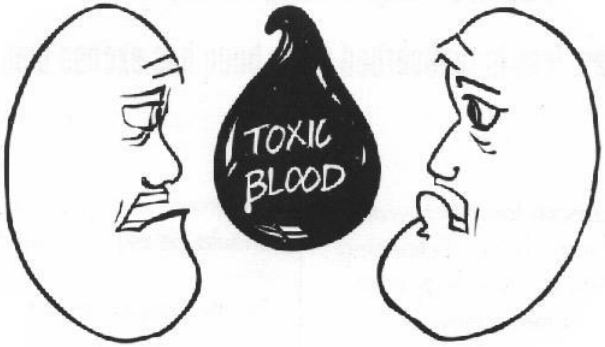
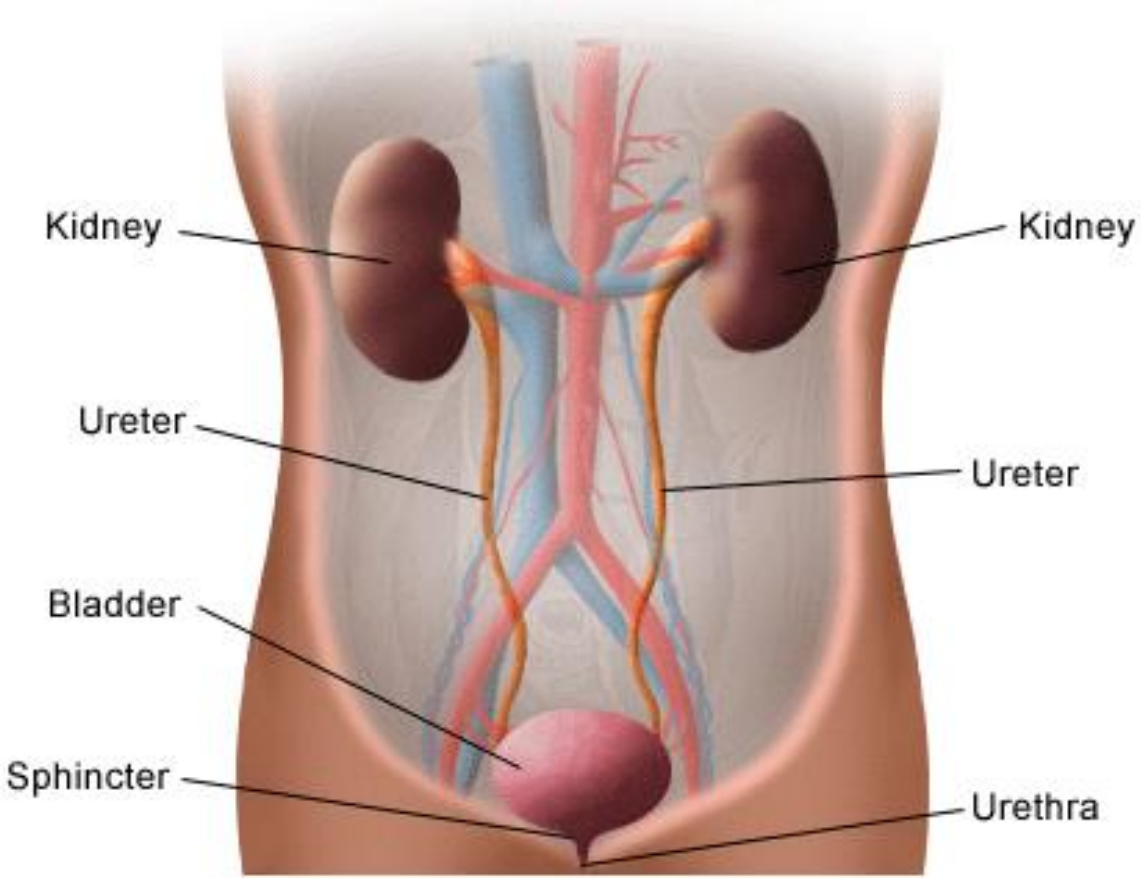
URINARY SYSTEM



FUNCTIONS

- ✓ **formation of urine (elimination of metabolic waste products)**
- ✓ **regulation of fluid and electrolyte balance (recycling of water and essential electrolytes)**
- ✓ **regulation of blood pressure (renin-angiotensin-aldosterone)**
- ✓ **synthesis and release of certain hormones (erythropoietin, hydroxylation of vitamin D_3 to 1,25 $(OH)_2D_3$)**



two **kidneys**, **ureters**, the **bladder,** and the **urethra**

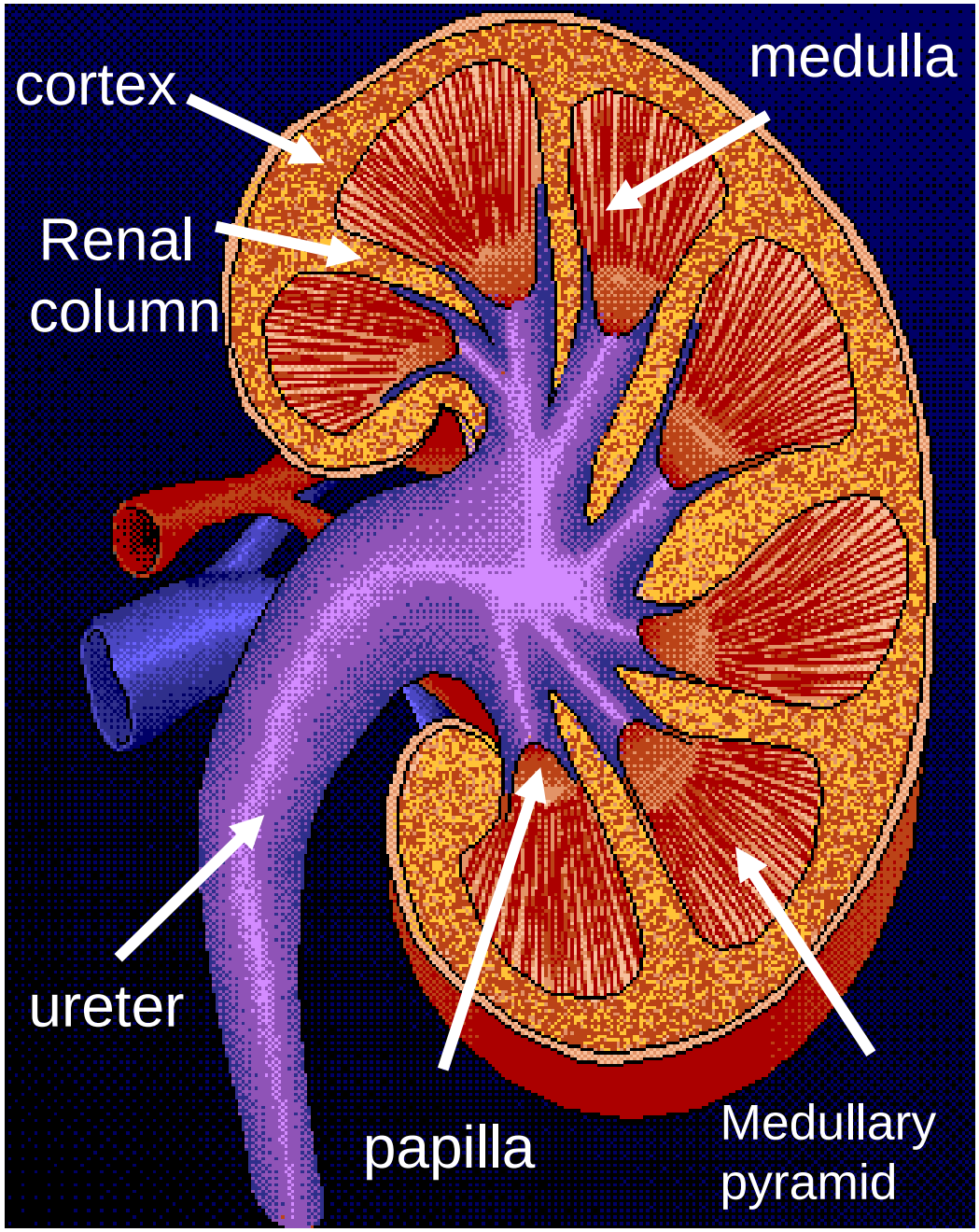
Fibrous capsule

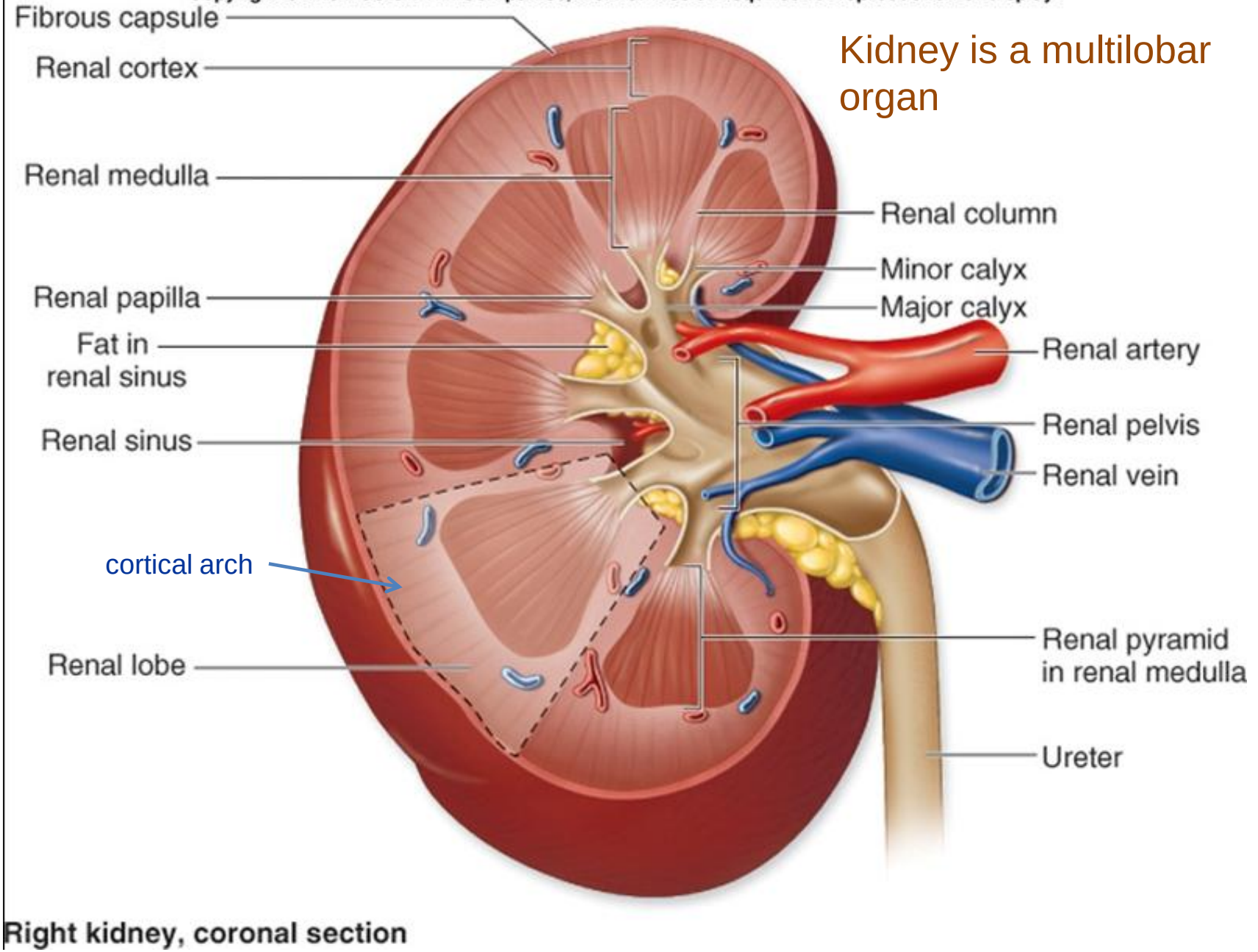
Cortex is subdivided into outer cortex and juxtamedullary cortex

Medulla consists about 20 medullary pyramids, which terminate in papilla surfaced by the area cribrosa

The papilla is surrounded by a minor calyx, which collects the urine from a papilla dripping from the area cribrosa

Minor calyces converge to form the major calyces which, in tern form the pelvis

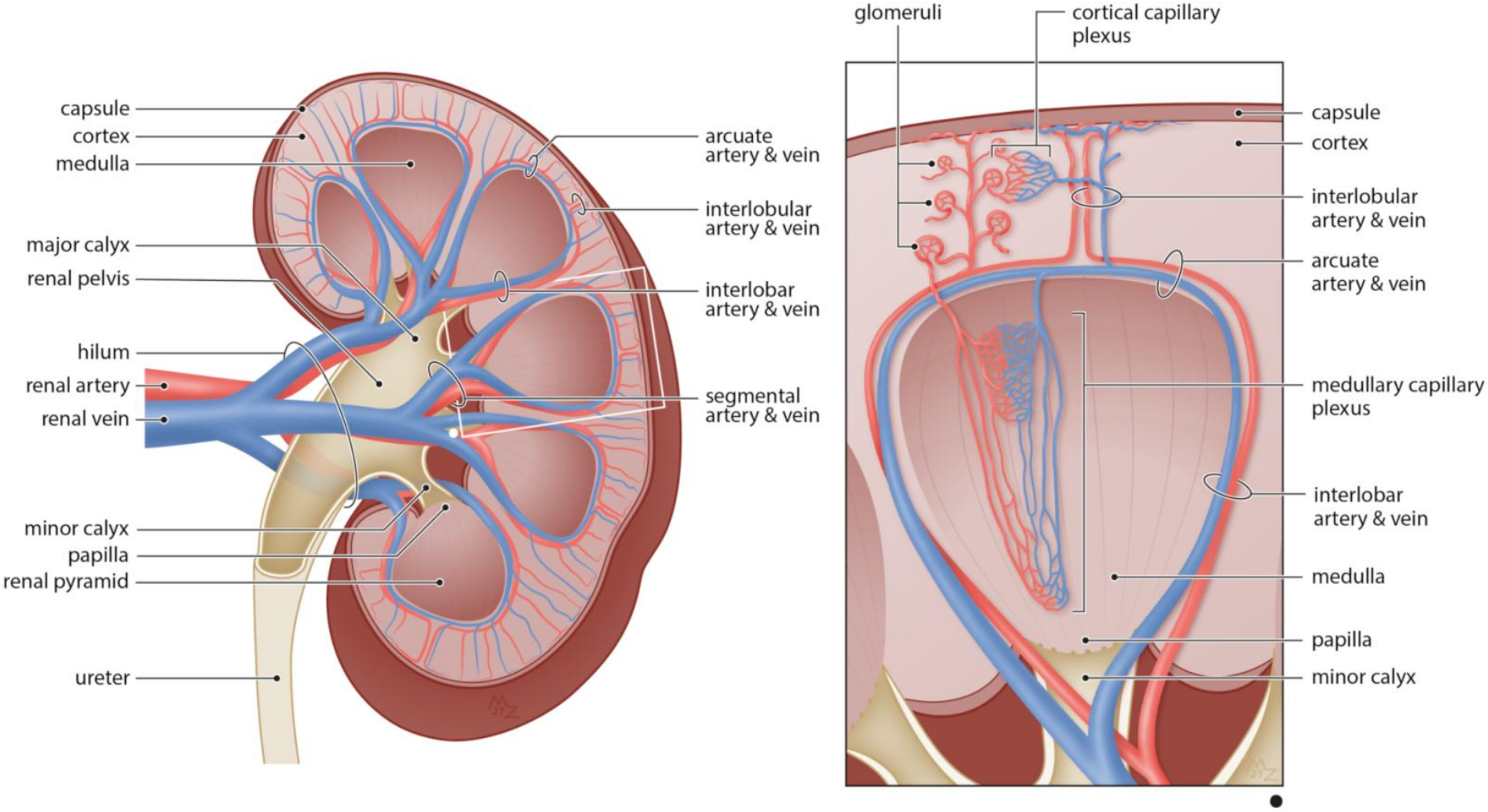


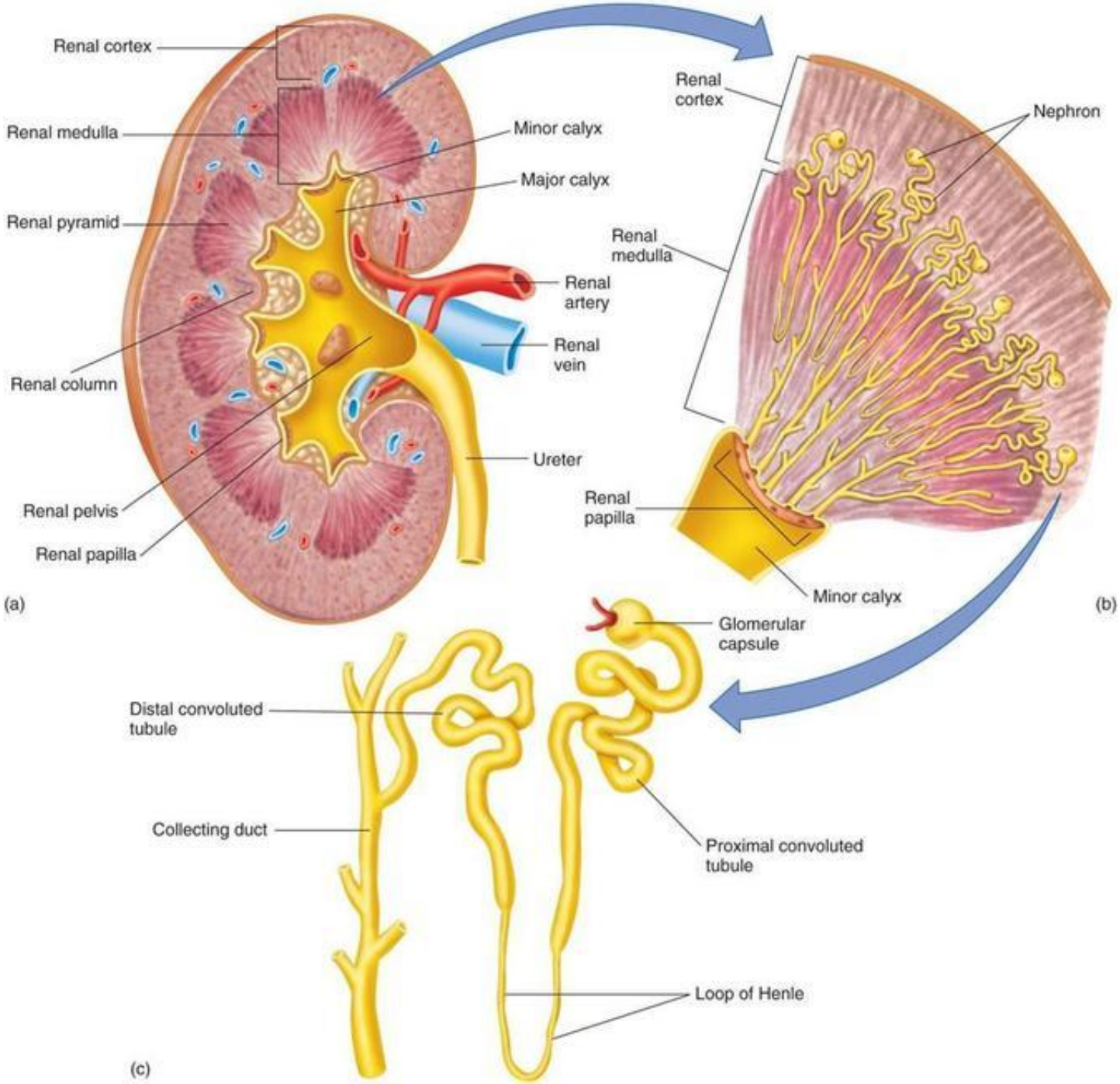


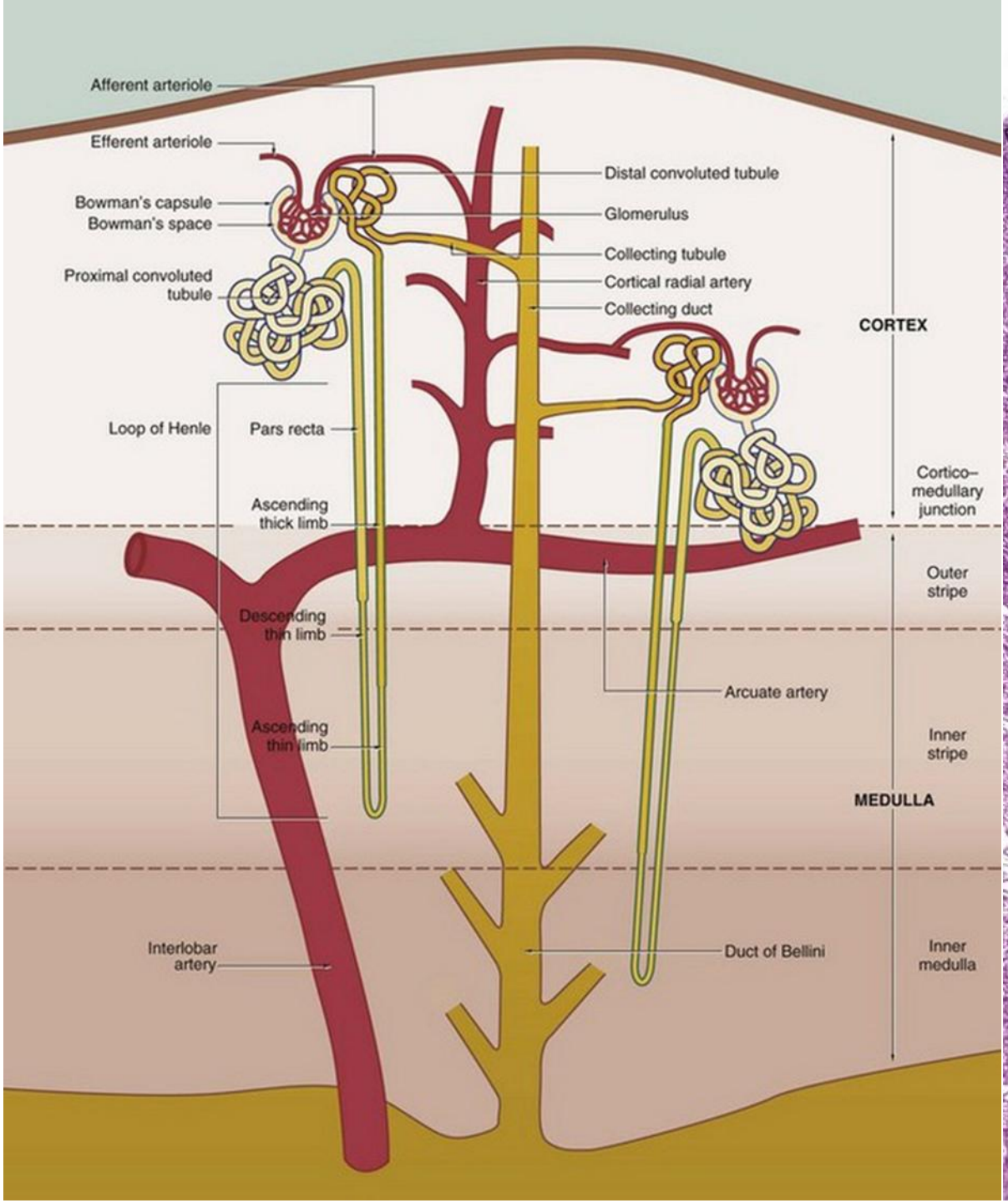
Kidney is a multilobar organ

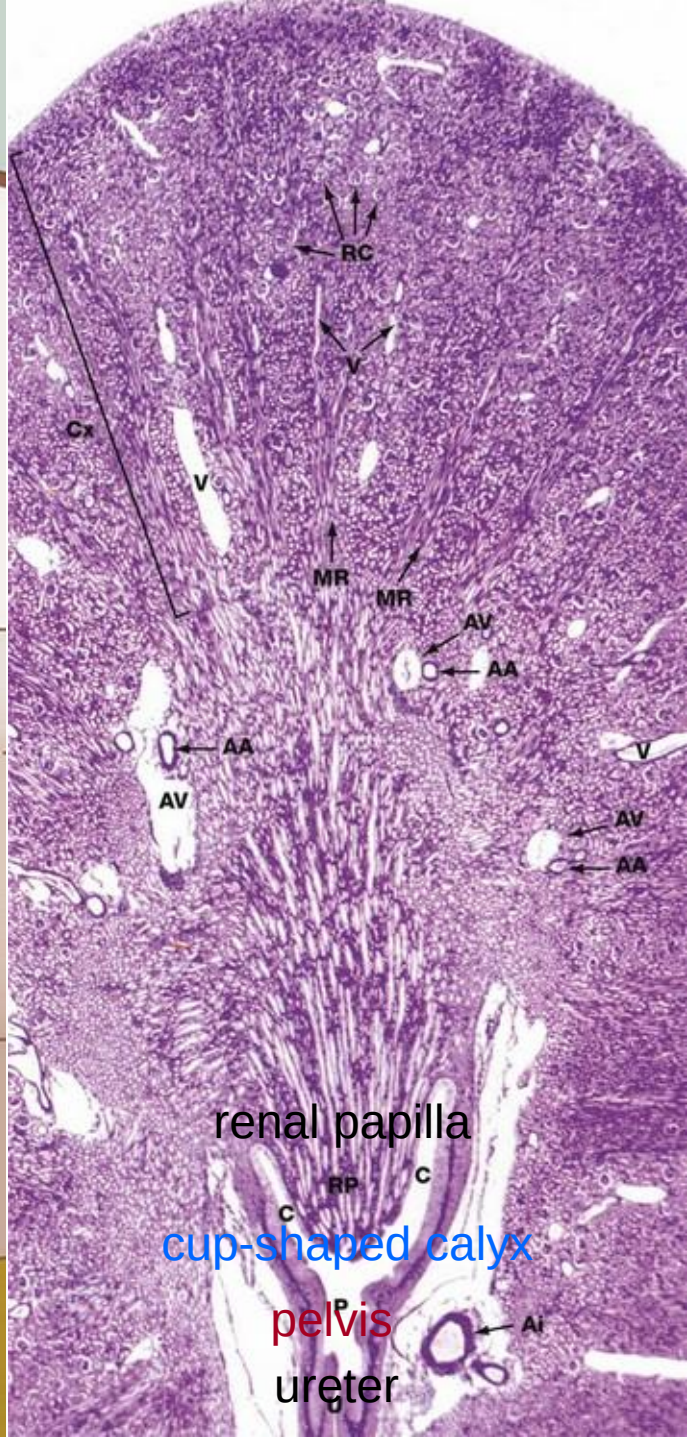
Right kidney, coronal section

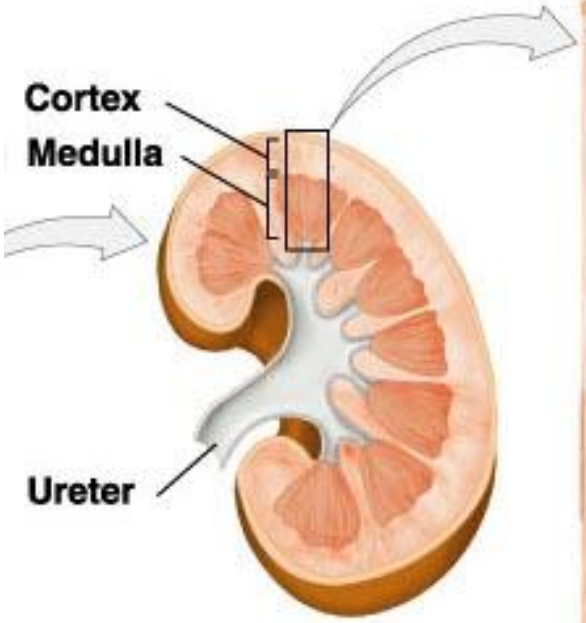
Renal pyramid, **renal column** and **cortical arch** form **renal lob**

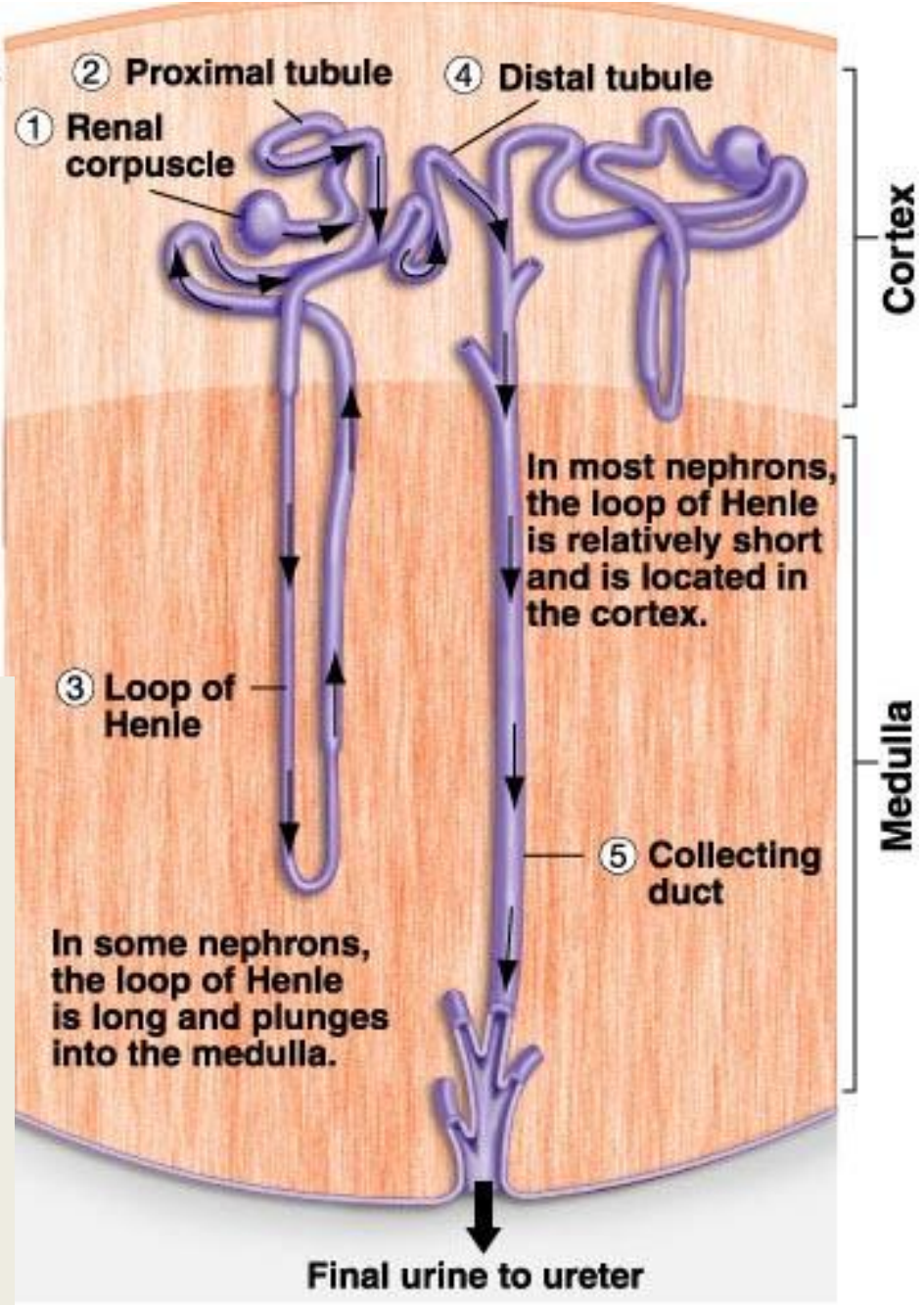

capsule
cortex
medulla
major calyx
renal pelvis
hilum
renal artery
renal vein
minor calyx
papilla
renal pyramid
ureter
arcuate artery & vein
interlobular artery & vein
interlobar artery & vein
segmental artery & vein
glomeruli
cortical capillary plexus
capsule
cortex
interlobular artery & vein
arcuate artery & vein
medullary capillary plexus
interlobar artery & vein
medulla
papilla
minor calyx


Renal cortex
Renal medulla
Renal pyramid
Renal column
Renal pelvis
Renal papilla
Minor calyx
Major calyx
Renal artery
Renal vein
Ureter
(a)
Renal cortex
Renal medulla
Renal papilla
Nephron
Minor calyx
(b)
Glomerular capsule
Distal convoluted tubule
Collecting duct
Proximal convoluted tubule
Loop of Henle
(c)


Afferent arteriole
Efferent arteriole
Bowman's capsule
Bowman's space
Proximal convoluted tubule
Loop of Henle
Pars recta
Ascending thick limb
Descending thin limb
Ascending thin limb
Interlobar artery
Distal convoluted tubule
Glomerulus
Collecting tubule
Cortical radial artery
Collecting duct
Arcuate artery
Duct of Bellini
CORTEX
Cortico–medullary junction
Outer stripe
Inner stripe
MEDULLA
Inner medulla


RC
V
Cx
V
MR
MR
AV
AA
AA
AV
V
AV
AA
RP
C
C
P
Ai
renal papilla
cup-shaped calyx
pelvis
ureter



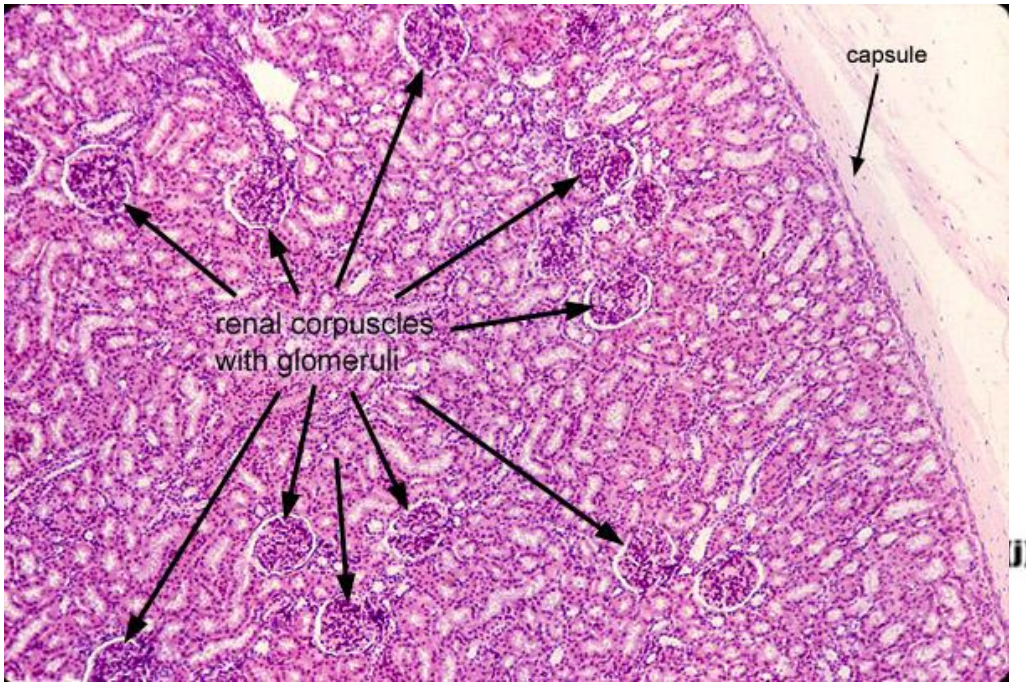


Uriniferous tubule

- is the **functional unit of the kidney**
- is composed of a **nephron** and a **collecting tubule**
- each nephron is composed of **renal corpuscle**, **proximal tubule**, **loop of Henle** and **distal tubule**
- two types of nephrons:

Cortical nephrons

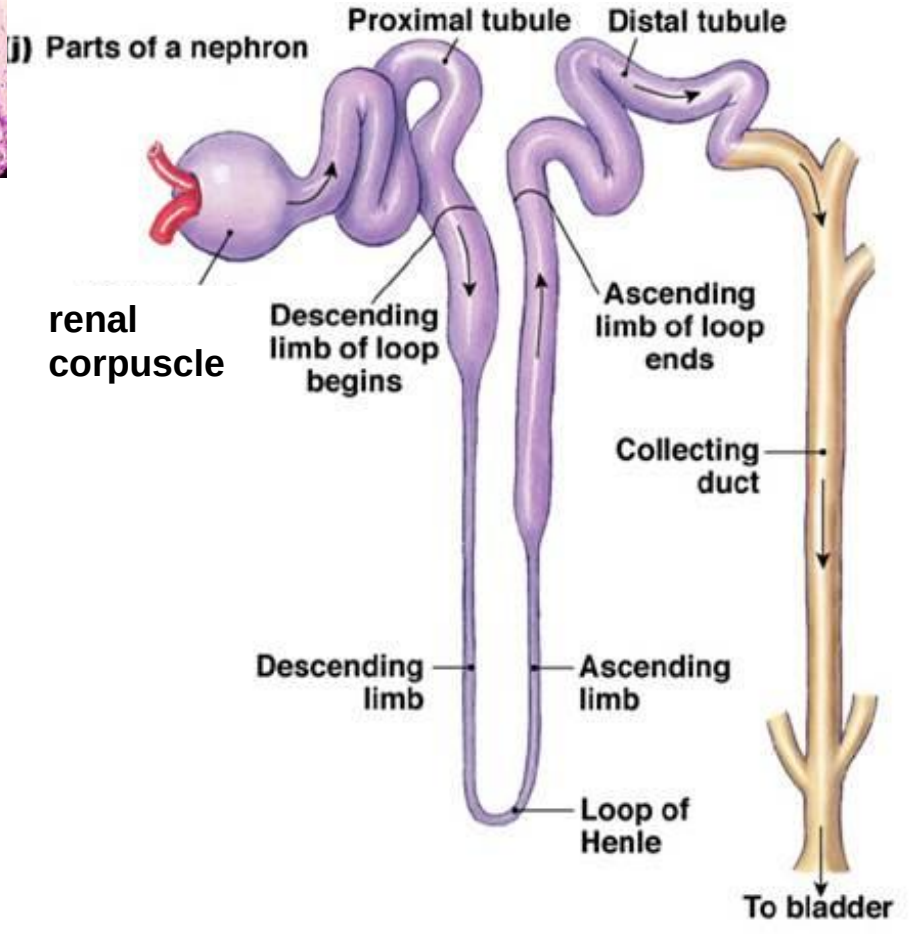
Juxtamedullary nephrons



Normal kidney contains about 1 million **nephrons**

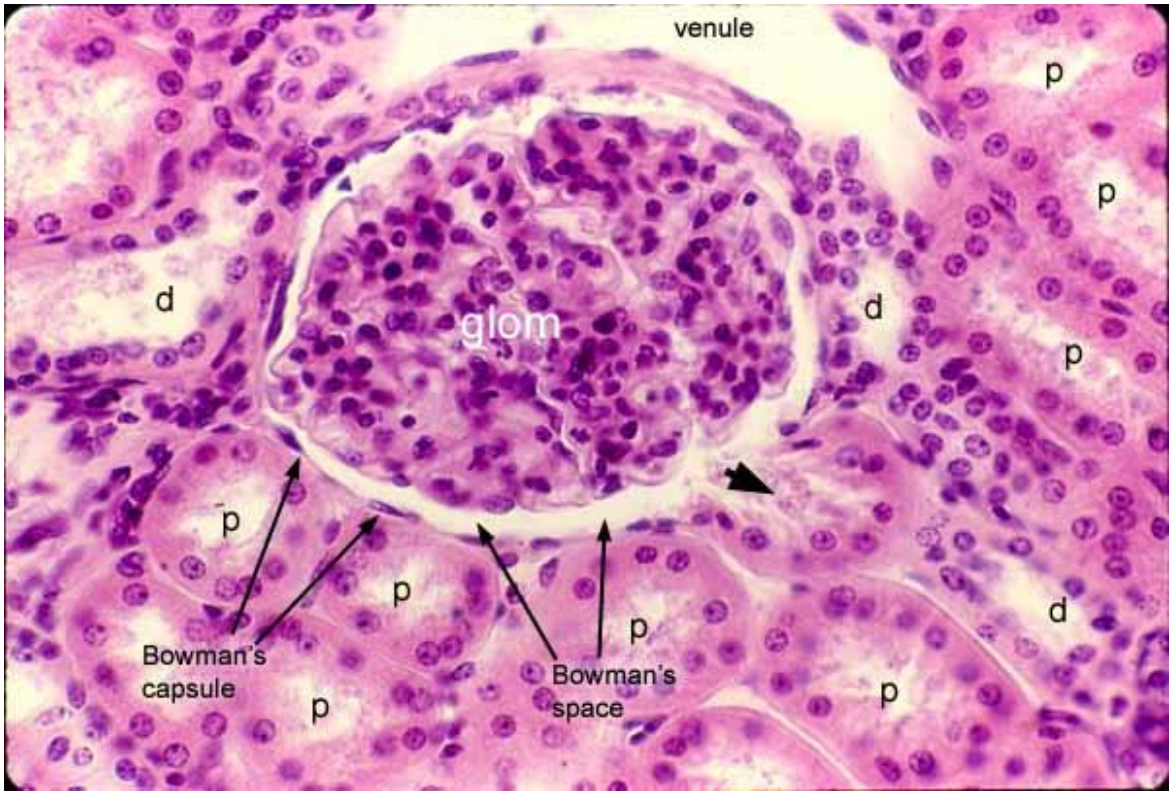
The renal corpuscle - filters the fluid expressed from the bloodstream

Proximal tubule, loop of Henle and **distal tubule –** modify the filtrate to form the urine



renal corpuscle

- is composed of a tuft of capillaries – **glomerulus** surrounded **by Bowman's capsule**



The renal corpuscle is formed when a mass of **glomerular capillaries** grows into the blind ending of a nephron (**Bowman's capsule)**

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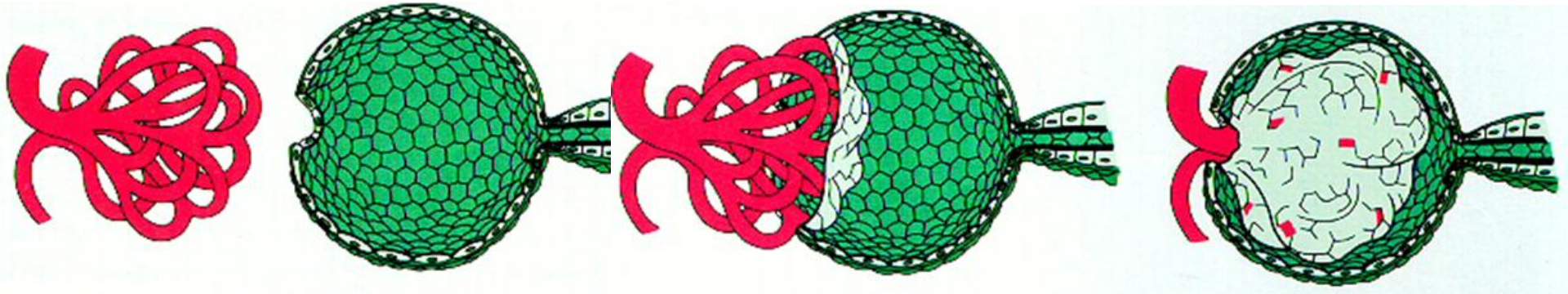
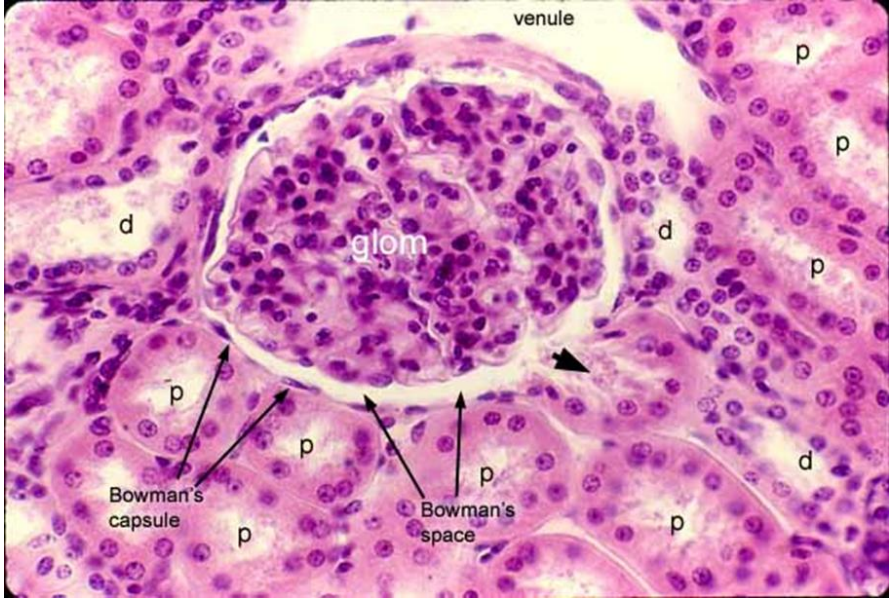
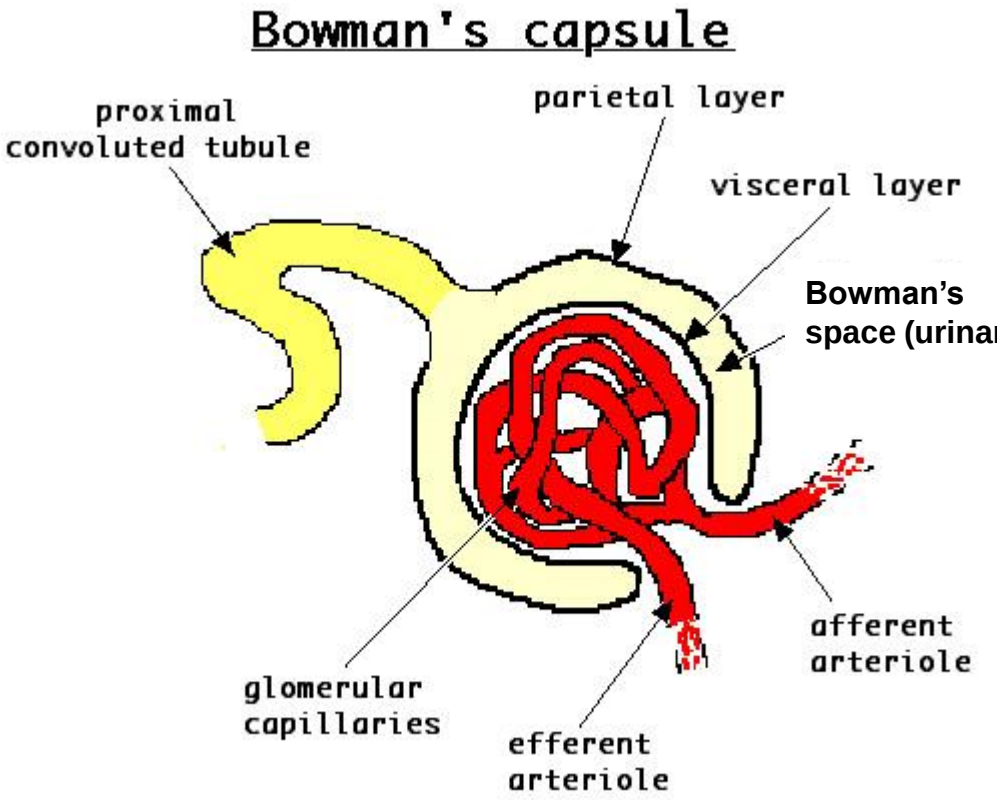


Bowman’s capsule

Bowman’s space (urinary space) – between the visceral and parietal layers, of Bowman’s capsule into which the filtrate enters after filtration.





