http://jpkc.fudan.edu.cn/s/426/main.htm

The Urinary System

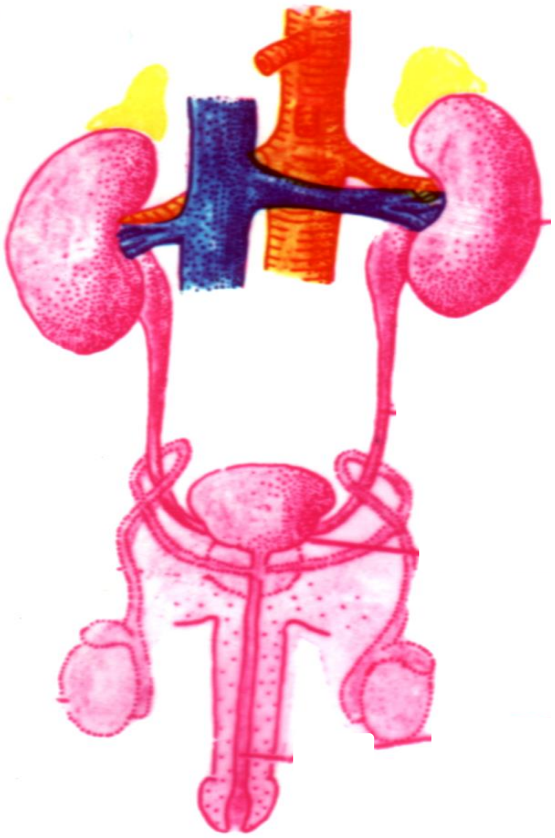
Prof. Hong CHEN MD, PhD
陈 红 教授 博士

Office: Building 9 E., Room 304
Tel: 54237019-9304
Mobile: 18602109425

Email: hchen30@hotmail.com
hchen@graduate.hku.hk

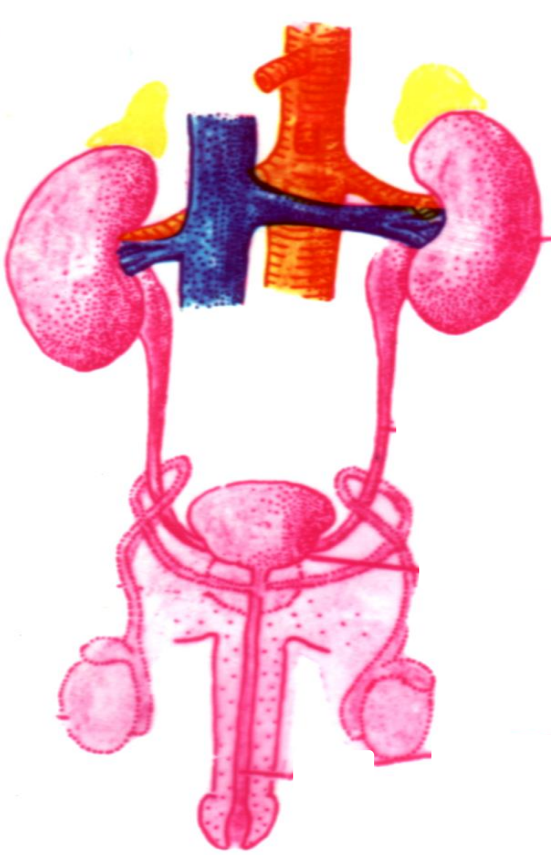
General Functions of Urinary System

- **Urine production**
  - Remove metabolic wastes from blood by filtration
  - Regulate the balance between water and electrolytes by
    - Re-absorption of water and electrolytes selectively
    - Excretion of urea, uric acid, creatinine etc.
- **Secretion of certain enzymes or cytokines**
  - Renin: to regulate the blood pressure
  - Erythropoietin: to stimulate RBC production

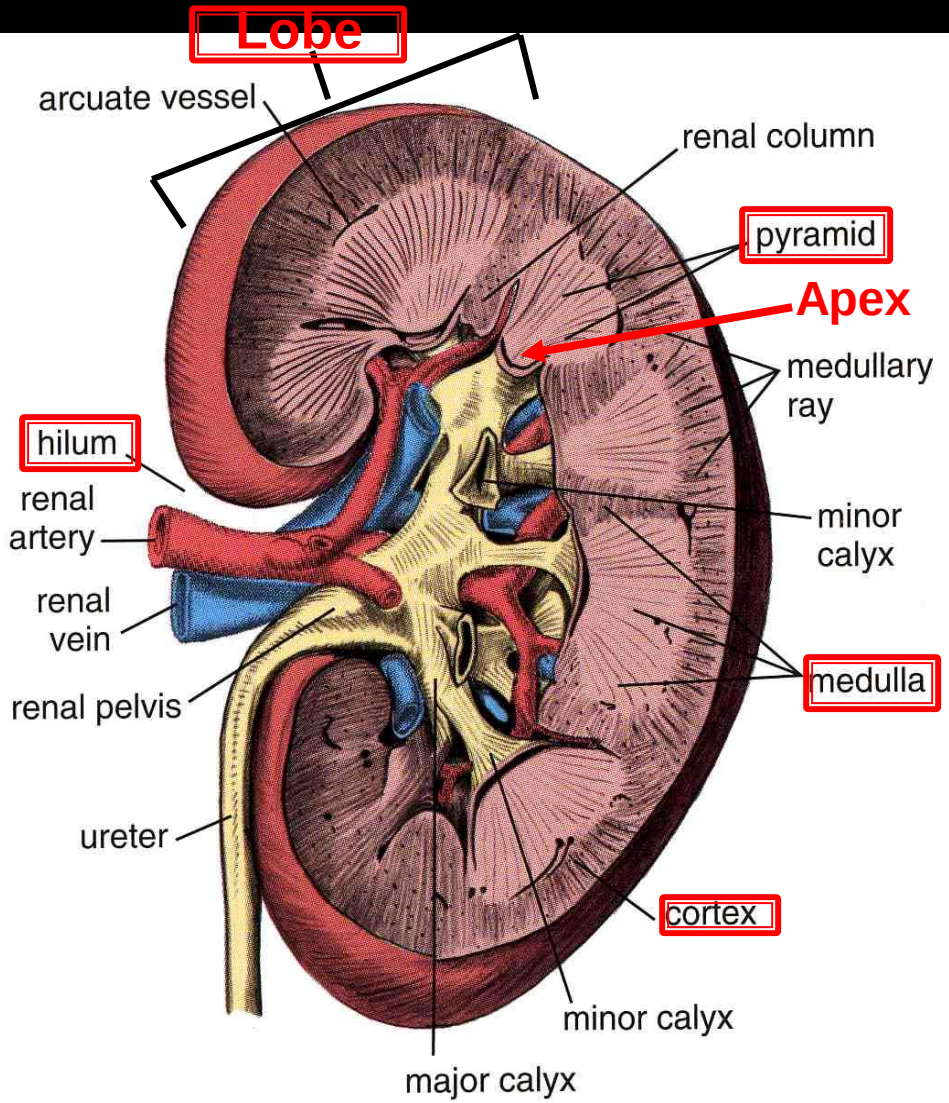


Objectives

- Kidney
  - Structure and function of
    - Nephron and uriniferous tubule
    - Filtration barrier
    - Podocyte and mesangial cells
    - Juxtaglomerular complex
- Ureter
- Urinary bladder

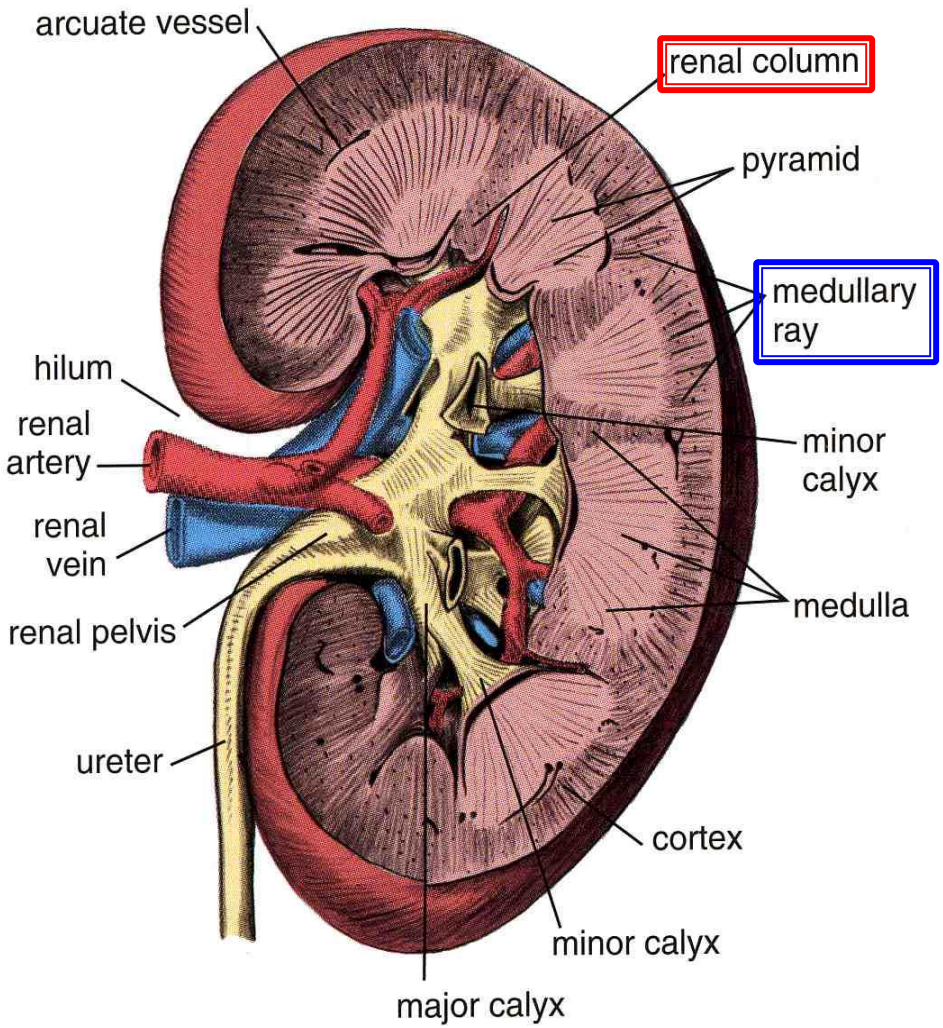


General structure (1)



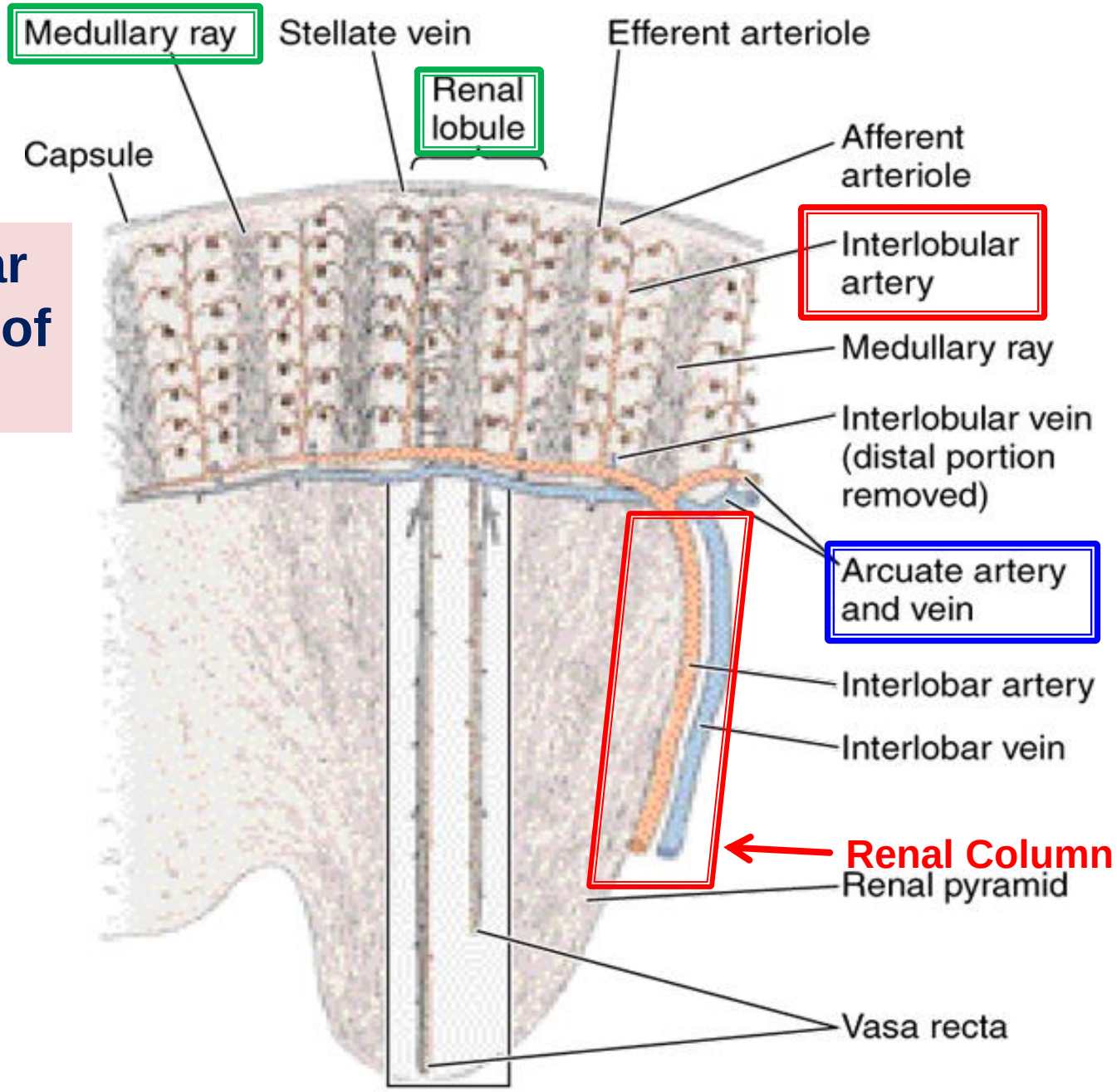
- **Hilum**: vessels, ureter-renal pelvis, major and minor calices
- **Capsule**: collagen
- **Lobes:** 8-18 each
- **Cortex**: darker, more "granular", renal corpuscles
- **Medulla**: paler, renal tubules but not renal corpuscles; vasa recta
- **Pyramids**: part of medulla, base is closely adhered to cortex, rounded apex [papilla] towards minor calyx

General structure (2)

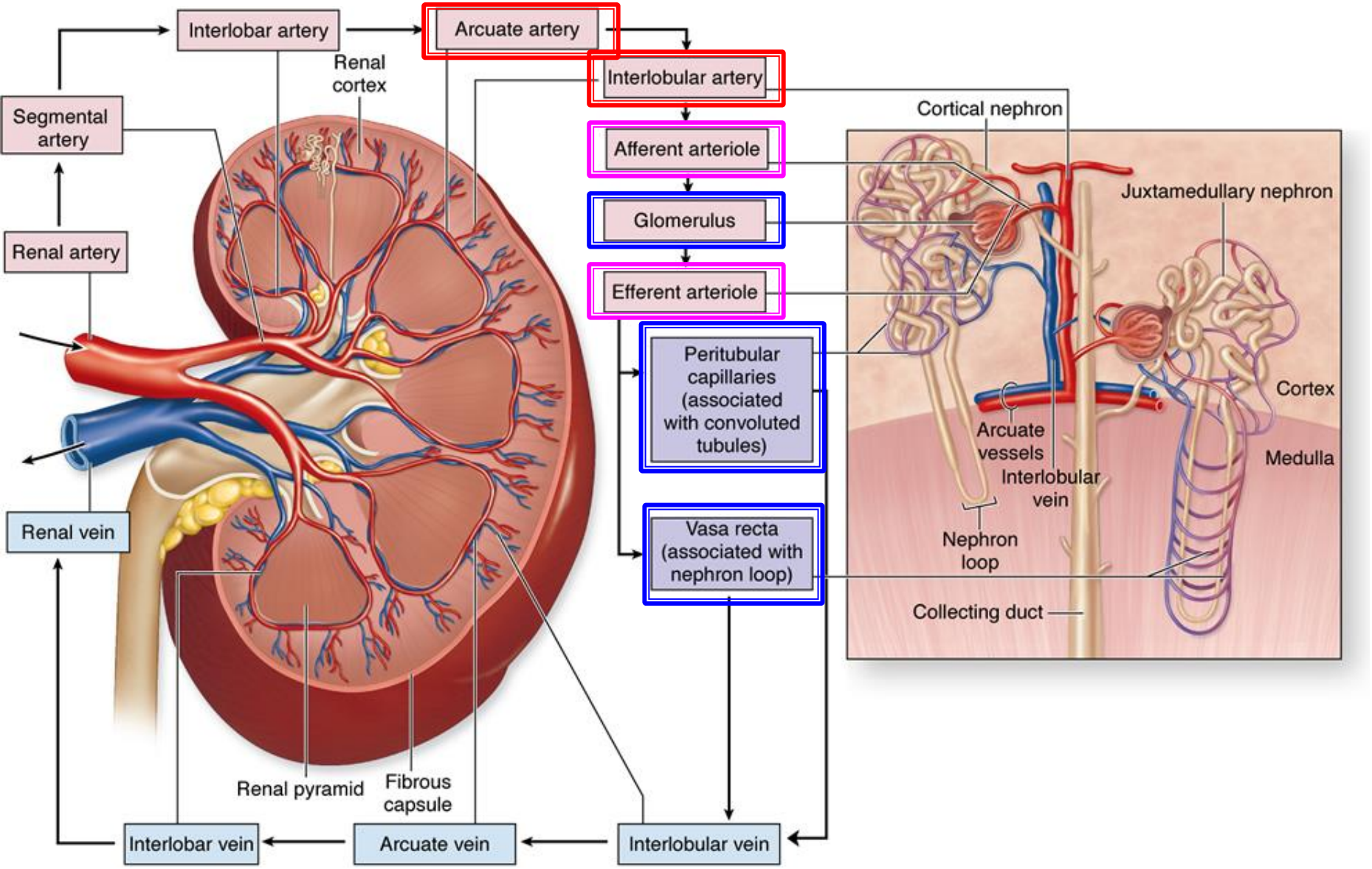


- **Medullary rays**: striations of medulla extend into cortex, collecting tubules/ducts, PST, DST(TAL).
- **Renal columns**: cortical tissue extending into medulla, usually between lobes
- Major vessels, via renal columns into kidney

Vascular Supply of Kidney

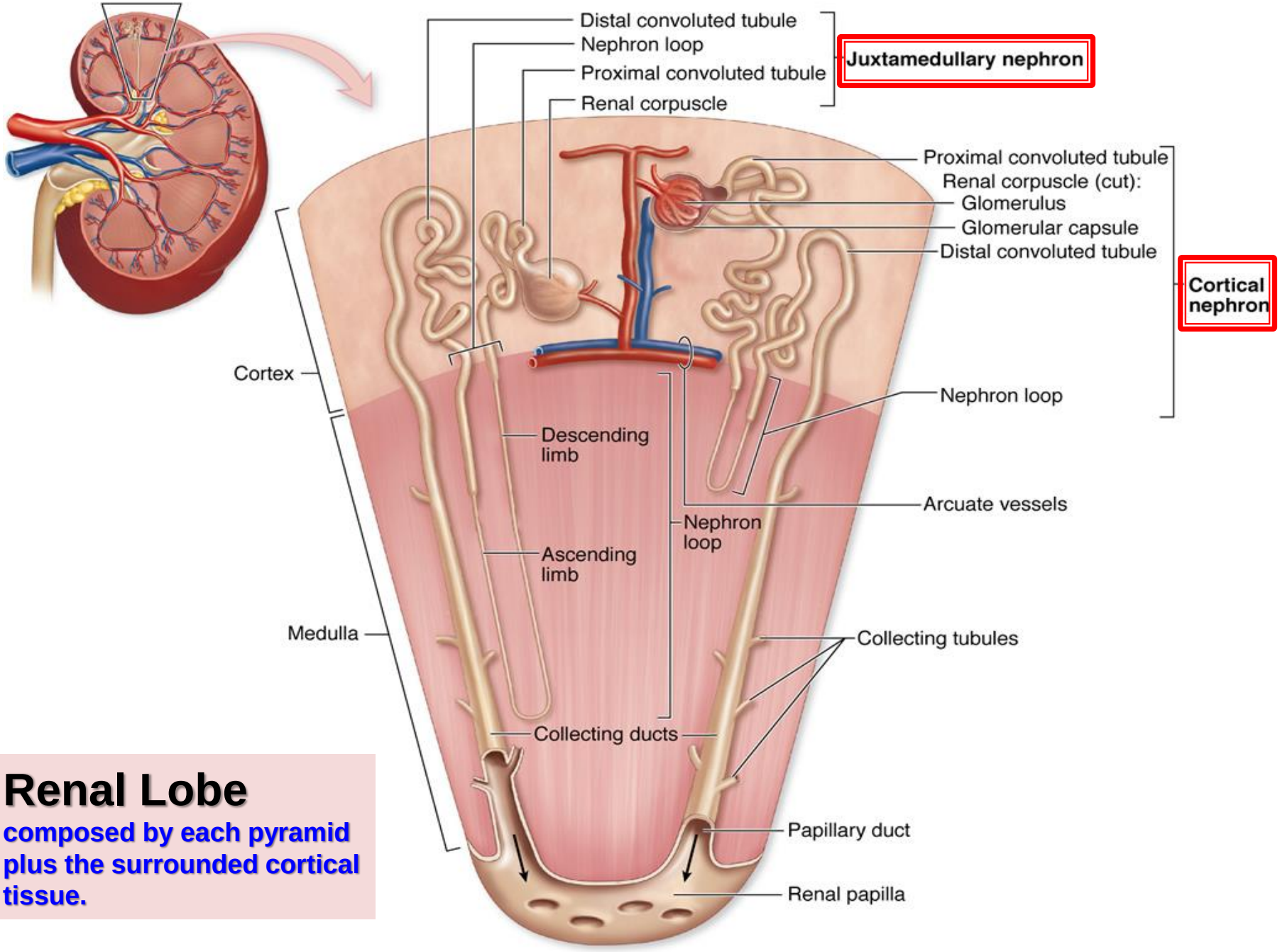


Vascular Supply of Kidney



Microvasculature of the renal cortex

- G: glomerulus
- A: afferent arterioles
- I: interlobular arteries
- PT: peritubular capillaries

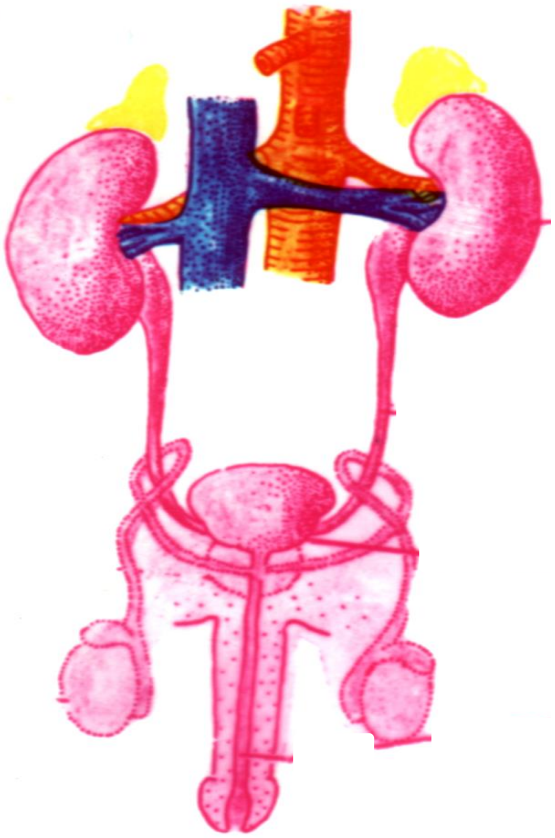


Renal Lobe

composed by each pyramid plus the surrounded cortical tissue.

Question 1

- **Urine production**
  - **Remove metabolic wastes from blood by filtration ?**
  - Regulate the balance between water and electrolytes
    - Re-absorption of water and electrolytes selectively
    - Excretion of urea, uric acid, creatinine etc.
- Secretion of certain enzymes or cytokines
  - Renin
  - Erythropoietin

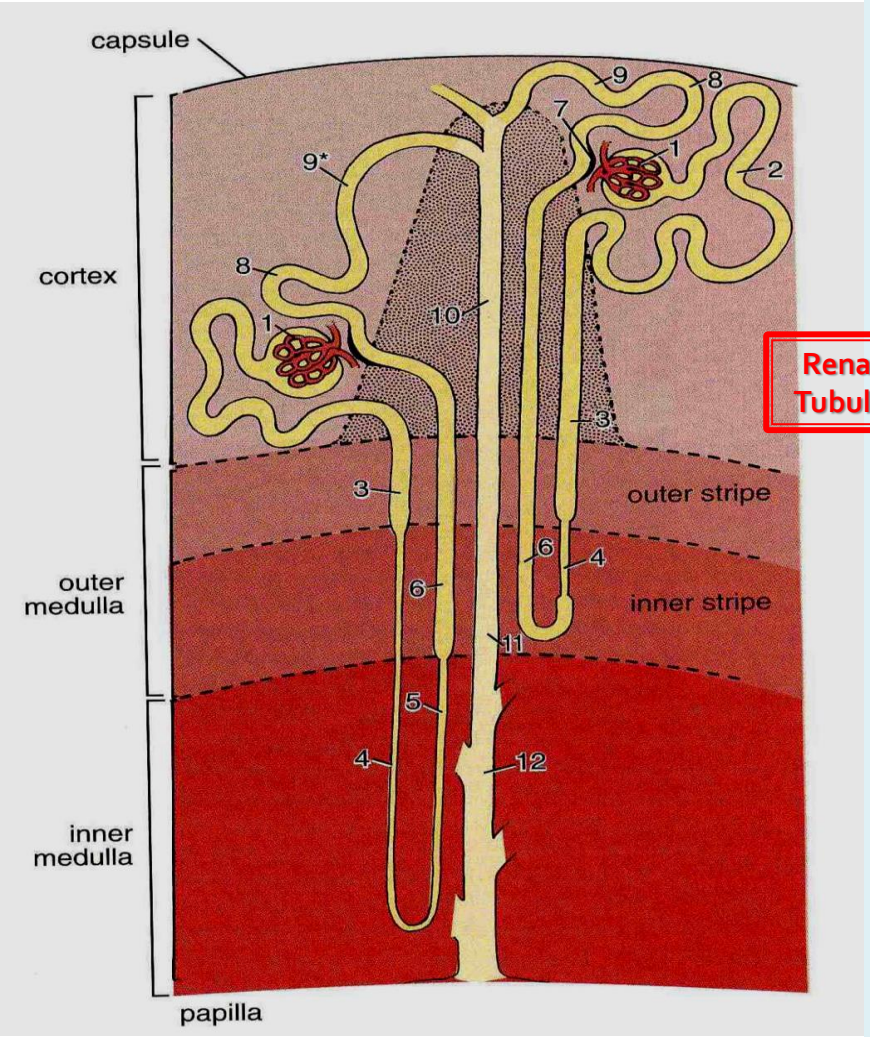


Key point to answer question 1

- Elaborate the following contents:

1. Structure and function of nephron and renal corpuscle.
2. Structure and function of podocyte, filtration barrier, and mesangial cells.

