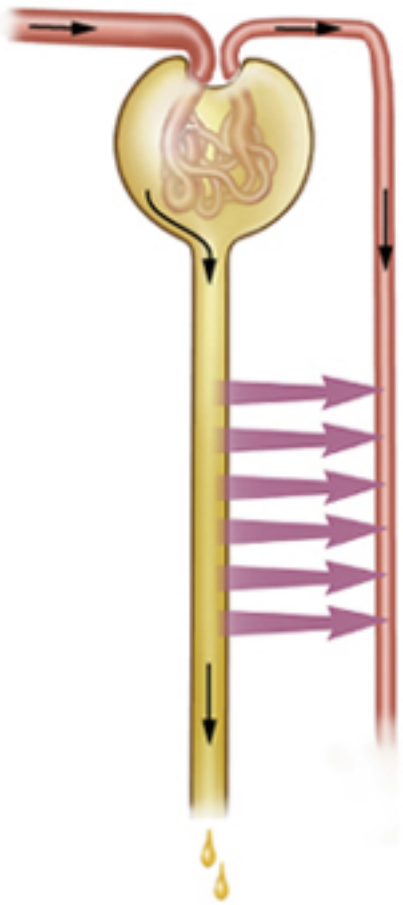
Sympathetic Control of GFR

- Strenuous exercise or acute conditions (circulatory shock) stimulate afferent arterioles to constrict
- ↓ GFR and urine production, redirecting blood flow to heart, brain and skeletal muscles

Hormonal Control of GFR



Effects of Angiotensin II



Angiotensin II → Causes constriction of efferent arteriole

↓

Increases glomerular blood pressure and filtration

and

Reduces blood pressure in peritubular capillary

↓

Reduces resistance to tubular reabsorption

↓

Tubular reabsorption increases

↓

Urine volume is less but concentration is high

Tubular Reabsorption and Secretion

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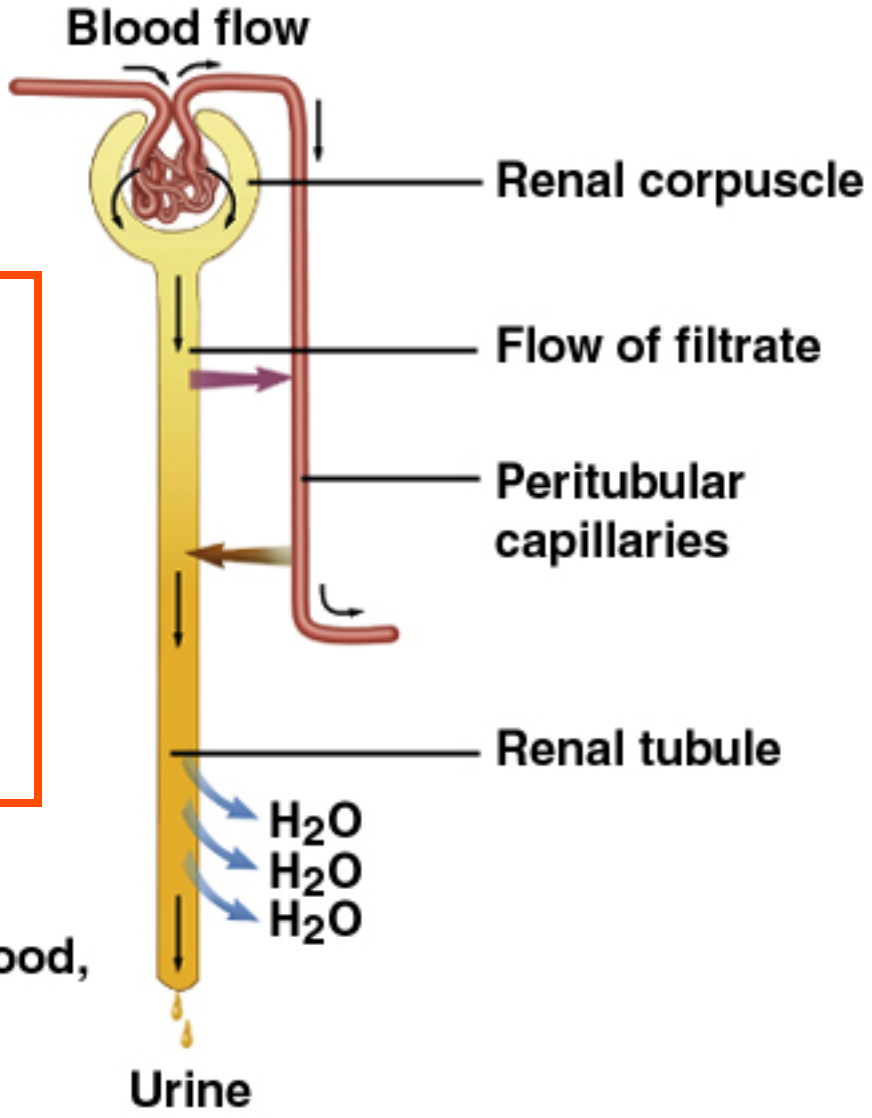
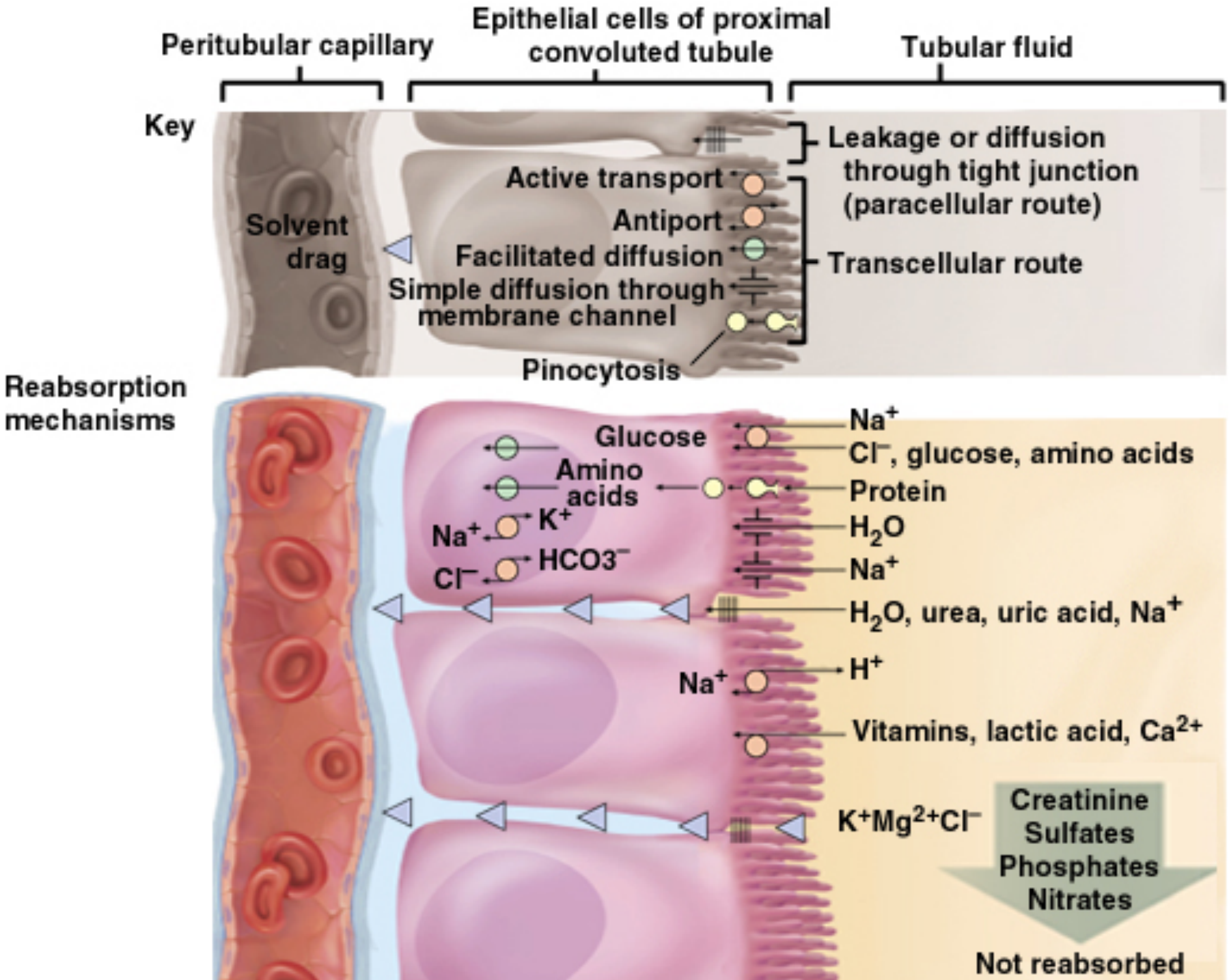