Visceral layer of Bowman’s capsule

- composed of modified epithelial cells - **podocytes**

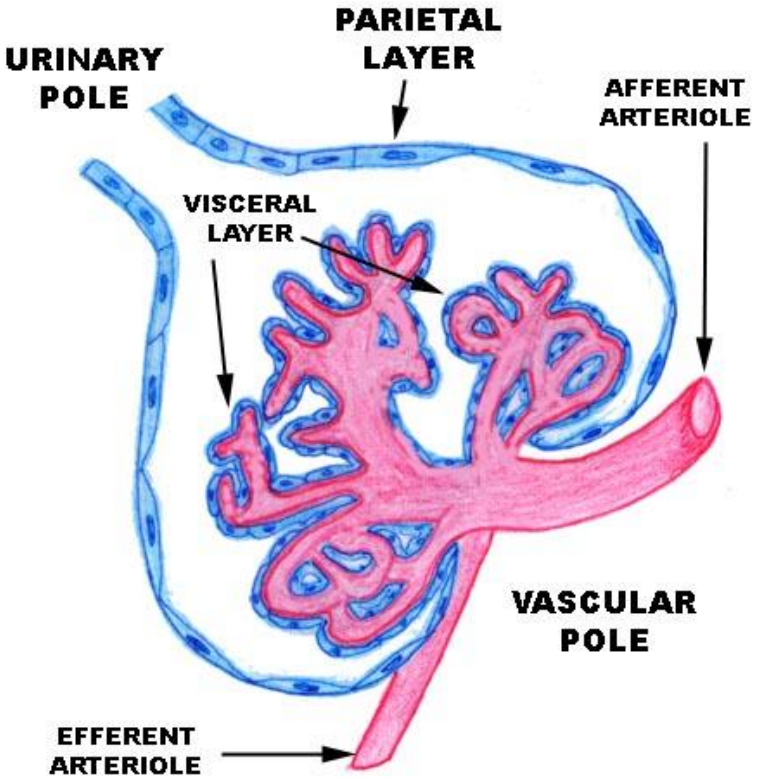
Parietal layer of Bowman’s capsule

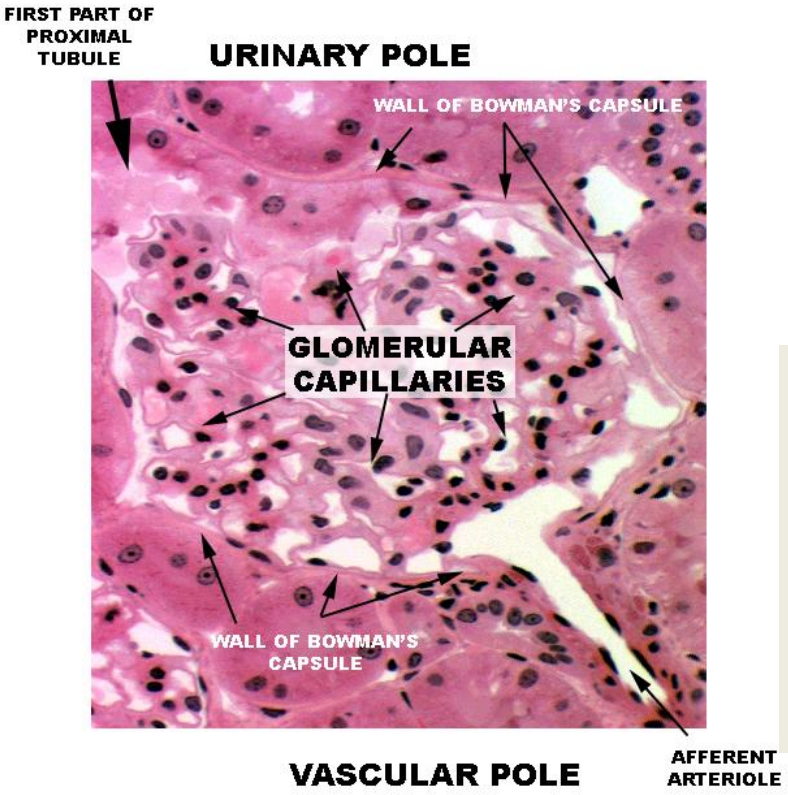
- simple squamous epithelium

renal corpuscle

Vascular pole – vessels (afferent and efferent arteriole) enter and exit Bowman' capsule

Urinary pole – between renal corpuscle and the proximal tubule, drains Bowman' space



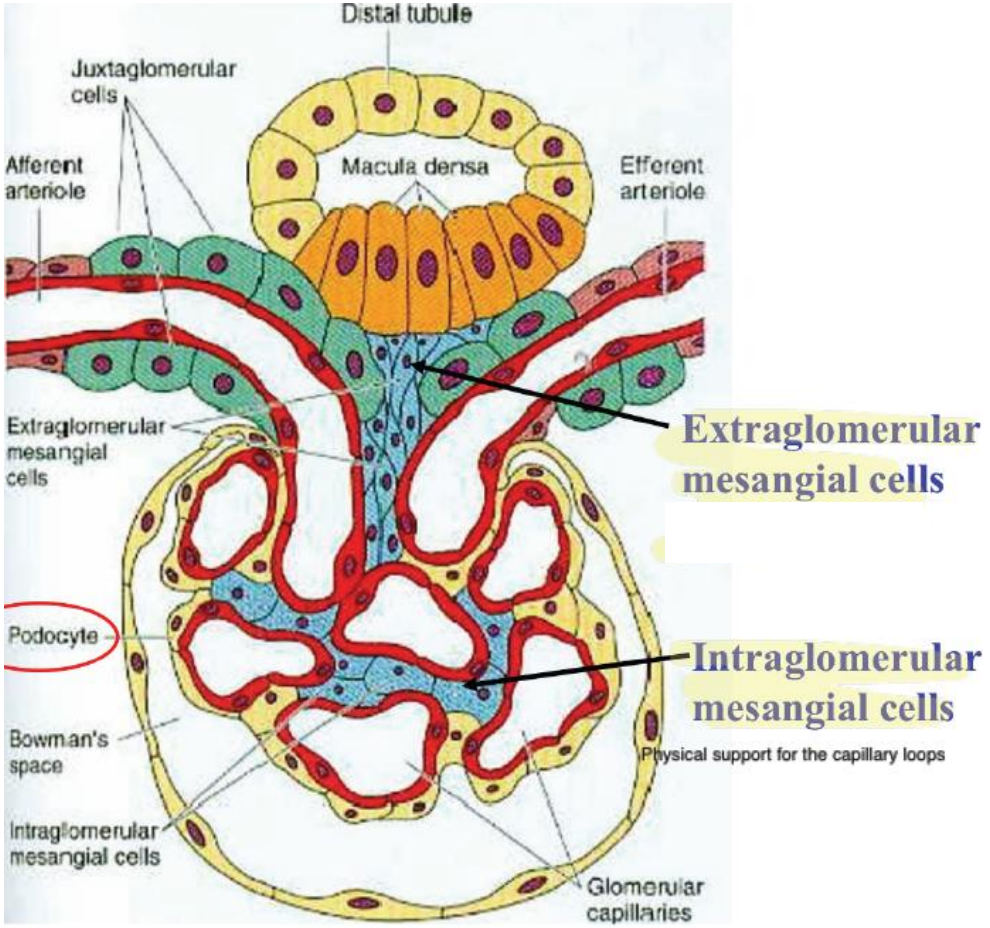


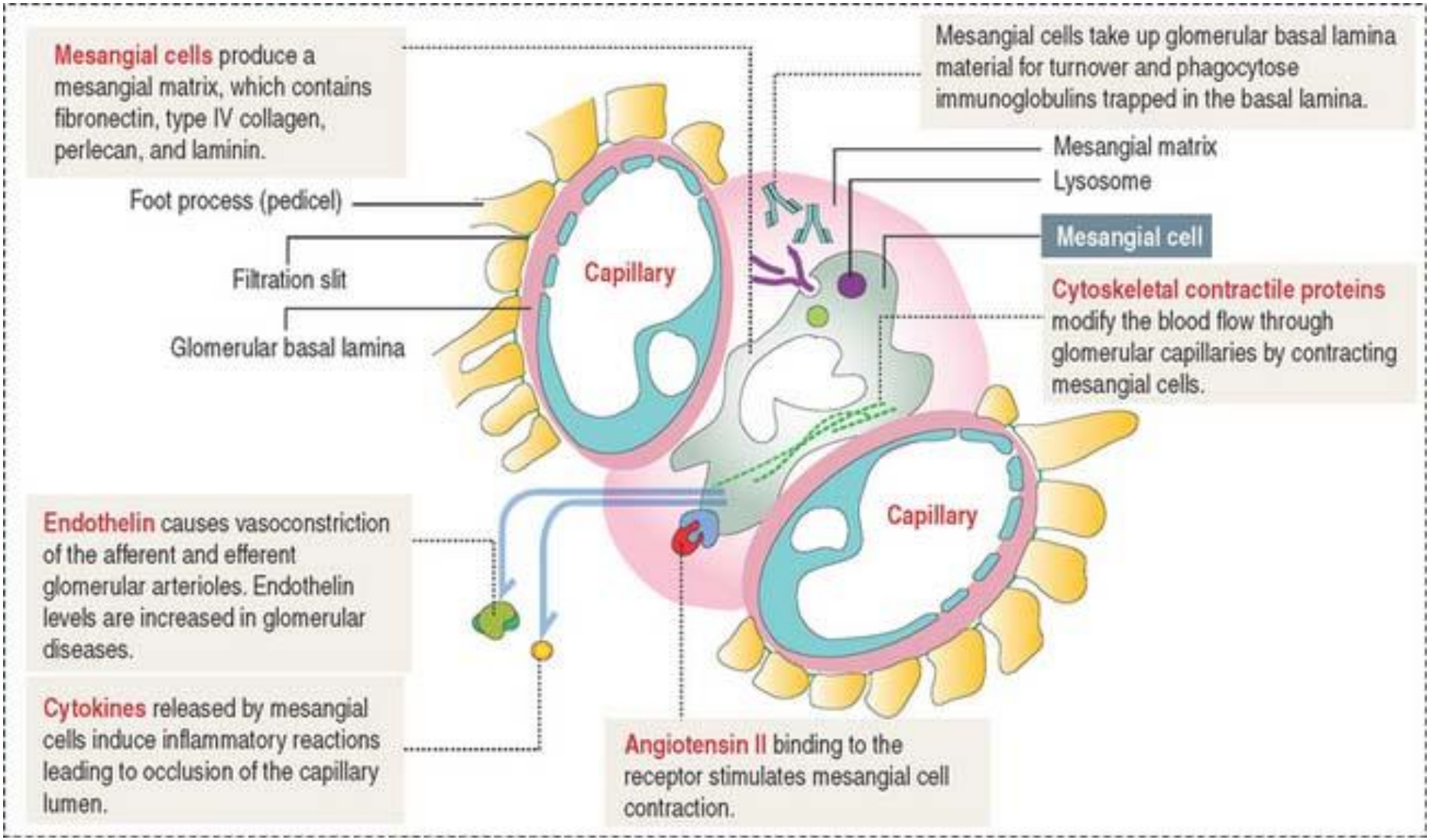
Glomerulus is completely **arterial bed** – is supplied by **afferent glomerular arteriole** and drained by **efferent glomerular arteriole**

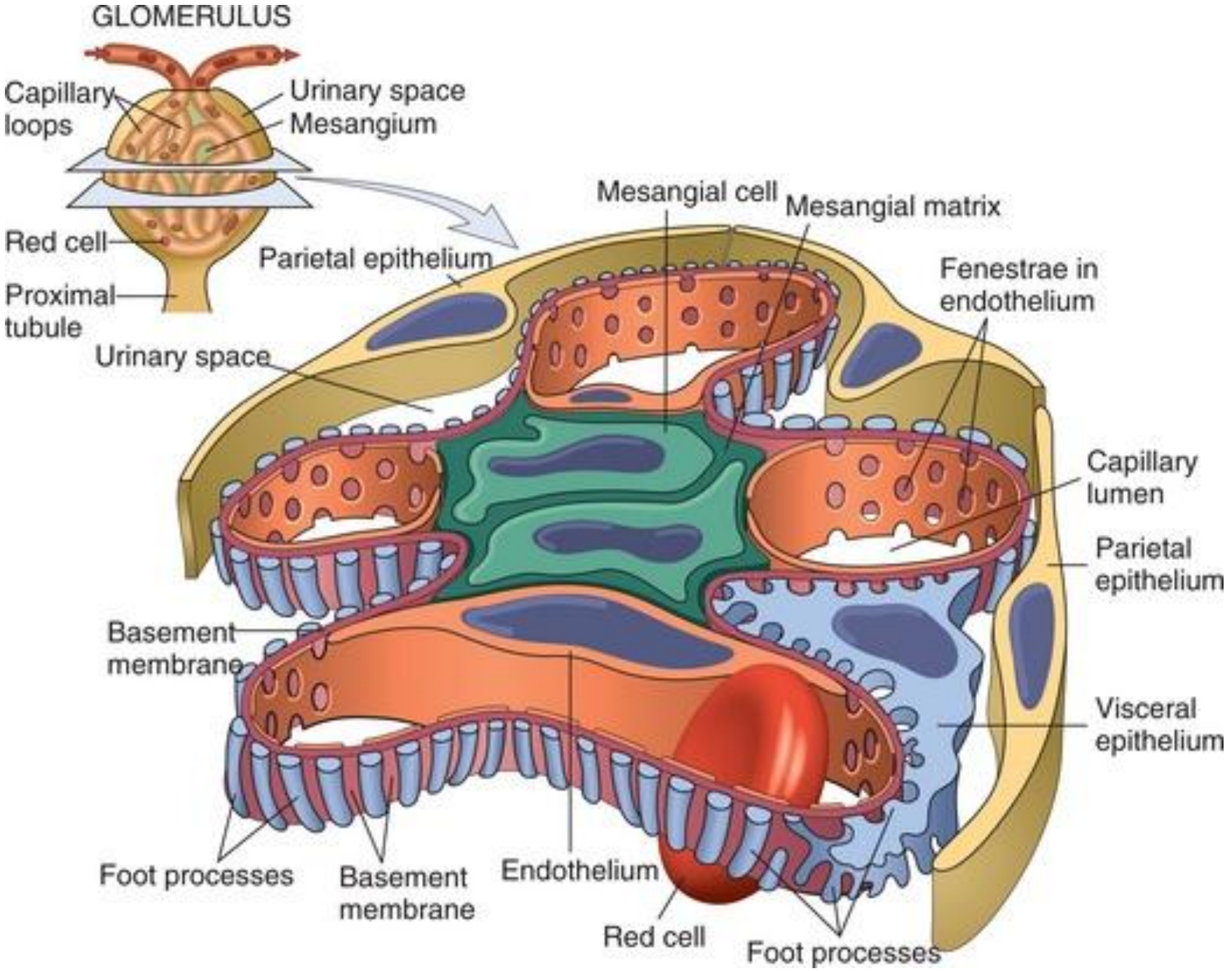
Glomerulus

- is composed of **fenestrated capillaries** and **mesangial cells**

- **extraglomerular mesangial cells**
- located at the vascular pole
- **intraglomerular mesangial cells**
- pericyte-like cells situated within the renal corpuscle – provide **physical support** to the capillary, **phagocytosis** and **regulate blood flow** of the glomerular capillaries by their contractile activity

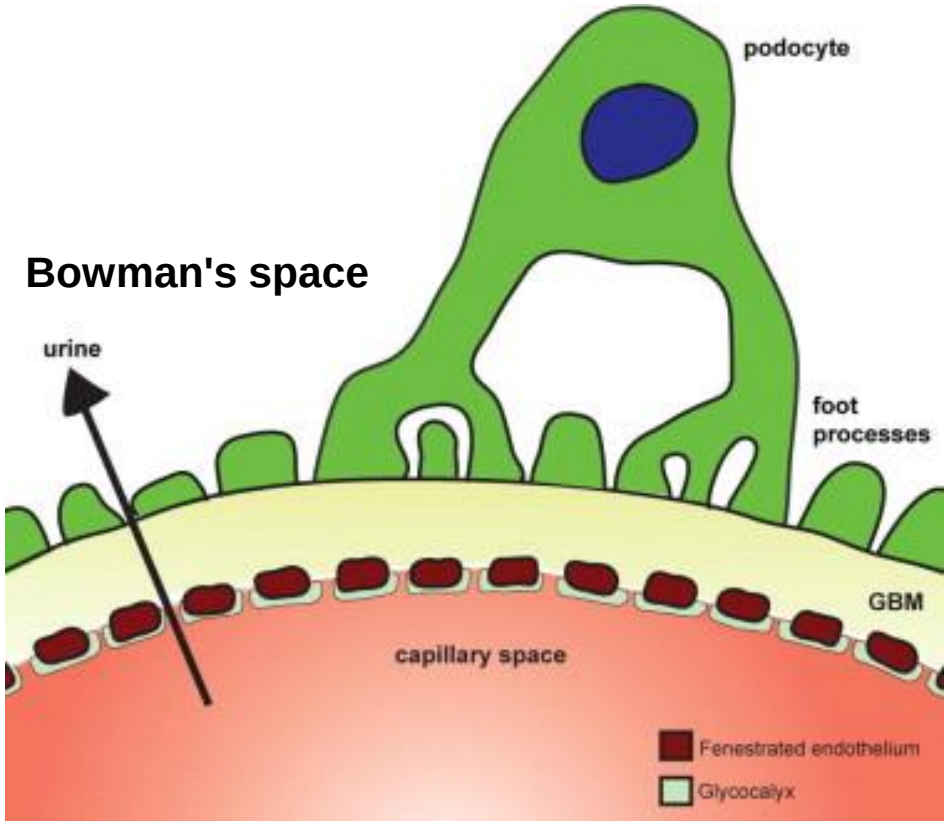



Mesangial cells produce a mesangial matrix, which contains fibronectin, type IV collagen, perlecan, and laminin.
Mesangial cells take up glomerular basal lamina material for turnover and phagocytose immunoglobulins trapped in the basal lamina.
Mesangial matrix
Lysosome
Foot process (pedicel)
Mesangial cell
Filtration slit
Capillary
Glomerular basal lamina
Cytoskeletal contractile proteins modify the blood flow through glomerular capillaries by contracting mesangial cells.
Capillary
Endothelin causes vasoconstriction of the afferent and efferent glomerular arterioles. Endothelin levels are increased in glomerular diseases.
Cytokines released by mesangial cells induce inflammatory reactions leading to occlusion of the capillary lumen.
Angiotensin II binding to the receptor stimulates mesangial cell contraction.


GLOMERULUS
Capillary loops
Urinary space
Mesangium
Red cell
Proximal tubule
Parietal epithelium
Urinary space
Mesangial cell
Mesangial matrix
Fenestrae in endothelium
Capillary lumen
Parietal epithelium
Basement membrane
Visceral epithelium
Foot processes
Basement membrane
Endothelium
Red cell
Foot processes

Glomerulus

- is a network (tuft) of capillaries that performs the **first step of filtering blood**



Filtration barrier

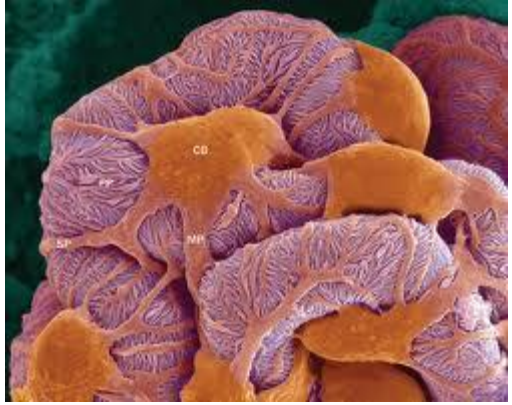
- the blood plasma is filtered through the capillaries of the glomerulus

- **glomerular capillary endothelial cells** (contain numerous pores – fenestrae), **glomerular basement membrane** (very thick), and **podocytes** (visceral layer of Bowman's capsule)

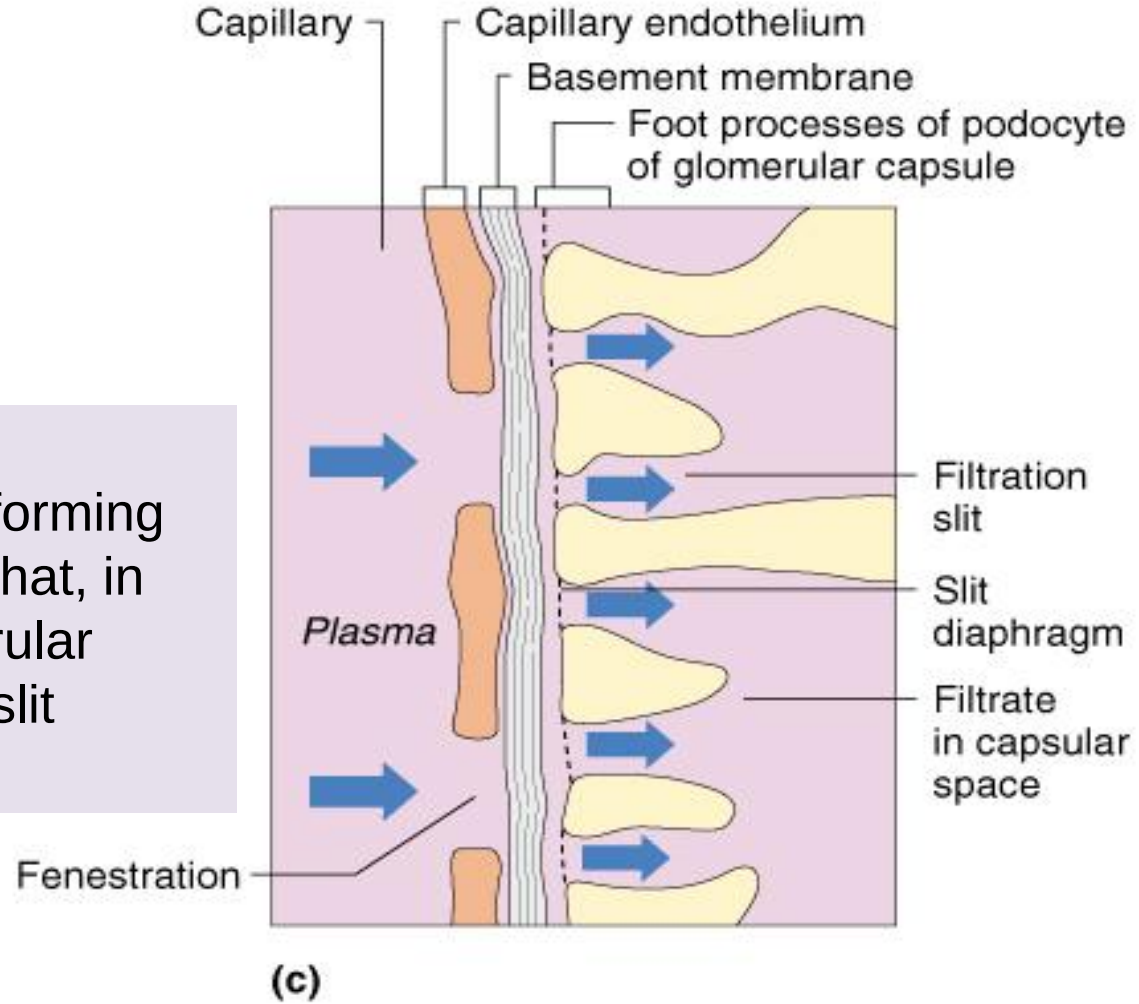
Intraglomerular mesangial cells are not part of the filtration barrier but are specialized pericytes that participate indirectly in filtration by contracting and reducing the glomerular surface area

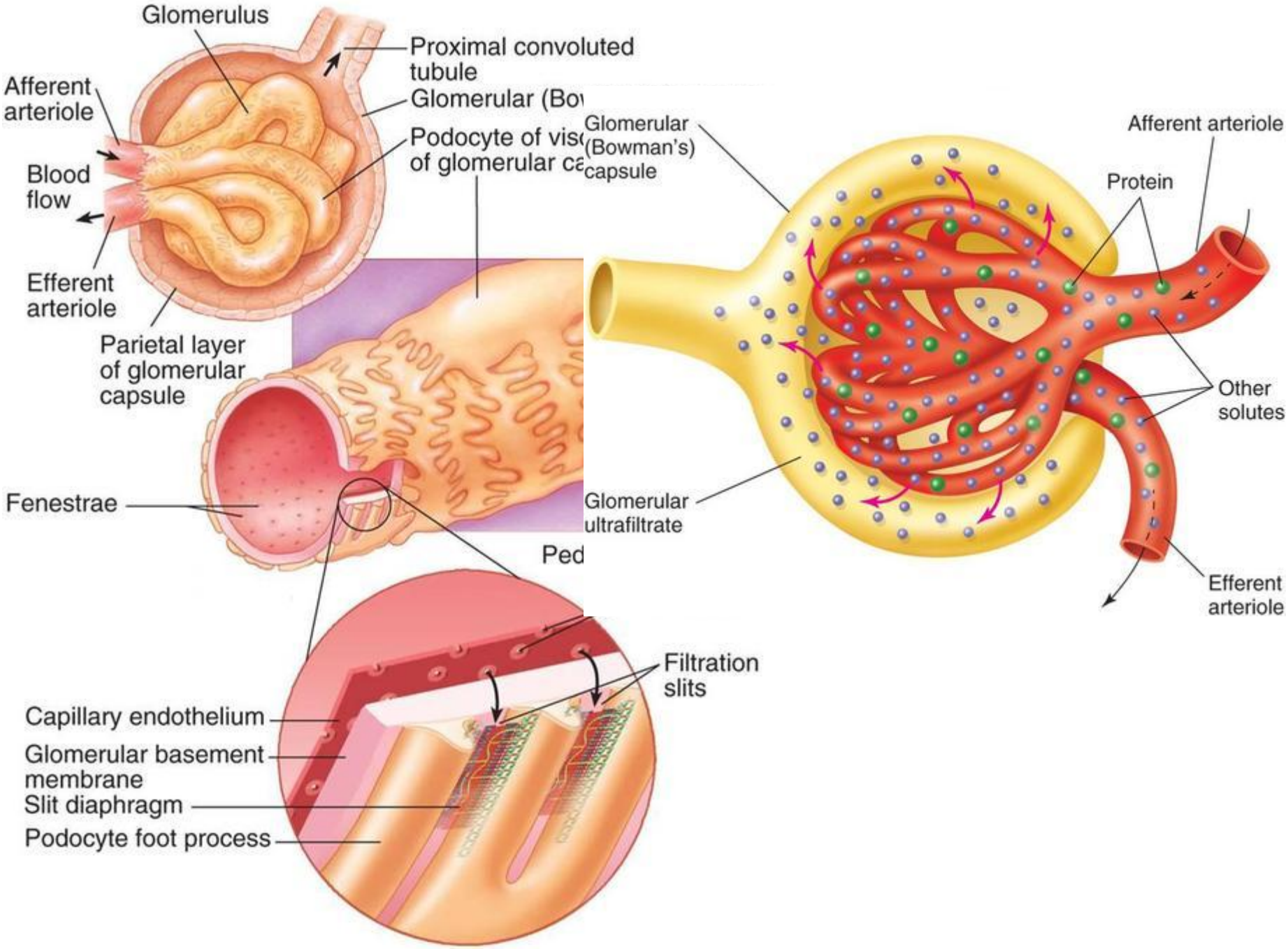
Podocytes

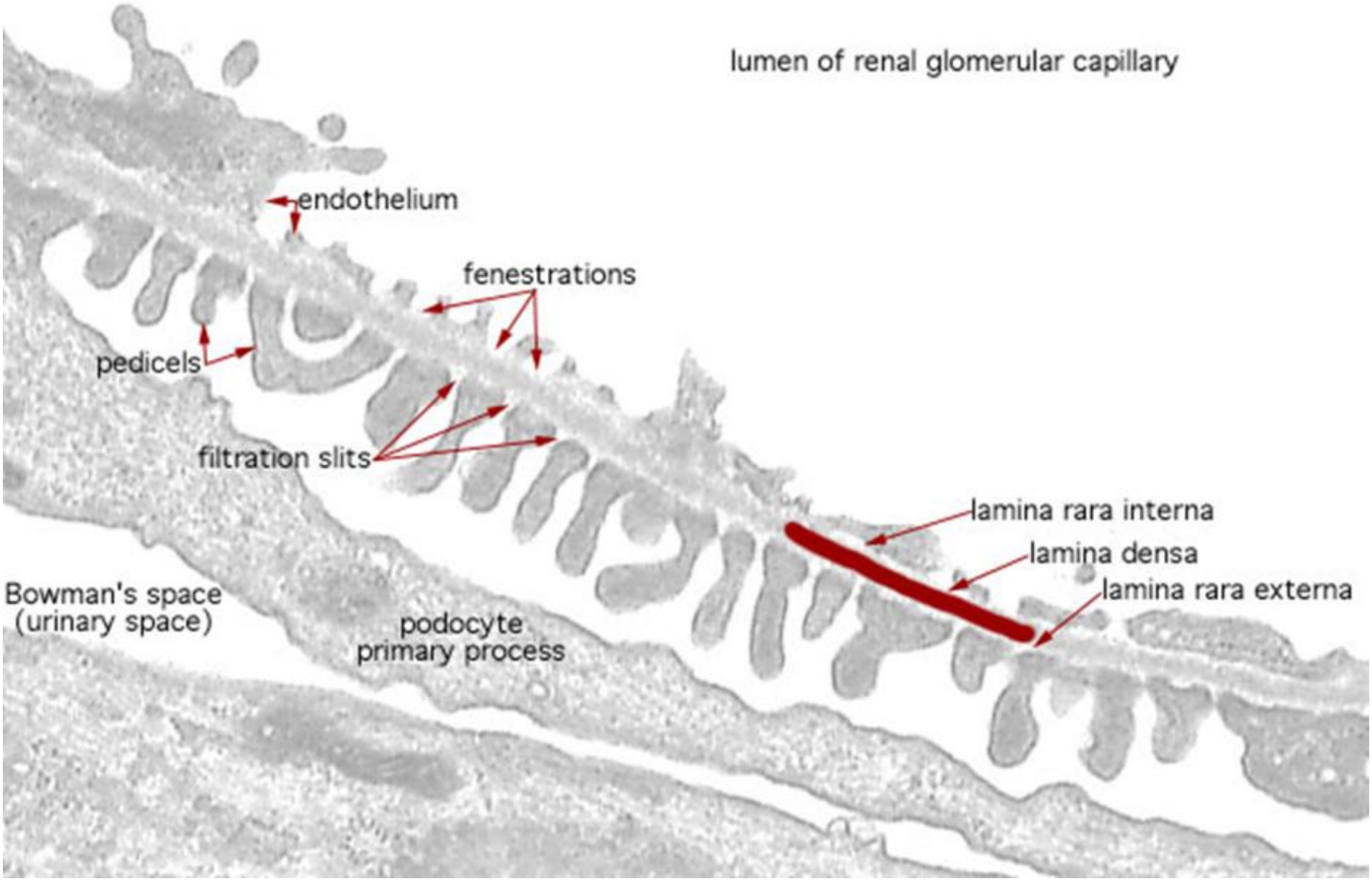
- cells of visceral layer of Bowman's capsule
- highly modified to perform a filtering function
- have numerous, long prosesses and secondary processes – **pidicels**

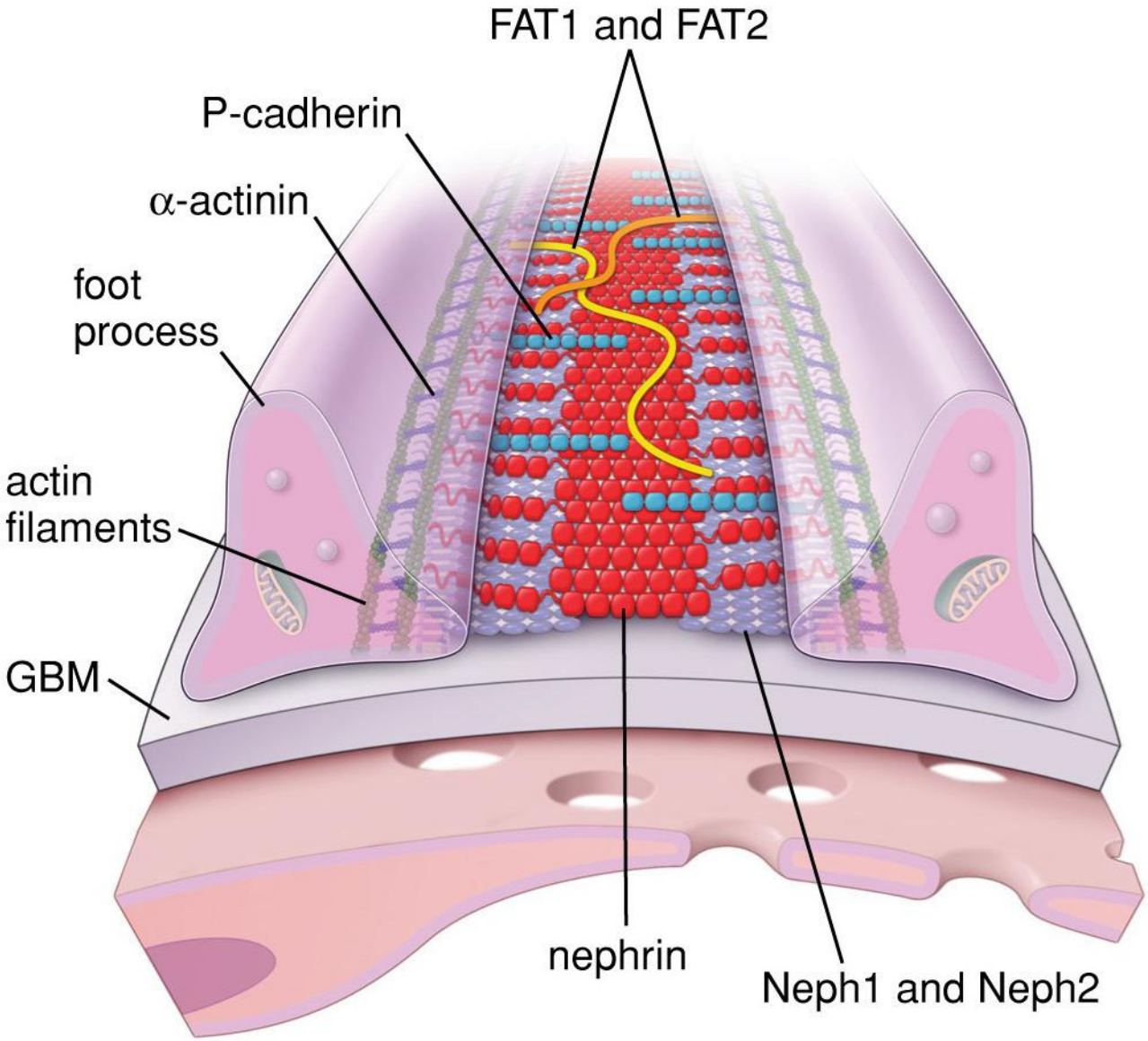


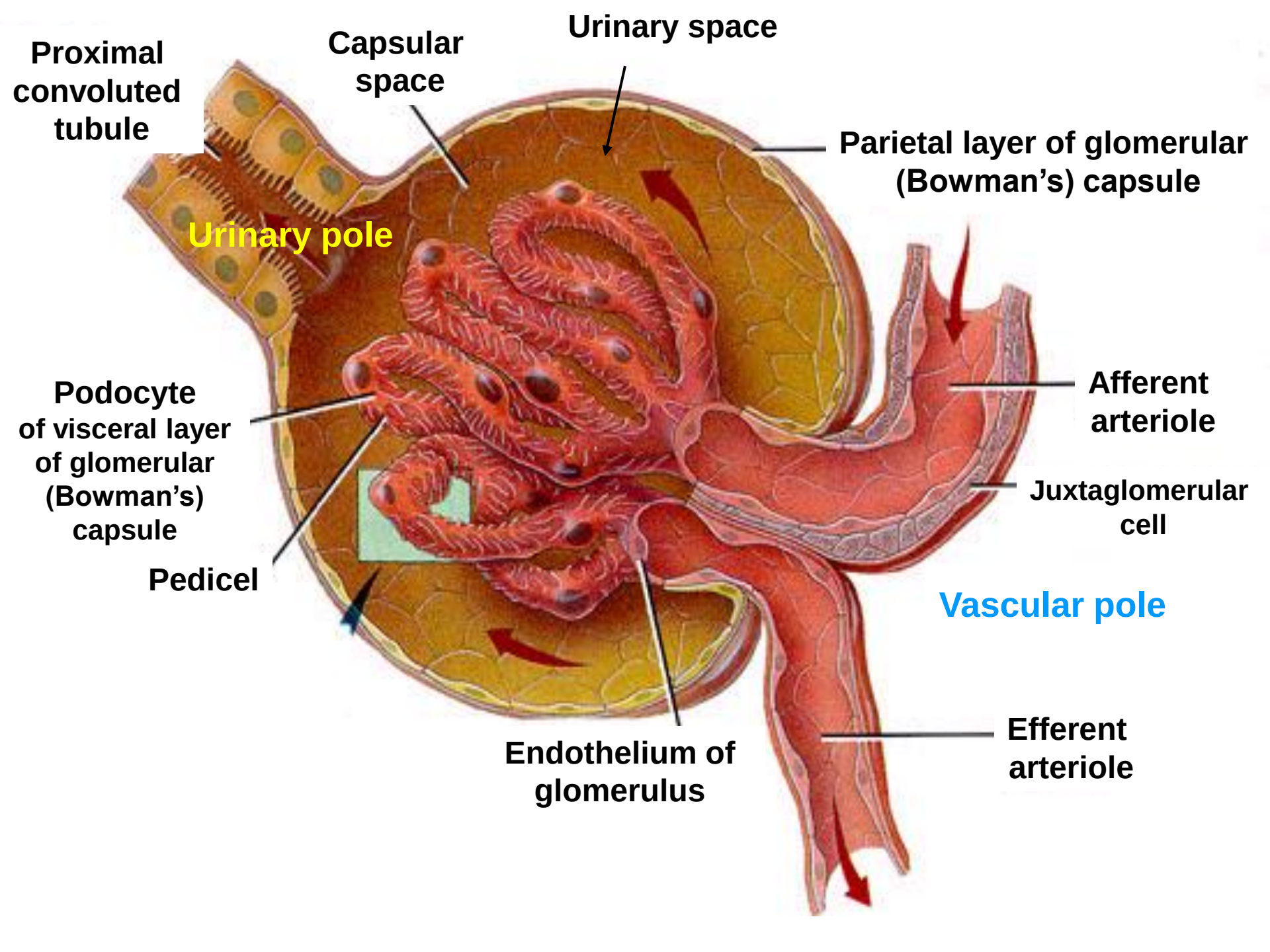
Foot processes of podocytes interdigitate with one another forming **filtration slits** (or **slit pores**) that, in contrast to those in the glomerular endothelium, are spanned by slit **diaphragms**.

