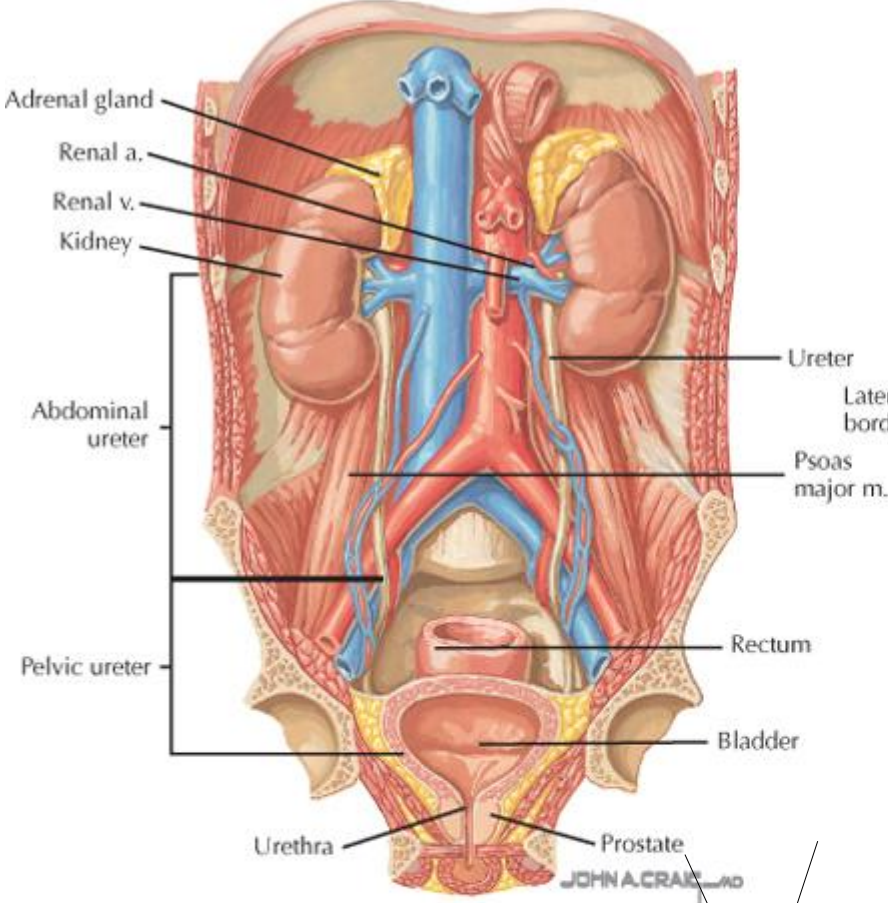
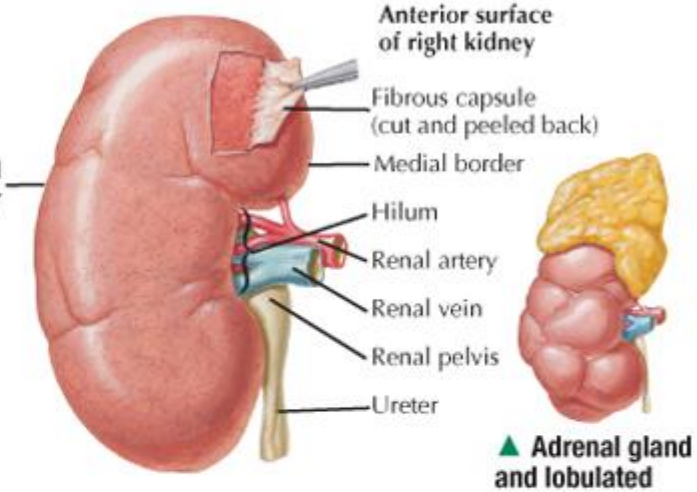
Urinary system

MUDr. Pavel Roštok

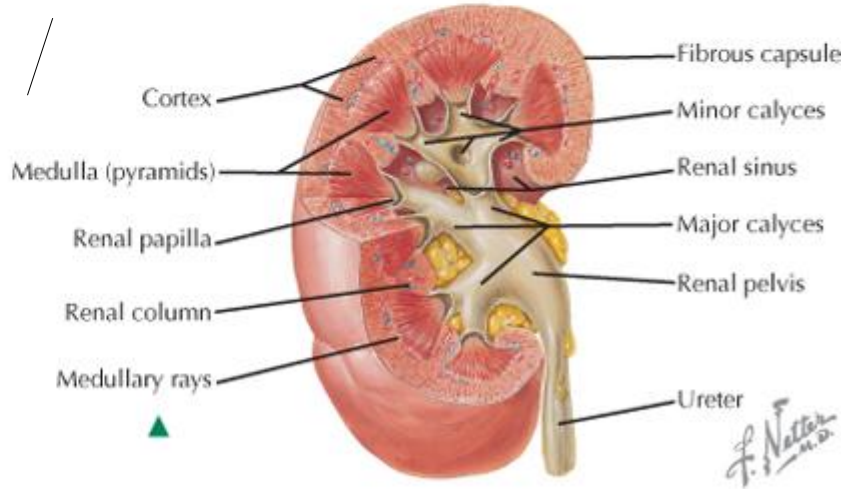


▲ **Regional anatomy of the urinary system.** The kidneys, embedded in fat, lie in a retroperitoneal position (behind the peritoneum, outside the abdominal cavity), just anterior to muscles of the posterior abdominal wall.

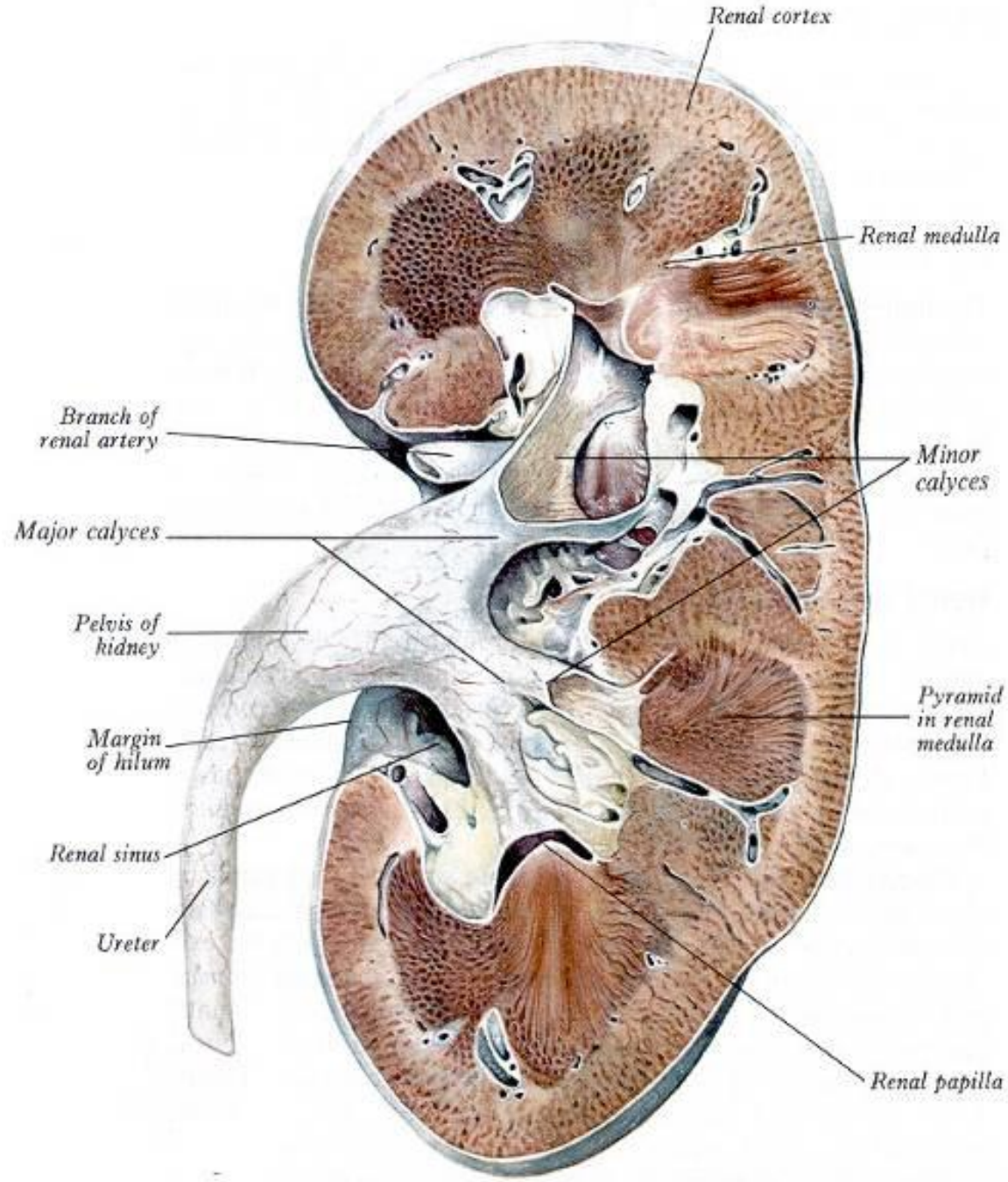
▼ **Gross structure of the kidney.**



▲ **Adrenal gland and lobulated kidney of infant.**



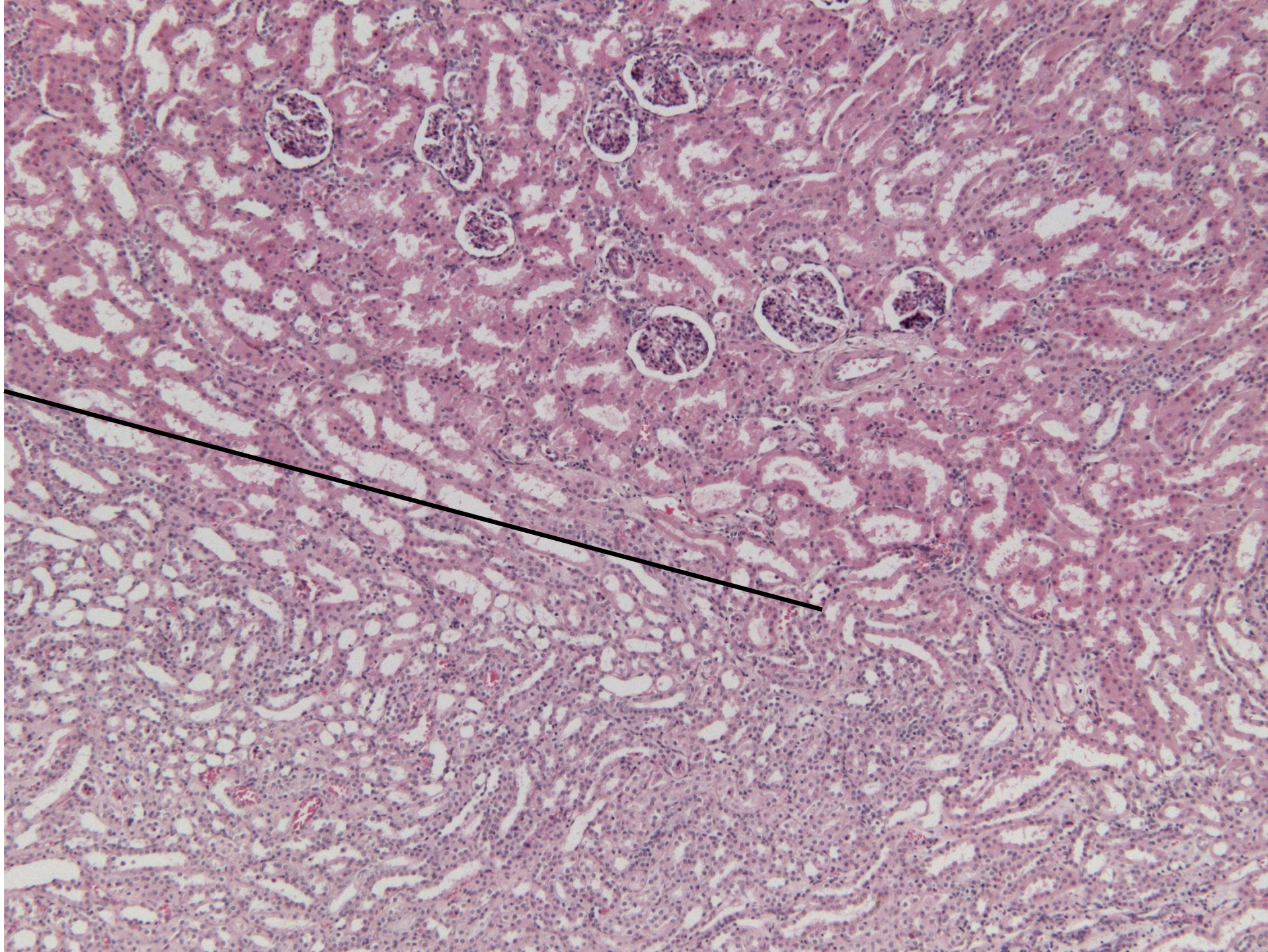
▲ **Right kidney sectioned in several planes, exposing parenchyma and renal pelvis.**

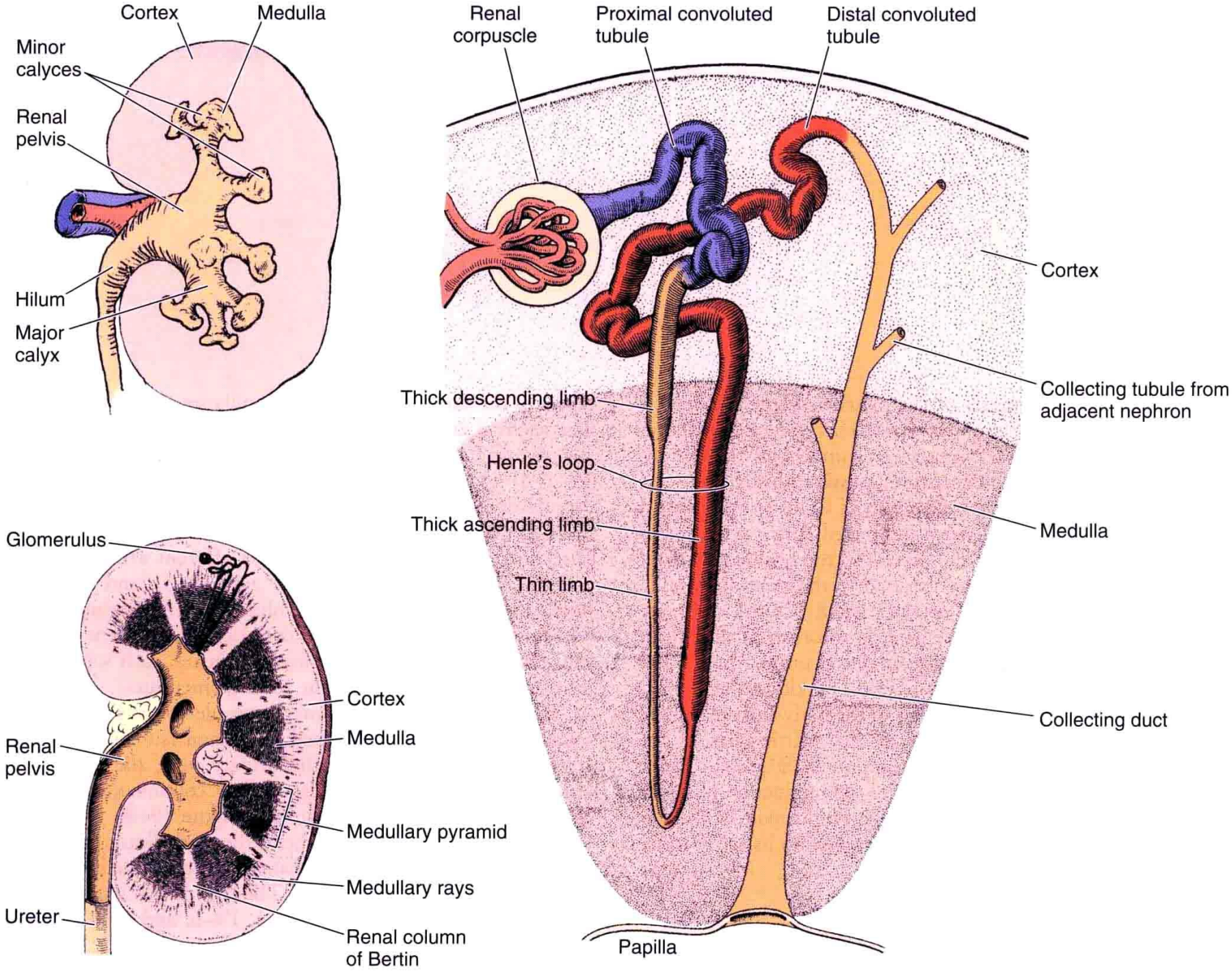

Renal cortex
Renal medulla
Branch of renal artery
Minor calyces
Major calyces
Pelvis of kidney
Pyramid in renal medulla
Margin of hilum
Renal sinus
Ureter
Renal papilla

Renal capsule also contains myofibroblasts

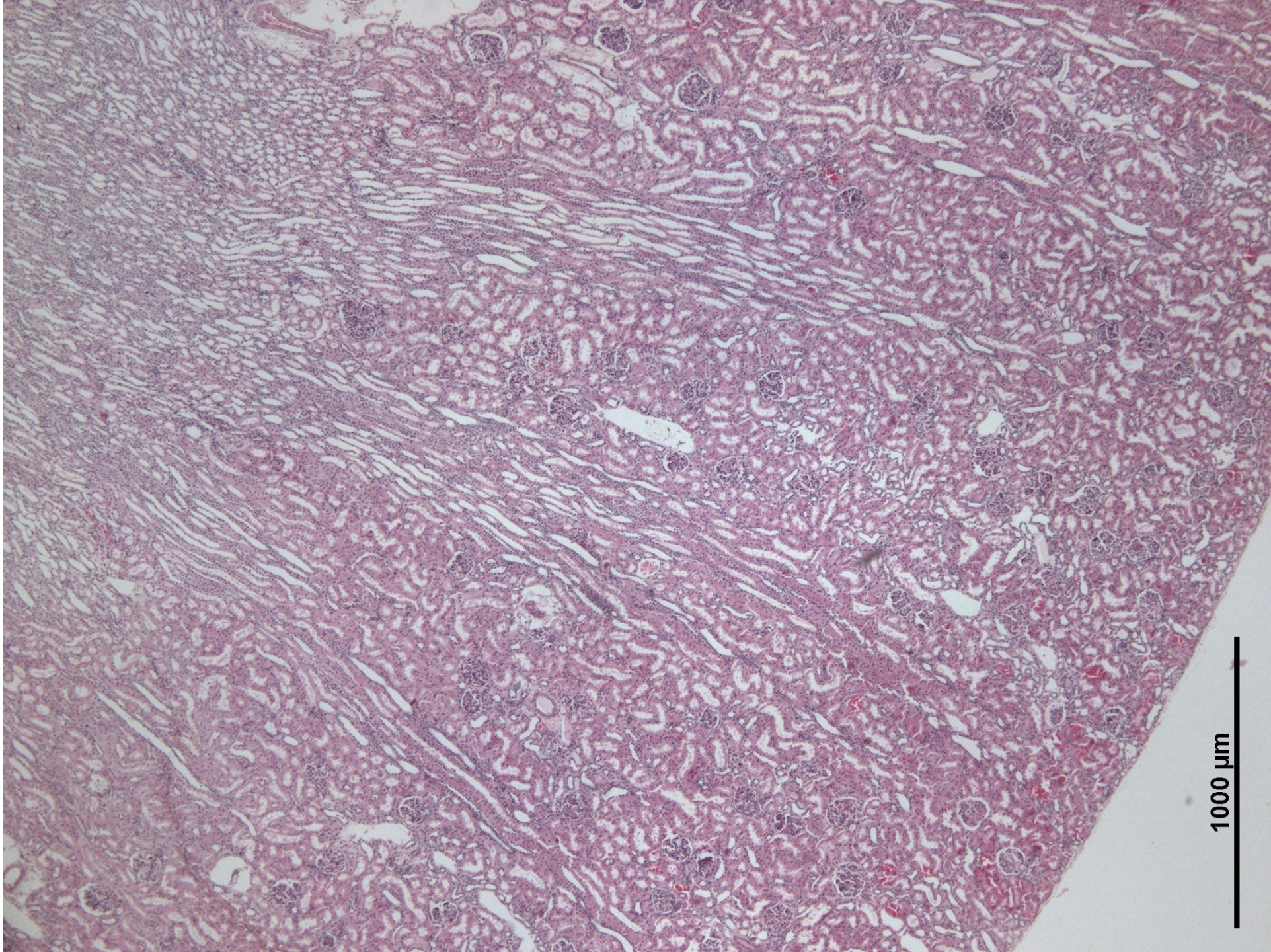
What‘s on the surface?

Medulla and cortex

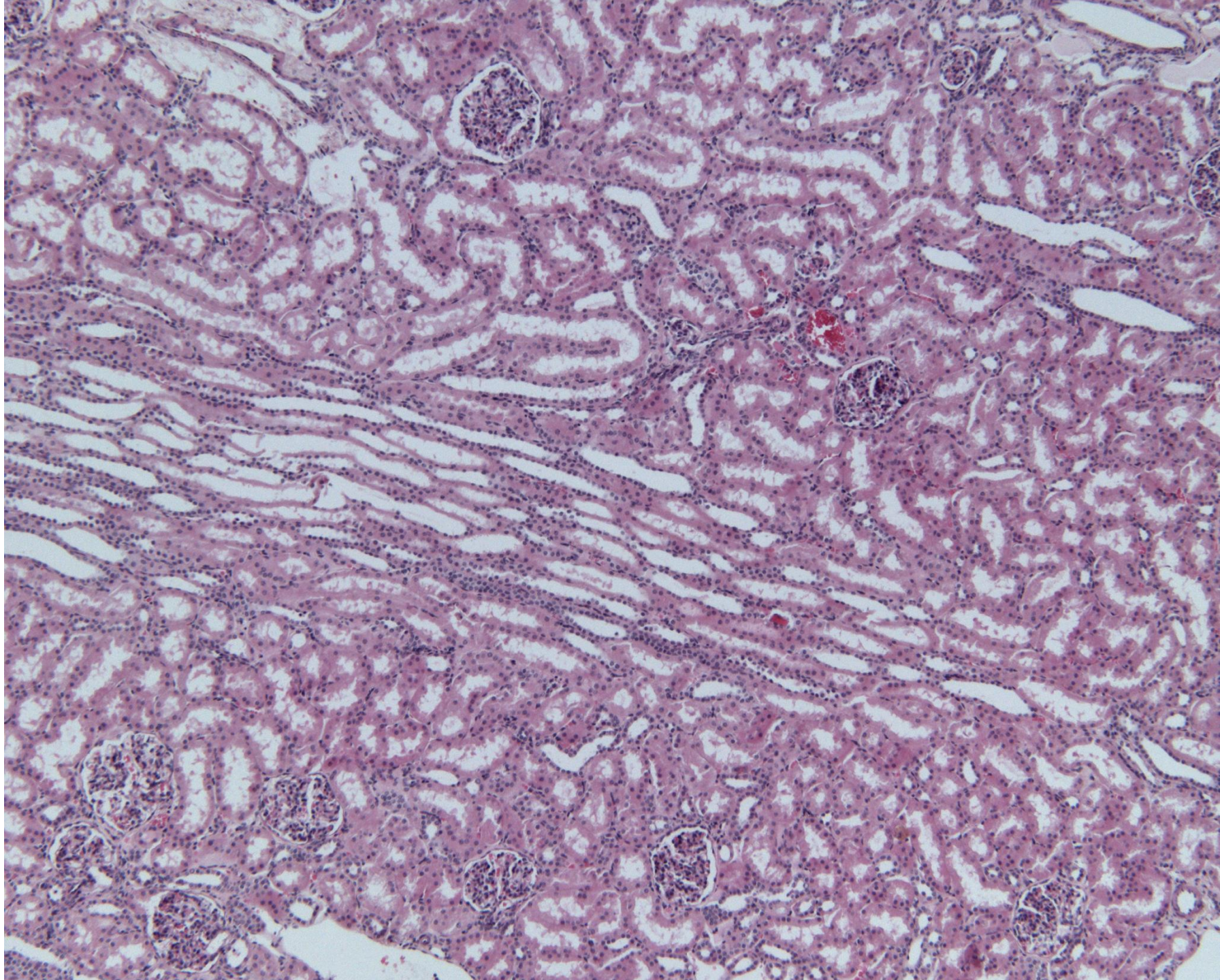


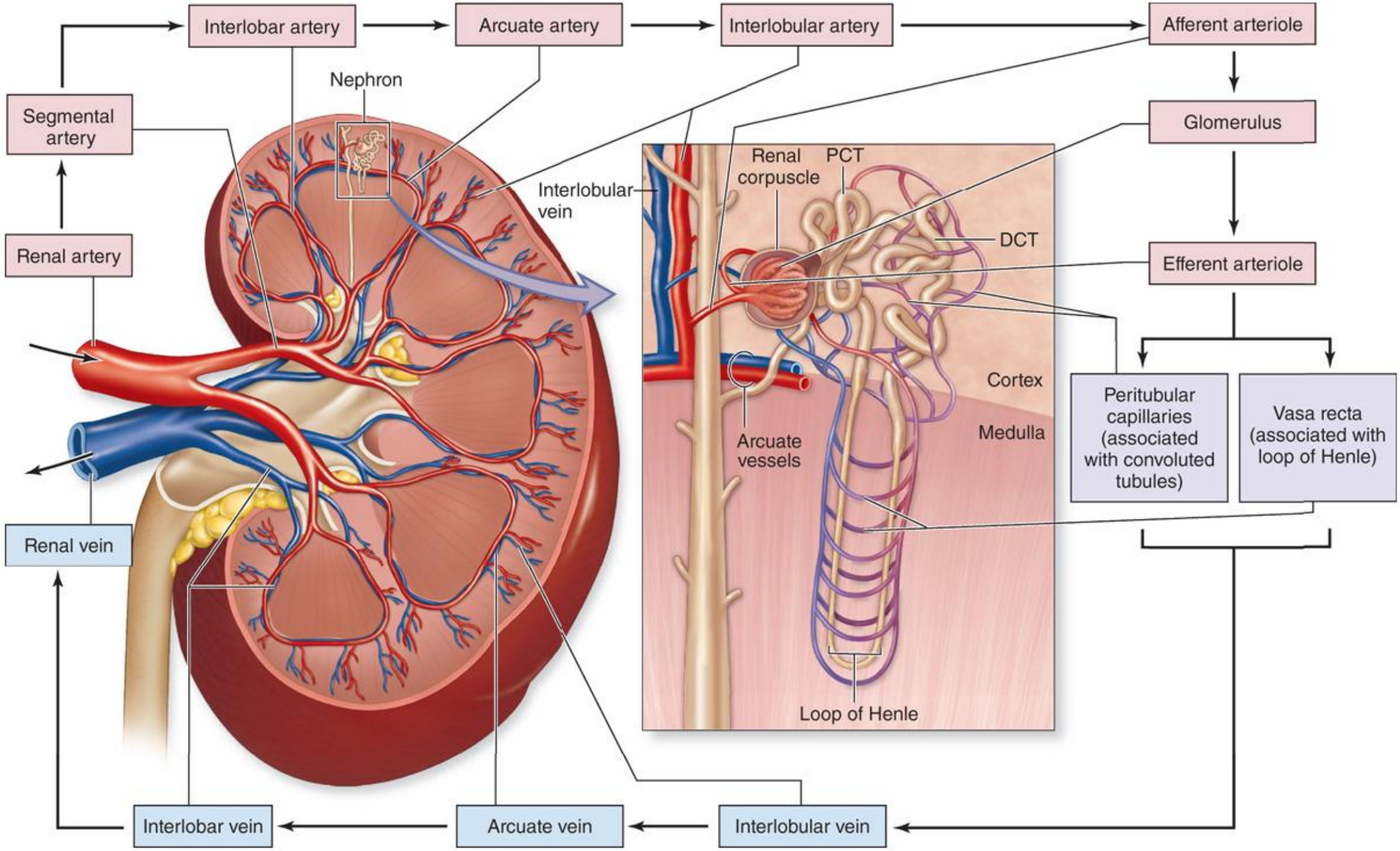

Cortex
Medulla
Minor calyces
Renal pelvis
Hilum
Major calyx
Renal corpuscle
Proximal convoluted tubule
Distal convoluted tubule
Cortex
Collecting tubule from adjacent nephron
Thick descending limb
Henle's loop
Thick ascending limb
Thin limb
Medulla
Collecting duct
Papilla
Glomerulus
Cortex
Medulla
Renal pelvis
Medullary pyramid
Medullary rays
Ureter
Renal column of Bertin

