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Histology of the Urinary Tract

Michael Hortsch, Ph.D.

Department of Cell and Developmental Biology

University of Michigan

Fall 2008





James A. Shannon, Robert Berliner, and Homer W. Smith (center) prior to Smith's lecture on April 26, 1960 (NIH, Bethesda, Maryland, USA).

PD-CGV

National Library of Medicine

There are those who say that the human kidney was created to keep the blood pure, or more precisely, to keep our internal environment in an ideal balanced state. I would deny this. I grant that the human kidney is a marvelous organ, but I cannot grant that it was purposefully designed to excrete urine, or even to regulate the composition of the blood, or to subserve the physiological welfare of *Homo sapiens* in any sense. Rather I contend that the human kidney manufactures the kind of urine that it does, and it maintains the blood in the composition which that fluid has, because this kidney has a functional architecture; and it owes that architecture not to design or foresight or any plan, but to the fact that the earth is an unstable sphere with a fragile crust, to the geological revolutions that for 600 million years have raised and lowered continents and seas, to the predacious enemies, and heat and cold, and storms and droughts, the unending succession of vicissitudes that have driven the mutant vertebrates from sea into fresh water, into desiccated swamps, out upon the dry land, from one habitation to another, perpetually in search of the free and independent life, perpetually failing for one reason or another to find it.

Homer W. Smith, "Studies In the Physiology of the Kidney" (1939)

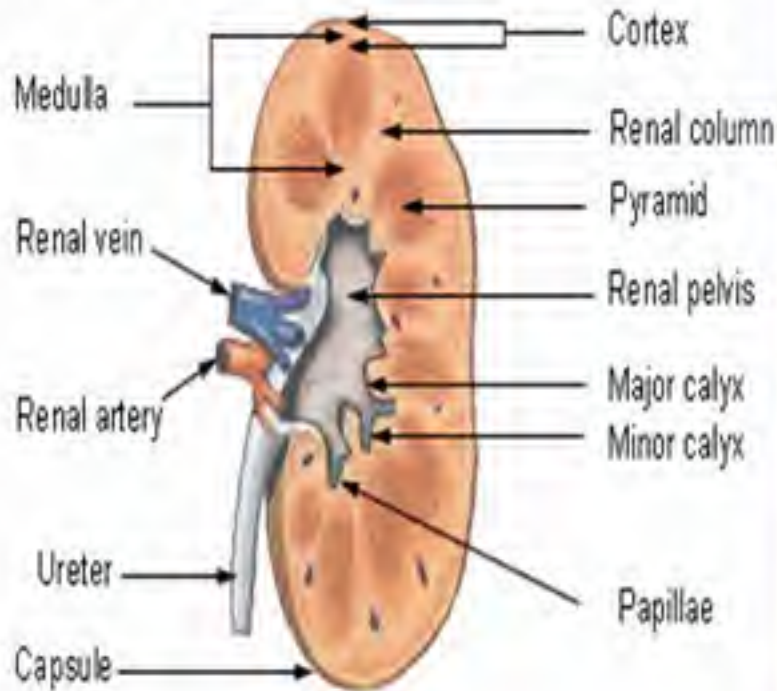
Objectives Renal Histology:

- Study the general organization of the kidney and how cortical and medullar structures relate to each other.
- Follow the blood supply distribution network throughout the kidney tissue.
- Define the nephron as the principle functional unit of the kidney.
- Learn about the different renal glomerular components and how they accomplish blood filtration.
- Discuss filtrate conditioning by the proximal convoluted tubules.
- Study the changes in the epithelial lining along the nephron and collecting tubules and how they tie into the physiological role of the kidney
- Understand the organization and function of the different postglomerular blood vessels.
- Recognize the cellular components of the juxtaglomerular junctions and their physiological roles.
- Learn about the histological appearance of the ureter and bladder.

Kidney Functions:

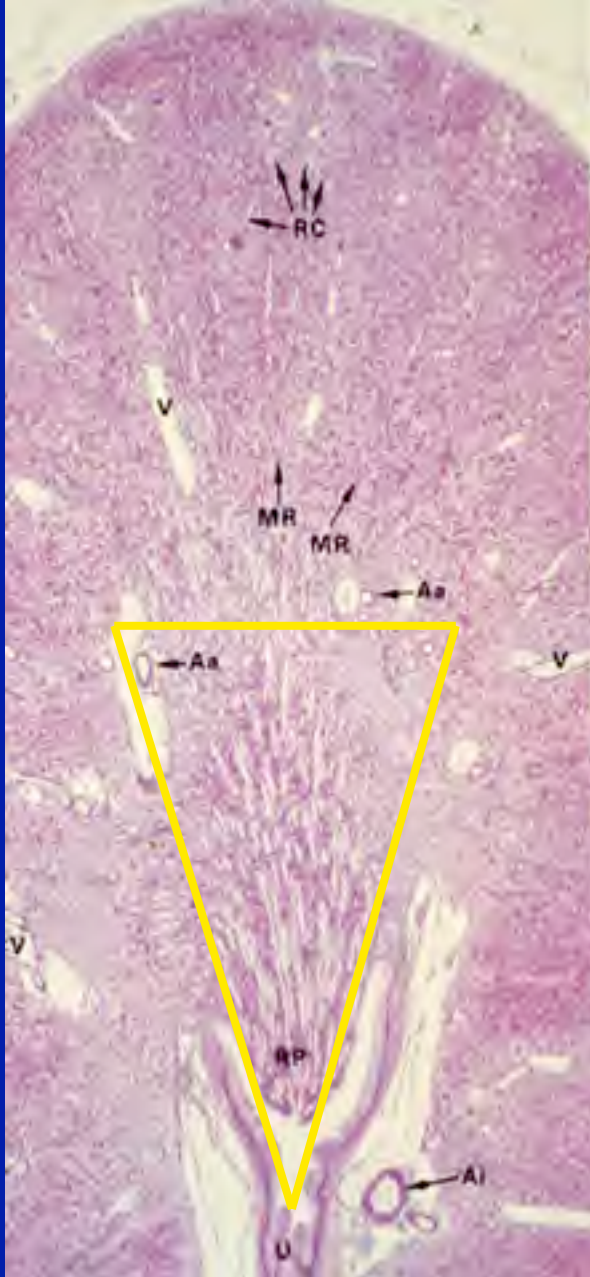
- Filtration of most small molecules from blood plasma to form a filtrate.
- Selective reabsorption of most of the water and other molecules from the filtrate, leaving behind waste products to be secreted.
- Secretion of some excretory products directly into the filtrate (e.g., H^+ by Na^+/H^+ exchanger).
- Endocrine functions: Maintenance of blood pressure (renin-angiotensin-aldosterone system), synthesis of erythropoietin, and activation/hydroxylation of 25-OH vitamin D_3 (Ca^{2+} metabolism).