Peritubular Capillaries

- Blood has unusually high COP here, and BHP is only 8 mm Hg (or lower when constricted by angiotensin II); this favors reabsorption
- Water absorbed by osmosis and carries other solutes with it (solvent drag)

Proximal Convoluted Tubules (PCT)

- Reabsorbs 65% of GF to peritubular capillaries
- Great length, prominent microvilli and abundant mitochondria for active transport
- Reabsorbs greater variety of chemicals than other parts of nephron
  - transcellular route - through epithelial cells of PCT
  - paracellular route - between epithelial cells of PCT
- Transport maximum: when transport proteins of plasma membrane are saturated; glucose > 220 mg/dL remains in urine (glycosuria)


Peritubular capillary
Epithelial cells of proximal convoluted tubule
Tubular fluid
Key
Leakage or diffusion through tight junction (paracellular route)
Active transport
Antiport
Facilitated diffusion
Transcellular route
Solvent drag
Simple diffusion through membrane channel
Pinocytosis
Reabsorption mechanisms
Glucose
Amino acids
Na+
K+
Cl−
HCO3−
Na+
Cl−, glucose, amino acids
Protein
H2O
Na+
H2O, urea, uric acid, Na+
Na+
H+
Vitamins, lactic acid, Ca2+
K+Mg2+Cl−
Creatinine
Sulfates
Phosphates
Nitrates
Not reabsorbed

Tubular Secretion of PCT and Nephron Loop

- Waste removal
  - urea, uric acid, bile salts, ammonia, catecholamines, many drugs
- Acid-base balance
  - secretion of hydrogen and bicarbonate ions regulates pH of body fluids
- Primary function of nephron loop
  - water conservation, also involved in electrolyte reabsorption