Medullary rays

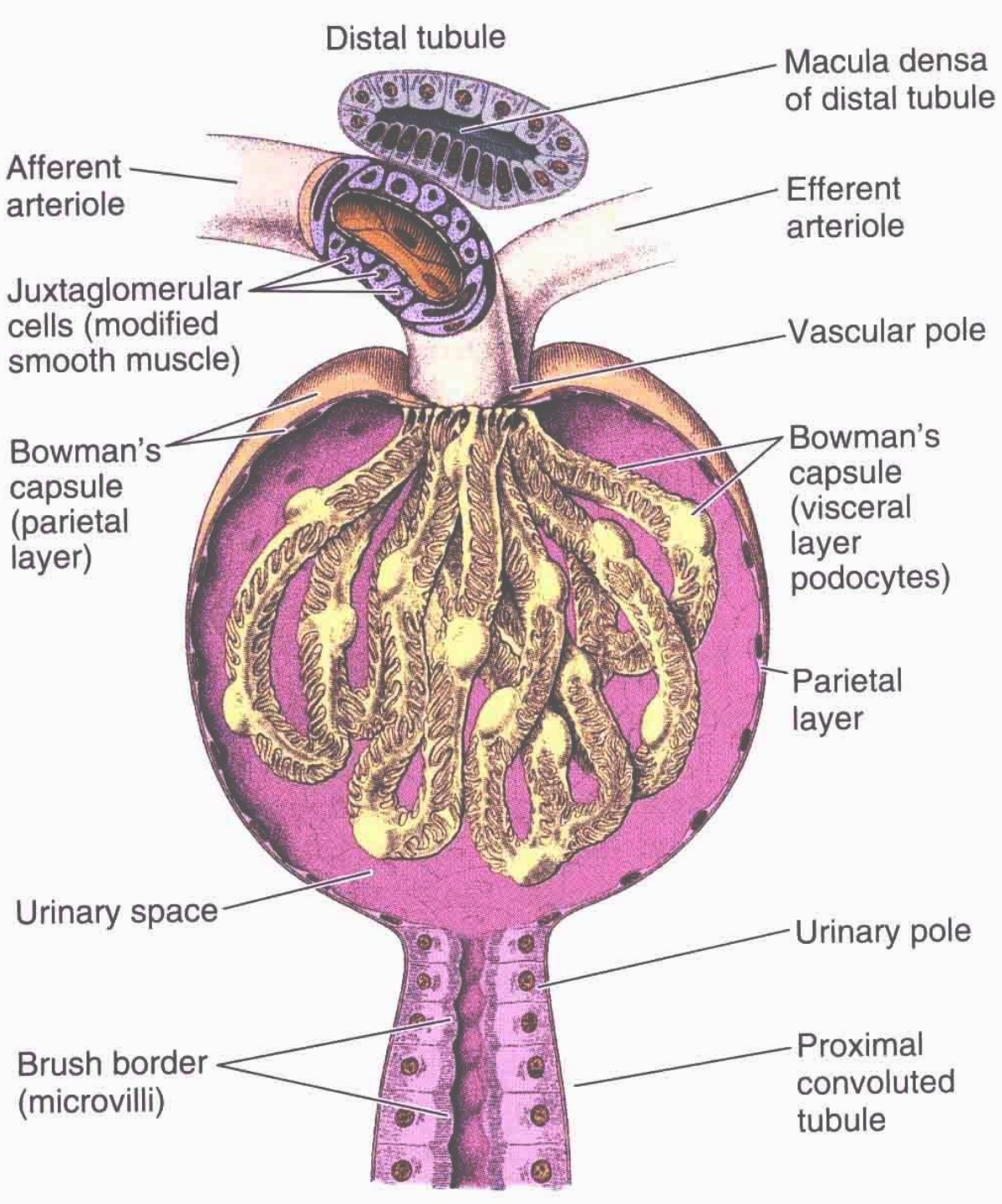


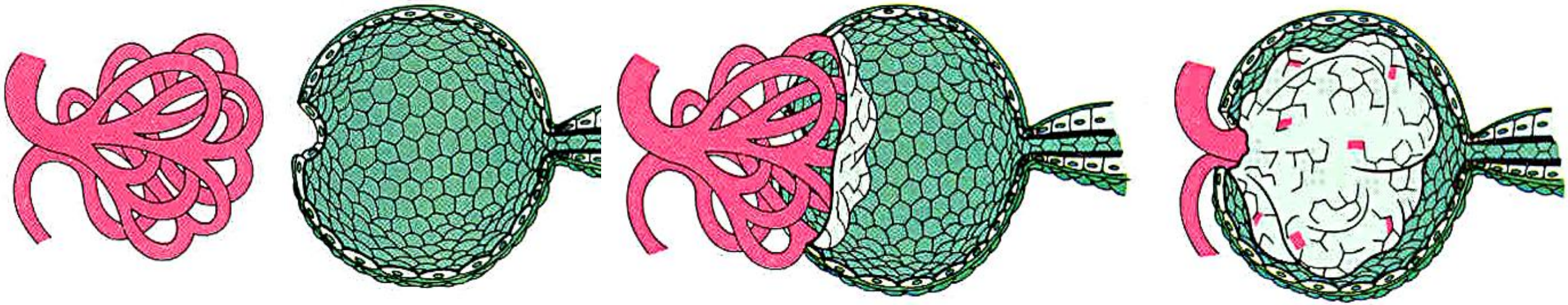
Close up on a medullary ray

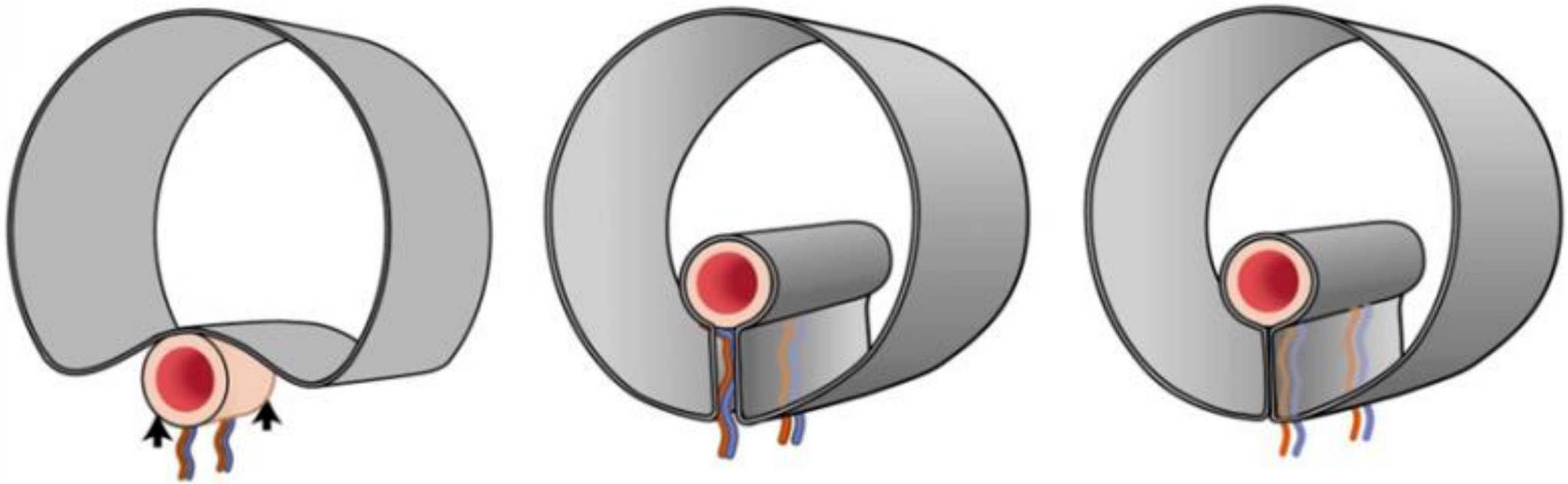


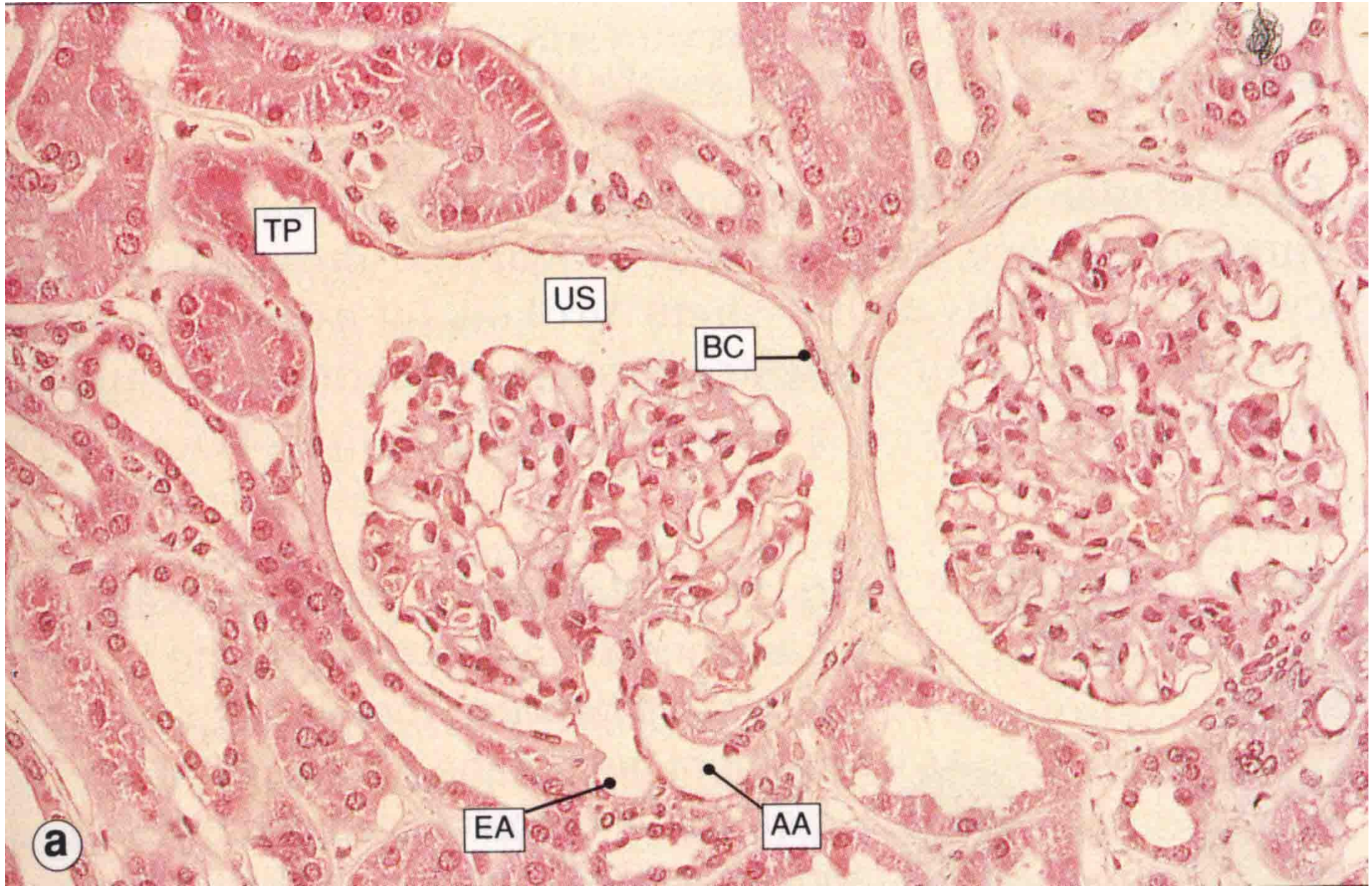

Interlobar artery
Arcuate artery
Interlobular artery
Afferent arteriole
Glomerulus
Efferent arteriole
Segmental artery
Renal artery
Renal vein
Nephron
Interlobular vein
Renal corpuscle
PCT
DCT
Cortex
Medulla
Arcuate vessels
Loop of Henle
Peritubular capillaries (associated with convoluted tubules)
Vasa recta (associated with loop of Henle)
Interlobar vein
Arcuate vein
Interlobular vein

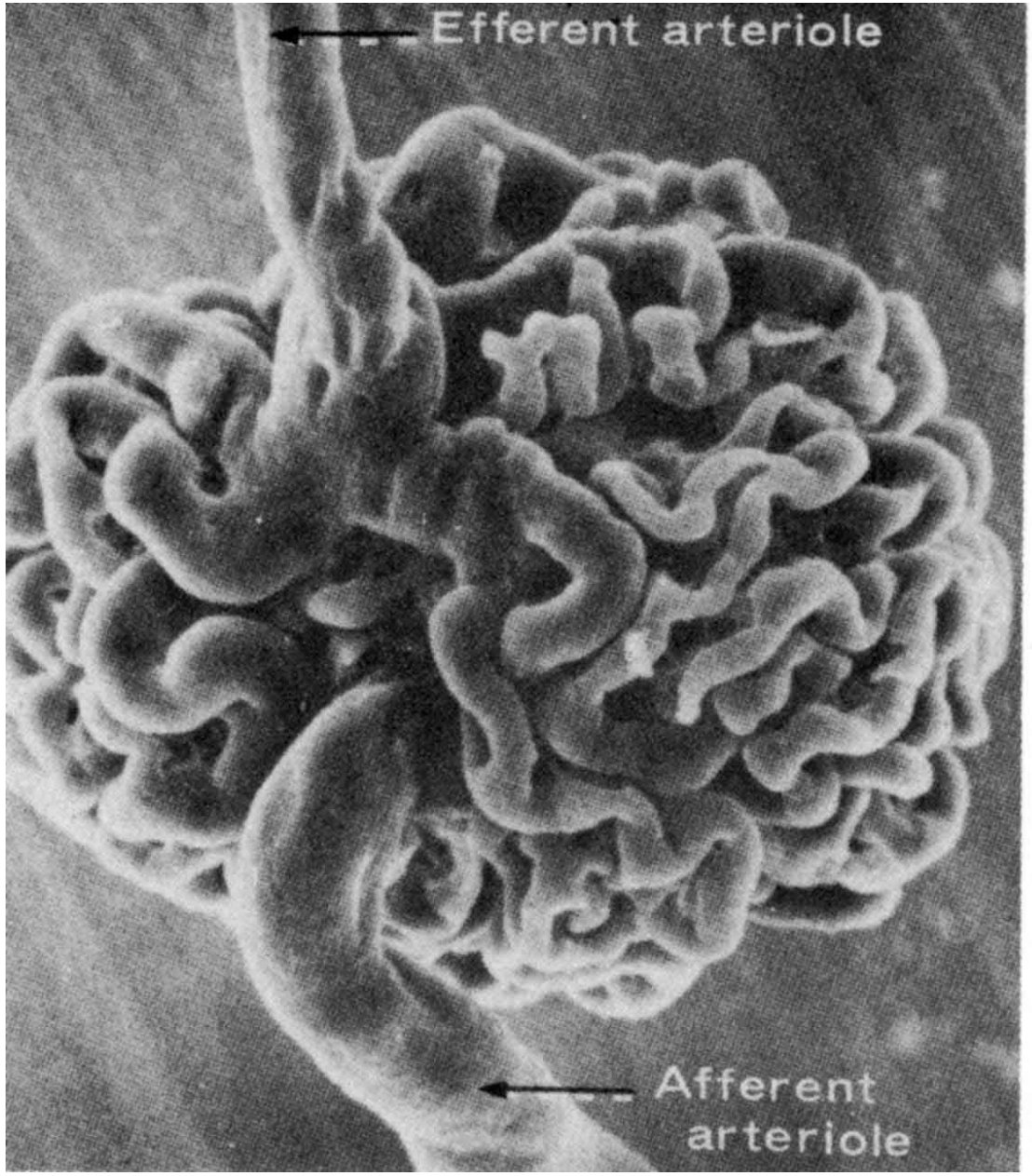
Renal corpuscle contains capillaries surrounded by epithelial cells. This arrangement is the basis of the kidney‘s filtration barrier.

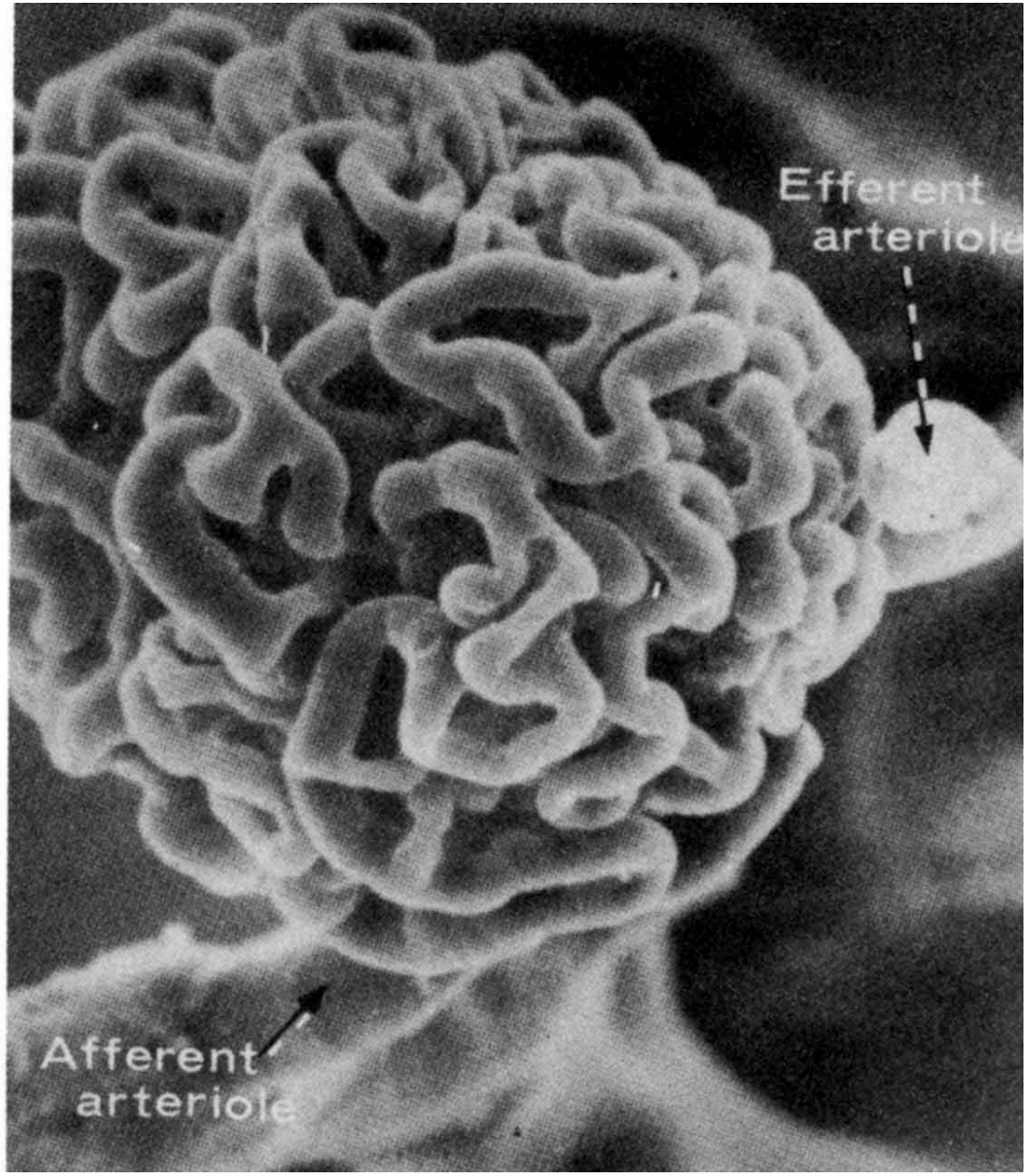




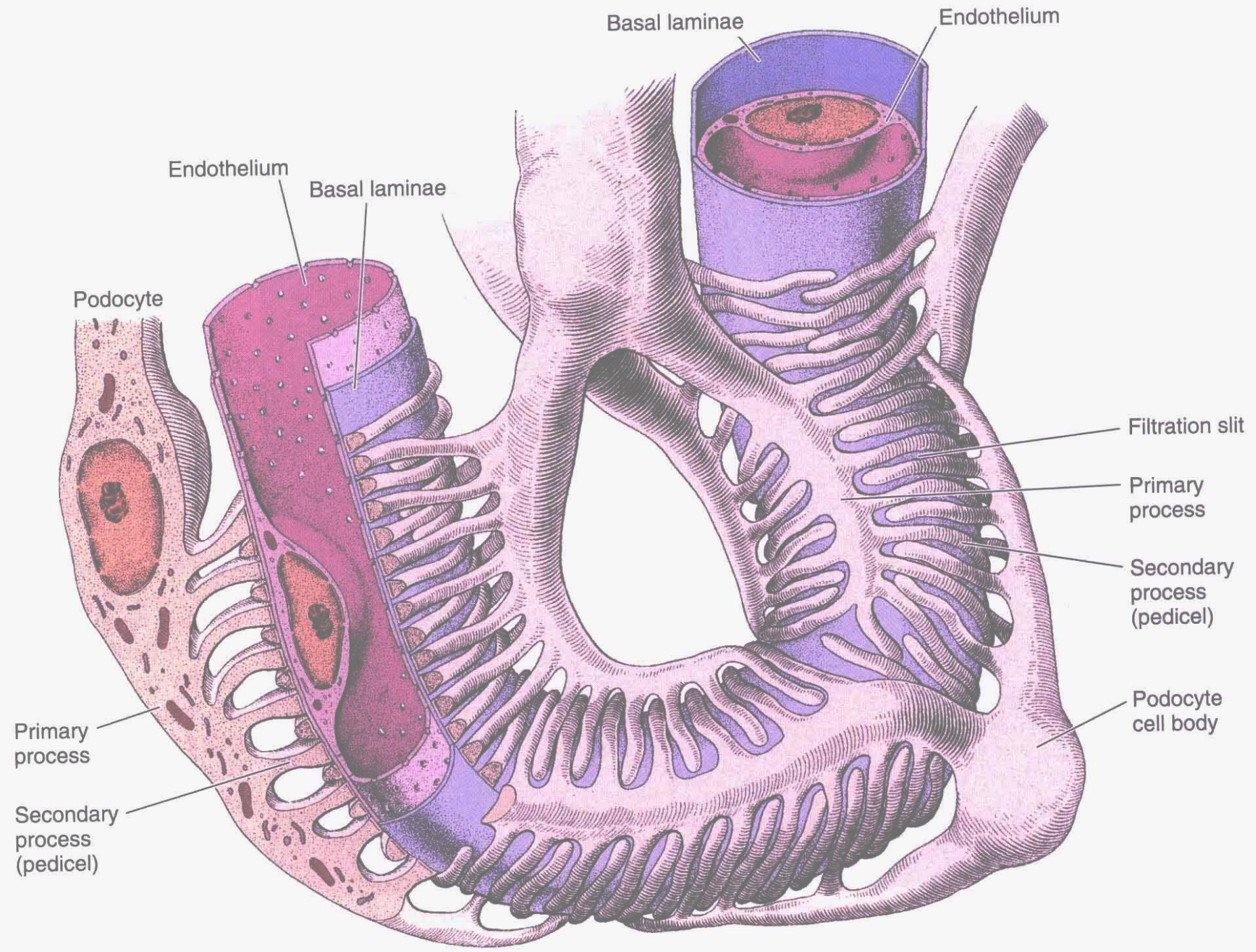



TP
US
BC
EA
AA
a

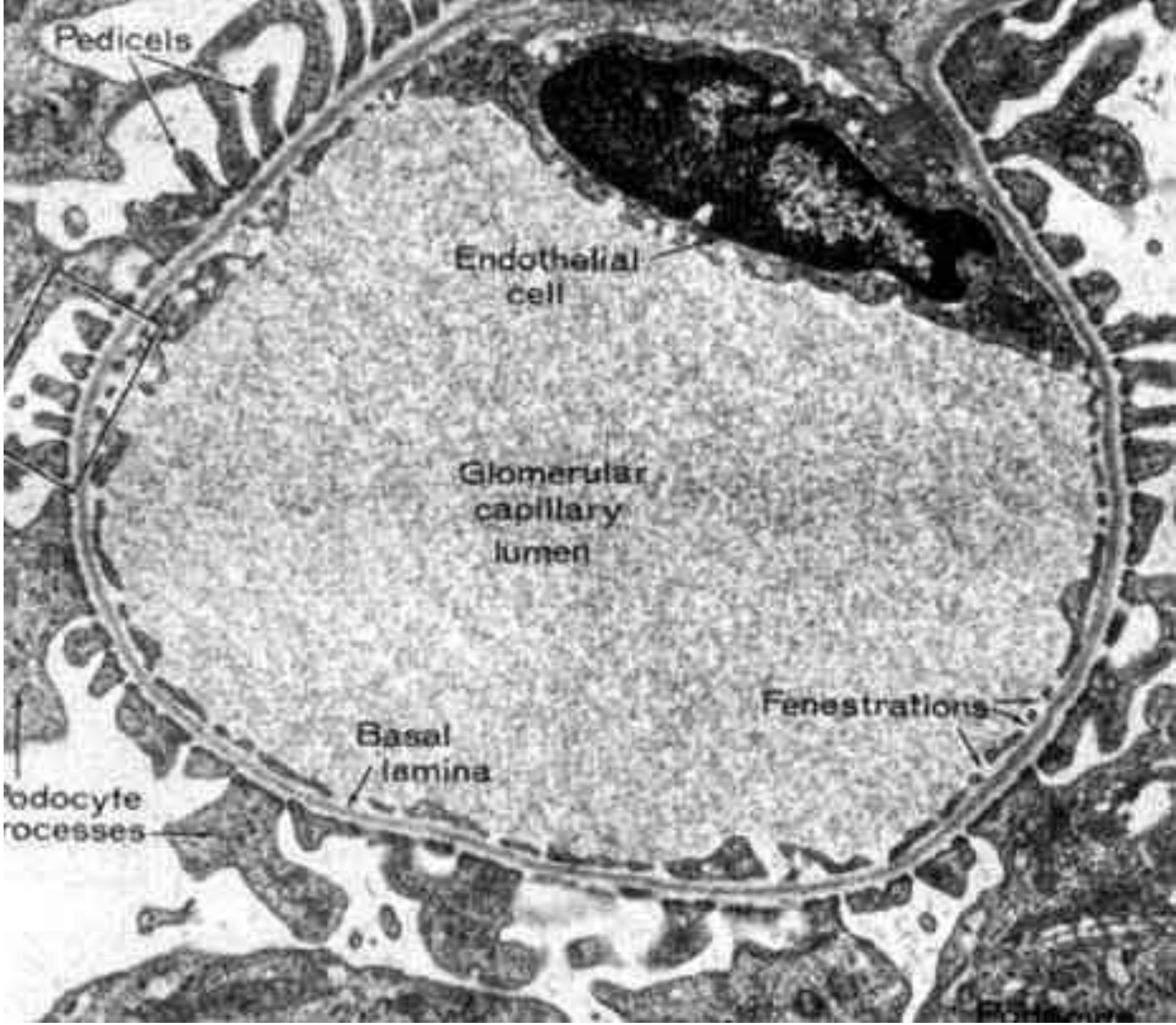

Efferent arteriole
Afferent arteriole


Efferent arteriole
Afferent arteriole

In the glomerulus, capillary endothelia are surrounded by epithelial cells with multiple processes – the podocytes.

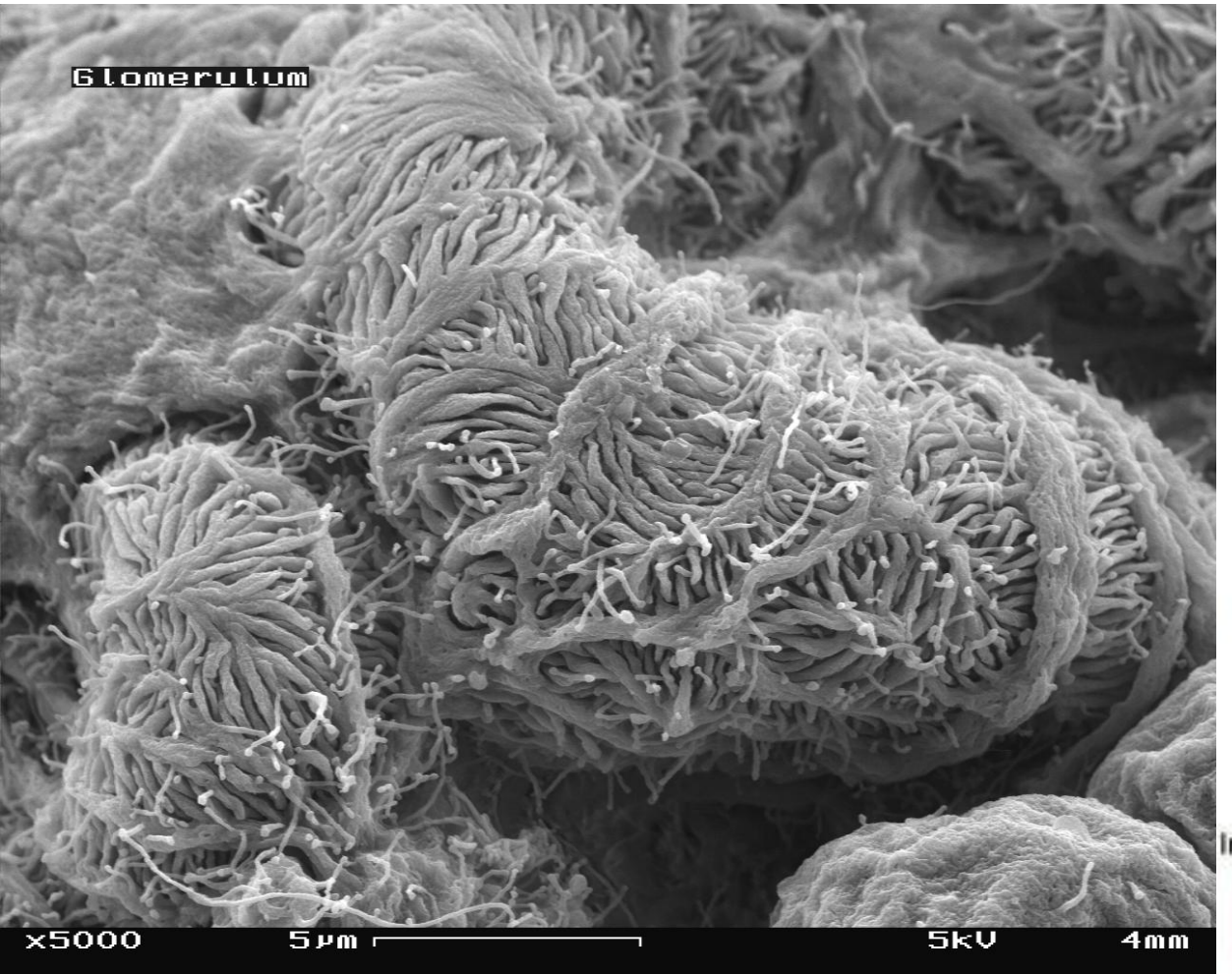


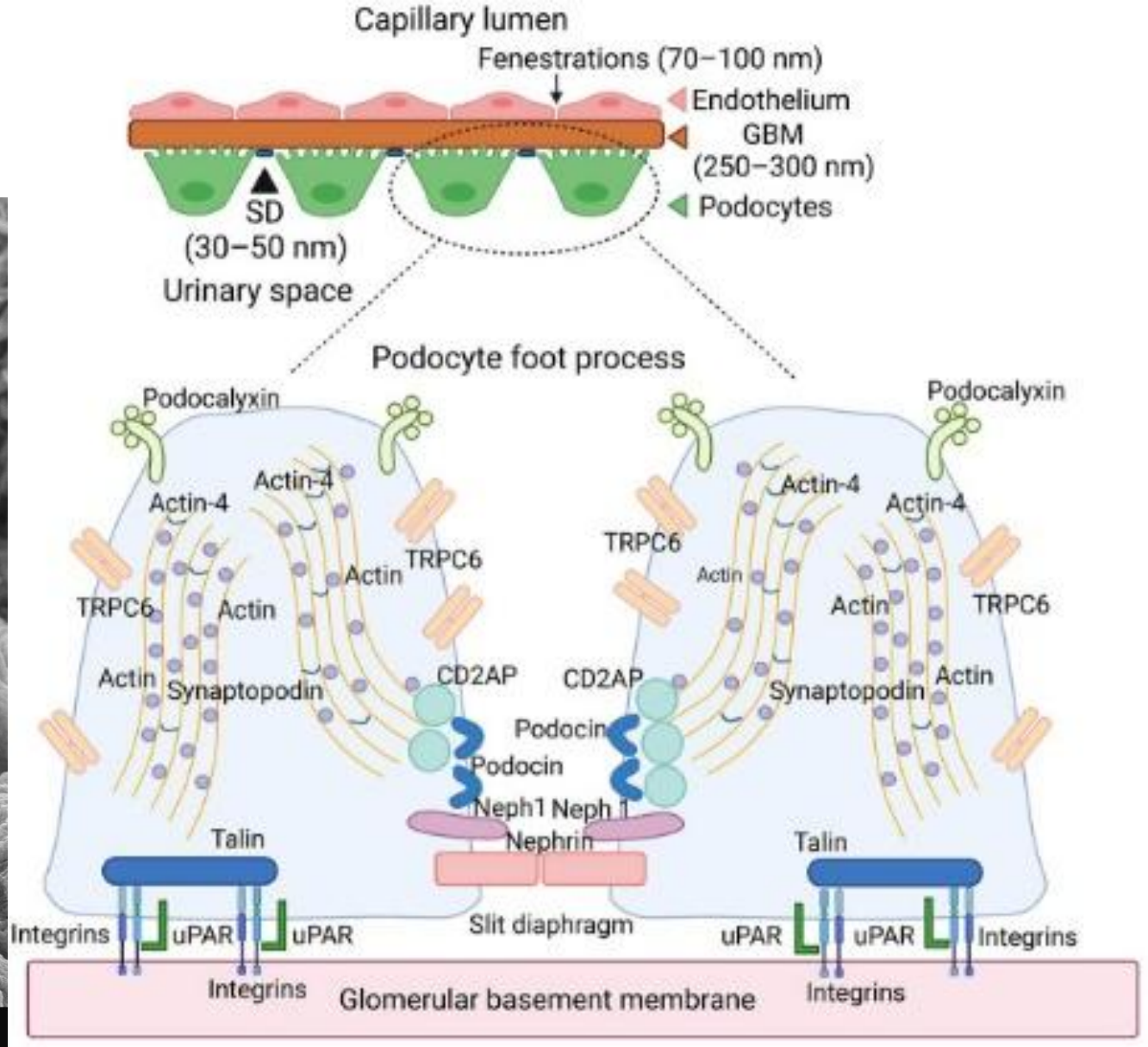
Pores in glomerular capillaries lack the diaphragm. They are about 70 – 90 nm in diameter.