Frontal section through the Kidney



The kidney is subdivided in lobes with medullary and cortical areas

The kidney is subdivided in lobes with medullary and cortical areas



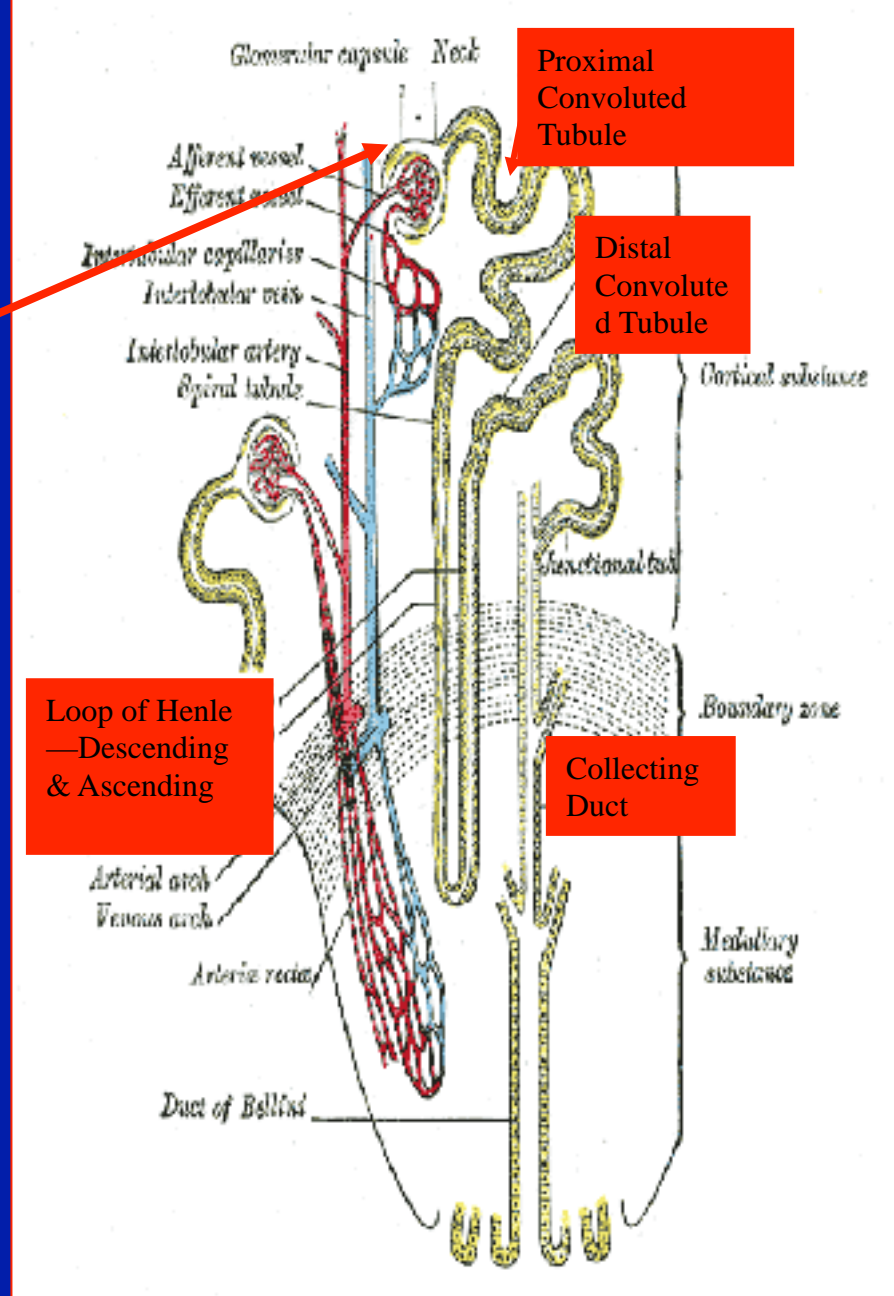
Medium magnification of a single kidney lobe:
The medulla is characterized by long straight tubules, which extend into cortical areas. It has a triangular shape with the tip pointing to the hilum (medullary pyramid)



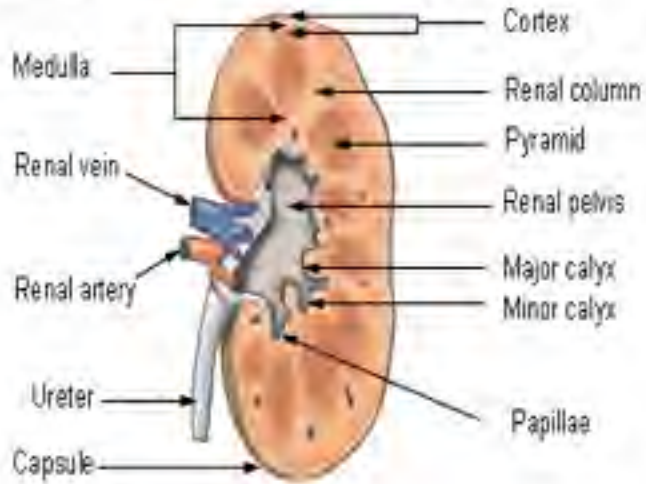
Marcello Malpighi (1628-1694)

Renal or Malpighian corpuscle

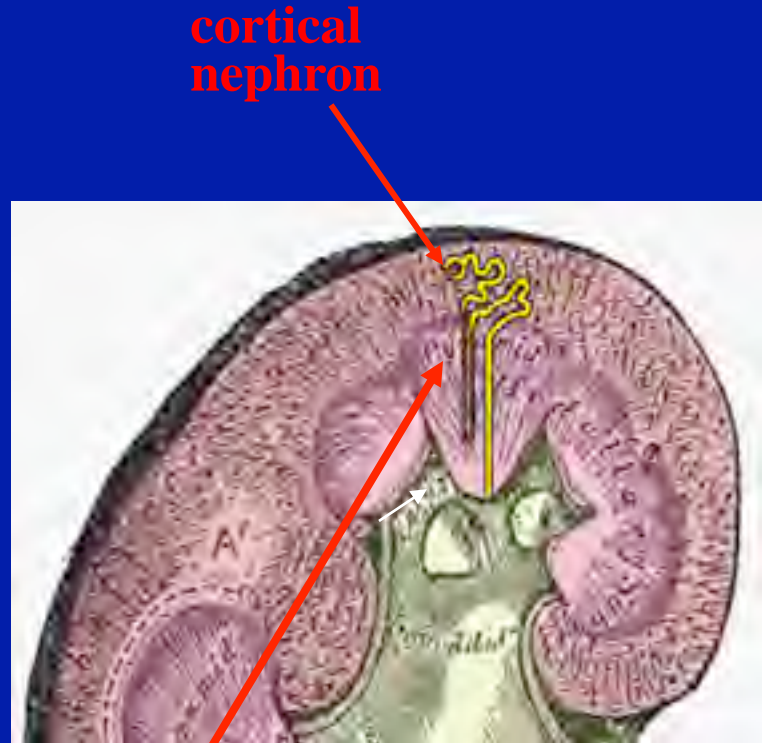
The nephron is the principle functional unit of the kidney. There are about 1.3 million nephrons in a normal human kidney. It consists of a ball-shaped renal or Malpighian corpuscle, which carries out blood filtration, and a long tubular part, which carries out filtrate conditioning and processing.



Frontal section through the Kidney



PD-GOV U.S. Federal Government



PD-EXP Gray's Anatomy

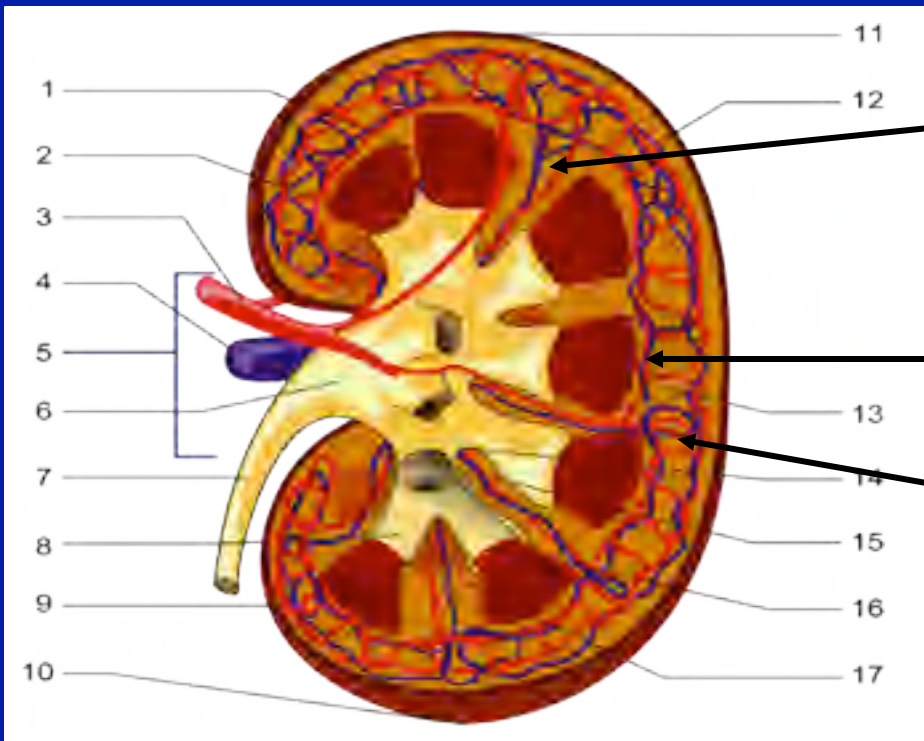
cortical nephron
cortico medullary nephron would be here



PD-INEL Histology – A Text and Atlas; 5th edition, 2006, Ross and Pawlina, Lippincott Williams and Wilkins Fig 20.6

Arteriogram of a human kidney:
Blood supply and drainage is via the hilum by the renal artery and the renal vein, respectively.