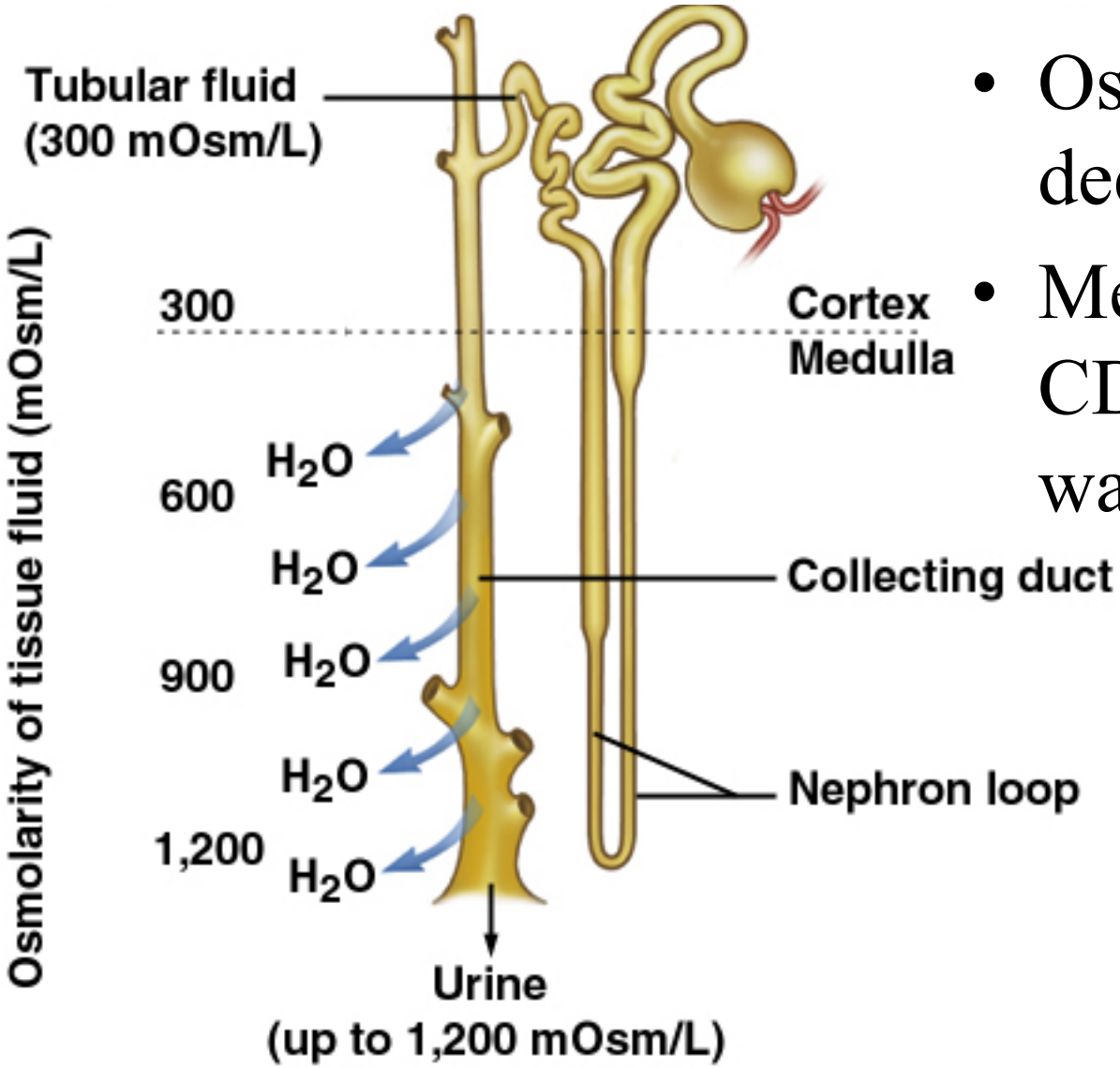
DCT and Collecting Duct

- Effect of aldosterone
  - ↓ BP causes angiotensin II formation
  - angiotensin II stimulates adrenal cortex
  - adrenal cortex secretes aldosterone
  - aldosterone promotes Na^+ reabsorption
  - Na^+ reabsorption promotes water reabsorption
  - water reabsorption ↓ urine volume
  - BP drops less rapidly

DCT and Collecting Duct 2

- Effect of atrial natriuretic factor (ANF)
  - ↑ BP stimulates right atrium
  - atrium secretes ANF
  - ANF promotes Na^+ and water excretion
  - BP drops
- Effect of ADH
  - dehydration stimulates hypothalamus
  - hypothalamus stimulates posterior pituitary
  - posterior pituitary releases ADH
  - ADH ↑ water reabsorption
  - urine volume ↓

Collecting Duct Concentrates Urine



- Osmolarity 4x as high deep in medulla
- Medullary portion of CD is permeable to water but not to NaCl