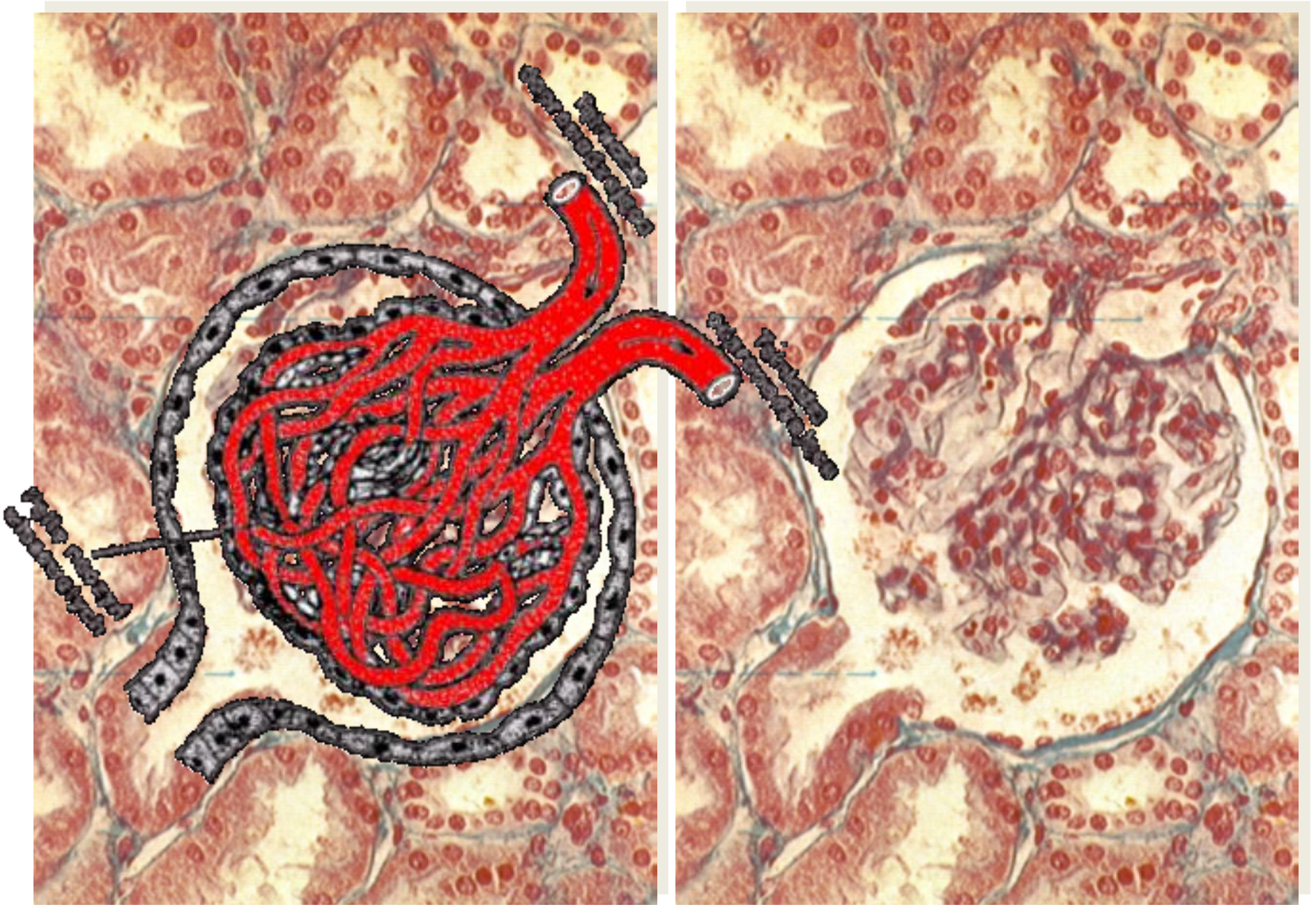



Glomerulus
Proximal convoluted tubule
Afferent arteriole
Glomerular (Bo
Podocyte of visc
of glomerular ca
Blood flow
Efferent arteriole
Parietal layer of glomerular capsule
Fenestrae
Ped
Glomerular (Bowman's) capsule
Afferent arteriole
Protein
Other solutes
Glomerular ultrafiltrate
Efferent arteriole
Filtration slits
Capillary endothelium
Glomerular basement membrane
Slit diaphragm
Podocyte foot process


lumen of renal glomerular capillary
endothelium
fenestrations
pedicels
filtration slits
lamina rara interna
lamina densa
lamina rara externa
Bowman's space
(urinary space)
podocyte
primary process

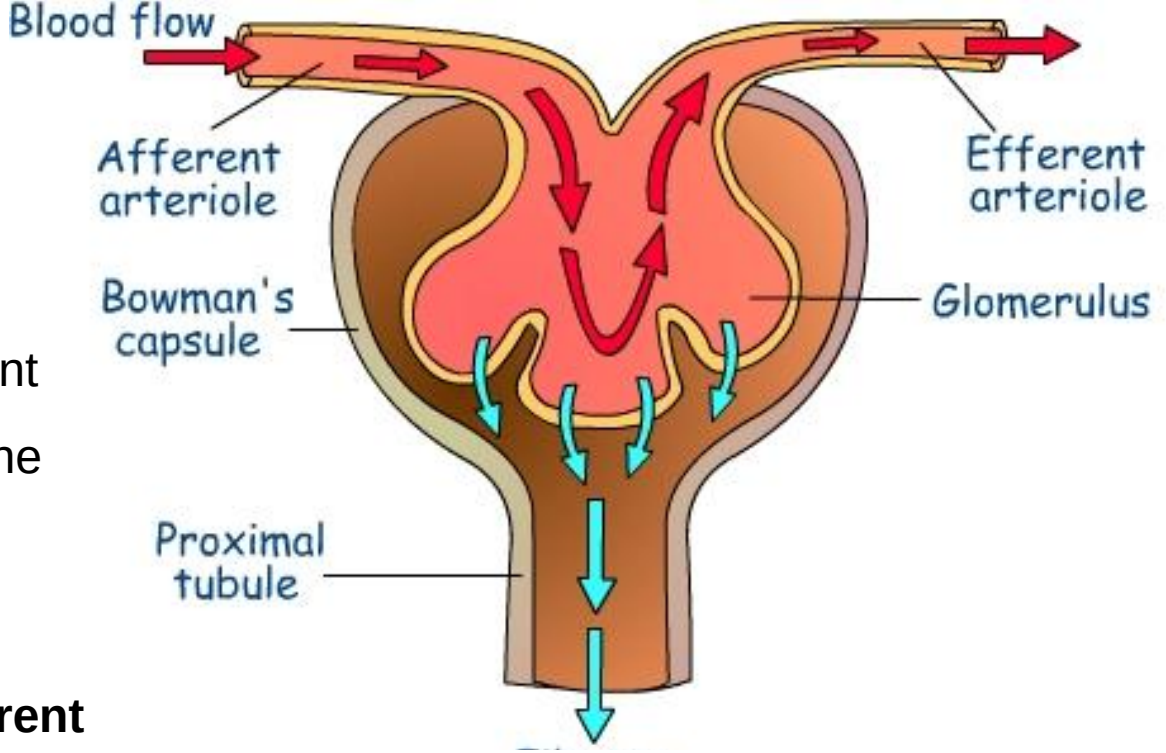



Proximal convoluted tubule
Capsular space
Urinary space
Parietal layer of glomerular (Bowman's) capsule
Urinary pole
Podocyte of visceral layer of glomerular (Bowman's) capsule
Afferent arteriole
Juxtaglomerular cell
Pedicel
Vascular pole
Endothelium of glomerulus
Efferent arteriole



Glomerular capillaries

Filtration process

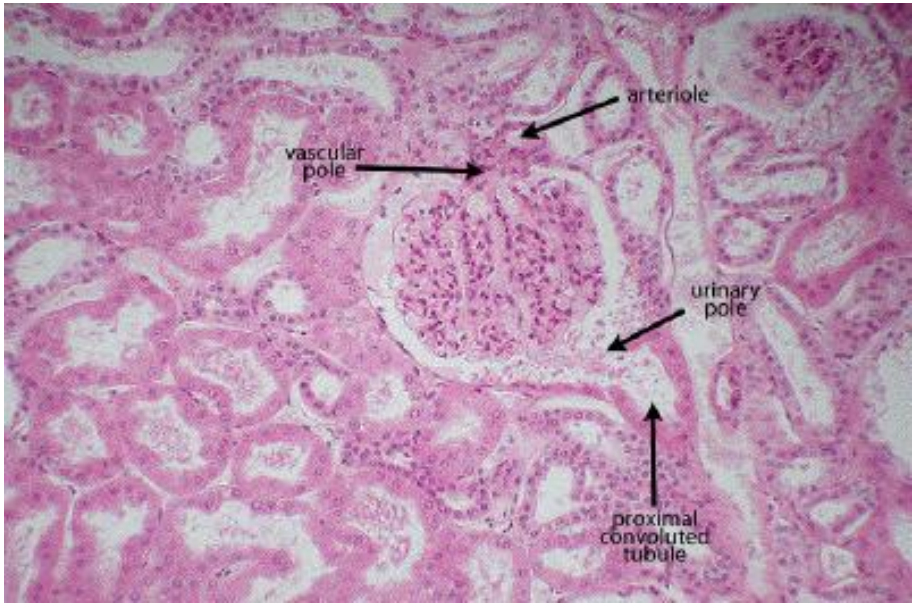


- blood flows through the afferent arteriole and leaves through the efferent arteriole.

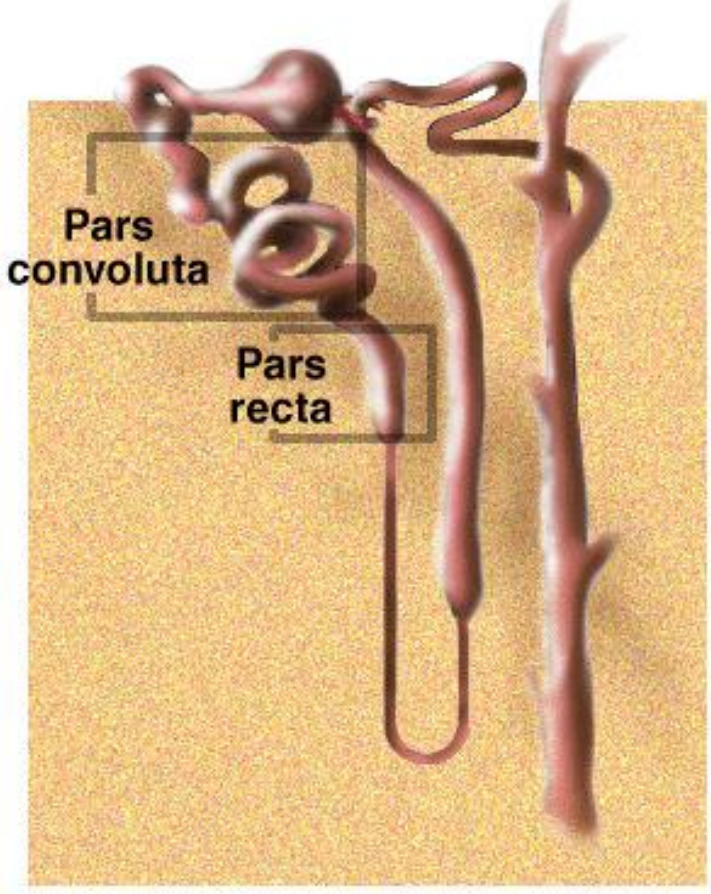
- the blood pressure in the **efferent arteriole** is **higher** than the blood pressure in the afferent arteriole.

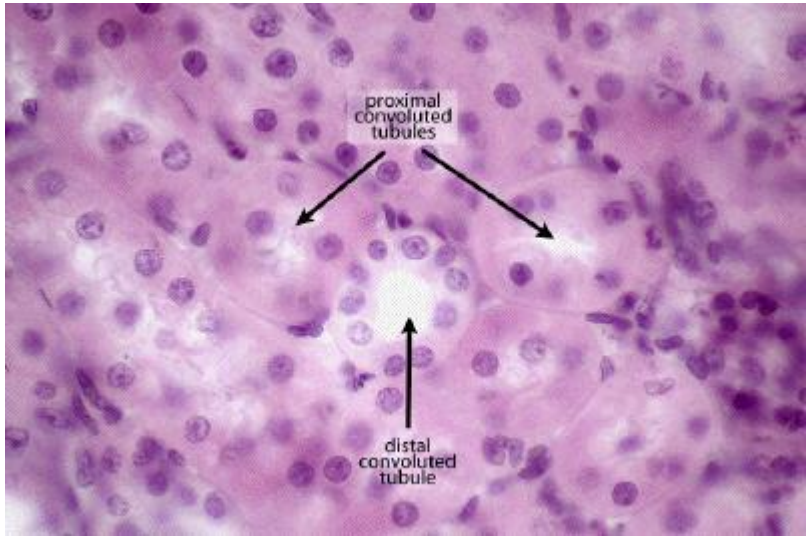
Glomerular ultrafiltrate
(contains water, glucose, amino acids, sodium chloride and urea)

- the high hydrostatic pressure forces small molecules through the filter, from the blood, across the filtration barrier, into the nephron. The fluid filtered in this way is called **glomerular filtrate**.



From Bowman's space glomerular filtrate flows to the **proximal tubule** at the urinary pole





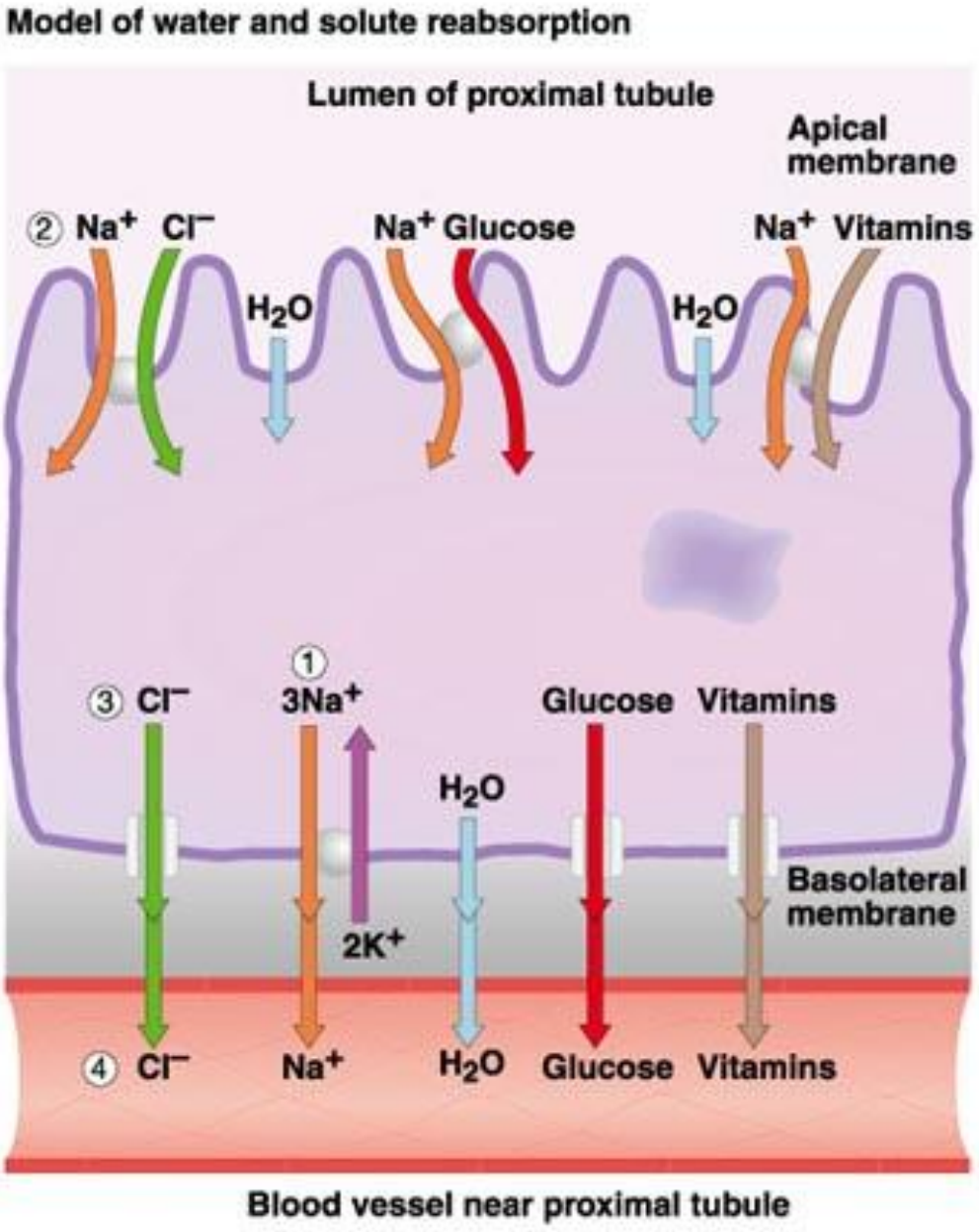
proximal convoluted tubule – is composed of simple cuboidal epithelium

Proximal tubule has two regions: **proximal convoluted tubule (pars convoluta)** and **descending thick limb of Henle's loop (pars recta)**

Function of proximal tubules

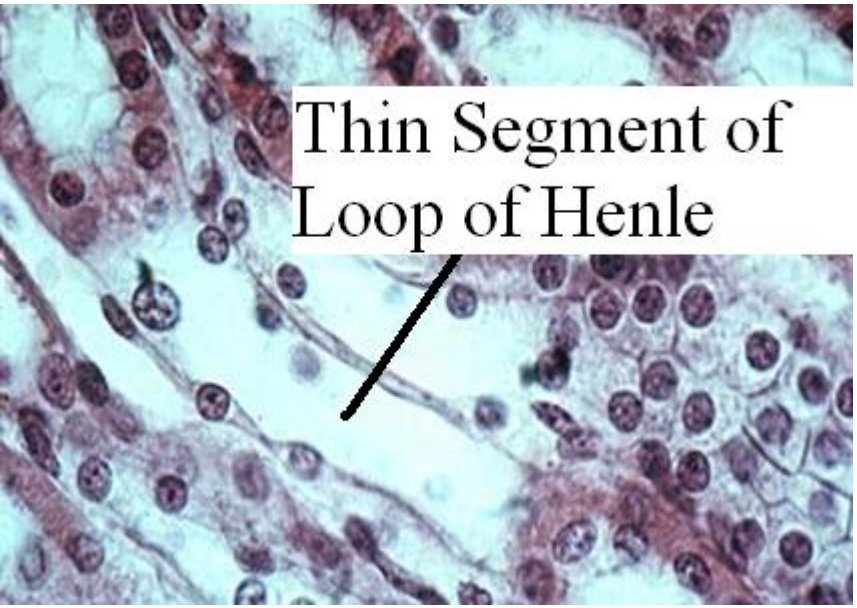
Cells of **proximal tubule** transport from the ultrafiltrate into the connective tissue stroma:

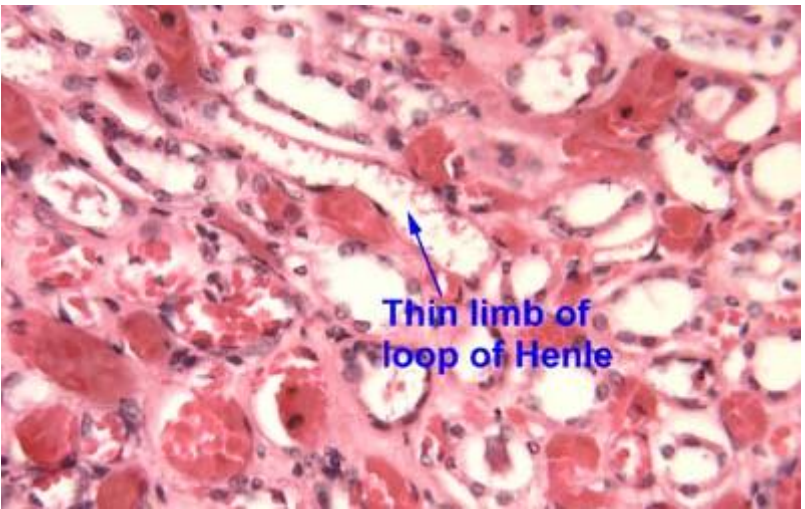
- **Na^+ and Cl^- ions**
- **Water (aquaporin channels)**
- **Glucose, amino acids and vitamins (endocytosis)**

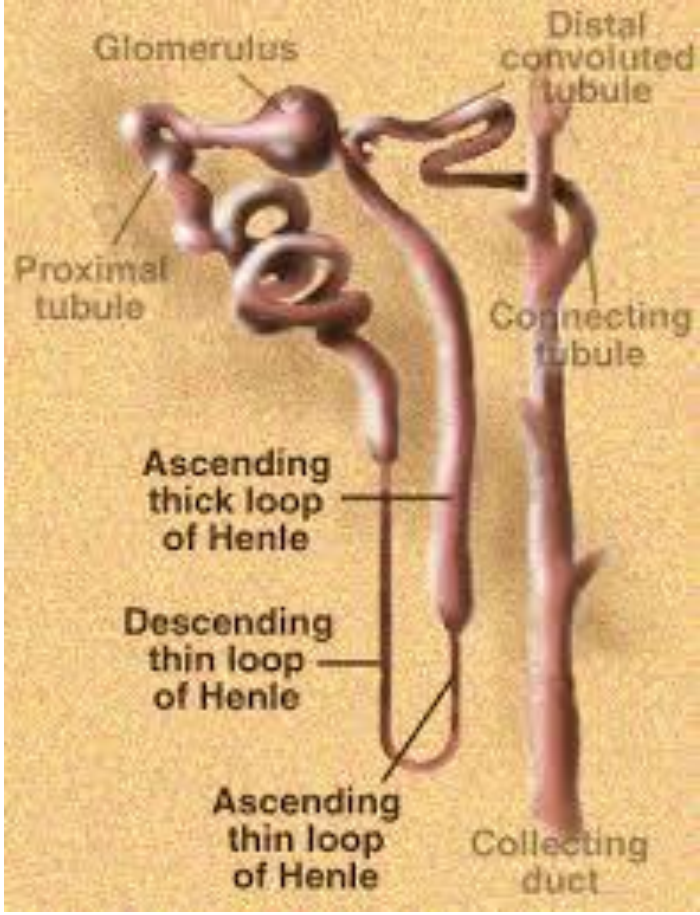


Thin limbs of Henle's loop

- leads from the **proximal convoluted** tubule to the distal convoluted tubule







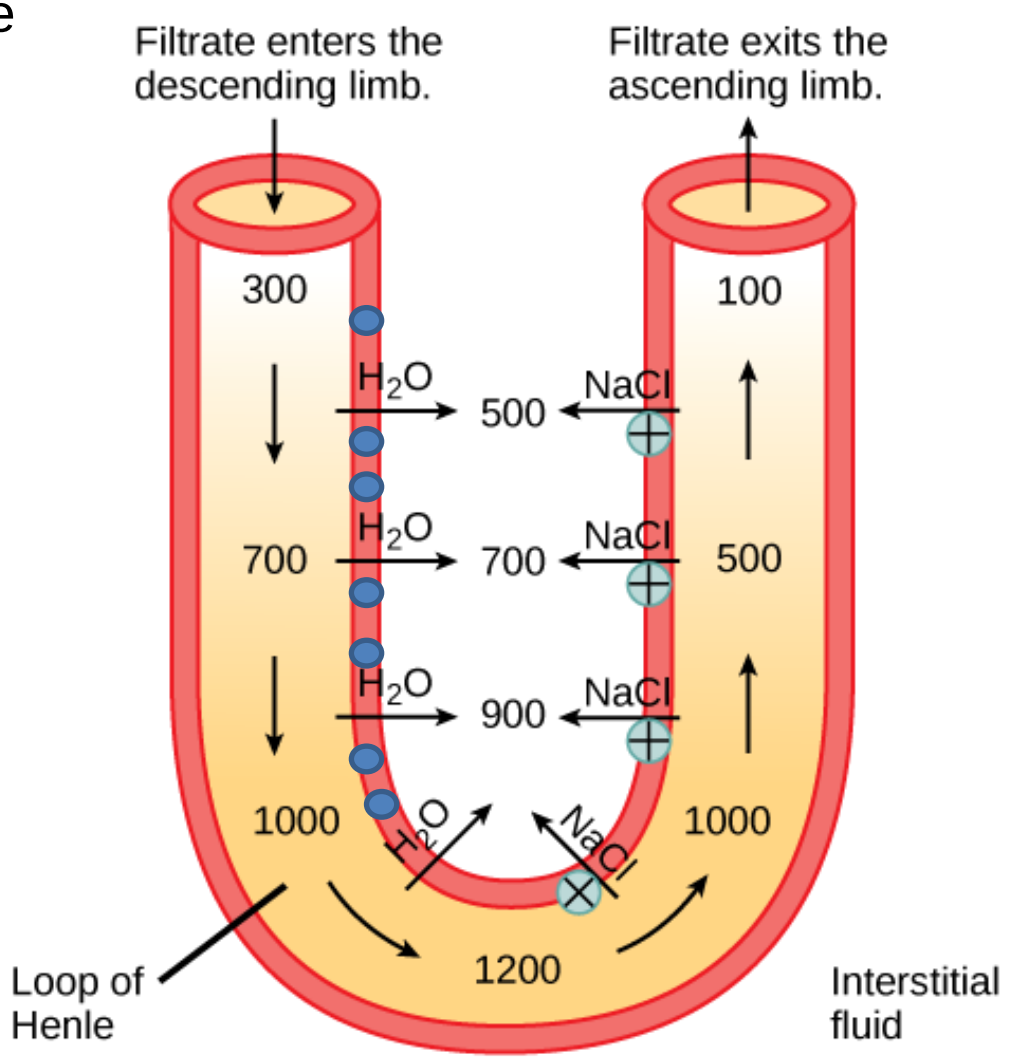
- Descending thin limb
- Henle's loop
- Ascending thin limb

- is composed of squamous epithelial cells
- resembles capillary in cross section

Thin limbs of Henle's loop - function

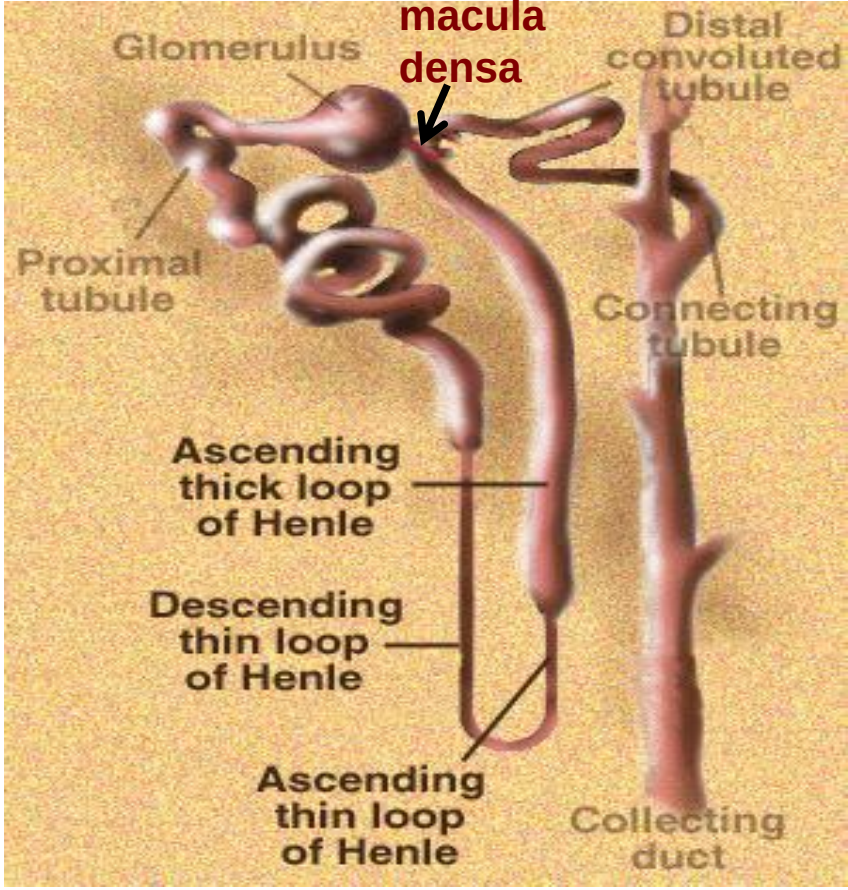
- the thin descending limb has **low** permeability to ions and urea, while being **highly** permeable to water (the concentration of the urine increases dramatically)
- the thin ascending limb is impermeable to water, but it is permeable to ions

- **contains aquaporins – water channels**

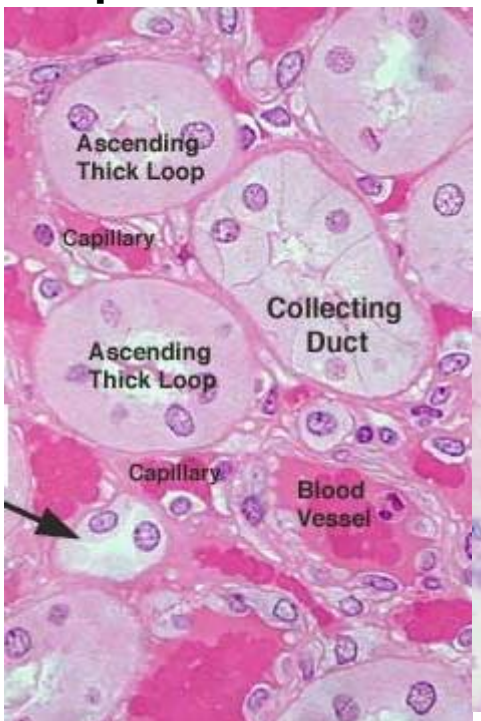


Distal tubule

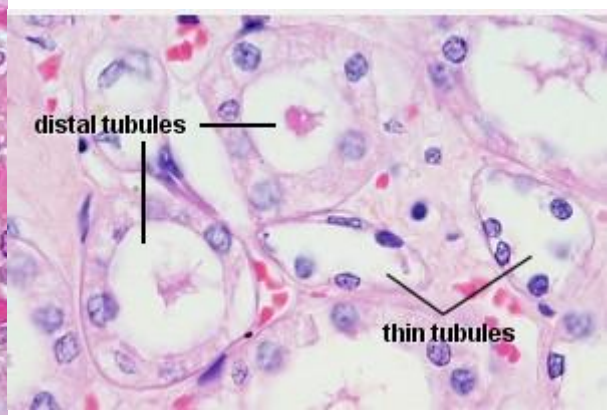
- the pars recta (the ascending thick limb of Henle's loop)
- the macula densa (closely packed specialized cells lining the wall of the distal convoluted tubule)
- the pars convoluta (the distal convoluted tubule)



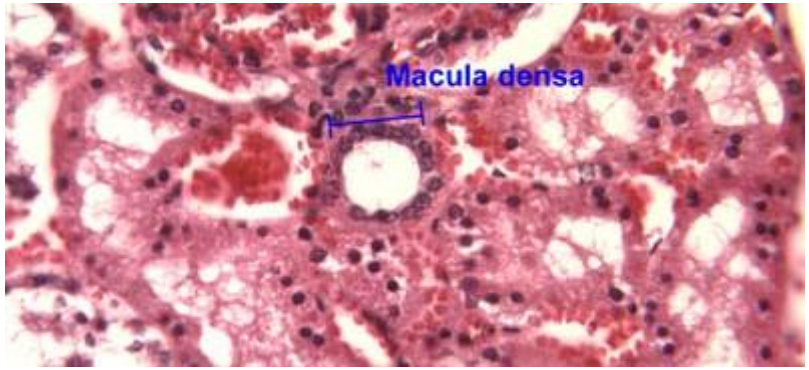
- low cuboidal epithelial cells



- low cuboidal epithelial cells
- the lumen is wide-open



- **modified cells of distal tubule**
- **cells are tall and narrow**



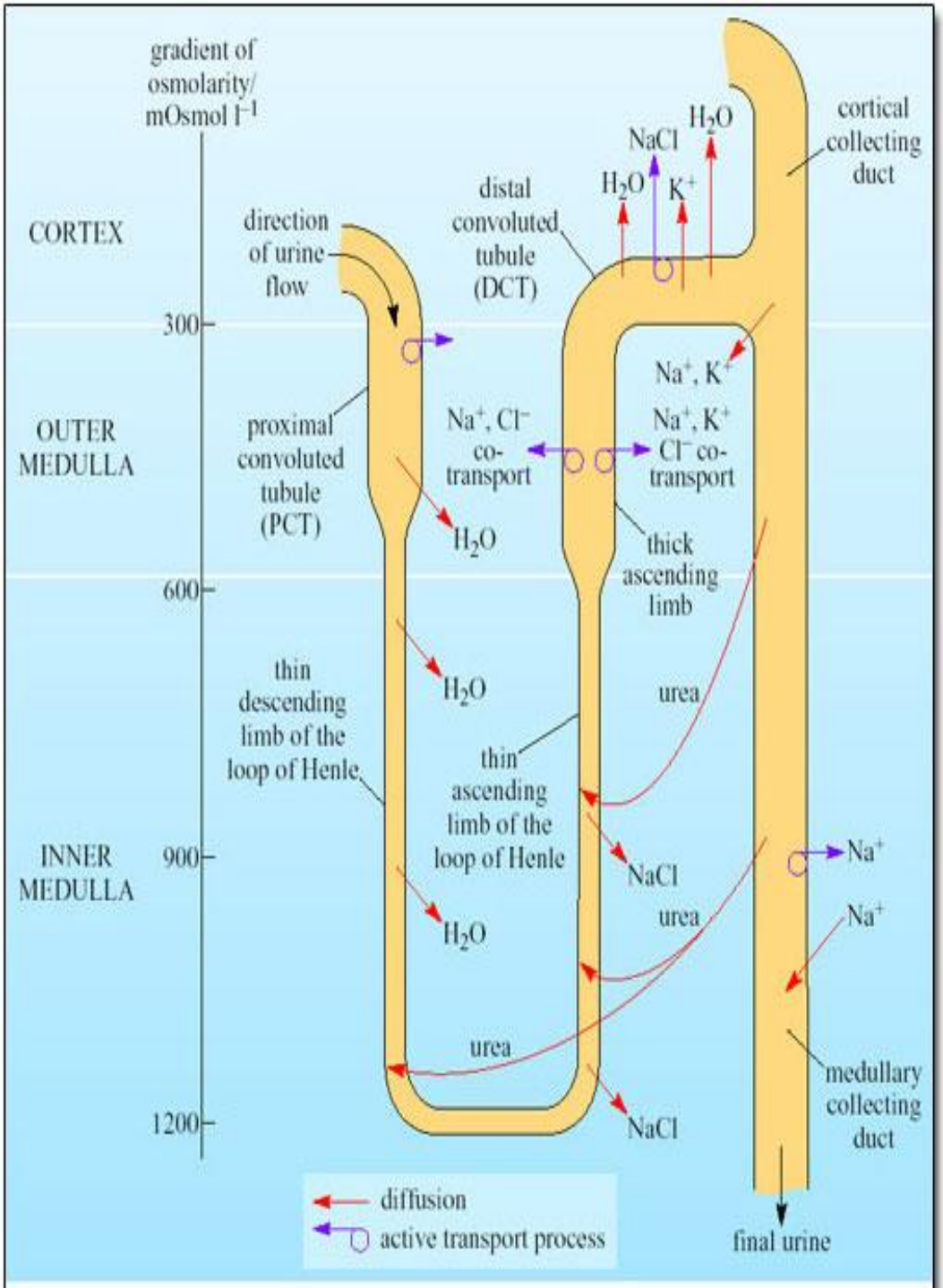
Distal tubule – function

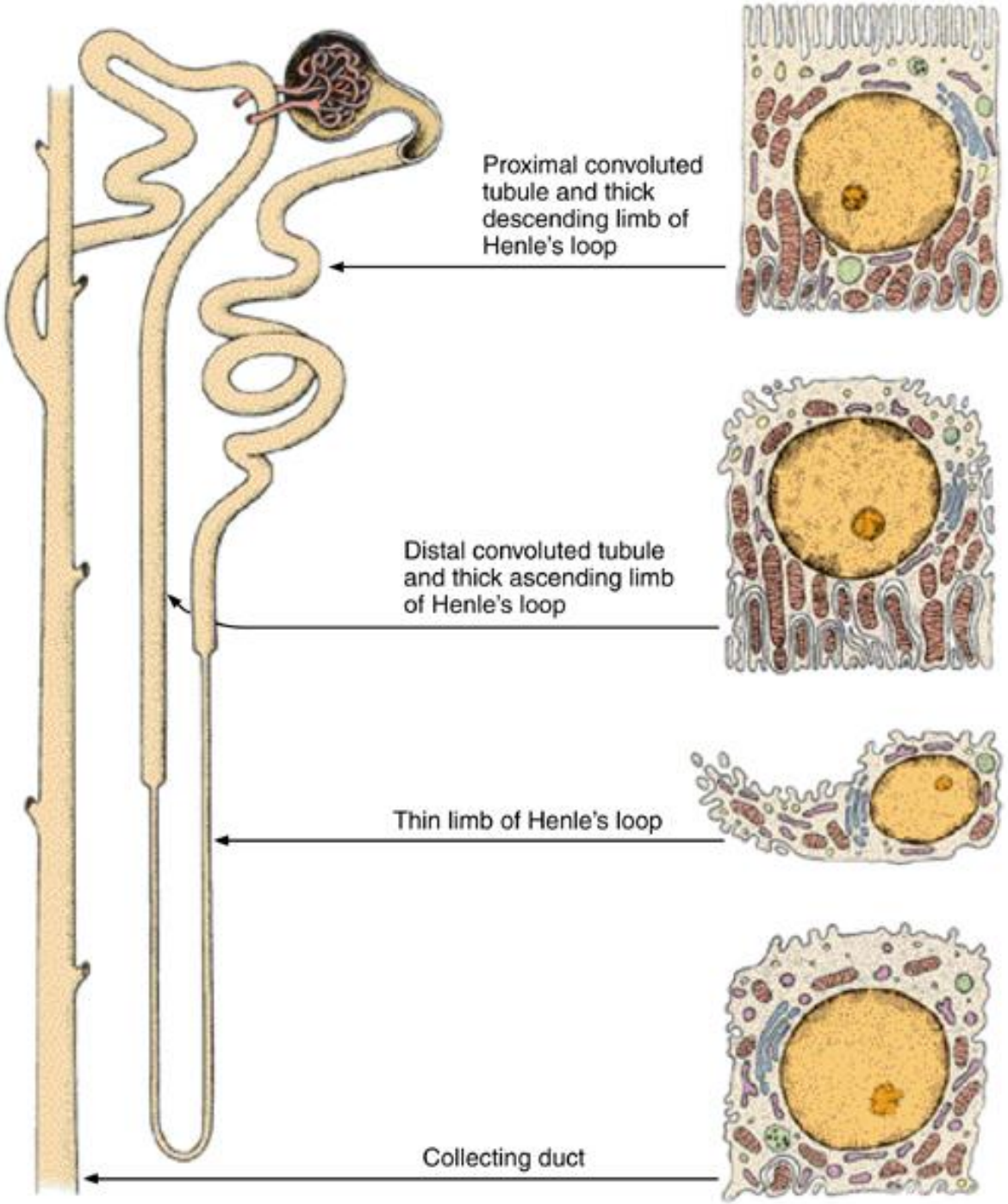
Thick ascending limb of Henle's loop

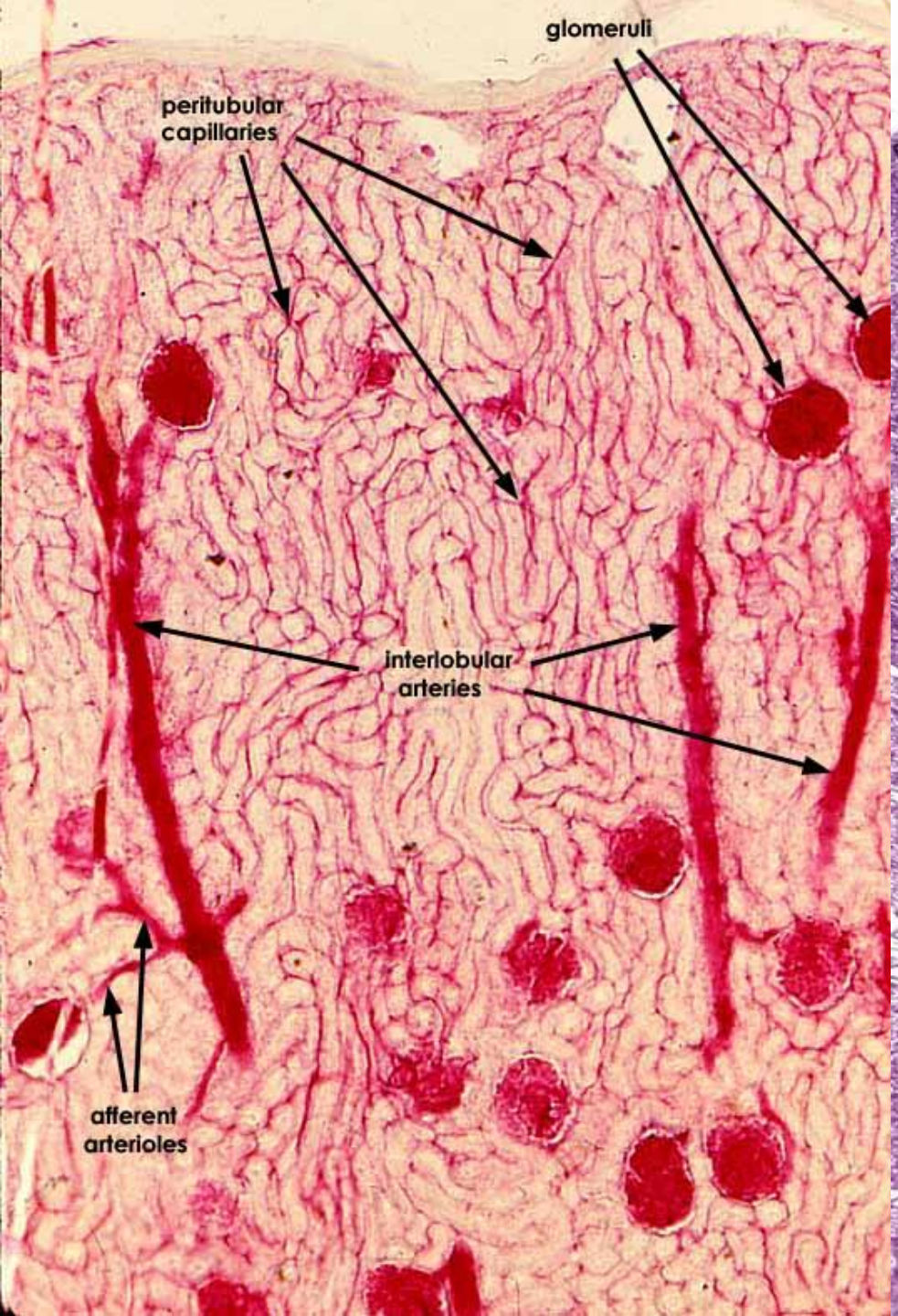
- is impermeable to water
- cells have chloride and sodium pumps (active transport of ions from the lumen of the tubule)