The Nephron

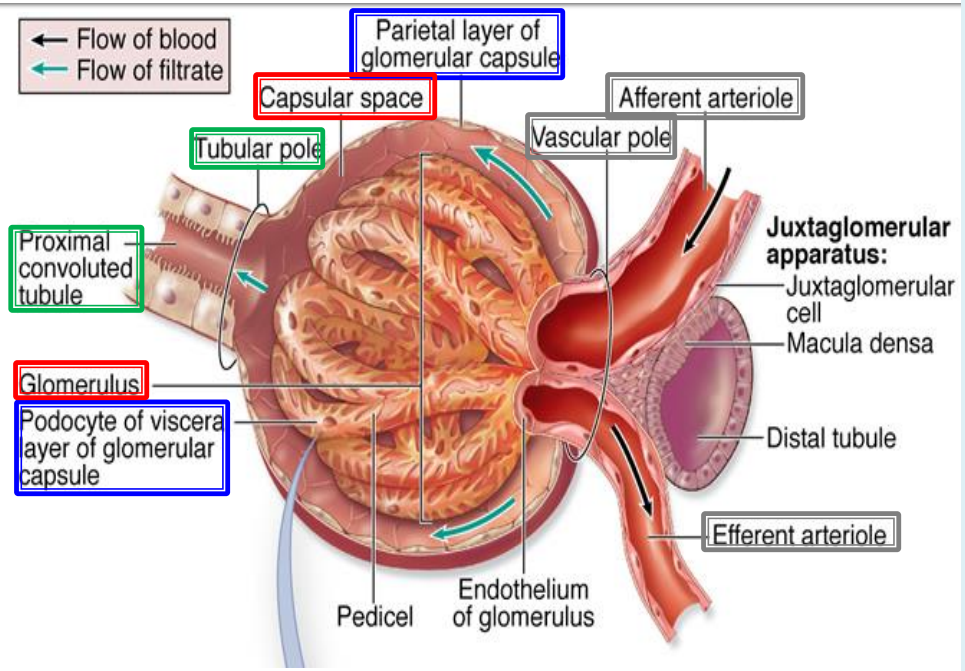


- Structural and functional unit [yellow]
- Consists of:
  - Renal corpuscle (1)
  - Proximal convoluted tubule, PCT (2)
  - Loop of Henle (3-6)
    - Thick descending limb, PST (3)
    - Thin segment (4,5)
    - Thick ascending limb, TAL (6)
  - Distal convoluted tubule, DCT (8)

Renal Tubule

- Cortical nephron: with short thin segment, it loops back in outer medulla region
- Juxtamedullary nephron: with long thin segment, it loops back in inner medulla region

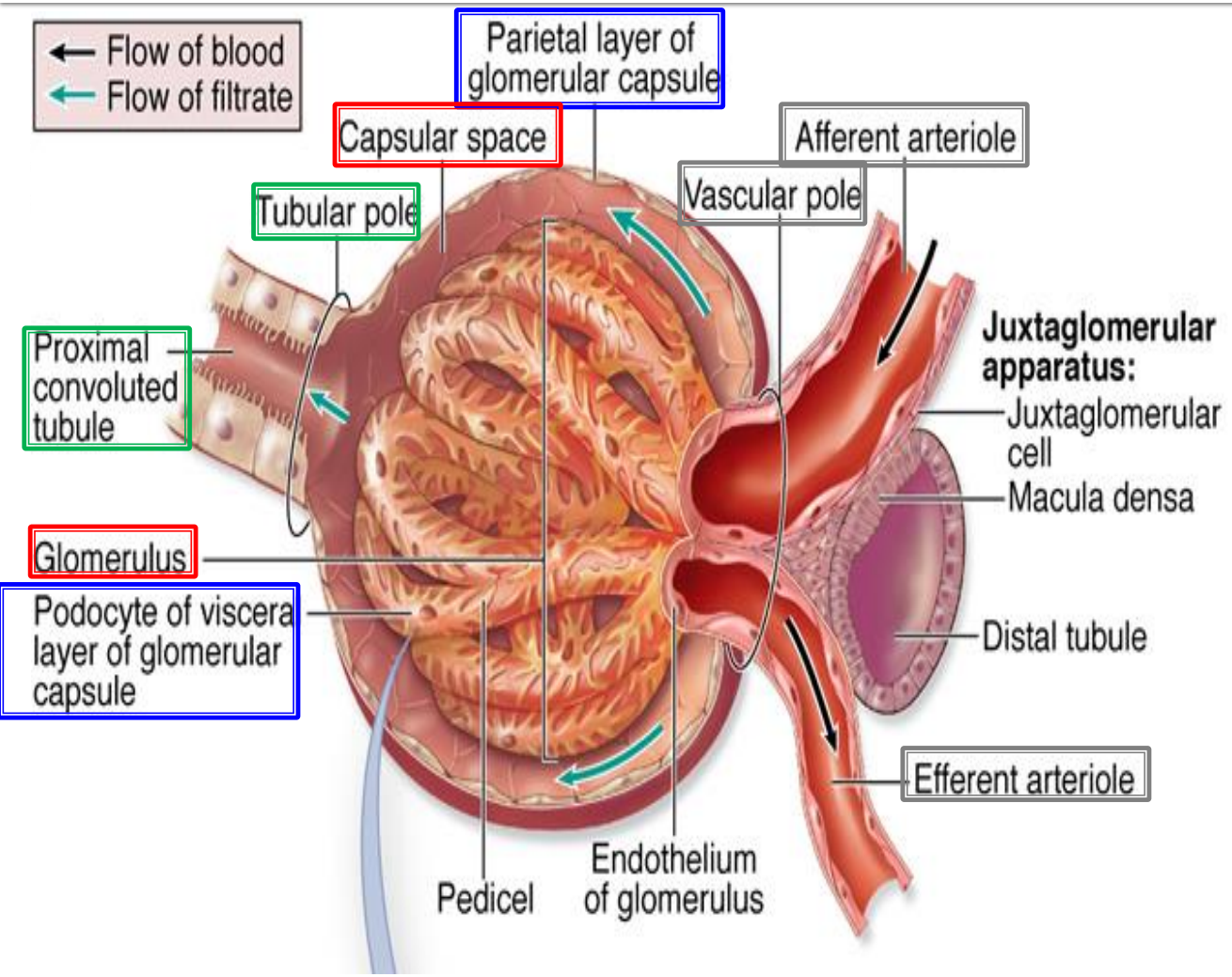
Renal Corpuscle



- **Flow rate: 1300ml/min through renal glomeruli**
- **Glomerular filtrate is formed at a rate of 125ml/min**
- **From this, only 1ml/min of urine is produced**
- **124ml/min is absorbed**

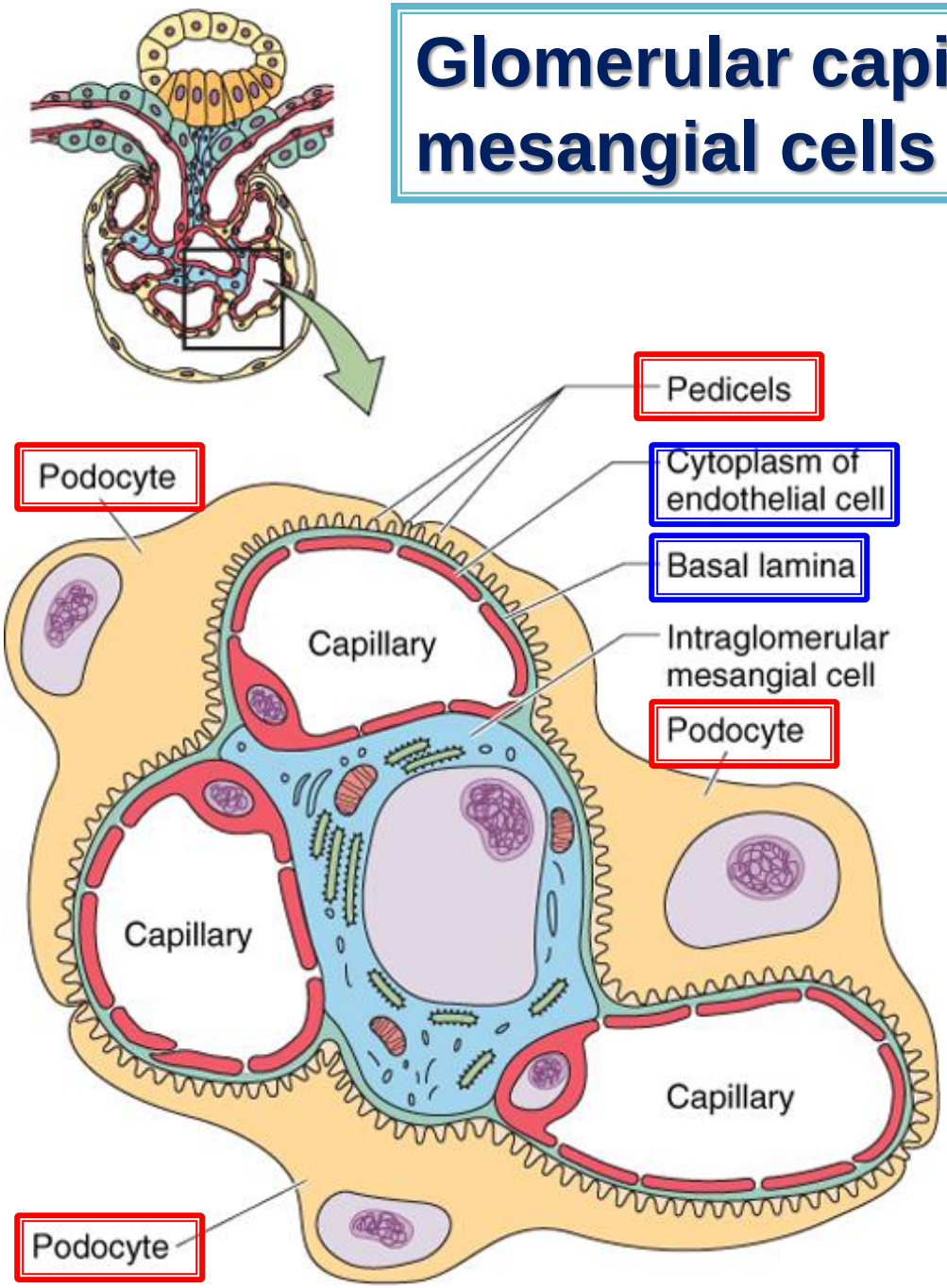
- Two poles: **Vascular** & **Tubular**
- Bowman's capsule
  - **Parietal layer**: simple squamous epithelium
  - **Visceral layer**: podocytes
- Glomerulus
  - Tufts of **fenestrated capillaries** closely **surrounded by podocytes** derived from visceral layer of Bowman's capsule
- Bowman's space
  - **Collection** of ultrafiltrate

Renal Glomerulus



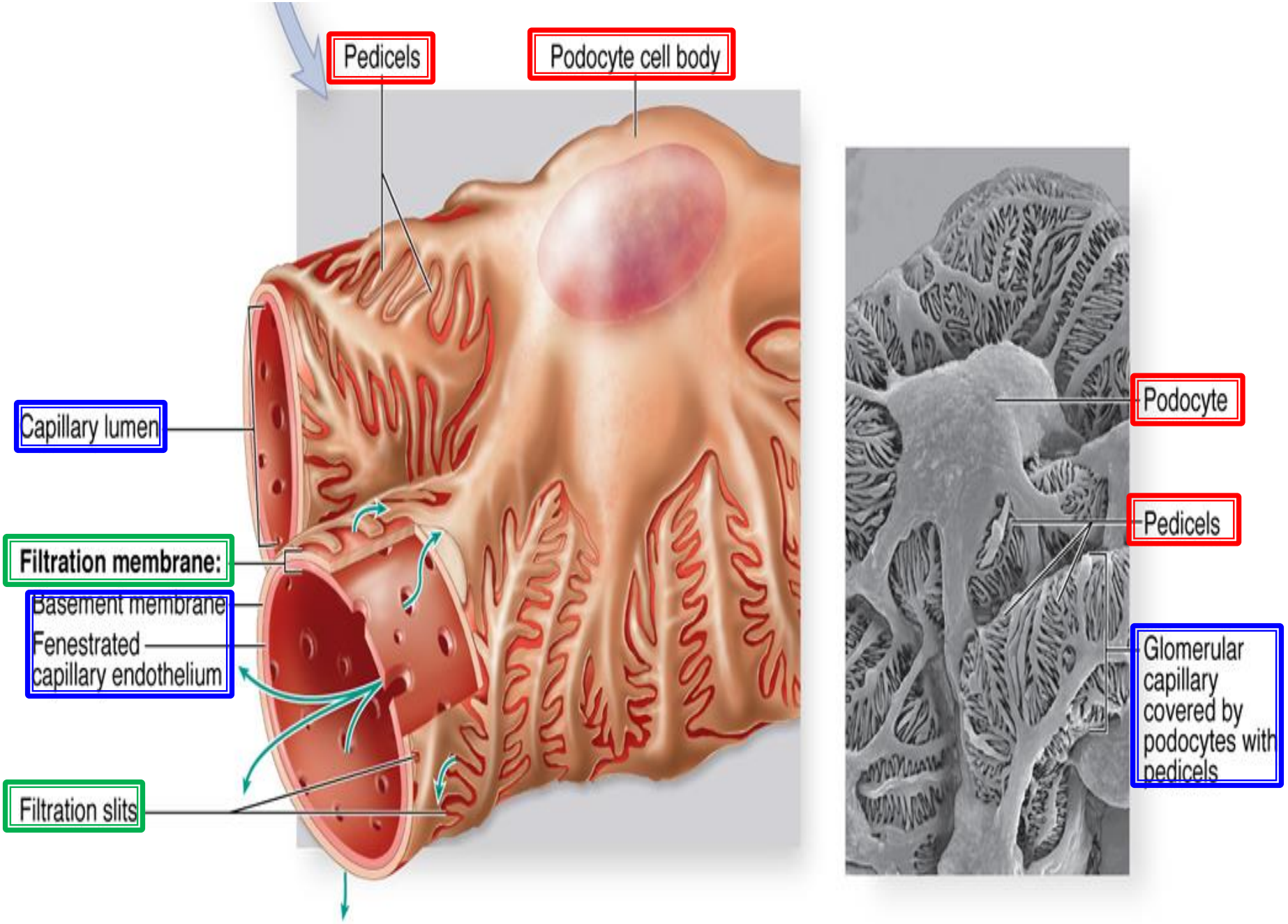
- Derived from **afferent arteriole**
- Drained by **efferent arteriole**
- **Capillaries** are **fenestrated type**
- Surrounded by **podocytes**
- Mesangial cells
- **High pressure** coming from the **thicker diameter** of **afferent** compared to efferent arteriole.

Glomerular capillaries, podocytes and mesangial cells

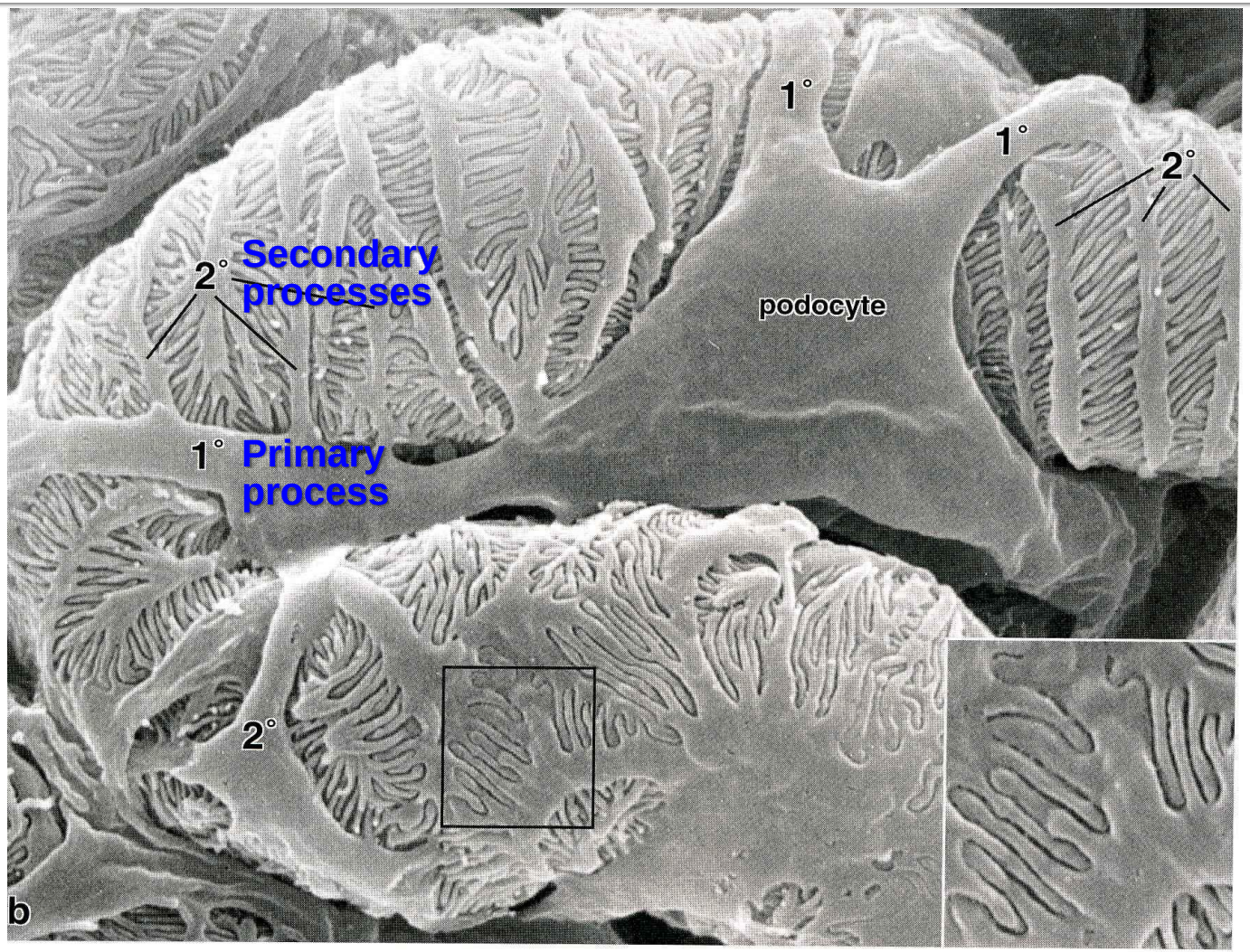


Podocytes:

1. Derived from visceral layer
2. Specialized to have many long cytoplasmic processes
3. Provide support for capillaries
4. Contribute to filtration barrier

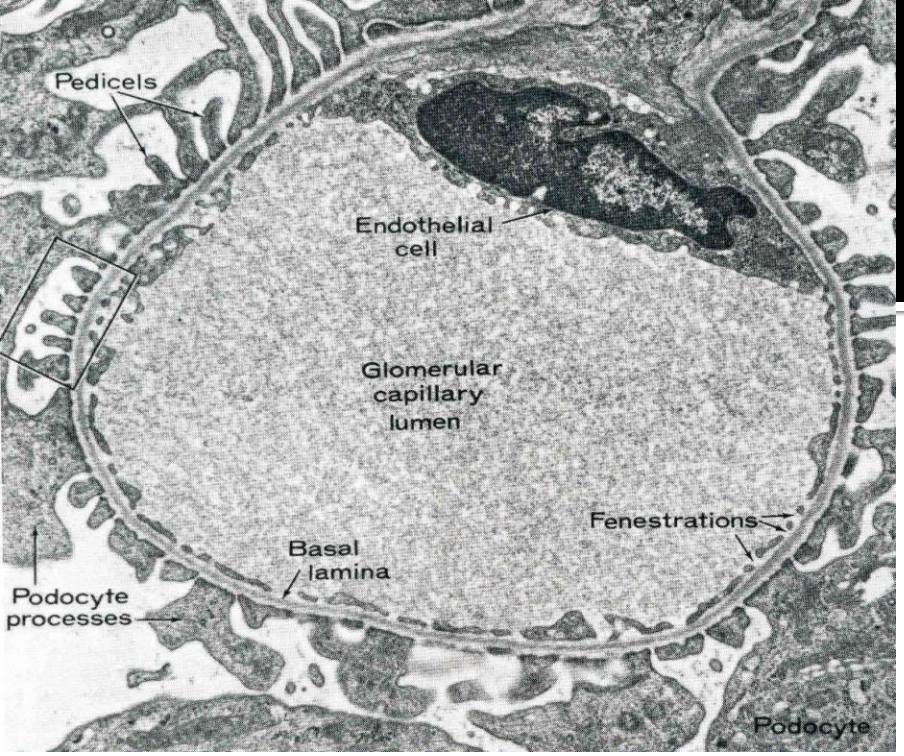

Pedicels
Podocyte cell body
Capillary lumen
Filtration membrane:
Basement membrane
Fenestrated capillary endothelium
Filtration slits
Podocyte
Pedicels
Glomerular capillary covered by podocytes with pedicels

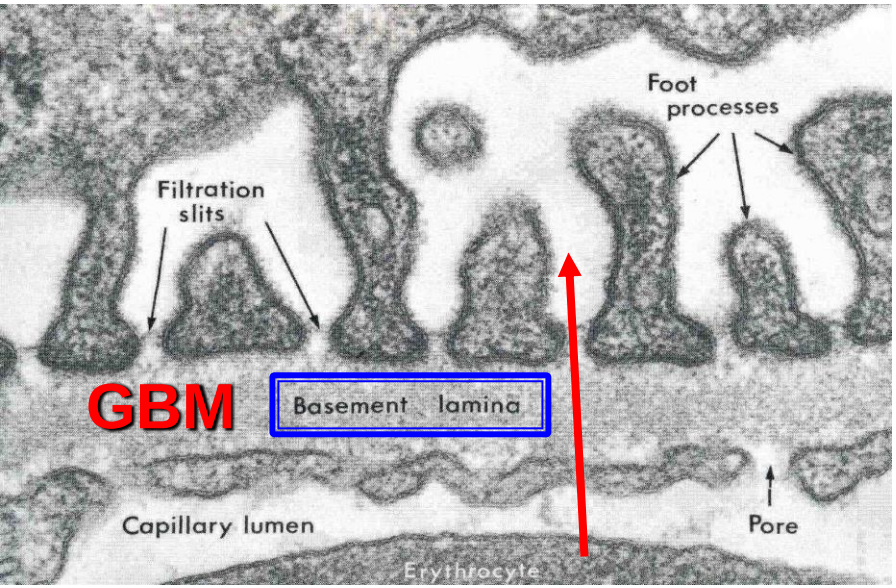
SEM of Glomerular capillary



Note:
The close interdigitating nature of foot processes of podocytes is wrapping around the outer surface of the capillary.