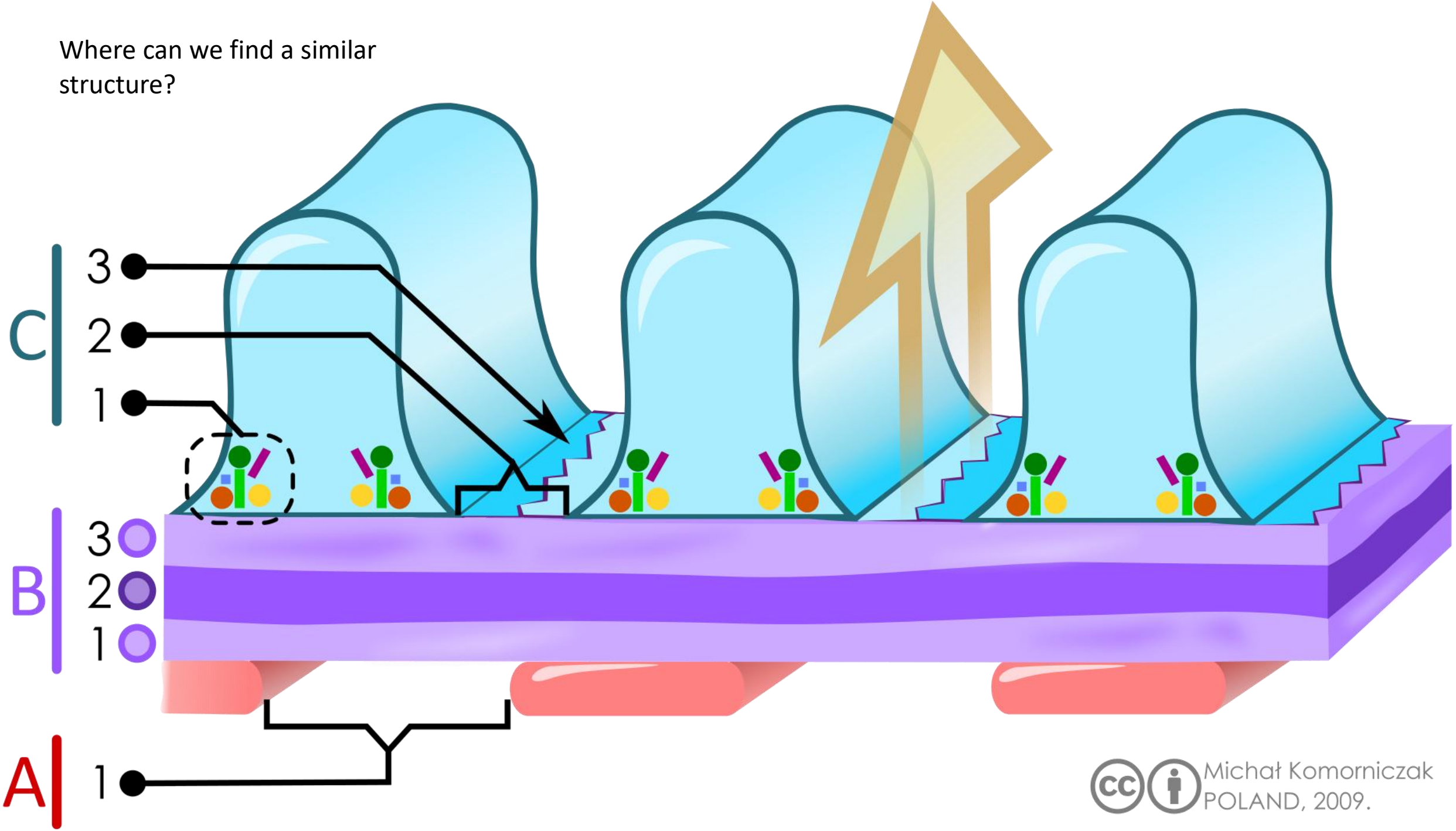
Glomerular basement membrane is a thickened basal lamina (300 – 370 nm). It contains type IV collagen, proteoglycans and multiple other proteins.

Podocytes interdigitate, the spaces between the pedicels, called filtration slits, are about 40 nm wide. There is a diaphragm in these slits.

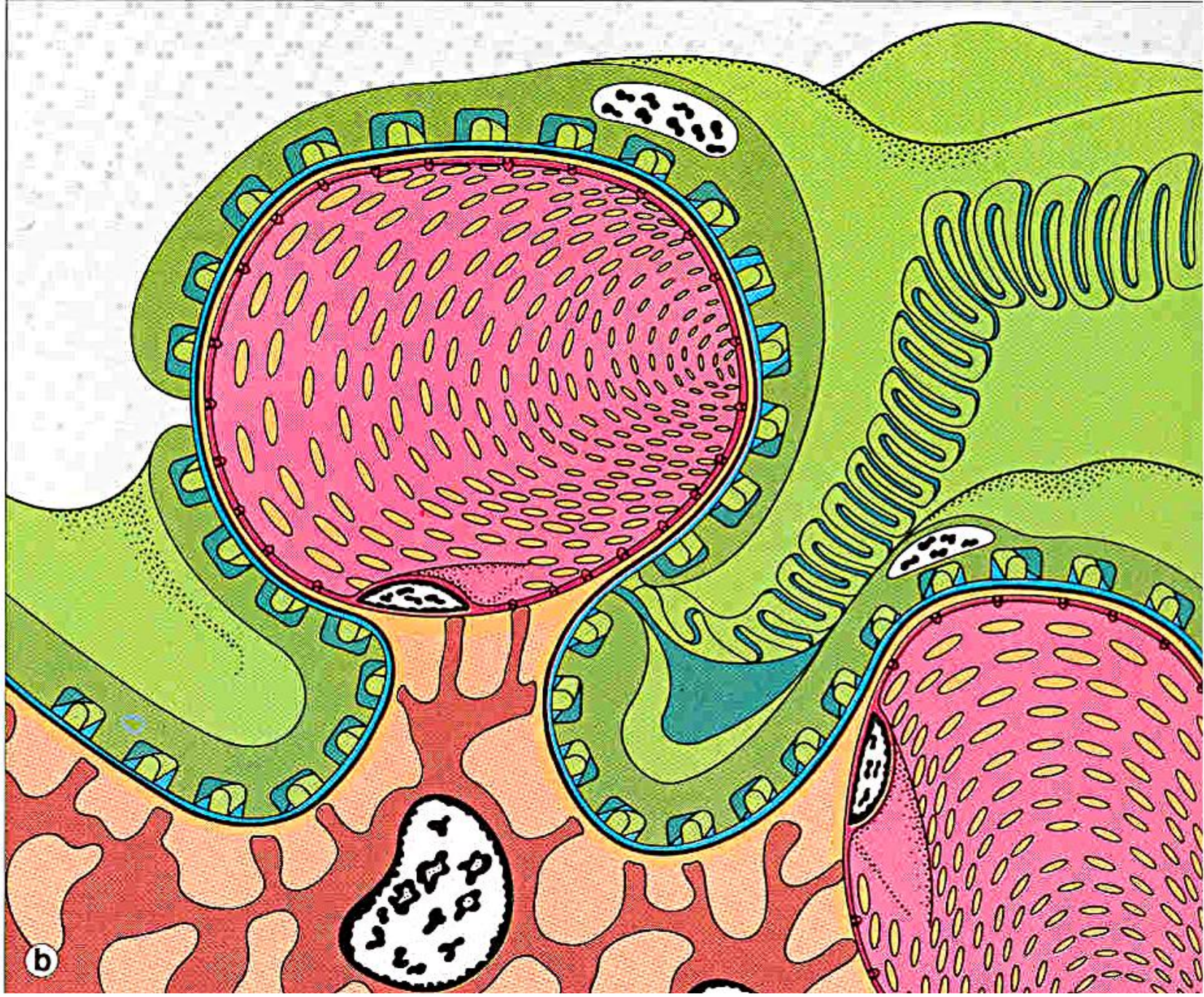




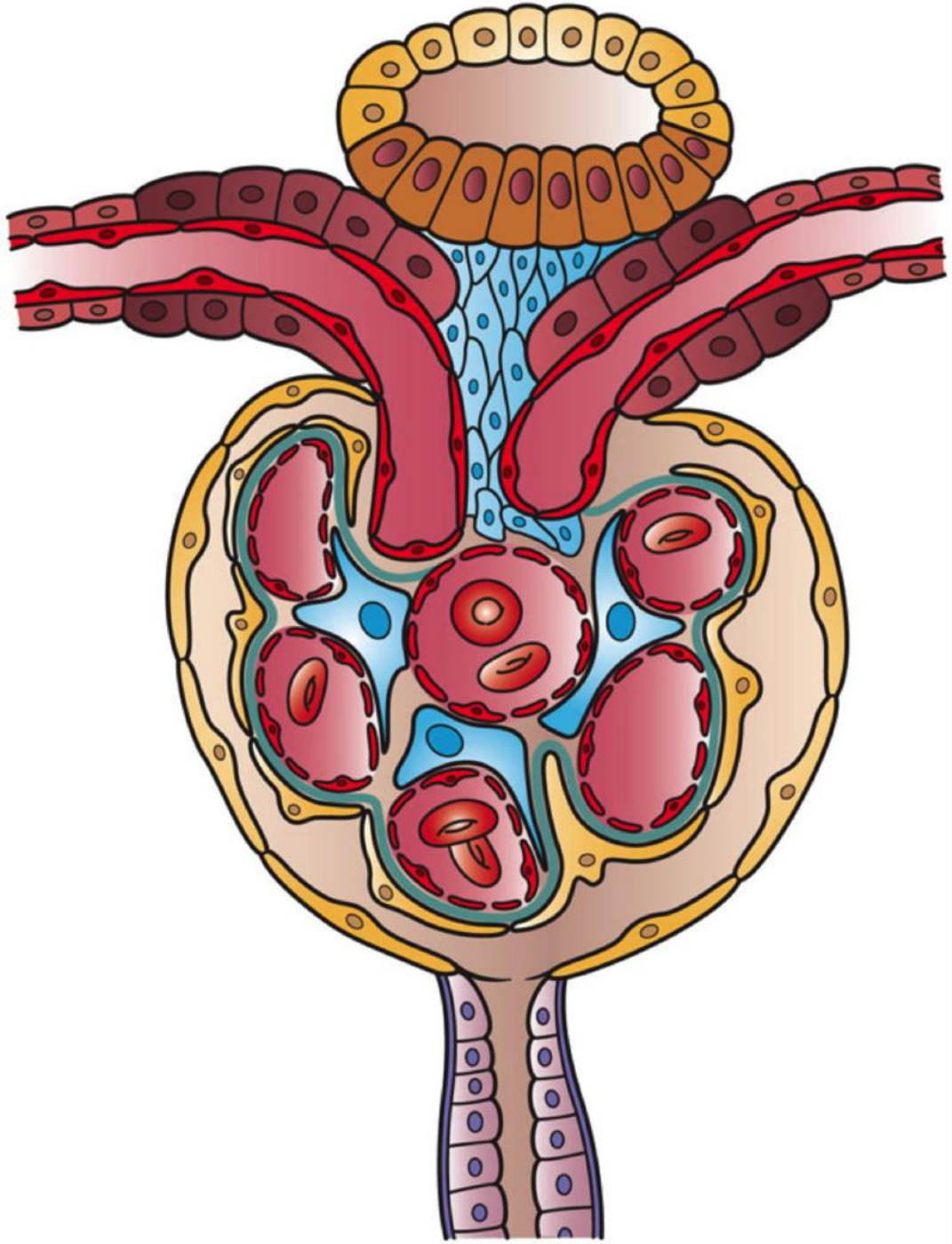
Where can we find a similar structure?

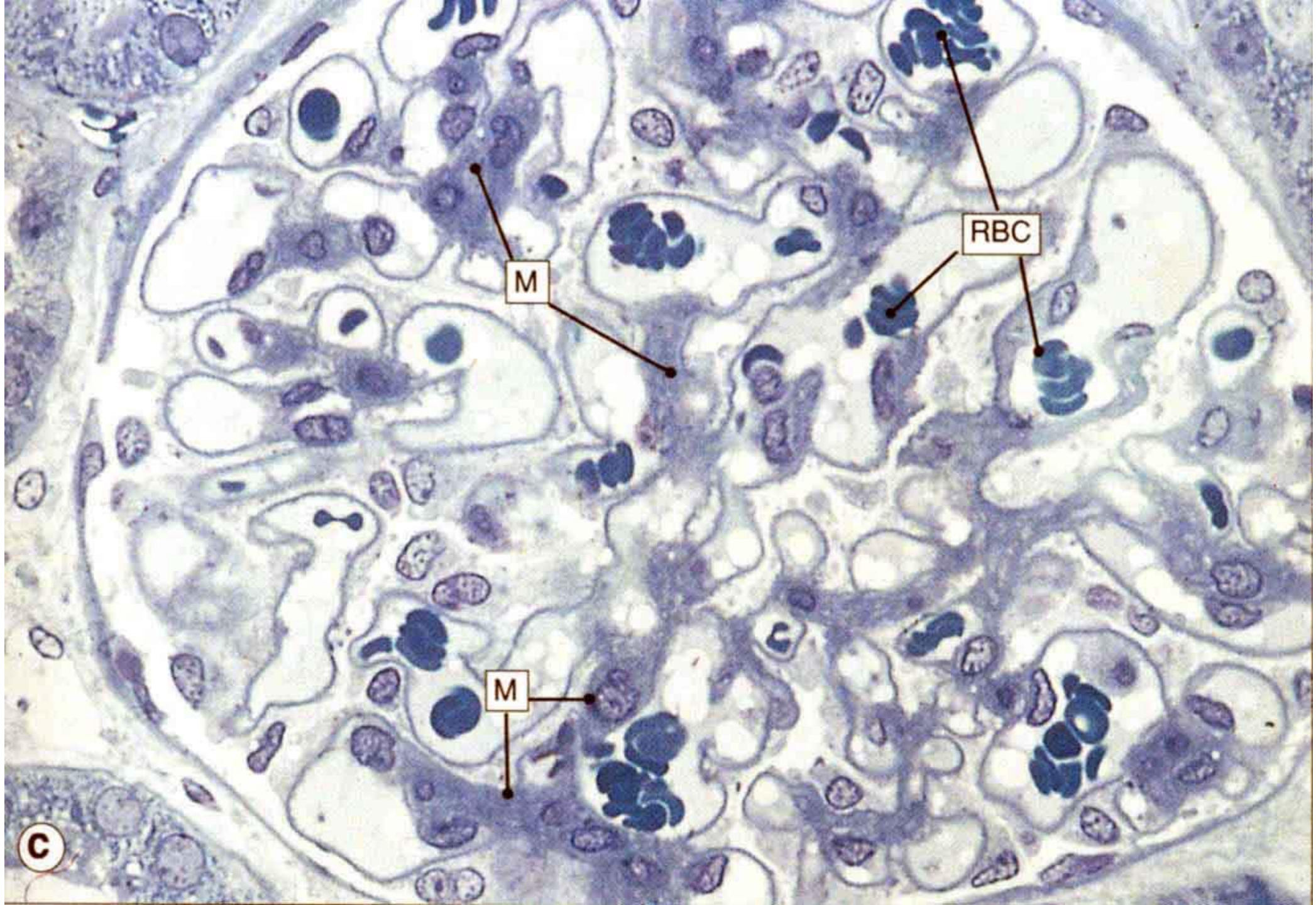


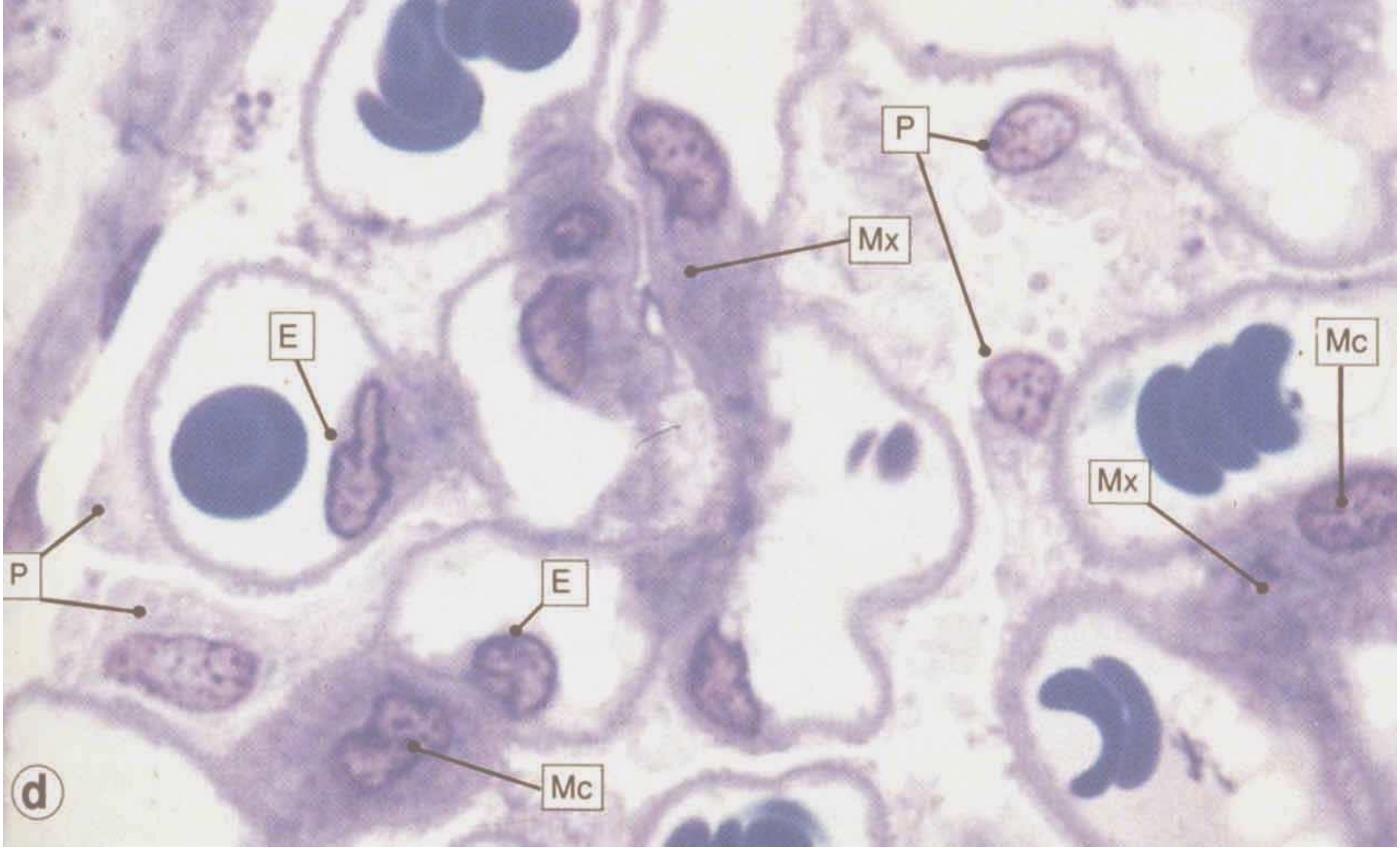

GC
EnC
BM
MM
M
a

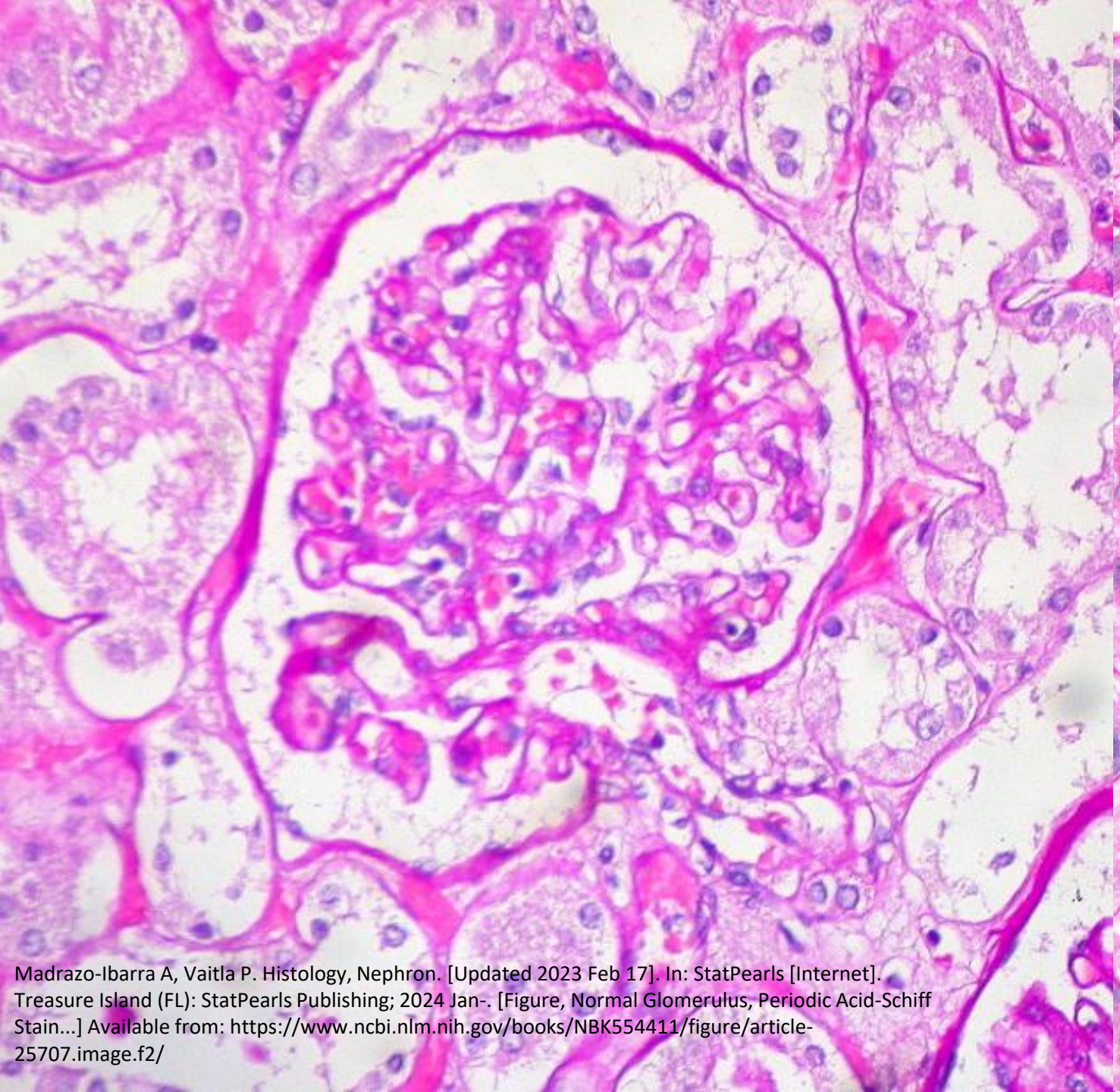

b

Mesangial cells (blue) proliferate in a variety of glomerular diseases. They can also be located outside of the glomerulus (extraglomerular MCs).

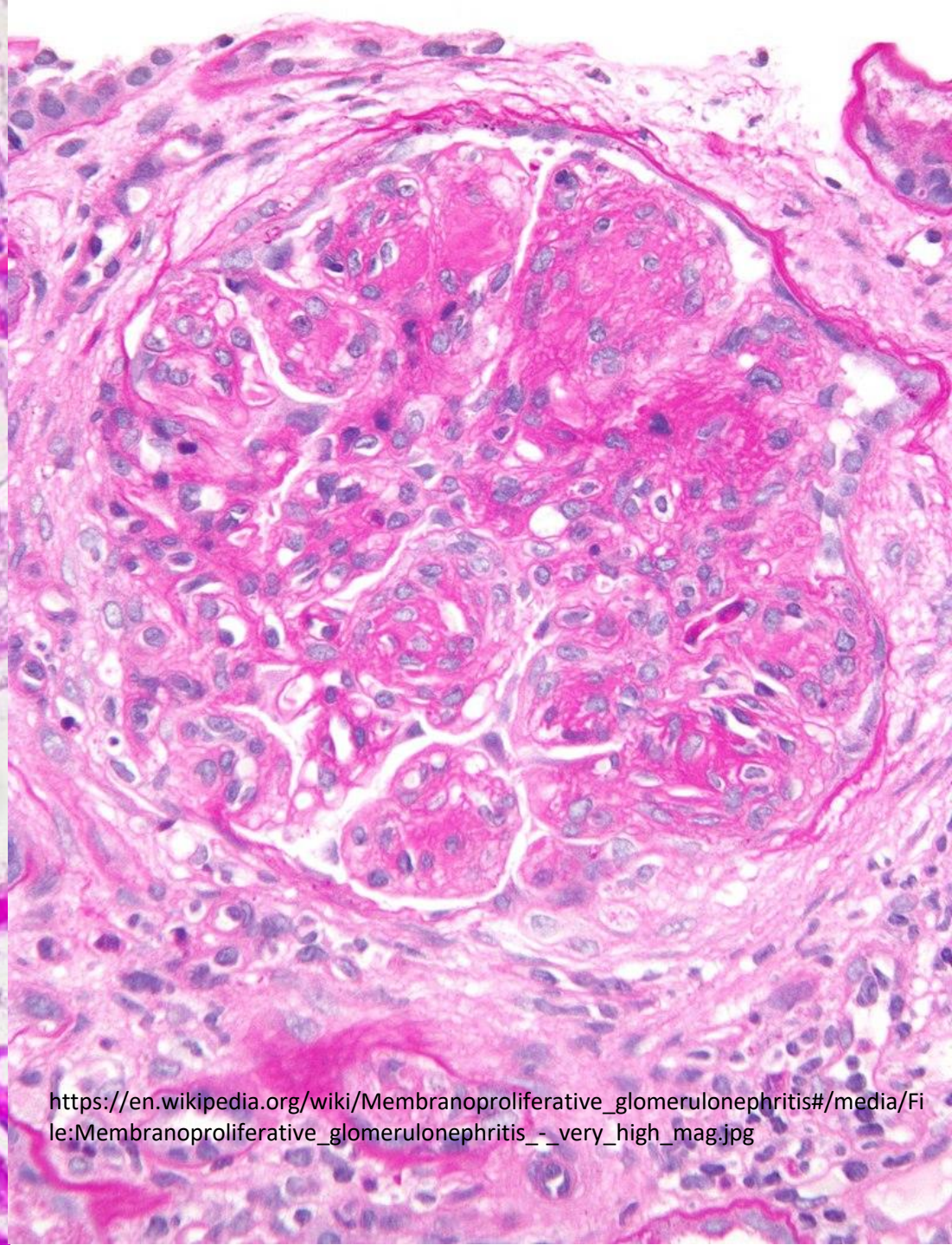



M
RBC
M
C


P
Mx
E
Mc
Mx
P
E
Mc
d



Madrazo-Ibarra A, Vaitla P. Histology, Nephron. [Updated 2023 Feb 17]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 Jan-. [Figure, Normal Glomerulus, Periodic Acid-Schiff Stain...] Available from: https://www.ncbi.nlm.nih.gov/books/NBK554411/figure/article-25707.image.f2/



https://en.wikipedia.org/wiki/Membranoproliferative_glomerulonephritis#/media/File:Membranoproliferative_glomerulonephritis_-_very_high_mag.jpg

The renal corpuscle

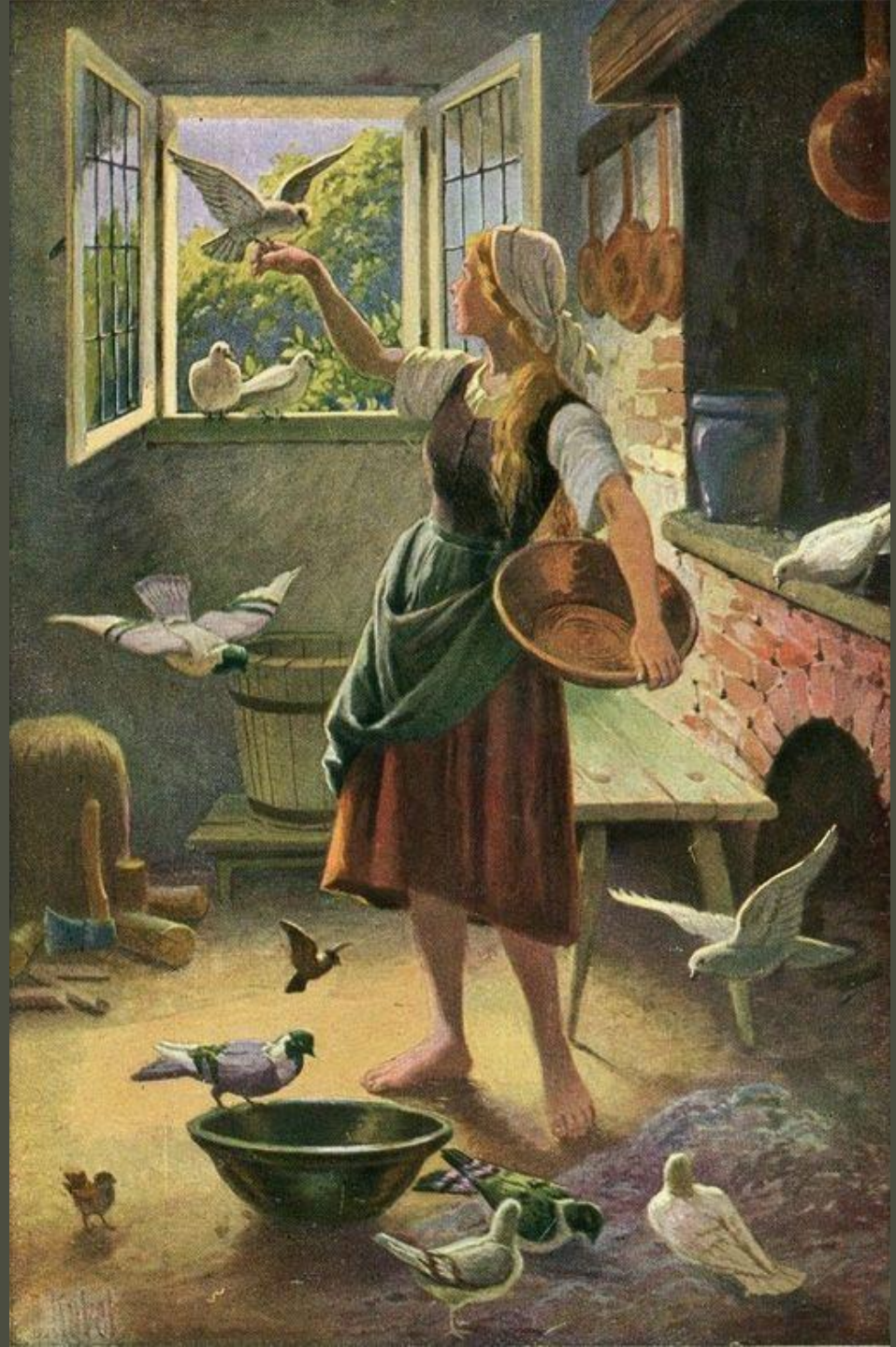
- Convoluted capillaries of the glomerulus are supplied by afferent arteriole and drained by an efferent arteriole – portal system of the kidney.
- The filtration membrane consists of porous endothelial cells, glomerular basement membrane and podocytes.
- GBM is actually a thickened basal lamina.
- Podocytes have primary processes that branch into secondary processes - pedicels, between the pedicels there is a filtration slit bridged by a very thin diaphragm.
- Cells and large proteins cannot pass through.
- Mesangial cells provide structural support, secrete several signal molecules, phagocytose and can contract.