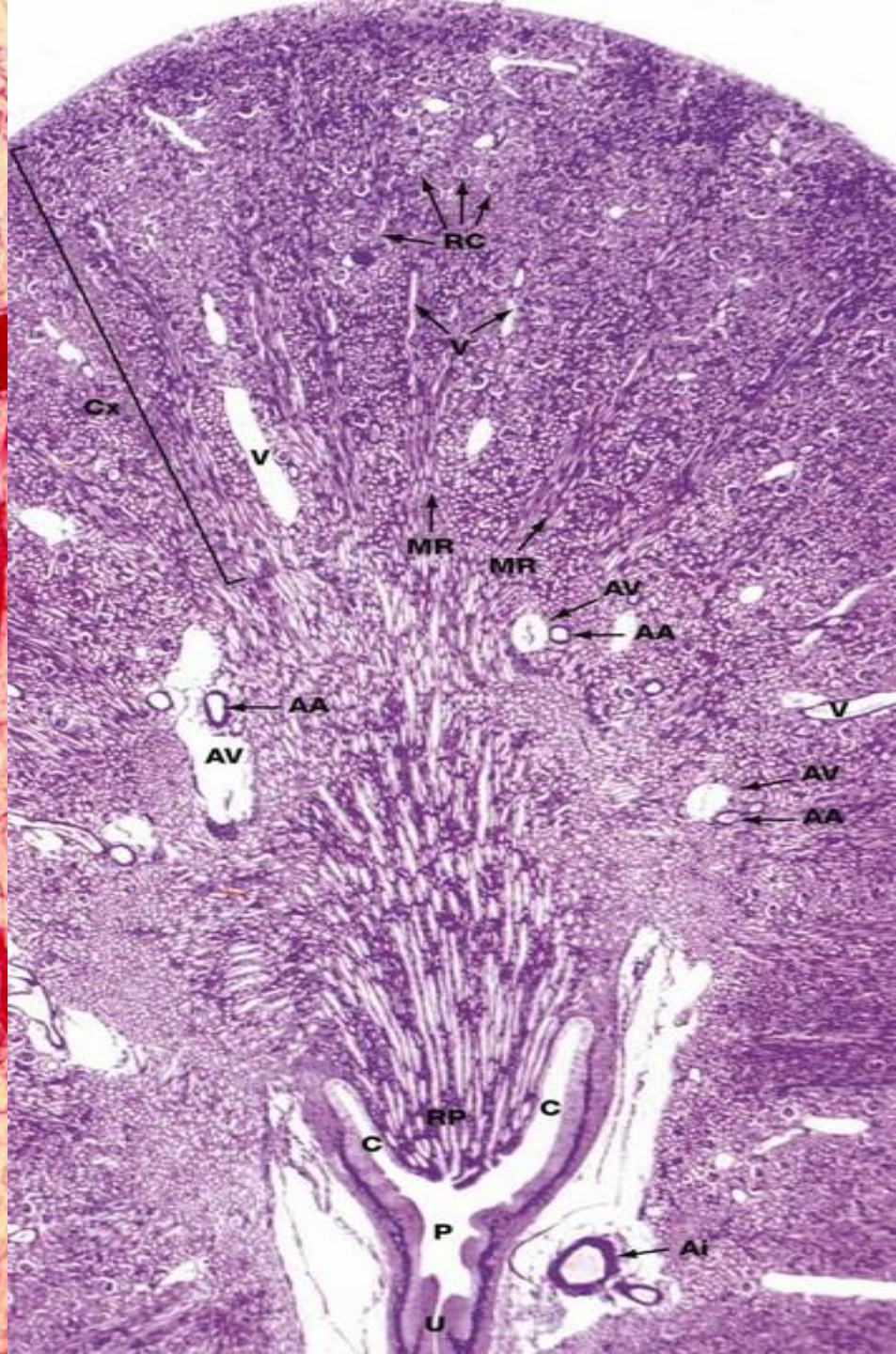
Distal convoluted tubule

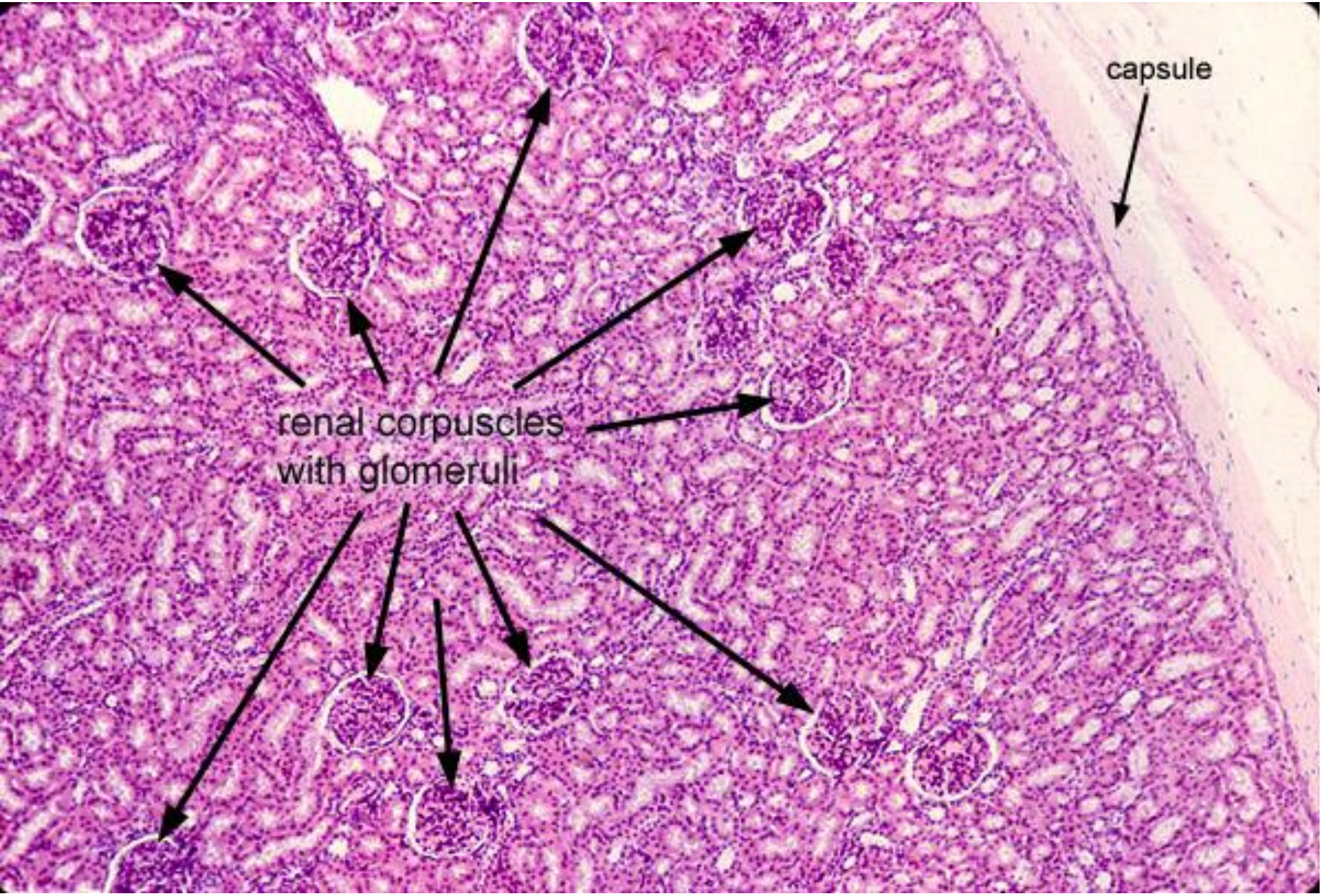
- is partly responsible for the regulation of potassium, sodium, calcium concentration (cells have pumps for ions)
- sodium absorption by the distal tubule is mediated by the hormone **aldosterone (**zona glomerulosa of the adrenal cortex)

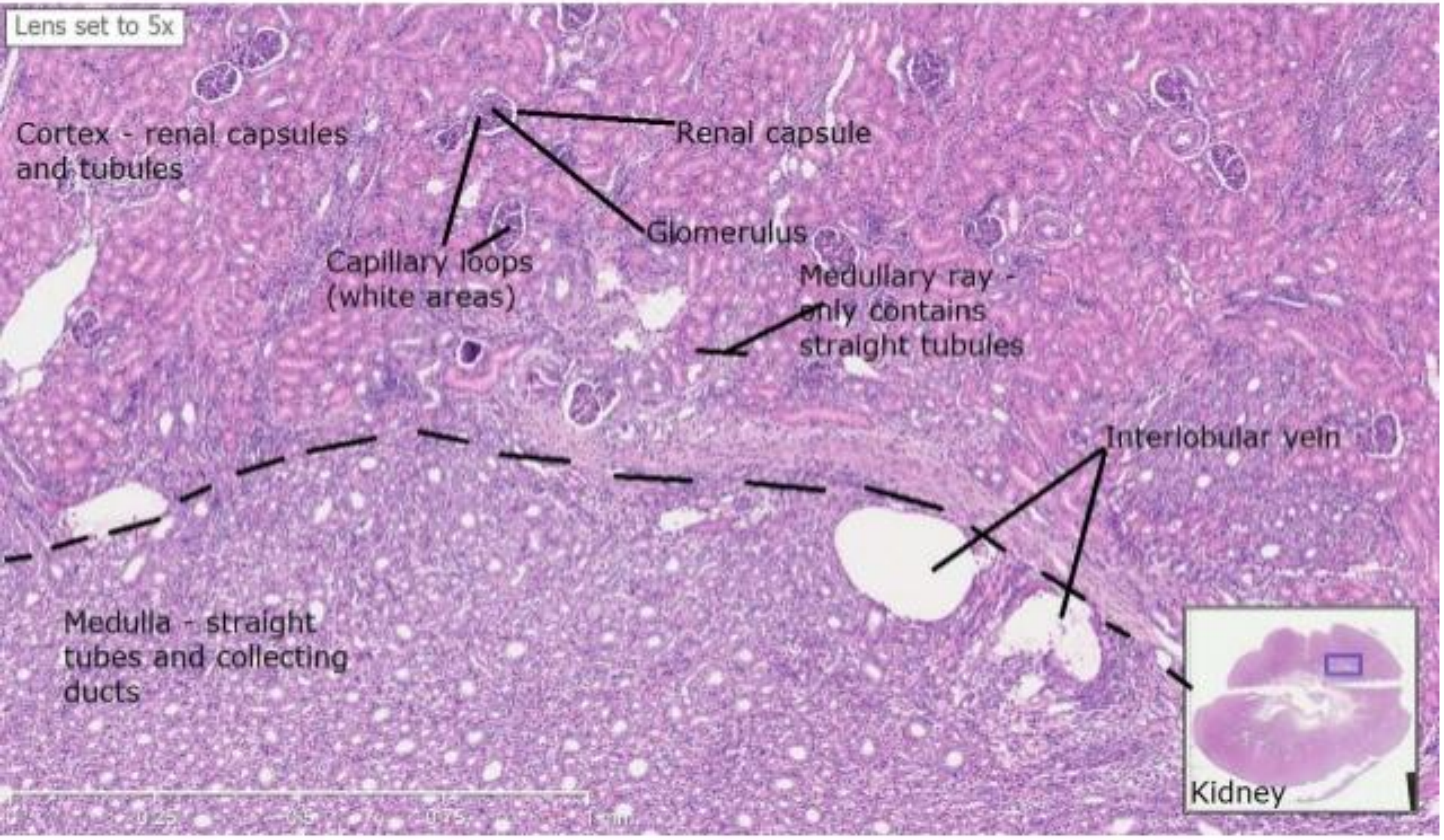


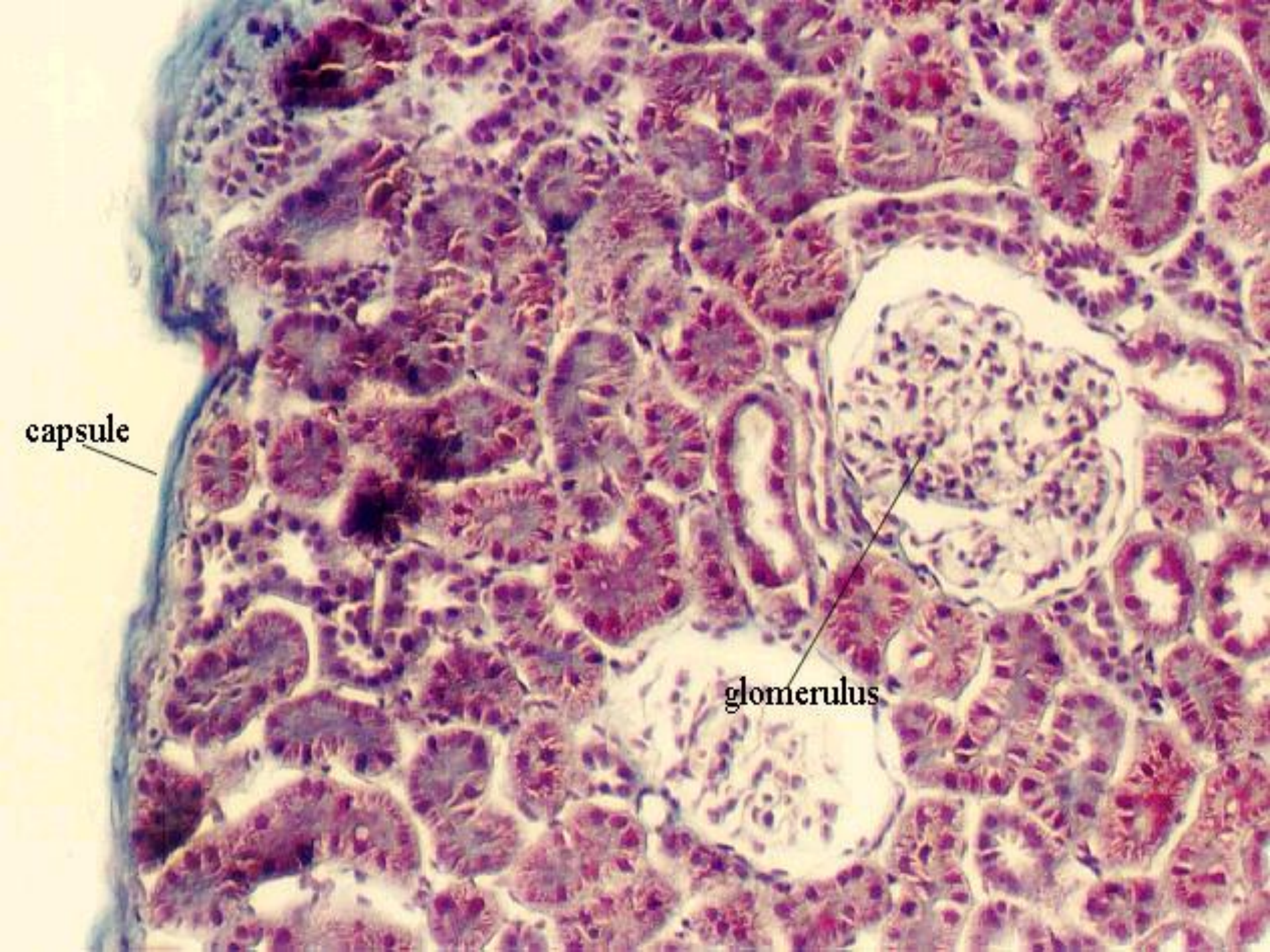

Proximal convoluted tubule and thick descending limb of Henle's loop
Distal convoluted tubule and thick ascending limb of Henle's loop
Thin limb of Henle's loop
Collecting duct

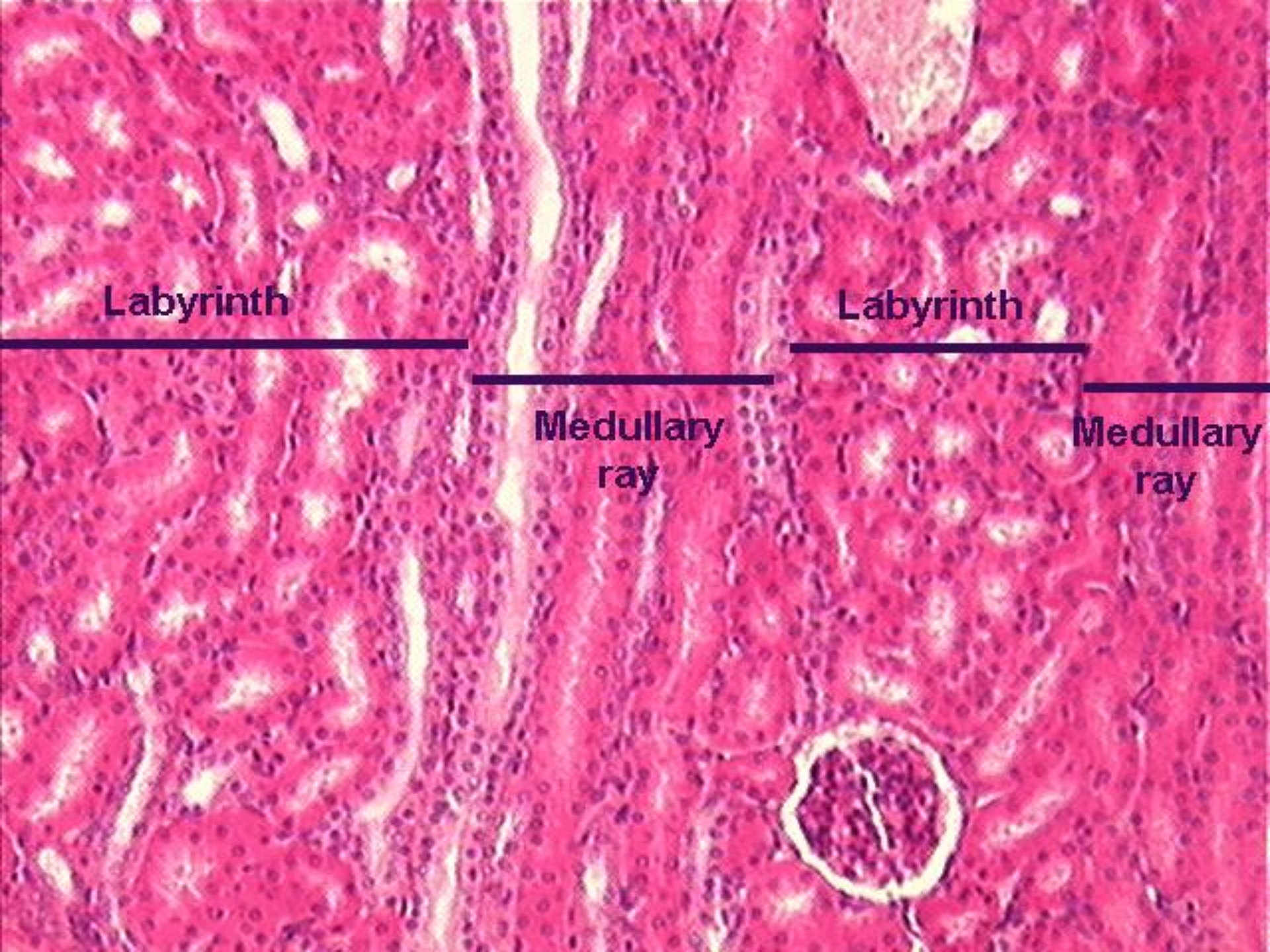

glomeruli
peritubular capillaries
interlobular arteries
afferent arterioles

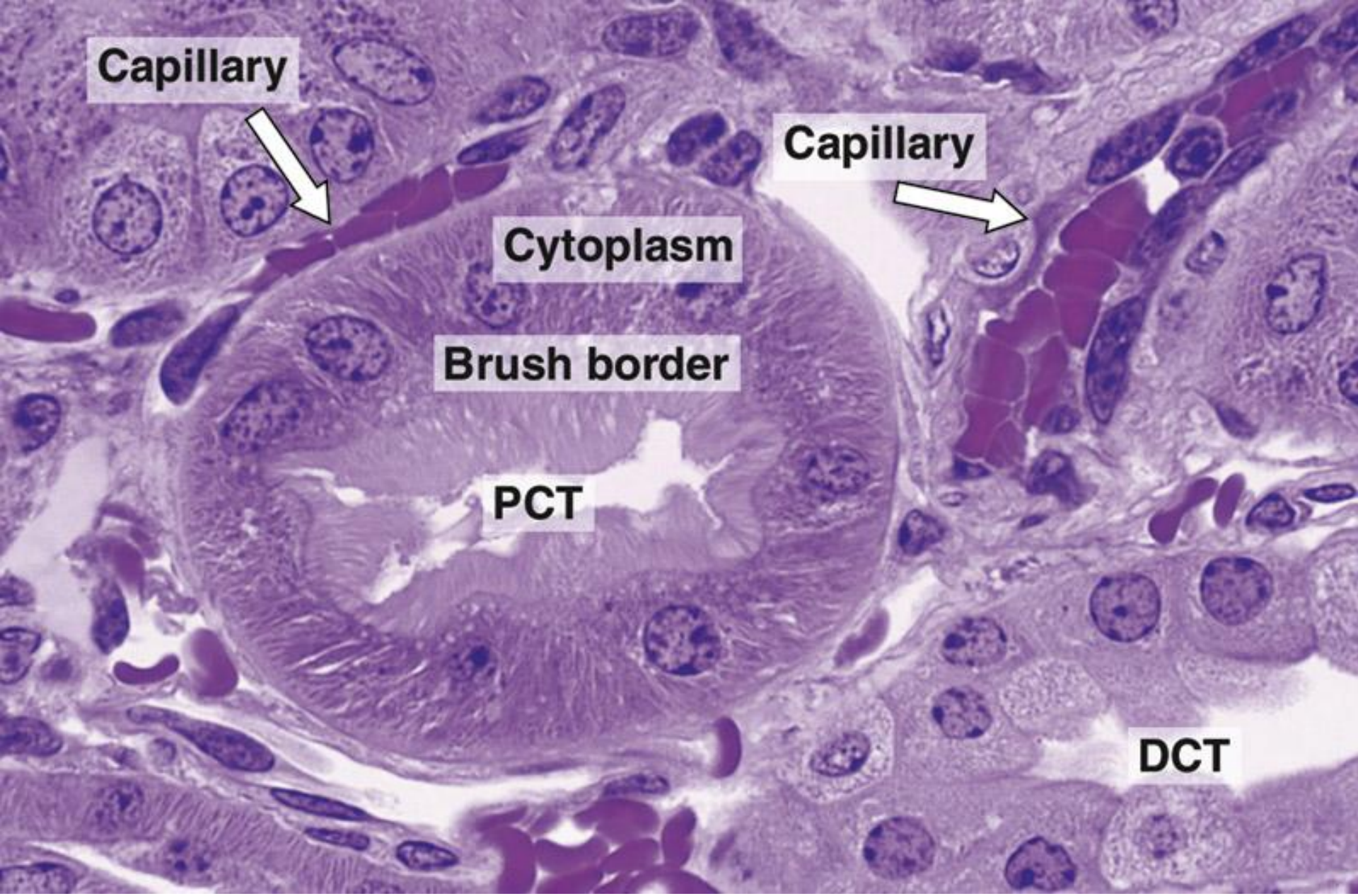

RC
V
Cx
V
MR
MR
AV
AA
AA
AV
V
AV
AA
C
RP
C
C
P
U
Ai


capsule
renal corpuscles
with glomeruli

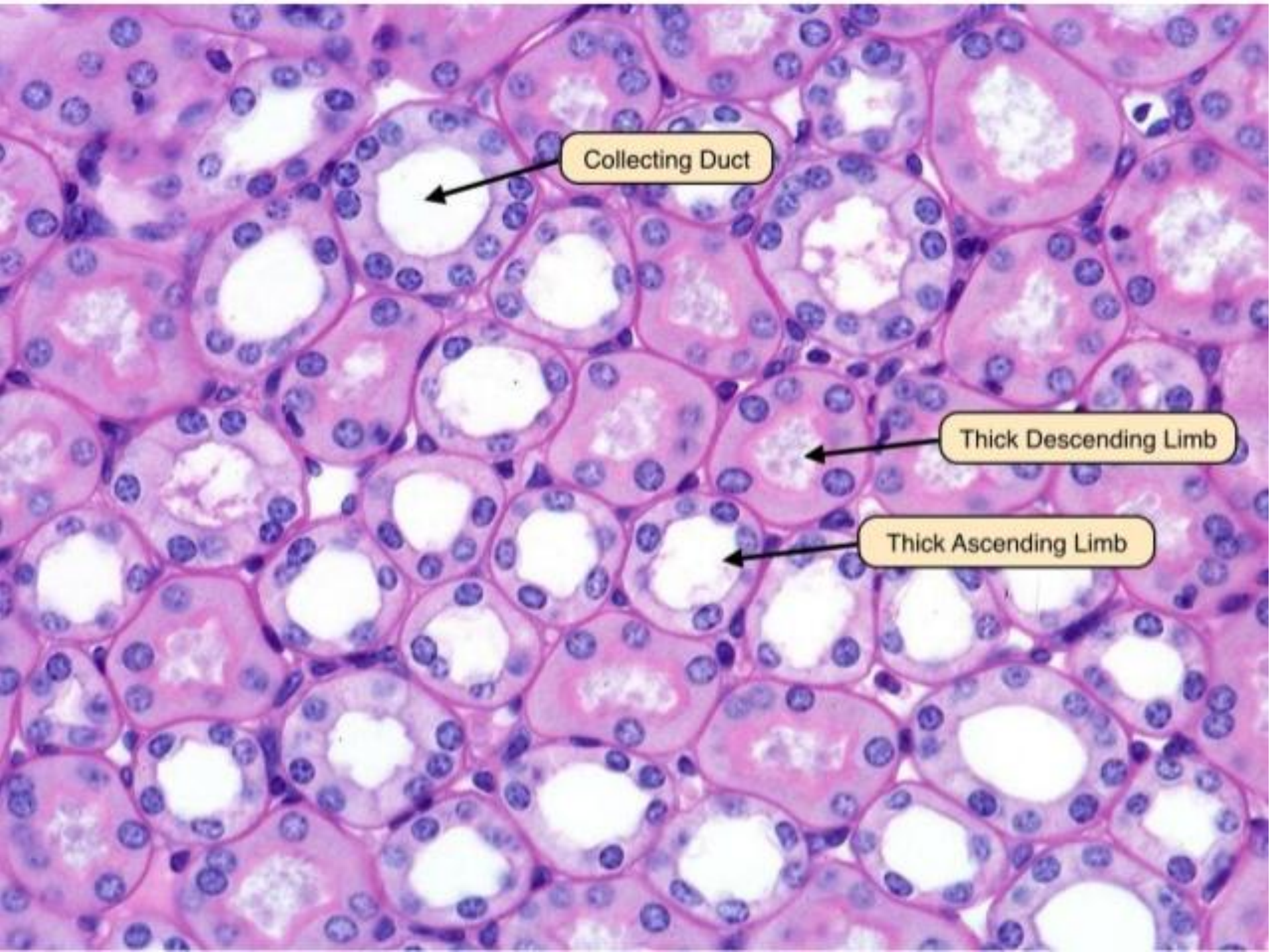

Lens set to 5x
Cortex - renal capsules and tubules
Renal capsule
Glomerulus
Capillary loops (white areas)
Medullary ray - only contains straight tubules
Interlobular vein
Medulla - straight tubes and collecting ducts
Kidney


capsule
glomerulus


Labyrinth
Medullary ray
Labyrinth
Medullary ray

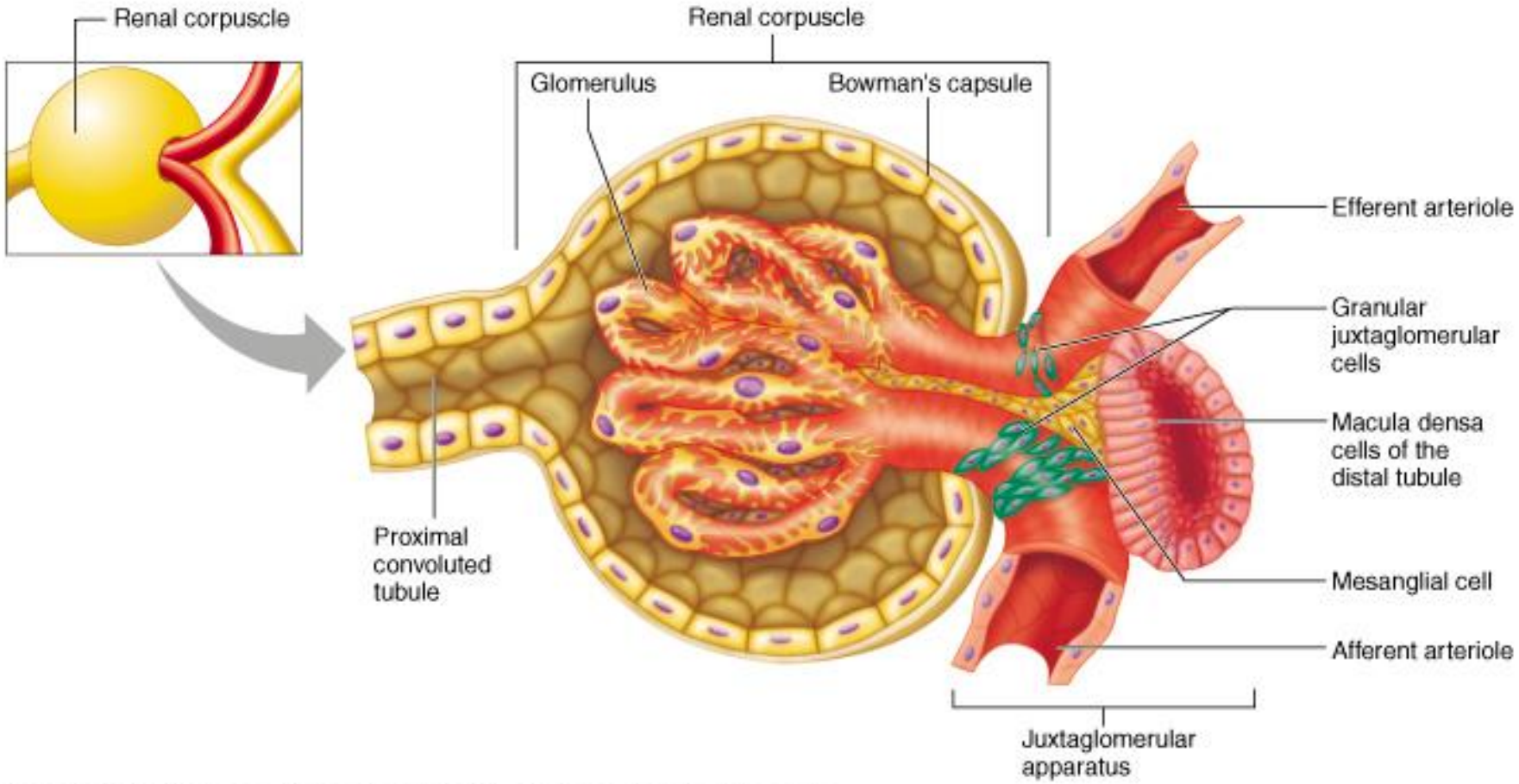


Renal cortex section showing a proximal convoluted tubule (PCT) with its large cuboidal cells presenting a brush border formed by numerous microvilli. Distal convoluted tubules (DCT) are also present.


Collecting Duct
Thick Descending Limb
Thick Ascending Limb

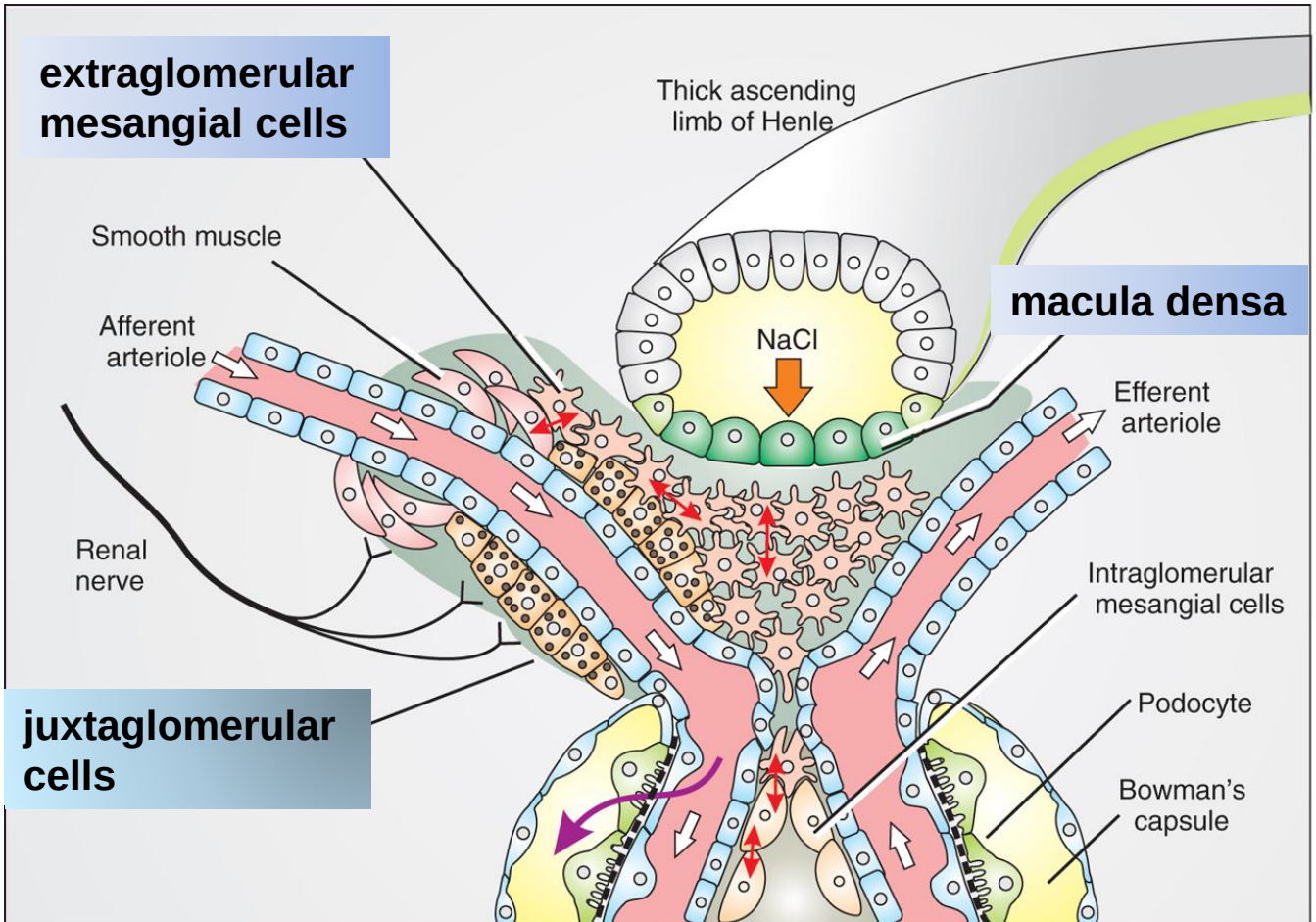
Juxtaglomerular apparatus

- regulates the function of each nephron
- is found between the vascular pole of the renal corpuscle and the distal convoluted tubule of the nephron
- is composed of the **macula densa** of the distal convoluted tubule, smooth muscle cells of the afferent arteriole known as **juxtaglomerular cells**, and **extraglomerular mesangial cells**

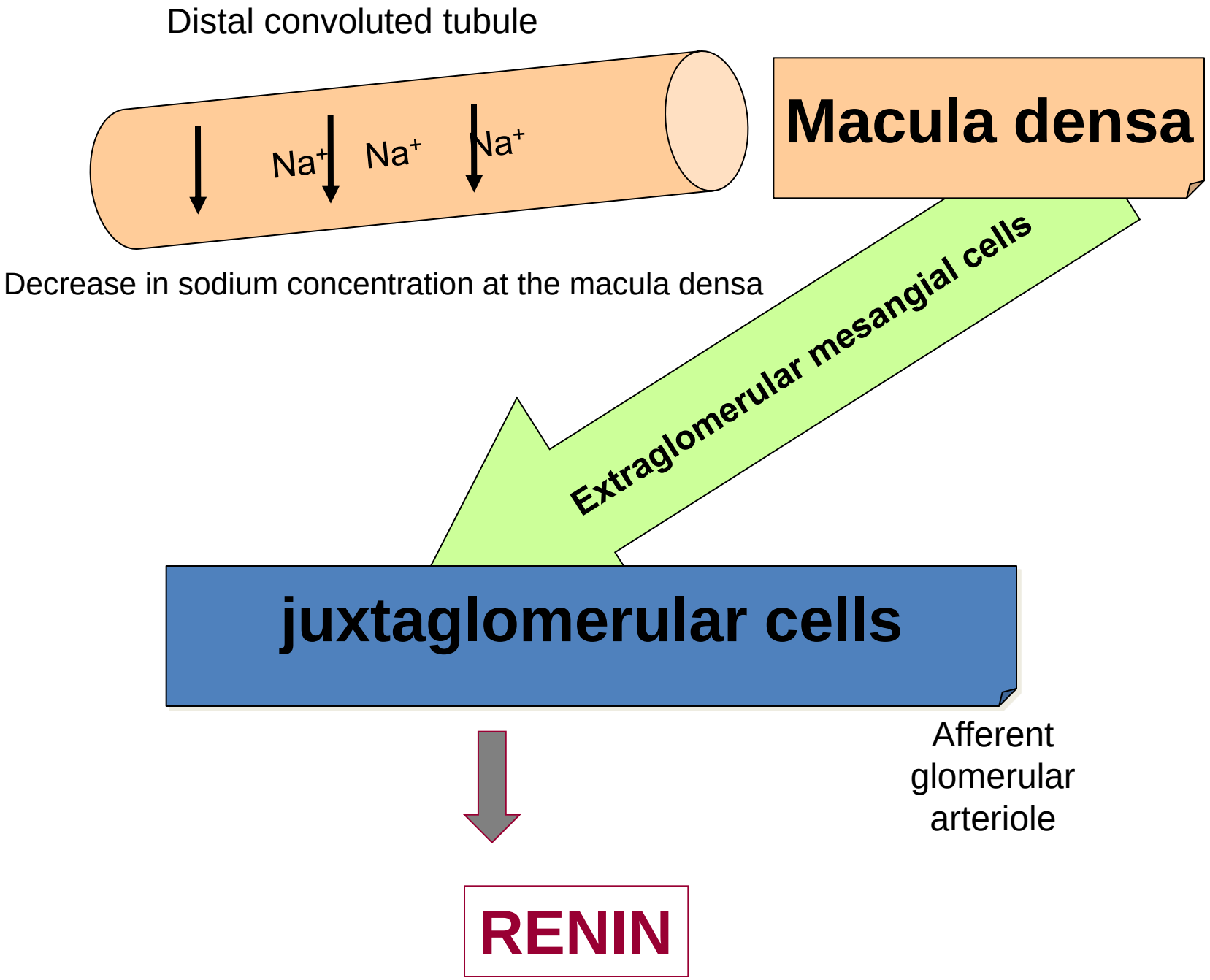


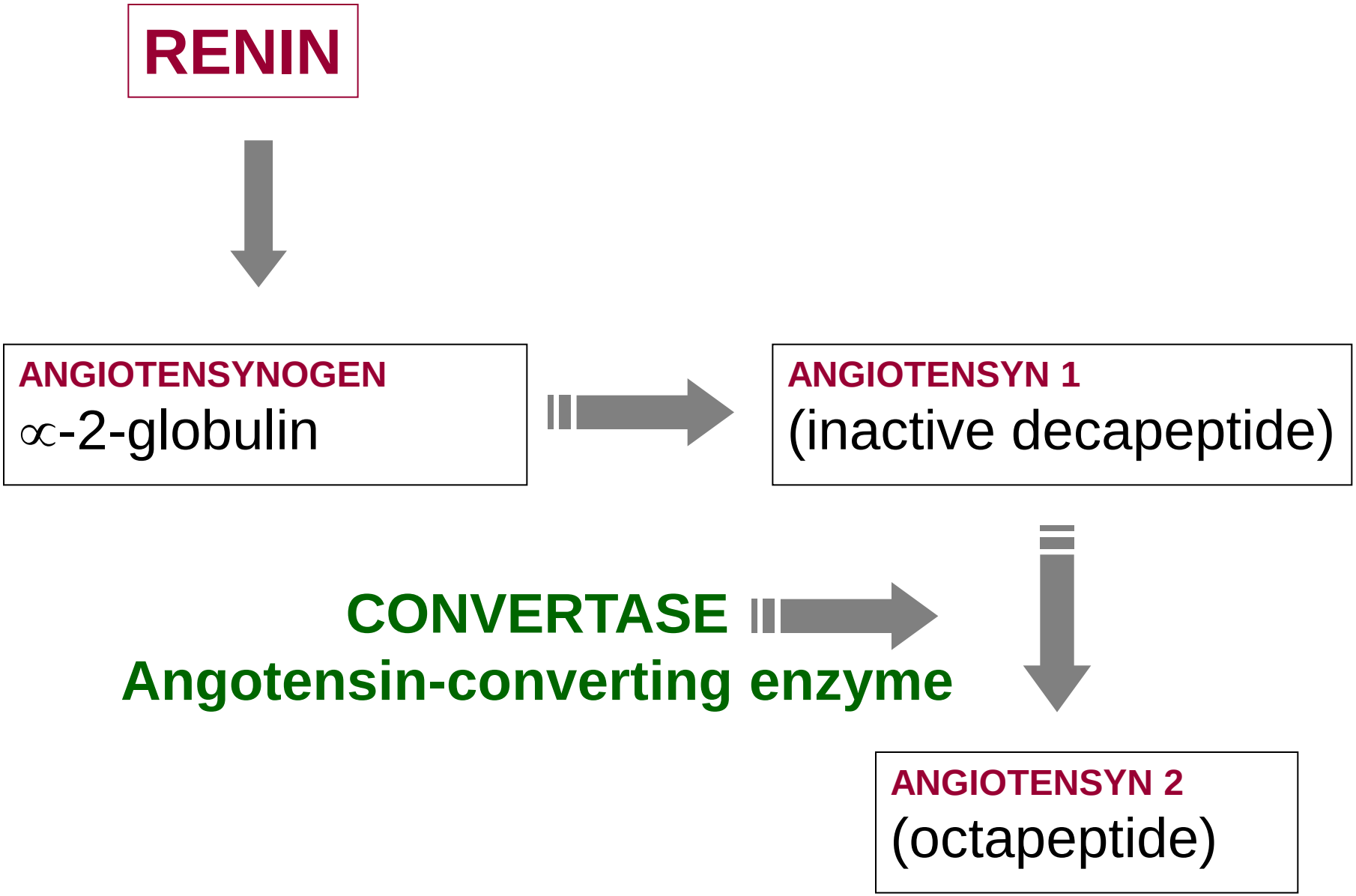
- **extraglomerular mesangial cells** found outside the glomerulus, near the vascular pole and macula densa.