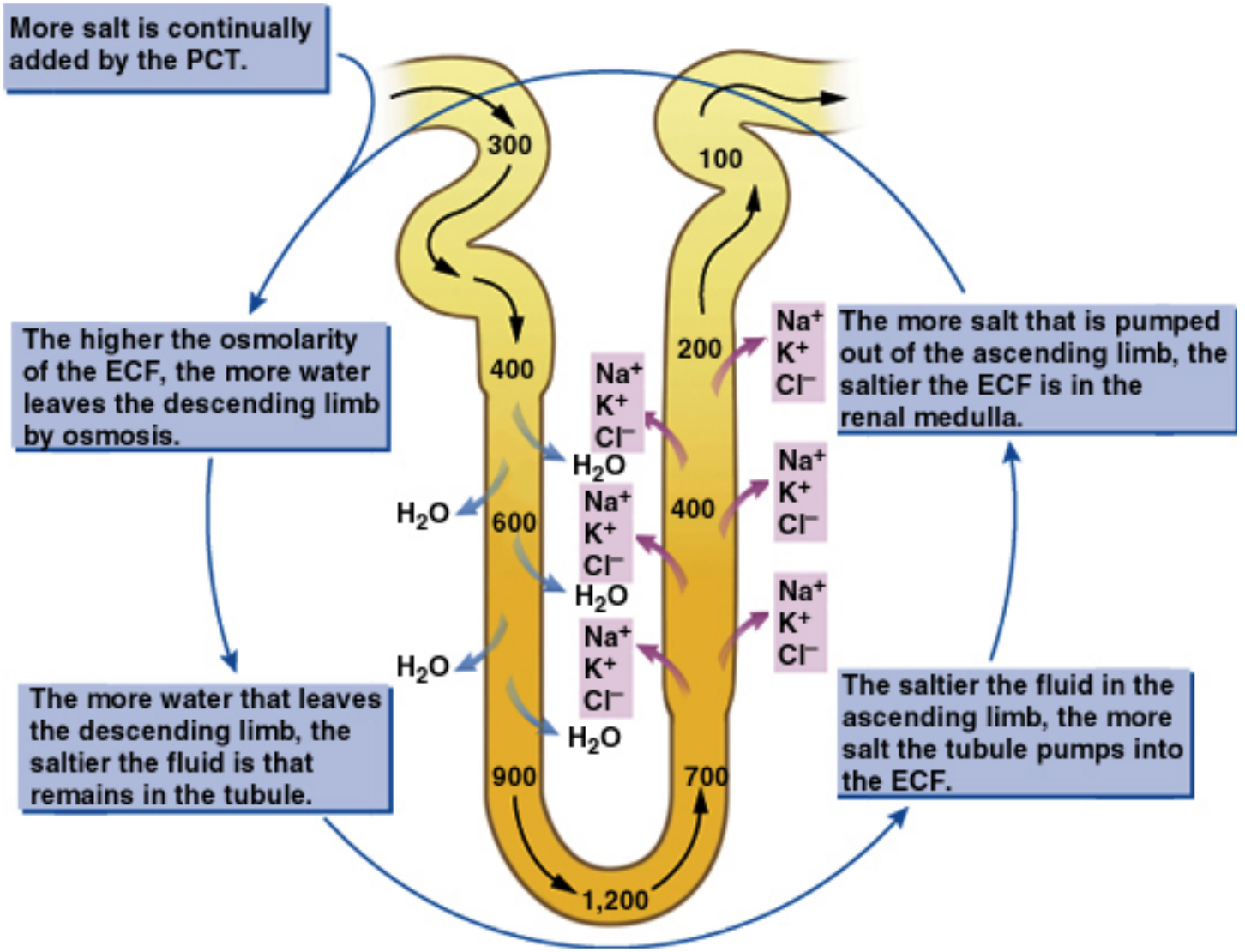
Control of Water Loss

- Producing hypotonic urine
  - NaCl reabsorbed by cortical CD
  - water remains in urine
- Producing hypertonic urine
  - GFR drops
  - tubular reabsorption ↑
  - less NaCl remains in CD
  - ADH ↑ CD's water permeability
  - more water is reabsorbed
  - urine is more concentrated

Countercurrent Multiplier

- Recaptures NaCl and returns it to renal medulla
- Descending limb
  - reabsorbs water but not salt
  - concentrates tubular fluid
- Ascending limb
  - reabsorbs Na^+, K^+, and Cl^-
  - maintains high osmolarity of renal medulla
  - impermeable to water
  - tubular fluid becomes hypotonic
- Recycling of urea: collecting duct-medulla
  - urea accounts for 40% of high osmolarity of medulla

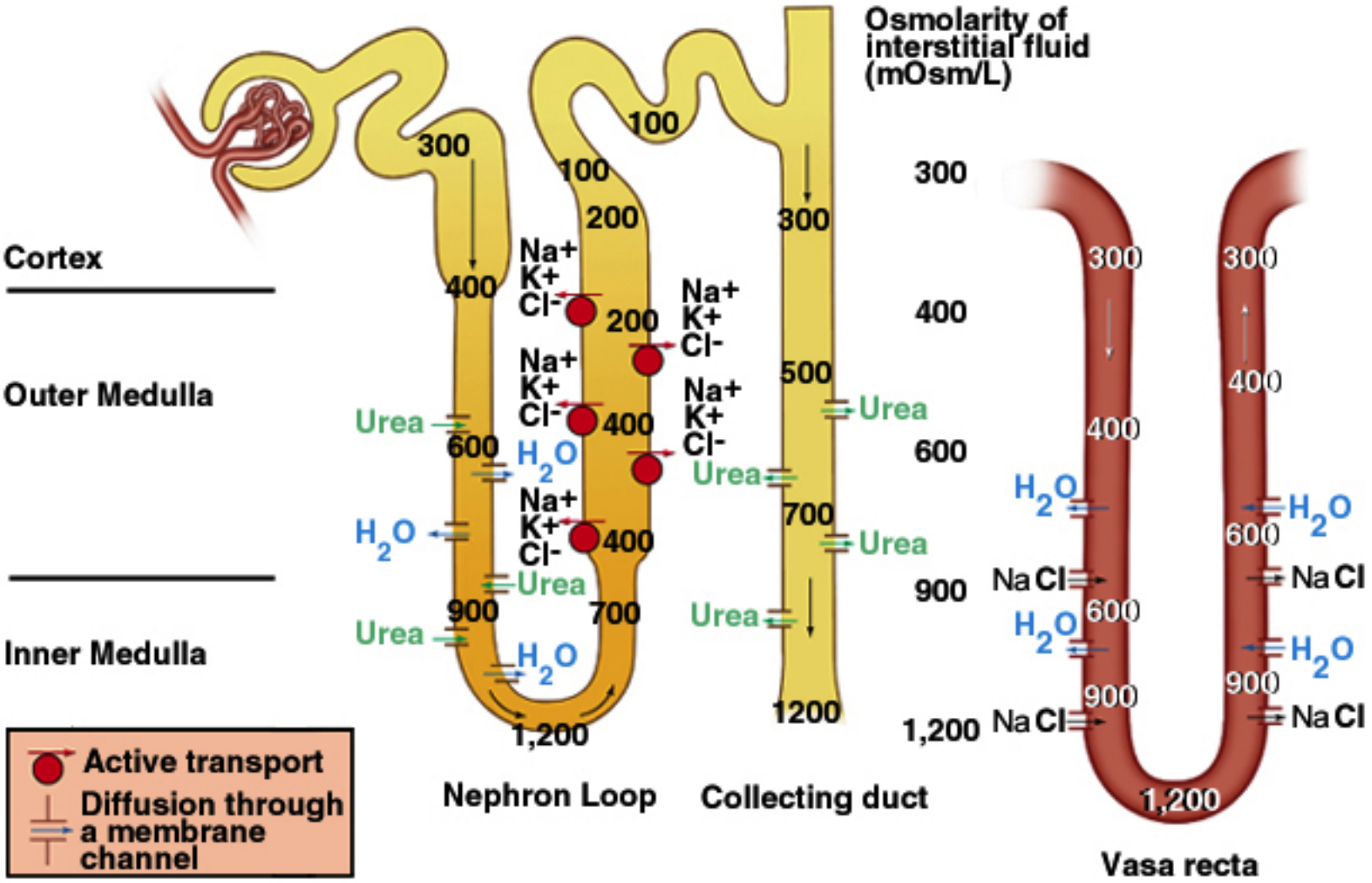
Countercurrent Multiplier of Nephron Loop Diagram