How does the kidney know the substances that should be eliminated?

„die guten ins Töpfchen,
die schlechten ins Kröpfchen!“

„the good ones in the pot,
the bad ones in the crop!“

Brothers Grimm, Cinderella
(1819)



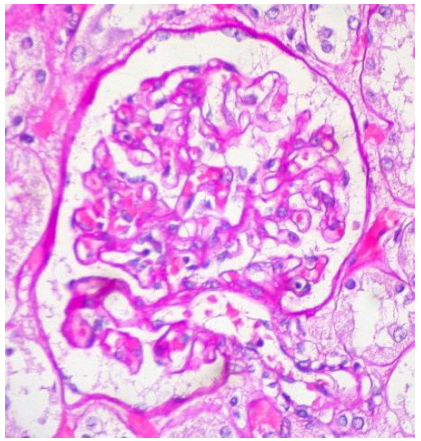
Painting by Otto Kubel
(1930)

https://upload.wikimedia.org
/wikipedia/commons/b/bd/C
endrillon.jpg

Blood cells

Larger proteins over 70 kDa

Lipoproteins



Small proteins and peptides

Aminoacids

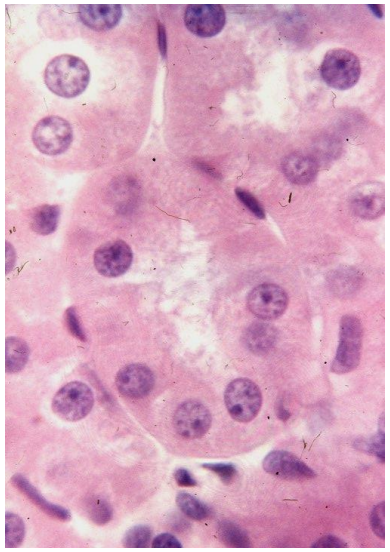
Glucose

Urea

Ions

Various small molecules

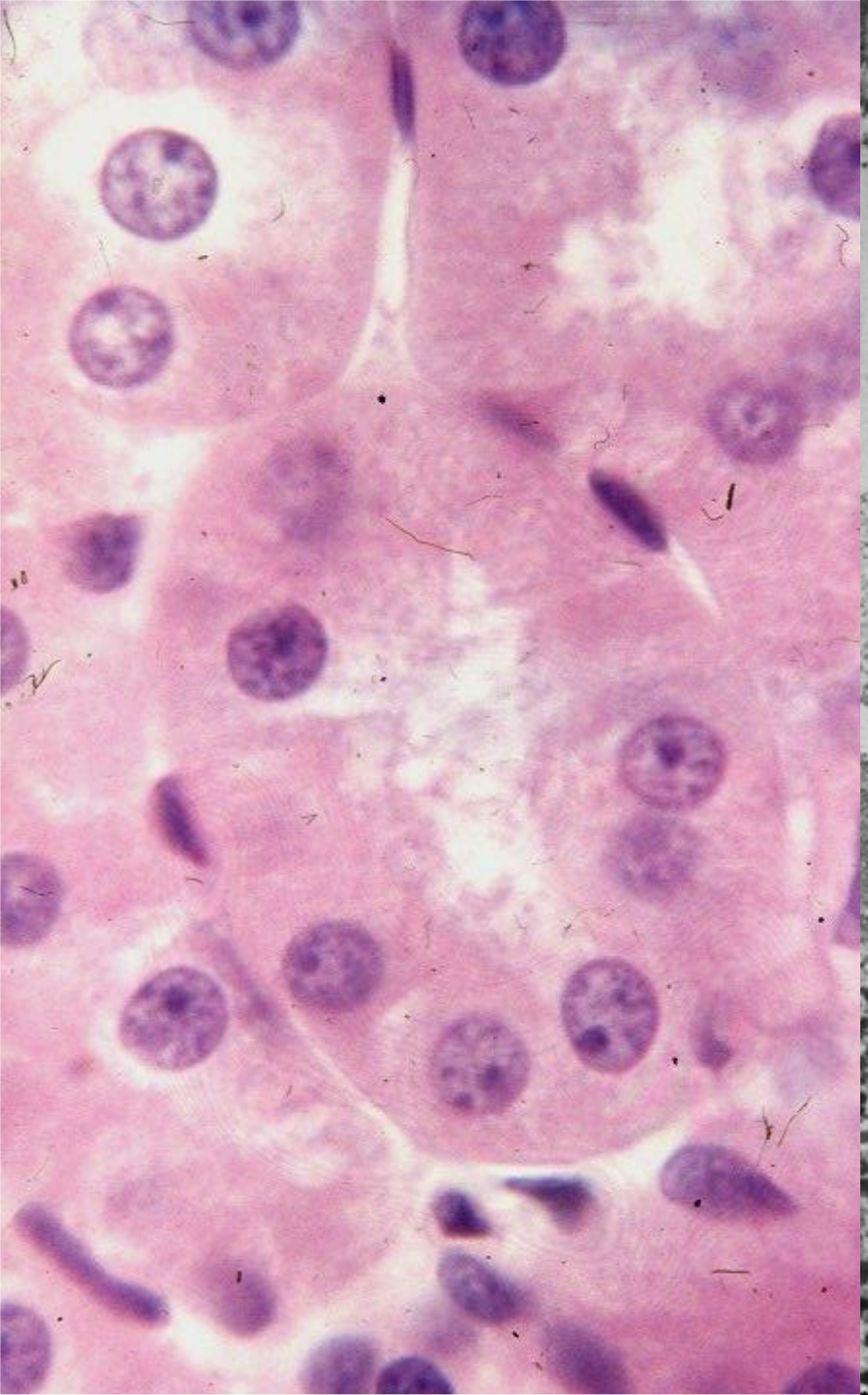
Blood plasma

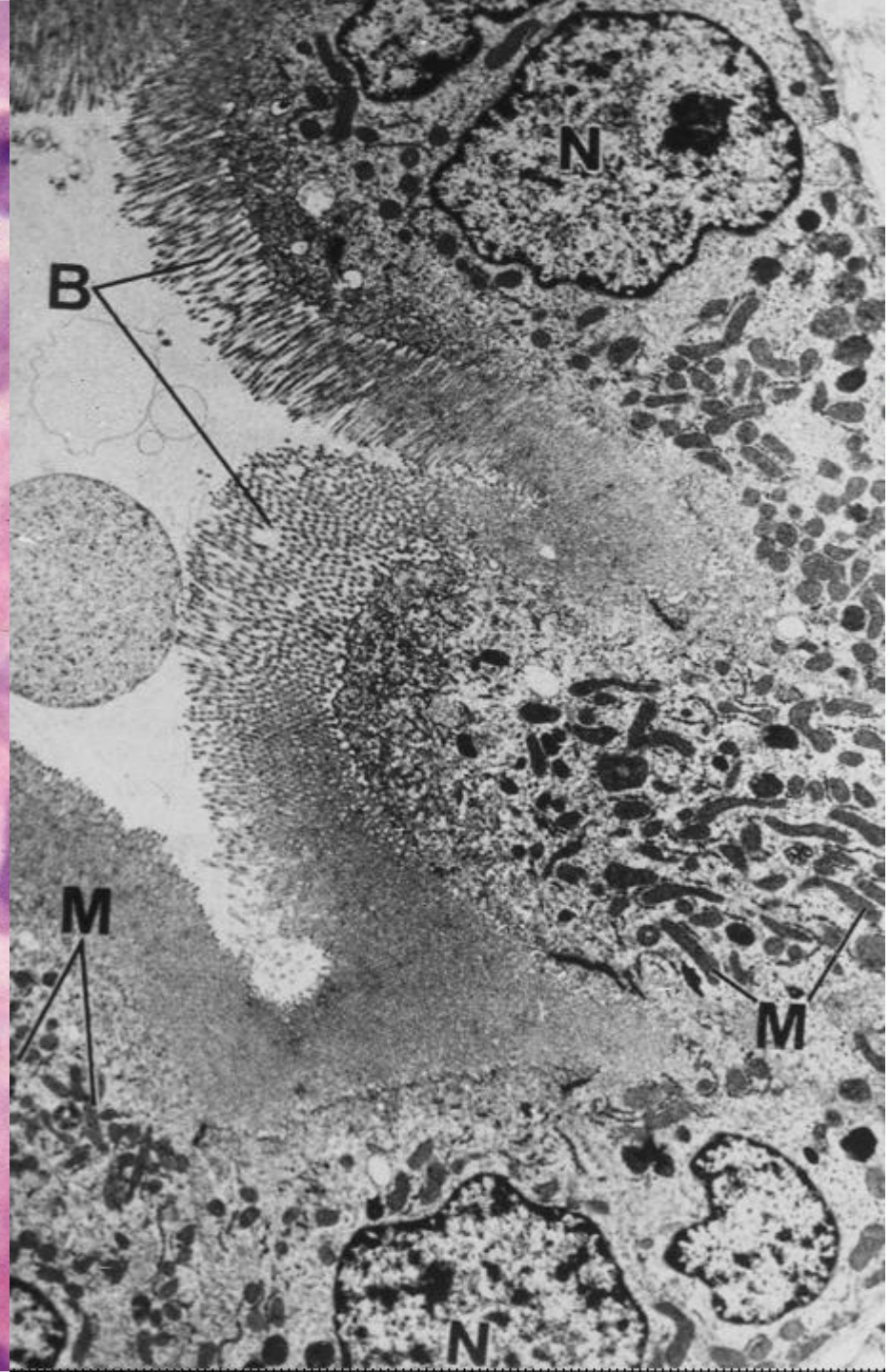


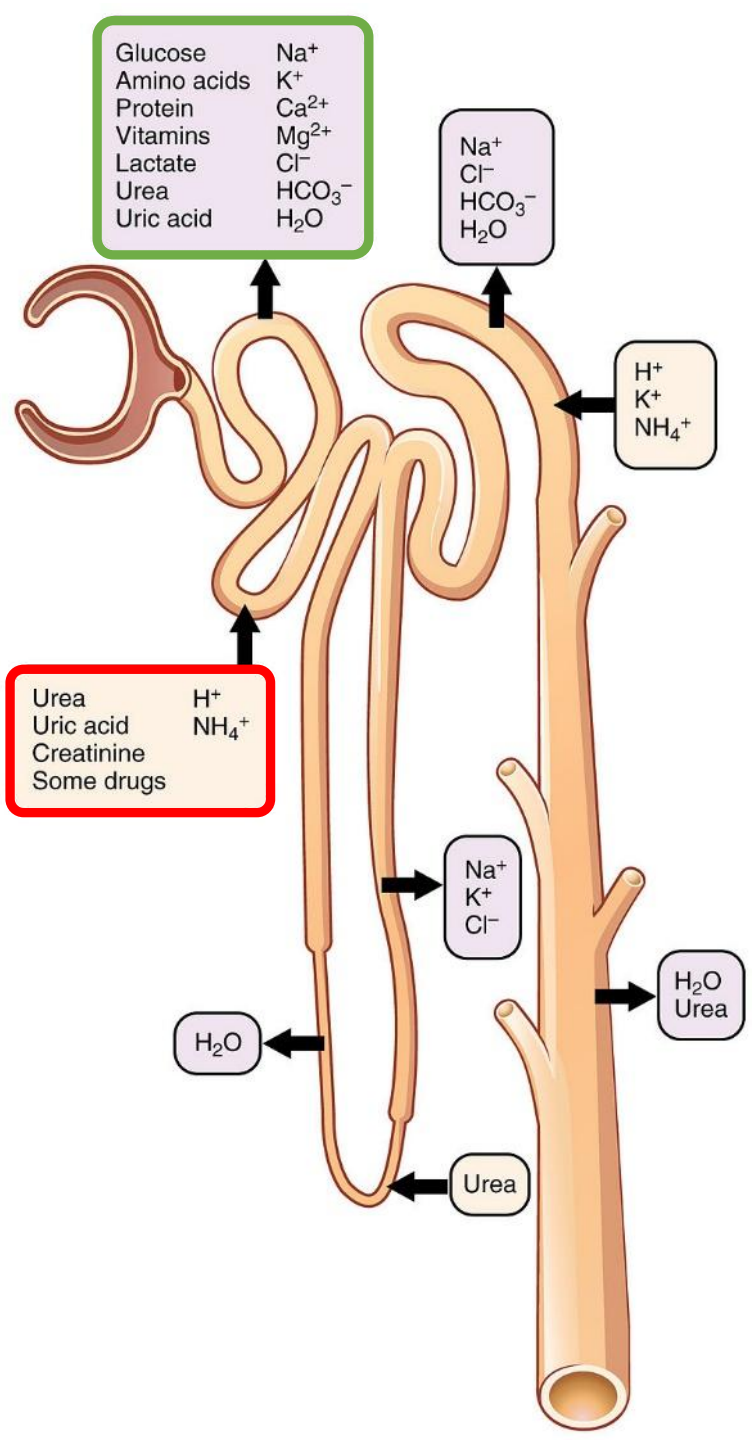
Quiz

A girl (9 years) has a urinary dipstick positive for hemoglobin. Microscopy of urine has revealed the following picture.

1. What is the differential diagnosis of a positive dipstick?
2. What additional information is supplied by microscopy?

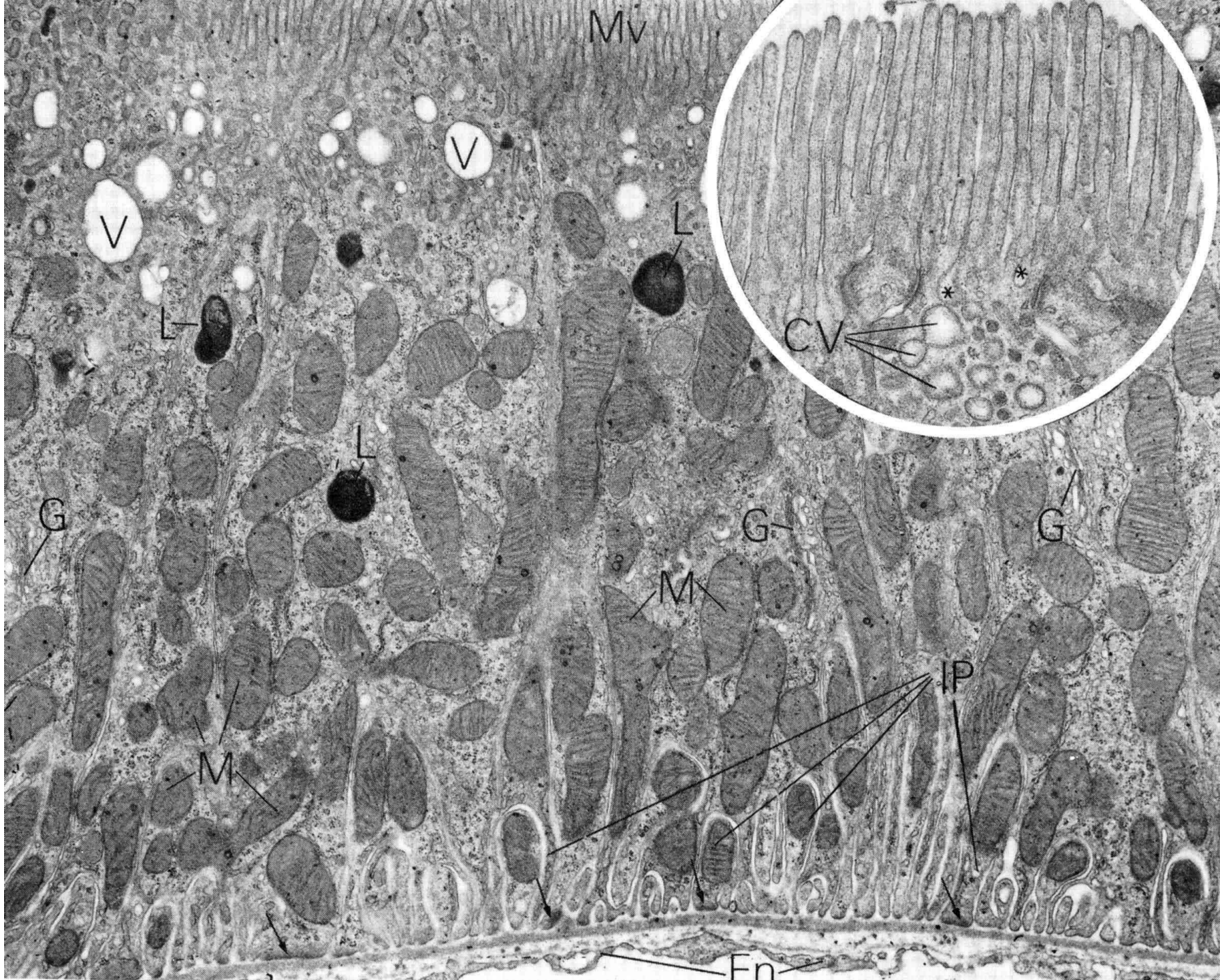



N
B
M
M
N


Glucose
Amino acids
Protein
Vitamins
Lactate
Urea
Uric acid
Na^+
K^+
Ca^{2+}
Mg^{2+}
Cl^-
HCO_3^-
H_2O
Na^+
Cl^-
HCO_3^-
H_2O
H^+
K^+
NH_4^+
Urea
Uric acid
Creatinine
Some drugs
H^+
NH_4^+
Na^+
K^+
Cl^-
H_2O
H_2O
Urea
Urea

Proximal convoluted tubule (PCT)

Have you already seen similar cells?

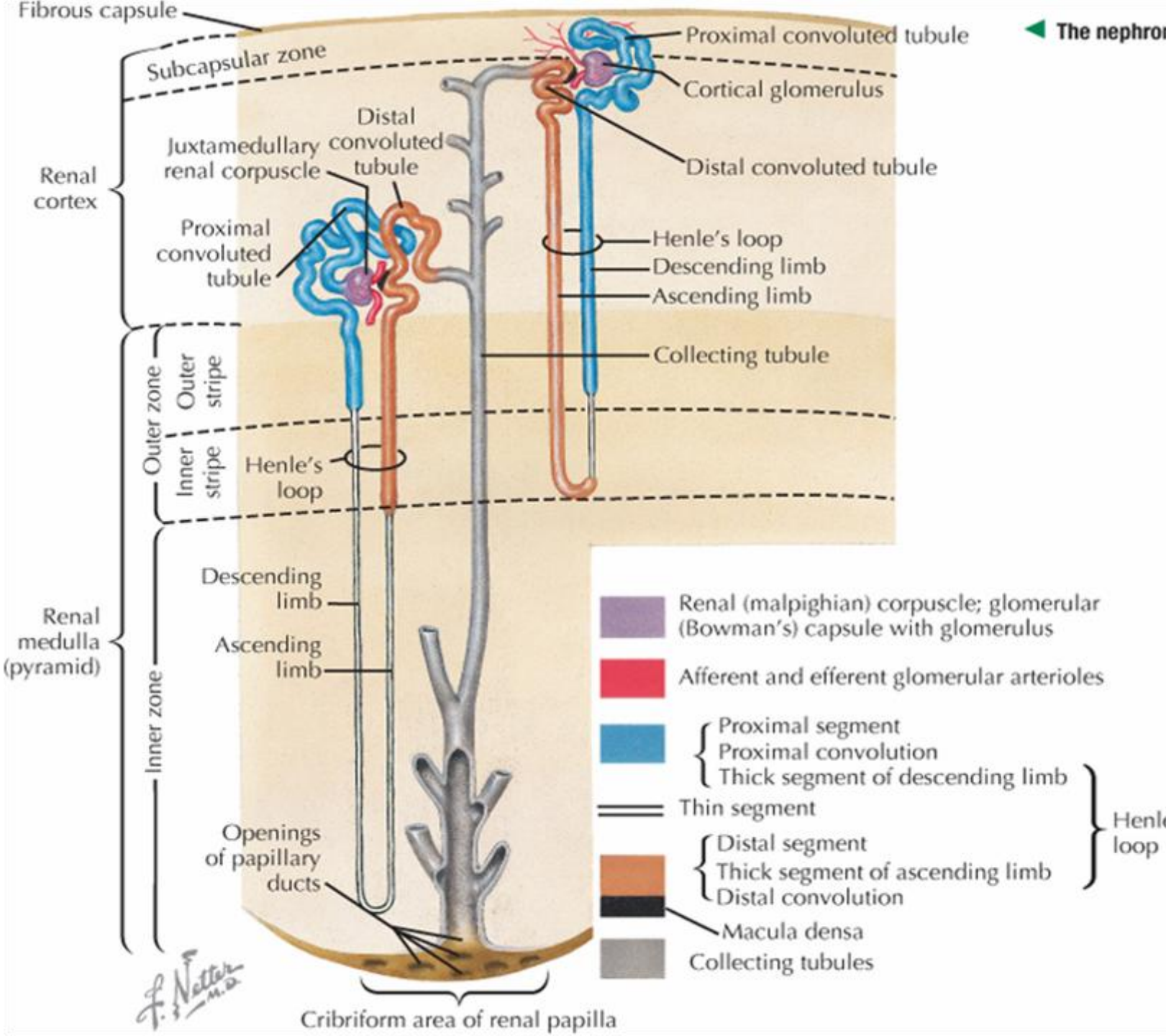


Basal labyrinth (striations)

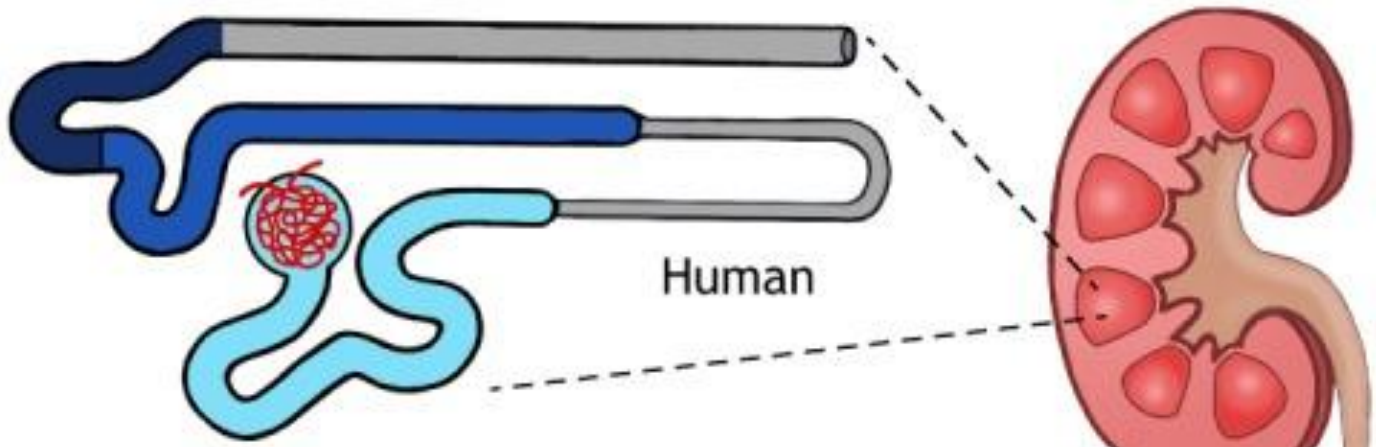
PT absorbs about 70% of water and sodium and 100% of glucose, proteins, AAs.

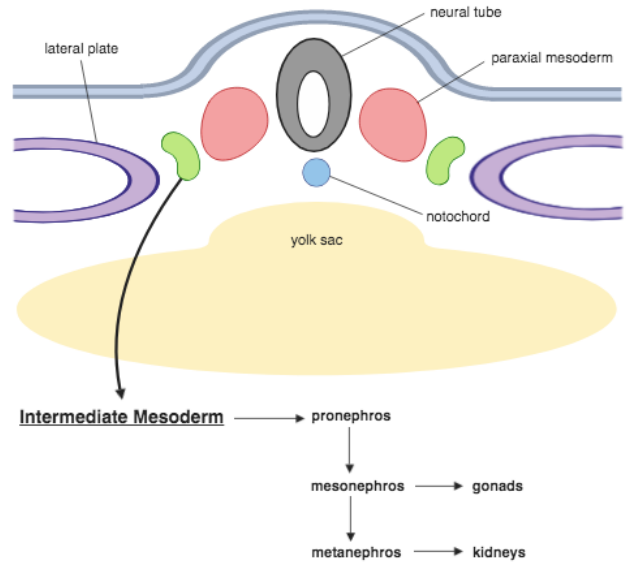
The **loop of Henle** is longer in juxtamedullary nephrons.

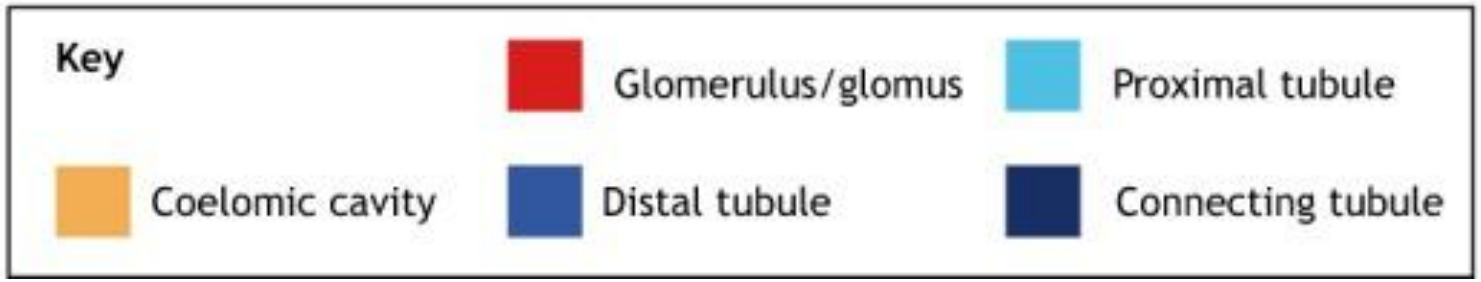
proximal straight tubule = thick descending limb of the loop of Henle
thin descending limb + thin ascending limb = ductus intermedius
thick ascending limb = distal straight tubule