macula densa is an area of closely packed specialized cells lining the wall of the distal convoluted tubule (are sensitive to the concentration of sodium chloride)



juxtaglomerular cells are specialized smooth muscle cells mainly in the walls of the afferent arterioles (synthesize, store, and secrete the enzyme **renin**)


Distal convoluted tubule
Na+
Na+
Na+
Macula densa
Decrease in sodium concentration at the macula densa
Extraglomerular mesangial cells
juxtaglomerular cells
Afferent glomerular arteriole
RENIN


RENIN
ANGIOTENSYNOGEN
∝-2-globulin
ANGIOTENSYN 1
(inactive decapeptide)
CONVERTASE
Angotensin-converting enzyme
ANGIOTENSYN 2
(octapeptide)

ANGIOTENSYN 2
(octapeptide)

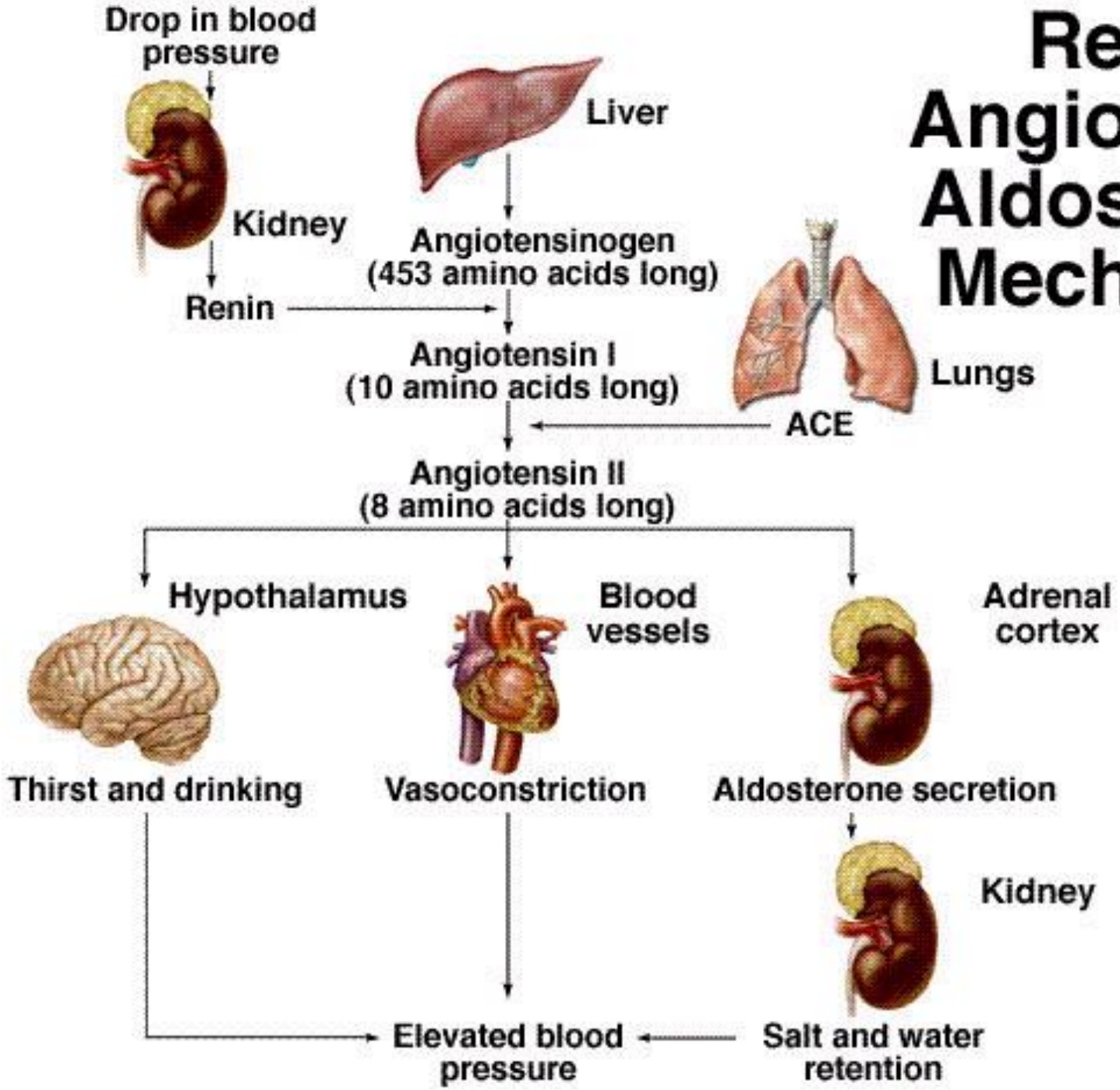
ALDOSTERONE
Release from the adrenal cortex

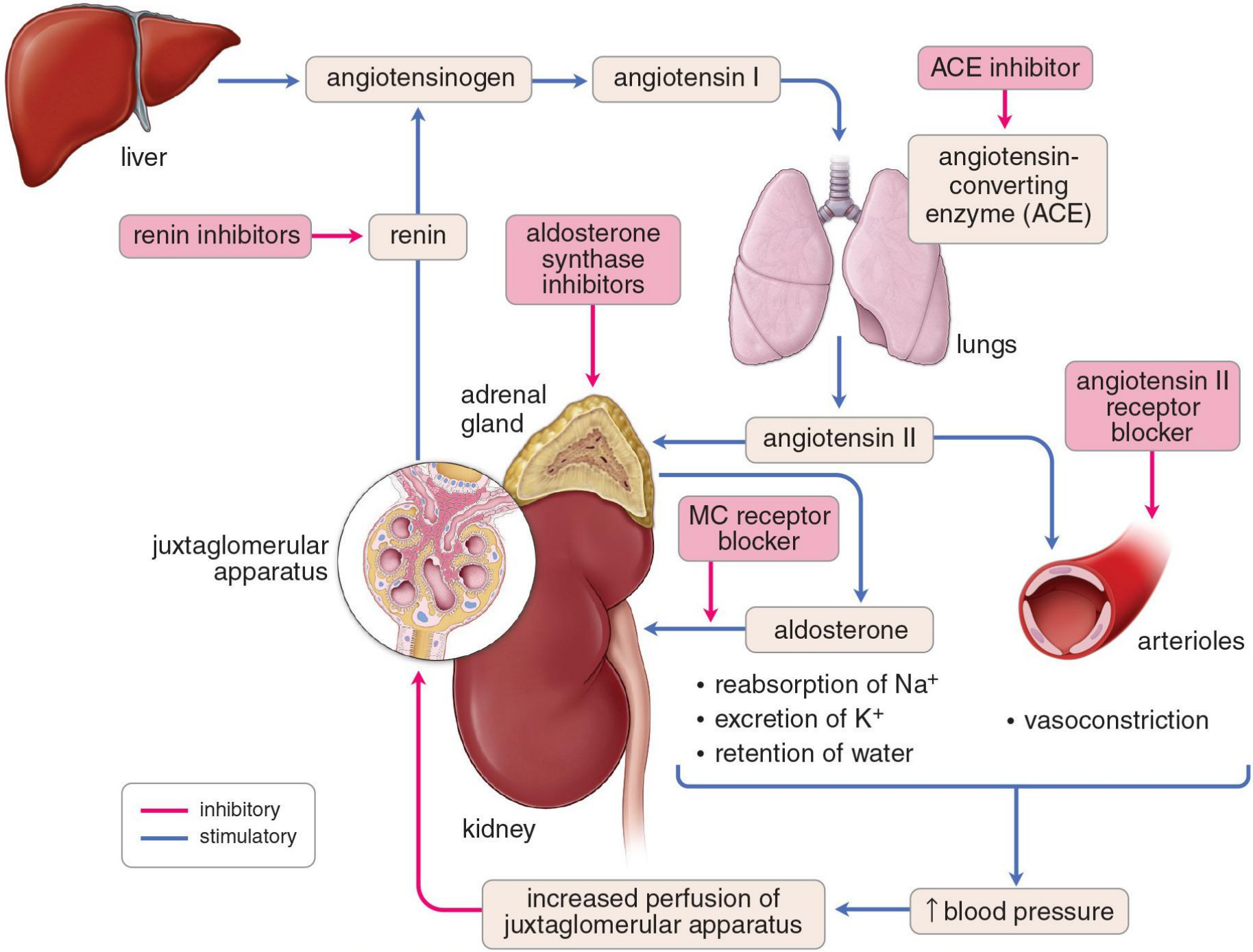
Smooth muscles of the arterioles
contraction

Blood pressure

- causes vasoconstriction, which, in turn, increases blood pressure
- enhances the reabsorption of NaCl by the DCTs of the nephron
- stimulates ADH release (increasing water readsorption)

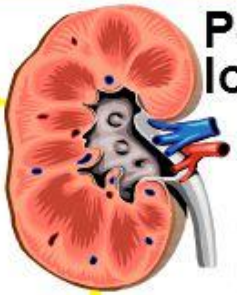
Renin-Angiotensin-Aldosterone Mechanism





Erythropoietin

Decrease in oxygen delivery to the kidneys



Peritubular interstitial cells detect low oxygen levels in the blood

Peritubular interstitial cells secrete erythropoietin (EPO) into the blood

EPO

Pro-erythroblasts in red bone marrow mature more quickly into reticulocytes

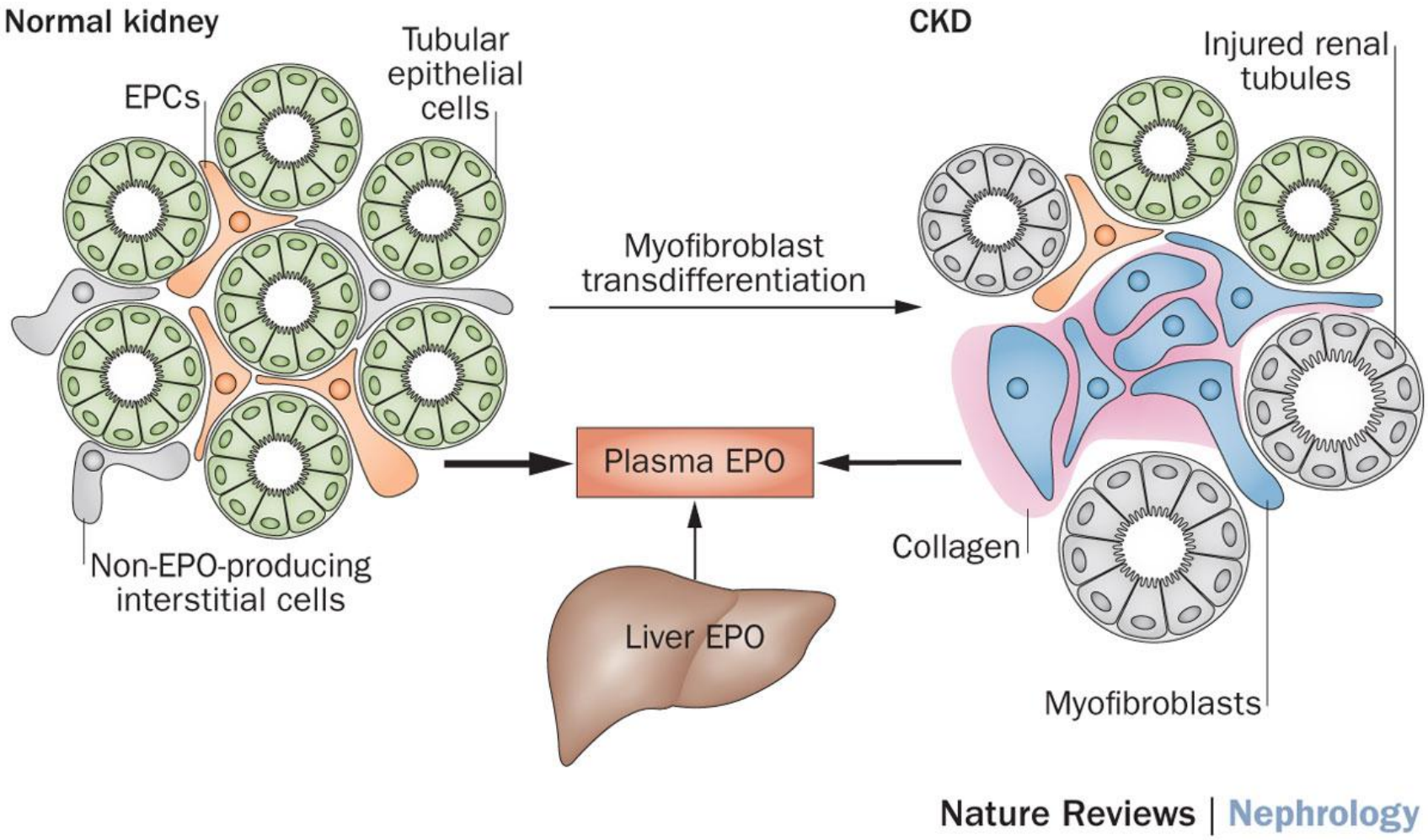
More reticulocytes enter circulating blood

Larger number of red blood cells (RBC) in circulation

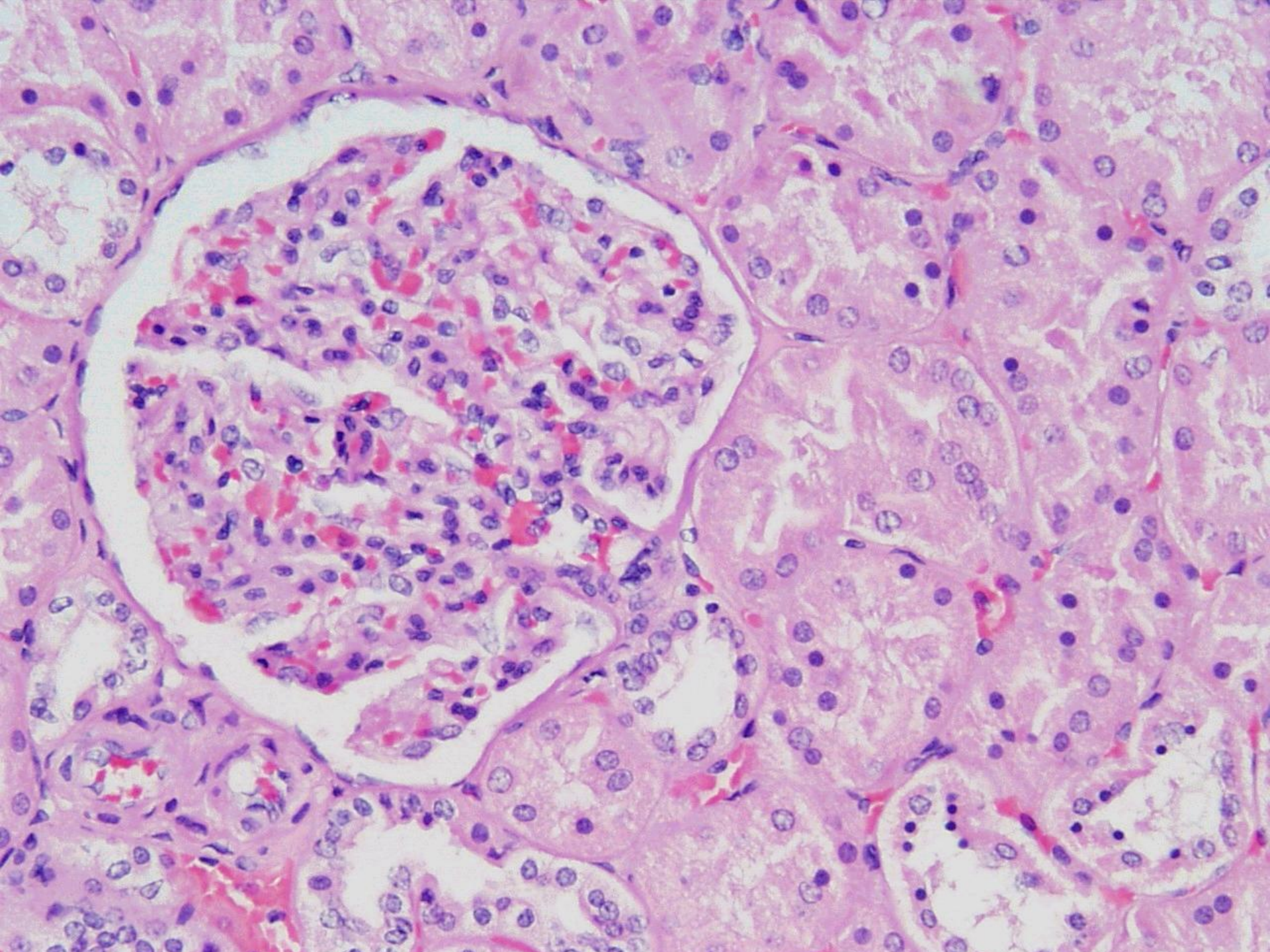
Increased oxygen delivery to tissues

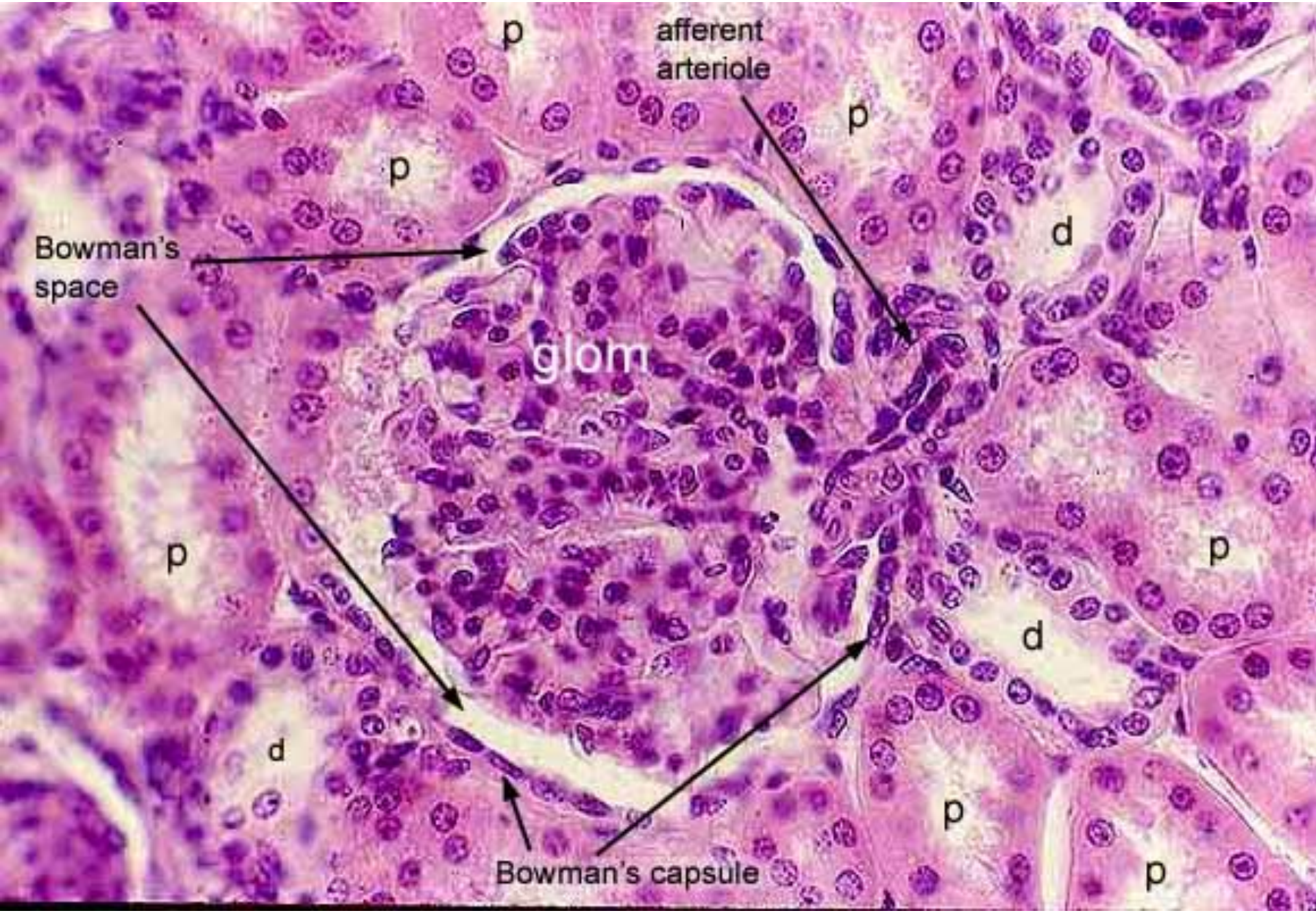
Return to homeostasis when response brings oxygen delivery to kidneys back to normal

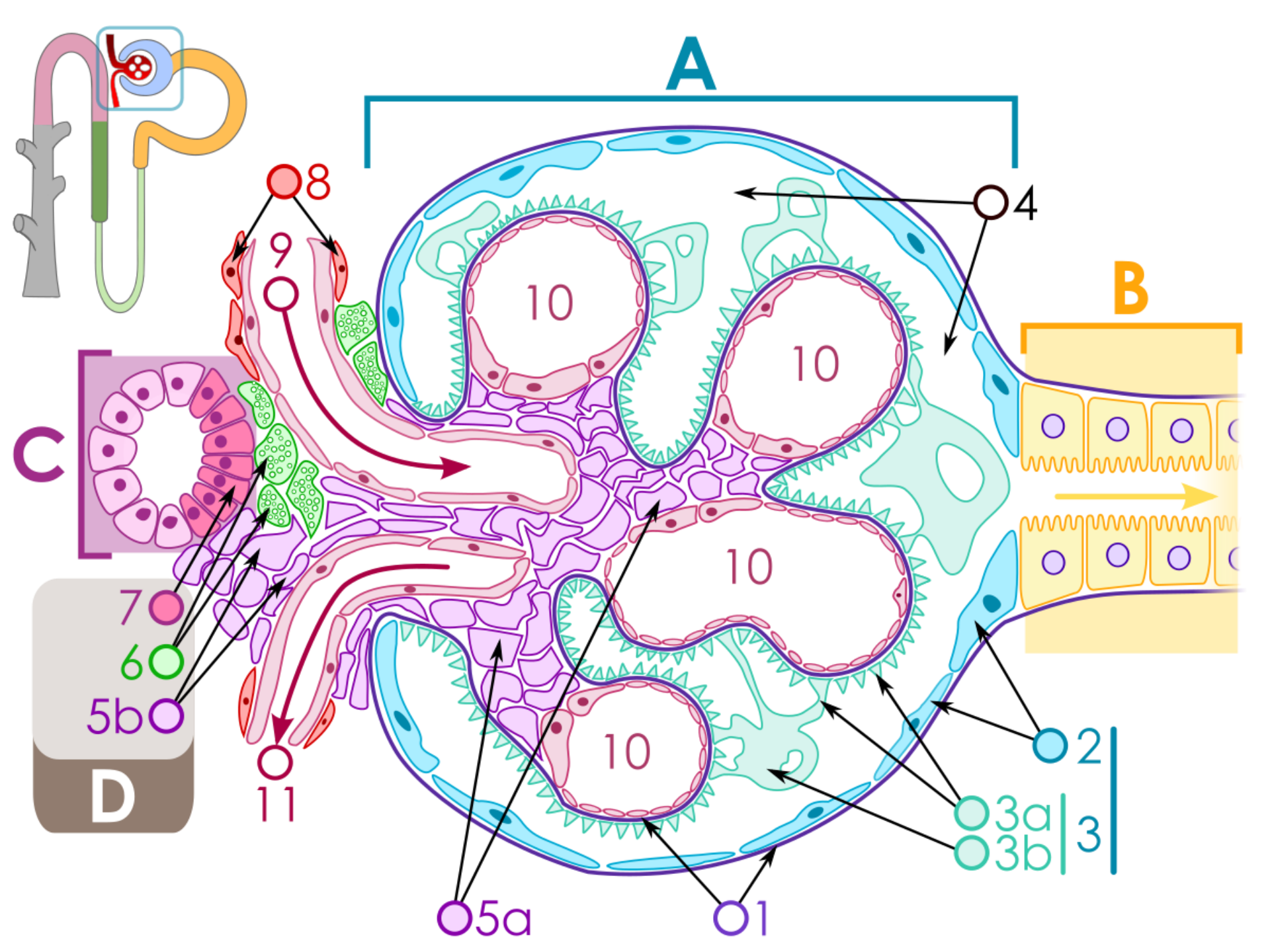
Cellular basis of erythropoietin deficiency in renal failure



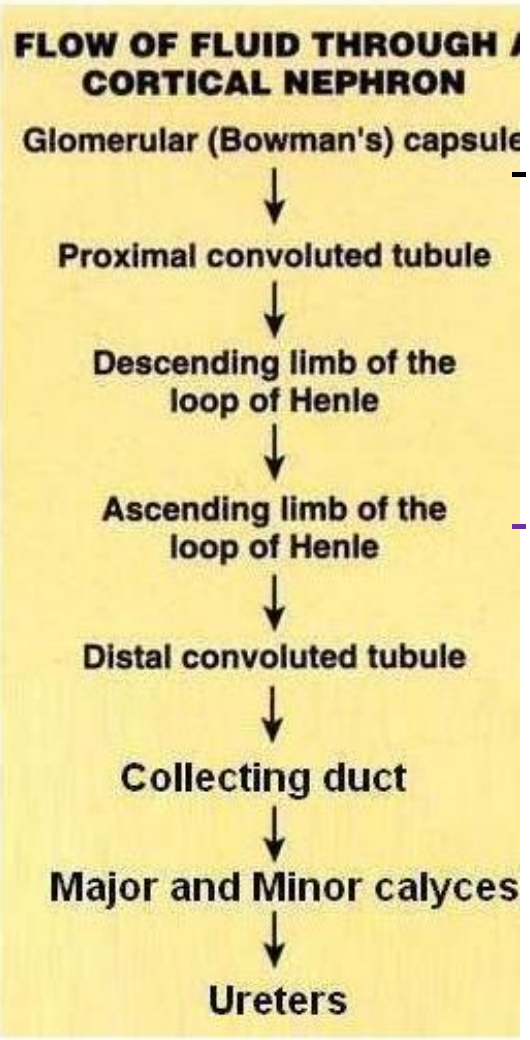
Koury, M. J. & Haase, V. H. (2015) Anaemia in kidney disease: harnessing hypoxia responses for therapy
Nat. Rev. Nephrol. doi:10.1038/nrneph.2015.82



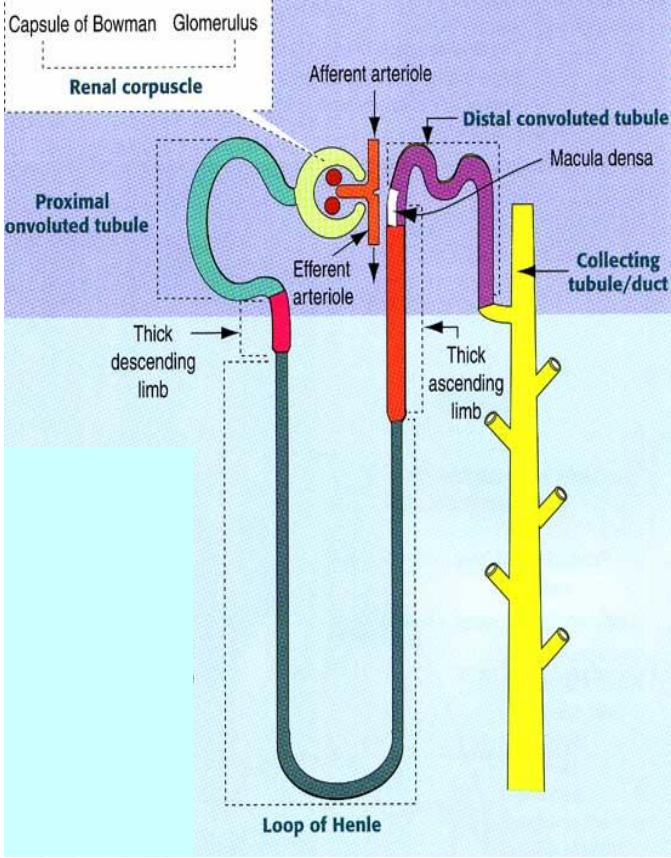

p
afferent
arteriole
p
p
d
Bowman's
space
glom
p
p
d
d
p
p
Bowman's capsule
p


A
B
C
D
8
9
10
10
10
10
10
4
7
6
5b
11
5a
1
2
3a
3b
3

Collecting tubules

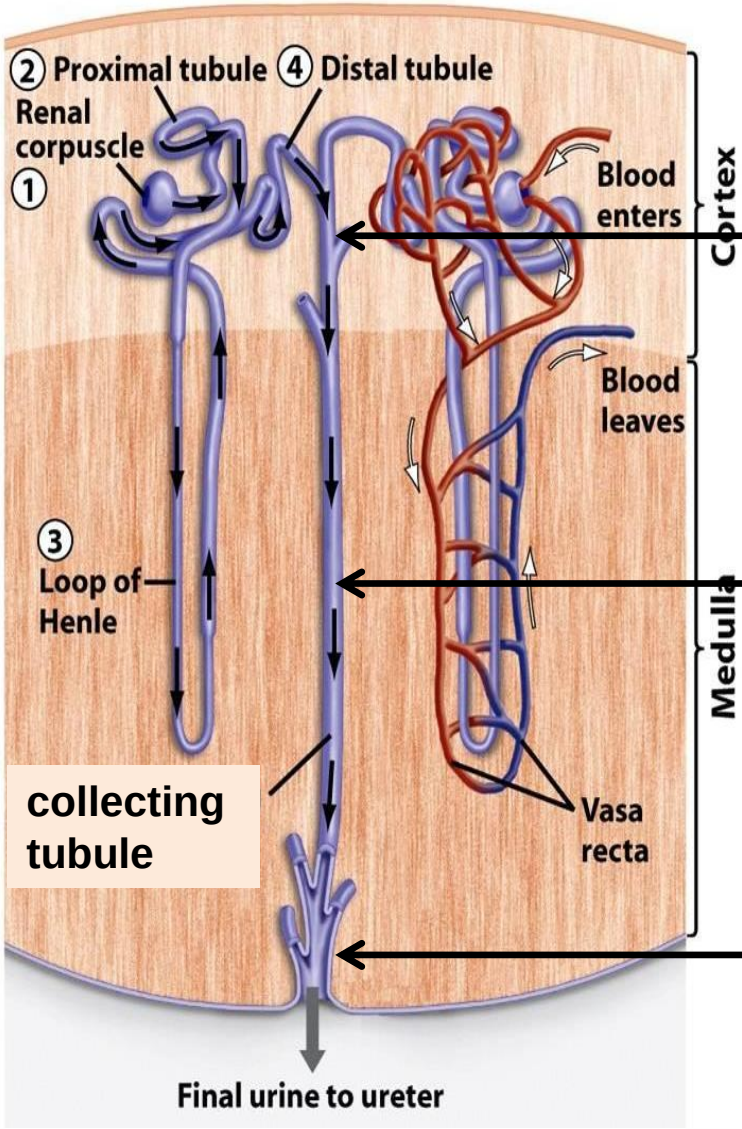


- convey the ultrafiltrate from the nephron to the minor calyces
- distal convoluted tubules of several nephrons join to form connecting tubule that leads to the **collecting tubule**
- **in collecting tubule ultrafiltrate is modified**



Collecting tubules are not a part of nephrons

Collecting tubule - function



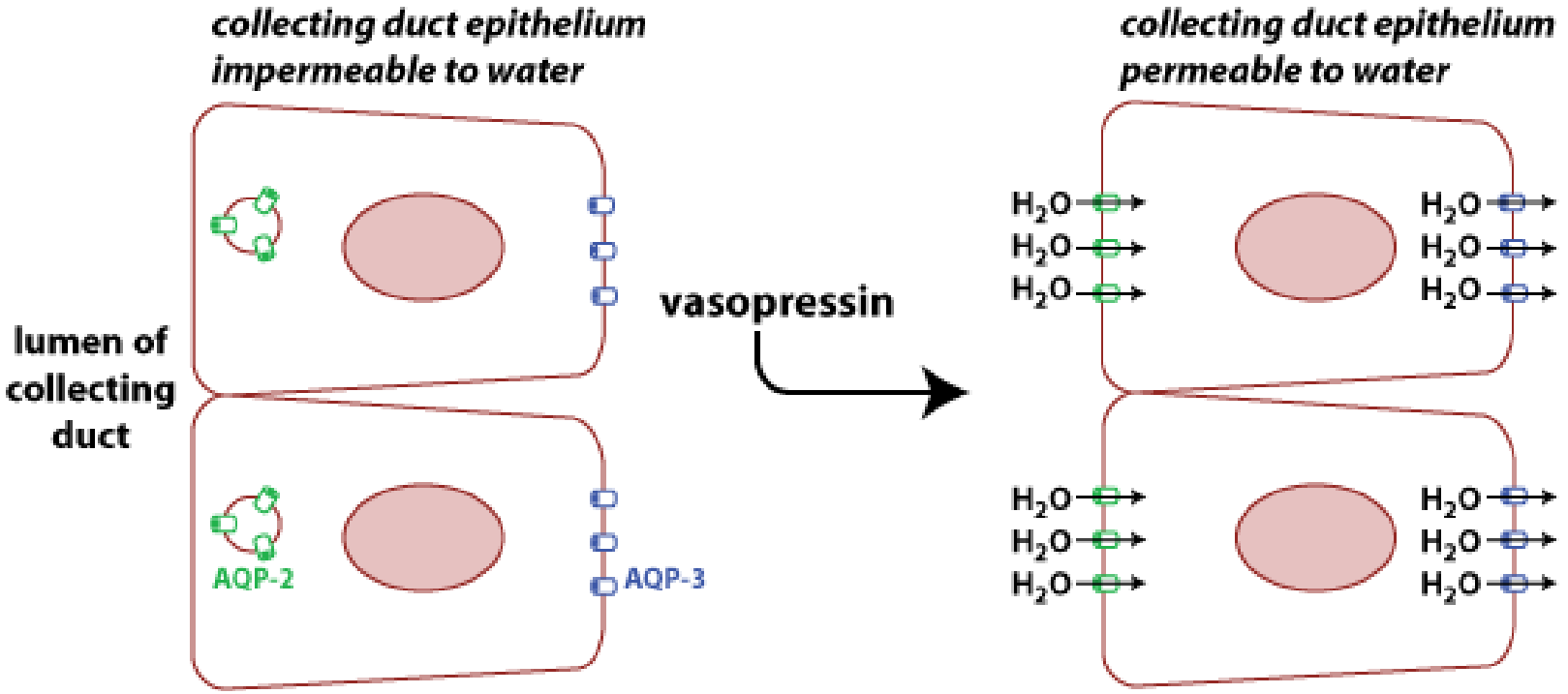
cortical collecting tubule

medullary collecting tubule

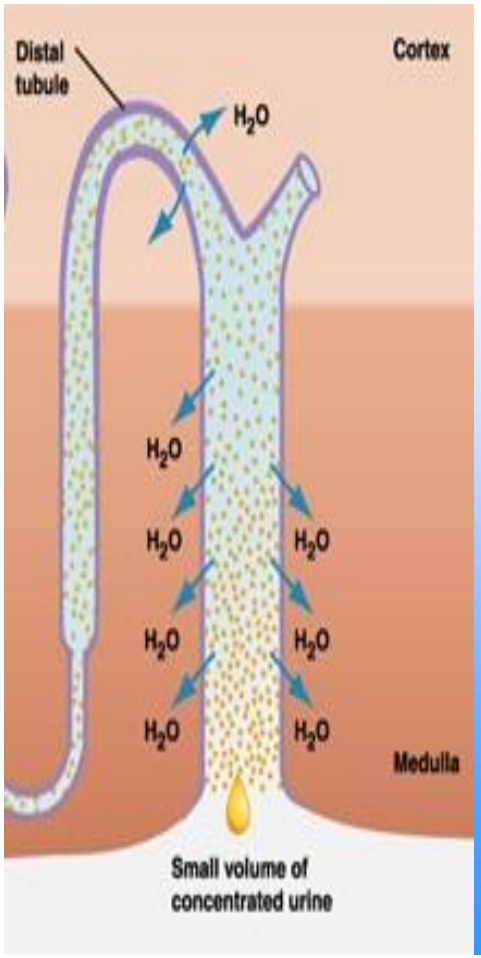
papillary collecting tubule (duct of Bellini)

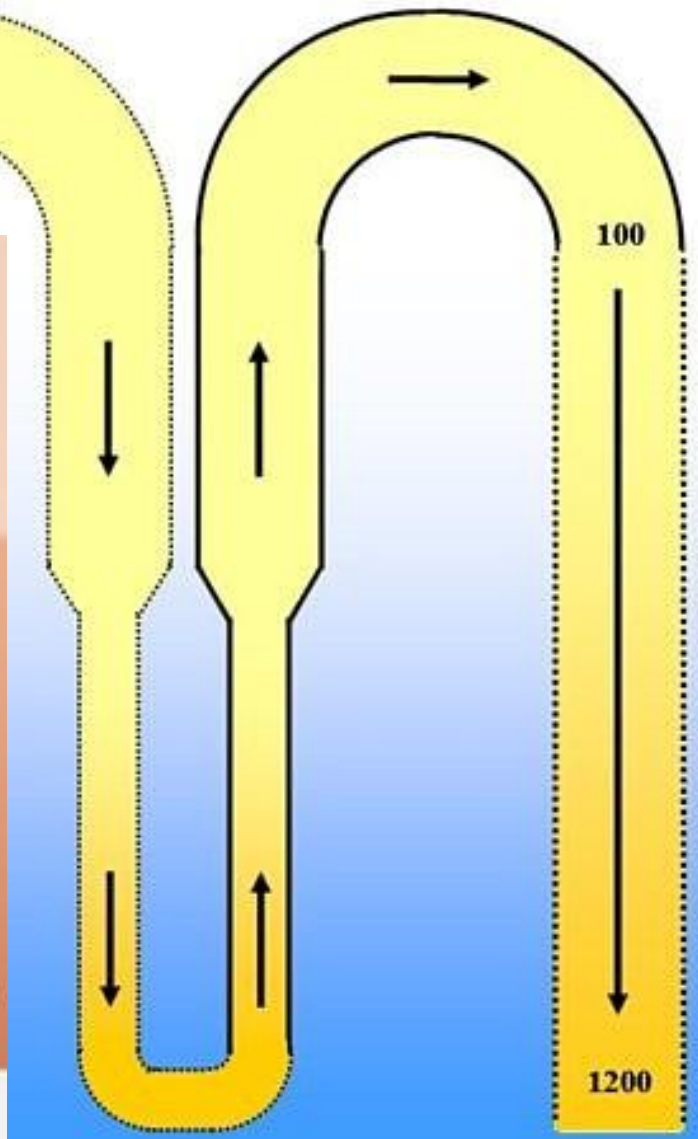
- reabsorption of **sodium and water**
- depends on **hormonal activation (ADH)**

Mechanism of action of antidiuretic hormone (vasopressin)



- ADH binds to the V_2 receptors on the basolateral surface of cells of collecting ducts
- Aquaporin-2 (AQP-2) channels are inserted into the plasma membrane
- Water from the lumen of the collecting duct enters the cell
- Water leaves the cell via aquaporin-3 and aquaporin-4 channels (are always present in cell membrane)





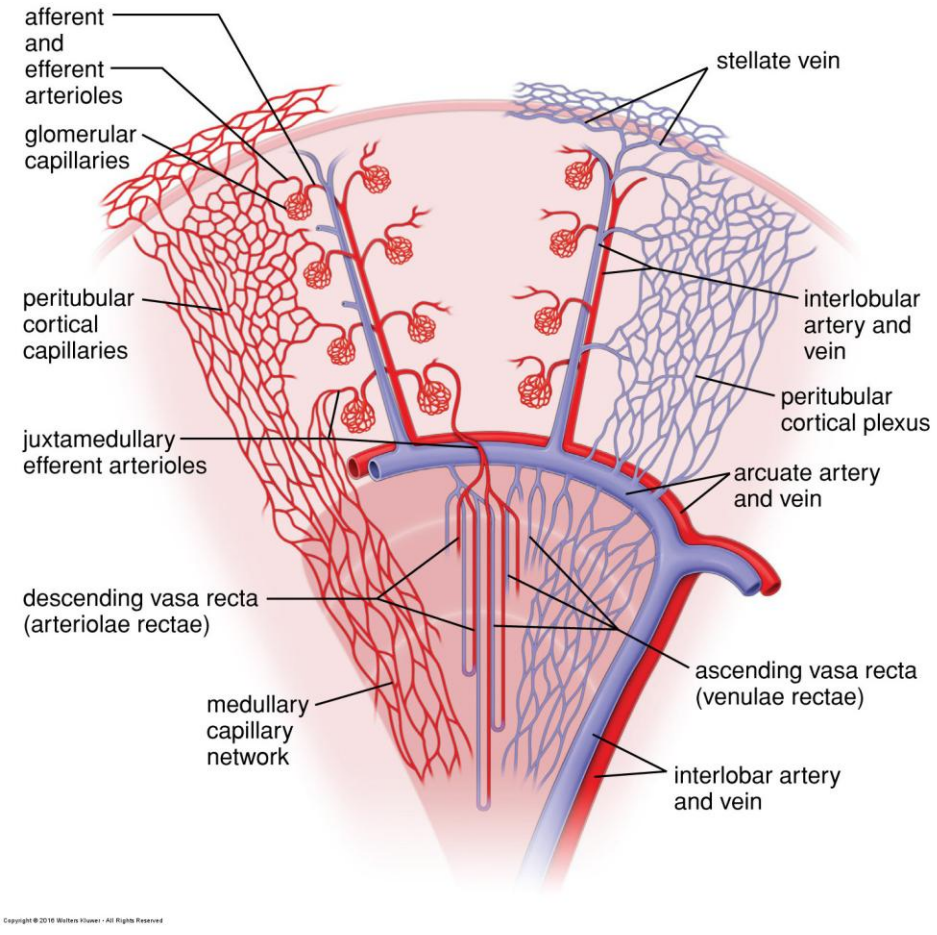
Vasopressin

- Anti-diuretic hormone (ADH)
- Secreted by posterior pituitary
- Acts on collecting duct and distal tubule
- Increases permeability of tubule epithelium