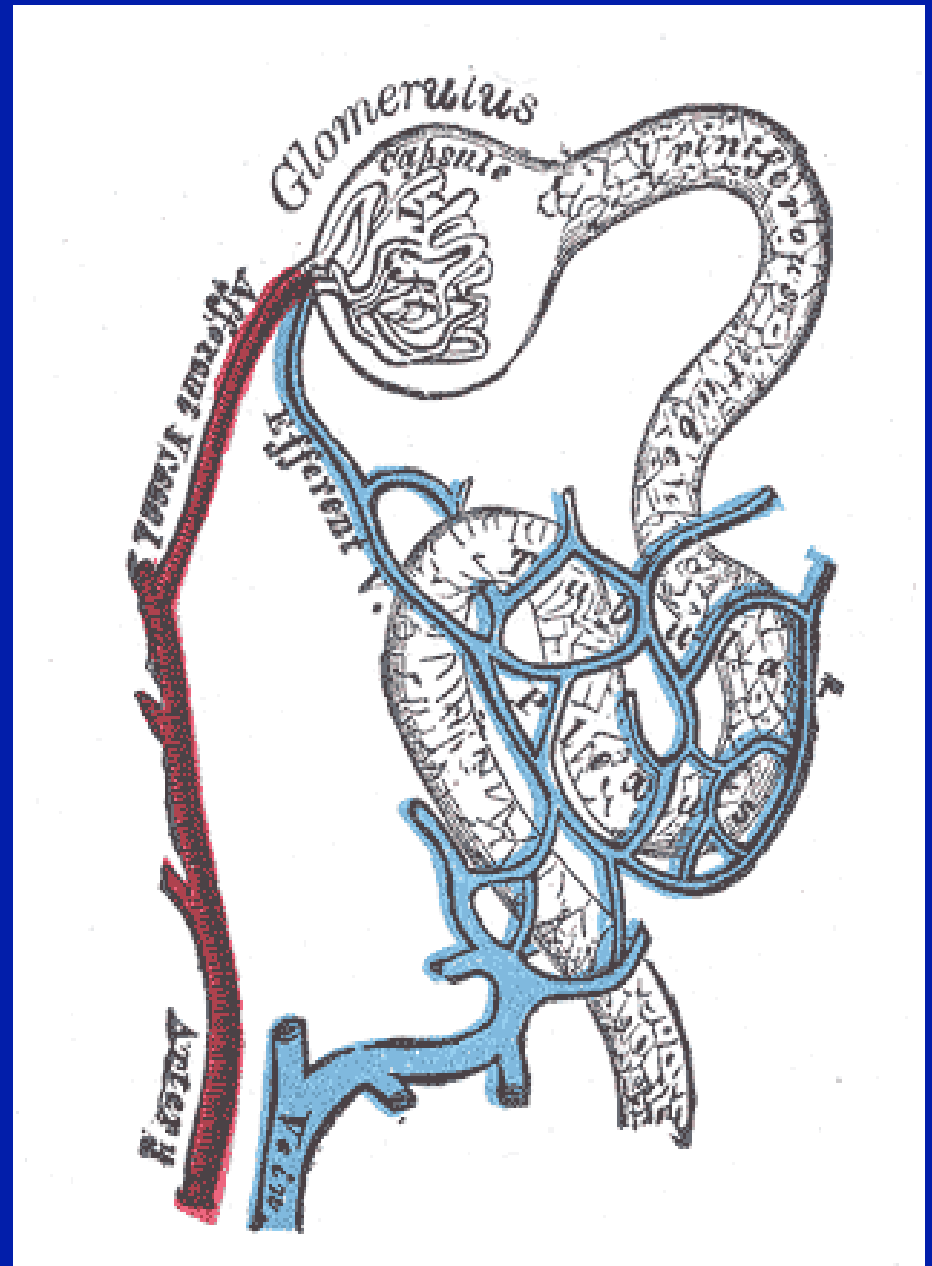


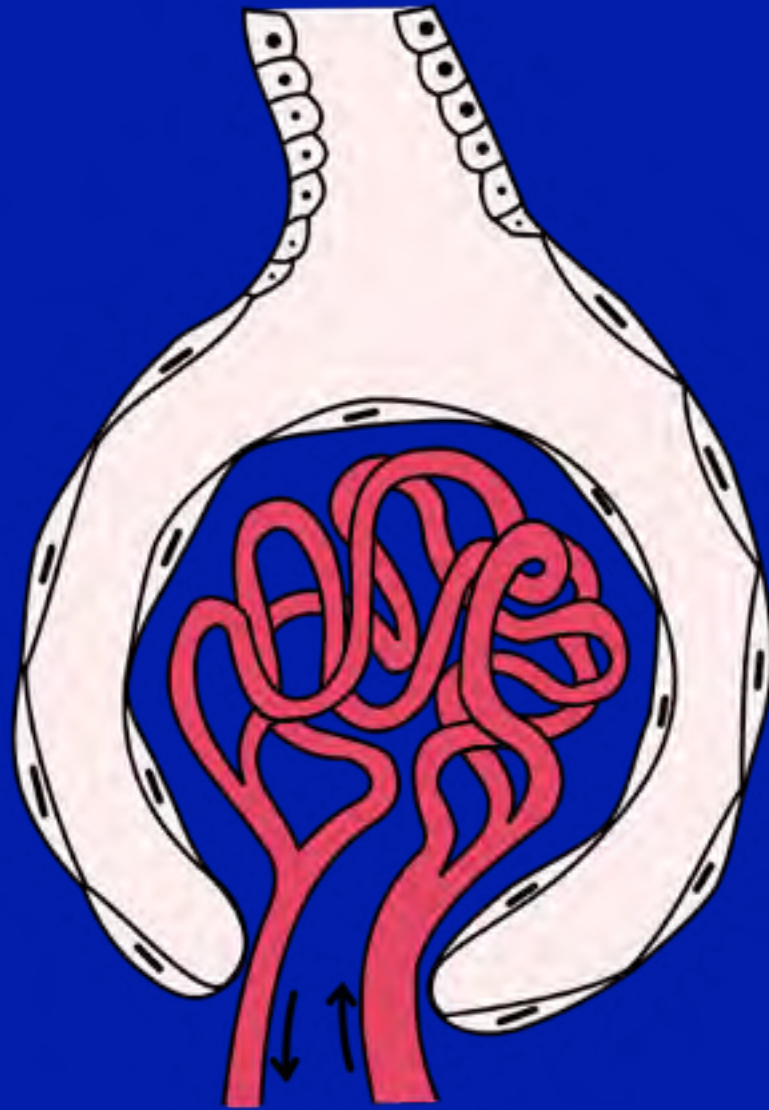


Interlobar arteries split at the cortico-medullary junction into arcuate arteries. Arcuate arteries branch into interlobular arteries, intralobular arteries, which both supply afferent arterioles.

- | | |
|----------------------|----------------------------|
| 1. Renal pyramid | 10. Inferior renal capsule |
| 2. Interlobar artery | 11. Superior renal capsule |
| 3. Renal artery | 12. Interlobar vein |
| 4. Renal vein | 13. Nephron |
| 5. Renal hilum | 14. Minor calyx |
| 6. Renal pelvis | 15. Major calyx |
| 7. Ureter | 16. Renal papilla |
| 8. Minor calyx | 17. Renal column |
| 9. Renal capsule | |

Blood filtration takes place in the renal corpuscle through the walls of the capillaries in the renal corpuscle. The residual blood components are drained by the efferent arteriole.