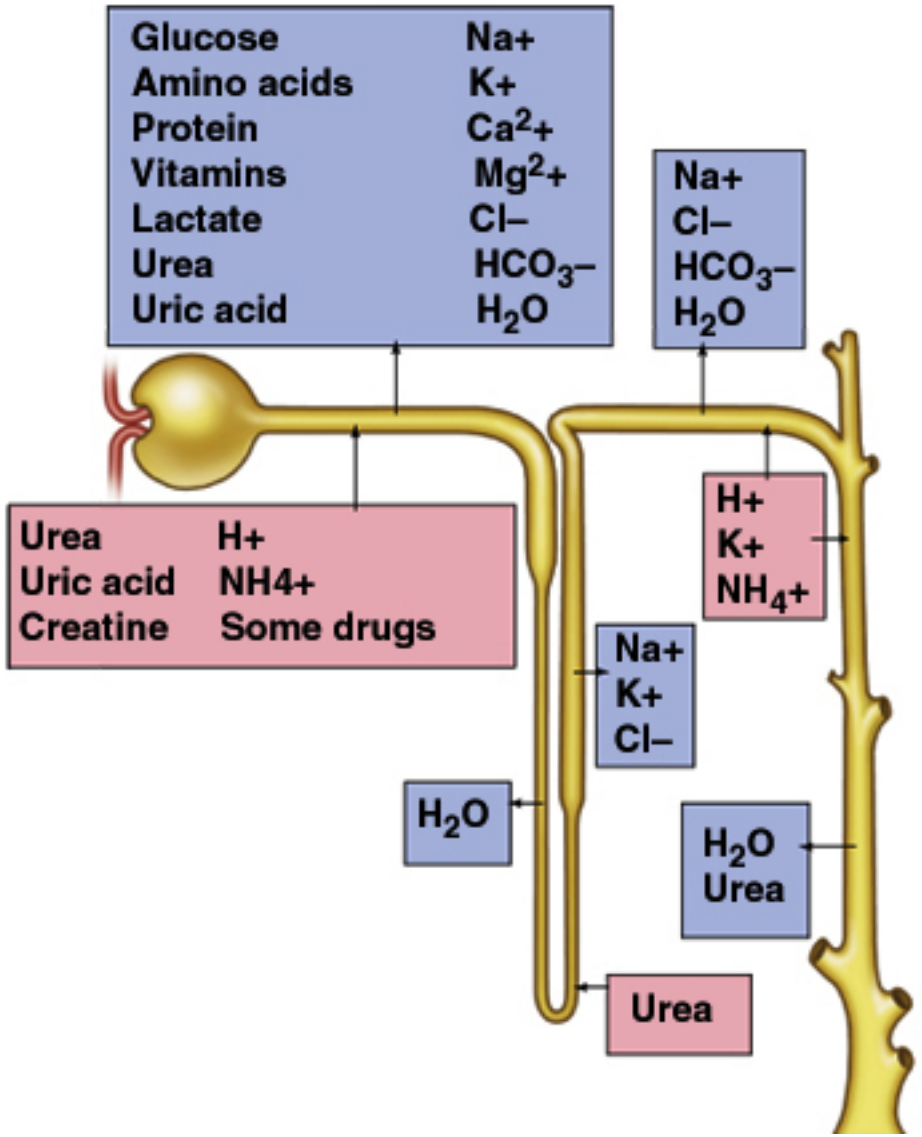
Countercurrent Exchange System

- Formed by vasa recta
  - provide blood supply to medulla
  - do not remove NaCl from medulla
- Descending capillaries
  - water diffuses out of blood
  - NaCl diffuses into blood
- Ascending capillaries
  - water diffuses into blood
  - NaCl diffuses out of blood

Maintenance of Osmolarity in Renal Medulla



Summary of Tubular Reabsorption and Secretion



Composition and Properties of Urine

- Appearance
  - almost colorless to deep amber; yellow color due to urochrome, from breakdown of hemoglobin (RBC's)
- Odor - as it stands bacteria degrade urea to ammonia
- Specific gravity
  - density of urine ranges from 1.000 -1.035
- Osmolarity - (blood - 300 mOsm/L) ranges from 50 mOsm/L to 1,200 mOsm/L in dehydrated person
- pH - range: 4.5 - 8.2, usually 6.0
- Chemical composition: 95% water, 5% solutes
  - urea, NaCl, KCl, creatinine, uric acid

Urine Volume

- Normal volume - 1 to 2 L/day
- Polyuria > 2L/day
- Oliguria < 500 mL/day
- Anuria - 0 to 100 mL

Diabetes

- Chronic polyuria of metabolic origin
- With hyperglycemia and glycosuria
  - diabetes mellitus I and II, insulin hyposecretion/insensitivity
  - gestational diabetes, 1 to 3% of pregnancies
  - pituitary diabetes, hypersecretion of GH
  - adrenal diabetes, hypersecretion of cortisol
- With glycosuria but no hyperglycemia
  - renal diabetes, hereditary deficiency of glucose transporters
- With no hyperglycemia or glycosuria
  - diabetes insipidus, ADH hyposecretion

Diuretics

- Effects
  - ↑ urine output
  - ↓ blood volume
- Uses
  - hypertension and congestive heart failure
- Mechanisms of action
  - ↑ GFR
  - ↓ tubular reabsorption