Filtration Barrier

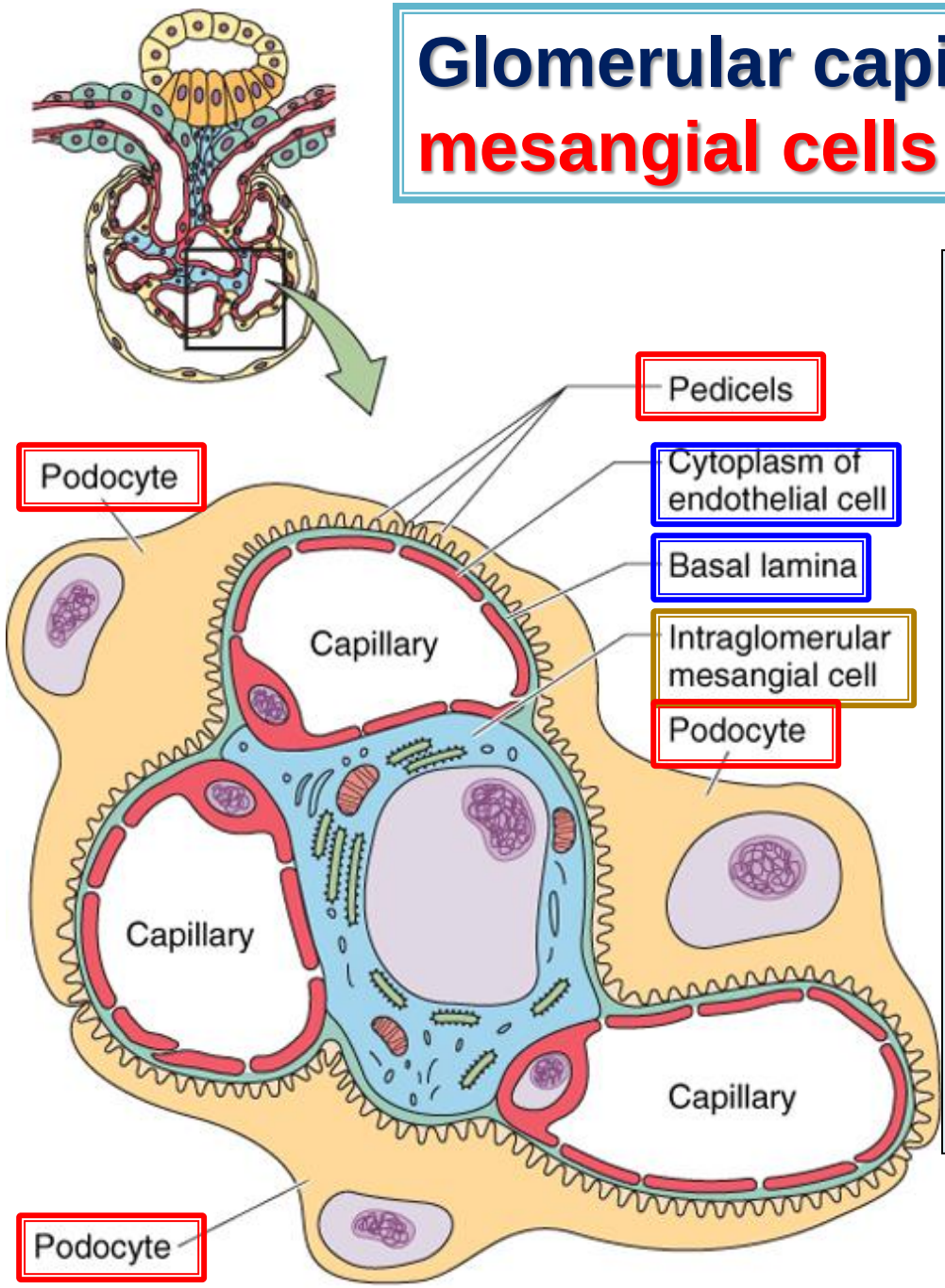




1. **Fenestrations of capillary endothelium to block cells**
2. **Basal lamina, GBM (fused from basal lamina of endothelium and podocyte), to restrict large proteins (>70KD) by the meshwork of cross-linked collagen and proteoglycans, and organic ions by negative charges of polyanionic GAGs.**
3. **Podocyte pedicels (foot processes), filtration slits with diaphragm (containing nephrin), to restrict small proteins and organic ions.**

➢ **Arrow indicates direction of filtration**

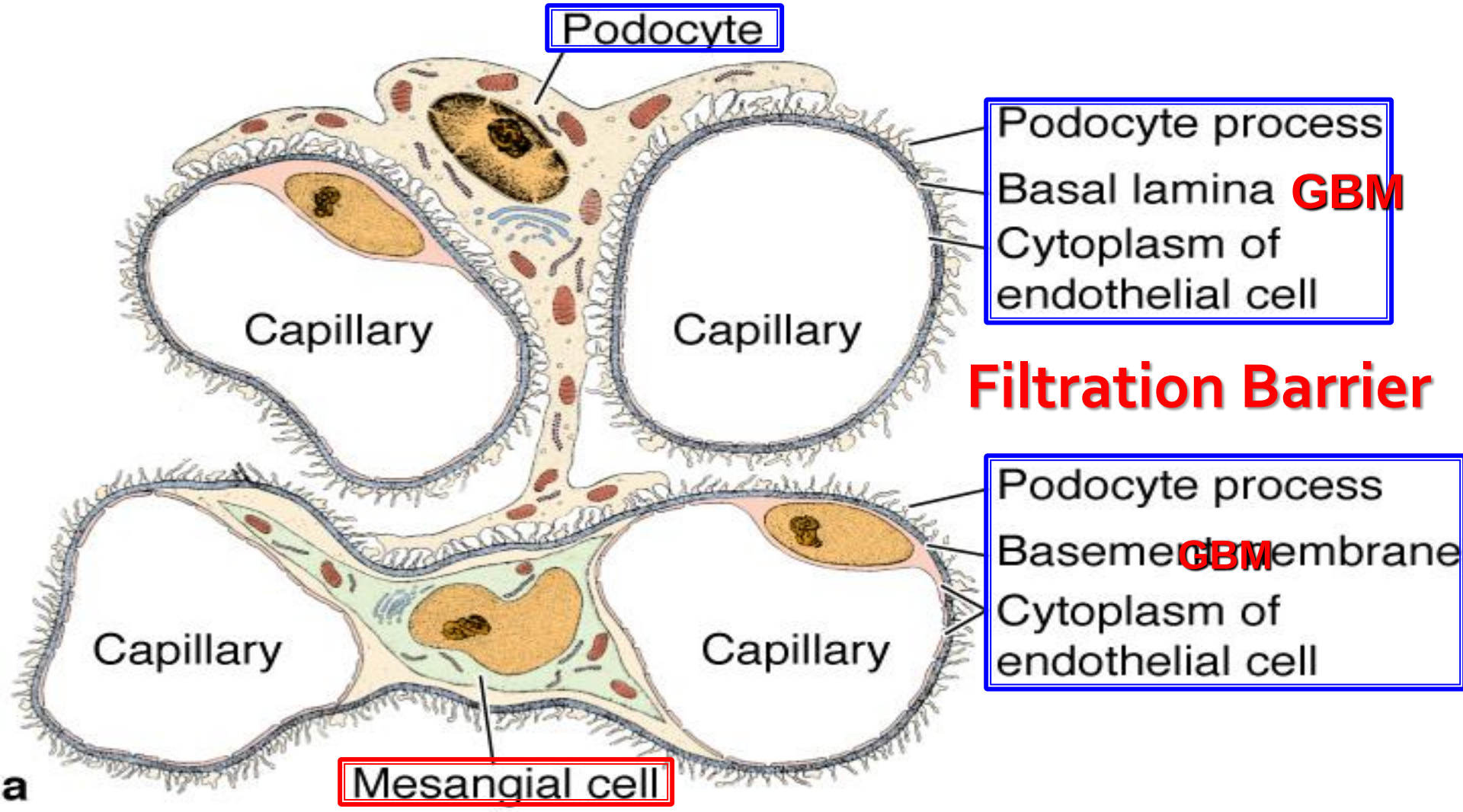
Glomerular capillaries, podocytes and mesangial cells

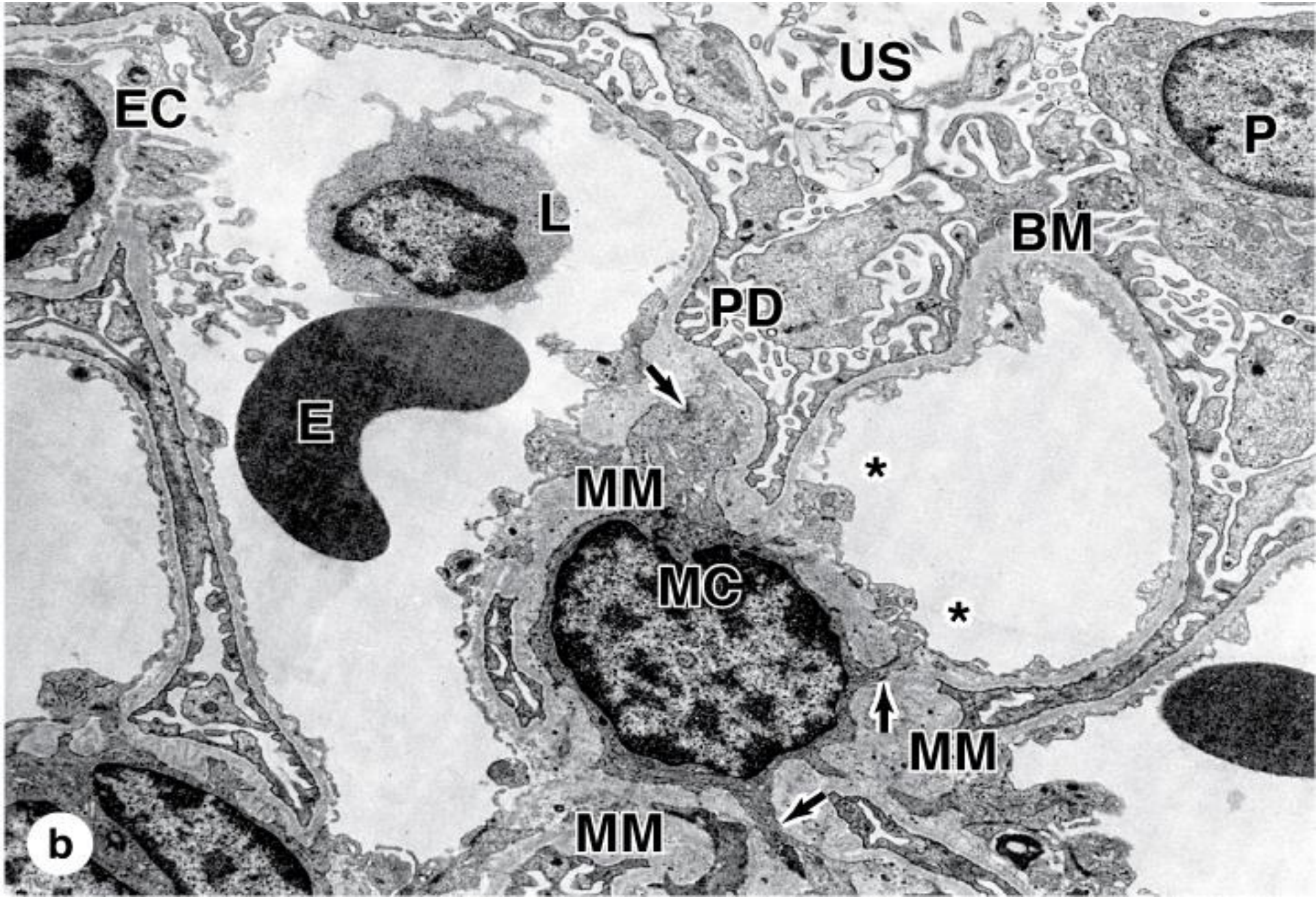


Mesangial cells:

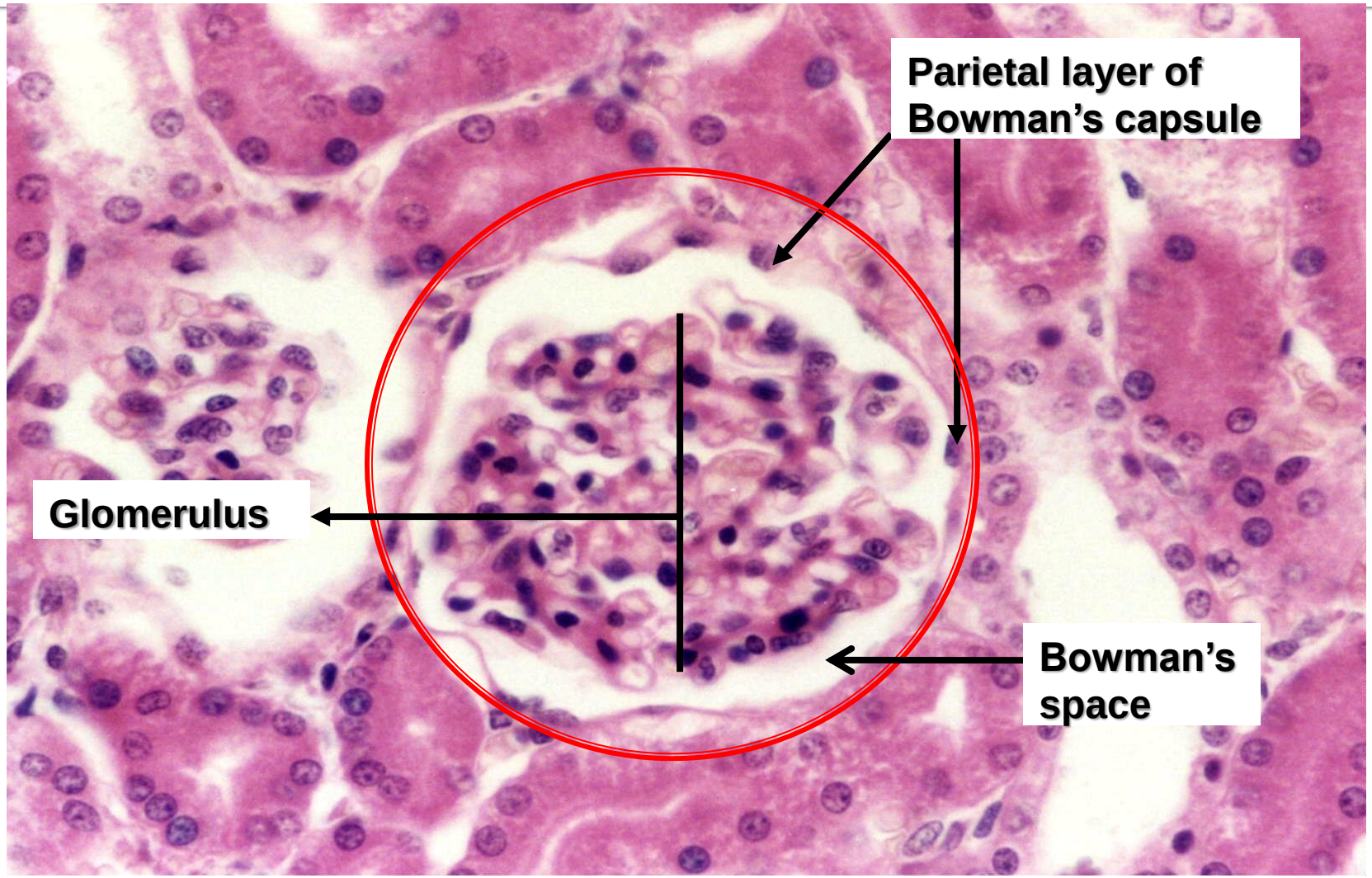
1. Resemble to pericytes in producing components of external lamina
2. Phagocytic cells
3. Mildly contractile
4. Maintain the wellness of basal lamina (GBM) of glomerulus
5. Cytokine secretion

Glomerular capillaries, podocytes and mesangial cells

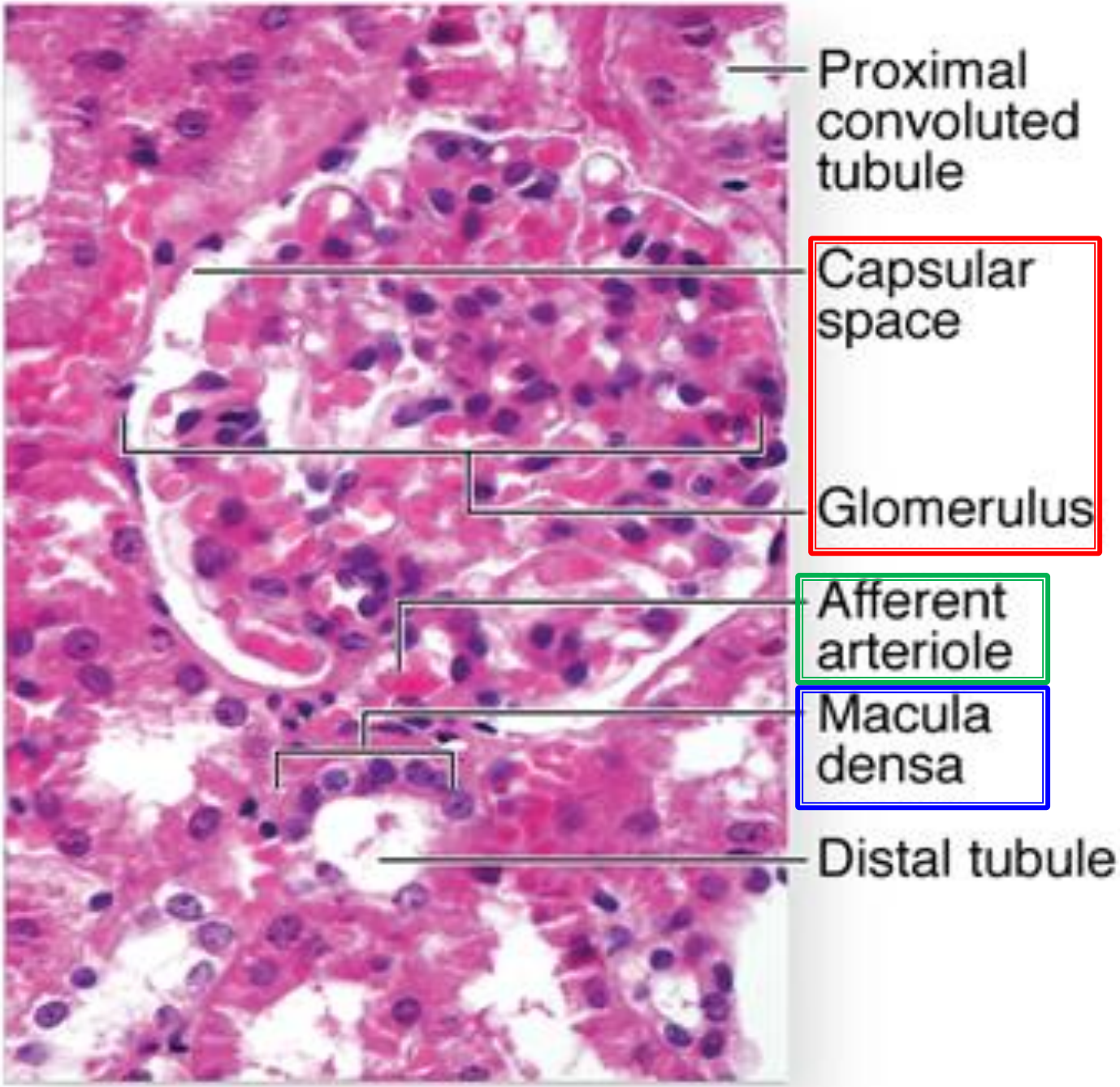



EC
US
P
L
BM
PD
E
MM
MC
MM
MM
b

Renal Corpusle



Renal Corpusle



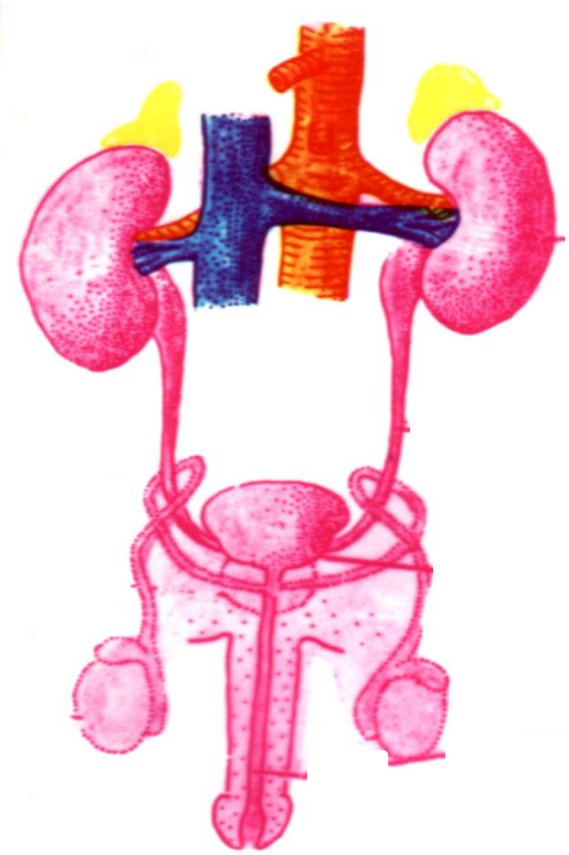
Functions of Renal Corpuscle

- Filtration of blood
- Glomerular ultrafiltrate
  - No cells
  - Very little if any proteins
  - Sugars
  - Electrolytes
  - Fluid
- Collected in Bowman's space
- Drained to proximal convoluted tubule (PCT)

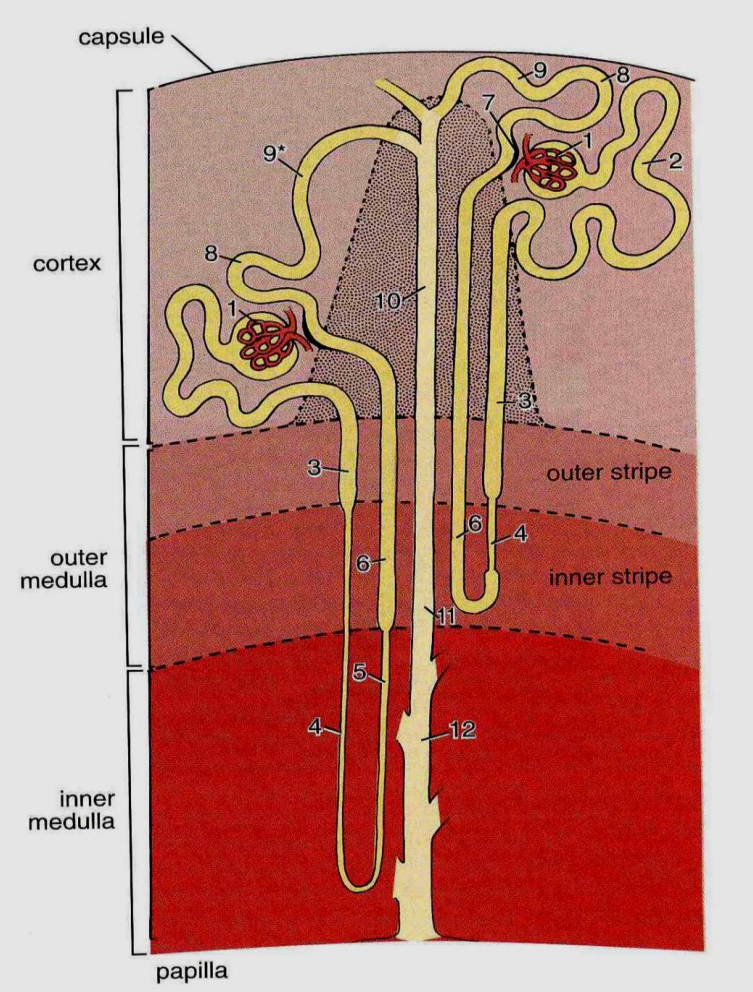
Question 2

- **Urine production**
  - Remove metabolic wastes from blood by filtration

    Renal Corpuscles
  - **Regulate** the balance between water and electrolytes ?
    - **Re-absorption** of water and electrolytes selectively
    - **Excretion of** urea, uric acid, creatinine etc.
- Secretion of certain enzymes or cytokines
  - Renin
  - Erythropoietin

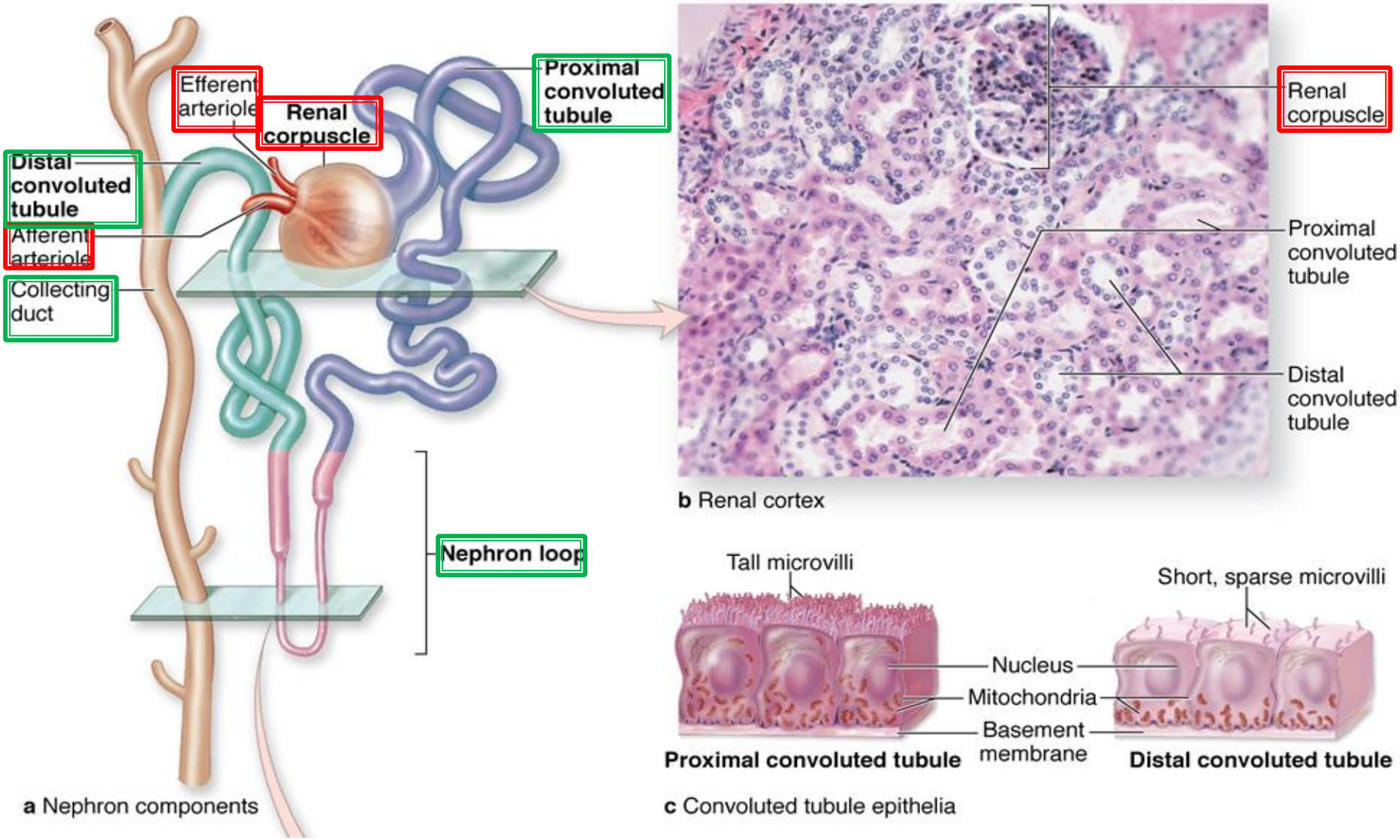


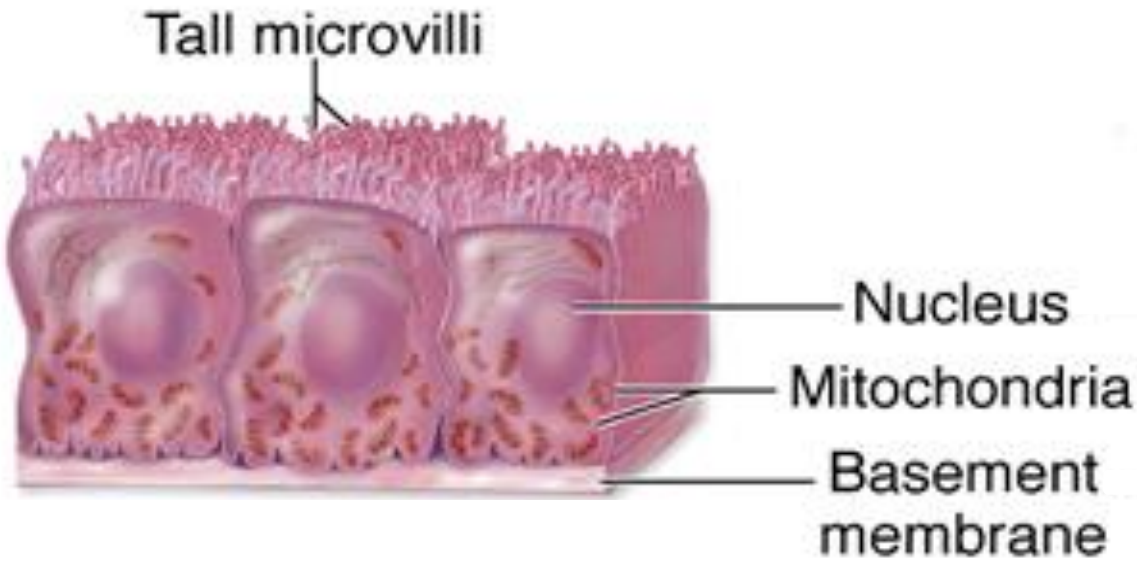
Key point to answer question 2



- **Structure and function** of **renal tubules.**
  - **Proximal convoluted tubule, PCT (2)**
  - **Loop of Henle (3-6)**
    - Thick descending limb, PST (3)
    - Thin segment (4,5)
    - Thick ascending limb, TAL (6)
  - **Distal convoluted tubule, DCT (8)**
- **Structure and function** of **uriniferous tubules.**
  - **Renal tubules**
  - **Collecting tubules/ducts**