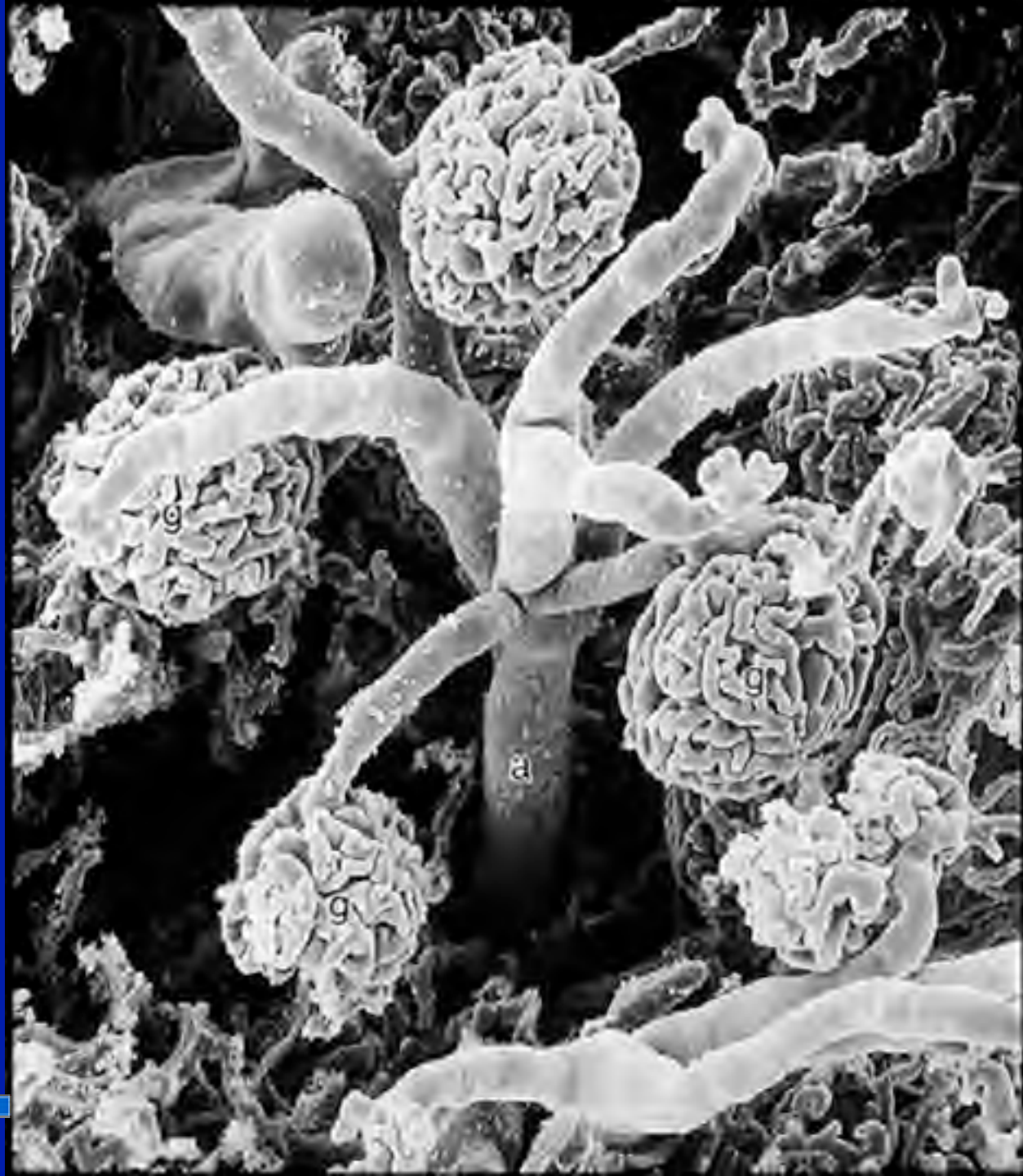


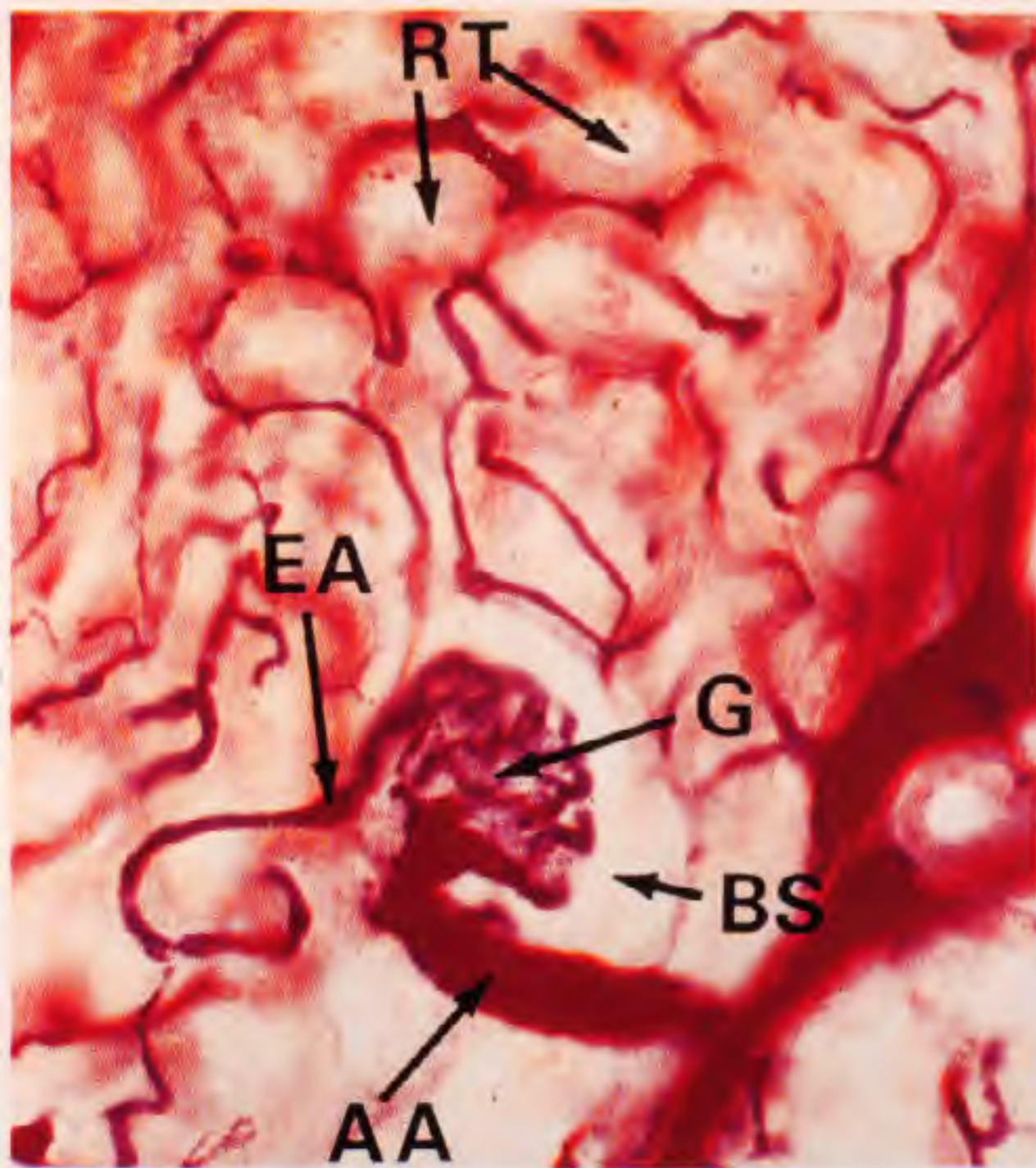


Reproduction of Gray's figure 1130 by Mysid, Wikipedia.

The capillary system of a renal corpuscle is called the glomerulus

Scanning electron
micrograph of a
cast of several
glomeruli





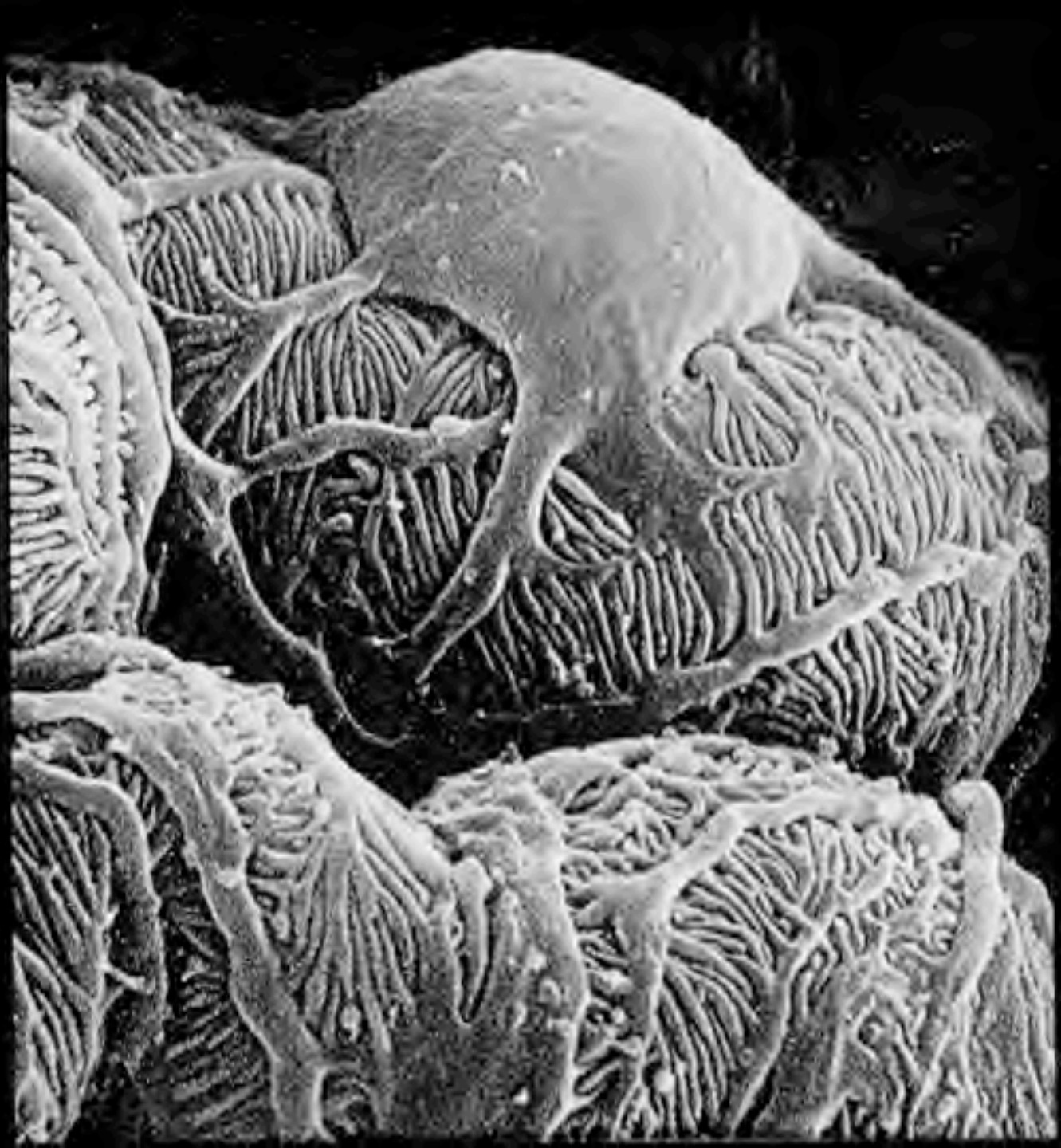
Blood supply of a glomerulus is supplied by the afferent arteriole and drained by the efferent arteriole. Both arterioles enter/exit the renal corpuscle at the vascular pole.