Conservation of nephron

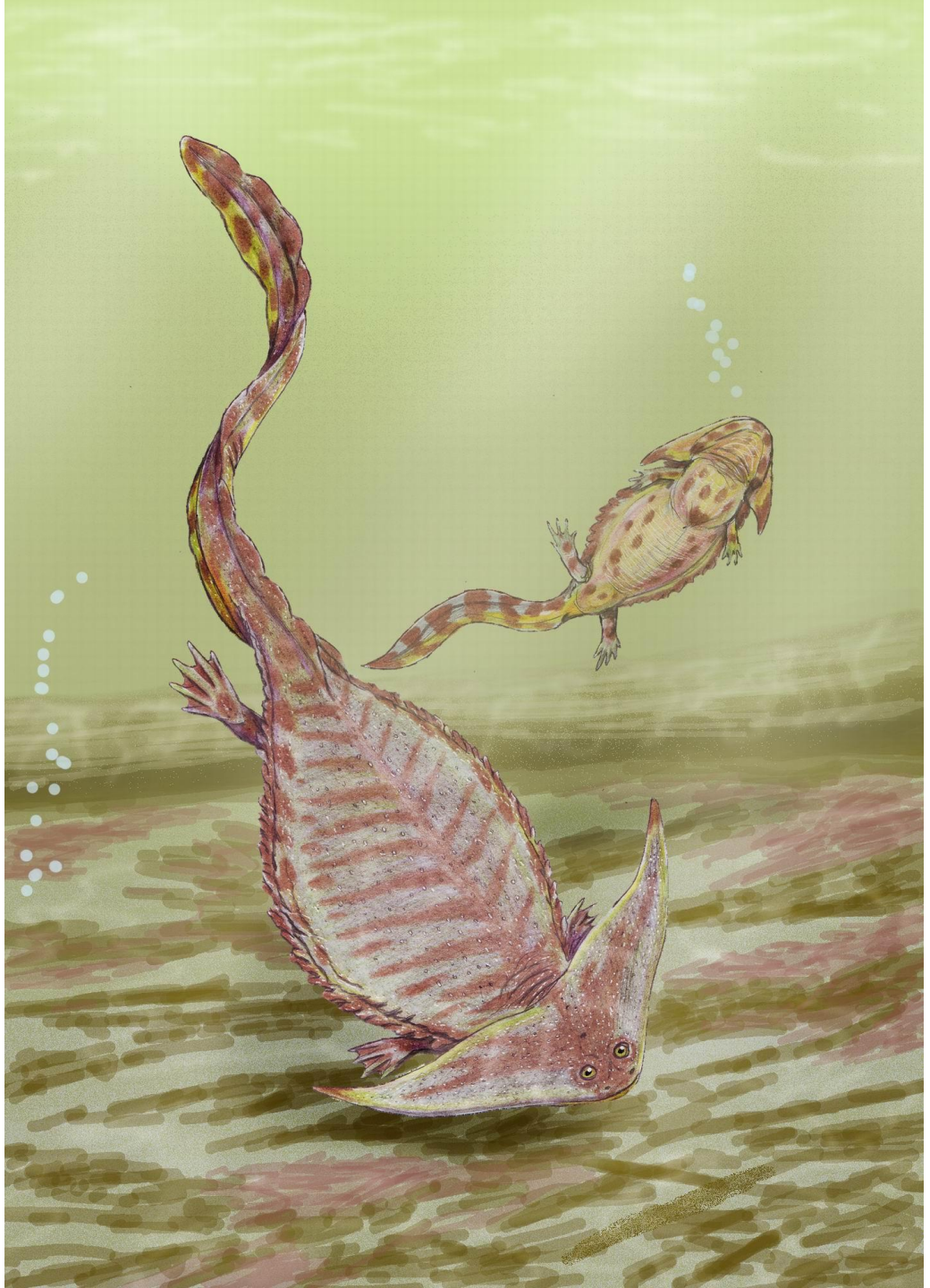




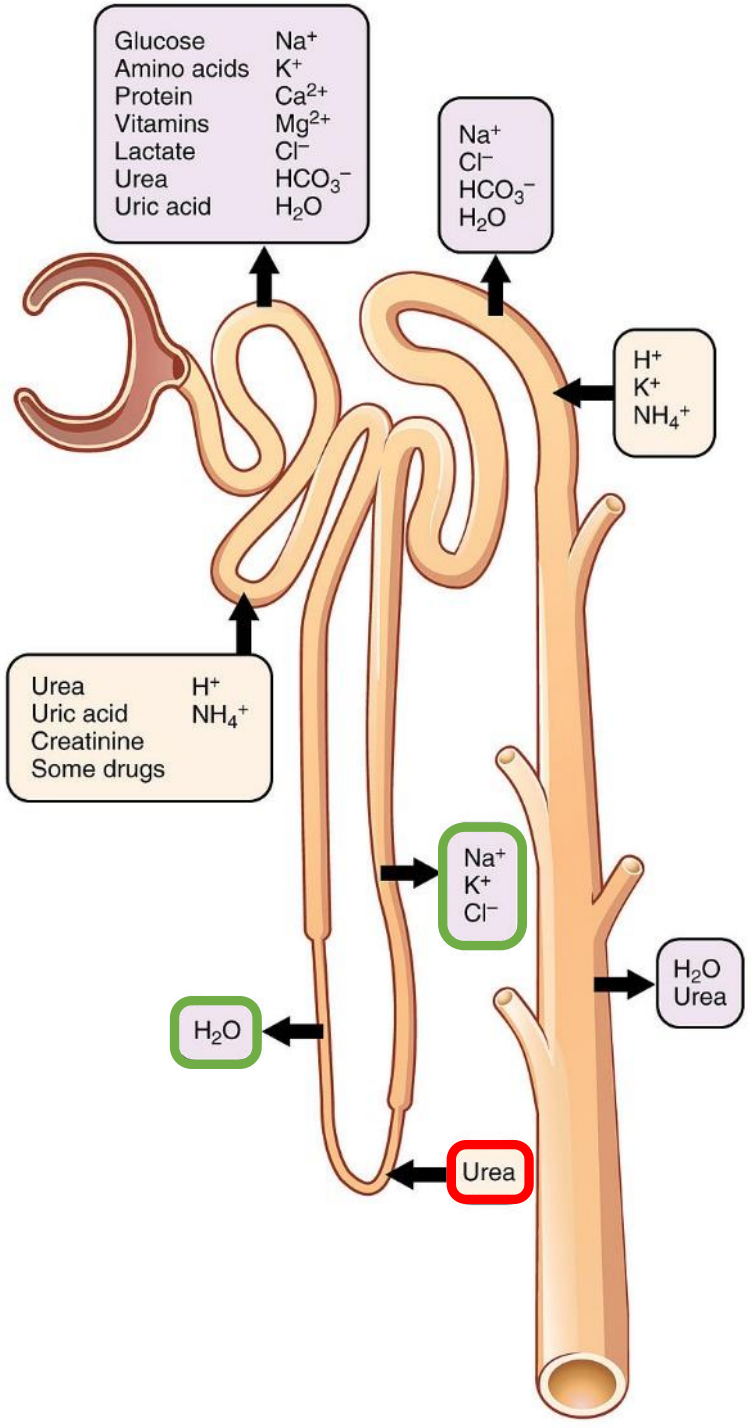


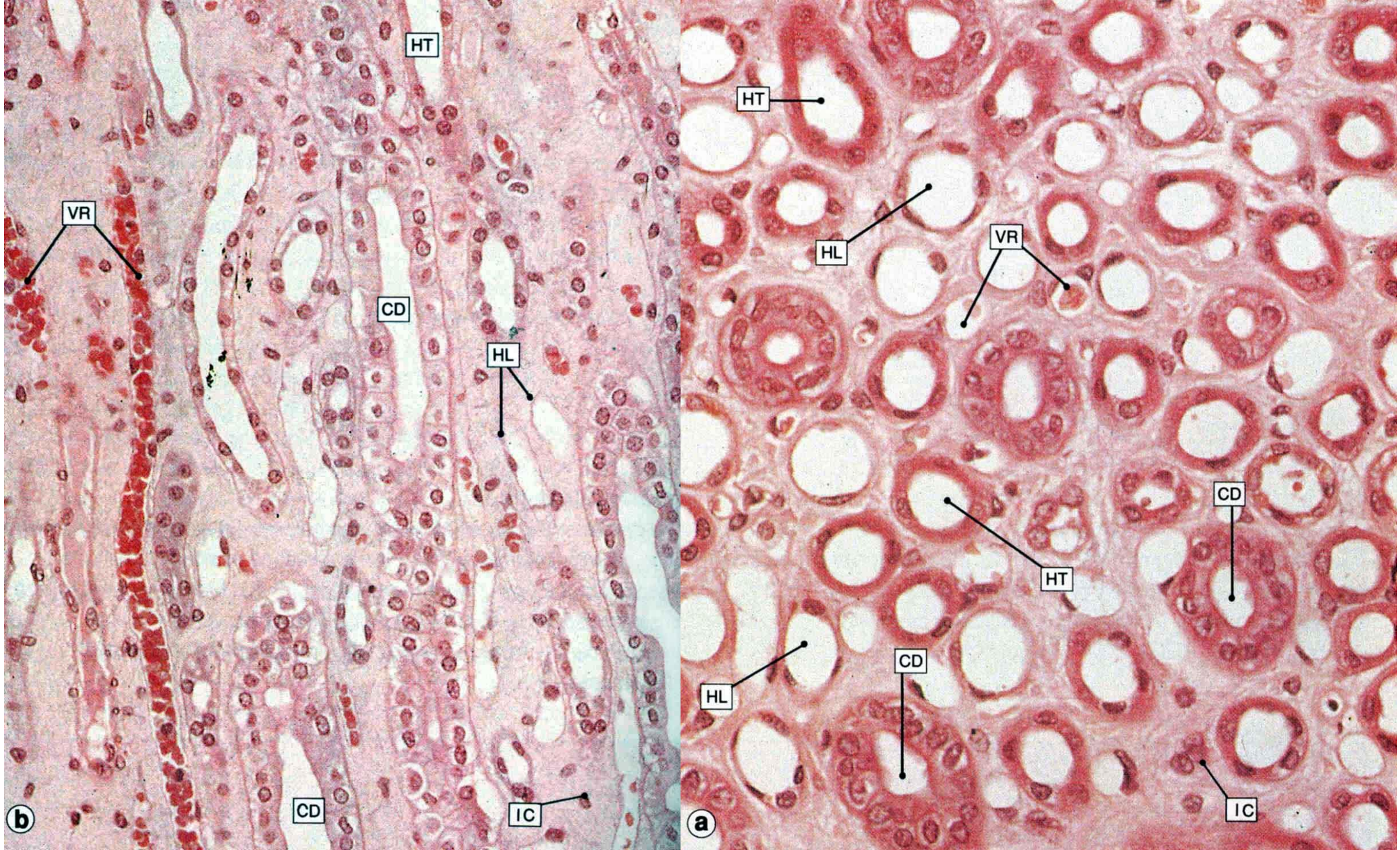
Blackburn ATM, Miller RK. Modeling congenital kidney diseases in Xenopus laevis. Dis Model Mech. 2019 Apr 9;12(4):dmm038604. doi: 10.1242/dmm.038604. PMID: 30967415; PMCID: PMC6505484.

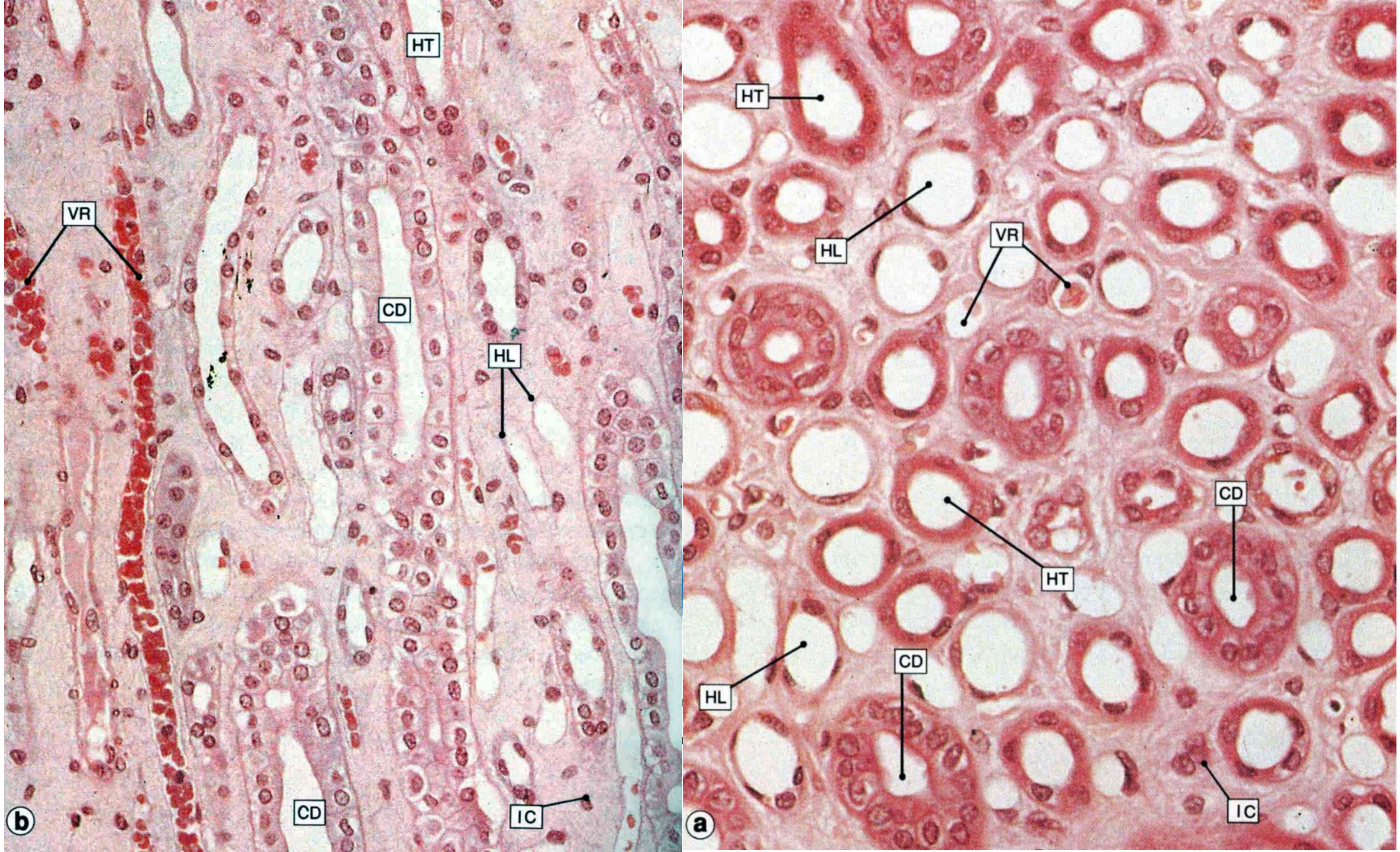
https://upload.wikimedia.org/wikipedia/commons/e/e5/Diplocaulus_vale21DB.jpg



LoH – medulla ECF concentration (up to 1200 mOsm/l in humans, 9000 mOsm/l in this mouse).




HT
VR
CD
HL
CD
IC
b
HT
HL
VR
CD
HT
HL
CD
IC
a


HT
VR
CD
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CD
IC
b
HT
HL
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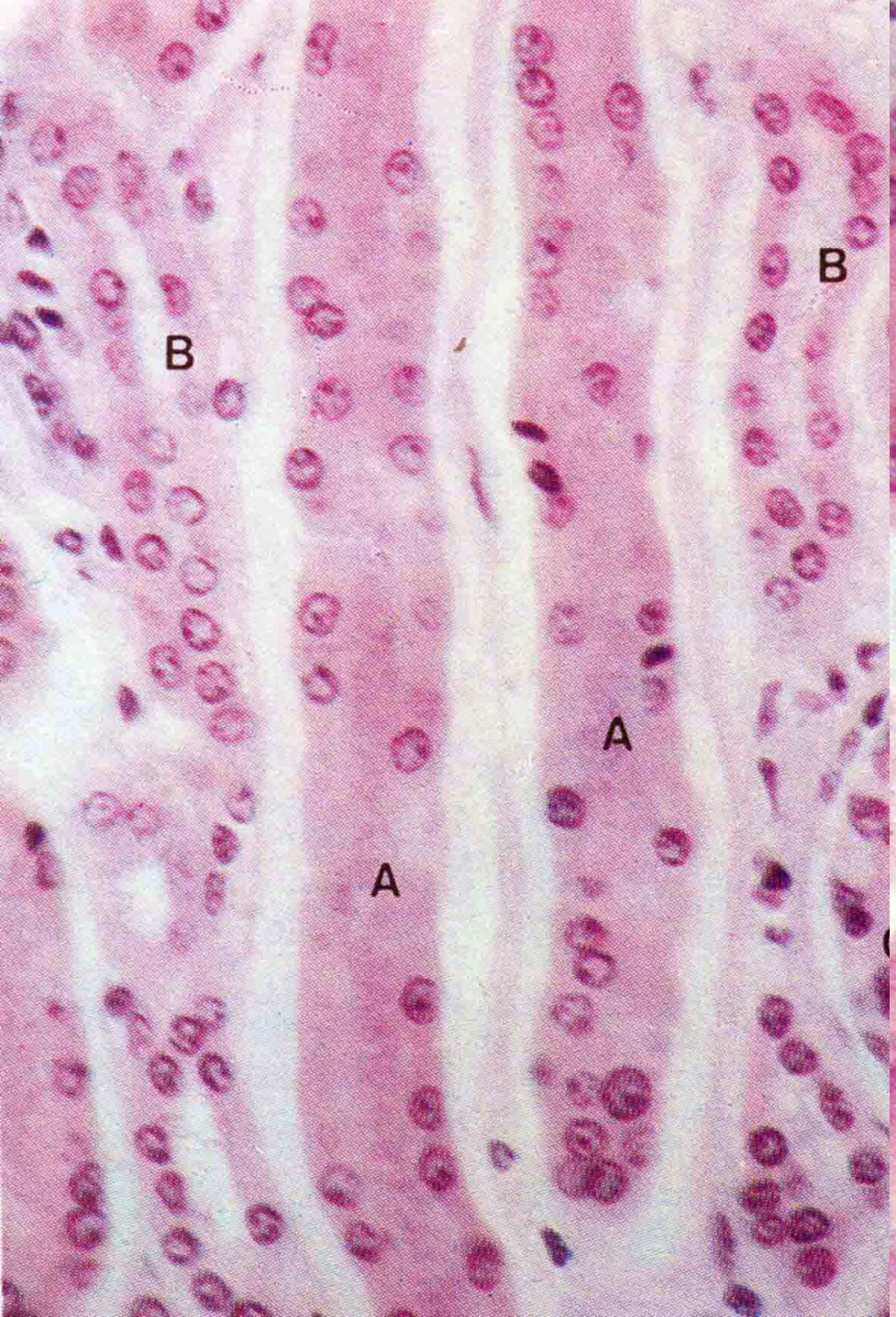
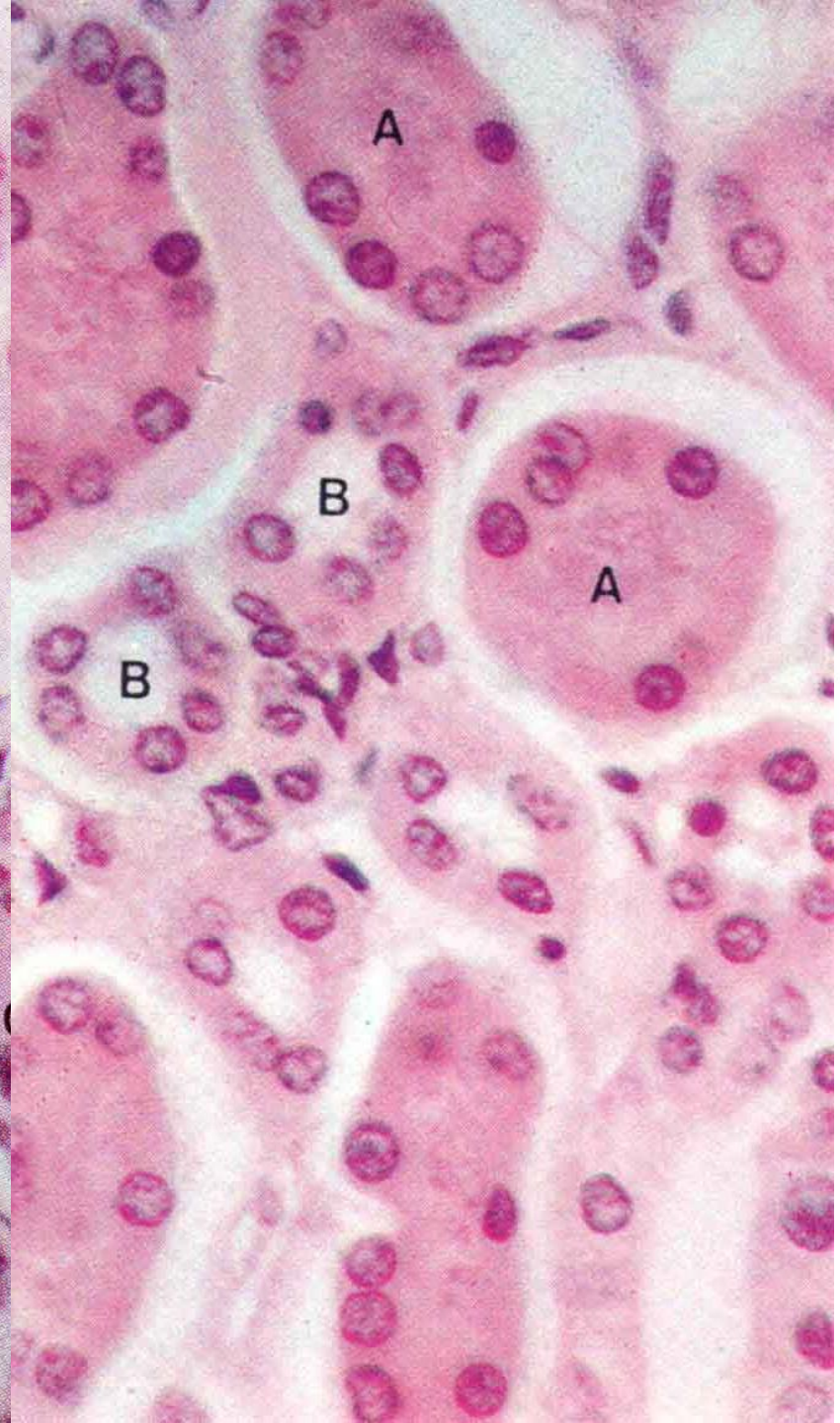
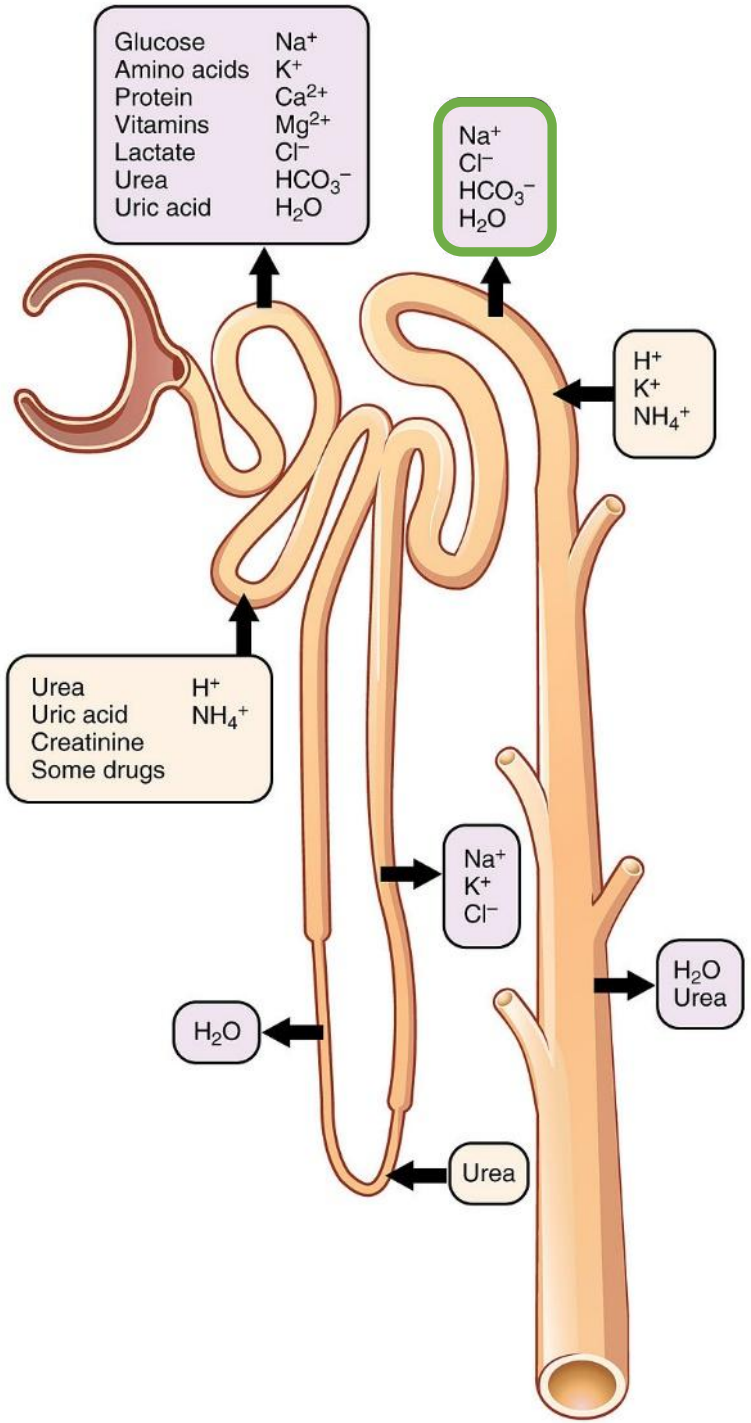
CD
HT
HL
CD
IC
a


B
B
A
A


A
B
A
B

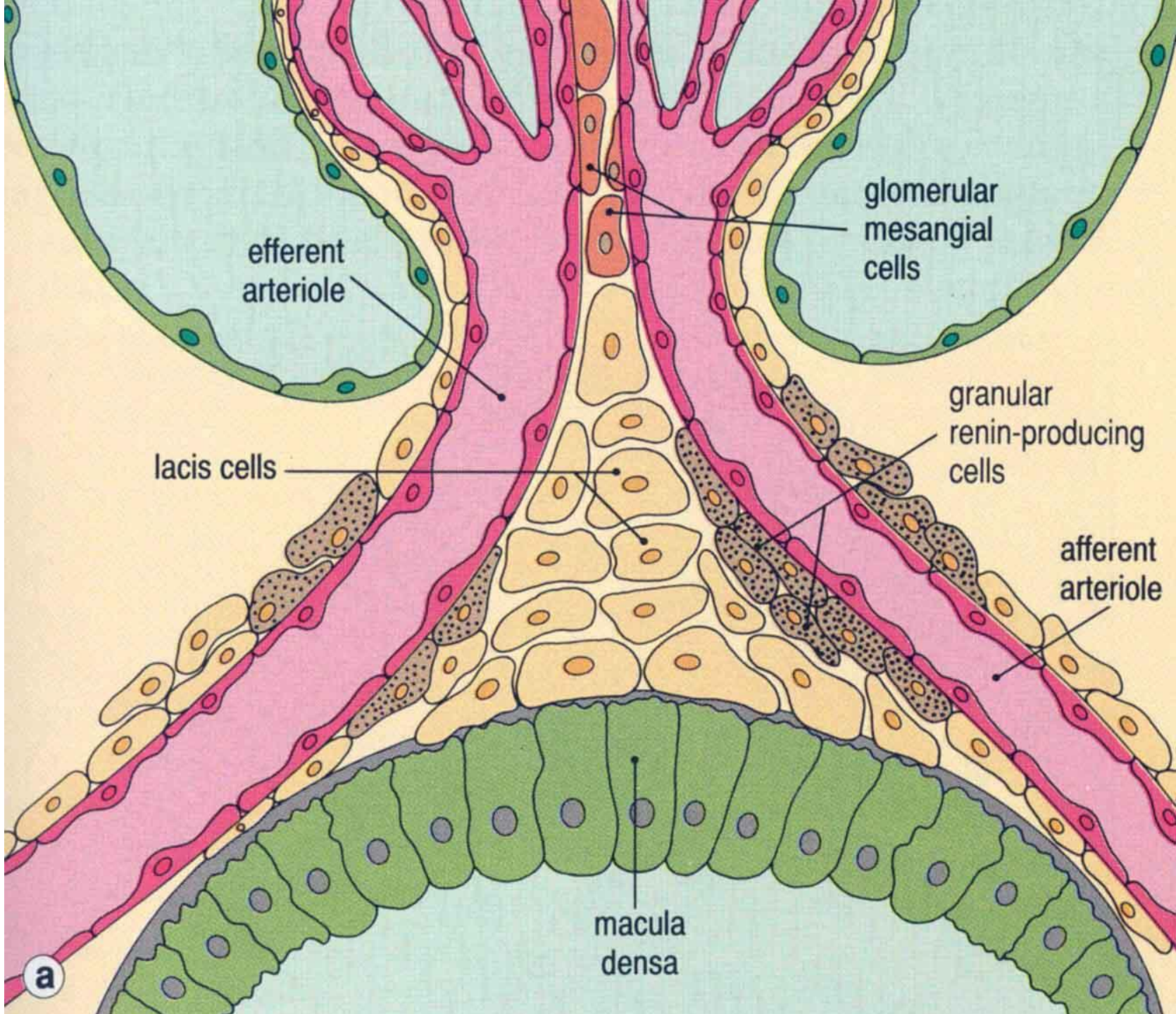

Glucose
Amino acids
Protein
Vitamins
Lactate
Urea
Uric acid
Na^+
K^+
Ca^{2+}
Mg^{2+}
Cl^-
HCO_3^-
H_2O
Na^+
Cl^-
HCO_3^-
H_2O
H^+
K^+
NH_4^+
Urea
Uric acid
Creatinine
Some drugs
H^+
NH_4^+
Na^+
K^+
Cl^-
H_2O
H_2O
Urea
Urea


NOOTRY

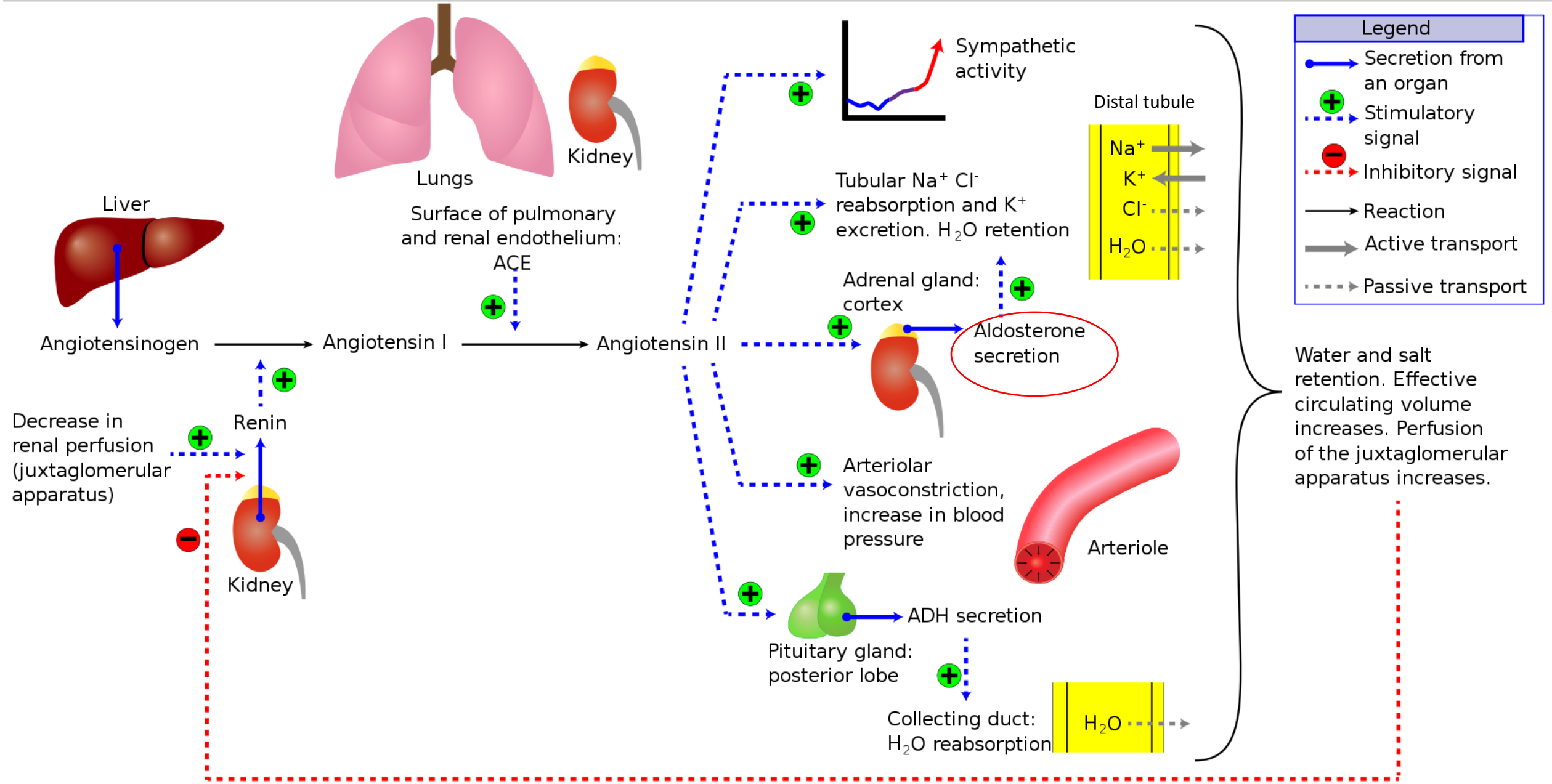
https://x.com/manusamoa/status/1464735494244159490/photo/1

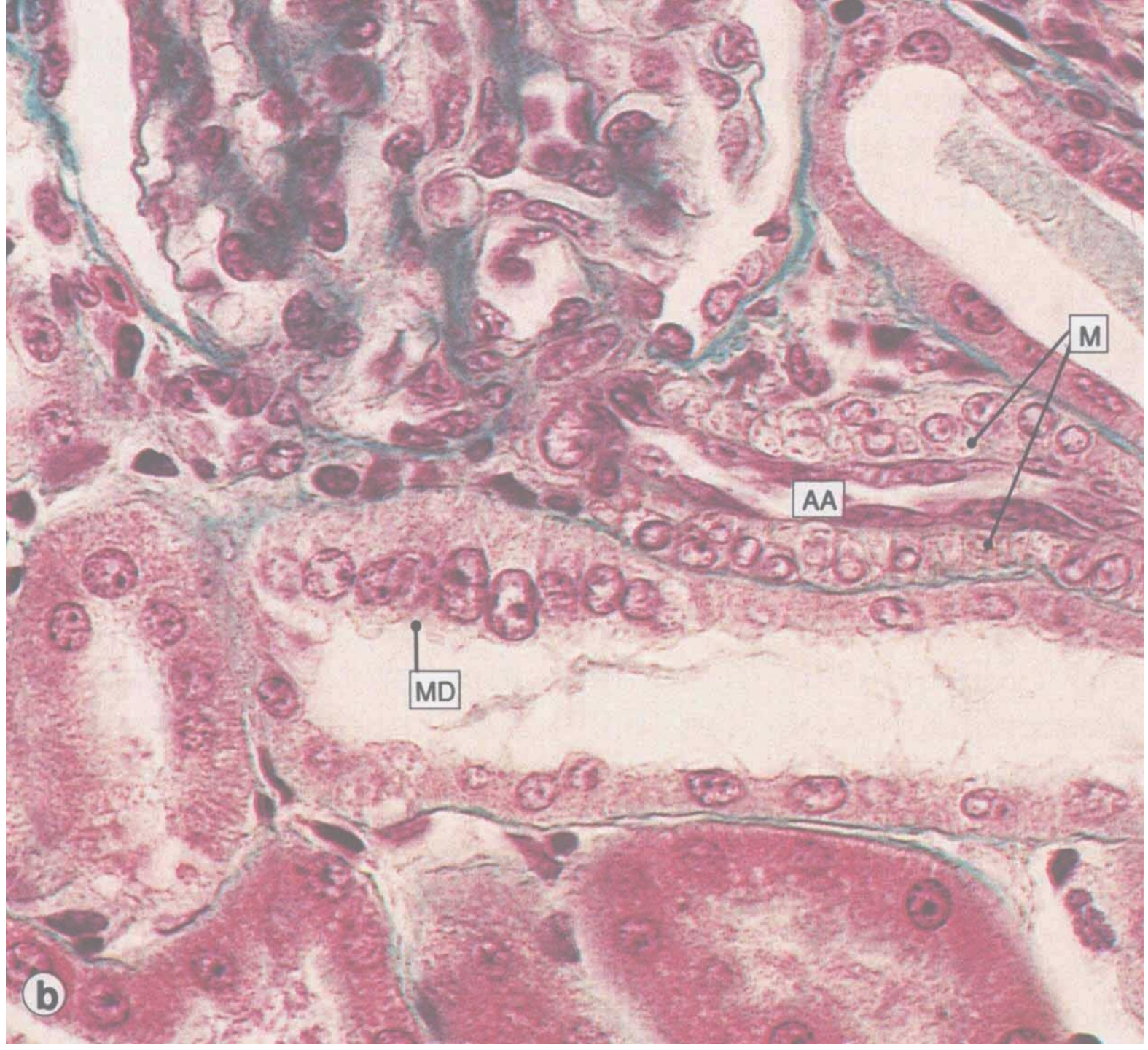
https://en.wikipedia.org/wiki/Yuzuru_Hanyu#/media/File:2019_Grand_Prix_Final_-_Yuzuru_Hanyu_SP_(4).jpg

Juxtaglomerular apparatus senses the amount of fluid and sodium in the distal tubule through macula densa. The release of renin increases when the concentration of sodium is low. It also increases the resistance of the afferent arteriole.