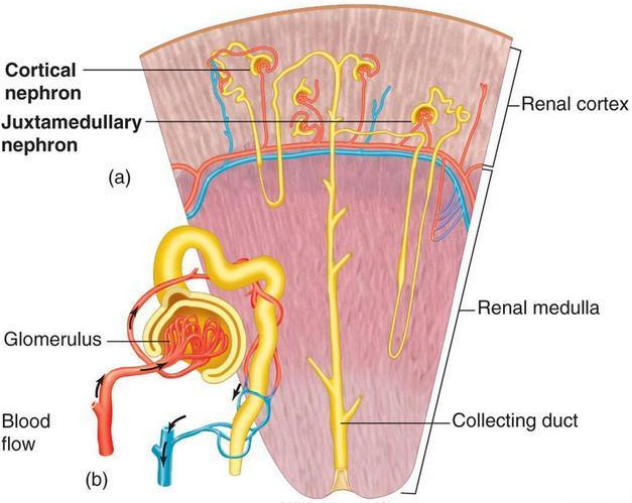
No vasopressin
collecting duct
impermeable to water
DILUTE URINE

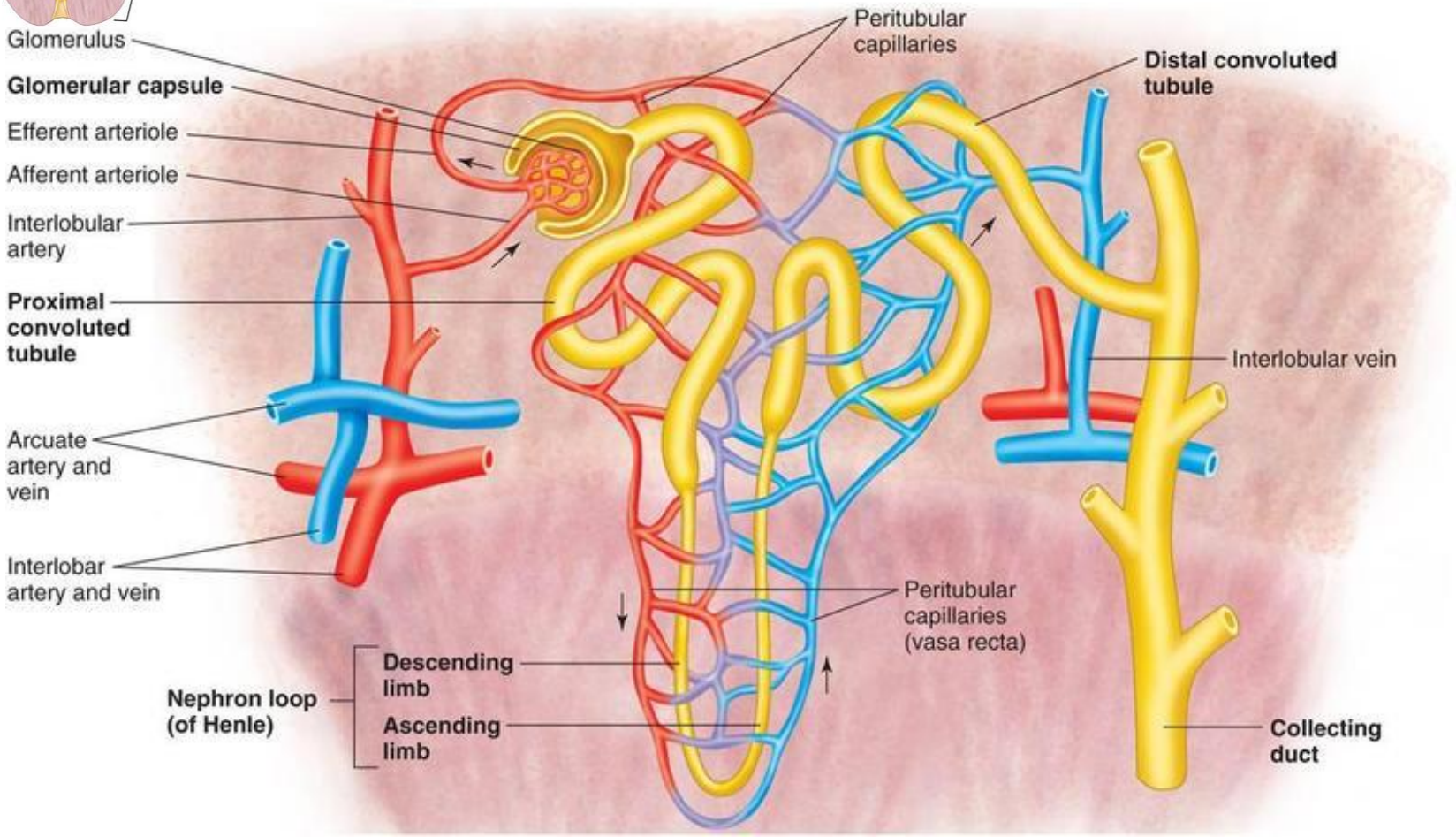
With vasopressin
collecting duct
permeable to water
CONCENTRATED URINE

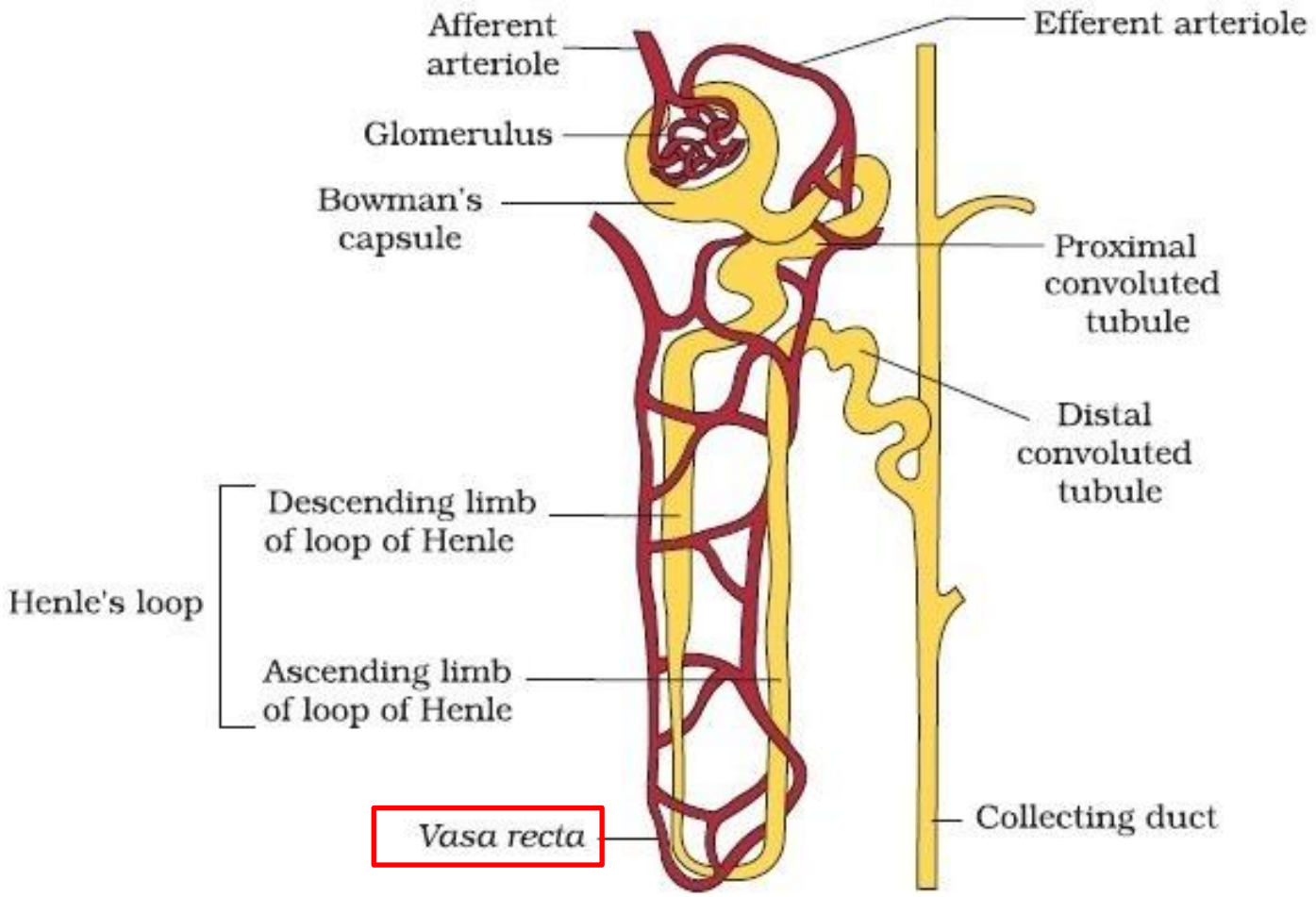
Kidney - blood supply



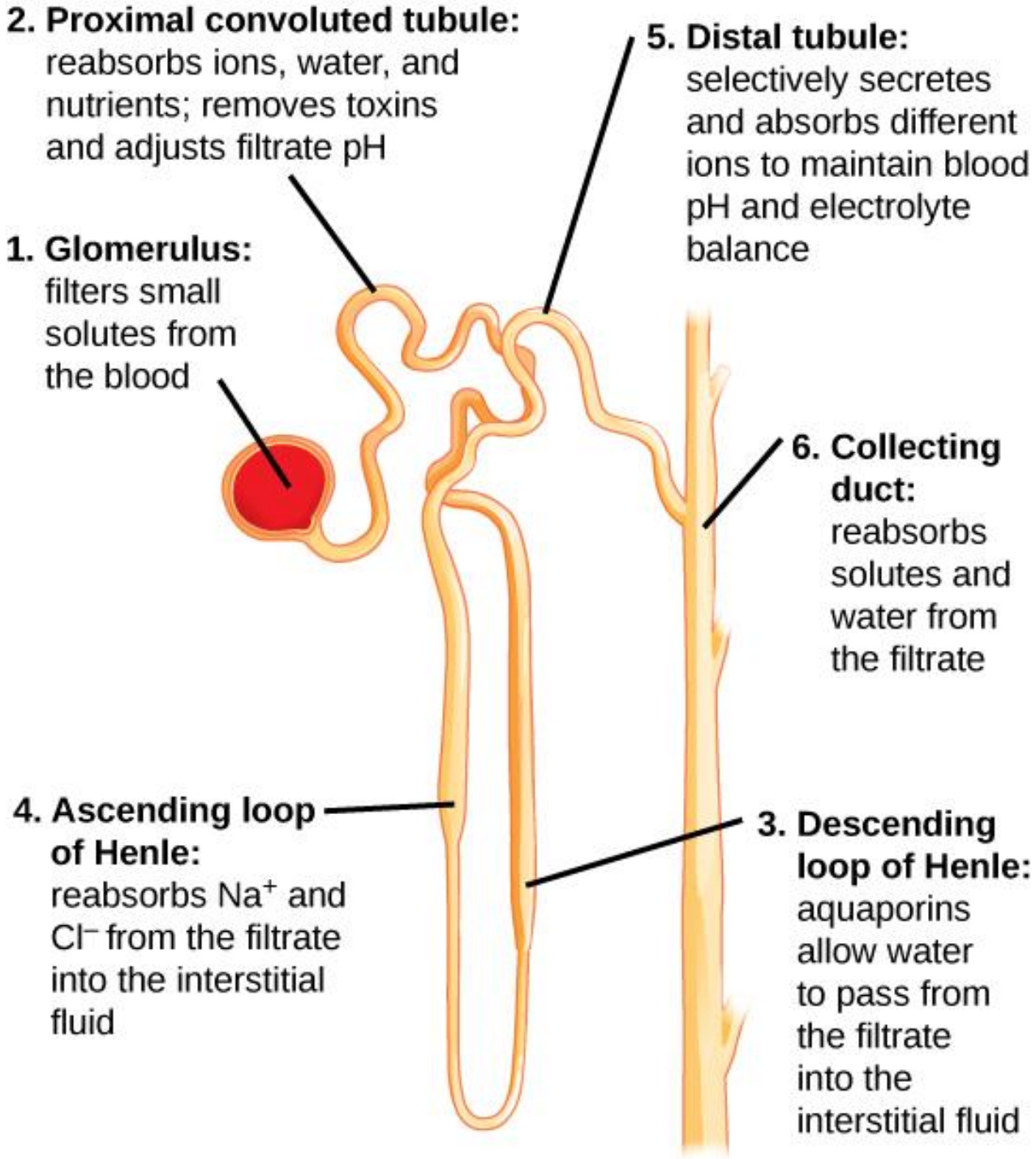
- receive blood from the **renal arteries**
- each renal artery branches into **segmental arteries**, dividing further into **interlobar arteries**
- the interlobar arteries supply blood to the **arcuate arteries** (run through the boundary of the cortex and the medulla).
- each arcuate artery supplies several **interlobular arteries** that feed into the **afferent arterioles** that supply the glomeruli
- the veins follow the same pattern


Cortical nephron
Juxtamedullary nephron
(a)
Renal cortex
Renal medulla
Glomerulus
Blood flow
(b)
Collecting duct


Glomerulus
Glomerular capsule
Efferent arteriole
Afferent arteriole
Interlobular artery
Proximal convoluted tubule
Arcuate artery and vein
Interlobar artery and vein
Peritubular capillaries
Distal convoluted tubule
Interlobular vein
Peritubular capillaries (vasa recta)
Nephron loop (of Henle)
Descending limb
Ascending limb
Collecting duct

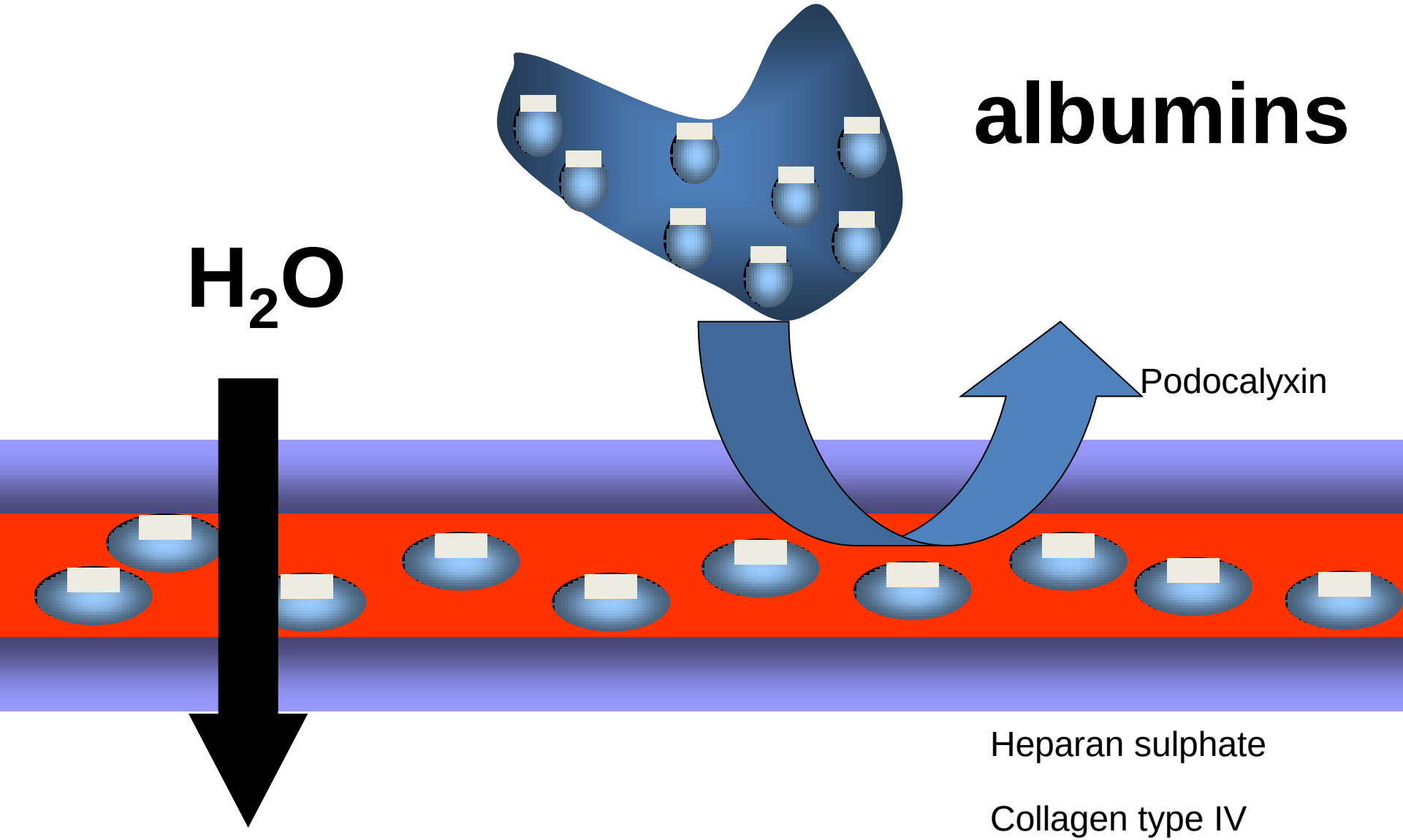


- glomerulus is completely **arterial bed** – is supplied by **afferent glomerular arteriole** and drained by **efferent glomerular arteriole**
- **efferent glomerular arteriole** of juxtamegullary nephrons branch off, enter the medulla, and surround the loop of Henle – form **vasa recta**
- **vasa recta** are necessary to the concentration of urine

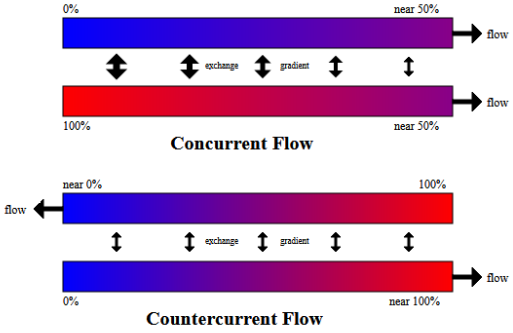


Urine formation

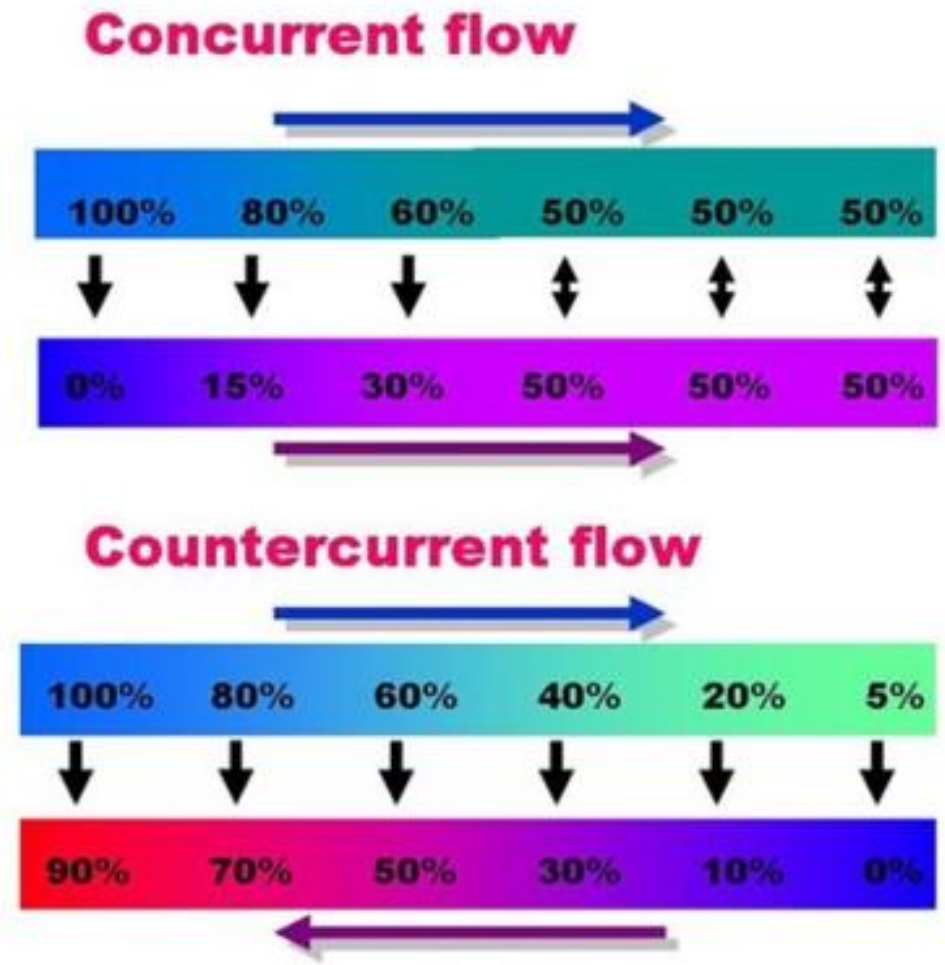
- about 180 L of glomerular filtrate is formed each day but only 1% is excreted



Permeable for water

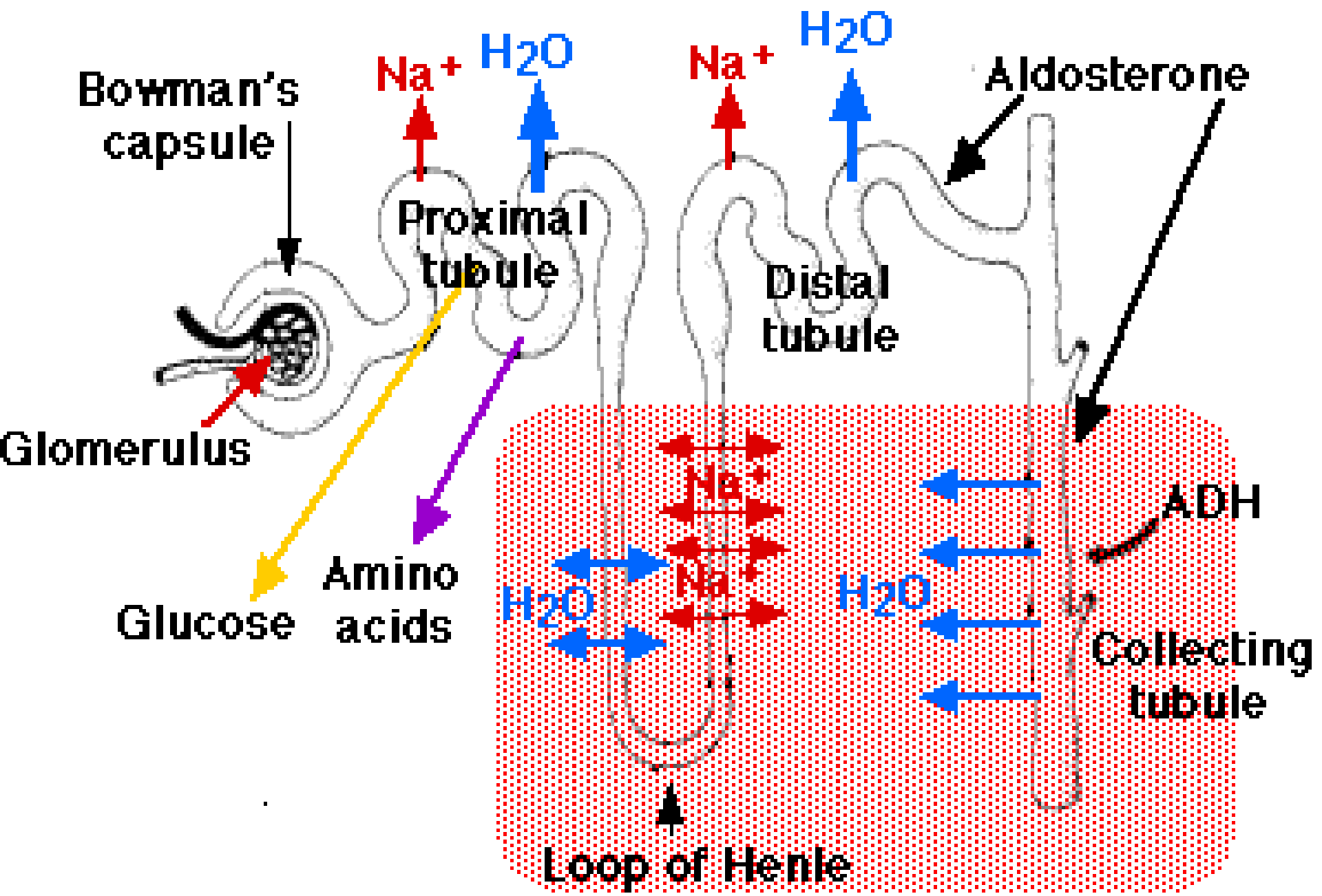


Countercurrent is the situation where a current flows to the opposite direction of that of the



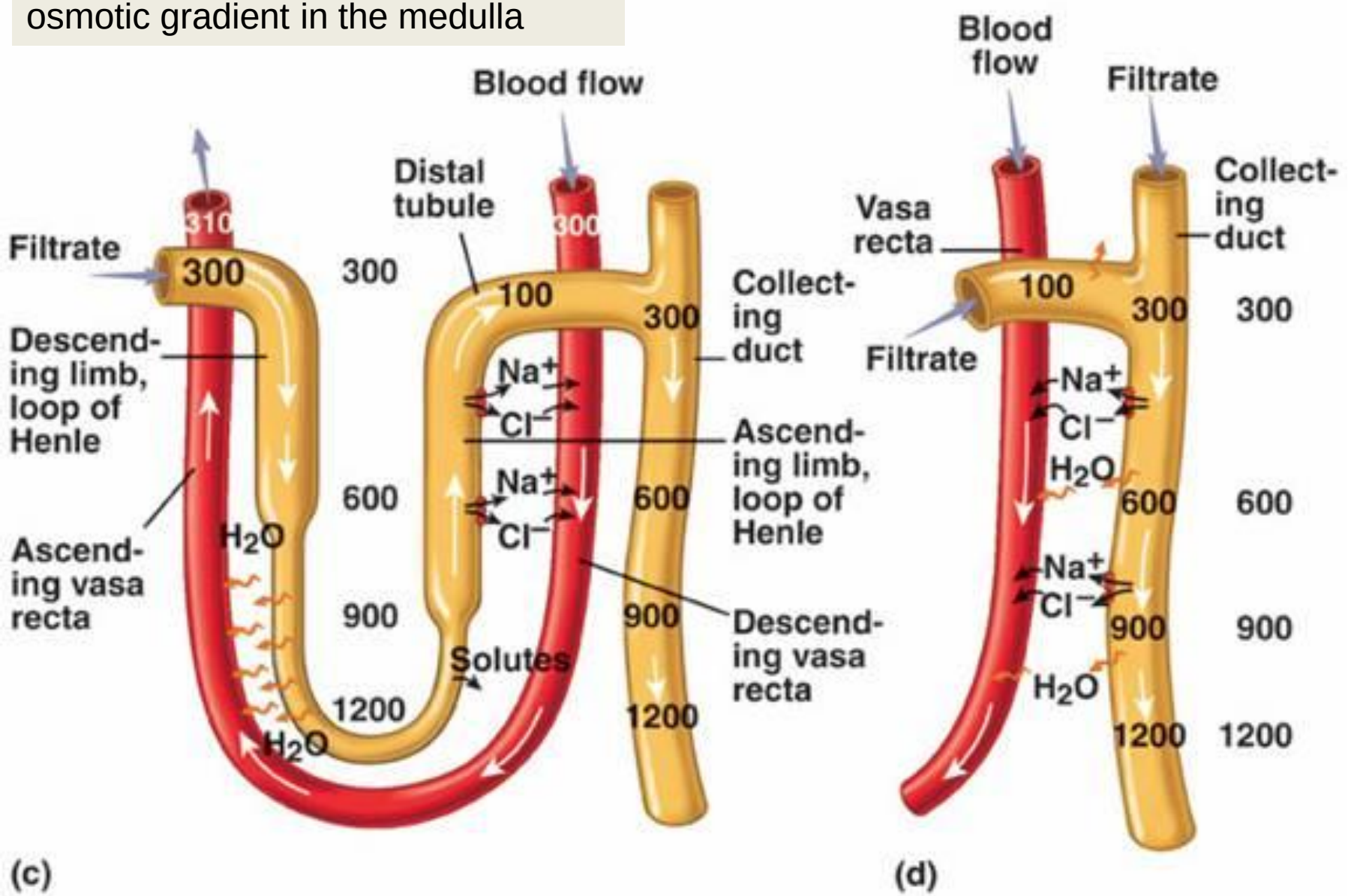
Systems reach equilibrium and no further exchange takes place.

Systems do not reach equilibrium and exchange takes place along entire length. More of the exchanged substance is transferred than in previous example.

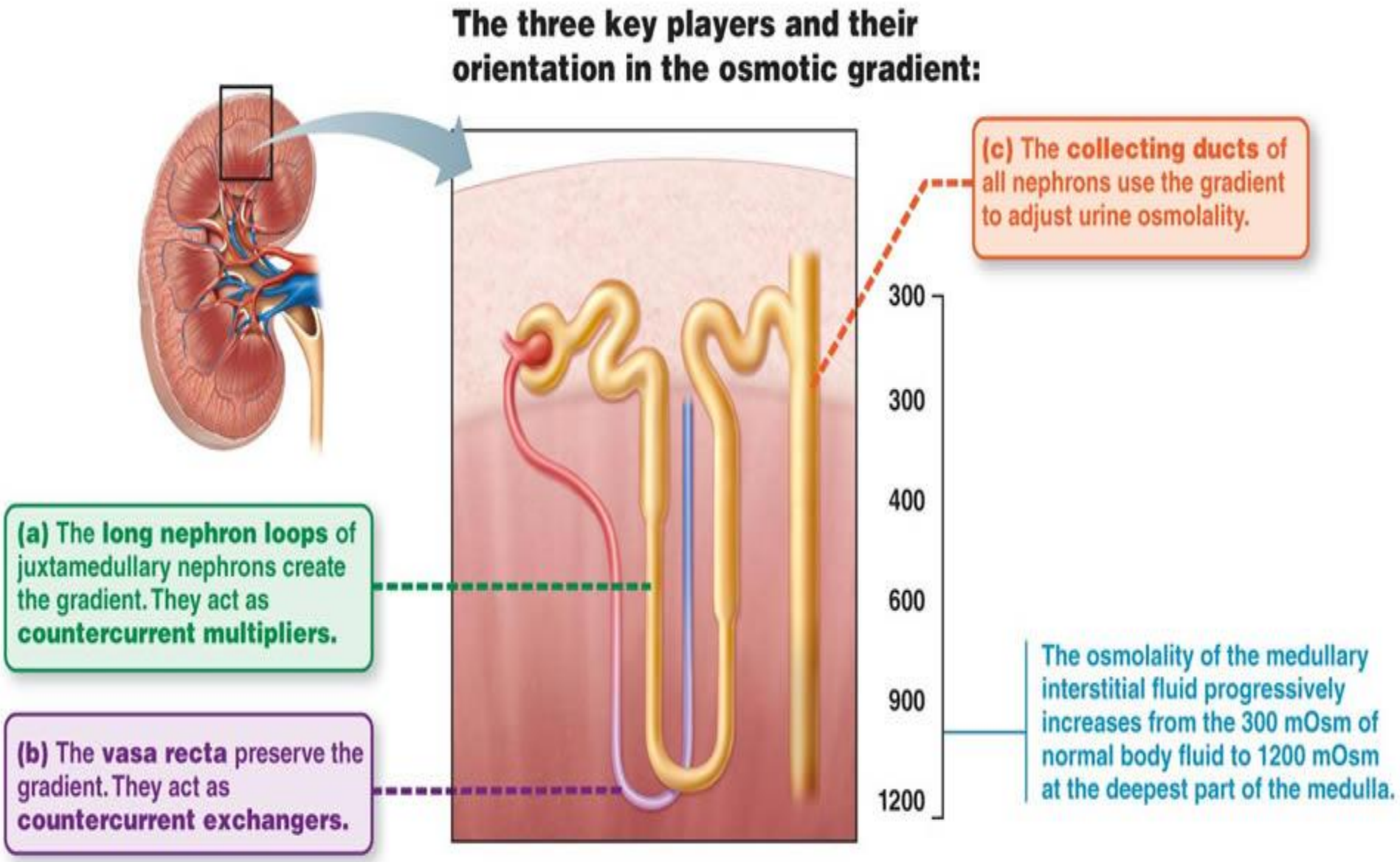

Bowman's capsule
Na+
H2O
Na+
H2O
Aldosterone
Proximal tubule
Distal tubule
Glomerulus
Glucose
Amino acids
Na+
Na+
H2O
H2O
ADH
Collecting tubule
Loop of Henle

Countercurrent exchanger system

Vasa recta helps maintain the osmotic gradient in the medulla



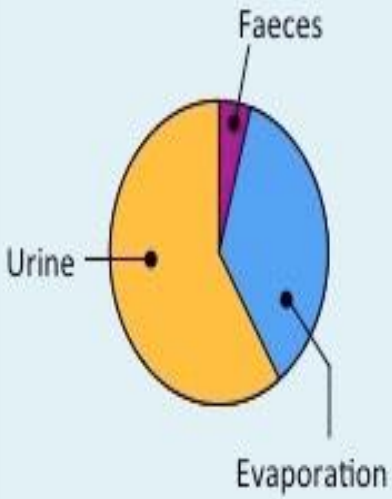
Preparation of osmotic gradient in the kidney is necessary for the production of urine