PD-INEL Color Atlas of Histology, 1992, Erlandsen and Magney, Mosby Book Fig 18-8

The renal blood filtration barrier consists of a specialized basement membrane and two cellular components, the fenestrated (diameter 50-100 nm) capillary endothelium and the podocytes.

Extensions of the podocyte cell, called pedicels, wrap around the capillary system of the glomeruli





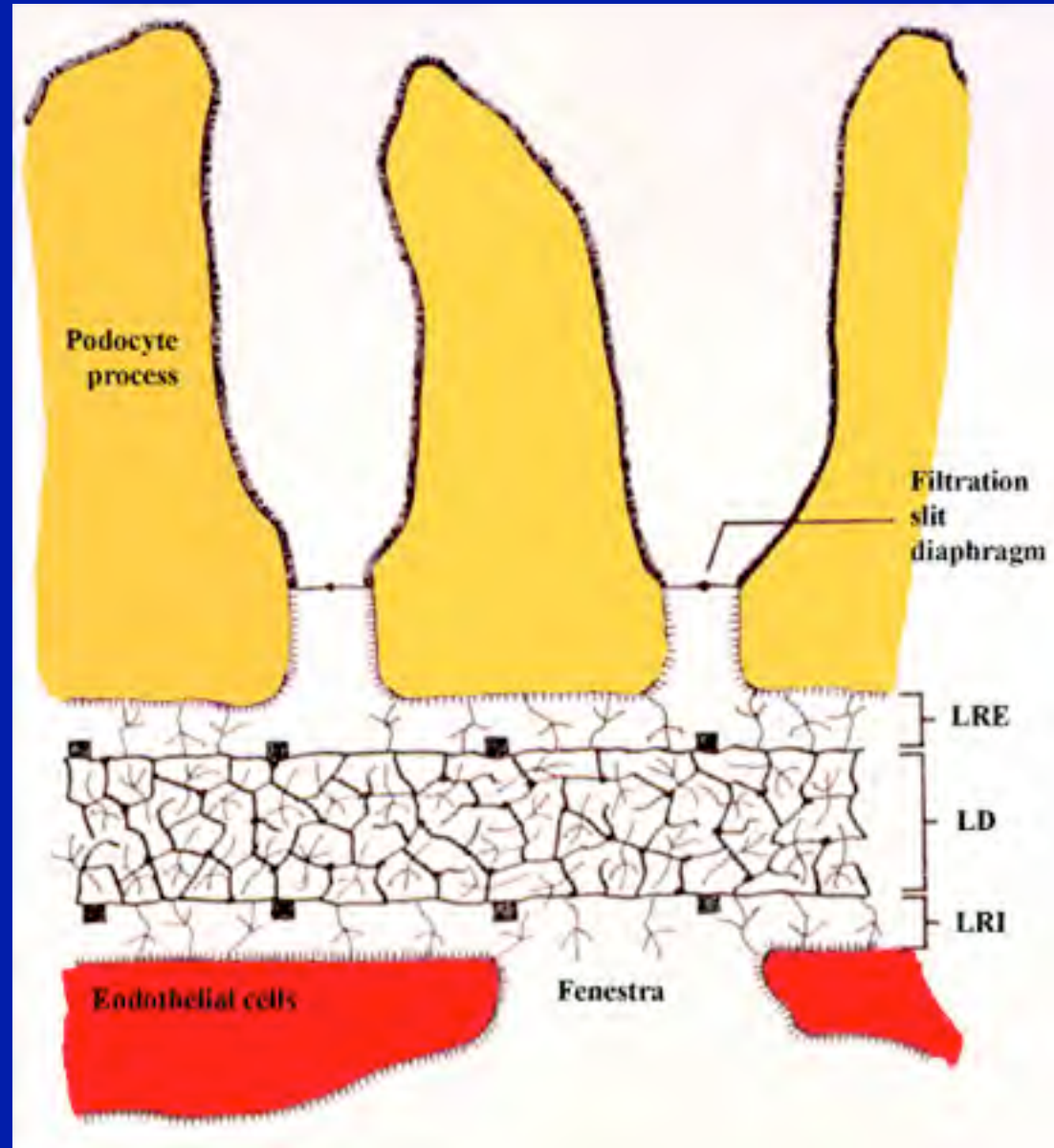
Artistic illustration of the renal filtration barrier

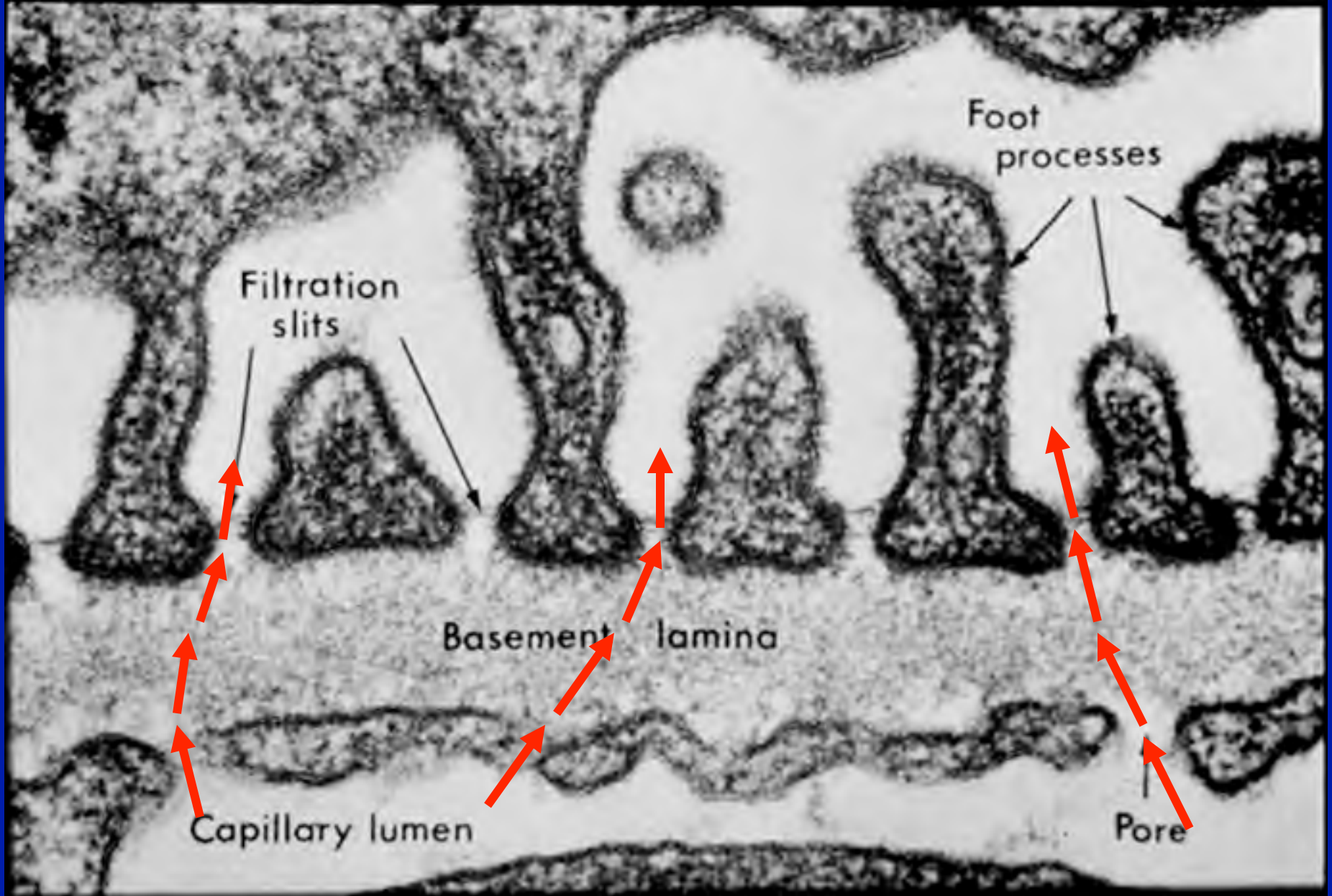


Image of renal
filtration barrier
removed

The pedicels of the podocytes form filtration slits, which are on average about 25 nm wide.