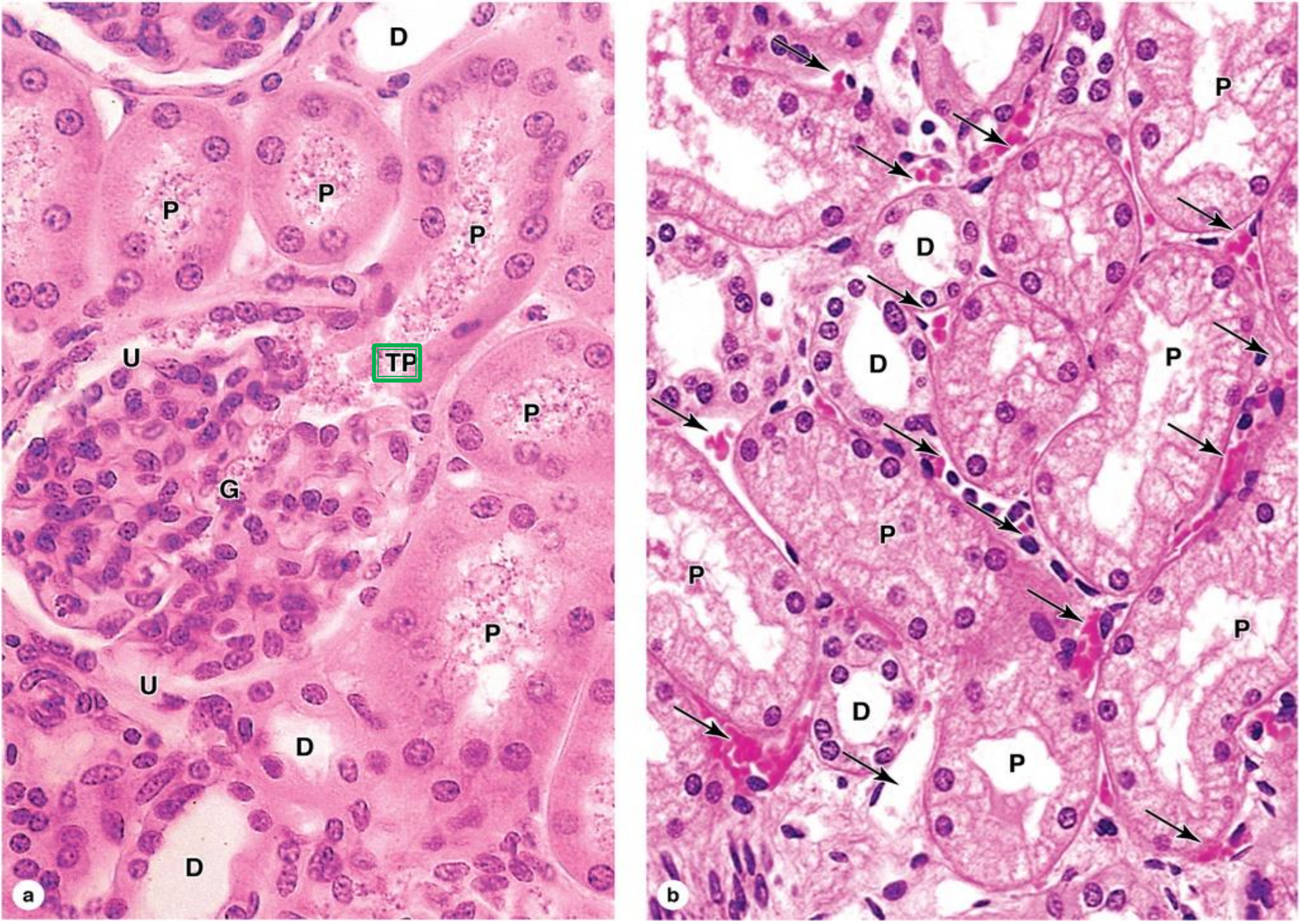
Nephron Components

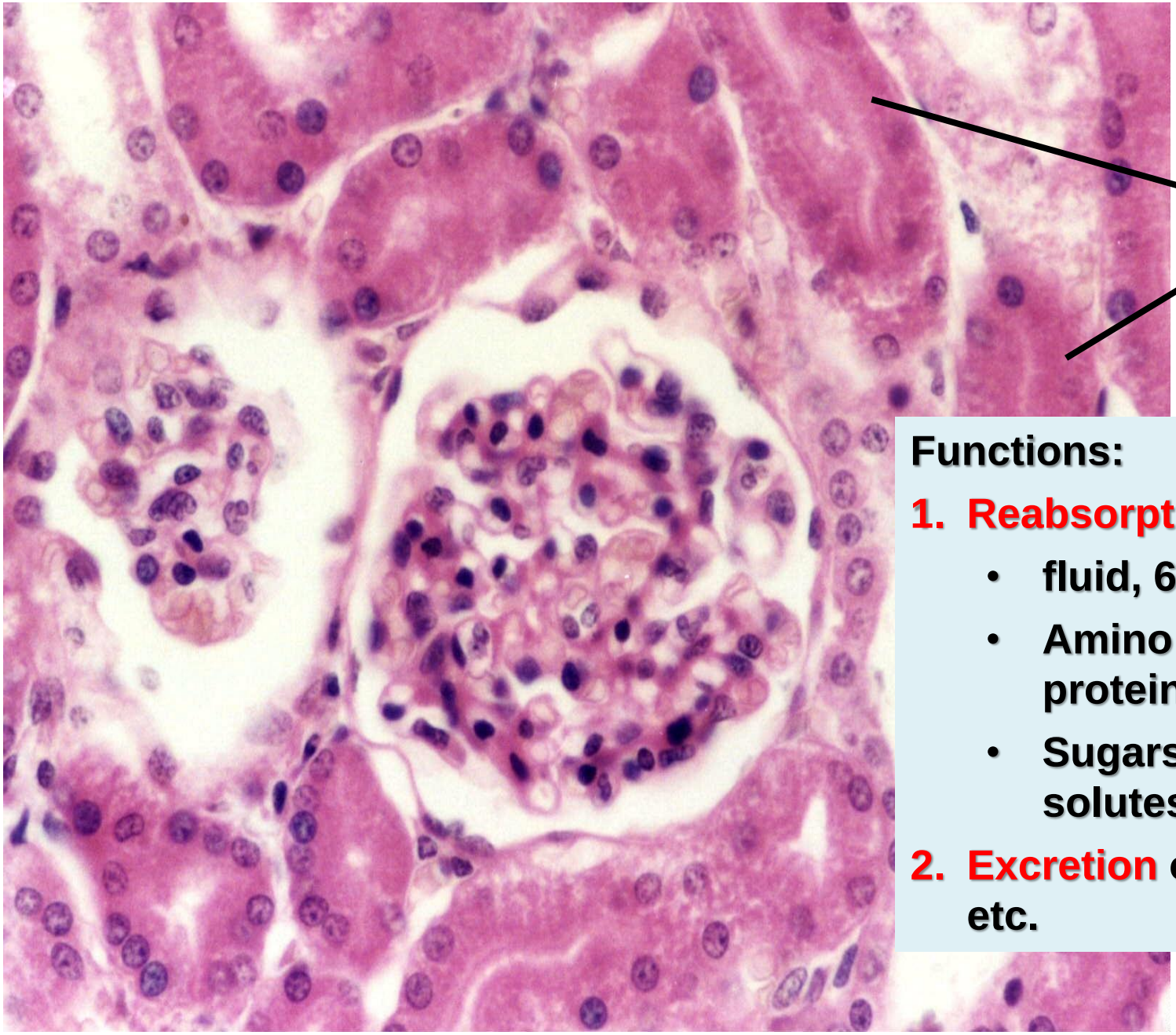




Proximal Convoluted Tubule, PCT

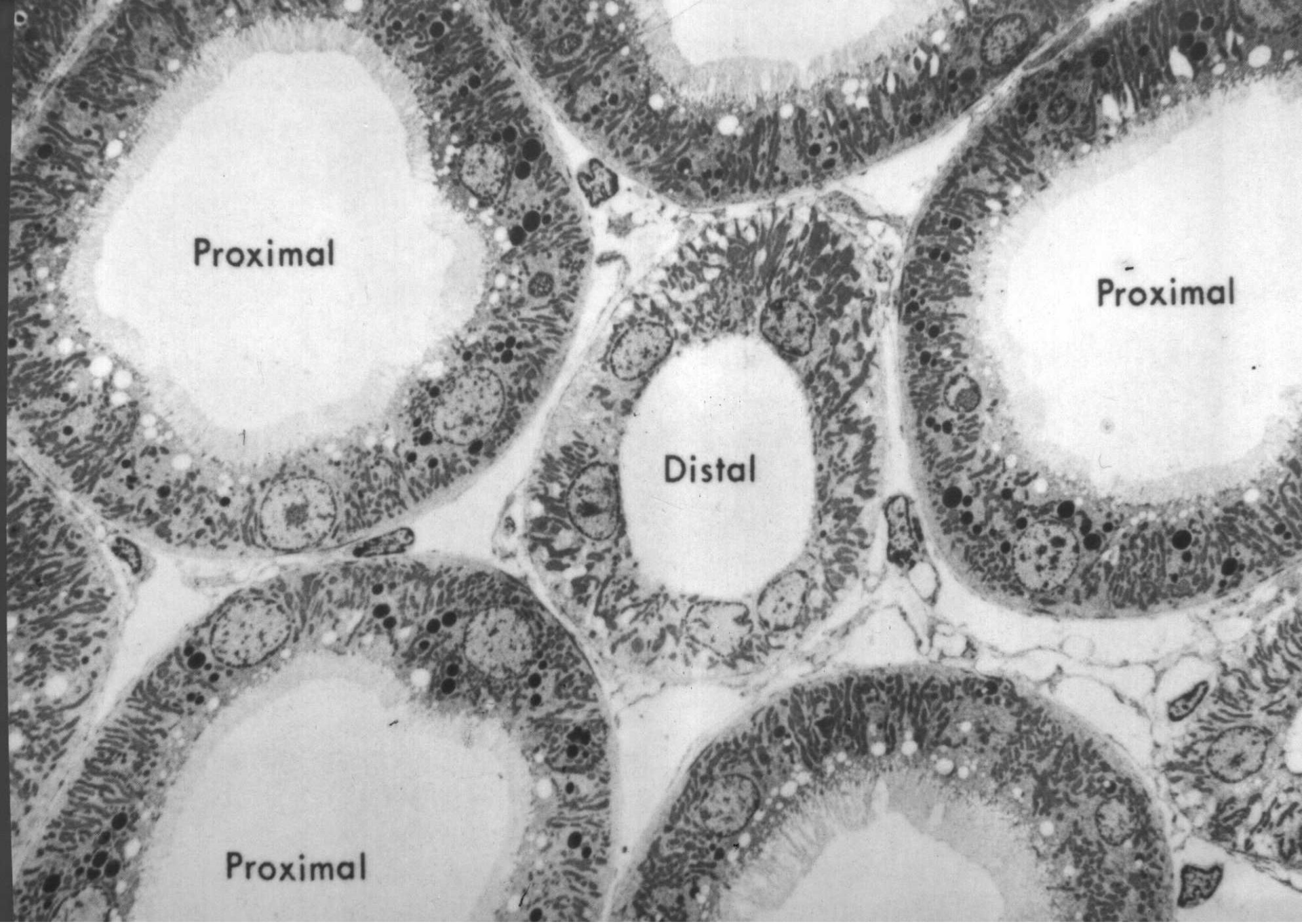
- **Long and convoluted**, more numerous in XS profile
- Cytoplasm strongly **eosinophilic**
- **Luminal brush border**, **MV** under EM, increase surface area for re-absorption
- **Basal striations**, basal **infoldings of membrane** and concentration of **mitochondria**
- **No distinctive cell border** due to extensive lateral membrane interdigitations, with channels, aquaporins, for water transport
- Relatively **few nuclei**/cross sectional profile


D
P
P
P
P
U
TP
P
G
P
U
D
D
a
P
D
D
P
P
P
D
P
b



Functions:

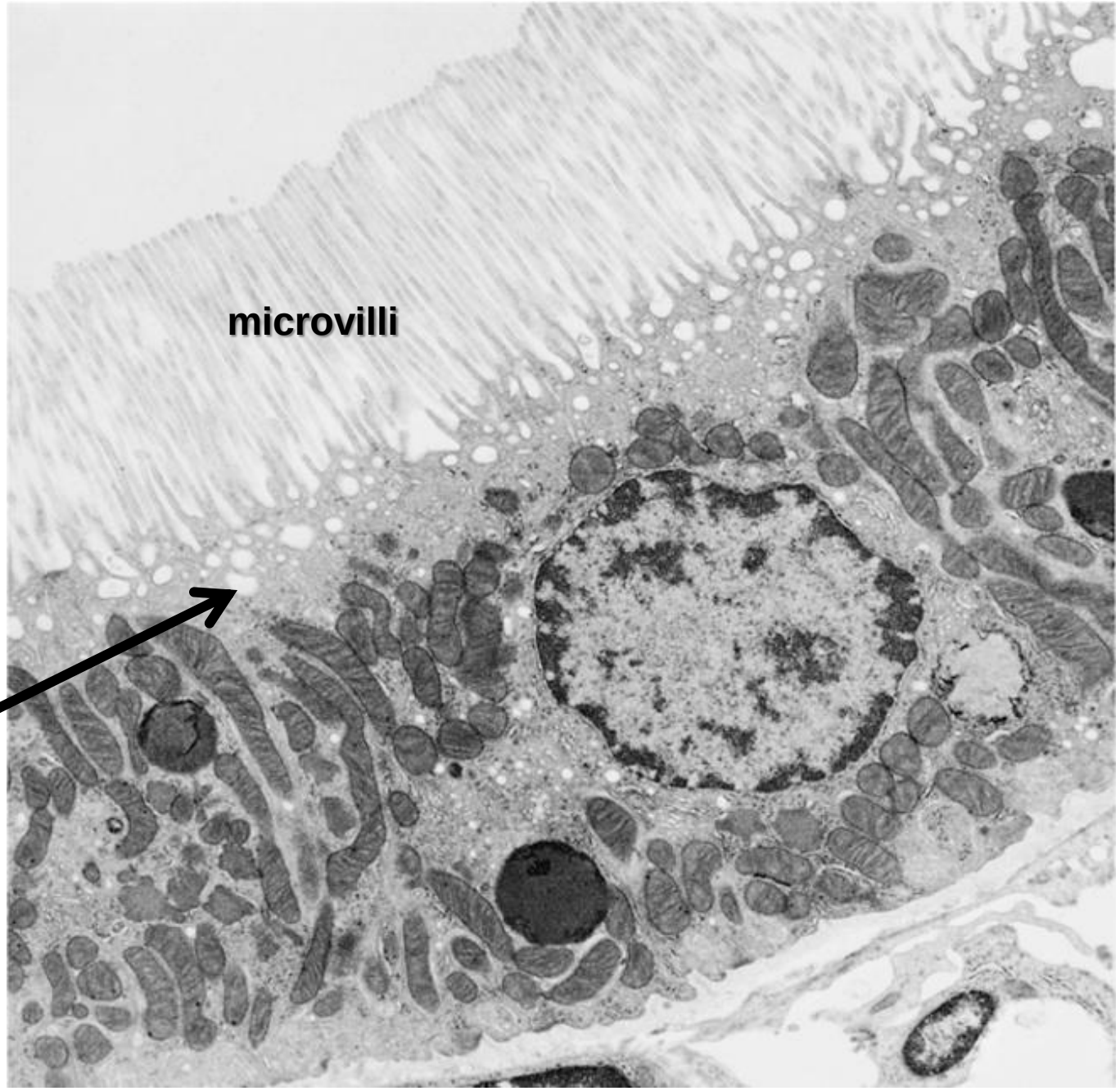
1. **Reabsorption of**
   - **fluid, 65%**
   - **Amino acids, proteins**
   - **Sugars and other solutes**
2. **Excretion of creatinine, etc.**