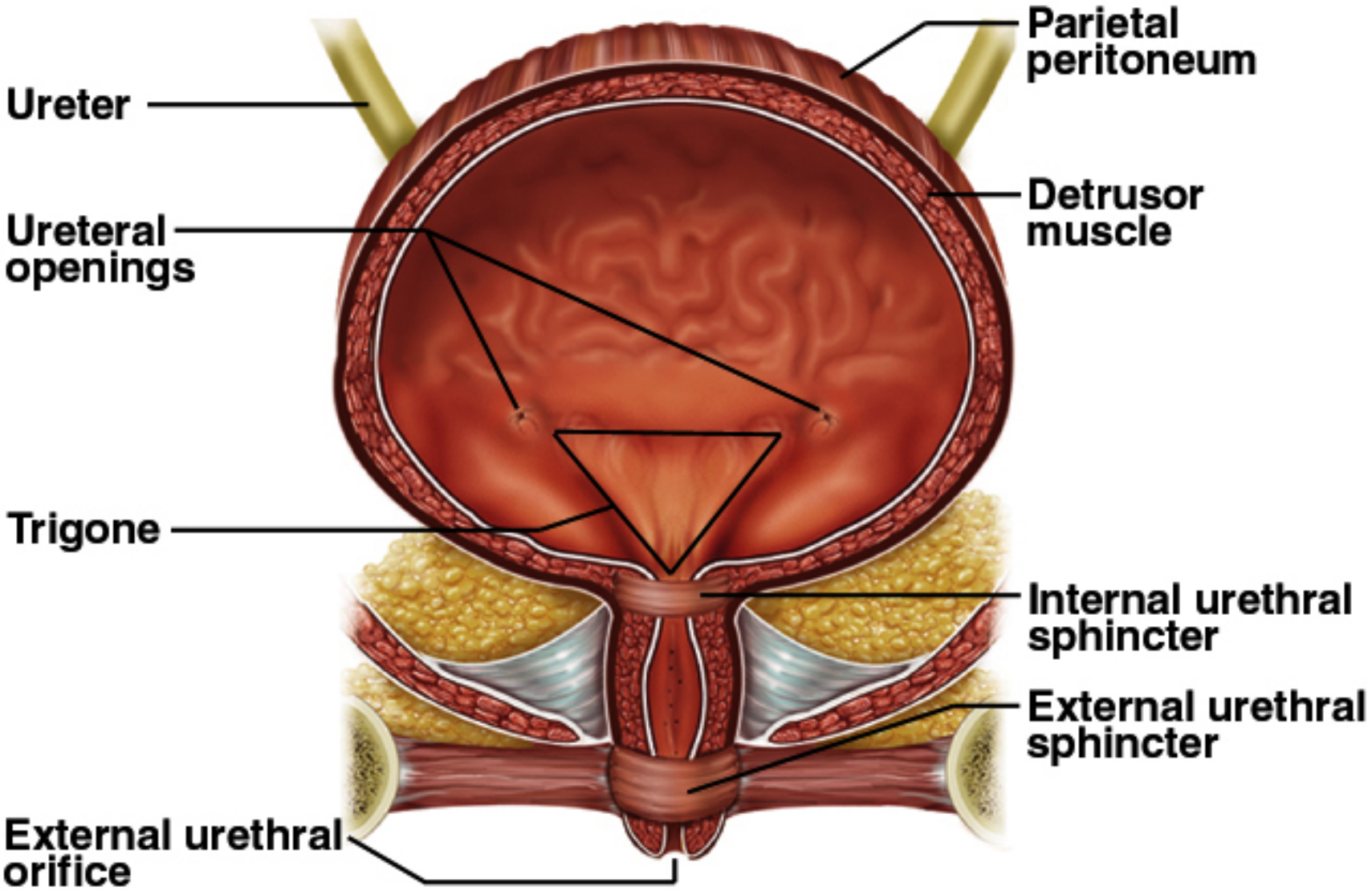
Renal Function Tests

- Renal clearance: volume of blood plasma cleared of a waste in 1 minute
- Determine renal clearance (C) by assessing blood and urine samples: $C = UV/P$
  - U (waste concentration in urine)
  - V (rate of urine output)
  - P (waste concentration in plasma)
- Determine GFR: inulin is neither reabsorbed or secreted so for this solute GFR = renal clearance $GFR = UV/P$

Urine Storage and Elimination

- Ureters
  - from renal pelvis passes dorsal to bladder and enters it from below, about 25 cm long
  - 3 layers
    - adventitia - CT
    - muscularis - 2 layers of smooth muscle
      - urine enters, it stretches and contracts in peristaltic wave
    - mucosa - transitional epithelium
  - lumen very narrow, easily obstructed