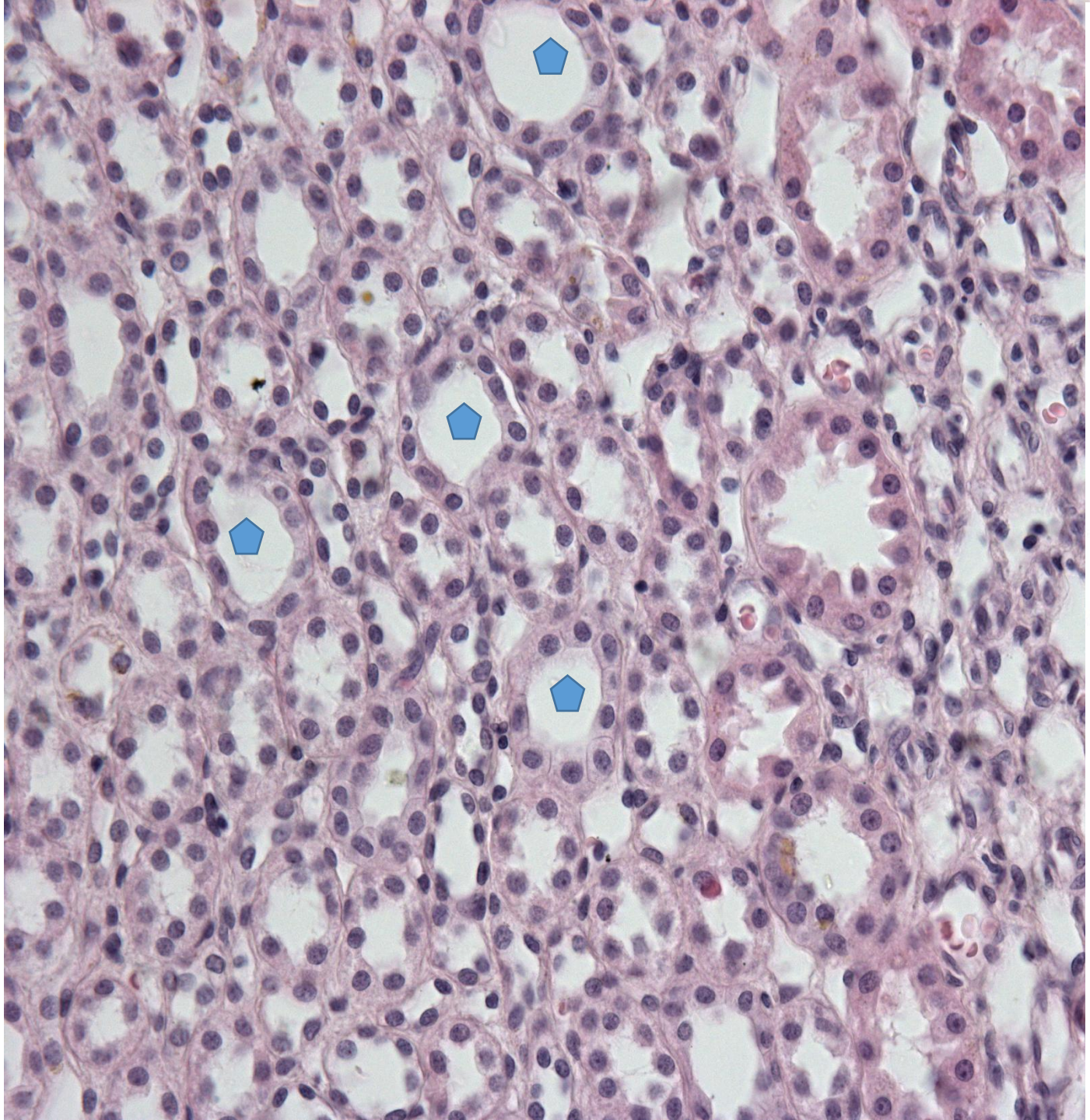


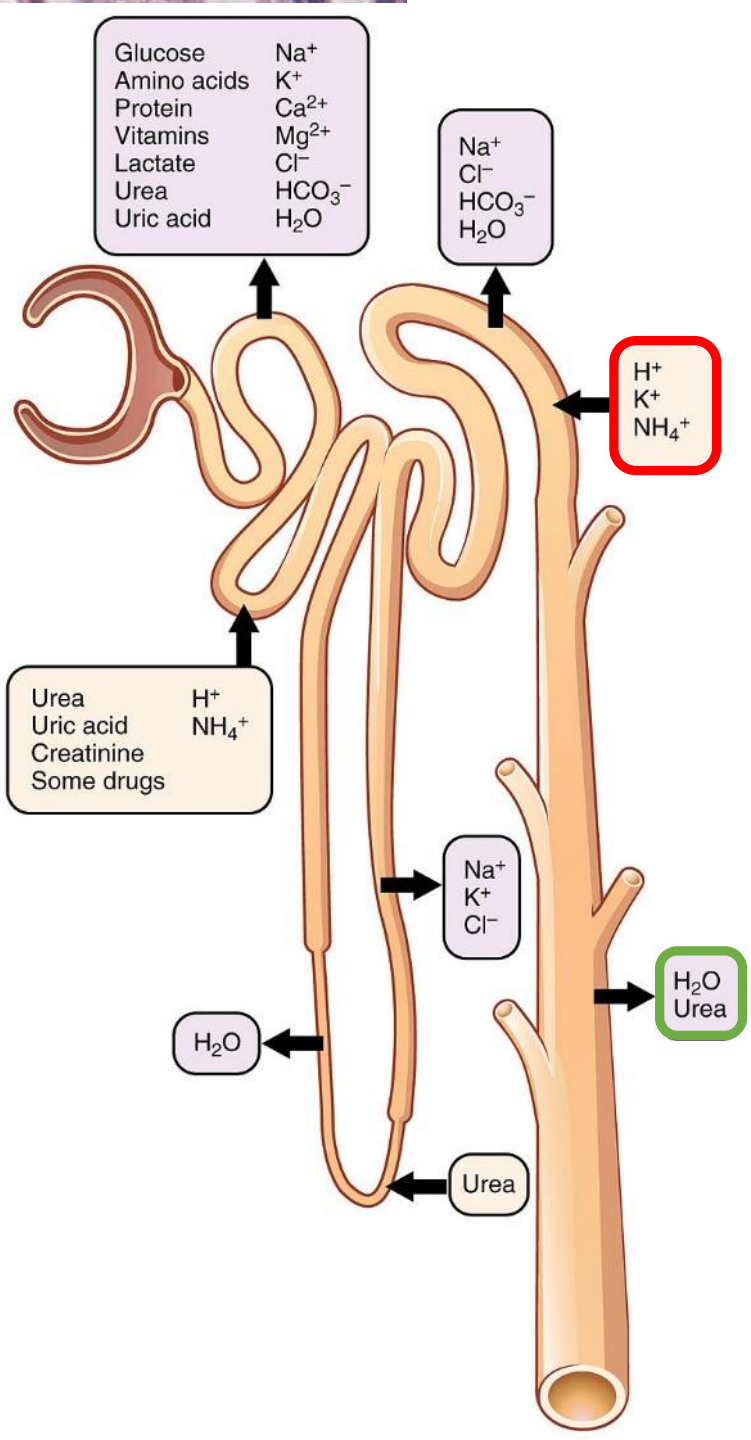
Renin–angiotensin–aldosterone system



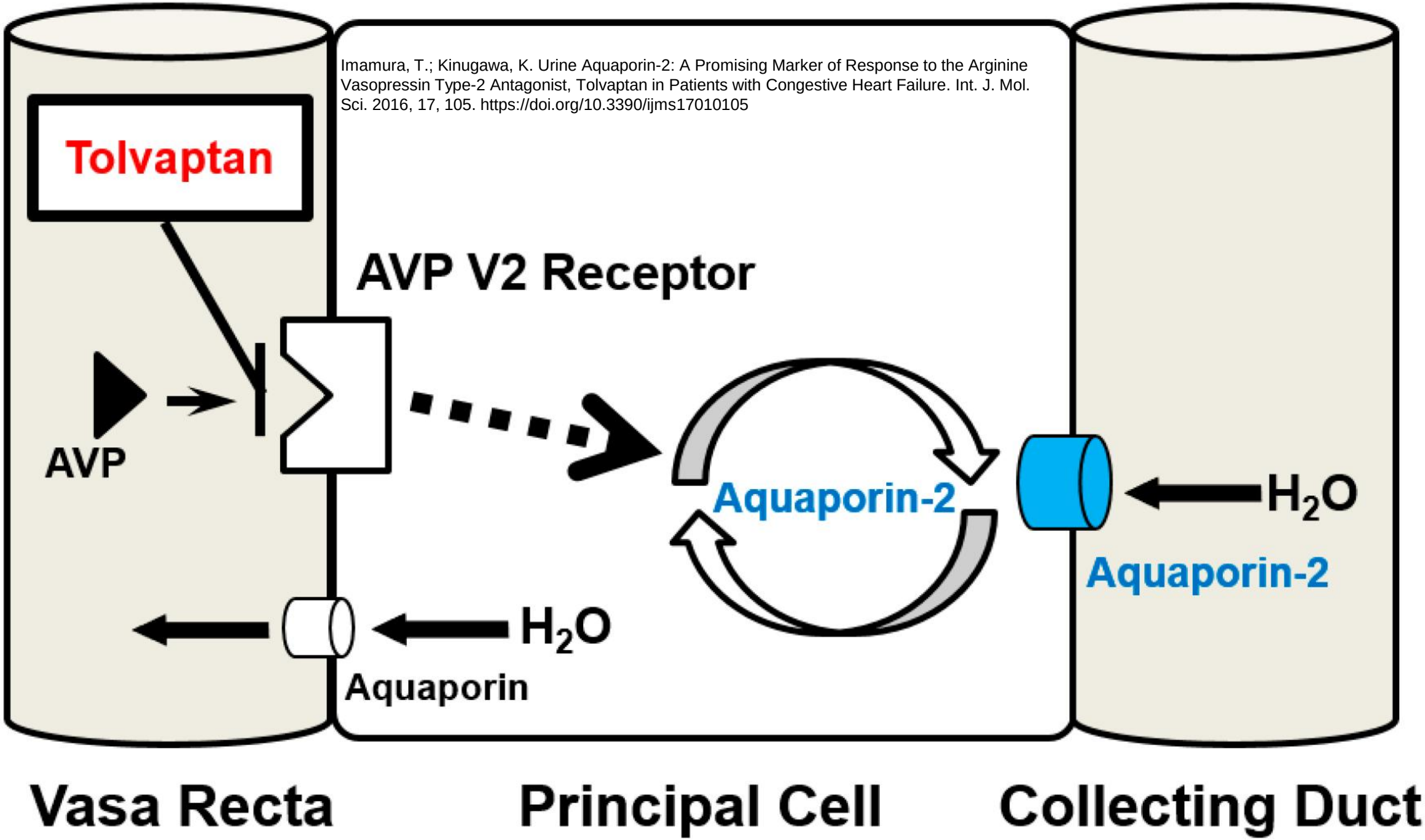

M
AA
MD
b

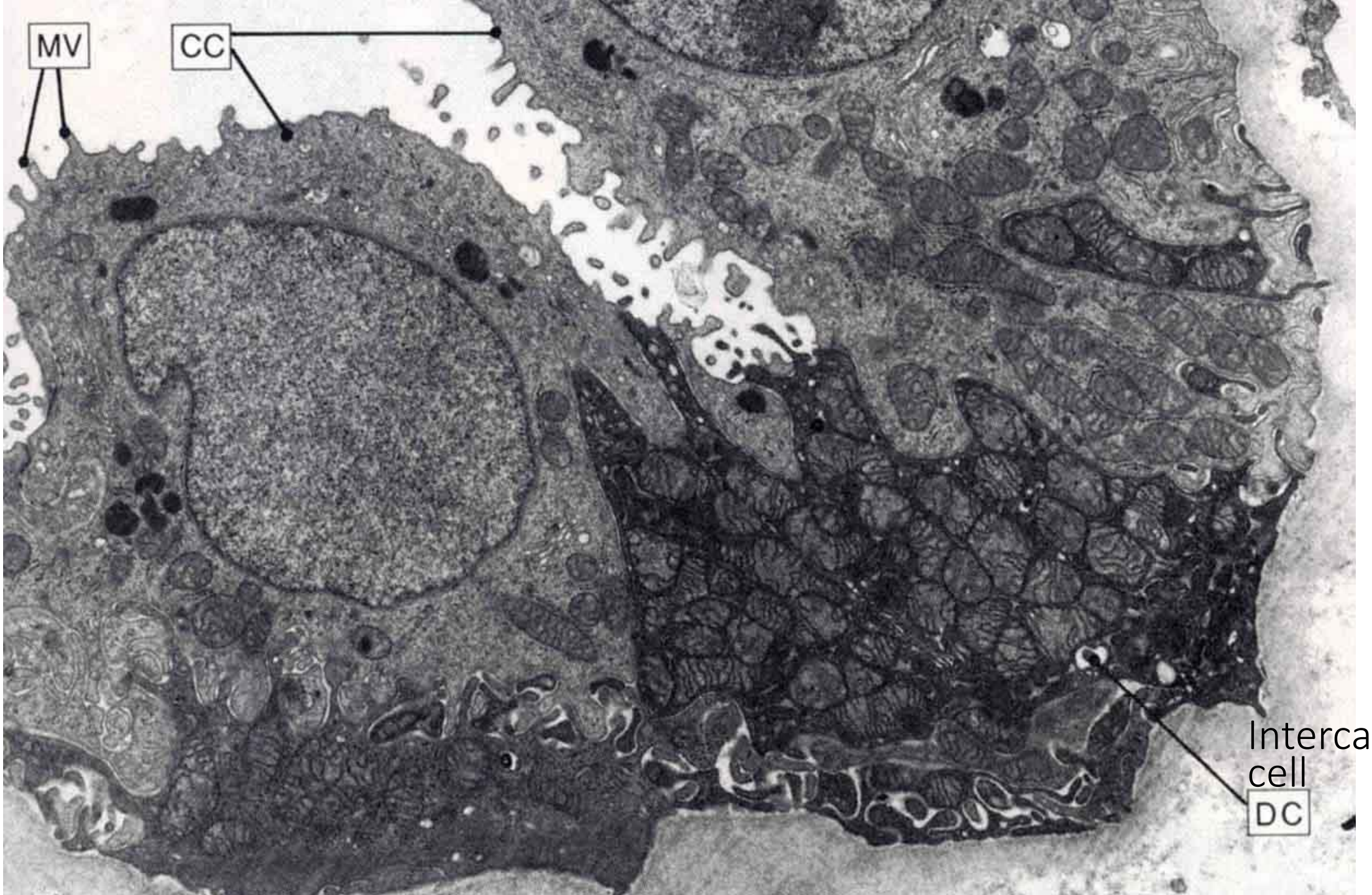
Section of medulla, some collecting ducts marked





Principal cells of the collecting system contain aquaporin.

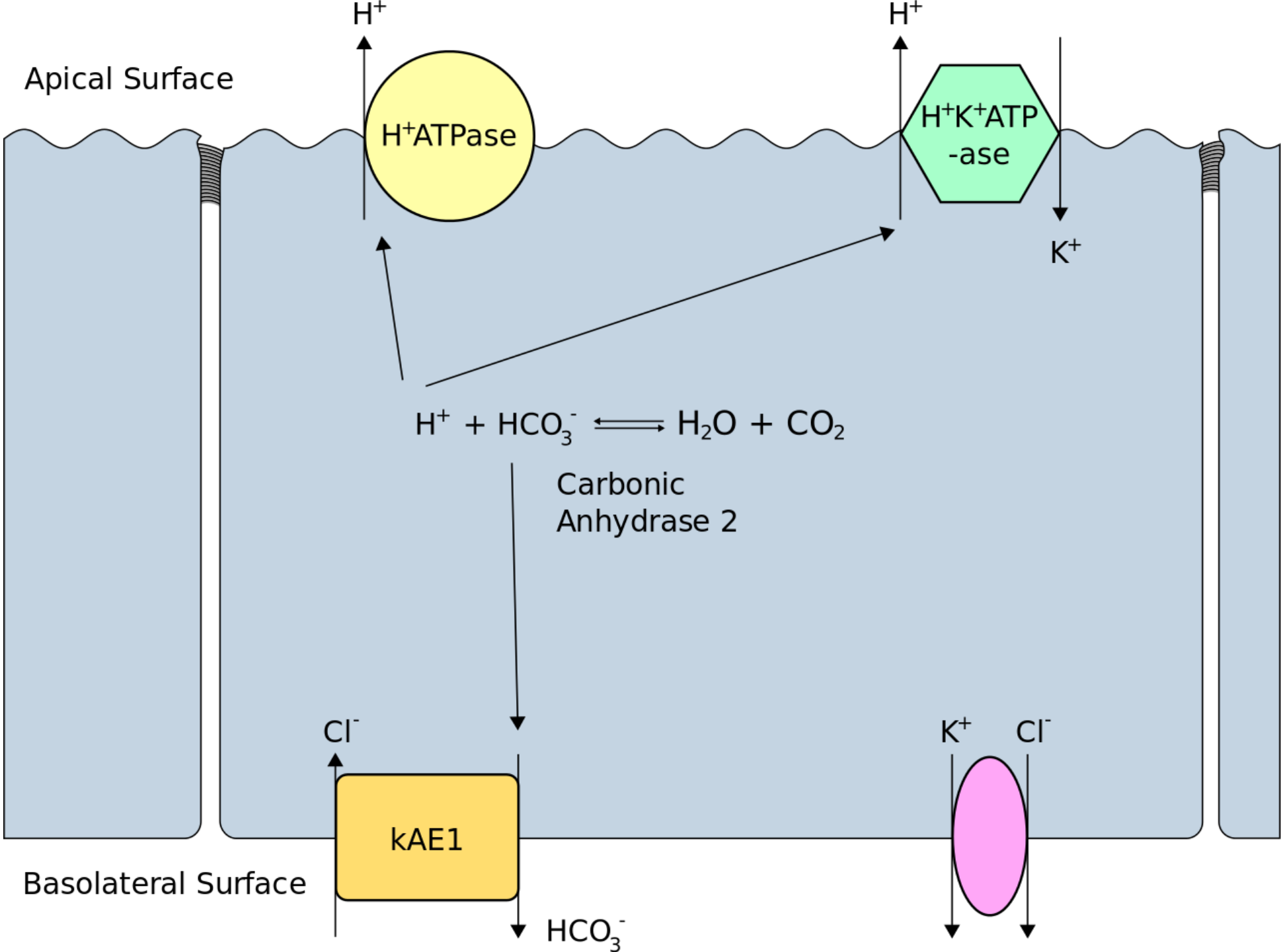

Imamura, T.; Kinugawa, K. Urine Aquaporin-2: A Promising Marker of Response to the Arginine Vasopressin Type-2 Antagonist, Tolvaptan in Patients with Congestive Heart Failure. Int. J. Mol. Sci. 2016, 17, 105. https://doi.org/10.3390/ijms17010105
Tolvaptan
AVP V2 Receptor
AVP
Aquaporin-2
H_2O
H_2O
Aquaporin
Aquaporin-2
Vasa Recta
Principal Cell
Collecting Duct



Intercalated cell

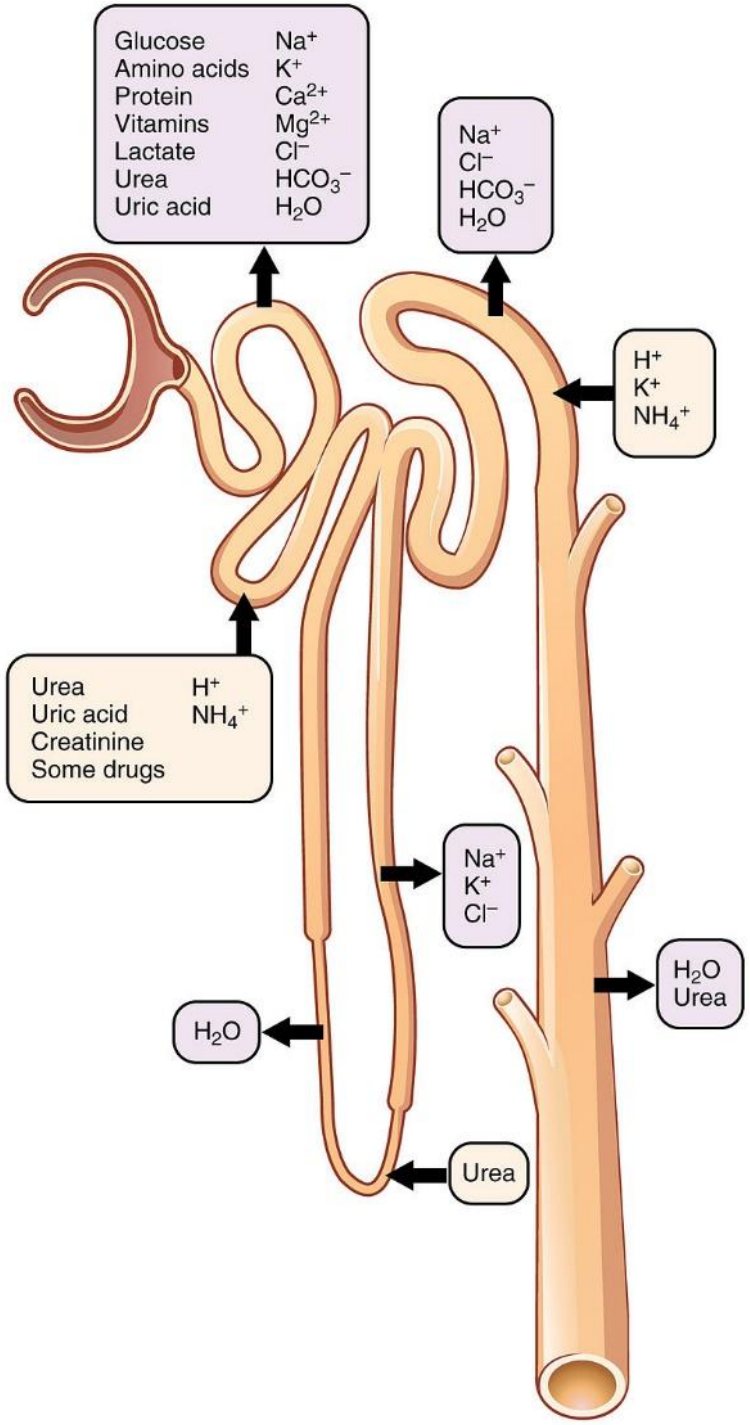
Intercalated cell

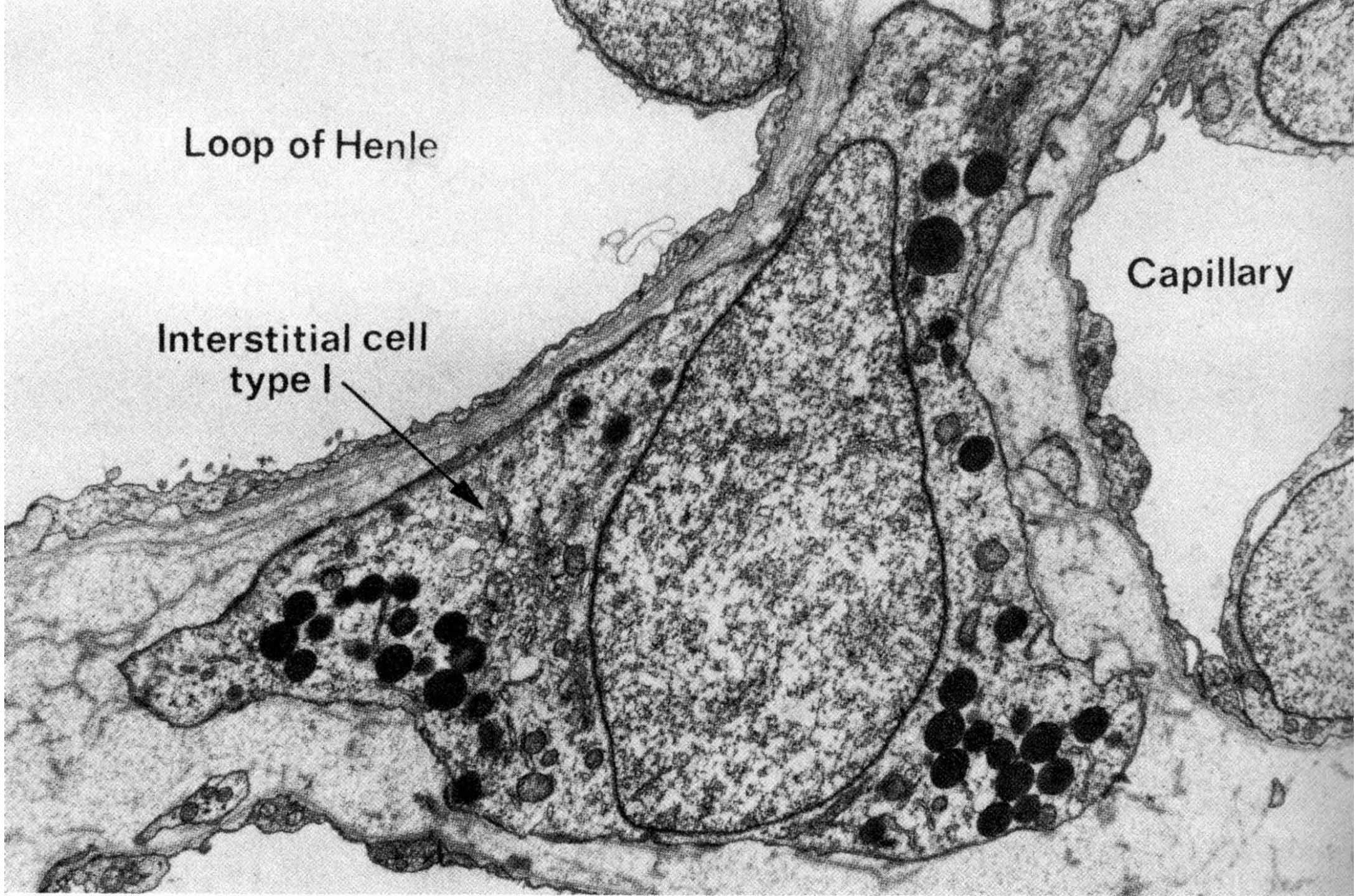
Have you already seen similar cells?