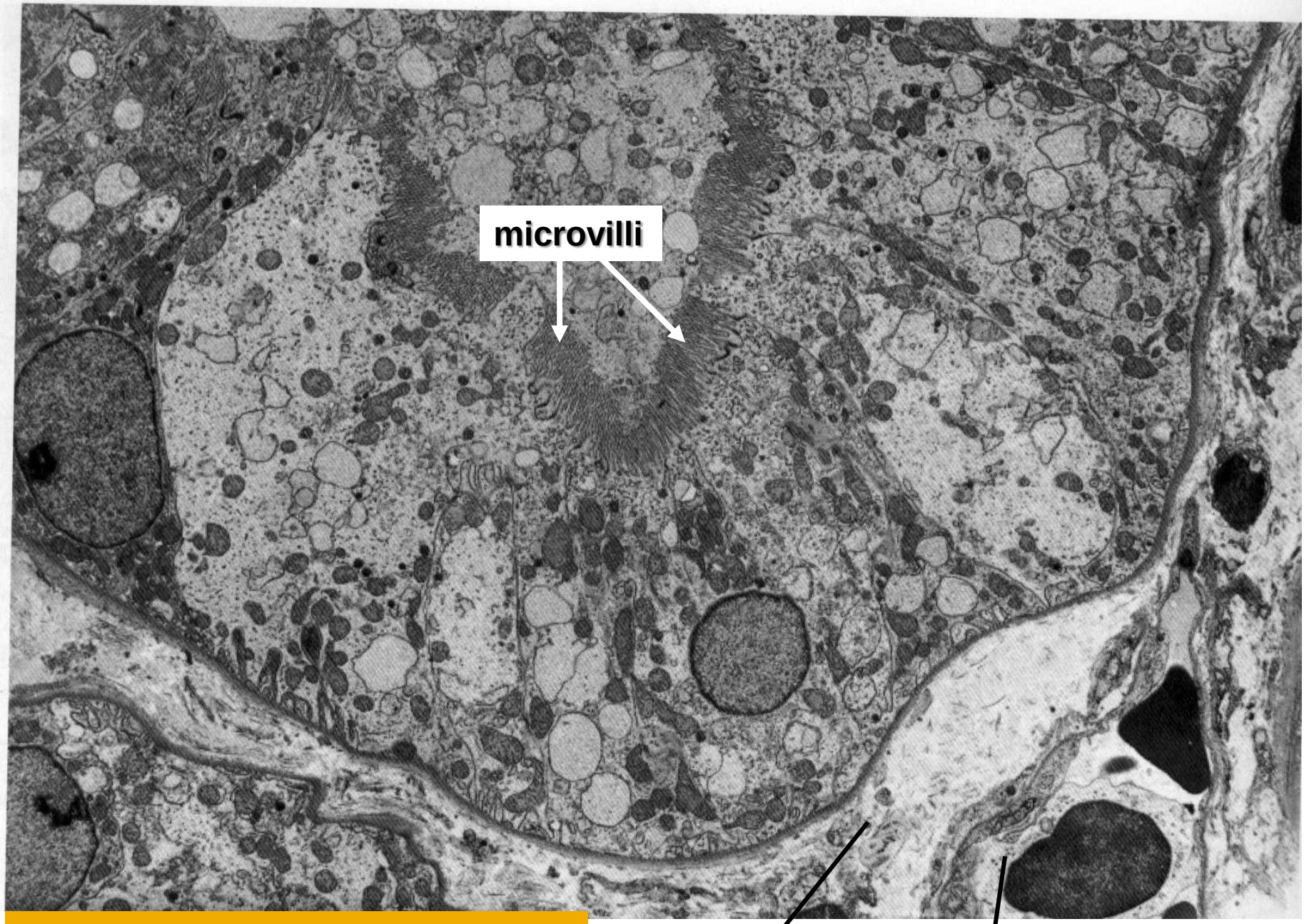

Proximal
Distal
Proximal
Proximal

PCT

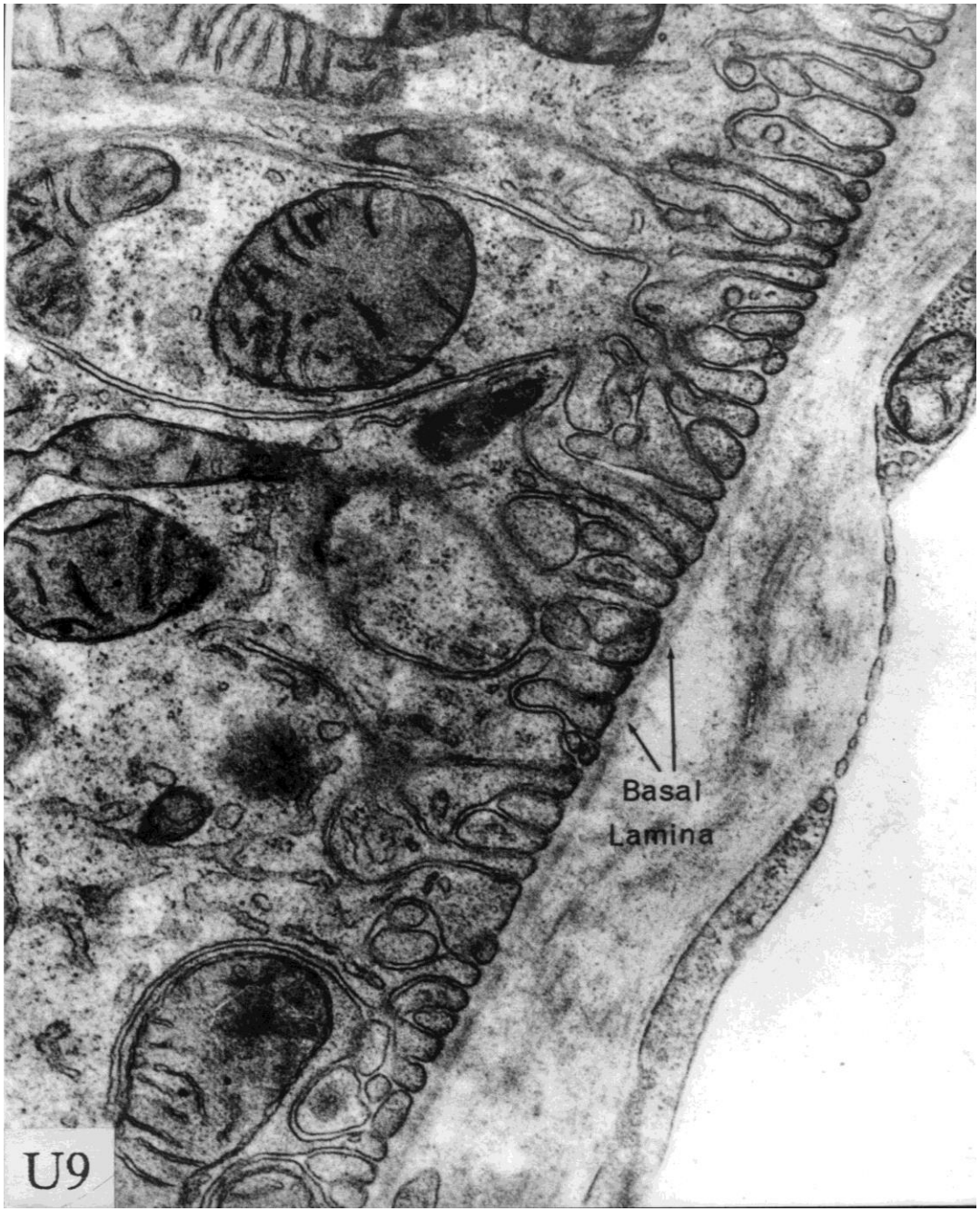
Note the long MV

Lots of endocytotic vesicles





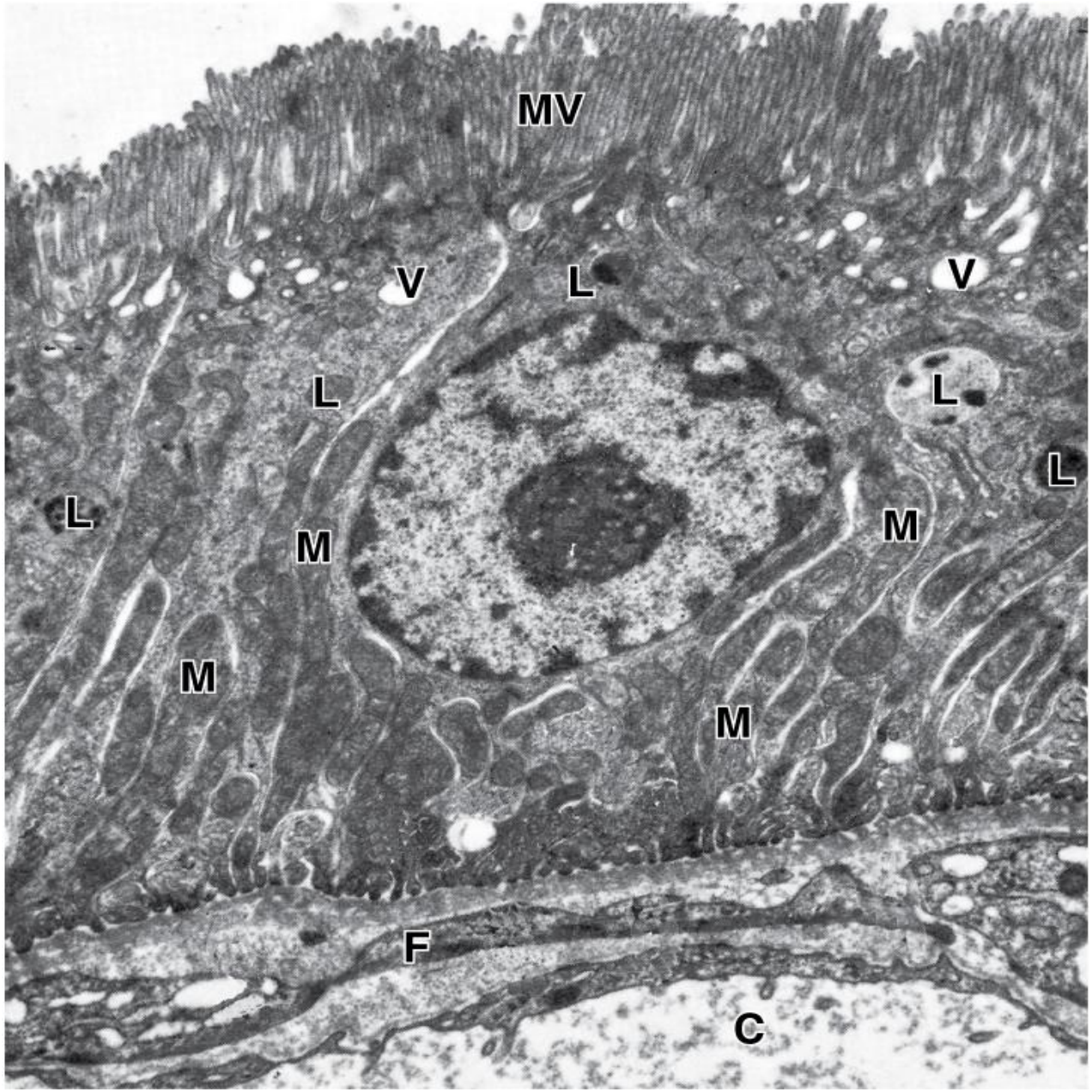
Proximal convoluted tubule



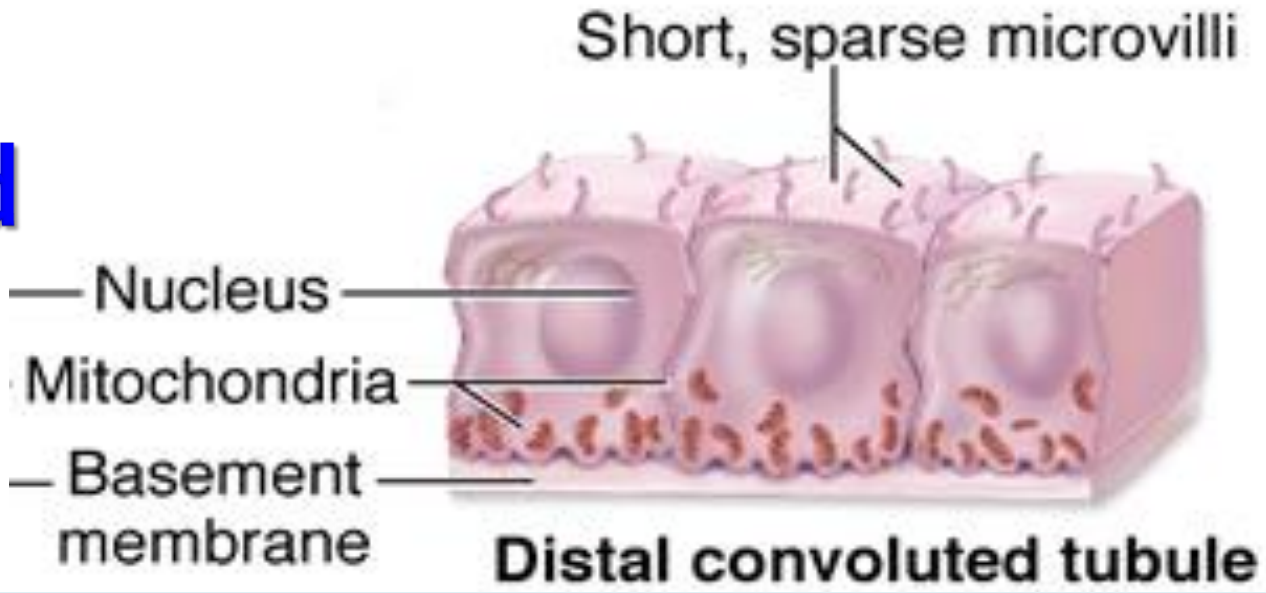
Proximal convoluted tubule:

1. **Basolateral interdigitations**

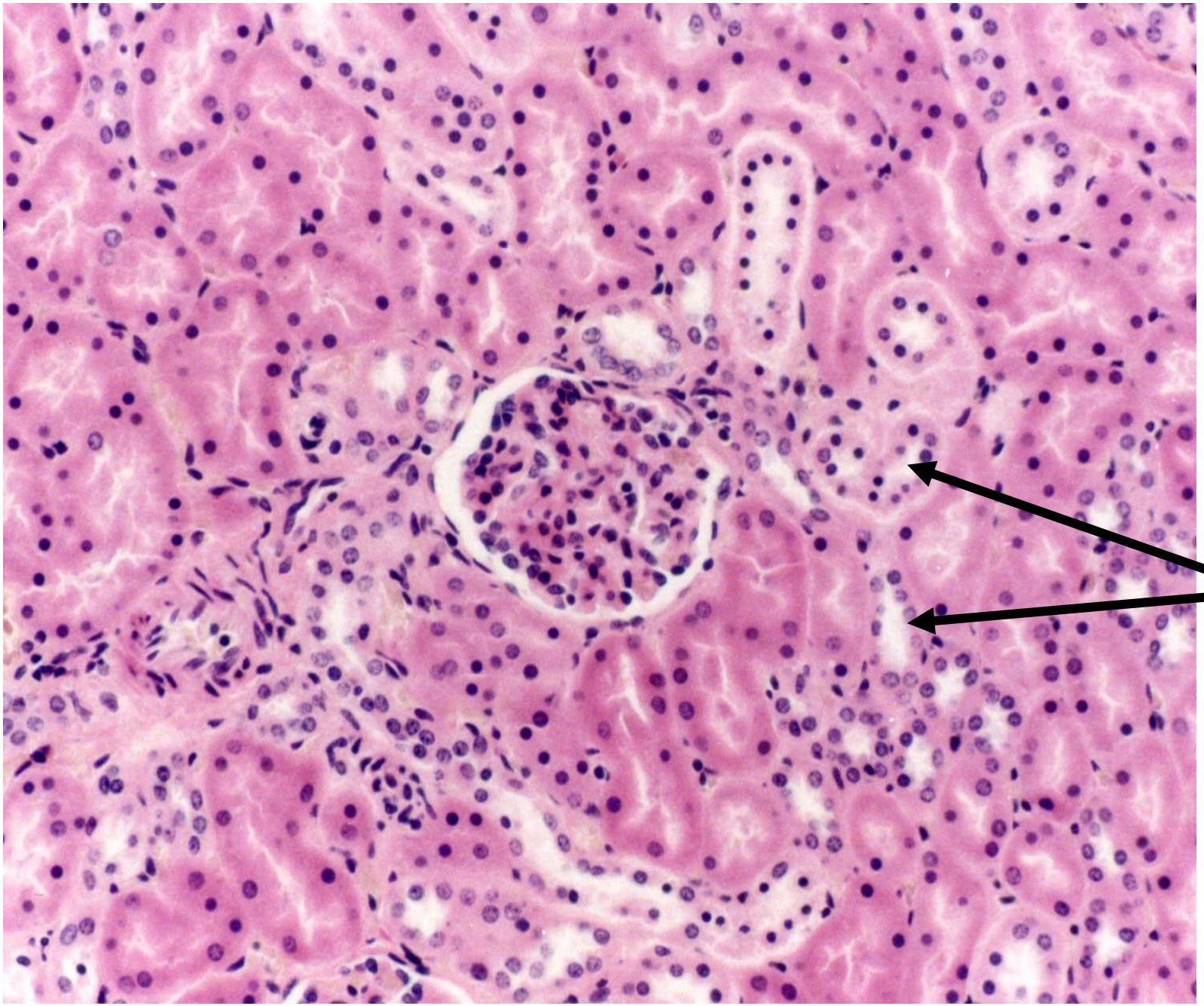
Proximal Convoluted Tubule, PCT

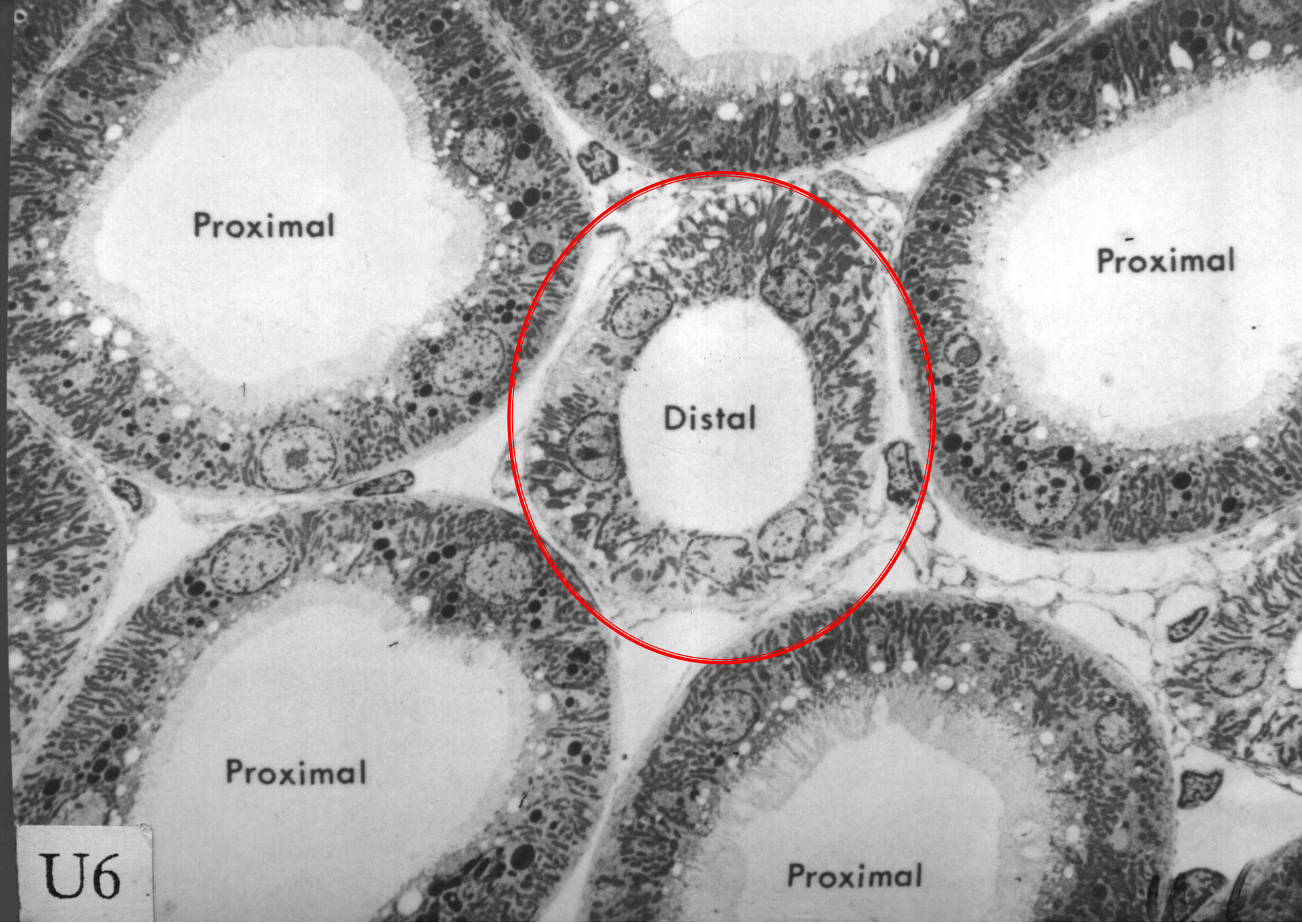


Distal Convoluted Tubule, DCT

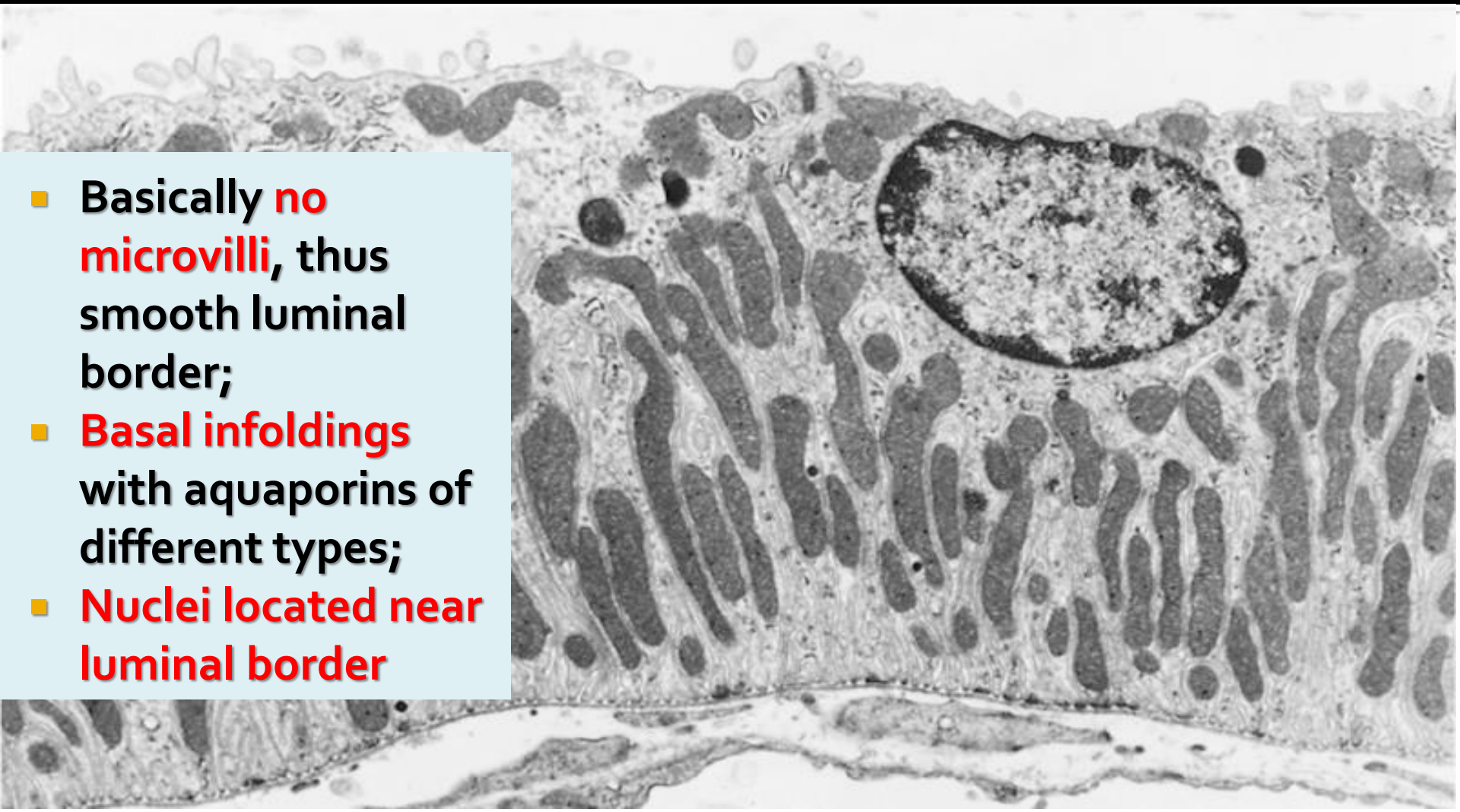


- **Shorter than PCT, thus less numerous in section**
- **Cuboidal cells, more palely stained**
- **Cells have no brush border**
- **With more distinctive border**
- **Smaller cells, thus more cells per profile**
- **Response to aldosterone**
- **Begins distal to macula densa**
- **End of DCT signals end of nephron**


Distal
Convoluted
Tubules


Proximal
Distal
Proximal
Proximal
Proximal
U6

Distal convoluted tubule



- Basically no microvilli, thus smooth luminal border;
- Basal infoldings with aquaporins of different types;
- Nuclei located near luminal border

Functions of Distal Convoluted Tubules

- **Reabsorption** of
  - Na^+ and secrete K^+
  - biocarbonate ions
- **Secretion** of ammonium
- **Response** to aldosterone from adrenal cortex
  - **Increase** reabsorption of Na^+
  - **Increase** secretion of K^+

Characteristic features of proximal and distal convoluted tubules

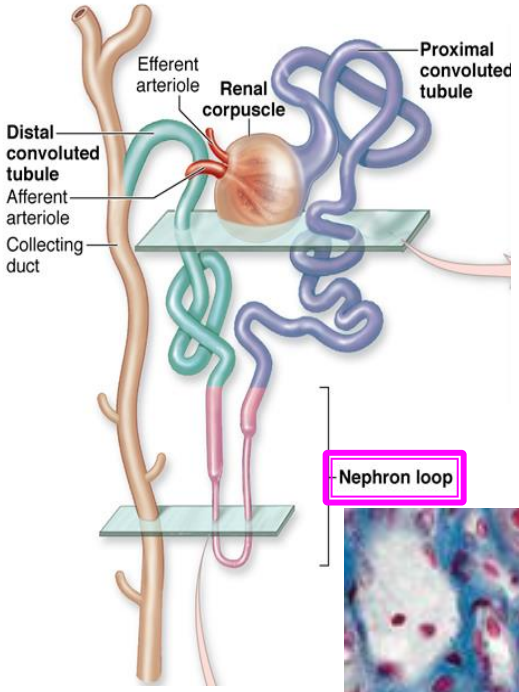
Proximal convoluted tubules

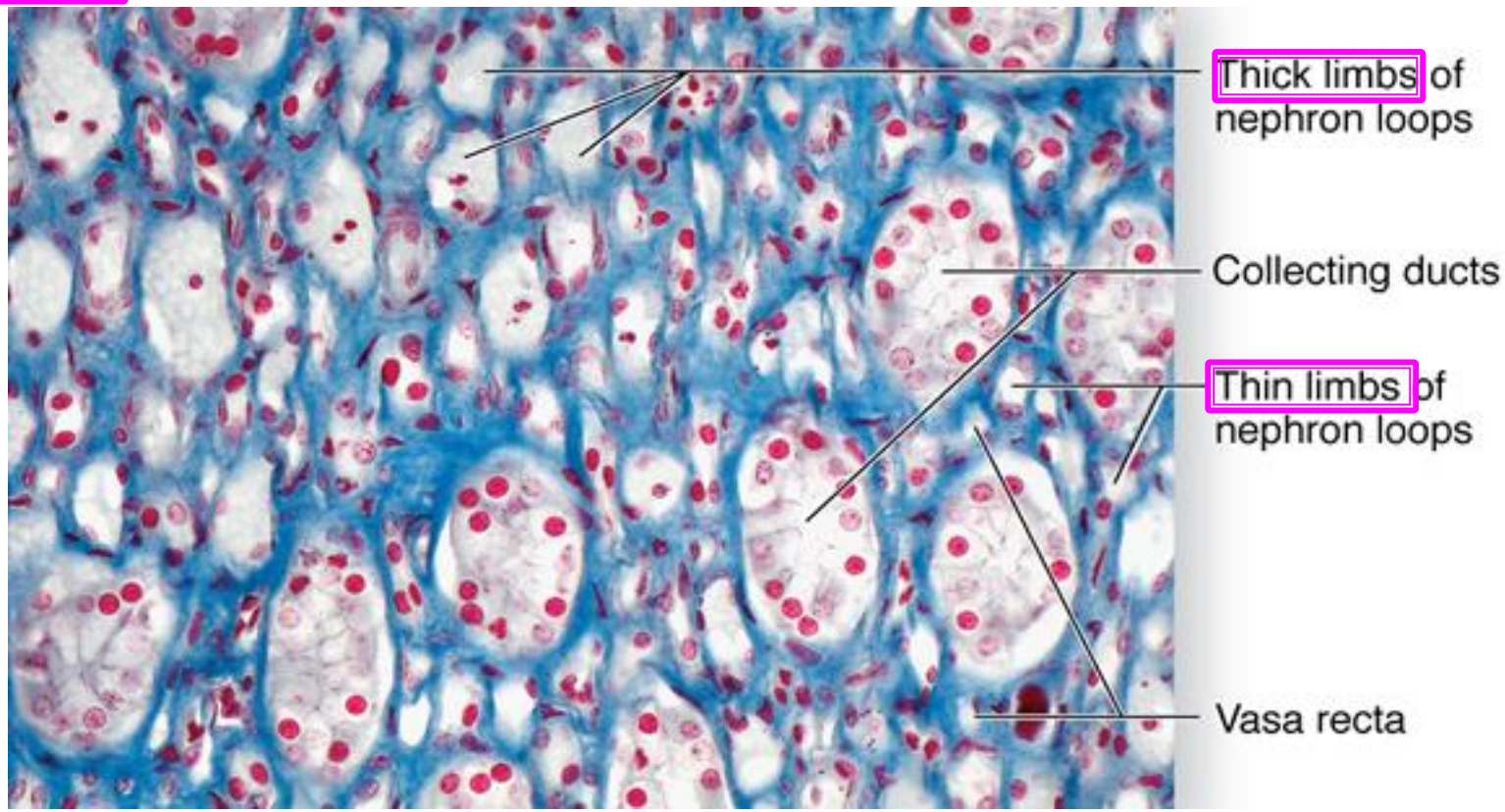
- Long more numerous in section
- Thicker wall
- Smaller lumen
- Numerous microvilli
- Indistinct cell boundary
- Acidophilic cytoplasm
- Fewer nuclei per XS of tubule
- Found in cortex
- Basolateral membrane interdigitation
- Numerous mitochondria

Distal convoluted tubules

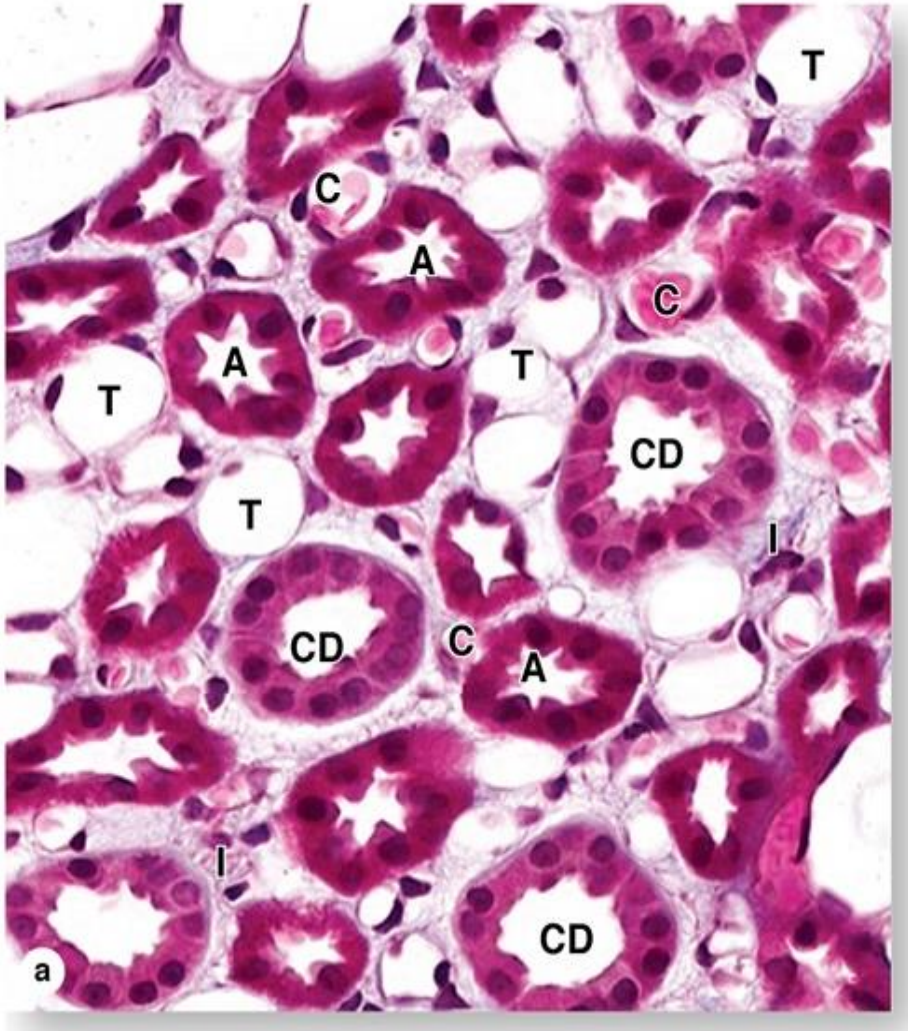
- Shorter less numerous in section
- Thinner wall
- Larger lumen
- No brush border/MV
- More distinct cell boundary
- Less acidophilic cytoplasm
- More nuclei per XS of tubule
- Found in cortex
- Basolateral membrane interdigitation, less extensive
- Numerous mitochondria
- Response to aldosterone

Nephron Loop



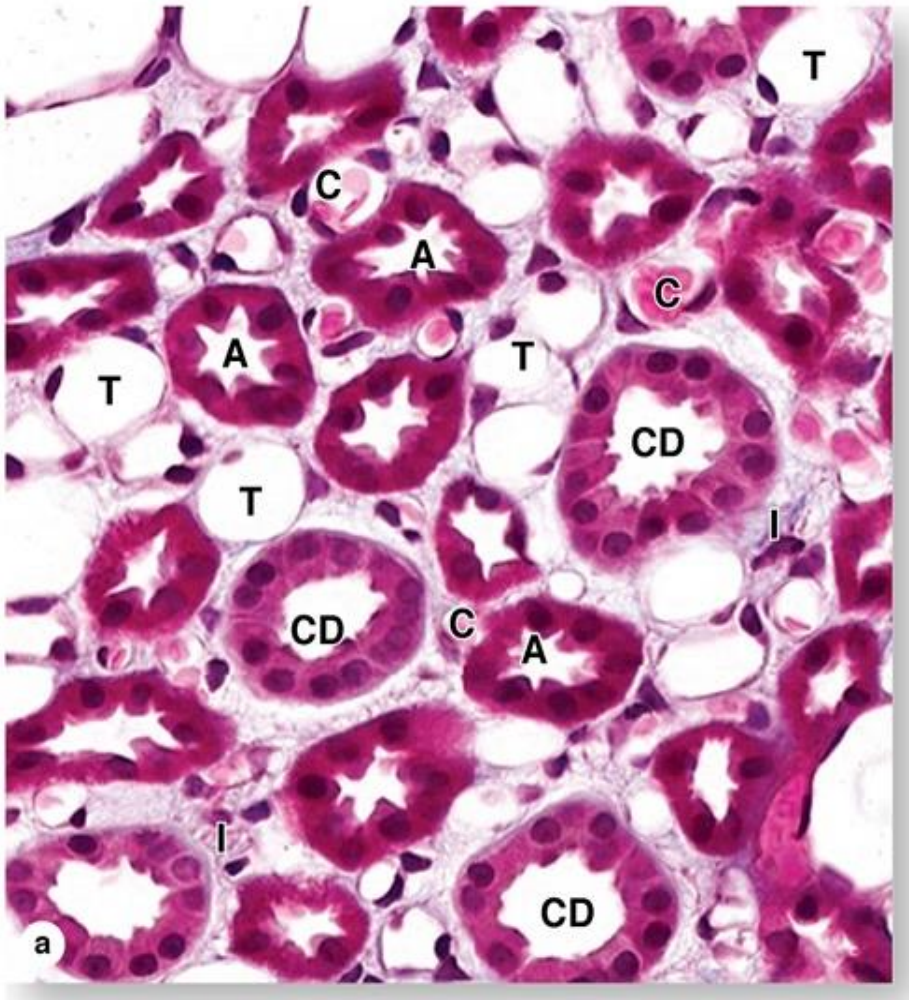


Loop of Henle



- Hairpin shape
- Thick descending limb or segment, similar to PCT
- Thin segment (T), squamous cells with bulging nuclei
- Thick ascending limb or segment (A), similar to distal convoluted tubule
- Re-absorption of fluid through "counter-current" mechanism [working closely with medullary capillary plexus, vasa recta, in the interstitium];
- Secretion of hyperosmotic urine.