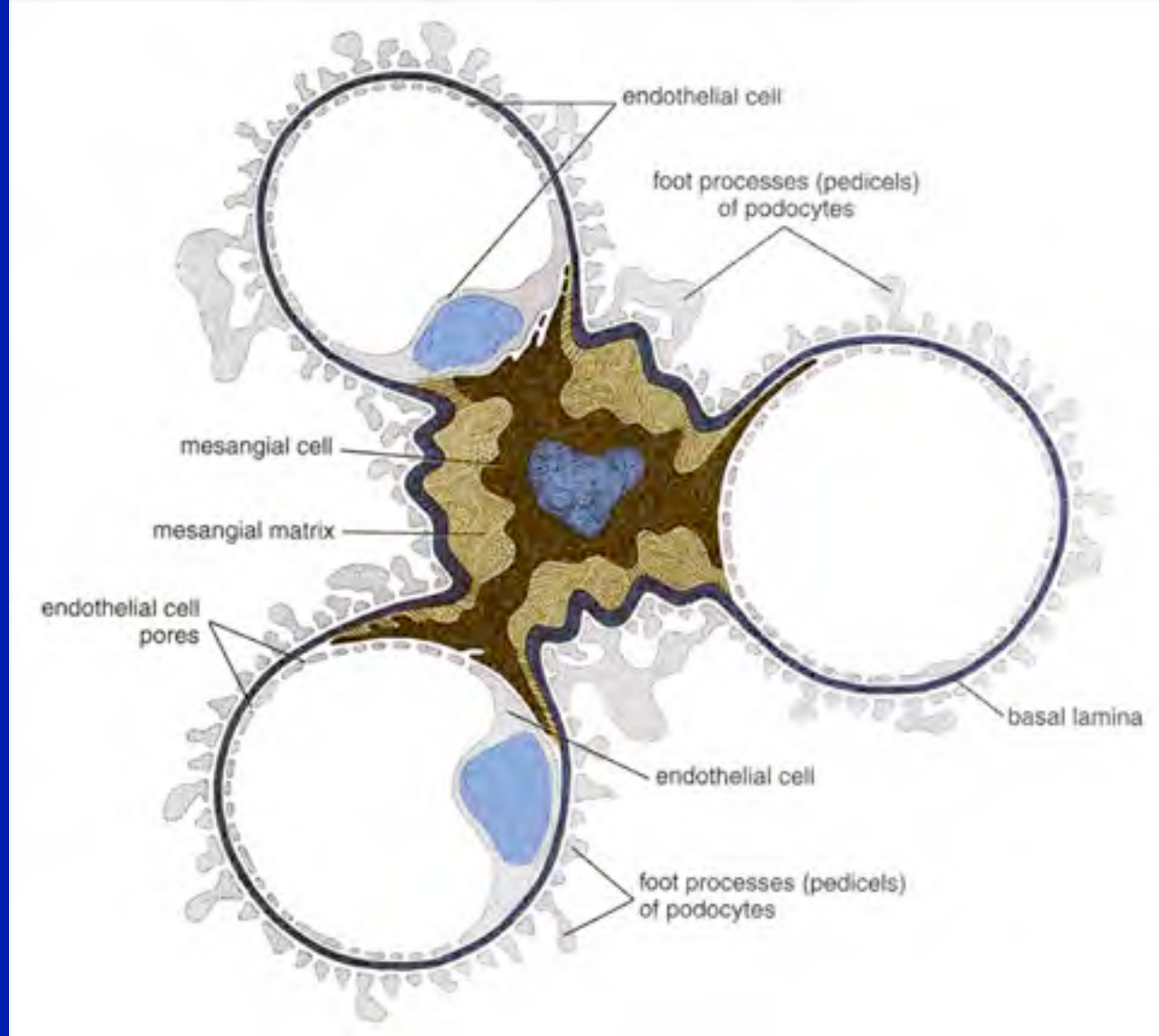
The renal filtration basement membrane is 240-350 nm thick and is produced by both by podocytes and capillary endothelial cells. It is rich in negatively charged glycoproteins. Since it is a double basement membrane, it contains two lamina rara layers. It will exclude particles larger than 10 nm and 60,000 to 70,000 Daltons in size.





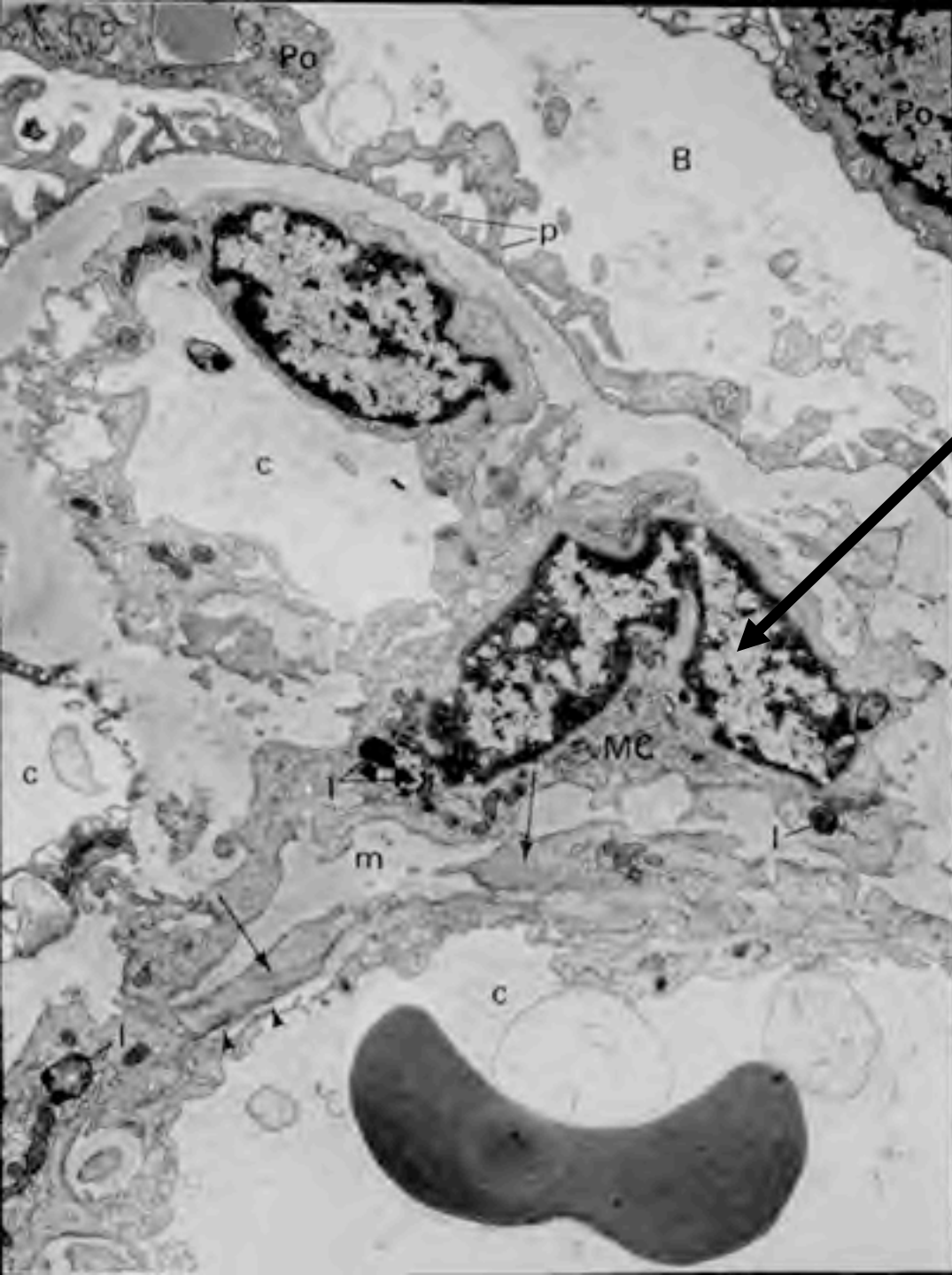
PO-1WEL "Concise Histology" by Fawcett and Jensch, 1997, Chapman & Hall Fig 21-8

Electron micrograph of the renal filtration barrier



 A Text and Atlas, 5th edition, 2006, Ross and Pawlina, Lippincott Williams and Wilkins Fig 20.10