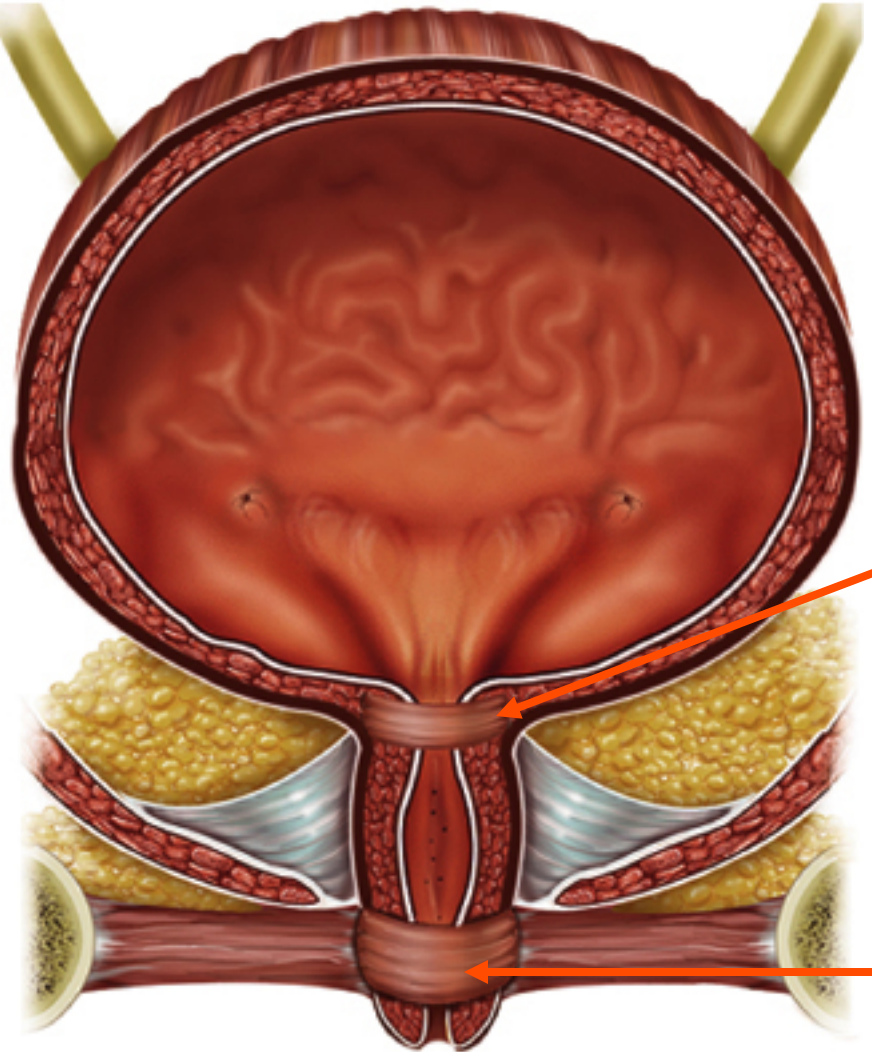
Urinary Bladder and Urethra - Female



Urinary Bladder

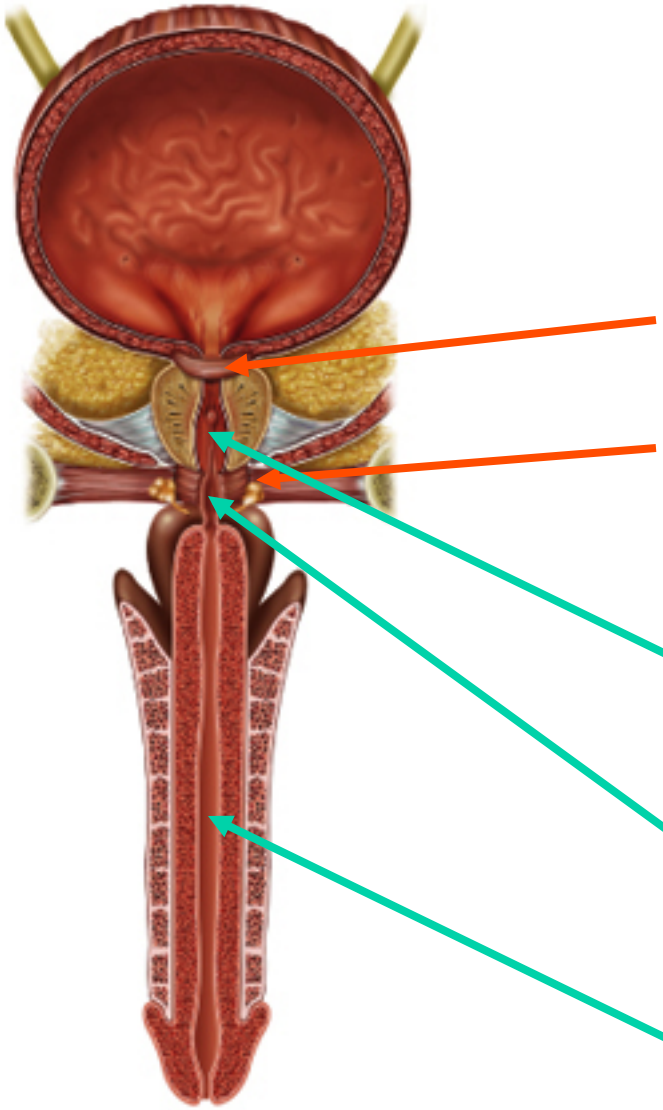
- Located in pelvic cavity, posterior to pubic symphysis
- 3 layers
  - parietal peritoneum, superiorly; fibrous adventitia rest
  - muscularis: detrusor muscle, 3 layers of smooth muscle
  - mucosa: transitional epithelium
- trigone: openings of ureters and urethra, triangular
- rugae: relaxed bladder wrinkled, highly distensible
- capacity: moderately full - 500 ml, max. - 800 ml

Female Urethra



- 3 to 4 cm long
- External urethral orifice
  - between vaginal orifice and clitoris
- Internal urethral sphincter
  - detrusor muscle thickened, smooth muscle, involuntary control
- External urethral sphincter
  - skeletal muscle, voluntary control