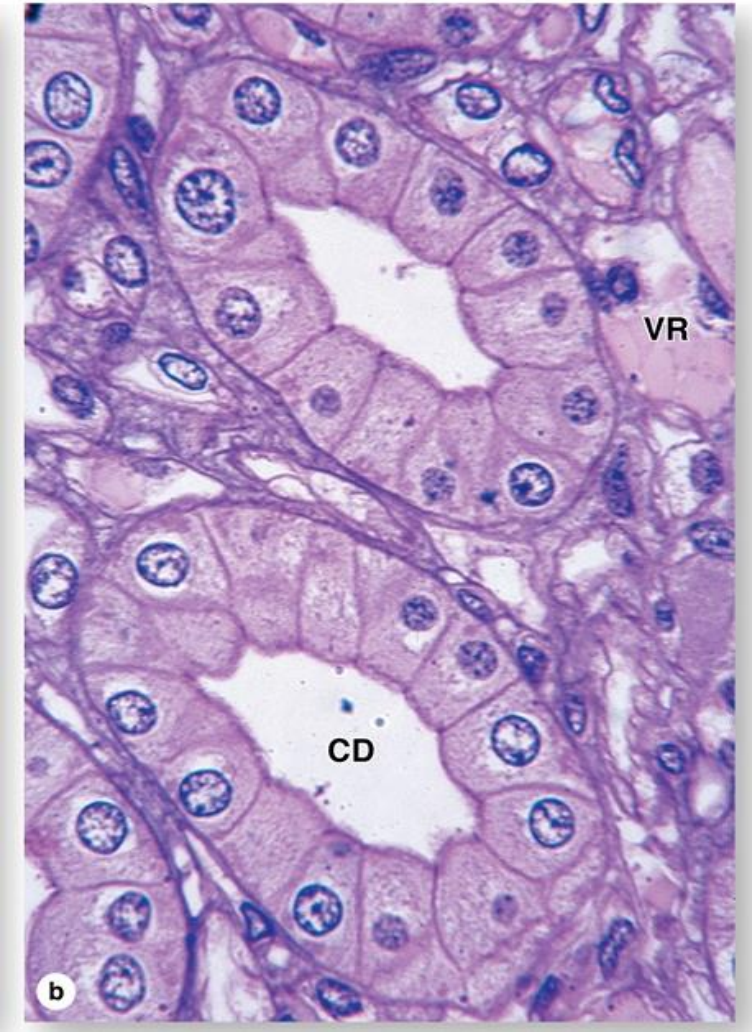
Loop of Henle



Uriniferous tubule

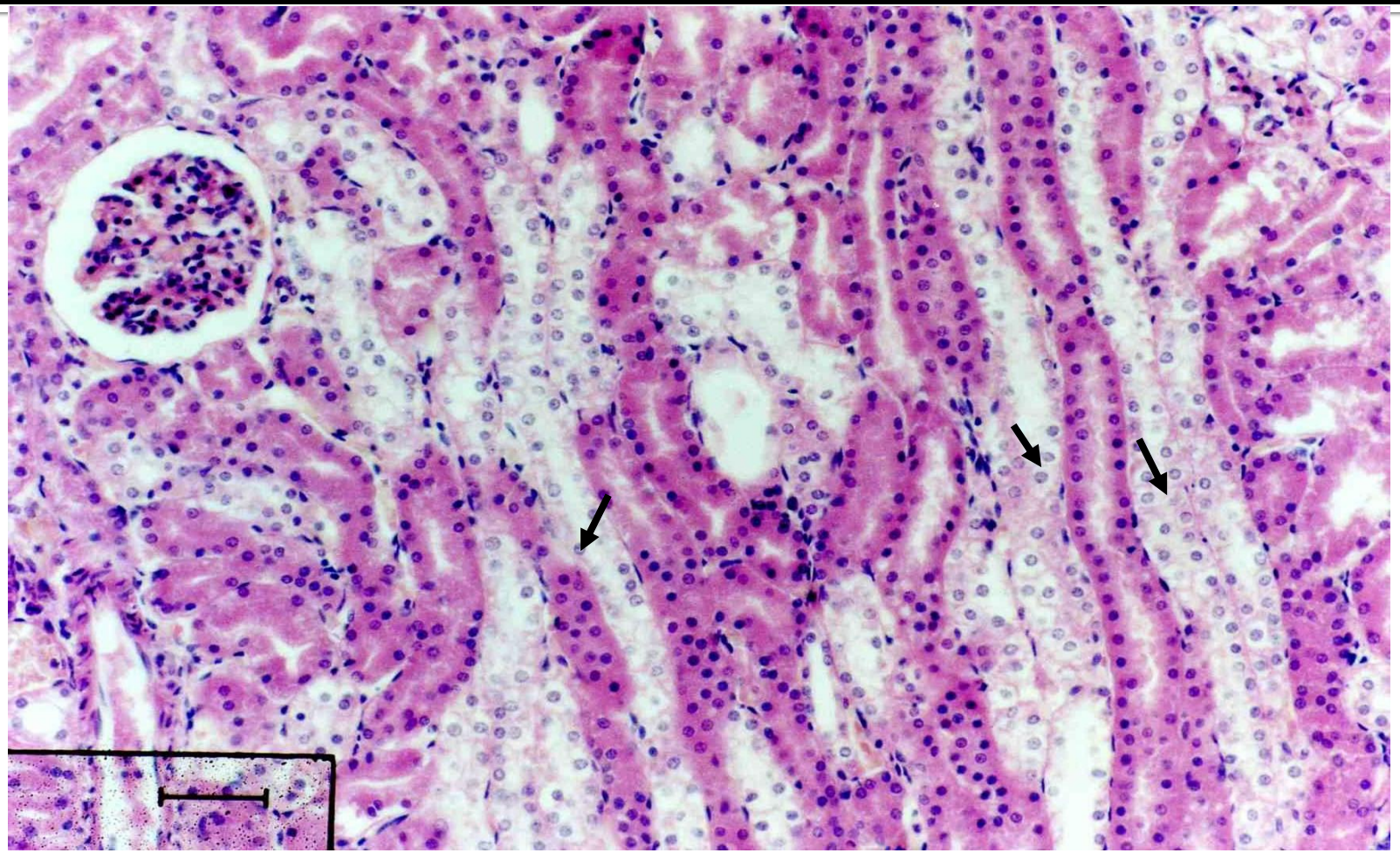
- Collecting tubule
- Collecting duct

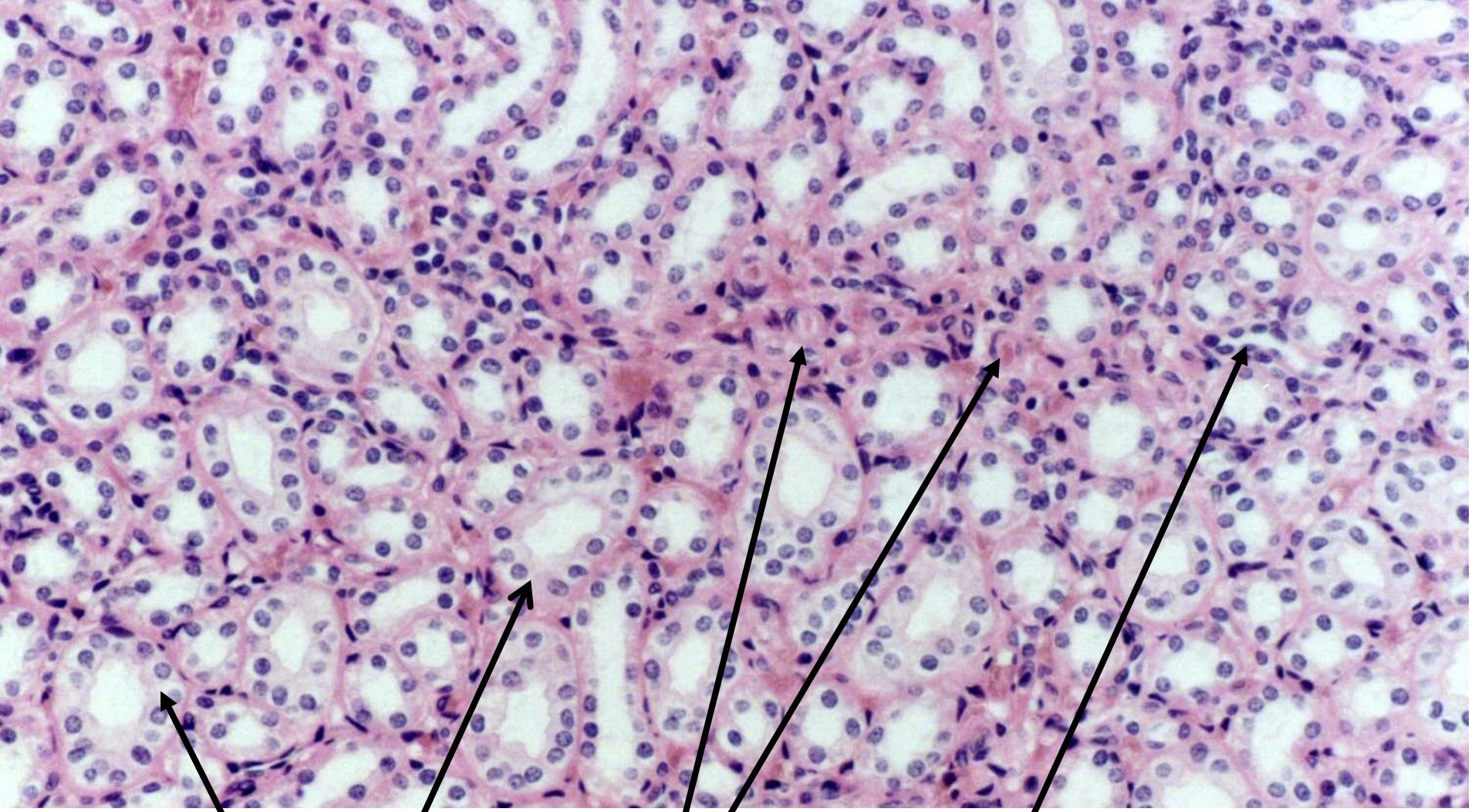
Collecting tubule



- Similar to DCT, with larger lumen
- Response to ADH [antidiuretic hormone, vasopressin]
- Not part of nephron as they are derived from ureteric bud
- In cortex and in medulla
- Many in medullary rays
- Cells with pale staining cytoplasm
- Tubules join to and form collecting ducts

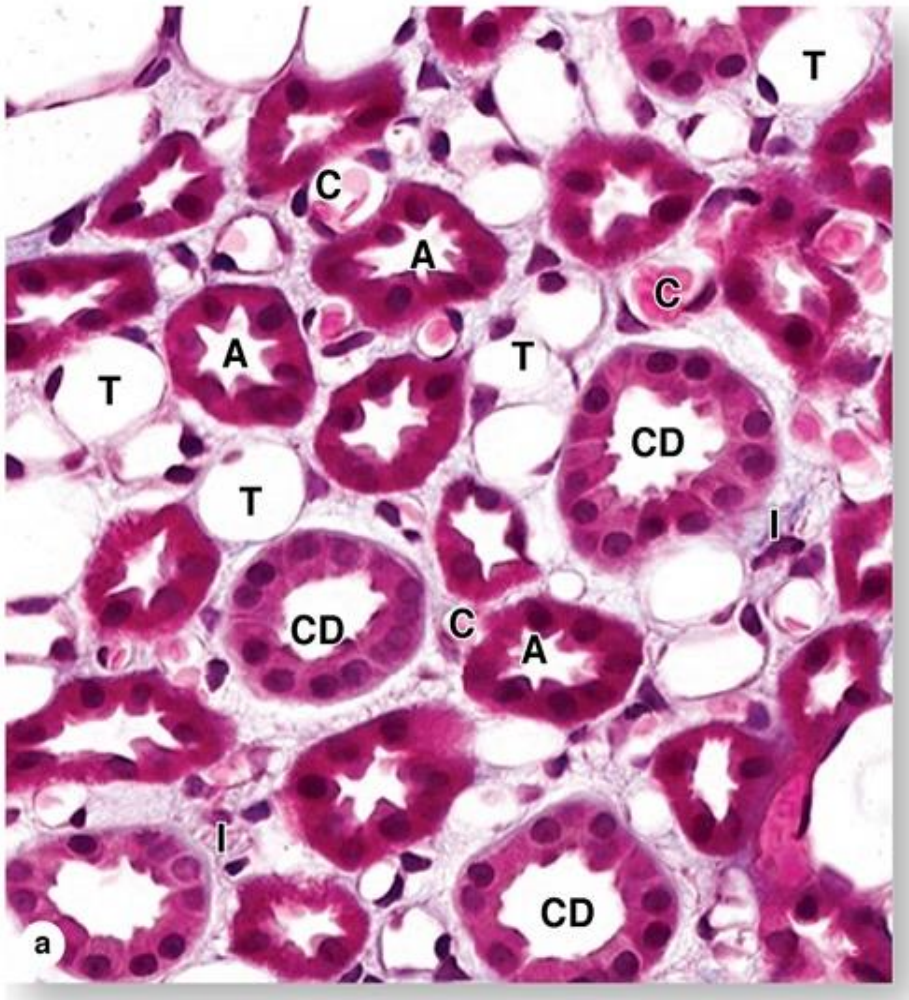
Collecting tubules



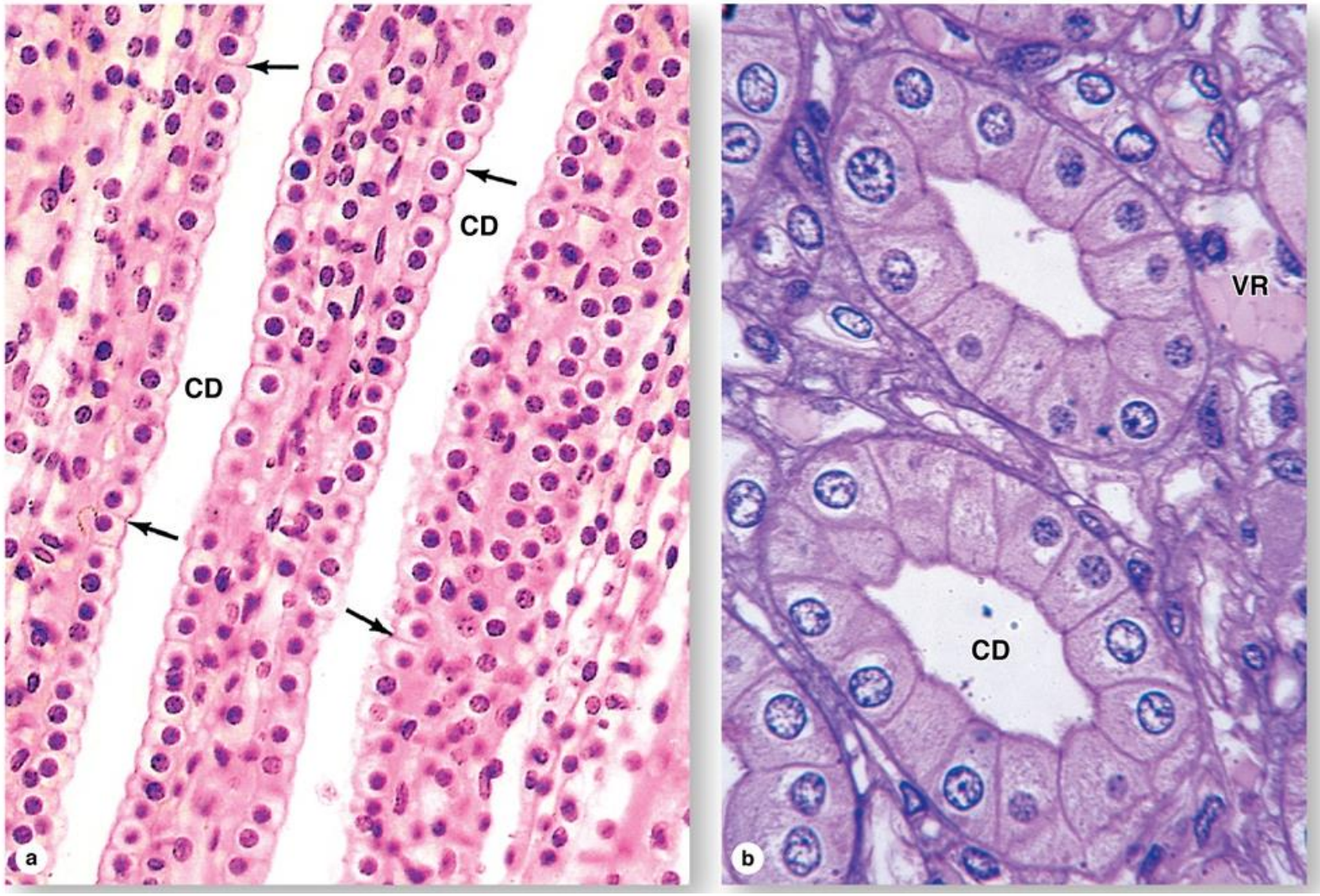

Collecting tubules
Capillaries
(vasa recta)
Thin segment
of Henle's loop

Medulla

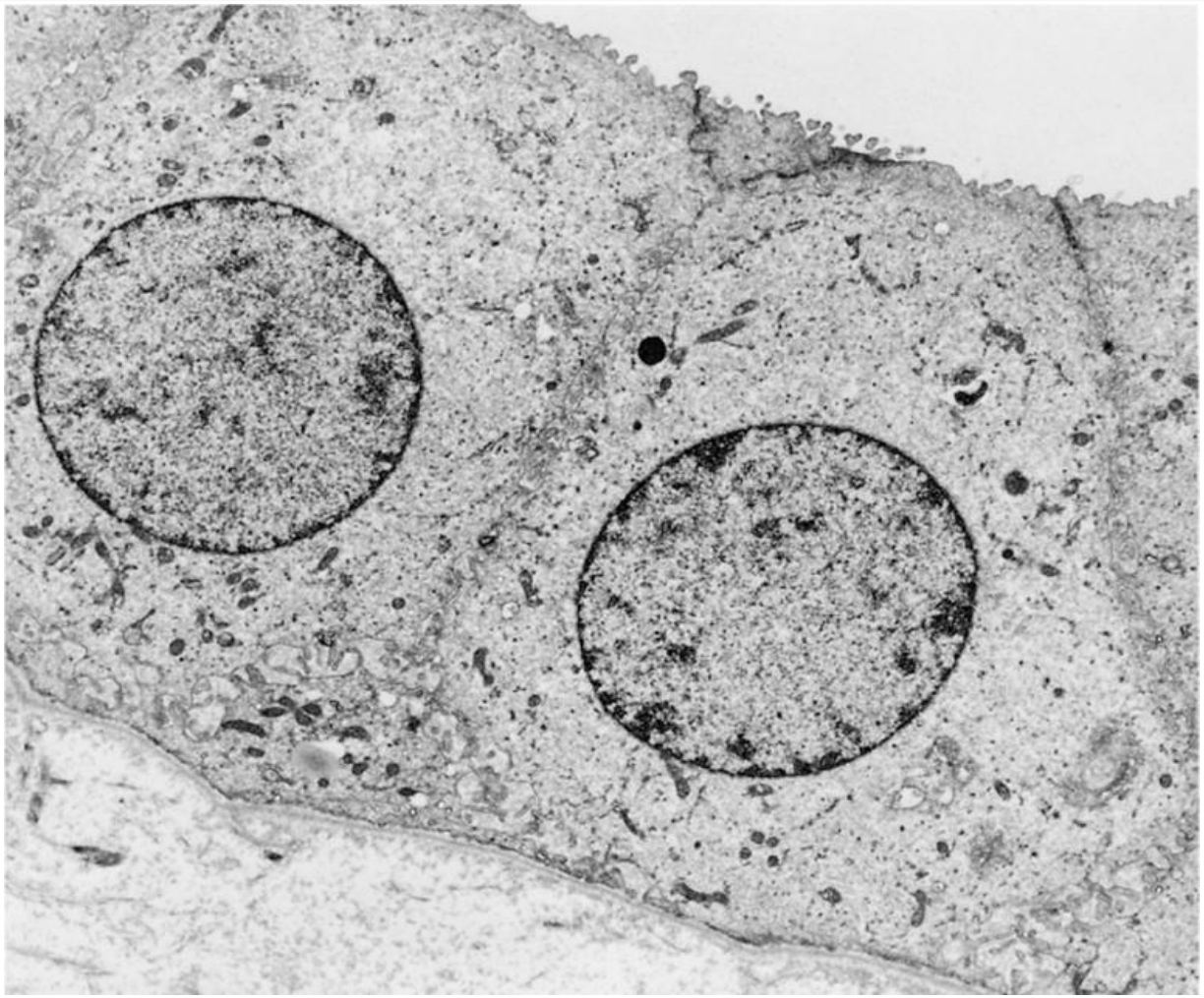
Collecting ducts



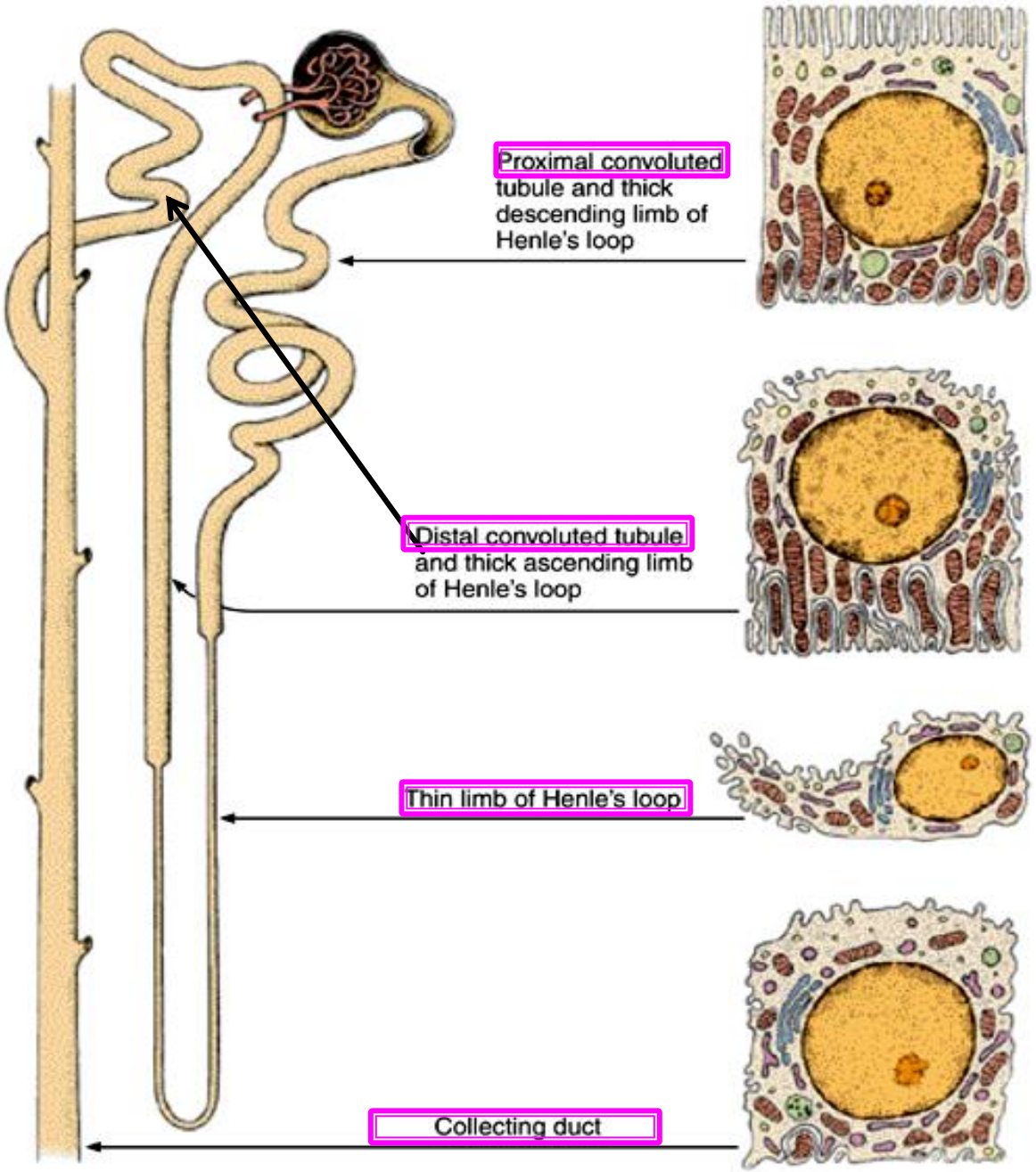
Collecting ducts



Collecting tubule/duct



Structural differences of various segments of uriniferous tubules

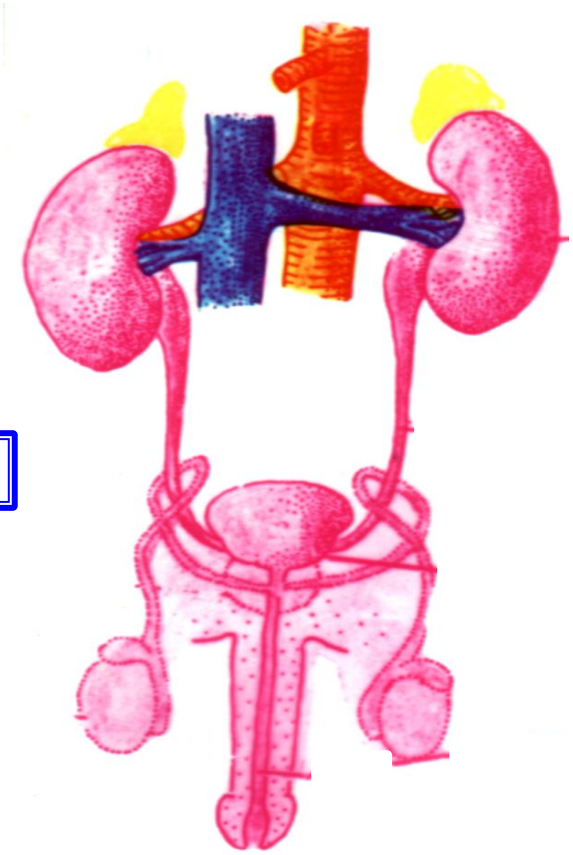


Question 3

- **Urine production**
  - Remove metabolic wastes from blood by filtration

    Renal Corpuscles
  - Regulate the balance between water and electrolytes
    - Re-absorption of water and electrolytes selectively
    - Excretion of urea, uric acid, creatinine etc.