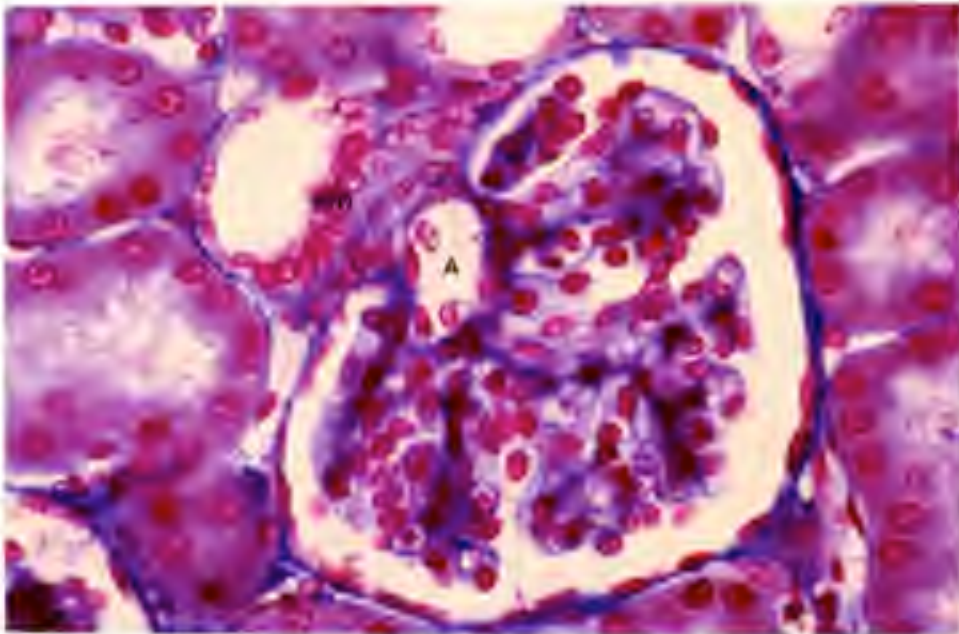
Mesangial cells maintain the glomerular basement membrane and also contribute to its formation.



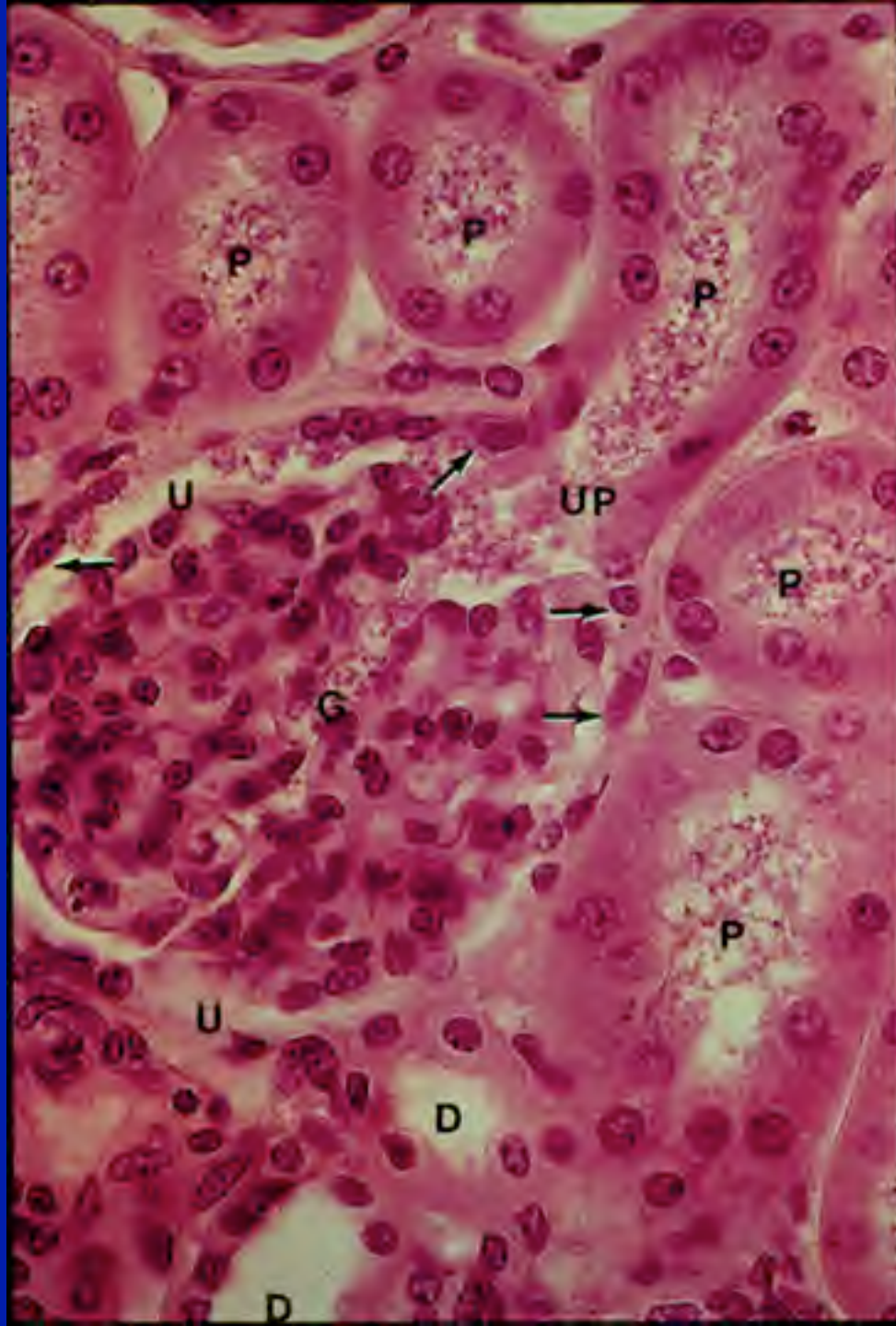
Electron micrograph
micrograph of a
mesangial cell.

In response to
angiotensin II the
extensions of mesangial
cells contract and reduce
the blood flow through
the glomerular
capillaries. Atrial
natriuretic peptide (ANP)
causes mesangial cells to
relax.

Bowman's capsule has a visceral (podocyte layer) and a parietal cell layer (simple squamous epithelium). The primary filtration product is collected between the two layers in the urinary space and is drained from the renal corpuscle at the urinary pole.



Sir William Bowman (1816-1892)