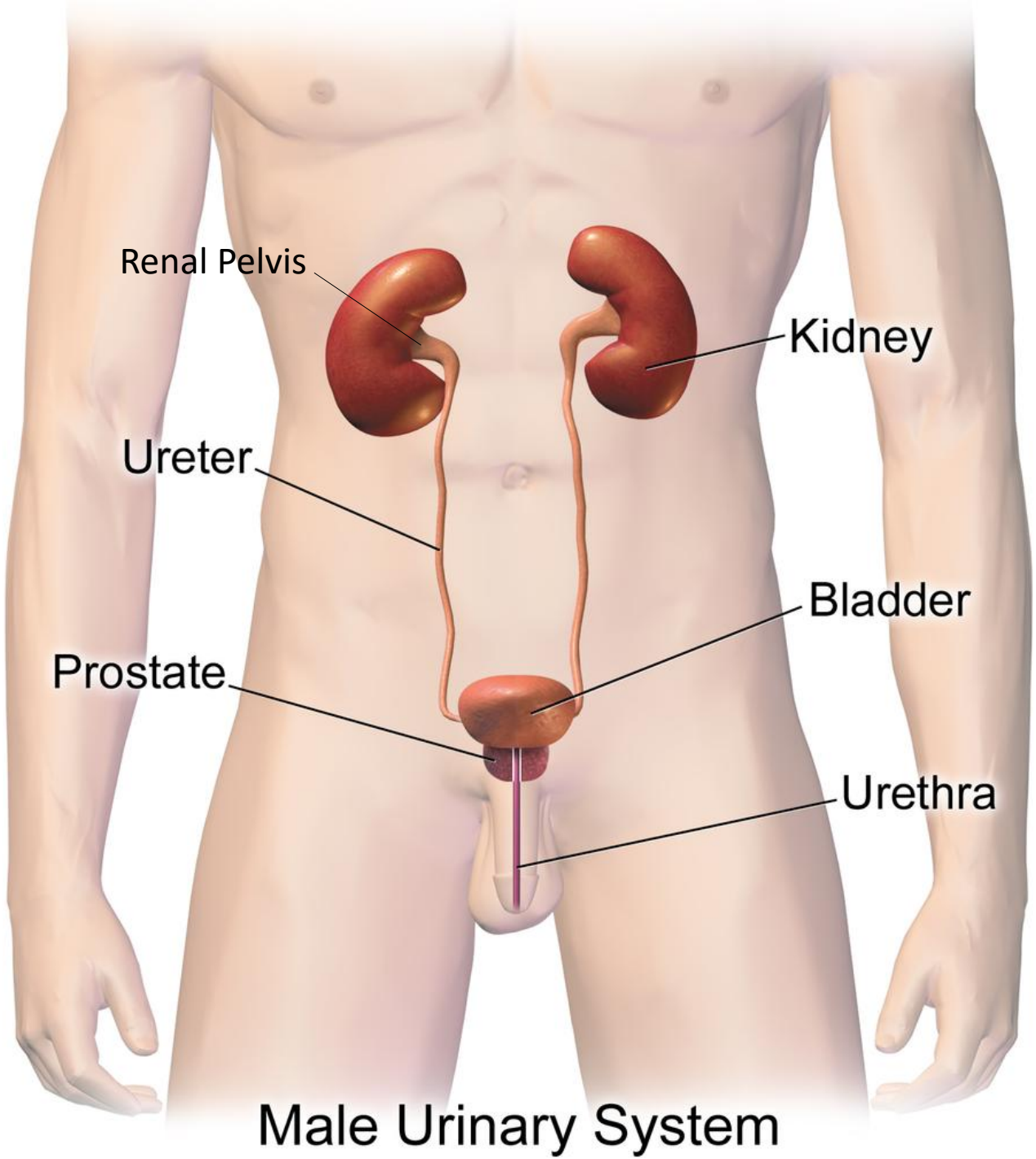
Functional arrangement of the kidney

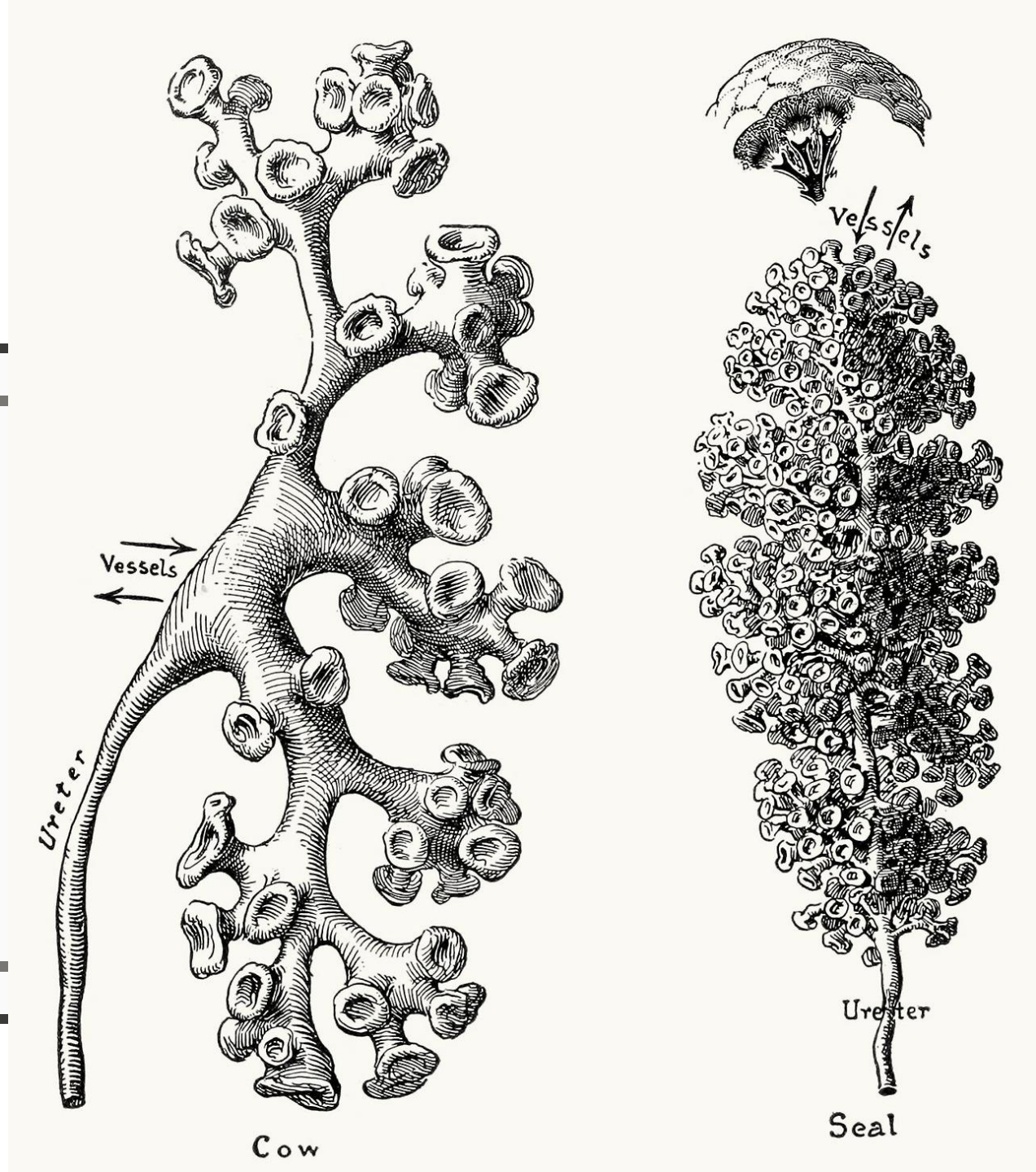
- Renal corpuscle
  - Glomerulus (convoluted porous capillaries), Bowman‘s capsule with podocytes in its visceral layer and simple squamous epithelium in its parietal layer
- Tubules
  - Proximal tubules (most absorption)
  - Loop of Henle (concentration of medullary ECF)
  - Distal tubule (ion absorption) regulated by aldosteron
- Collecting tubules and ducts (not a part of a nephron)
  - CDs (water absorption, urine acidity) regulated by ADH



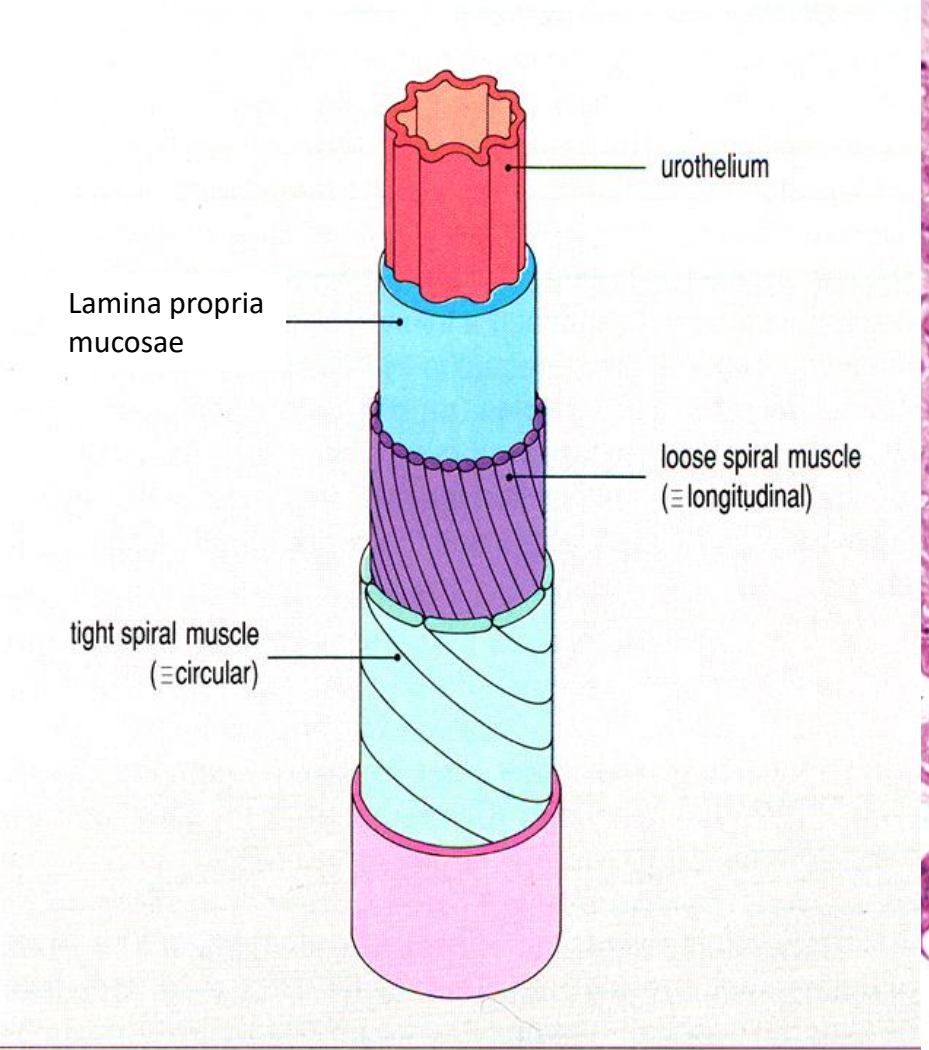

Loop of Henle
Capillary
Interstitial cell
type I

Excretory pathways: calyx minor, calyx maior, pelvis renalis, ureter, vesica urinaria, urethra

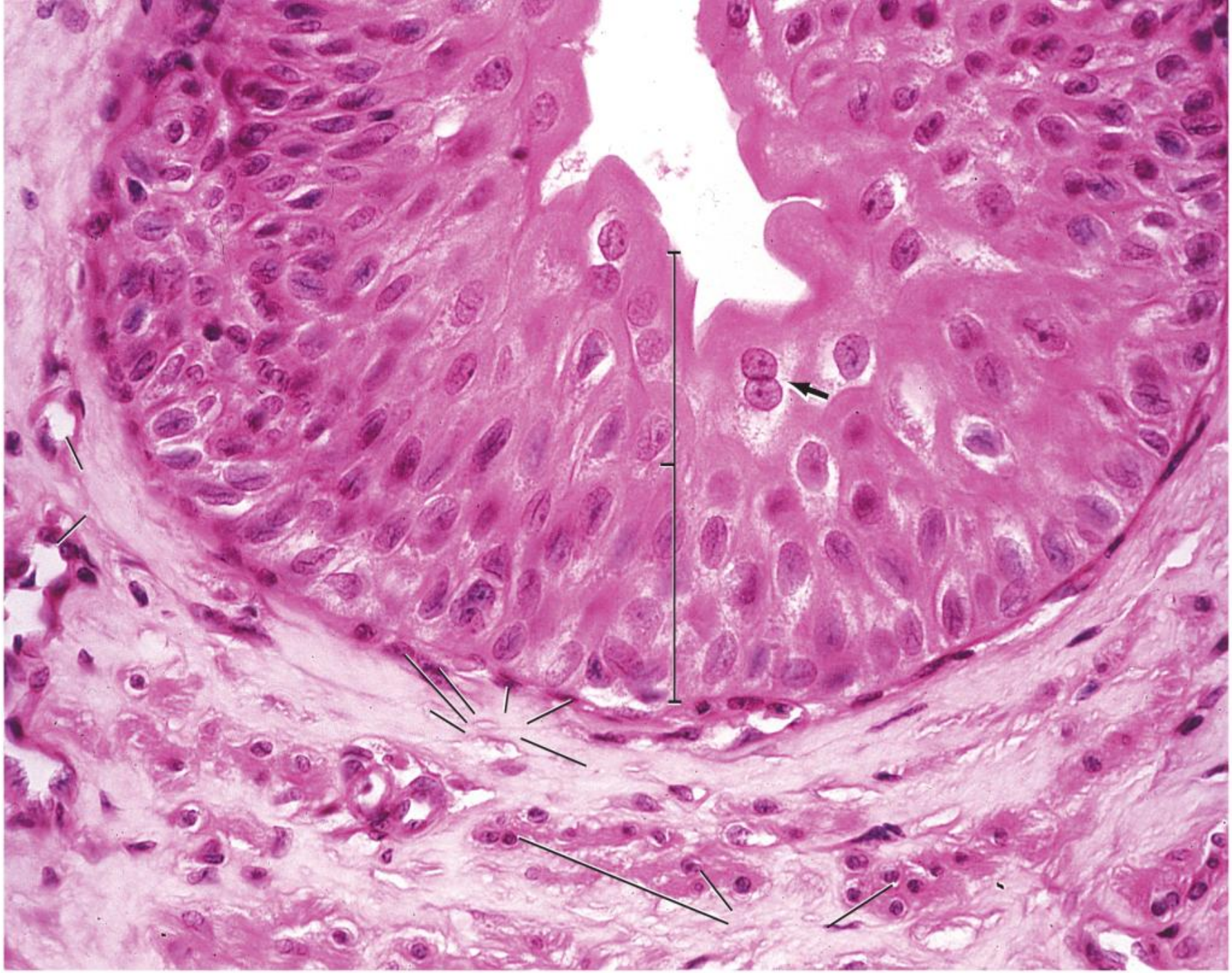


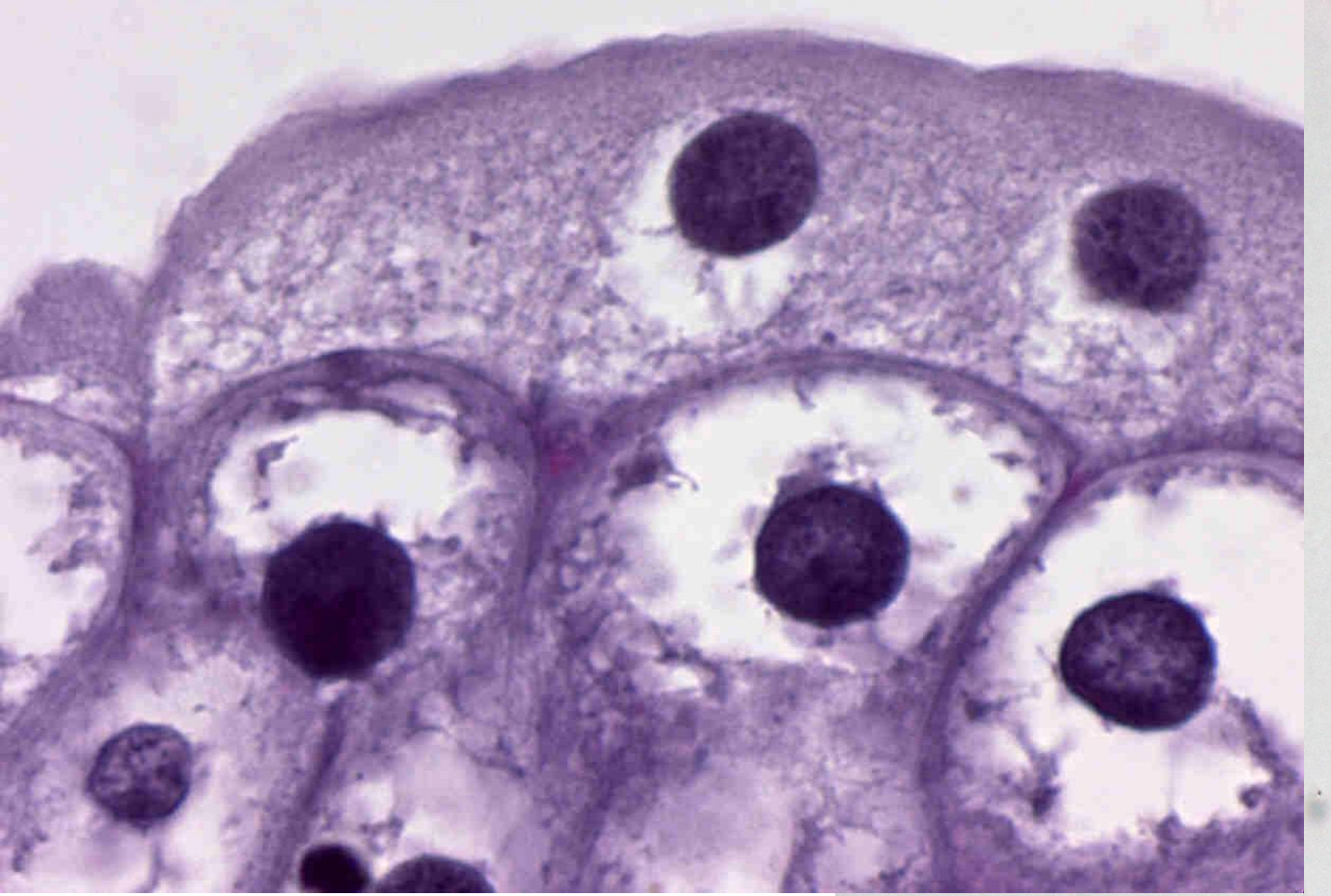

Vessels
Ureter
Cow
Vessels
Ureter
Seal

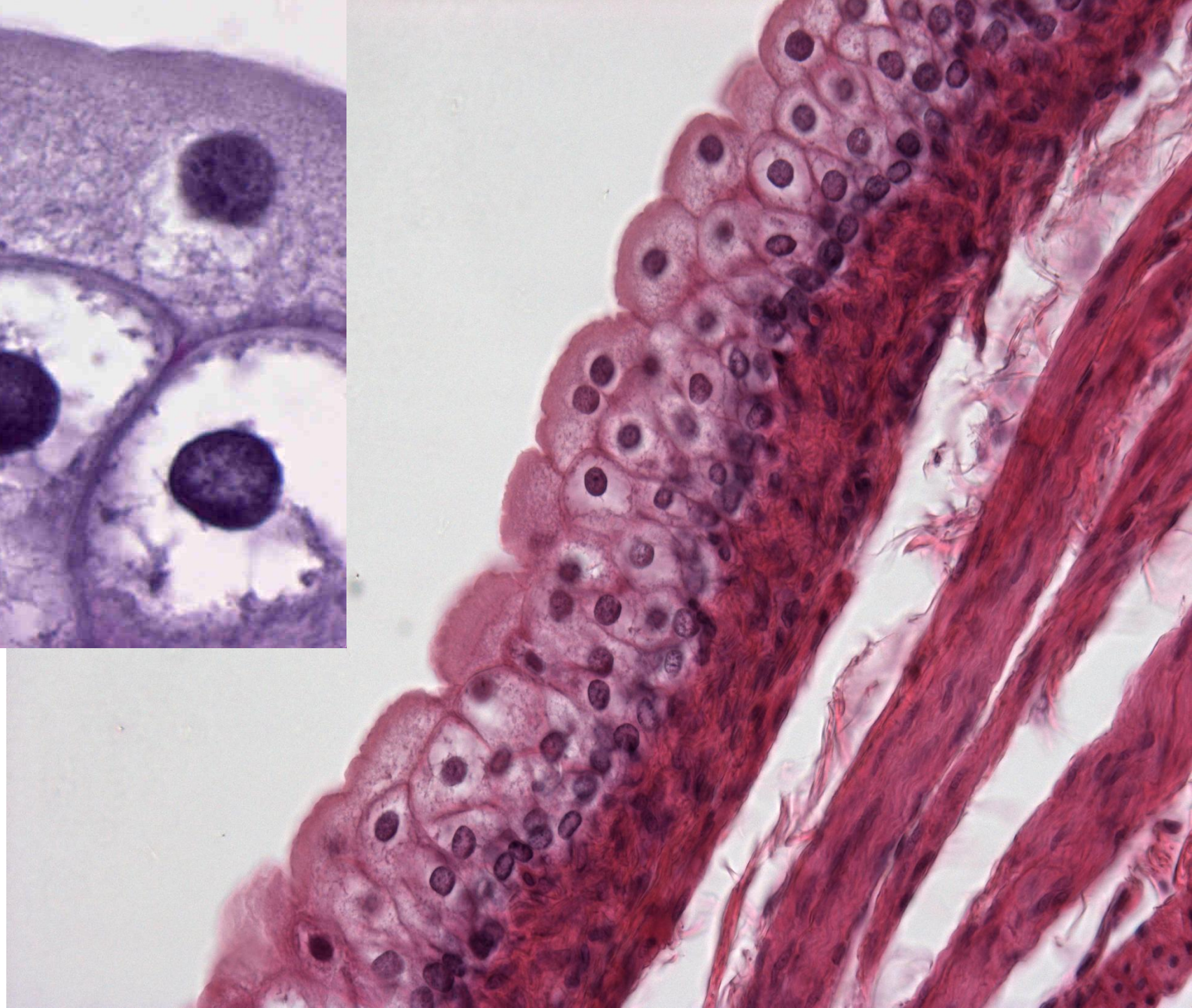
Excretory passages



Transitional epithelium (urothelium)

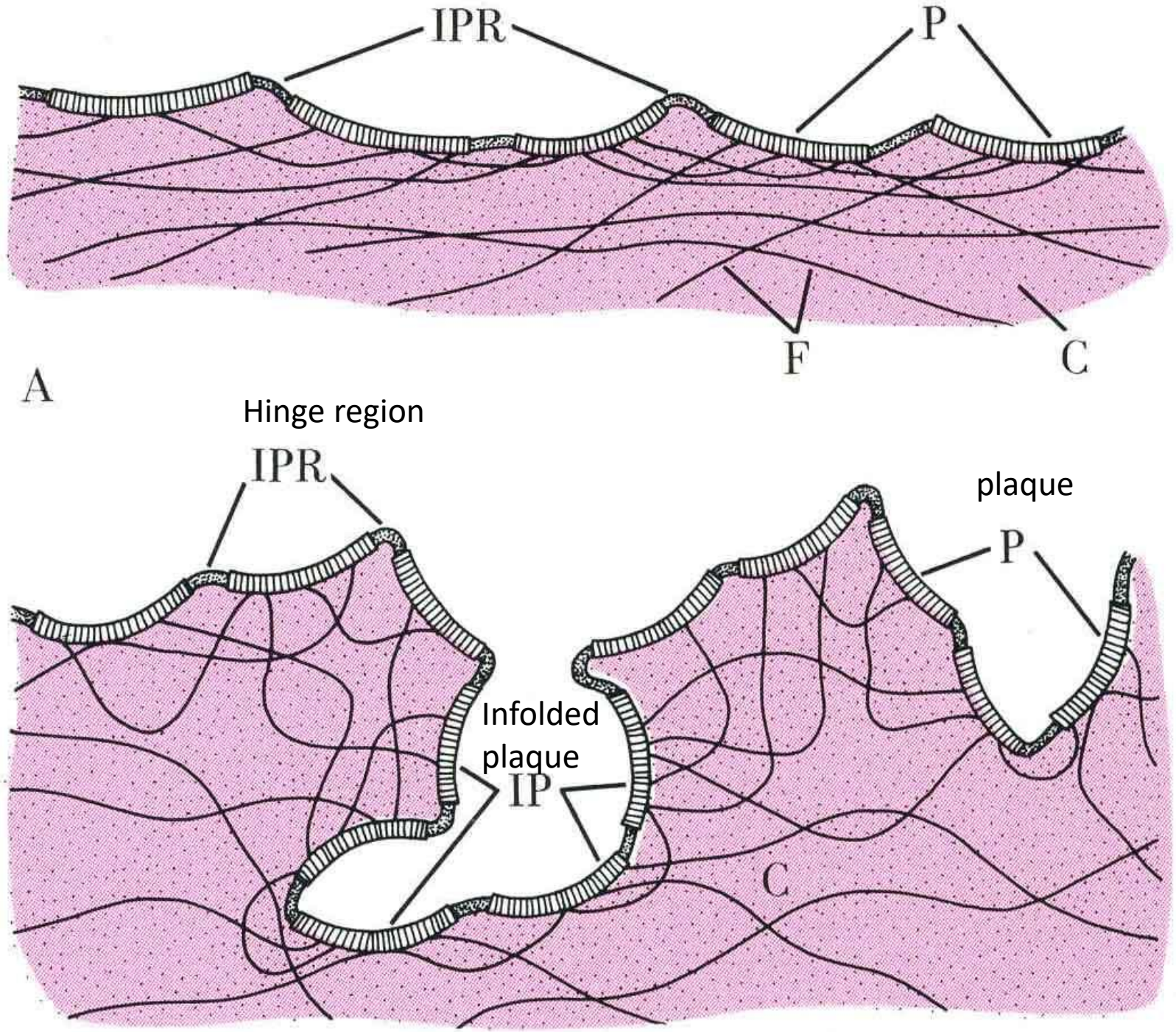




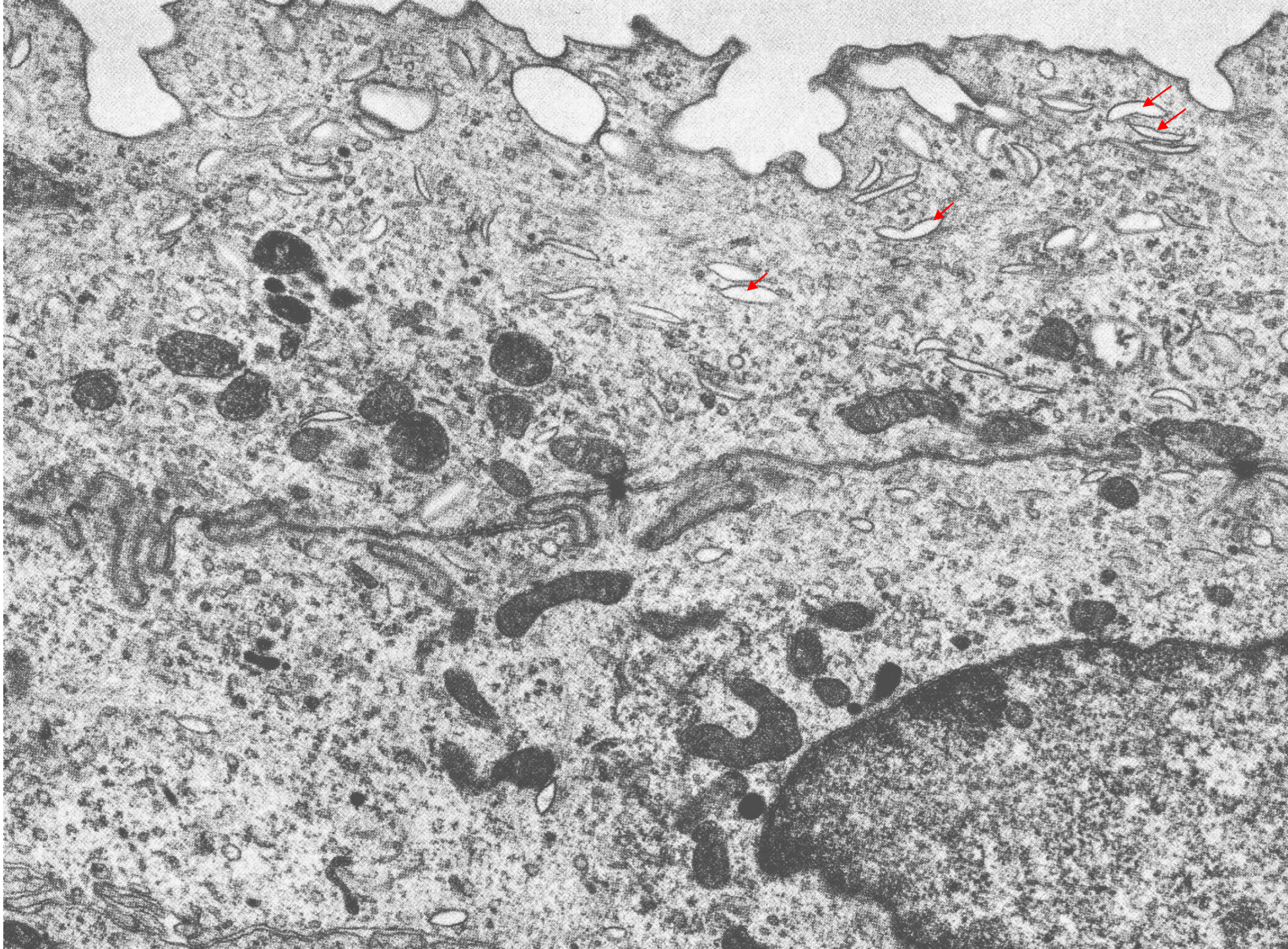


Transitional epithelium (urothelium) – umbrella cells

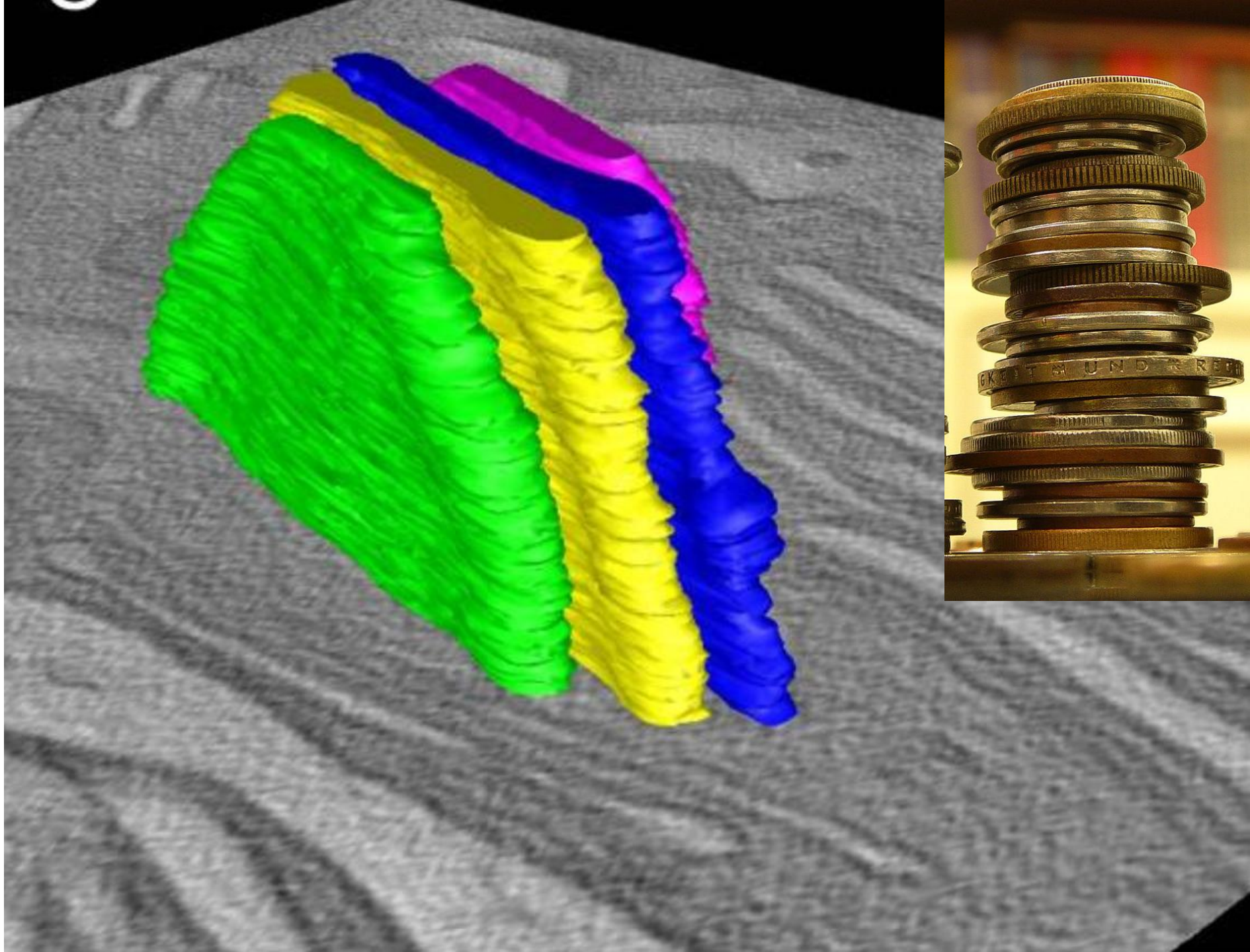
Transitional epithelium (urothelium) – plaques containing uroplakins. Their infolding can appear as a fusiform vesicle. These vesicles serve as a reserve to increase the membrane surface area during distension.