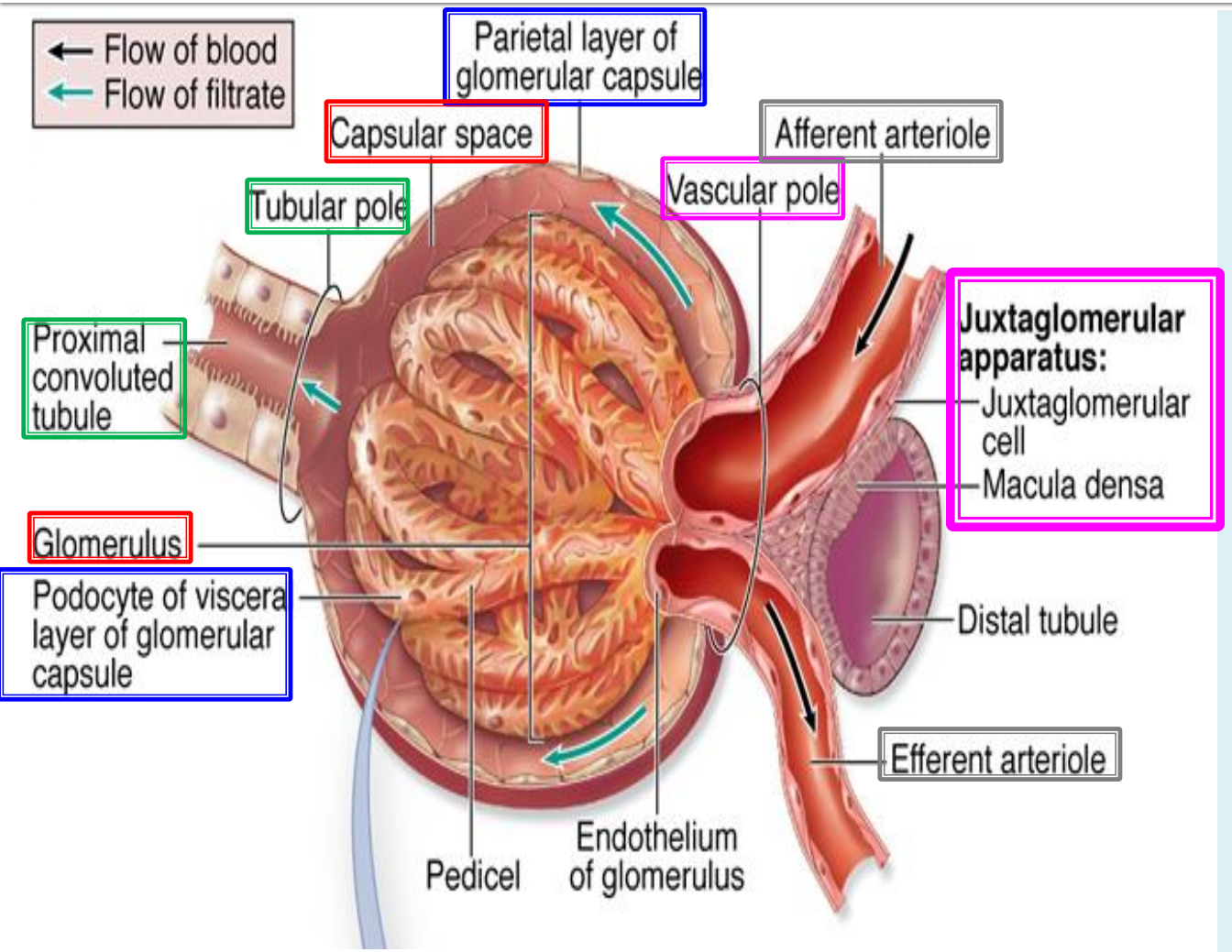
    Renal tubules & collecting tubules/ducts
- **Secretion of certain enzymes or cytokines ?**
  - **Renin**
  - **Erythropoietin**



Key point to answer question 3

- **Elaborate the following contents:**
  - **Structure and function** of **Juxtaglomerular complex.**
  - **Structure and function** of **interstitium**

Juxtaglomerular Apparatus



- Located at **vascular pole**
- Consisting of:
  1. **JG cell:** modified muscle cell
  2. **Macula densa**
  3. Extraglomerular mesangial cells (**Lacis cells**)

Juxtaglomerular (JG) cells

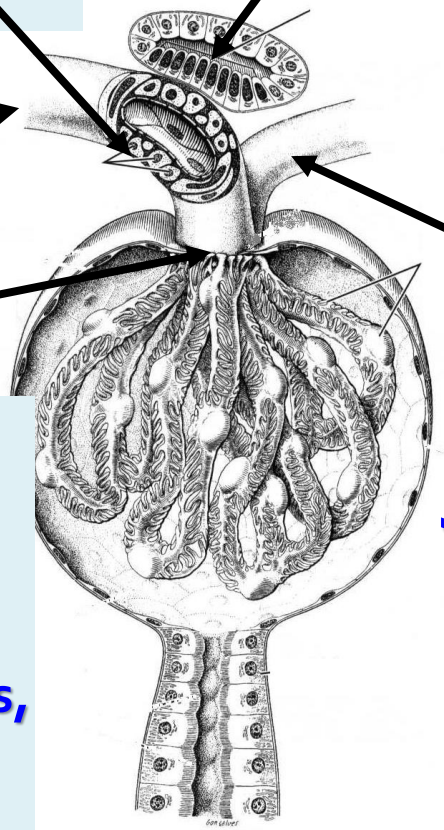
1. Modified smooth muscle cells of afferent arteriole
2. Secrete renin (activates angiotensin II)

Macula densa, MD

1. Modified DCT cells
2. With single cilium
3. Sensitive to osmolarity and volume of filtrate
4. Regulates glomerular filtration rate

Afferent arteriole

Efferent arteriole

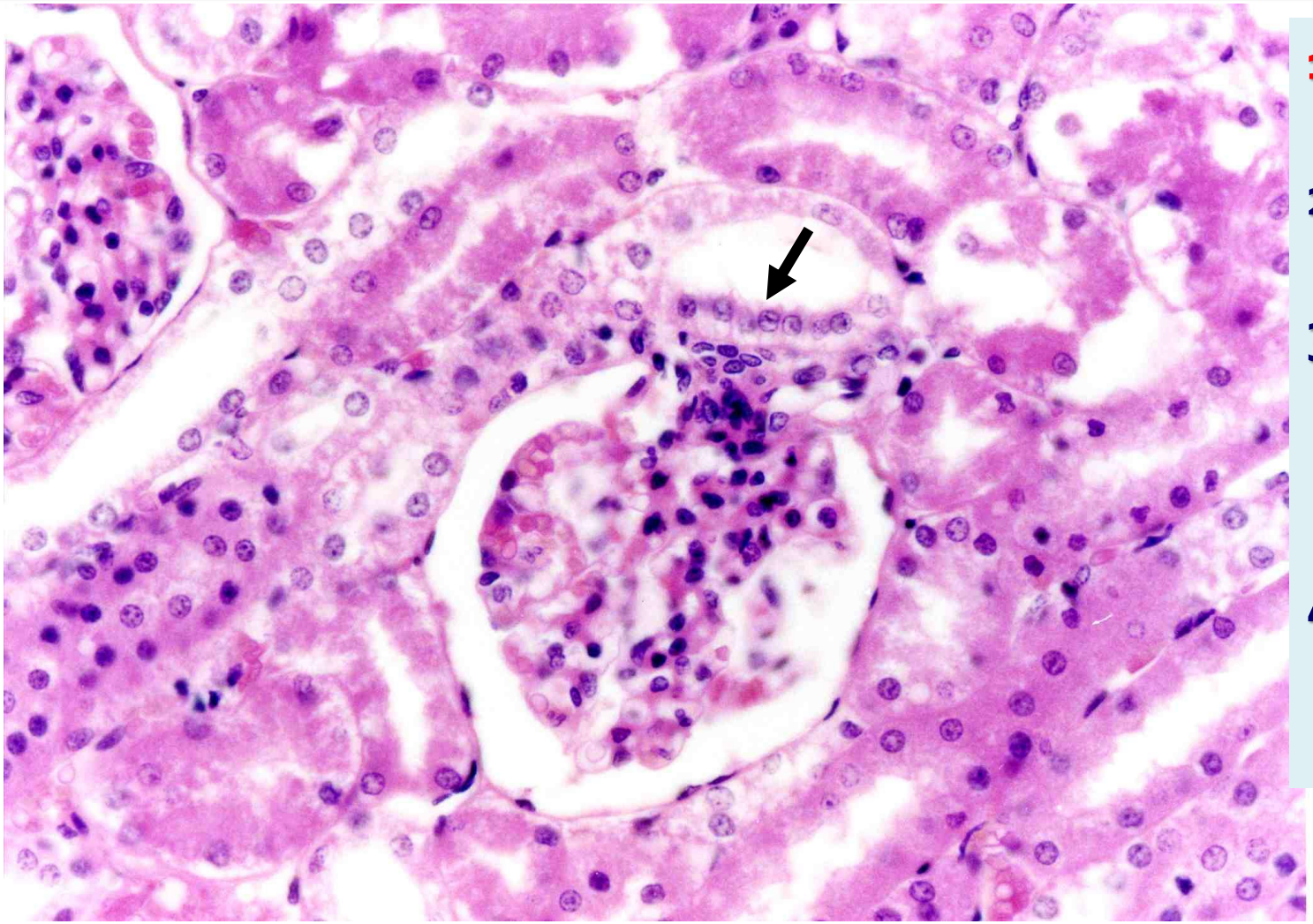


Lacis cell, L

1. Extraglomerlar mesangial cells
2. Function not well understood
3. Involved in phagocytosis, maintenance of GBM
4. secrete growth factors

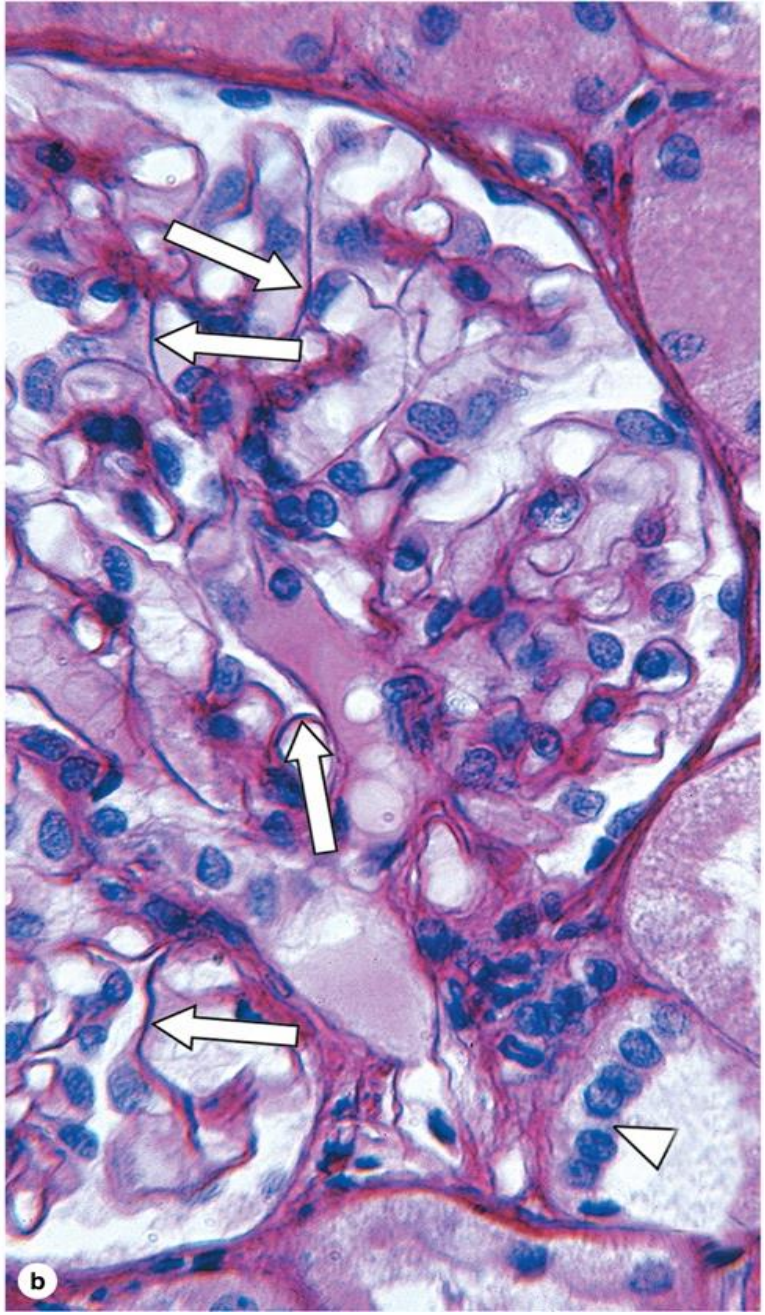
Juxtaglomerular Apparatus and Functions

Macula Densa, MD



1. Modified DCT cells
2. With single cilium
3. Smaller and regularly arranged
4. Cells with reversed polarity

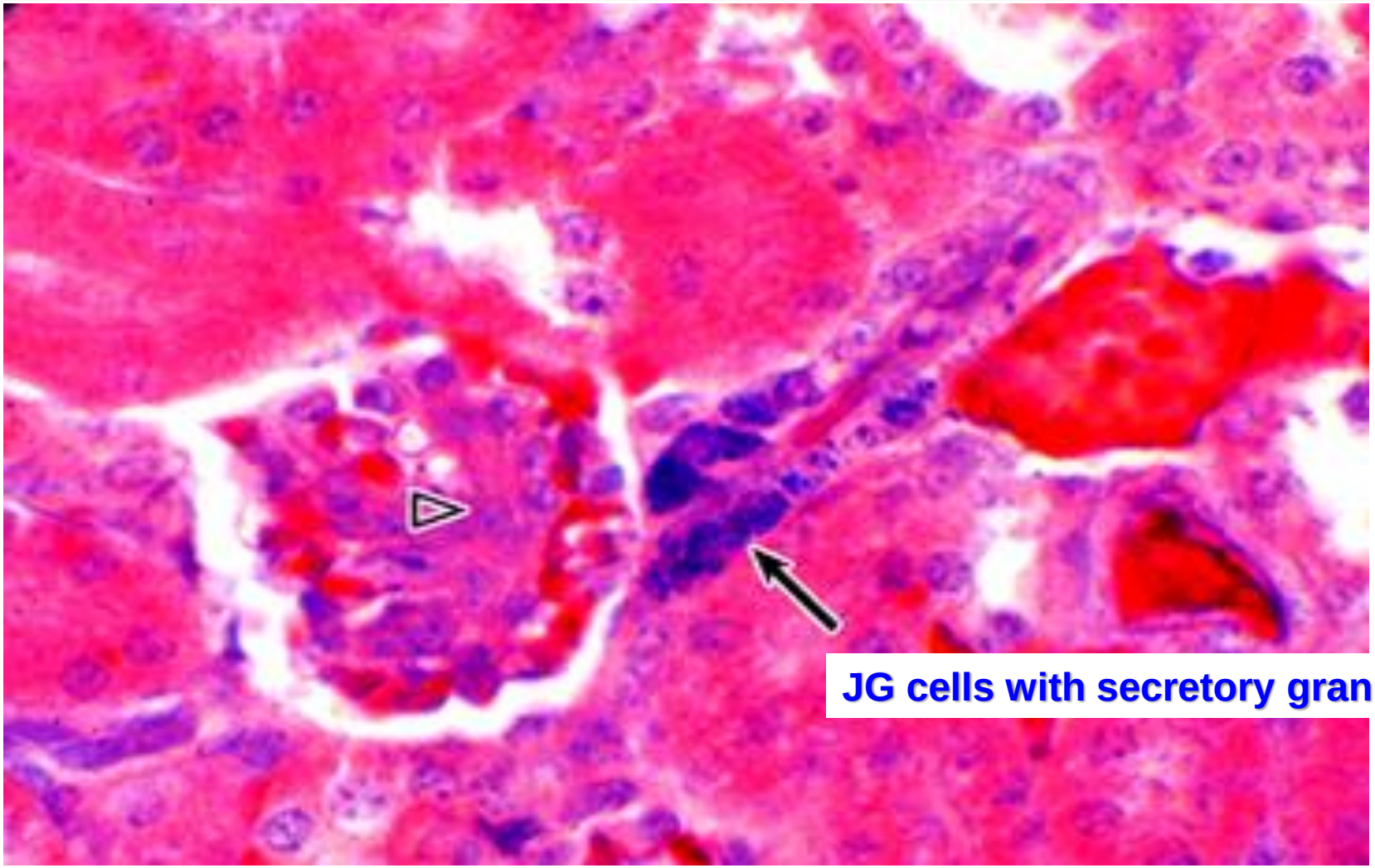
Macula Densa, MD



⇩: Thick basement membrane of glomerular capillaries

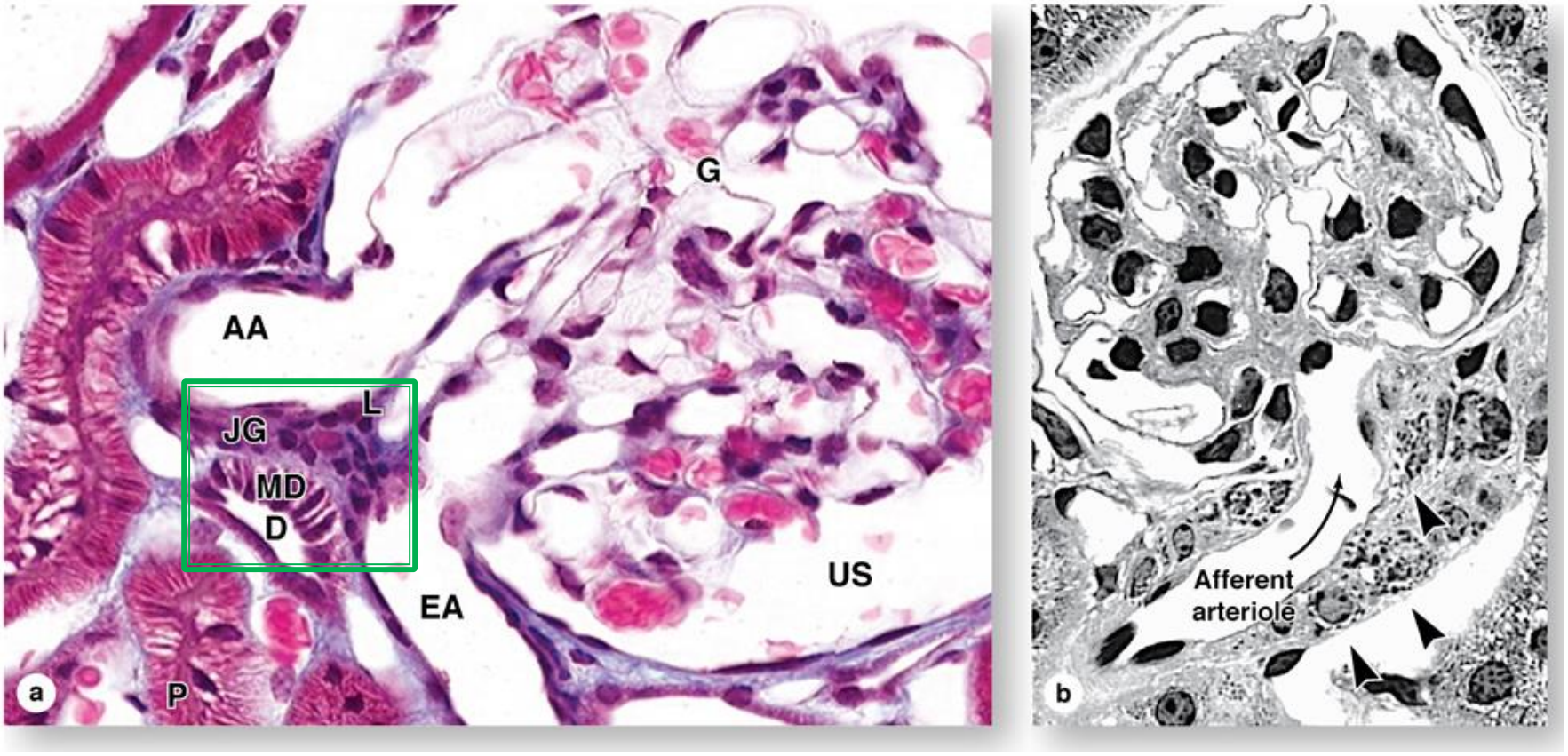
▽: MD

JG cells

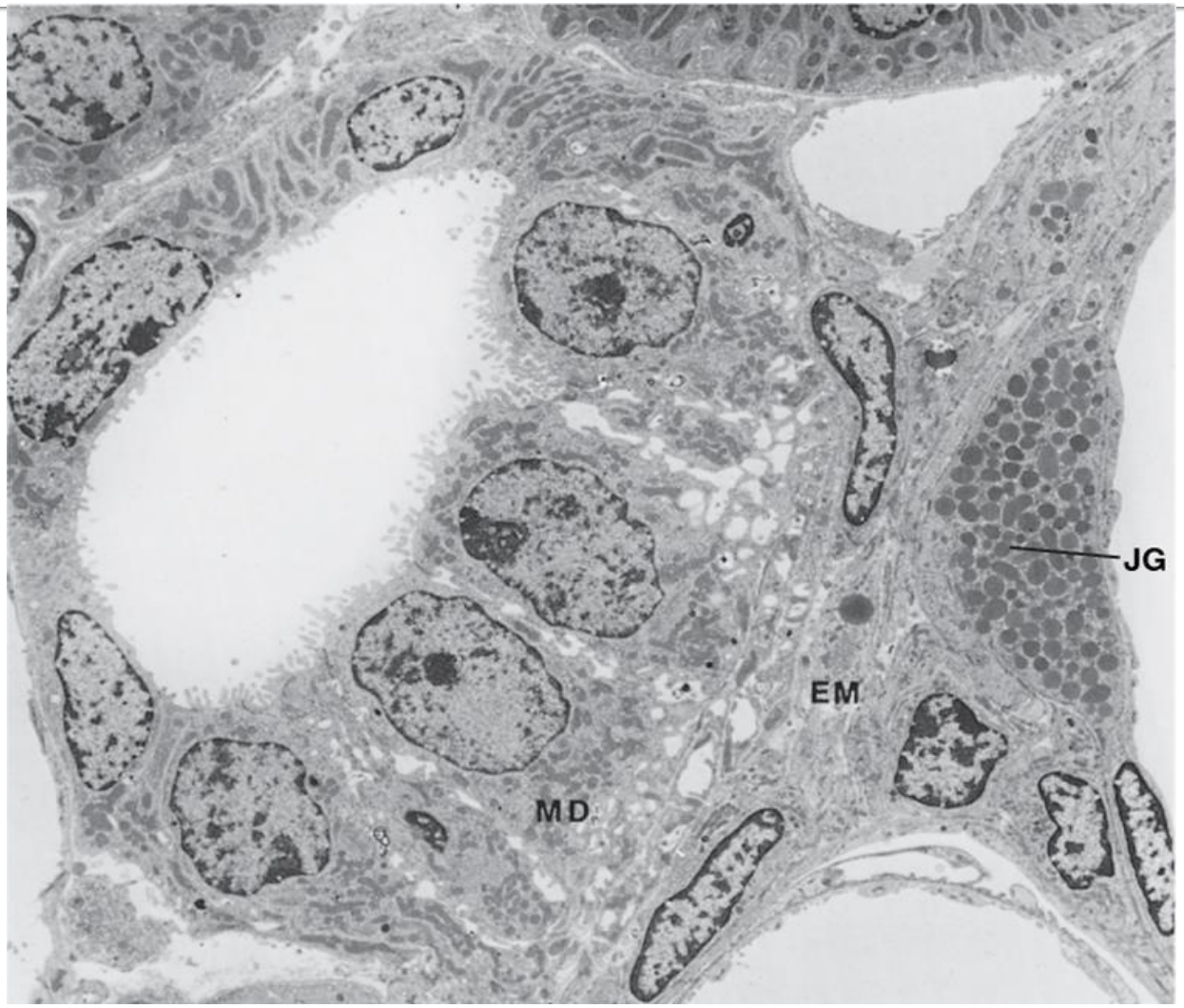


JG cells with secretory granules

JG apparatus



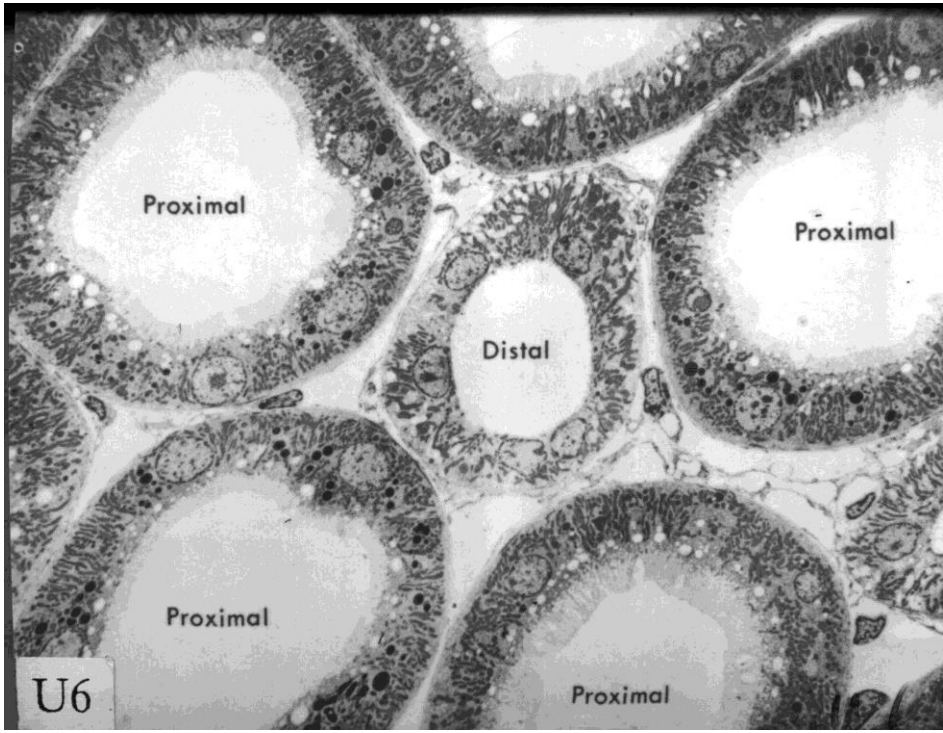
JG apparatus



- Macula densa, MD
- JG cells with secretory granules (renin)

Interstitial tissue

- Located between renal tubules and vessel network
- Fibroblast-like cells
- Synthesize collagen
- Secrete erythropoietin (?)