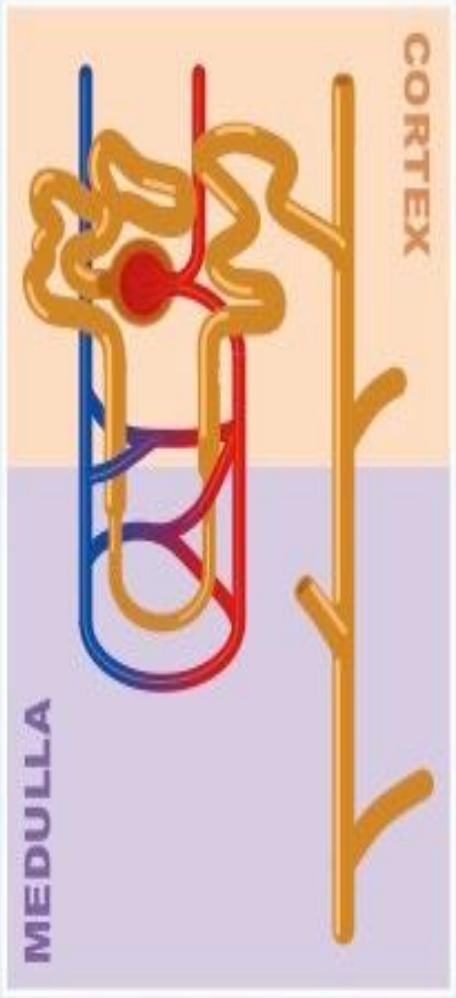
NORMAL (MESIC) CONDITIONS

Cow

Water Loss



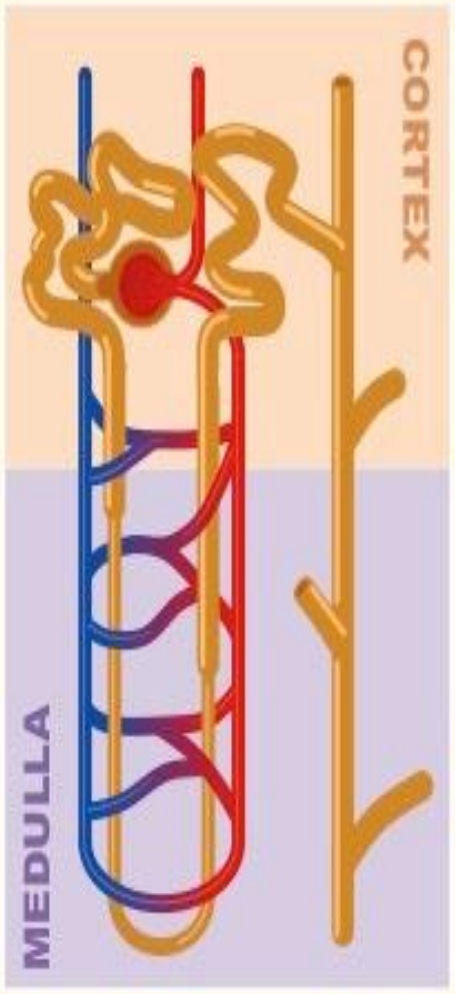
Cortical Nephron



***Less** water retention*

ARID (DESERT) CONDITIONS

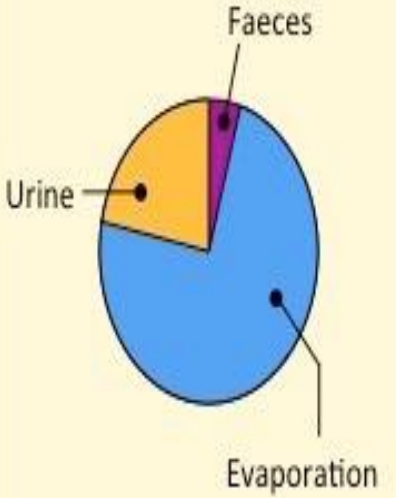
Juxtamedullary Nephron

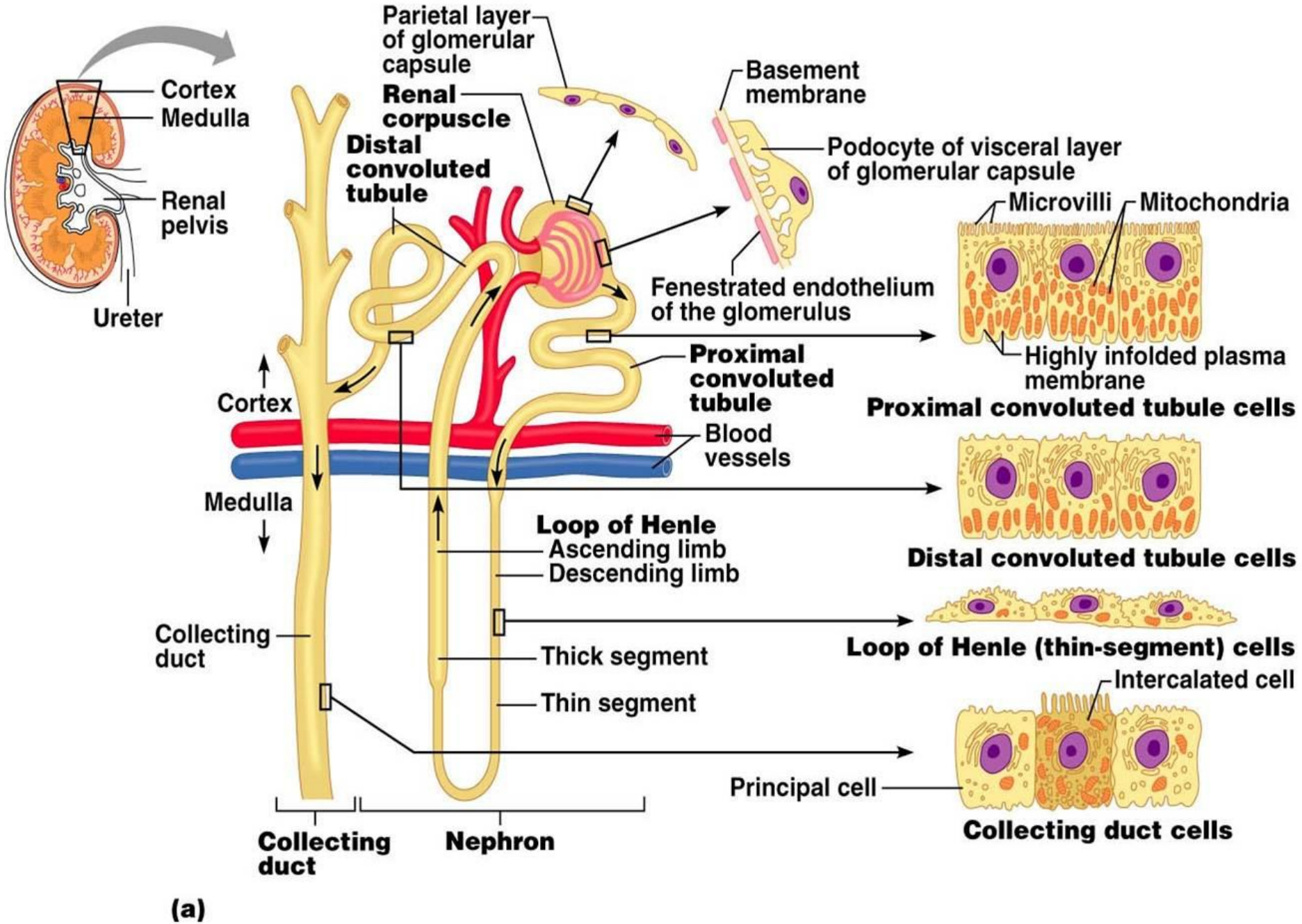


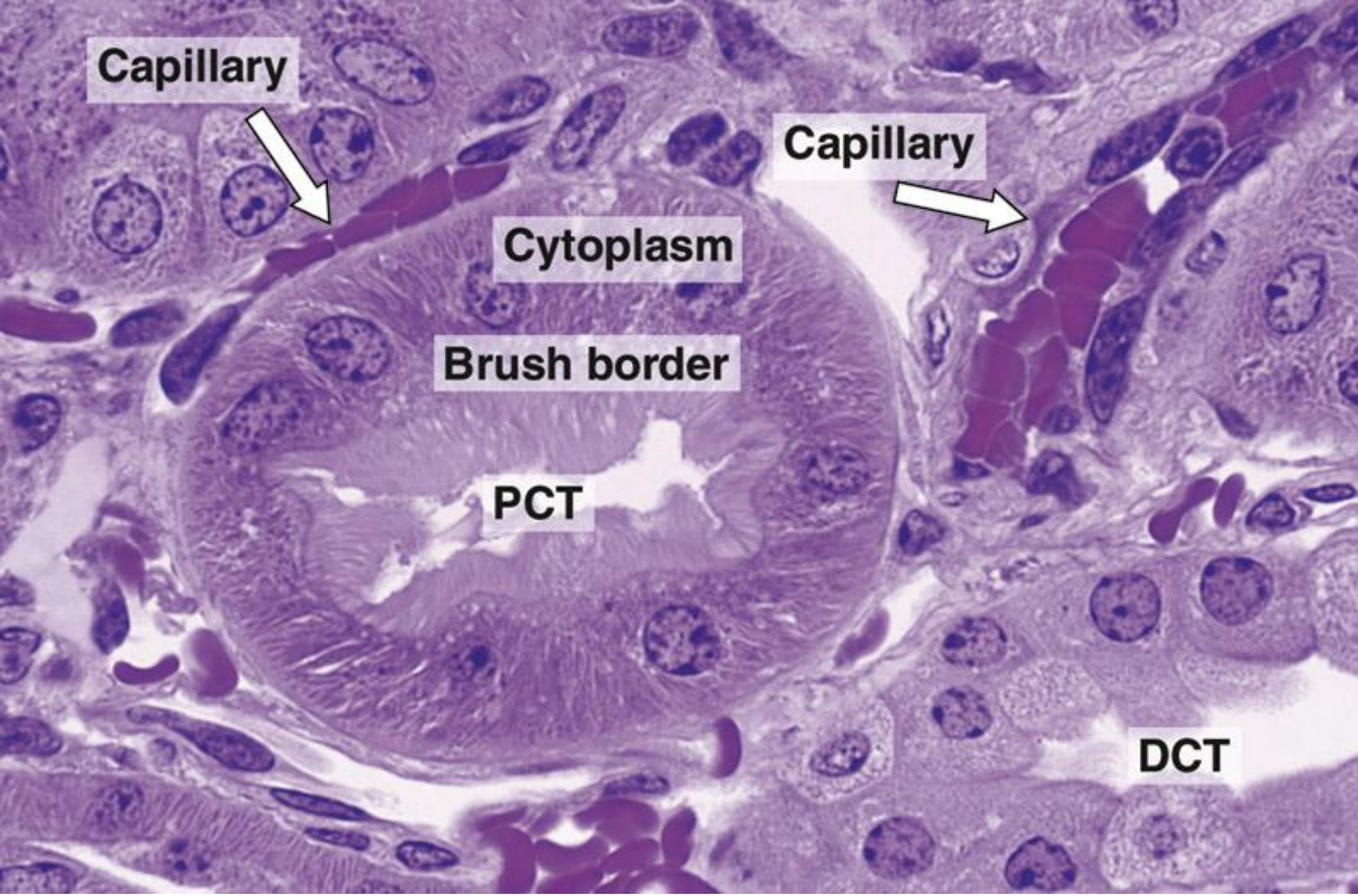
***More** water retention*

Desert Rat

Water Loss

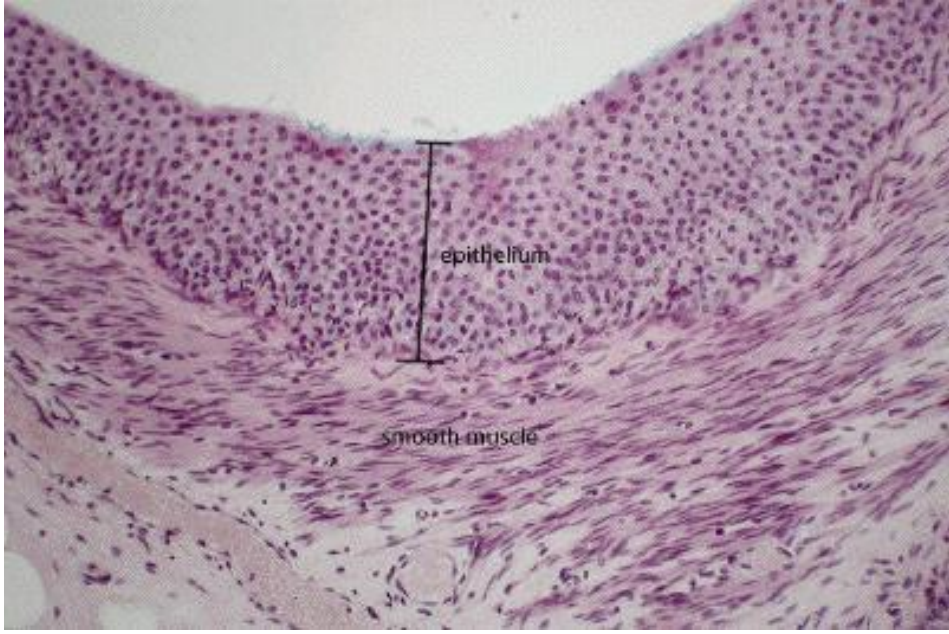


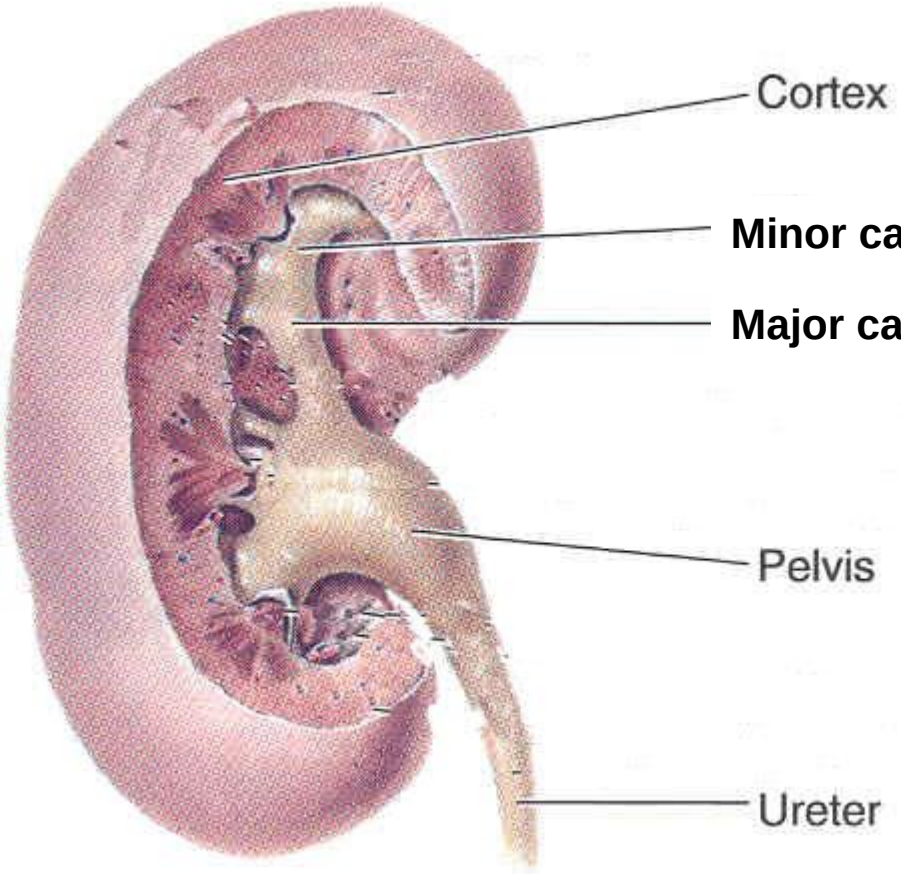

Cortex
Medulla
Renal pelvis
Ureter
Parietal layer of glomerular capsule
Renal corpuscle
Distal convoluted tubule
Basement membrane
Podocyte of visceral layer of glomerular capsule
Fenestrated endothelium of the glomerulus
Microvilli
Mitochondria
Highly infolded plasma membrane
Proximal convoluted tubule cells
Proximal convoluted tubule
Cortex
Blood vessels
Medulla
Loop of Henle
Ascending limb
Descending limb
Distal convoluted tubule cells
Collecting duct
Thick segment
Thin segment
Loop of Henle (thin-segment) cells
Intercalated cell
Principal cell
Collecting duct cells
Collecting duct
Nephron
(a)



Renal cortex section showing a proximal convoluted tubule (PCT) with its large cuboidal cells presenting a brush border formed by numerous microvilli. Distal convoluted tubules (DCT) are also present.

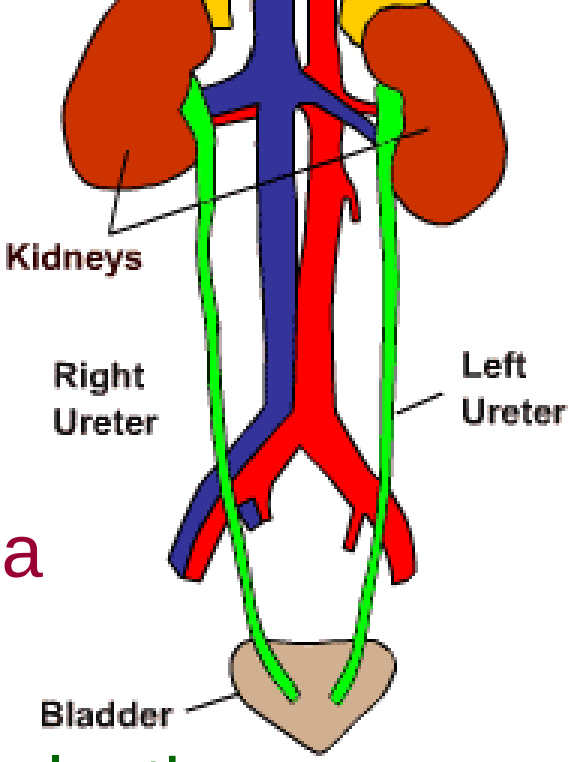
Urine moves from the nephrones collecting duct system to the **minor calyx** and then the **major calyx** before entering the **renal pelvis**



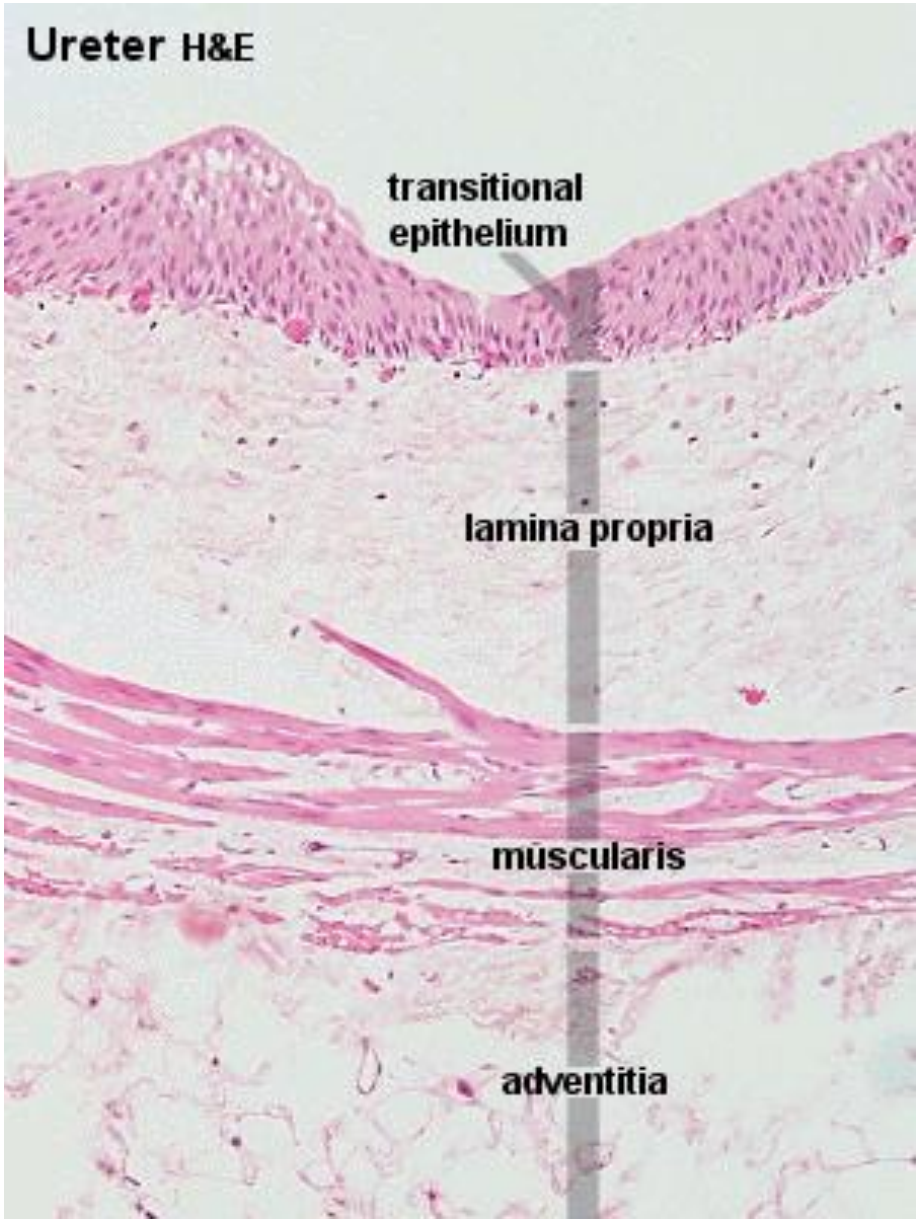


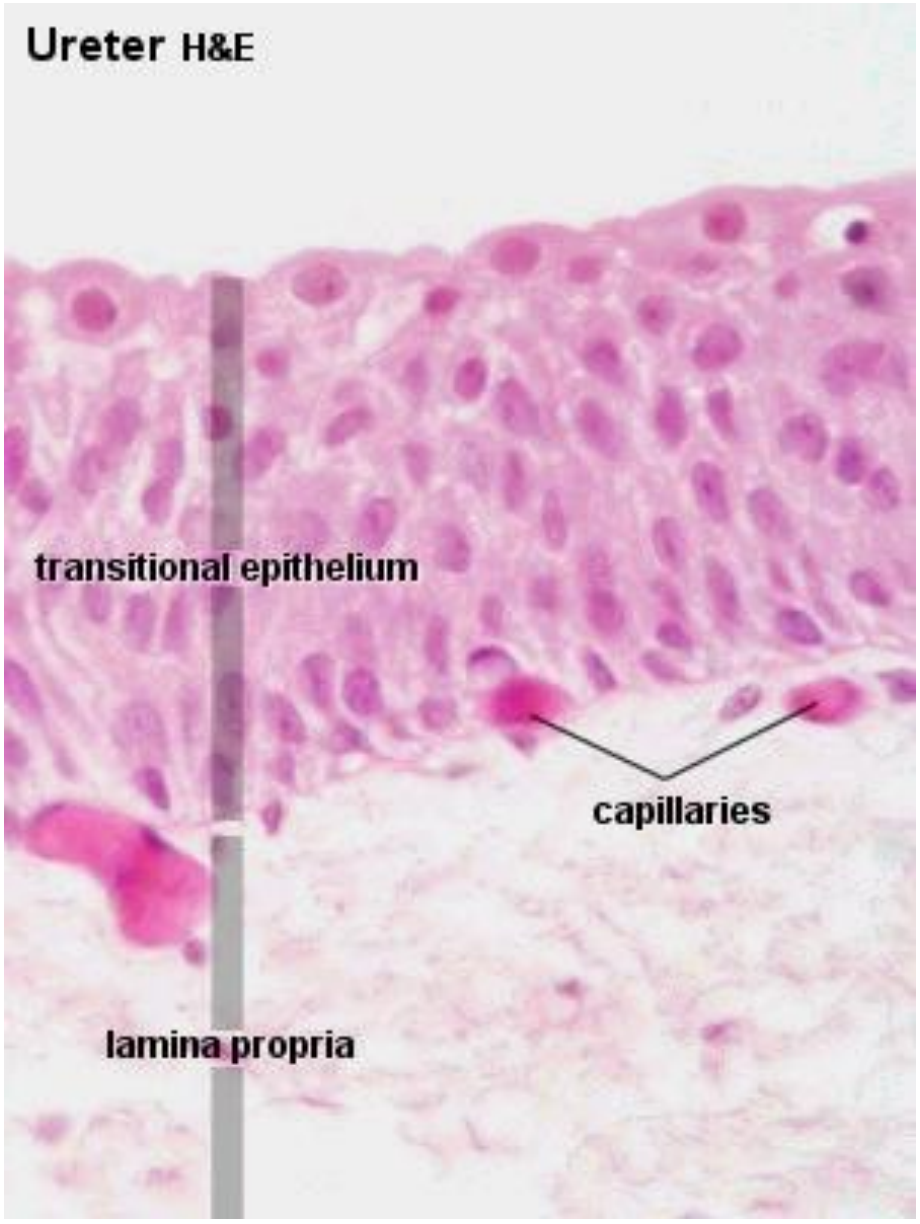
minor calyx, major calyx and **renal pelvis are lined by the transitional epithelium**

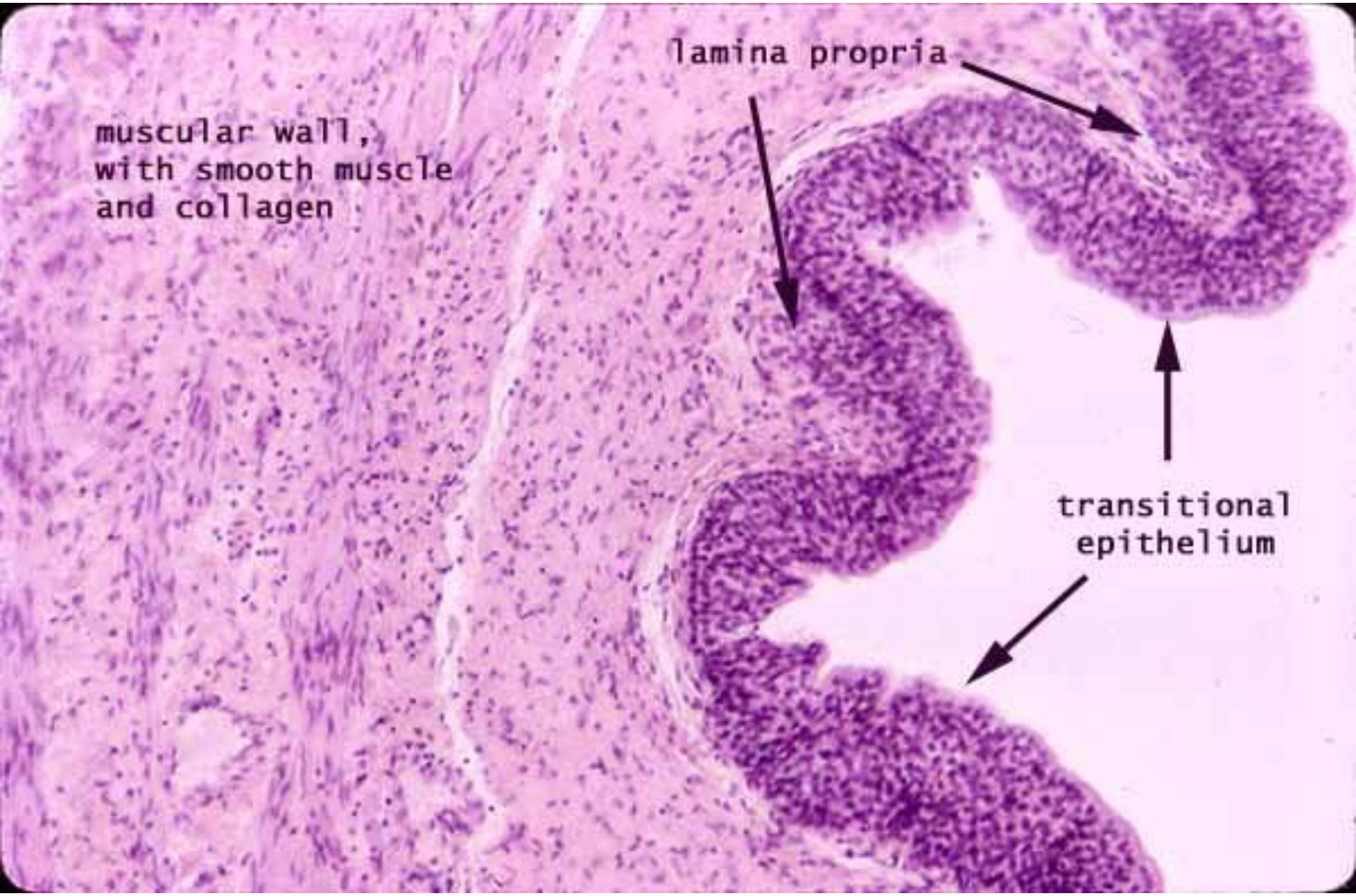
Ureter

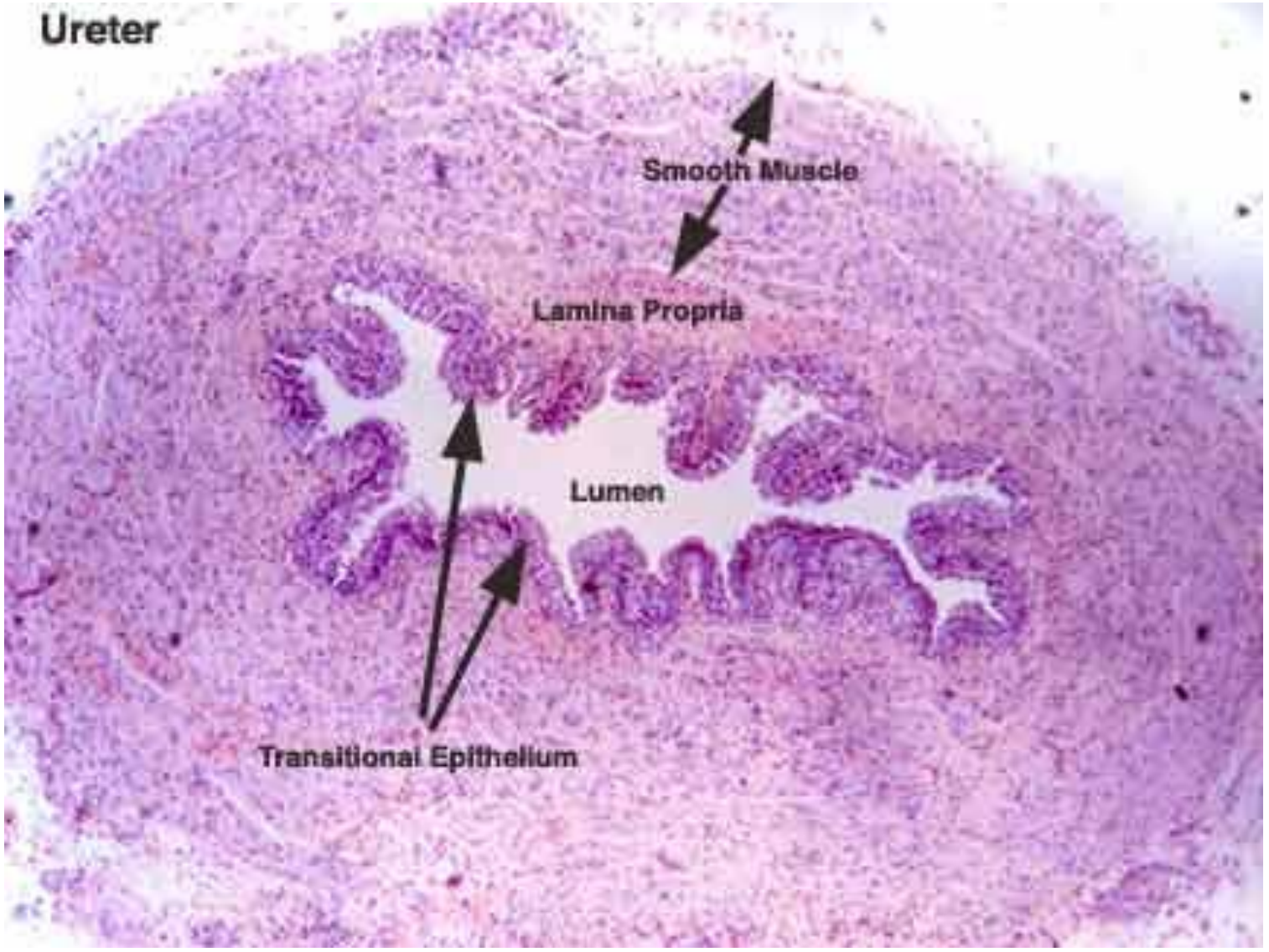


- The mucosa of the ureter is lined by a transitional epithelium (urothelium)
- The mucosa is surrounded by a fibroelastic lamina propria and a muscularis with two to three layers of smooth muscle
- The ureter is surrounded by an adventitia containing adipose tissue


Ureter H&E
transitional epithelium
lamina propria
muscularis
adventitia


Ureter H&E
transitional epithelium
capillaries
lamina propria

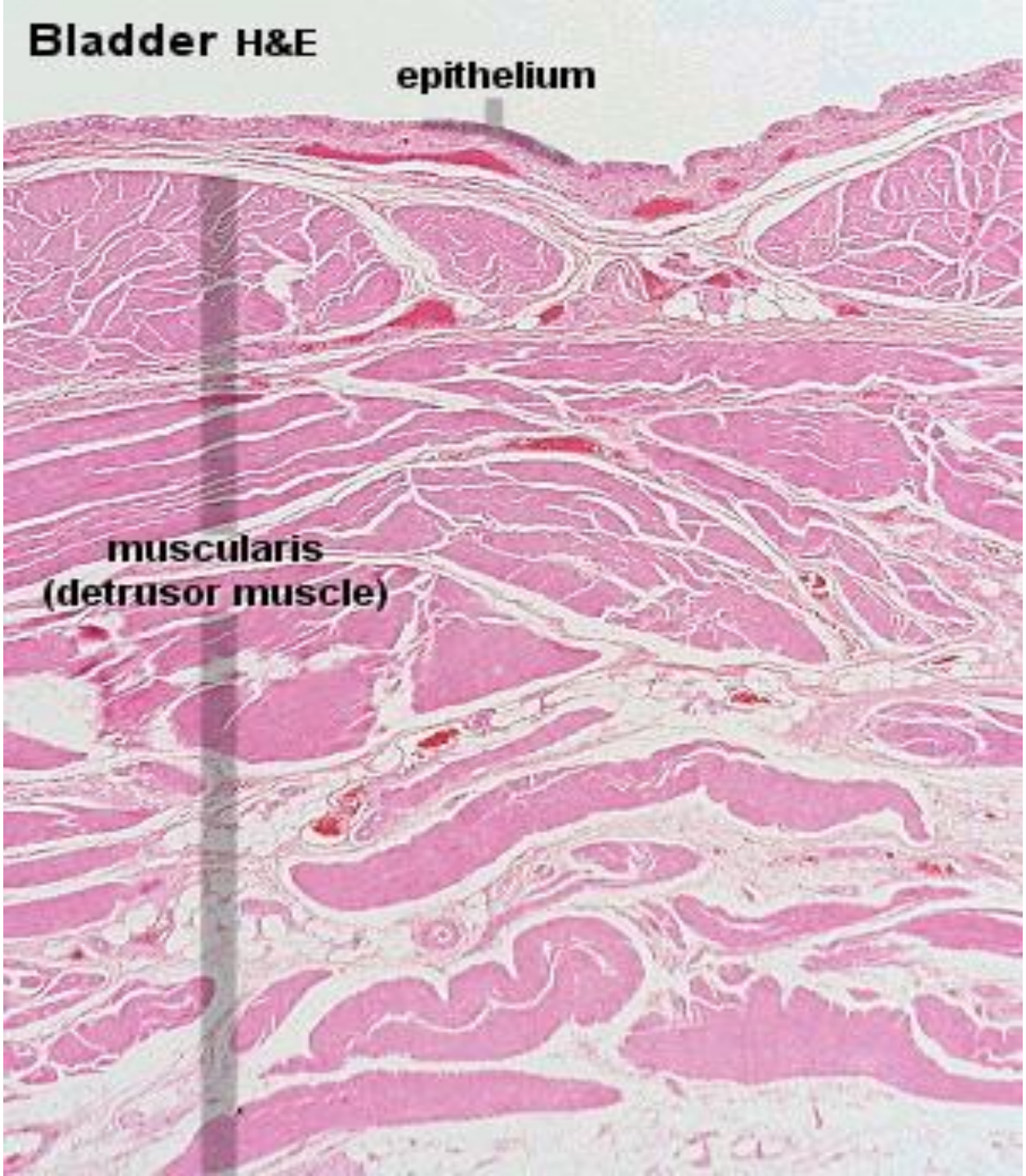

lamina propria
muscular wall,
with smooth muscle
and collagen
transitional
epithelium

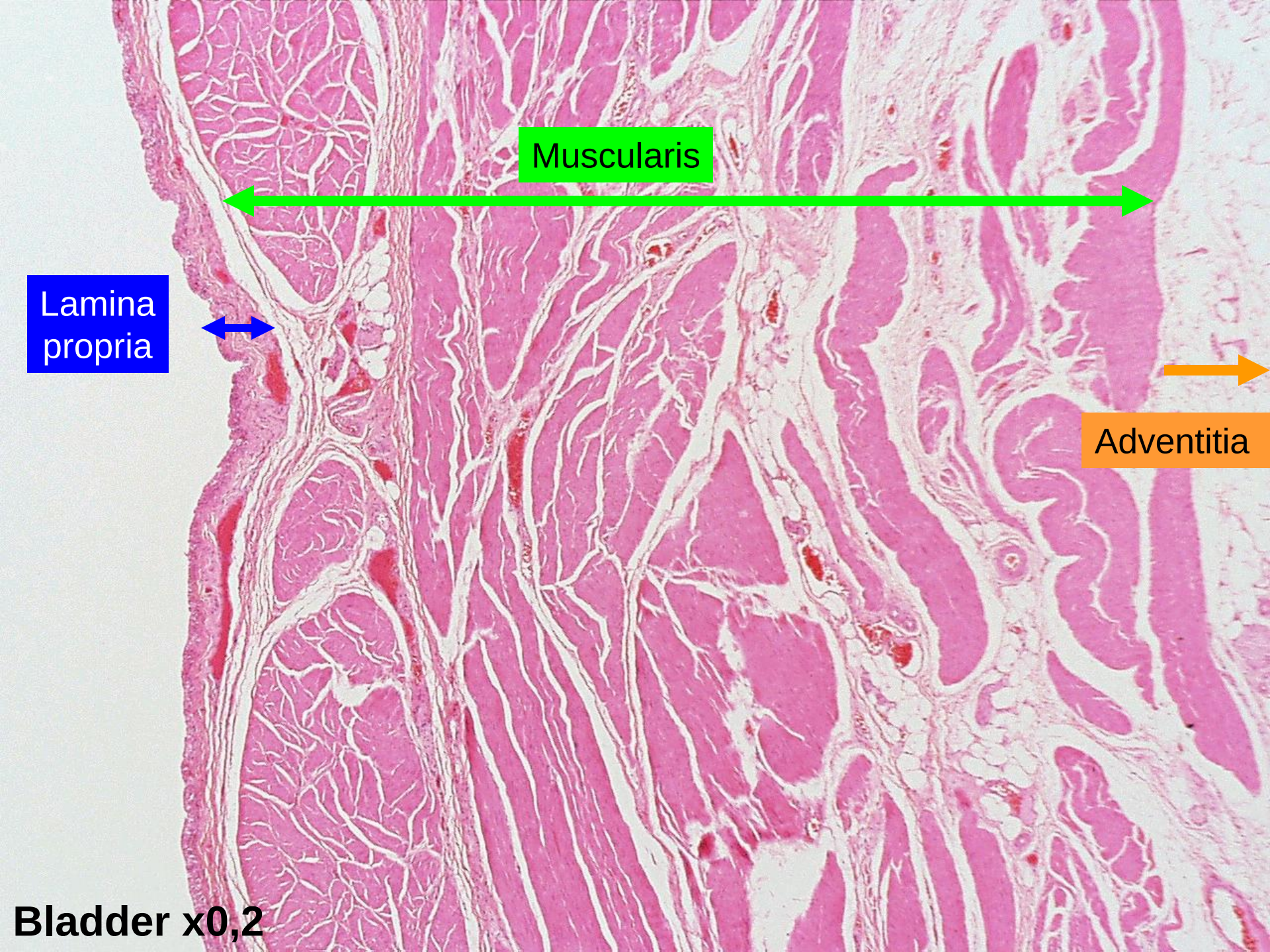


The mucosa of the ureter forms folds which project into the lumen when the ureter is empty

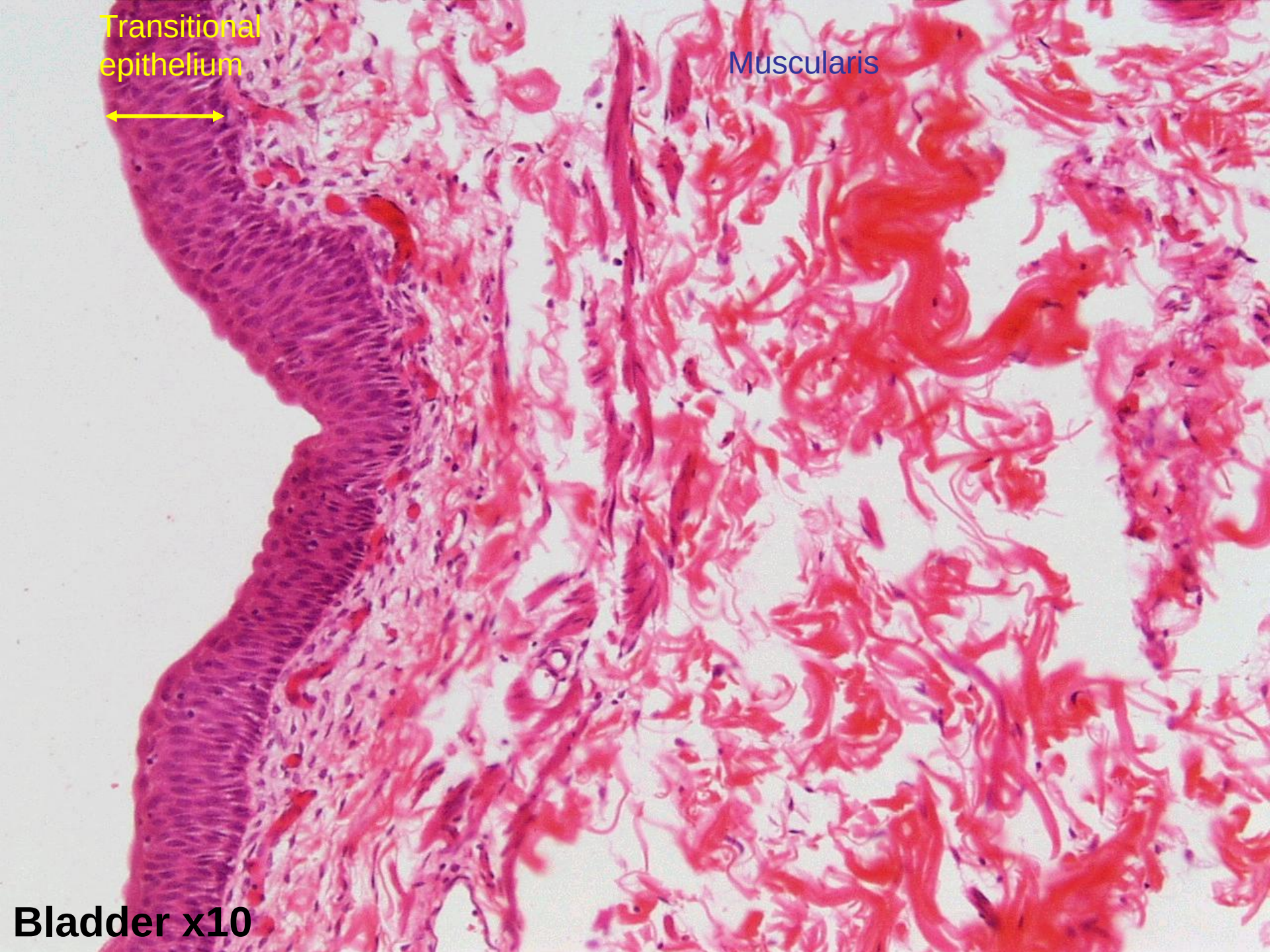
Urinary Bladder

- Lined by a transitional epithelium, the urothelium, composed of basal and superficial cells
- The columnar-like urothelium can strech and resemble a stratified squamous epithelium when urine is present in the urinary bladder
- Apical plaques generate a thickened domain able to adjust to large changes in surface area
- Lamina propria are surrounder by combined helical and longitudinal layers of smooth muscle fibers
- At the neck of the urinary bladder, the muscle fibers form a three-layer (inner longitudinal, middle circular, outer longitudinal)

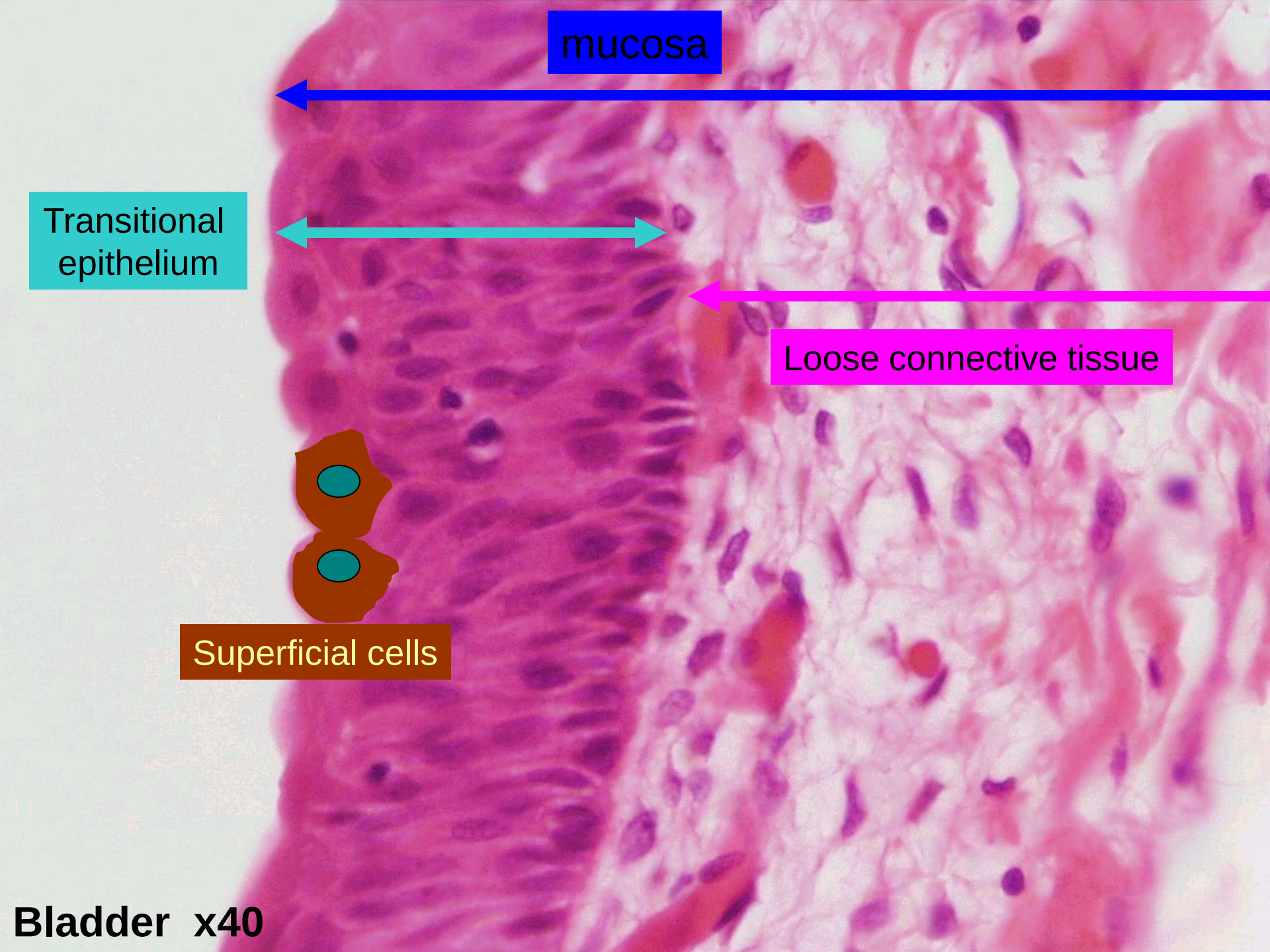

Bladder H&E
epithelium
muscularis
(detrusor muscle)