Uroplakins cause the unusual shape of the apical membrane. Note multiple fusiform vesicles (red arrows).



3D imaging of the fusiform vesicles

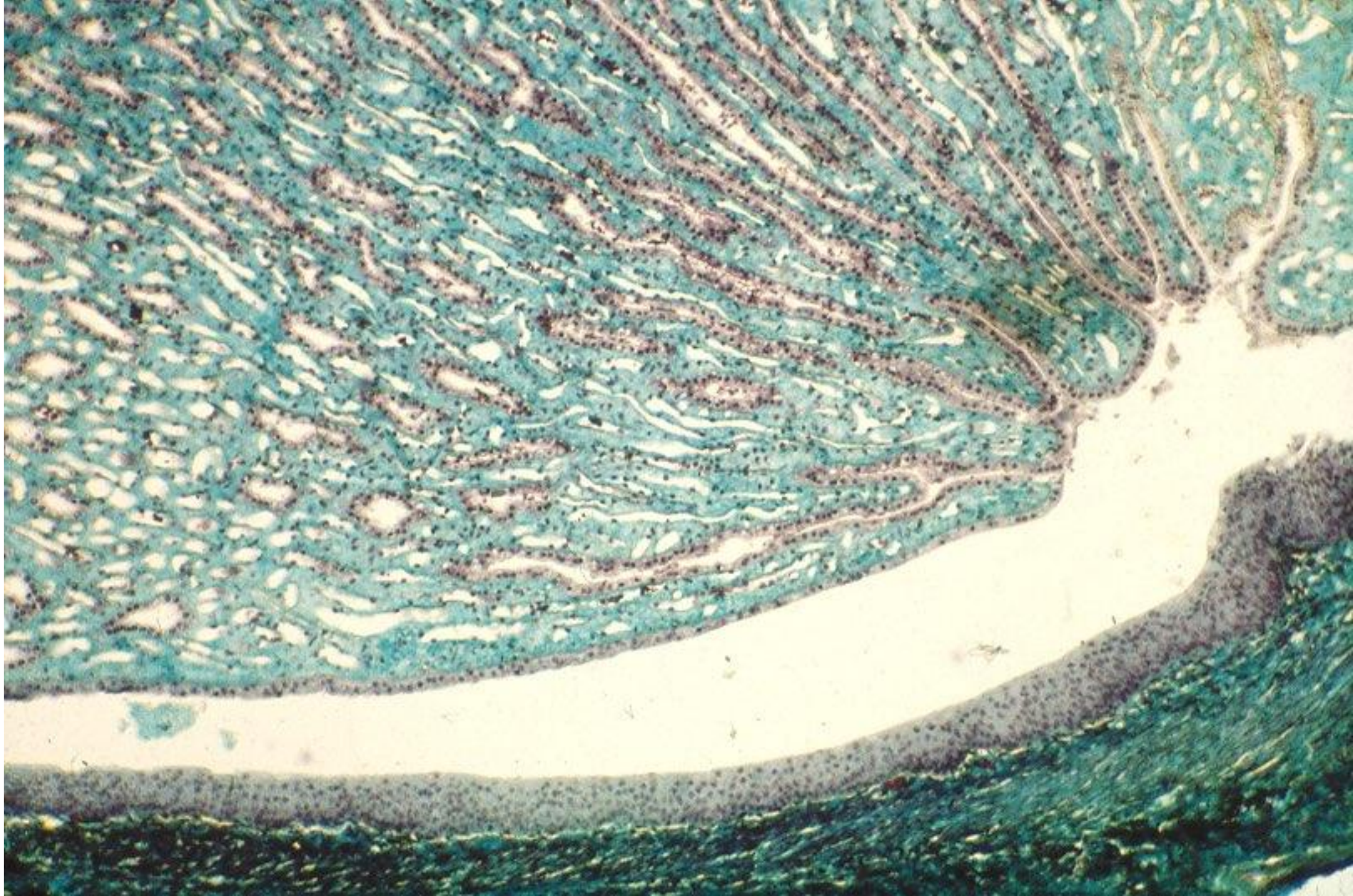


Hudoklin S, Jezernik K, Neumüller J, Pavelka M, Romih R. Electron tomography of fusiform vesicles and their organization in urothelial cells. PLoS One. 2012;7(3):e32935. doi: 10.1371/journal.pone.0032935. Epub 2012 Mar 12. PMID: 22427911; PMCID: PMC3299716.

Urothelium

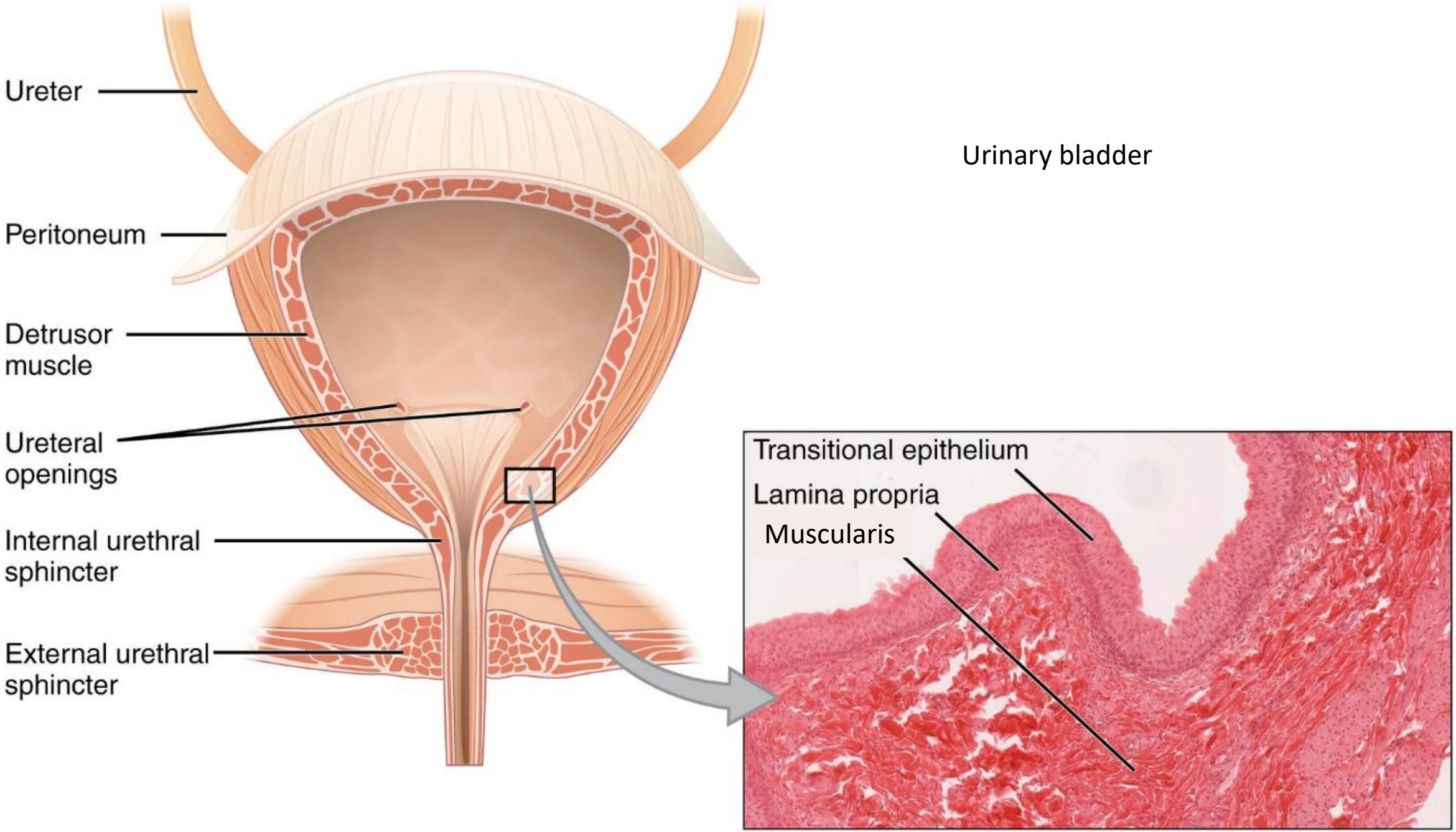
- Transitional epithelium (urothelium) is a type of epithelium specific for the excretory pathway of the urinary system.
- In male urethra, it is only found in the two proximal parts (pars vesicalis, pars prostatica), in female urethra in the proximal portion.
- It is adapted for changes in organ volume.
- The cells of the superficial layer are called the umbrella cells, they can change their shape in response to organ distension. They contain uroplakins, that make the membrane less permeable.
- Fusiform vesicles can be used to expand apical cell membrane.

Minor calyx

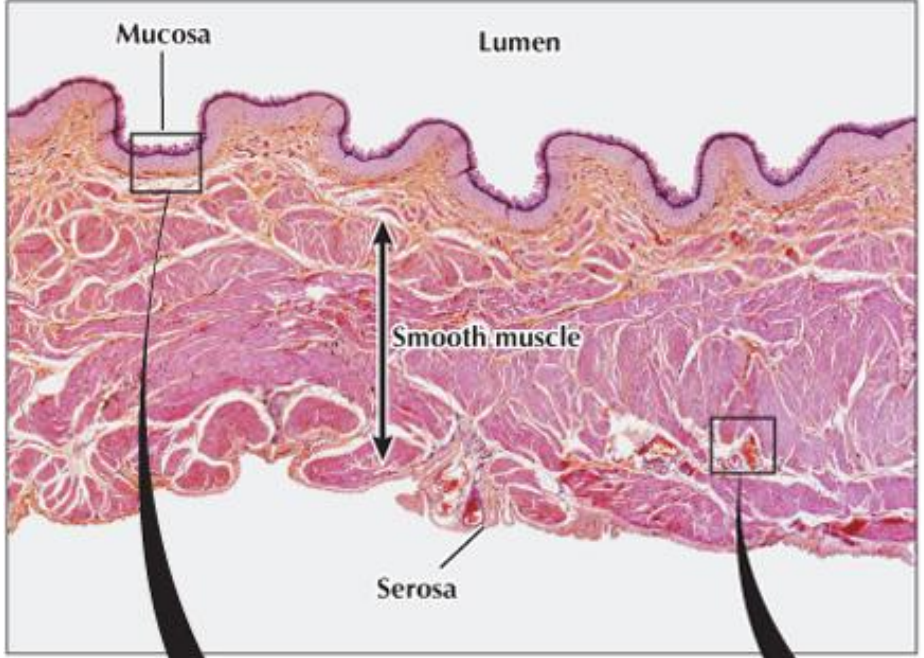


Ureter has three layers of muscularis (l, c, l)

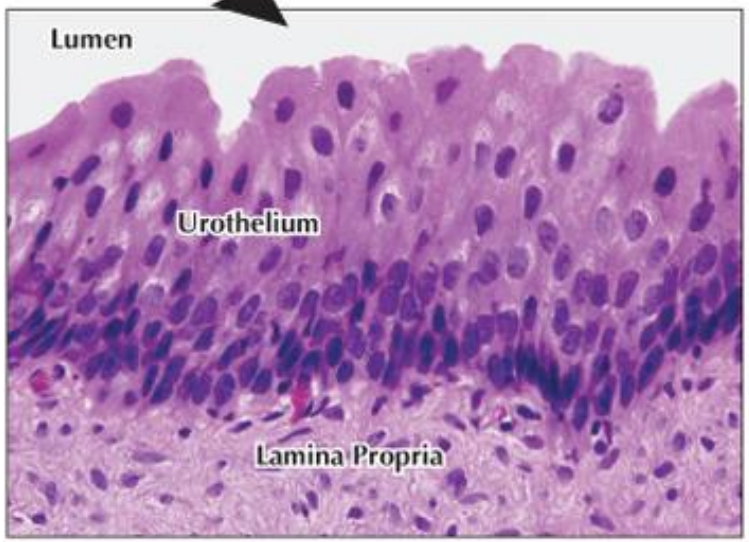
Urinary bladder



Urinary bladder



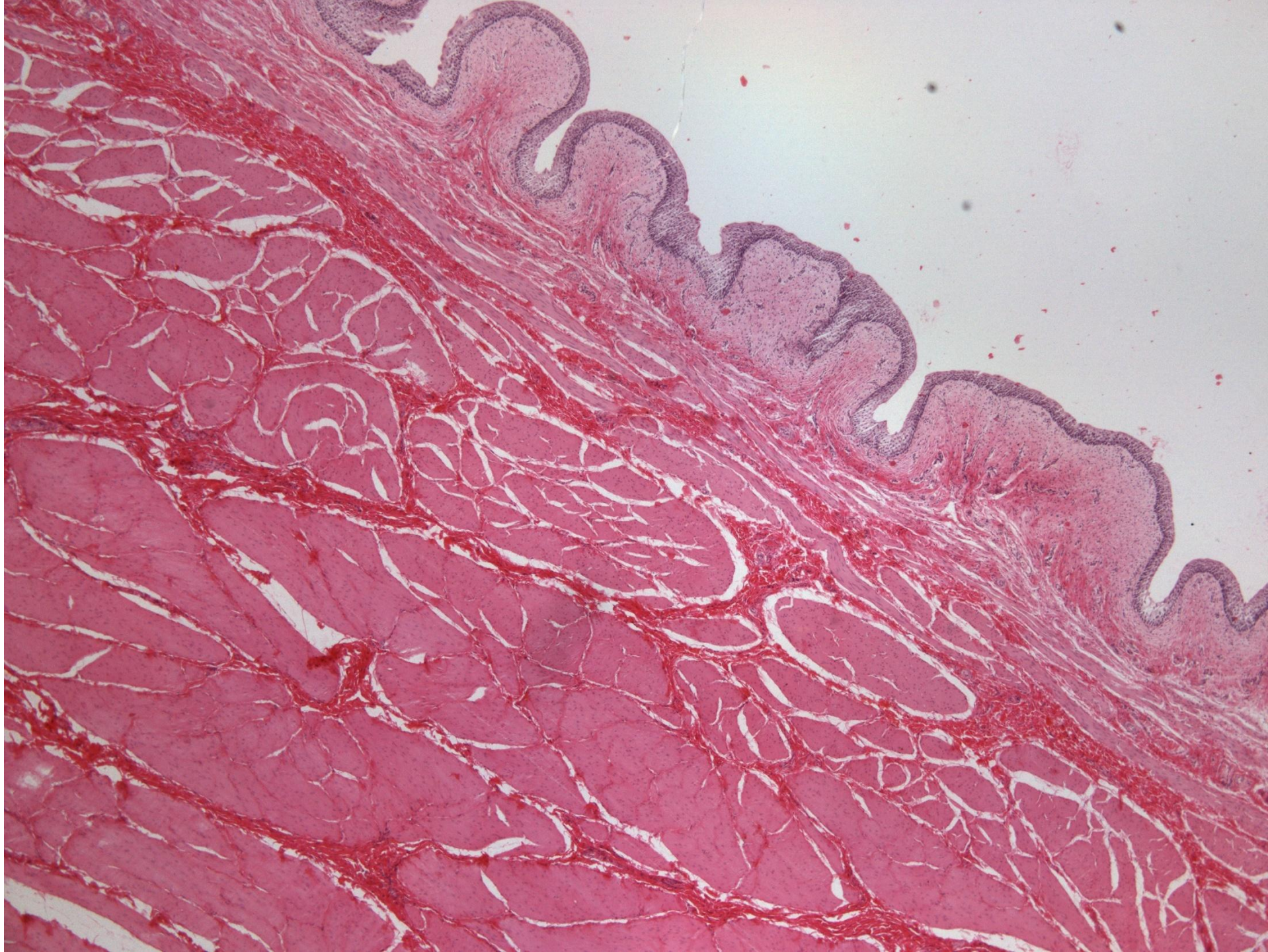
◀ **LM of the wall of the urinary bladder in transverse section.** The mucosa, according to the degree of distention, may look corrugated, with irregular longitudinal folds created by shape changes. Smooth muscle in the muscularis externa is thicker than that of the ureter. The superior bladder surface is covered externally by a serosa of peritoneum rather than by adventitia, the usual outer layer in the rest of the bladder. The serosa consists of connective tissue covered externally by thin, simple squamous epithelium made of a continuous layer of mesothelial cells (not seen at this magnification). 17×. *H&E.*



▲ **LM of the mucosa of the bladder at high magnification.** In the empty bladder the urothelium has an increased thickness—up to 8-10 cell layers. The lamina propria is highly fibrous with scattered connective tissue cells and a few capillaries. 420×. *H&E.*

▲ **LM of part of the muscularis externa of the bladder at high magnification.** Fibrous connective tissue surrounds irregular smooth muscle cell bundles. An arteriole and venule are in the area. 420×. *H&E.*

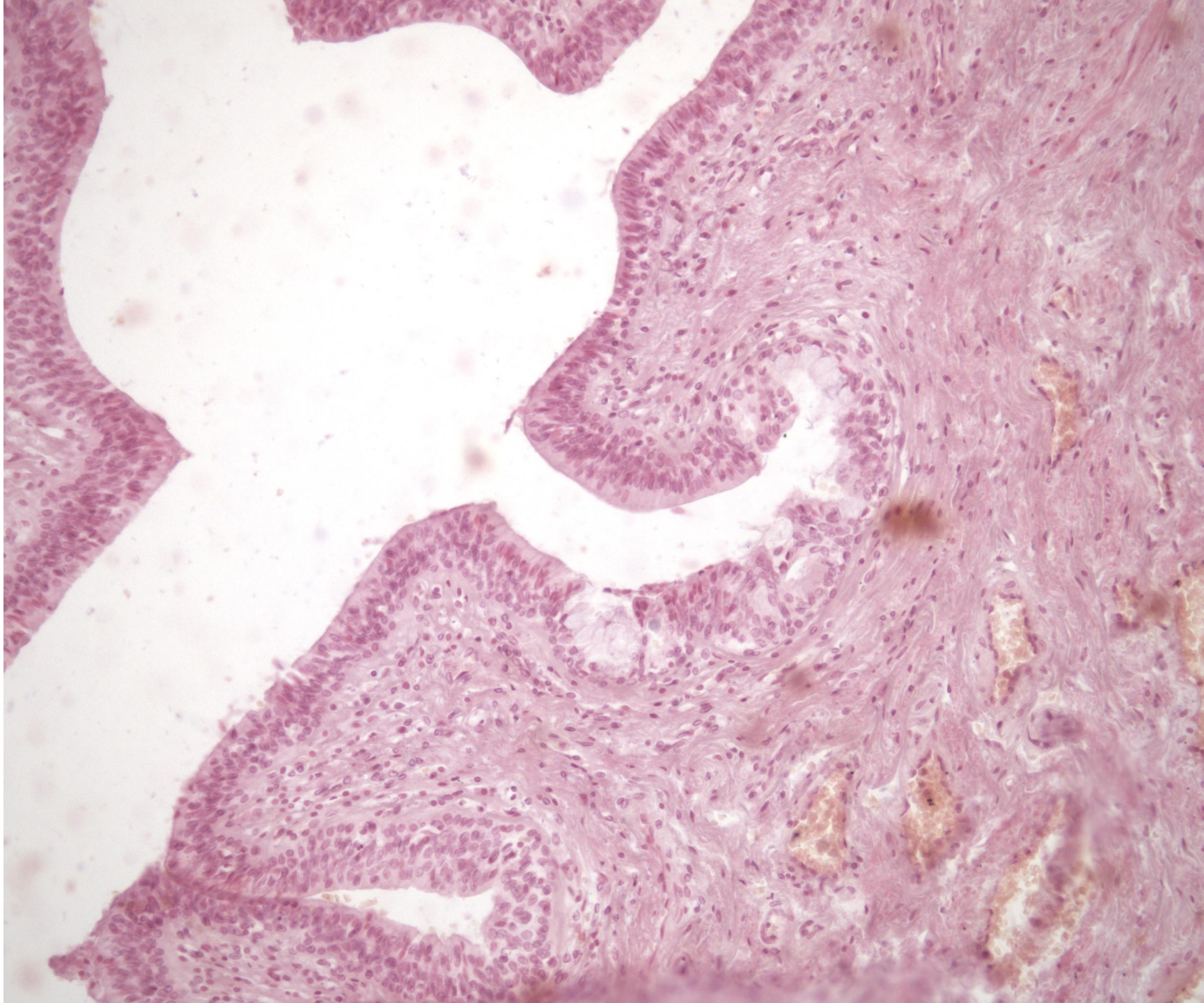
Urinary bladder



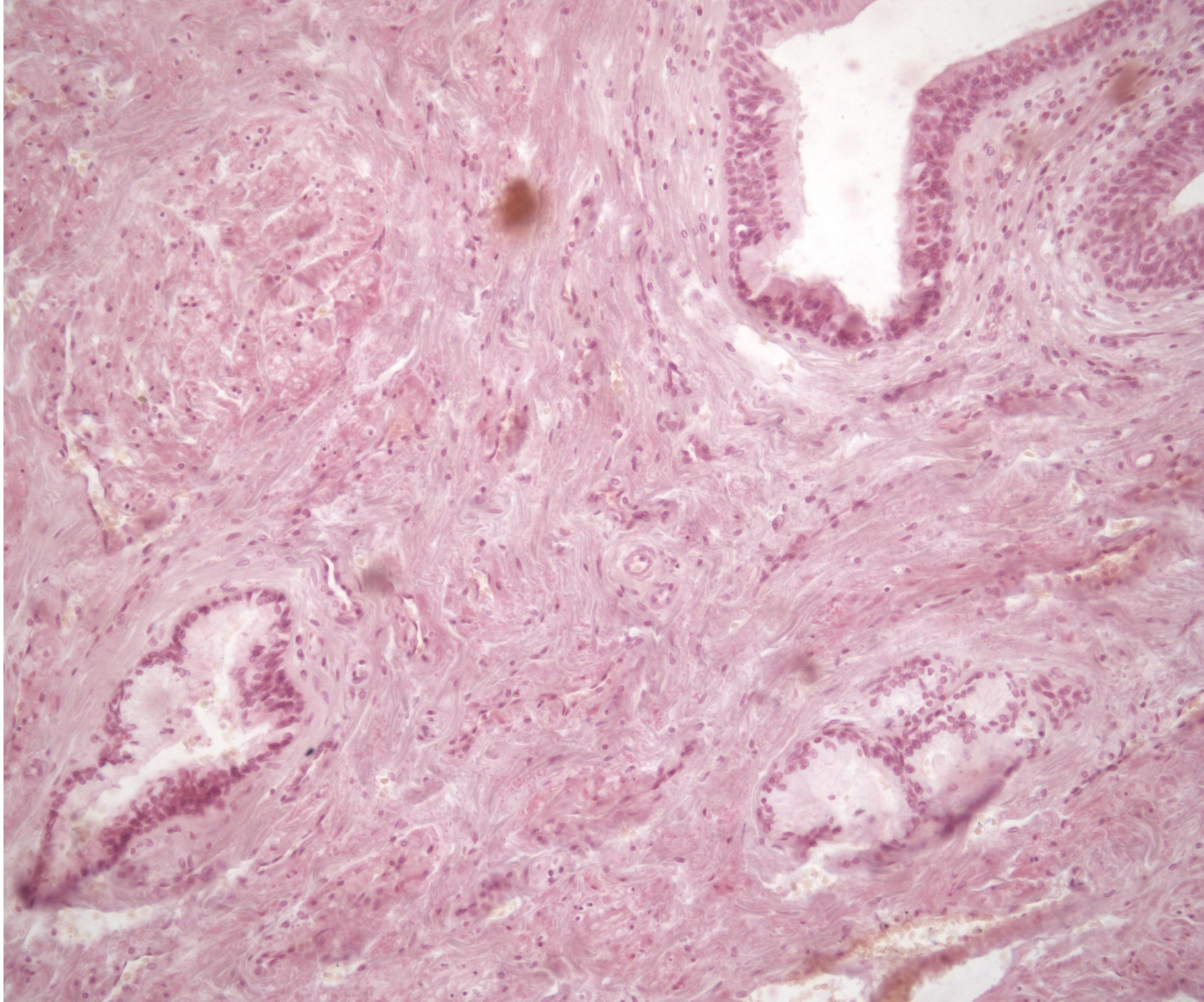
Ureter, urinary bladder

- Ureter
  - Mucosa with urothelium, three layers of smooth muscle, adventitia rich in adipose tissue, vessels, nerves.
  - Outer longitudinal layer of smooth muscle is found in the terminal portion of ureter and is continuous with the musculature of the urinary bladder.
- Urinary bladder
  - Trigone is relatively smooth and constant in thickness, it has a different embryologic origin from the rest of the bladder.
  - The smooth muscle of the urinary bladder is less regularly arranged (in comparison with the ureter) forms the detrusor muscle and the sphincter urethrae internus.
  - Similarly to ureter, the smooth muscle is mixed with connective tissue.

Urethra – lacunae urethrales Morgagni



Glandulae paraurethrales Littrei



Urethra

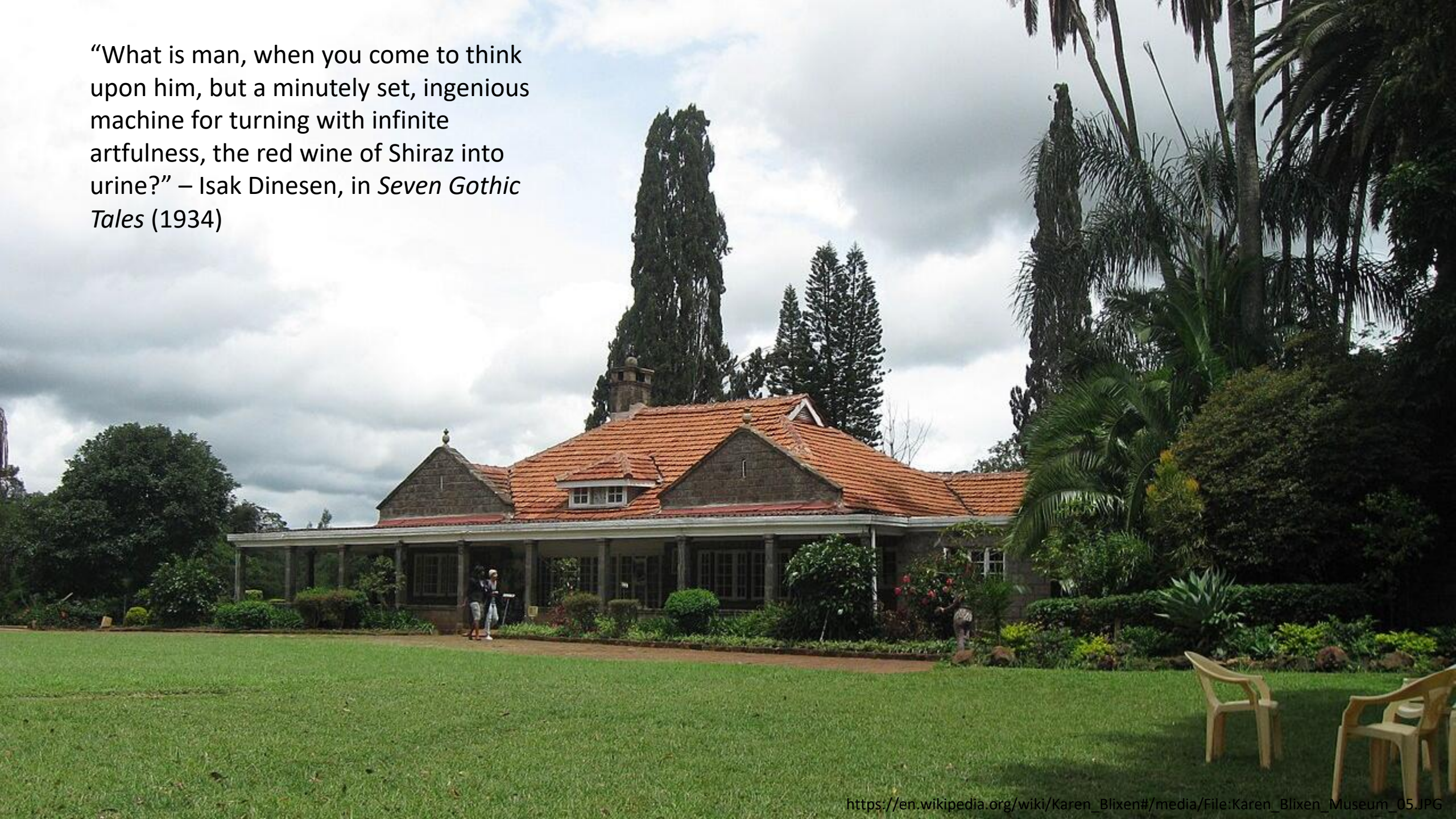
- Male urethra

Pars	Epithelium
Intramuralis	urothelium
Prostatica	urothelium
Diaphragmatica	Stratified columnar
Spongiosa	Stratified columnar
Fossa navicularis	Stratified squamous

- Female urethra
  - Initially urothelium, distally stratified squamous, glands of Skene analogous to male prostate
  - Lamina propria highly vascularized, external urinary sphincter

Intramuralis	urothelium
Prostatica	urothelium
Diaphragmatica	Stratified columnar
Spongiosa	Stratified columnar
Fossa navicularis	Stratified squamous

“What is man, when you come to think upon him, but a minutely set, ingenious machine for turning with infinite artfulness, the red wine of Shiraz into urine?” – Isak Dinesen, in *Seven Gothic Tales* (1934)



https://en.wikipedia.org/wiki/Karen_Blixen#/media/File:Karen_Blixen_Museum_05.JPG