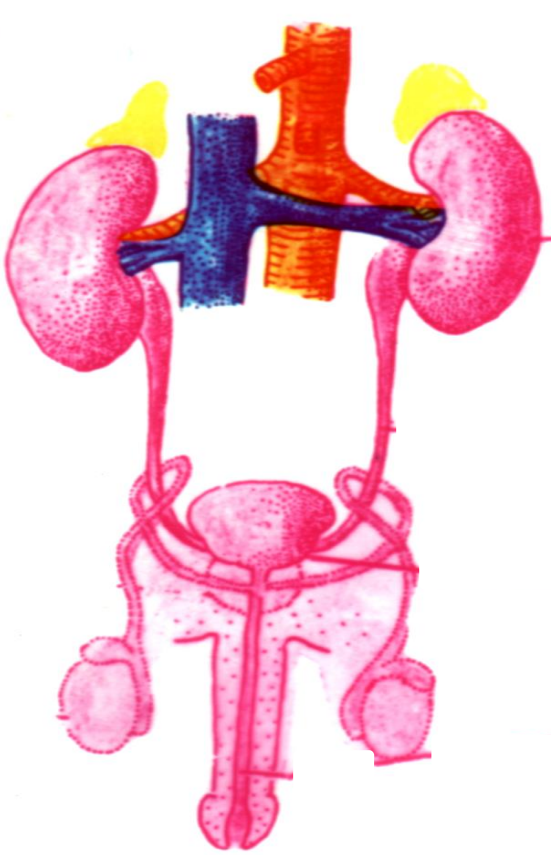


SUMMARY 1

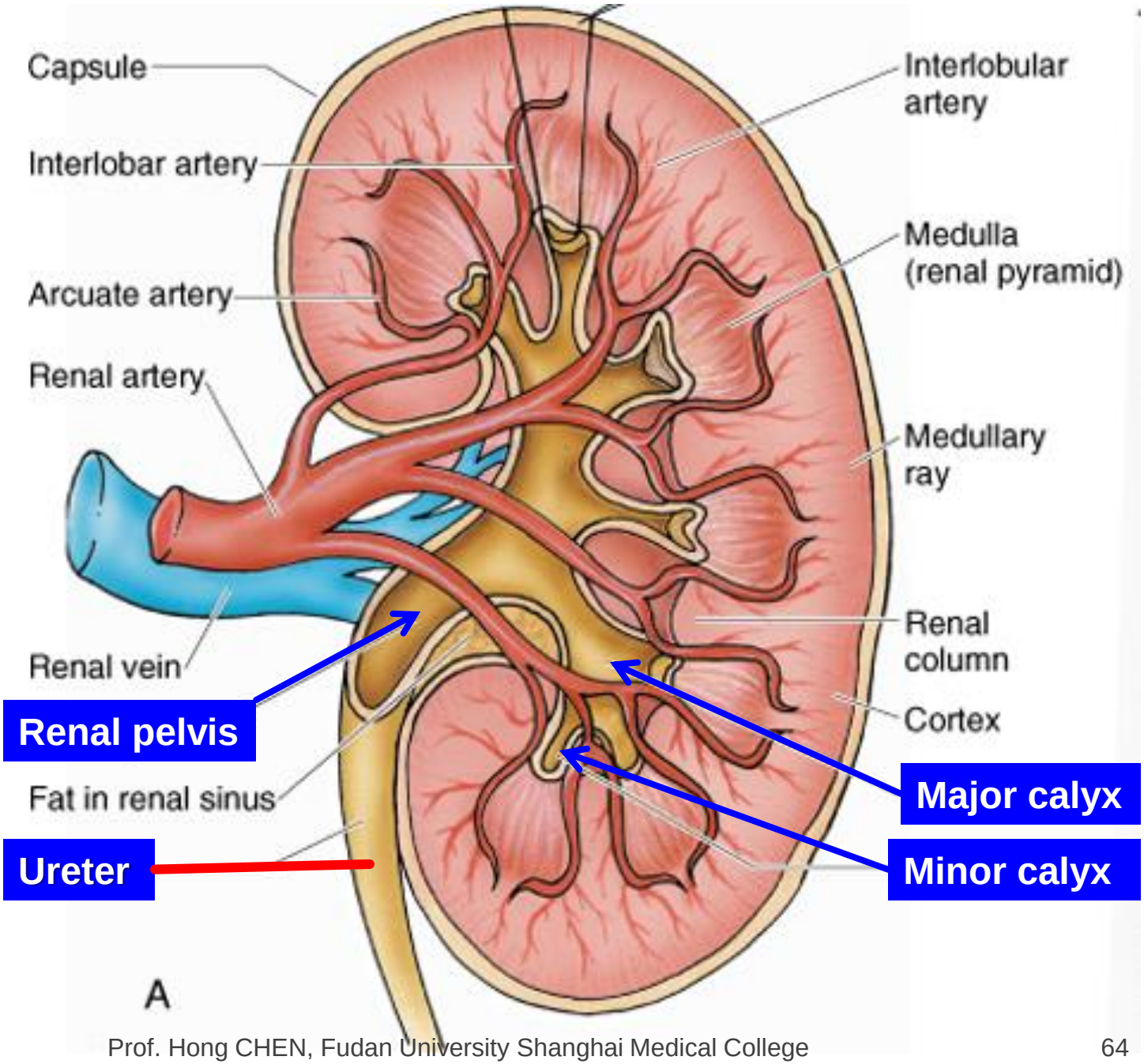
- **Urine production**
  - Remove metabolic wastes from blood by filtration

    Renal Corpuscles
  - Regulate the balance between water and electrolytes
    - Re-absorption of water and electrolytes selectively
    - Excretion of urea, uric acid, creatinine etc.

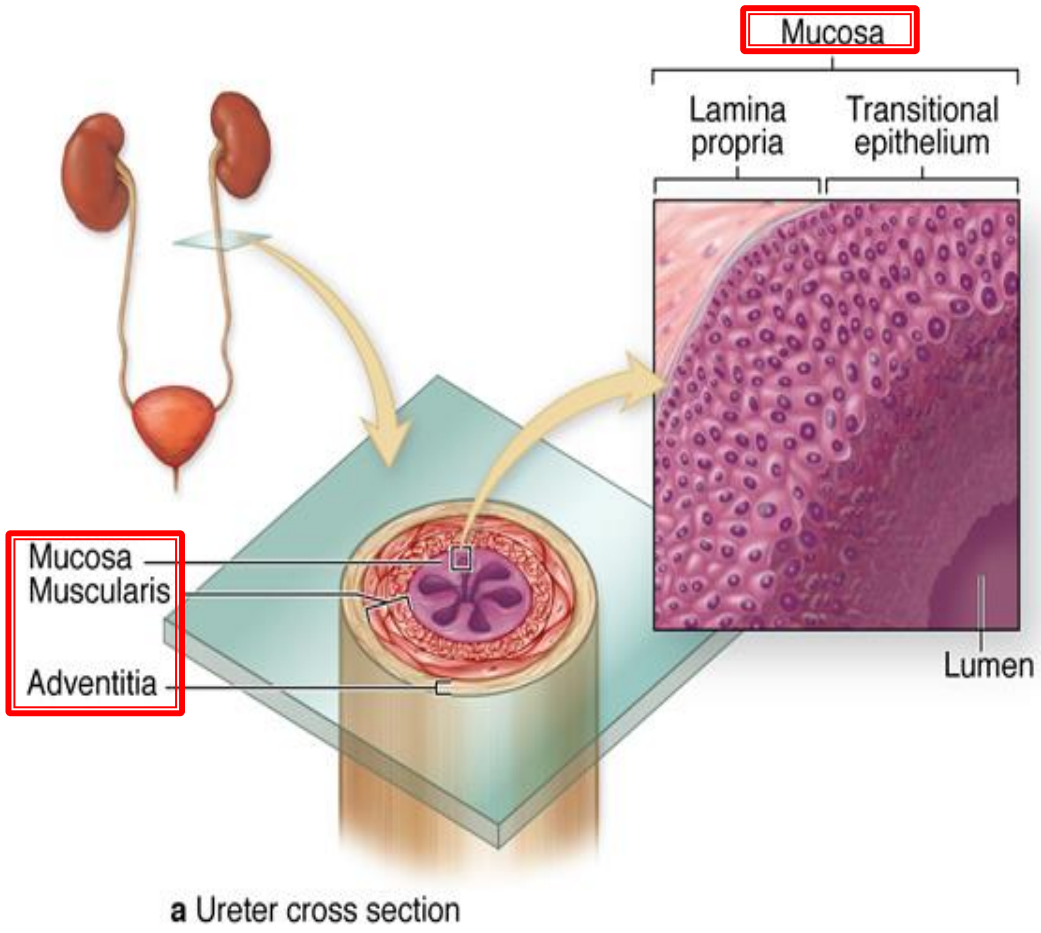
    Renal tubules & collecting tubules/ducts
- **Secretion of certain enzymes or cytokines**
  - Renin: Juxtaglomerular (JG) cells
  - Erythropoietin: interstitial cells



Ureter


Capsule
Interlobar artery
Arcuate artery
Renal artery
Renal vein
Renal pelvis
Fat in renal sinus
Ureter
A
Interlobular artery
Medulla (renal pyramid)
Medullary ray
Renal column
Cortex
Major calyx
Minor calyx

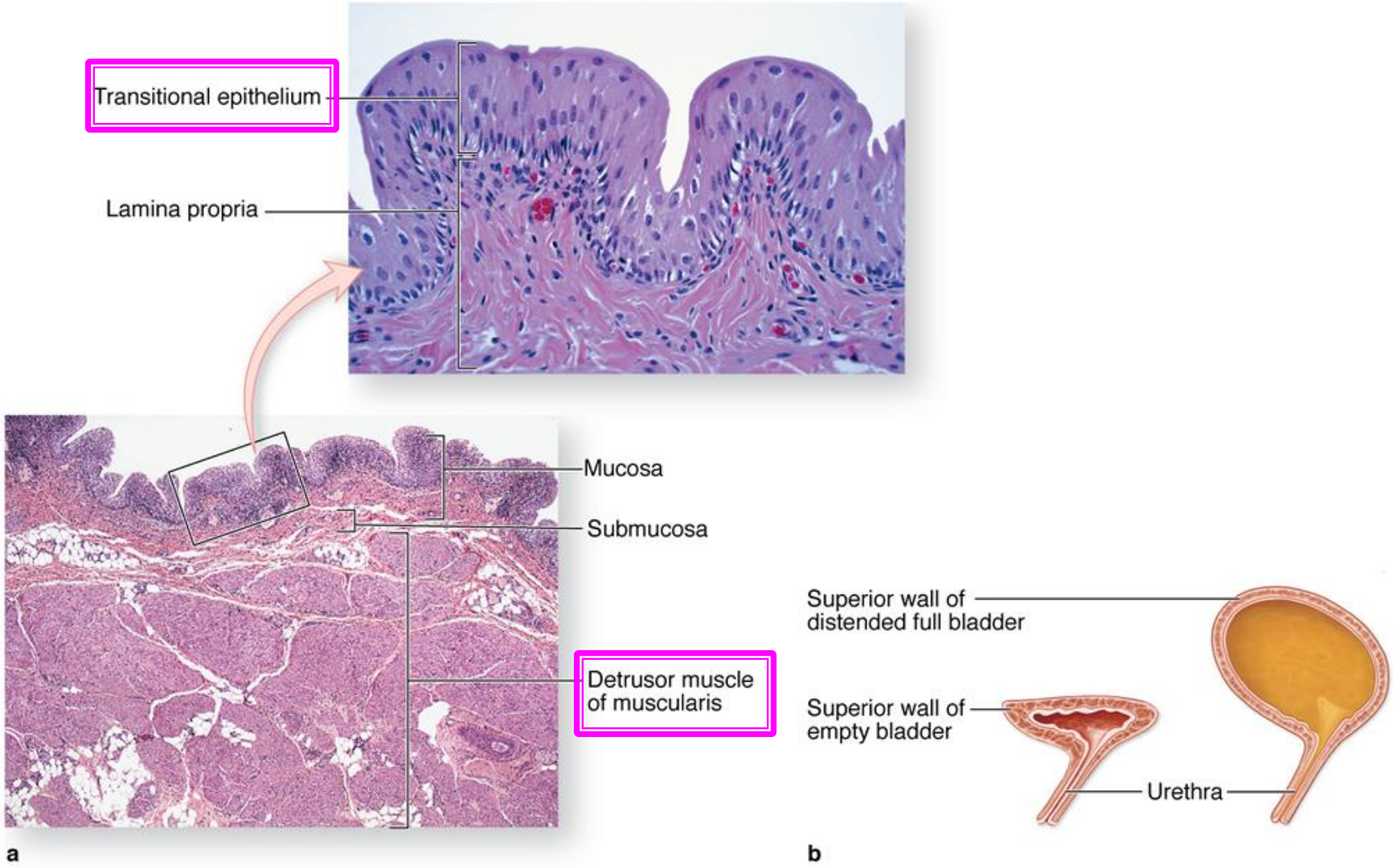
Ureter



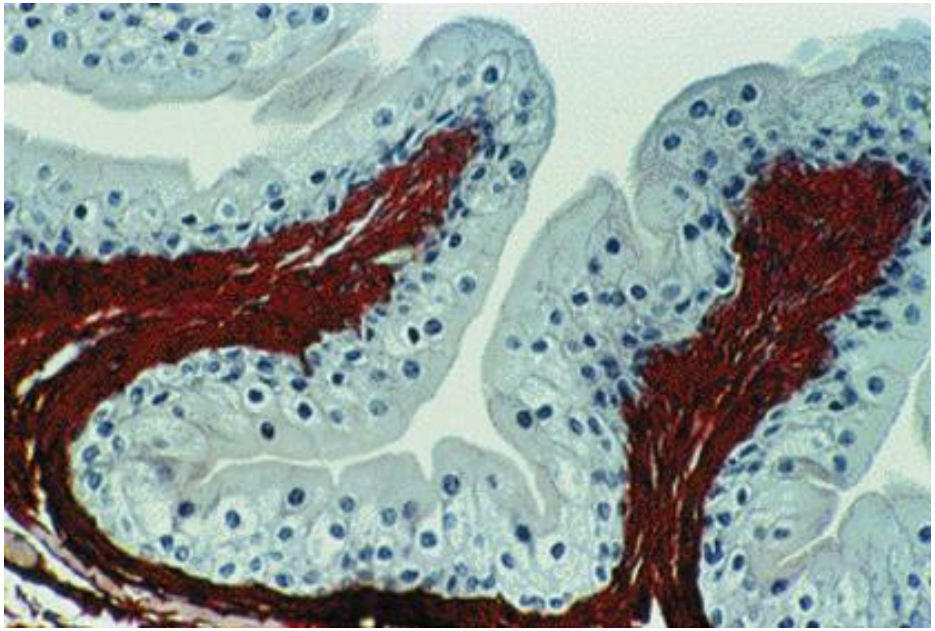
a Ureter cross section

b

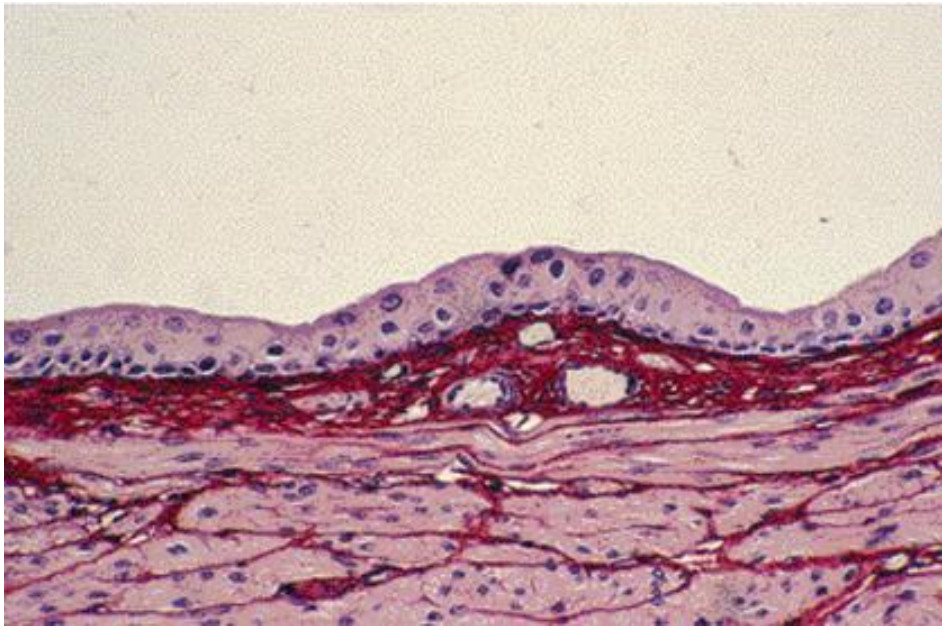
Urinary bladder



Urothelium



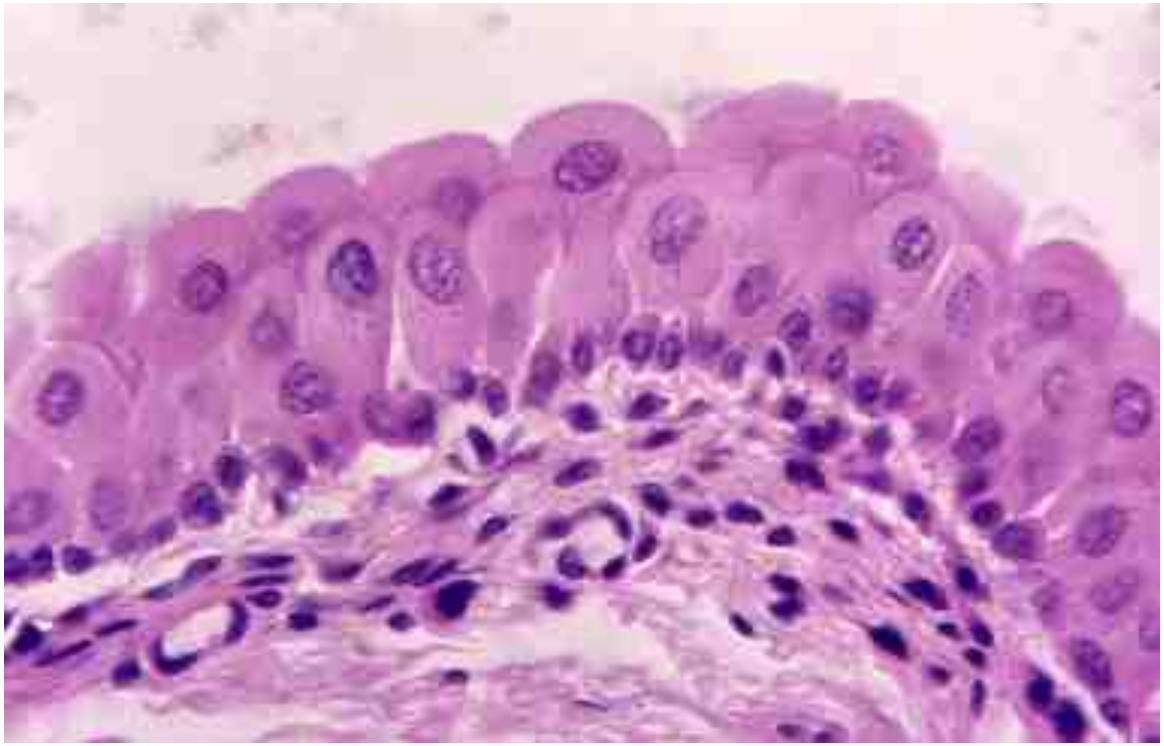
Collapsed



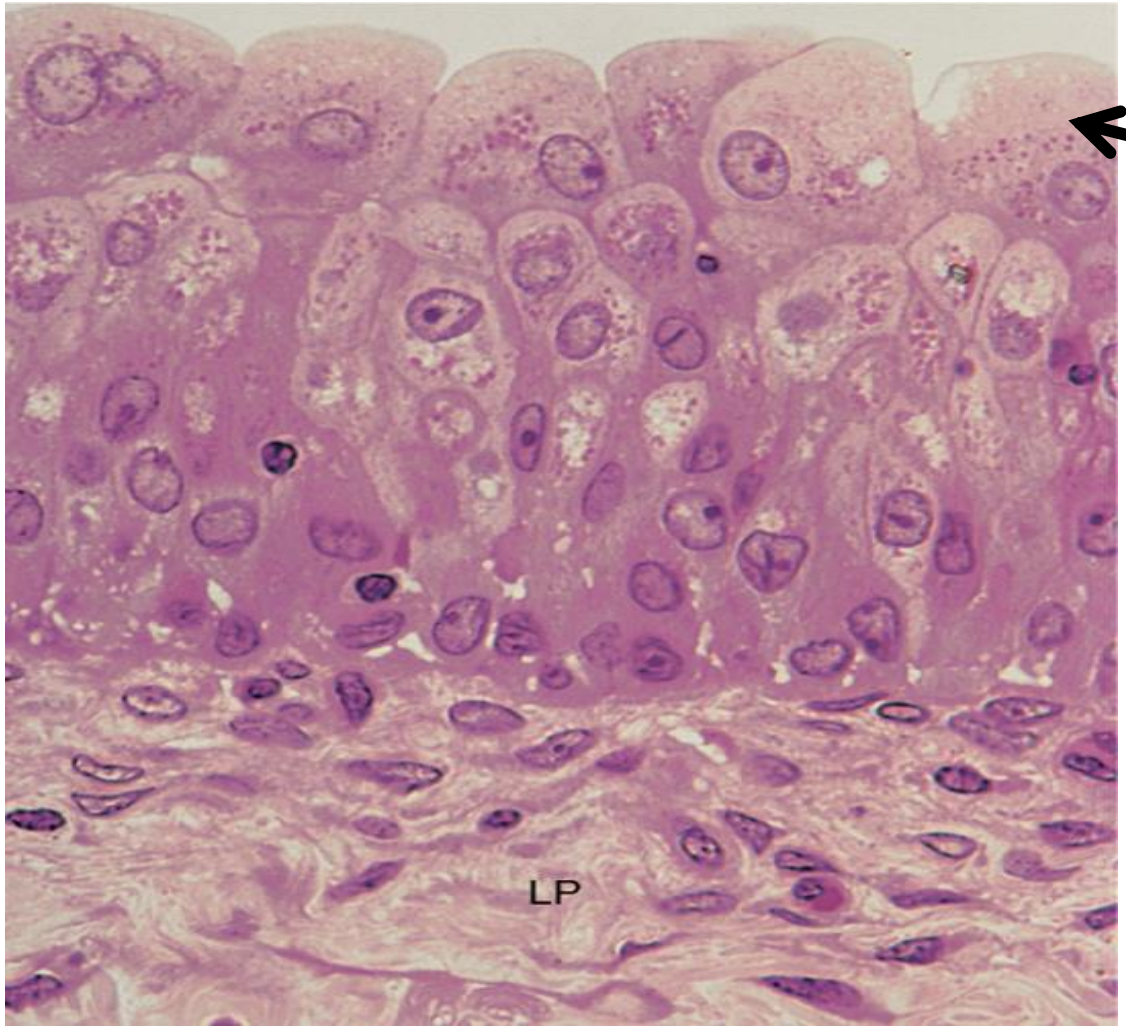
Distended

Transitional epithelium

Large superficial (facet or umbrella) cells with two nuclei



Urothelium



- Giant superficial (facet or umbrella) cells
- To enable them to stretch
- To withstand high tonicity urine
- With specialized luminal membrane

Summary 2

- **Lobes vs lobules** of kidney
- **Nephron** structure and function
- **Uriniferous tubules** and function
- **JG apparatus** and function
- Ureter/bladder and urothelium and its **membrane specialization**

End

Review questions

- What is a nephron?
- What constitutes the filtration barrier?
- Summarize the histological features of the renal tubules in the form of a table.
- What constitutes the JG apparatus? What is its function?