Male Bladder and Urethra

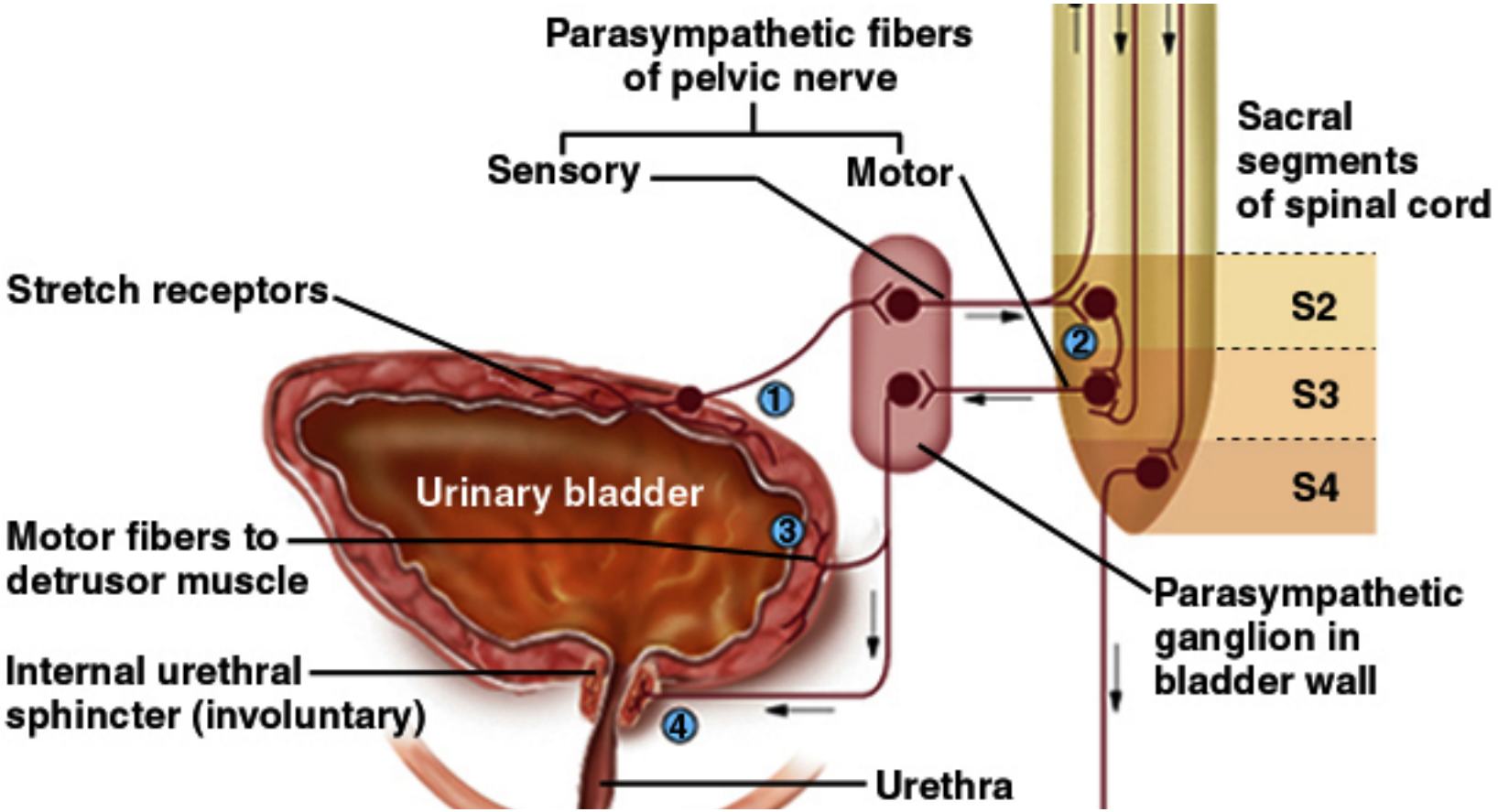


- 18 cm long
- Internal urethral sphincter
- External urethral sphincter
- 3 regions
  - prostatic urethra
    - during orgasm receives semen
  - membranous urethra
    - passes through pelvic cavity
  - penile urethra

Voiding Urine - Micturition

- Micturition reflex
  1) 200 ml urine in bladder, stretch receptors send signal to spinal cord (S2, S3)
  2) parasympathetic reflex arc from spinal cord, stimulates contraction of detrusor muscle
  3) relaxation of internal urethral sphincter
  4) this reflex predominates in infants

Infant Micturition Reflex Diagram



Voluntary Control of Micturition

5) micturition center in pons receives stretch signals and integrates cortical input (voluntary control)

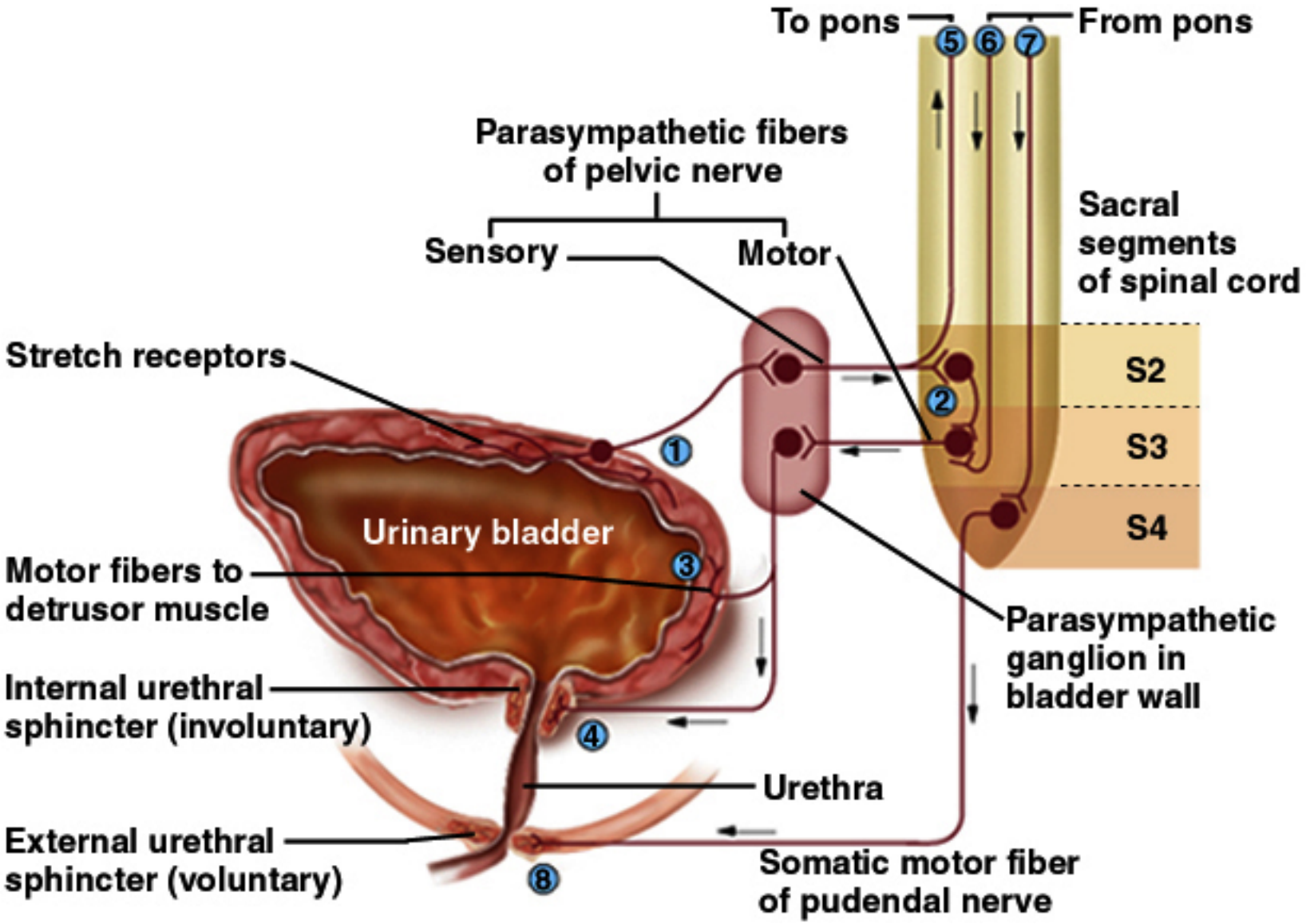
6) sends signal for stimulation of detrussor and relaxes internal urethral sphincter

7) to delay urination impulses sent through pudendal nerve to external urethral sphincter keep it contracted until you wish to urinate

8) valsalva maneuver

- aids in expulsion of urine by ↑ pressure on bladder
- can also activate micturition reflex voluntarily

Adult Micturition Reflex Diagram



Hemodialysis