Bladder x0,2

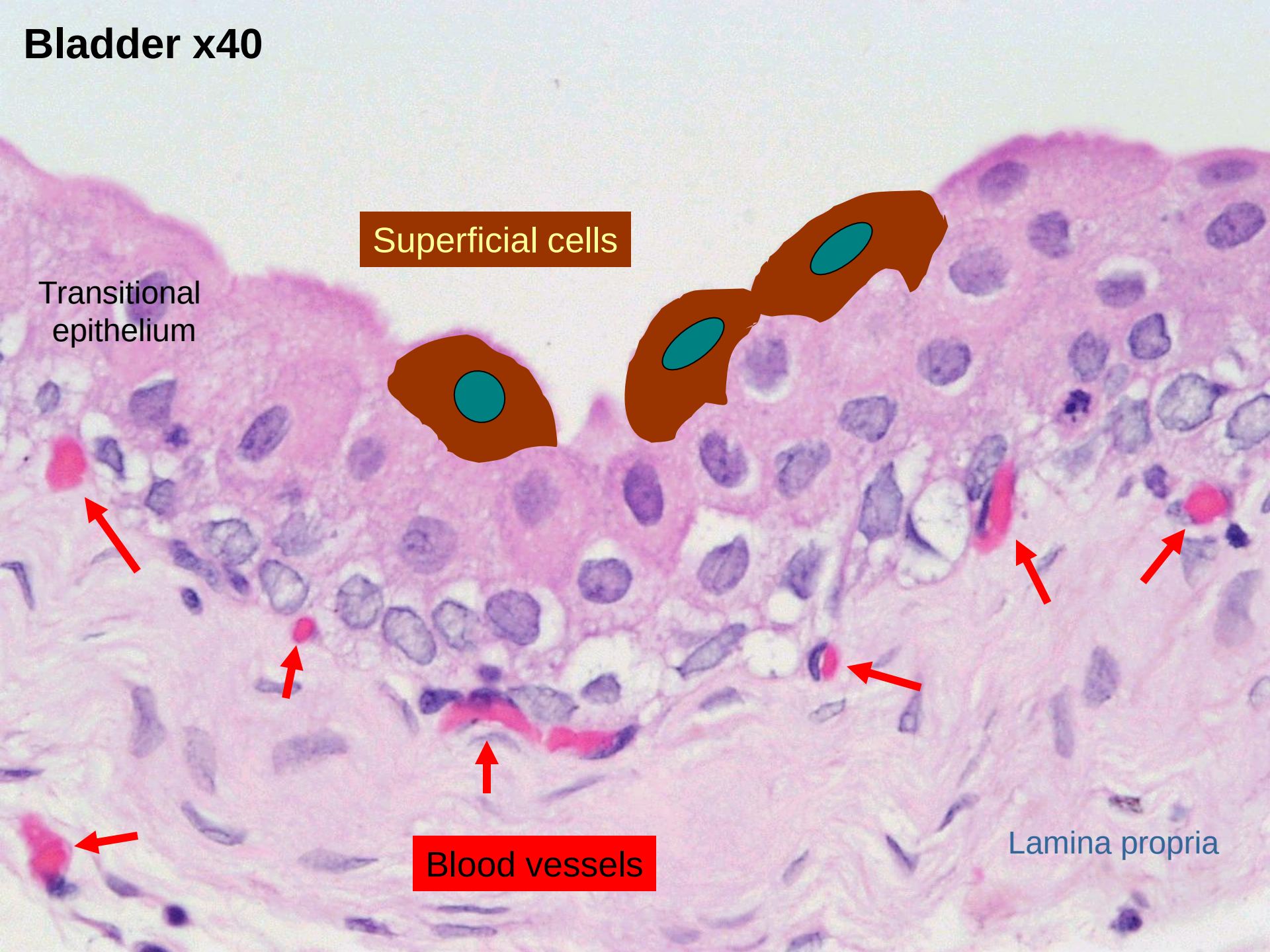


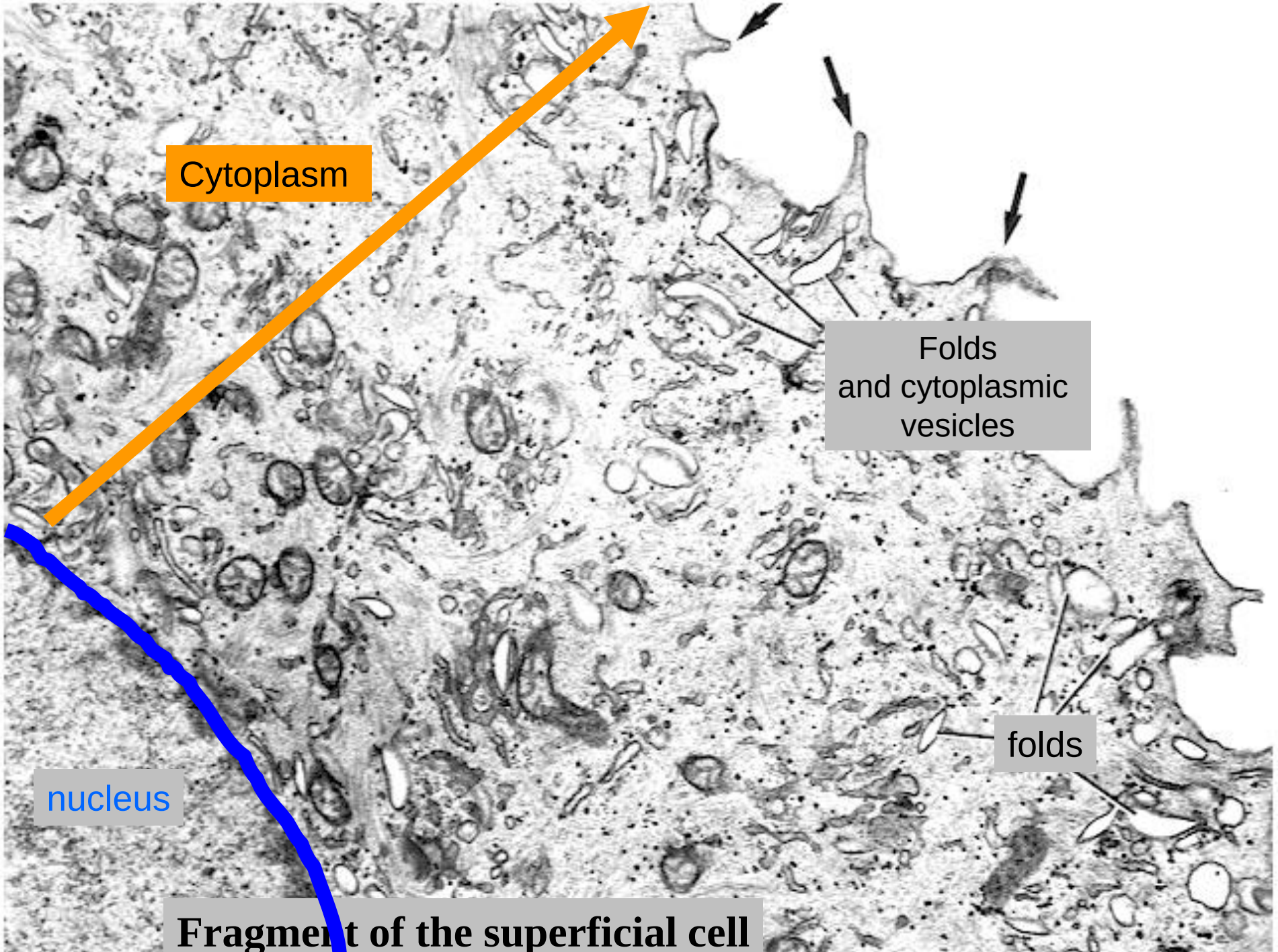
Bladder x10


mucosa
Transitional epithelium
Loose connective tissue
Superficial cells

Bladder x40

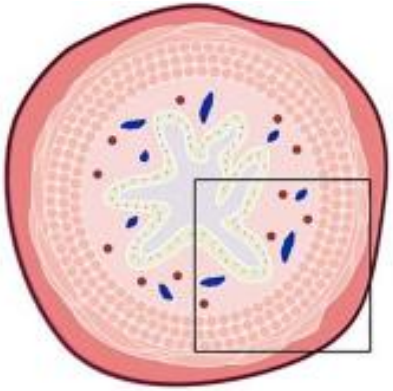
Bladder x40

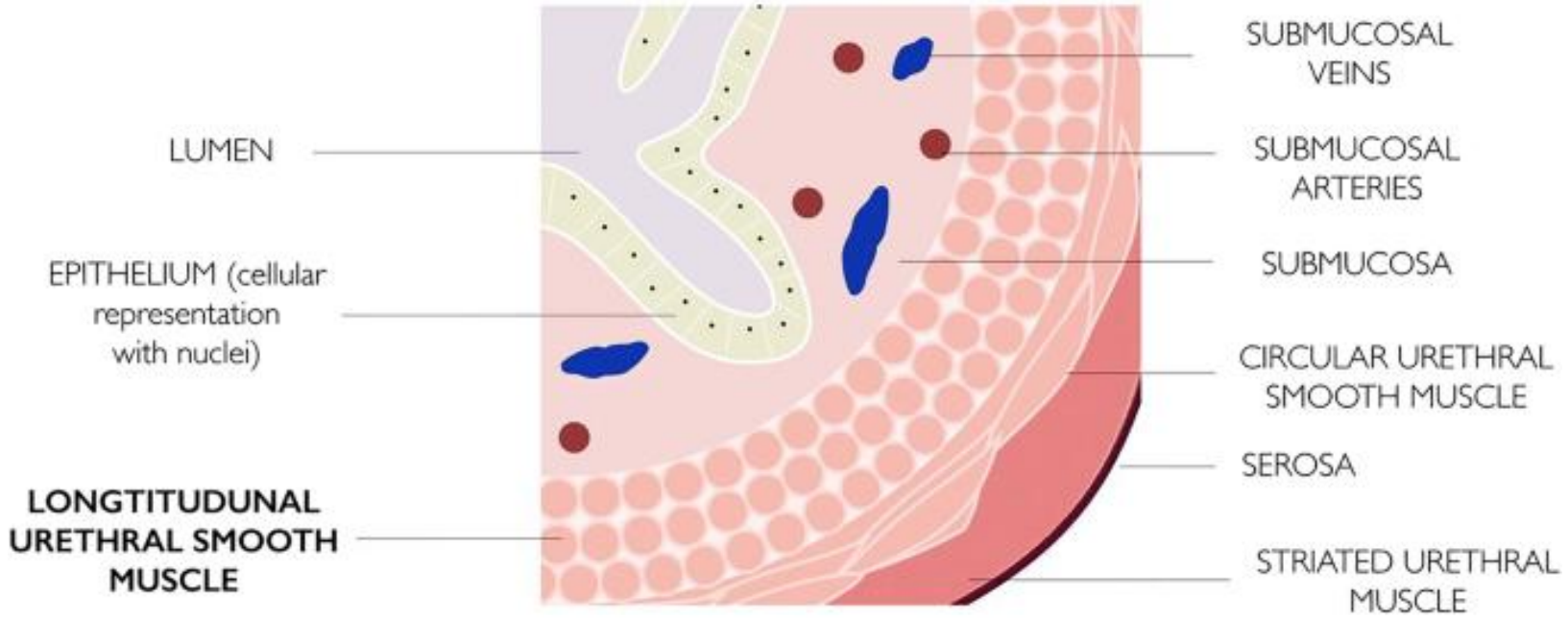

Superficial cells
Transitional epithelium
Blood vessels
Lamina propria



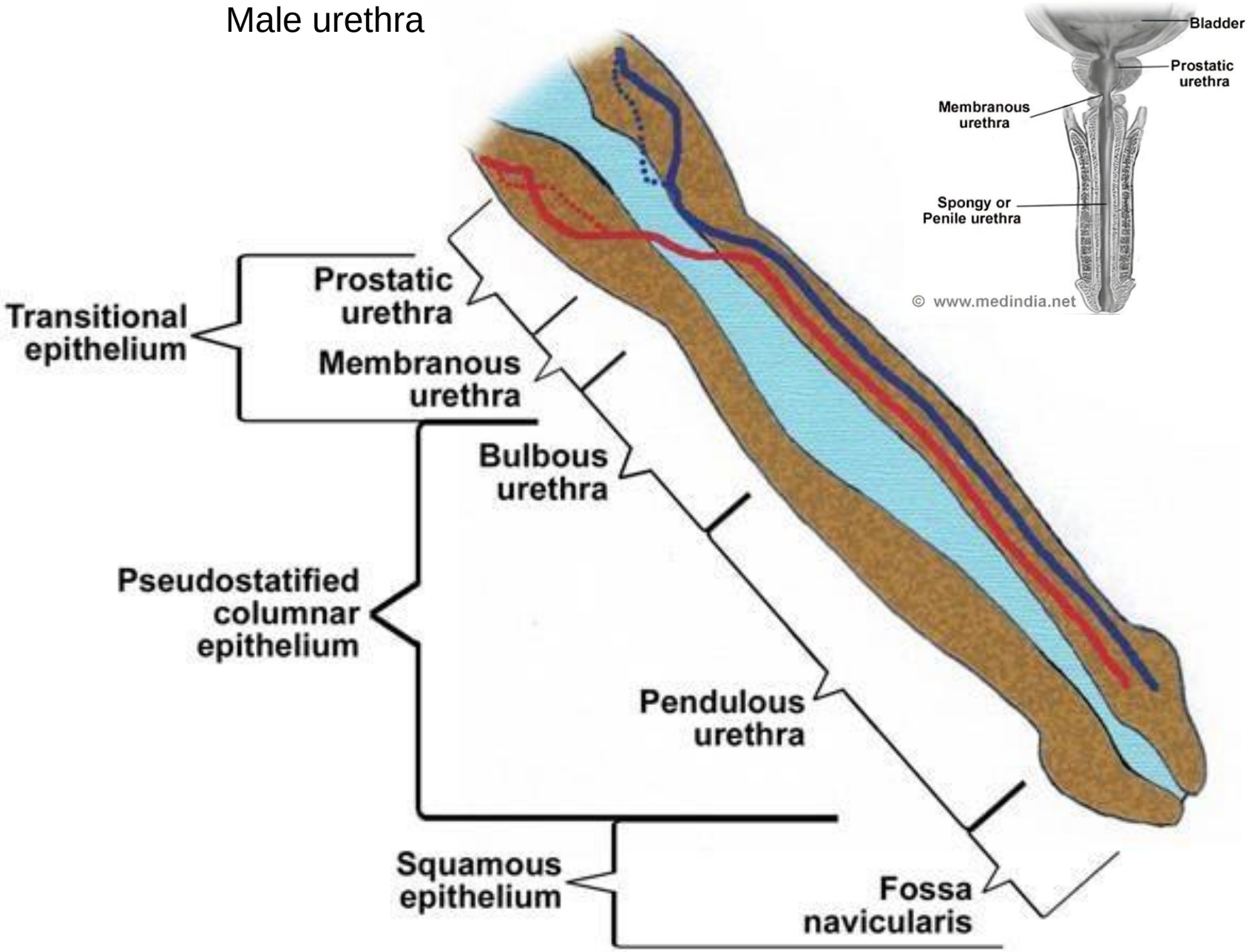
Fragment of the superficial cell

Female urethra

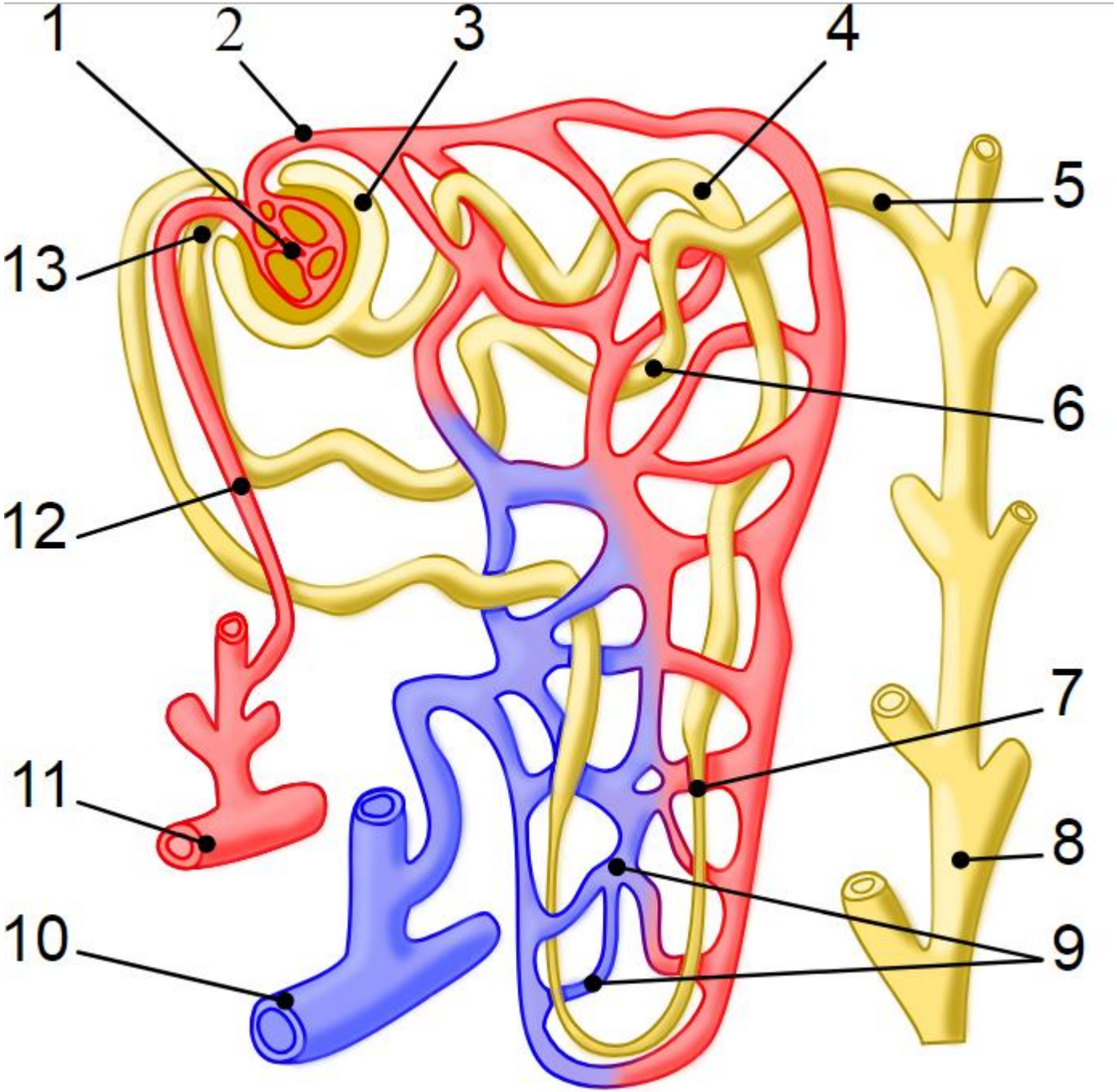




Male urethra



SLIDES for today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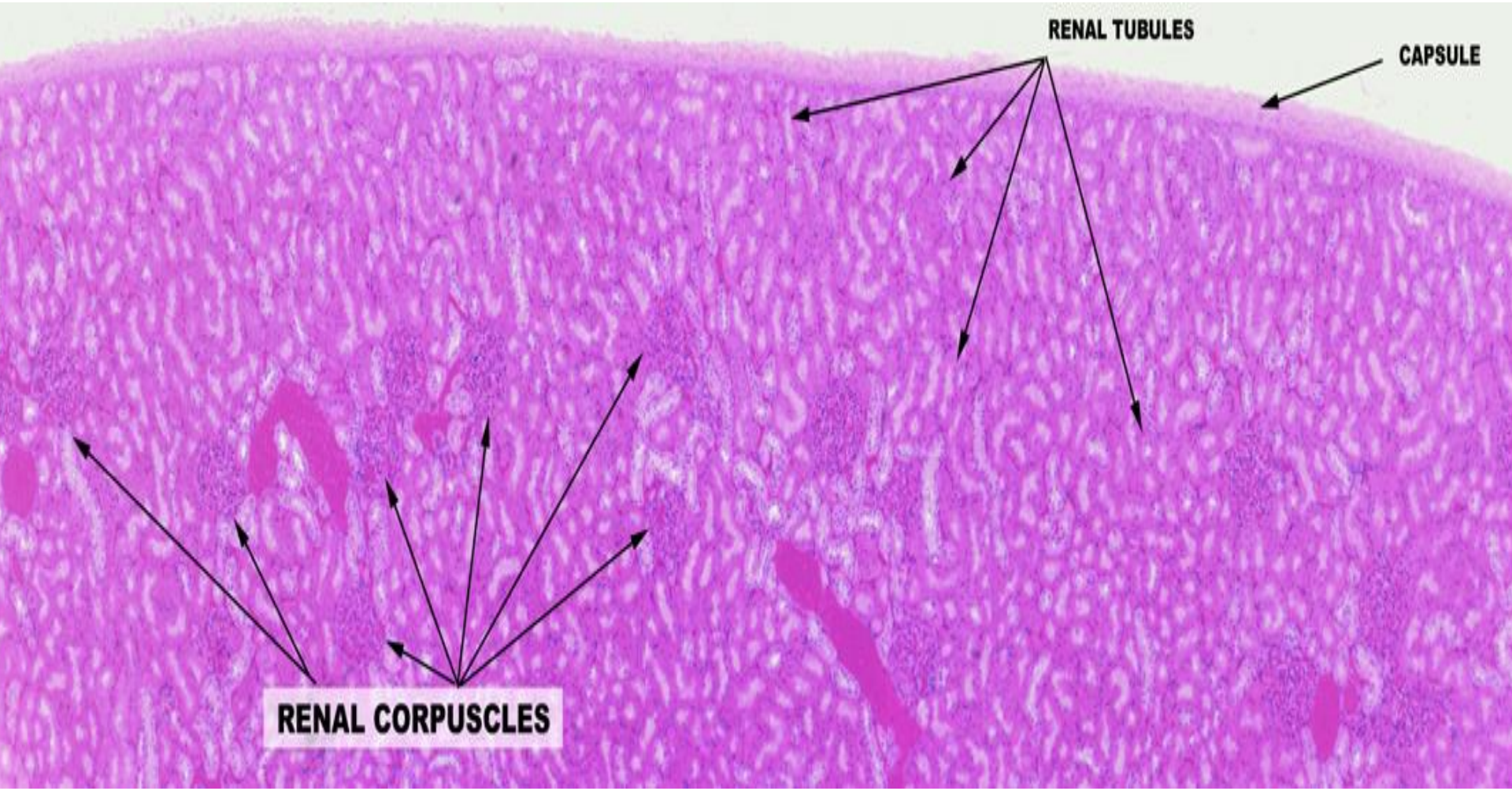
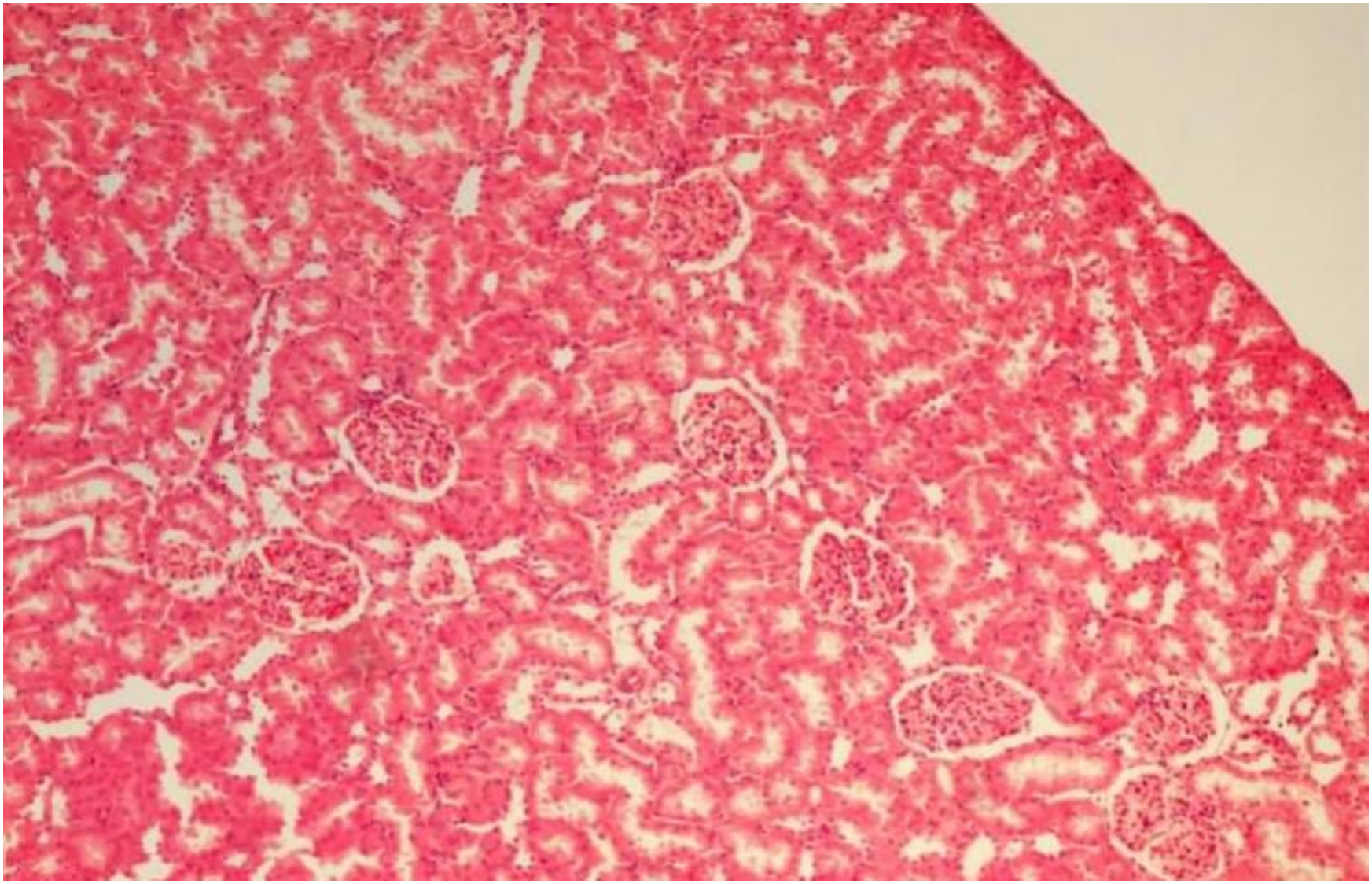
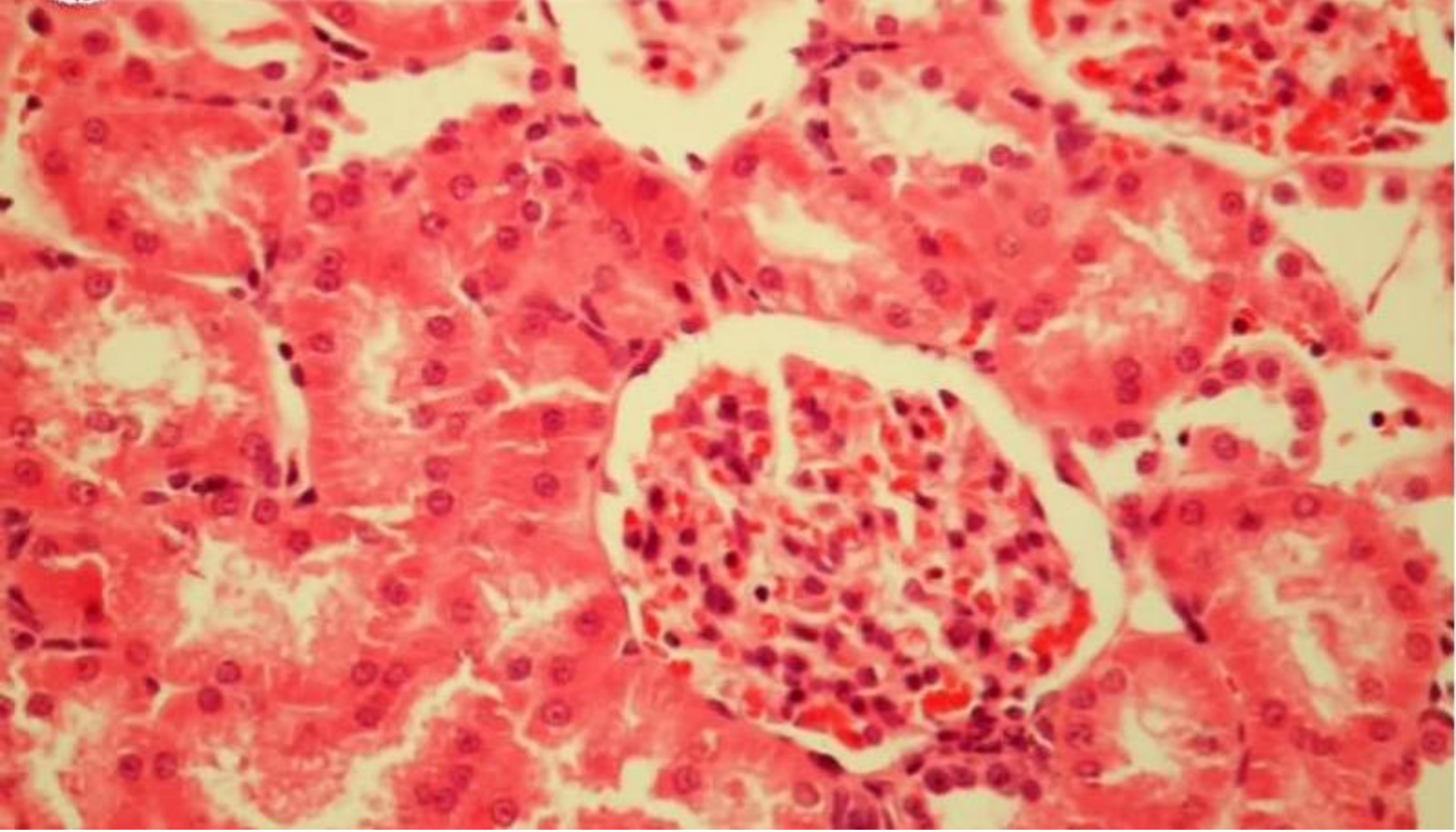


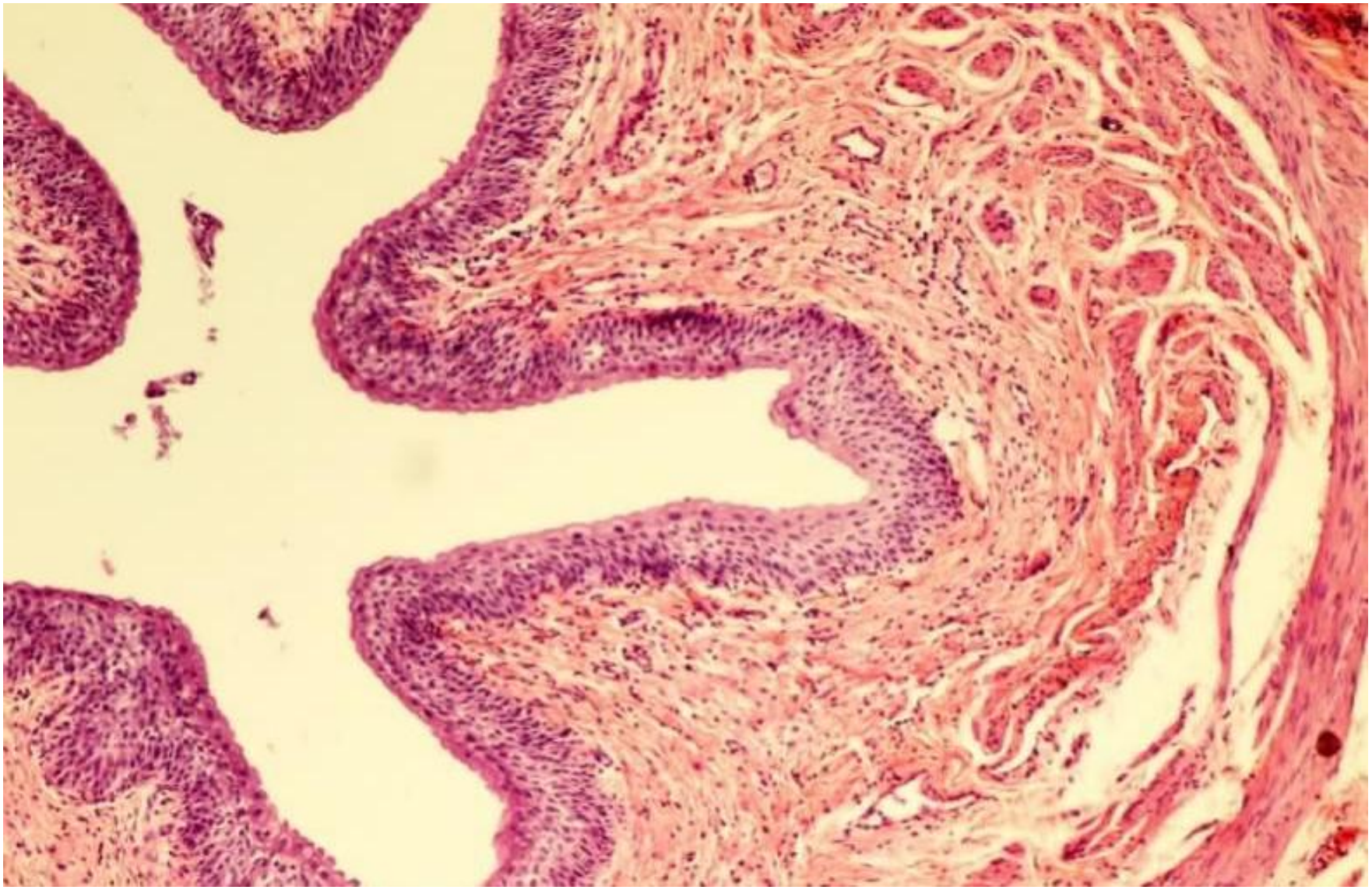
kidney – cortex (no. 63)



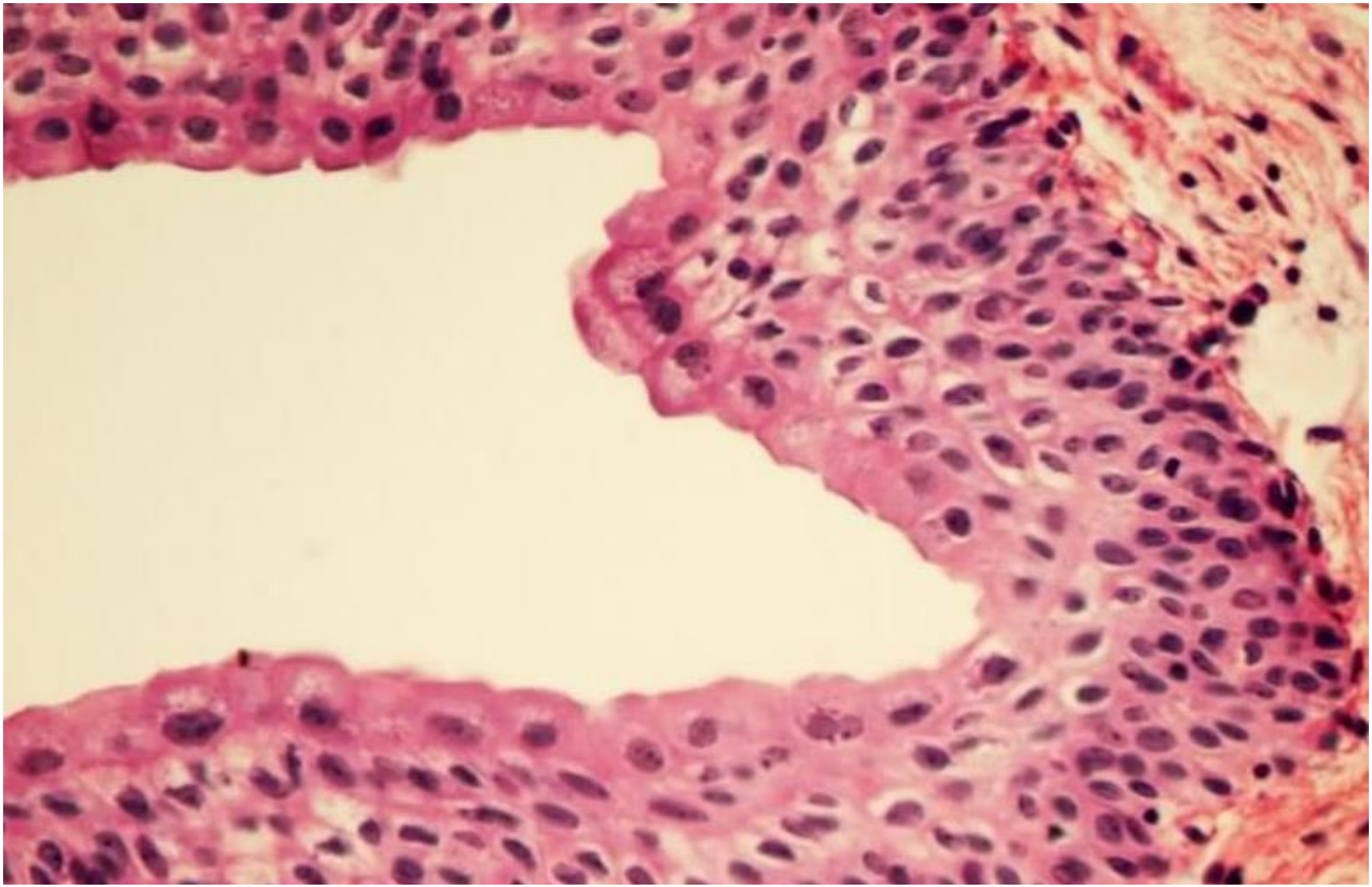
kidney – cortex (no. 63)



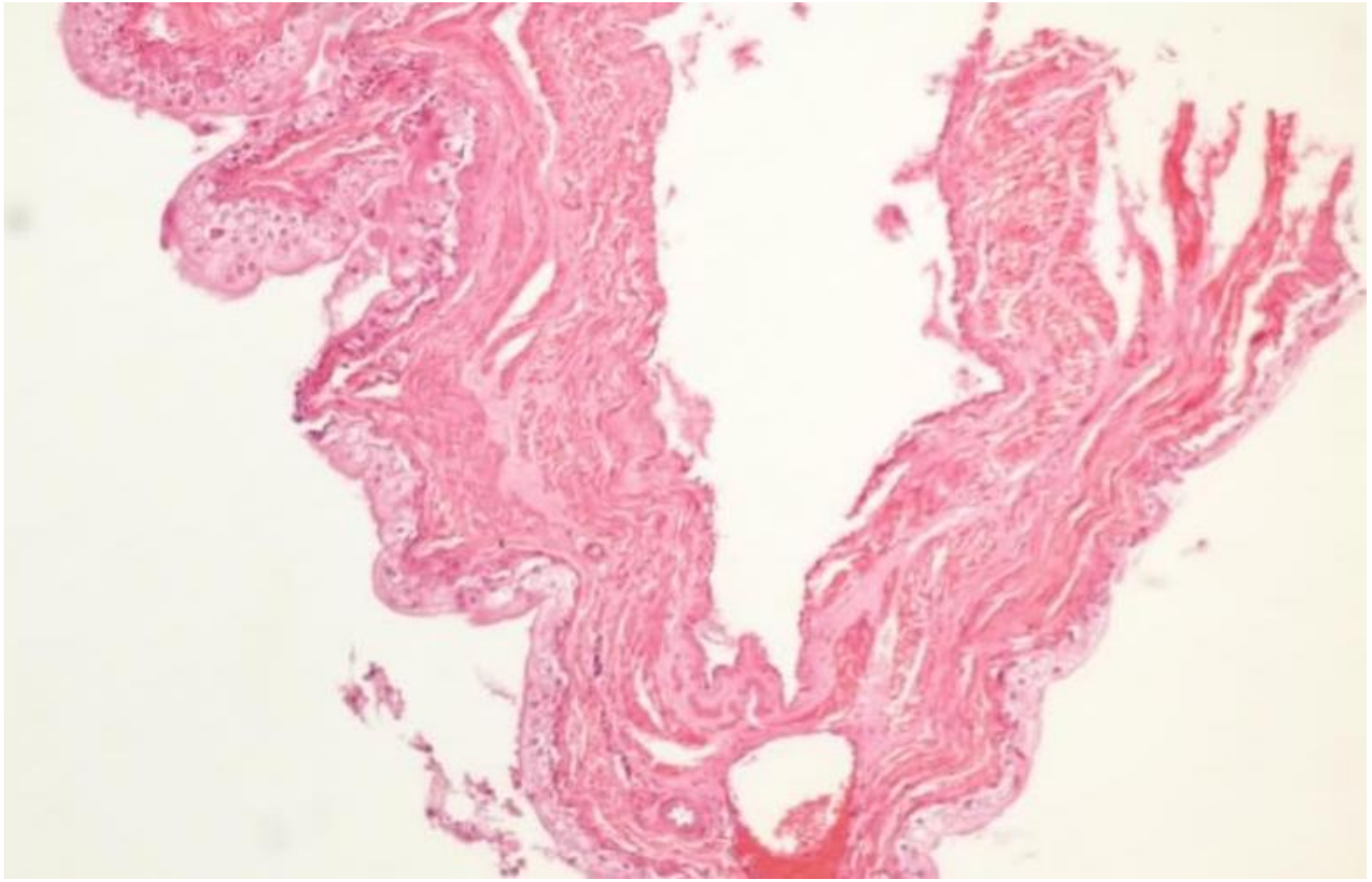
kidney – renal corpuscle (no. 63)



ureter (no. 66)

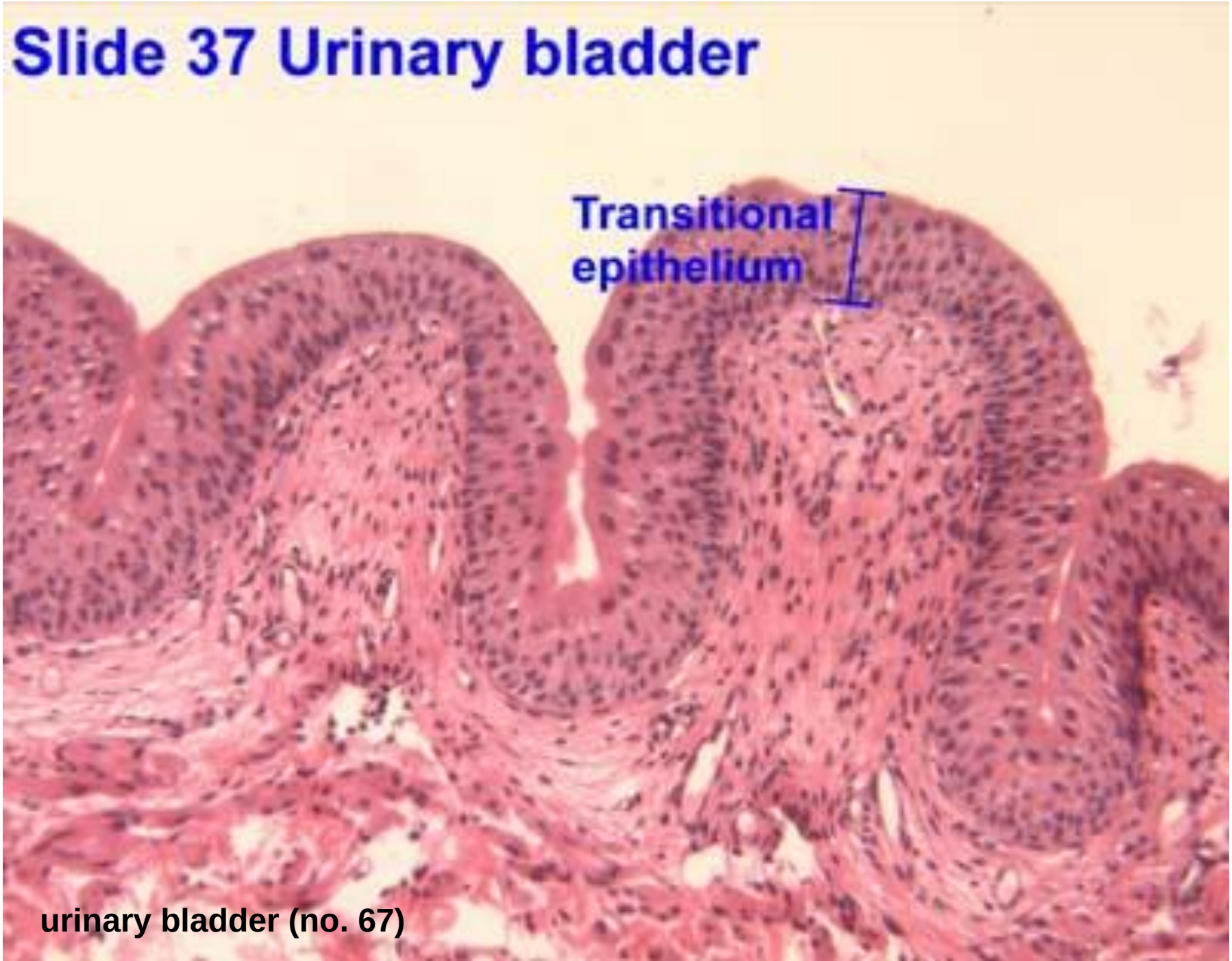


ureter (no. 66)



urinary bladder (no. 67)

Slide 37 Urinary bladder



urinary bladder (no. 67)

urinary bladder (no. 67)


NEXT CLASS – SKIN
AND MAMMARY GLAND