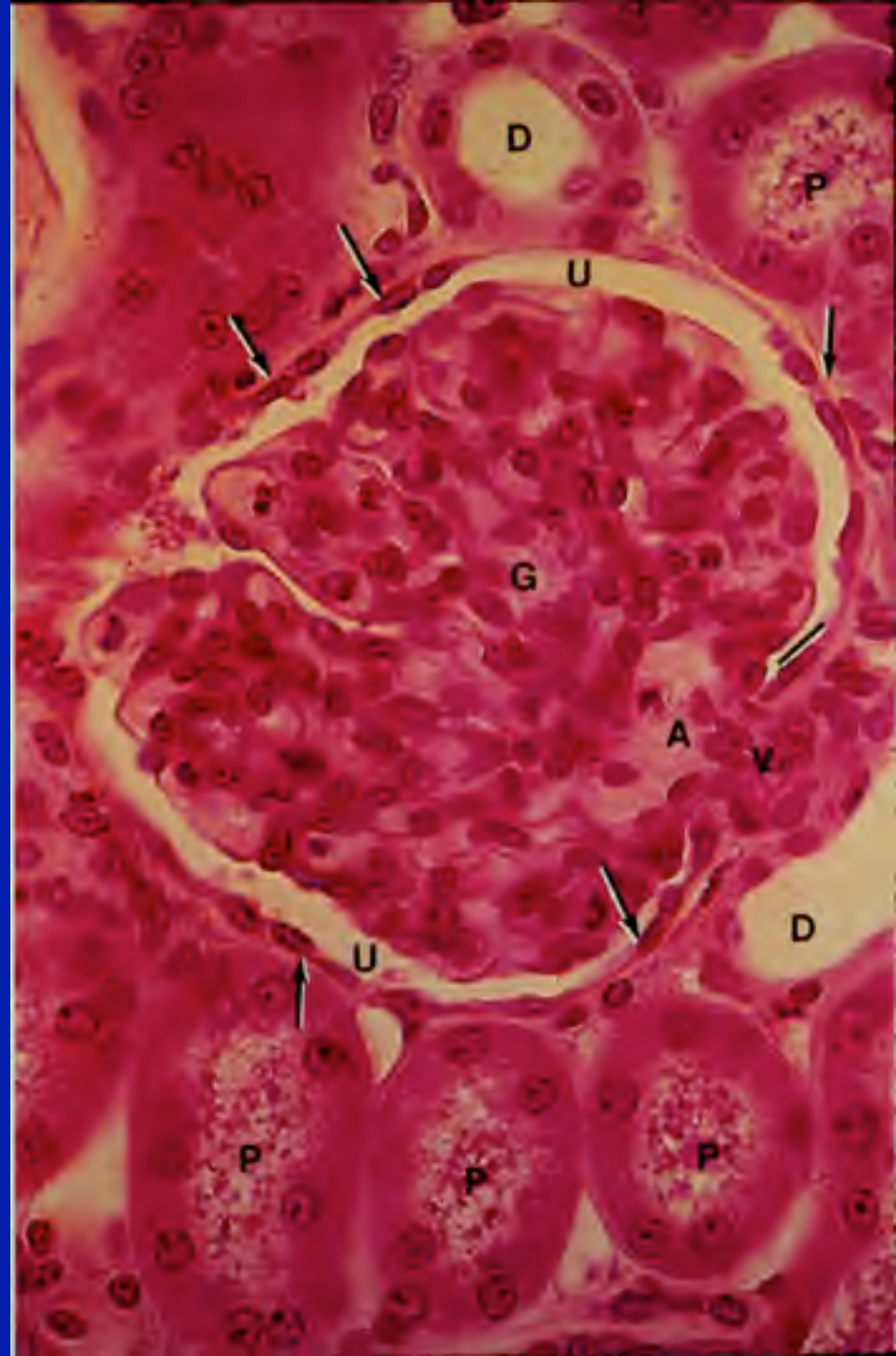


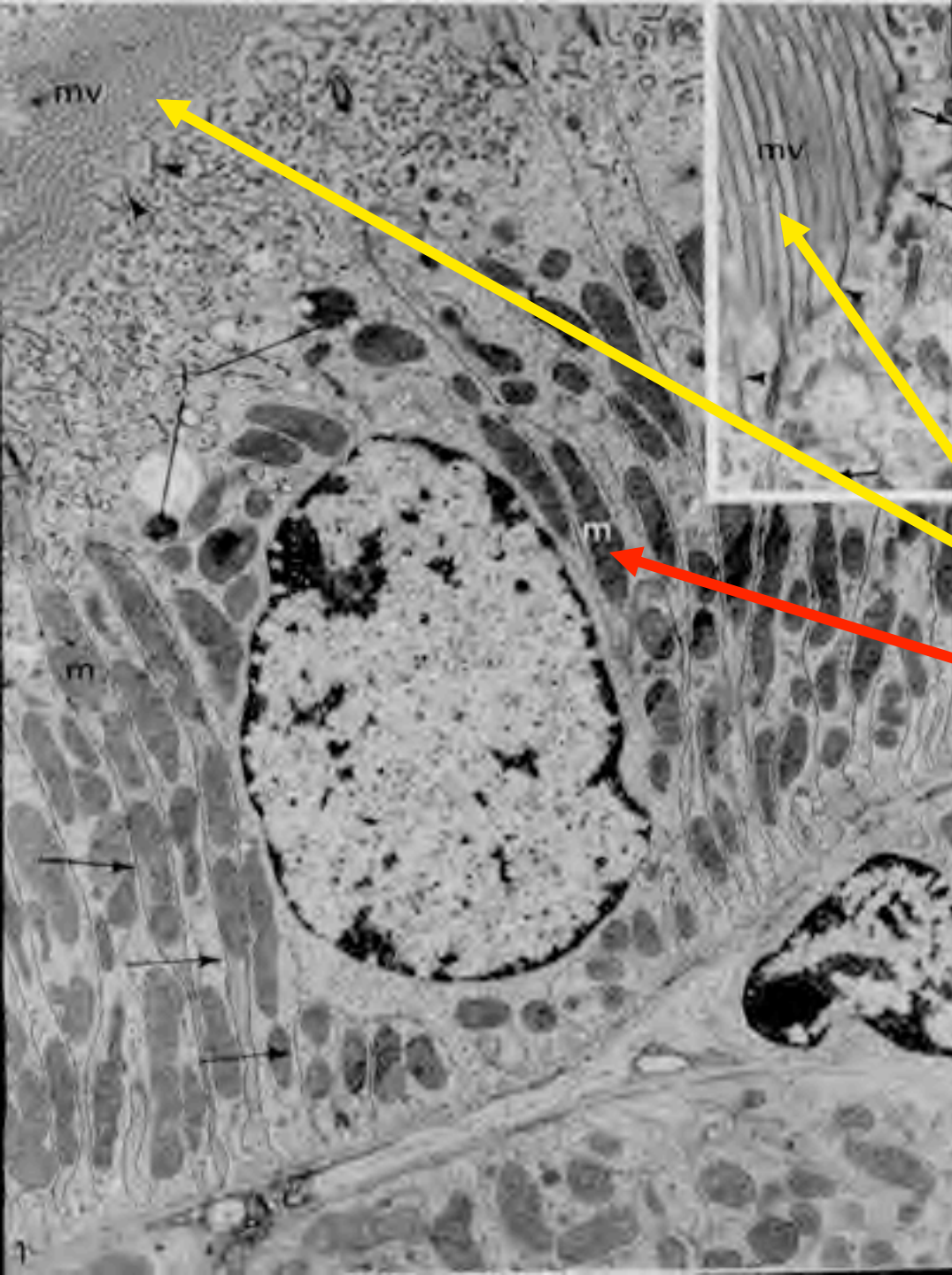
At the urinary pole starts the proximal convoluted tubular system (PCT).



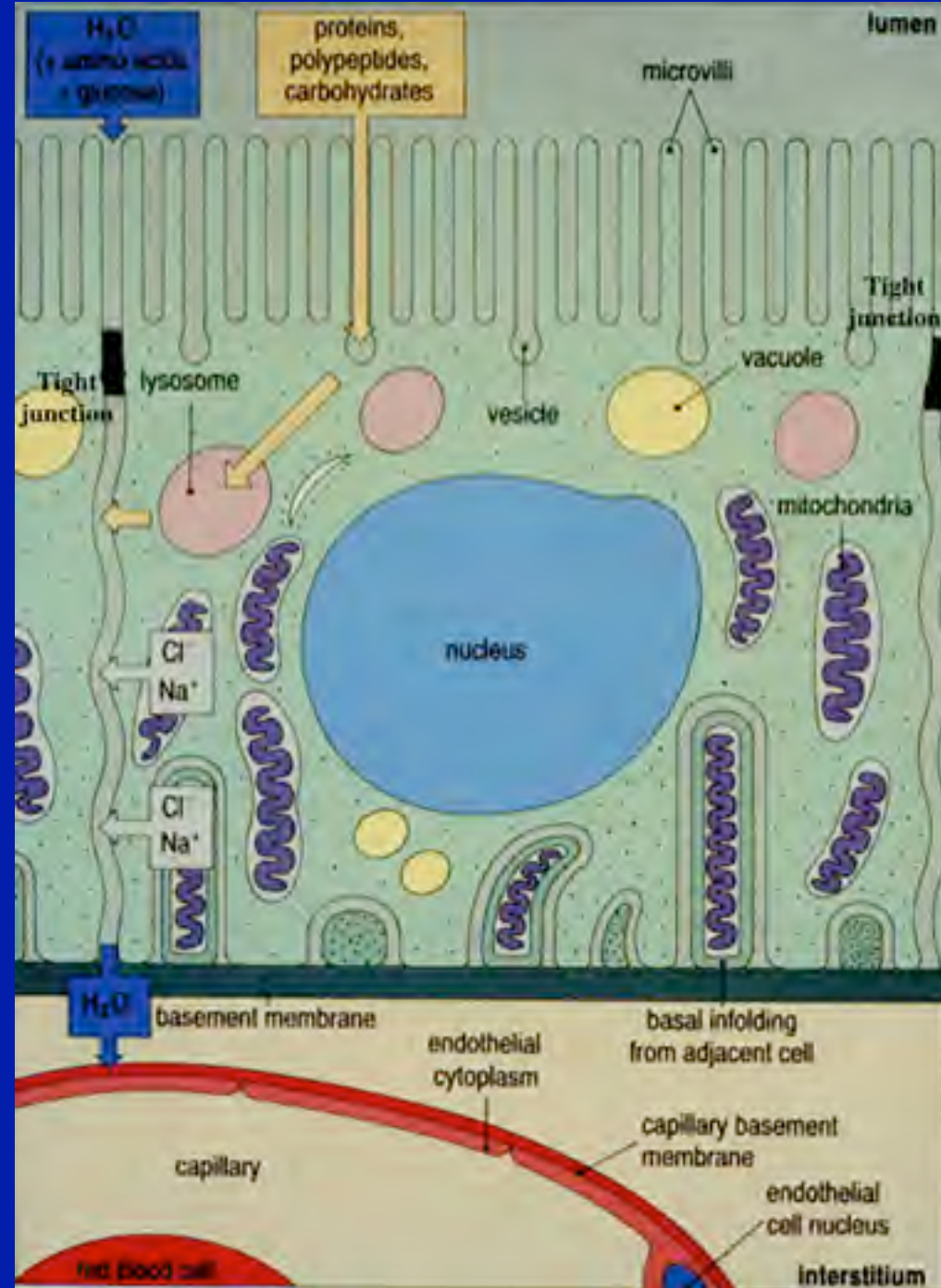
The PCT system has a simple cuboidal epithelium, that contains a characteristic apical brush border.

The PCT section is the longest subregion of the nephron tubular system (in humans about 15 mm). Therefore, in the cortex most cross-sections of tubules will represent PCT.





This electron micrograph shows the characteristic brush border and numerous mitochondria that provide energy for various pump and salvage processes.



The PCT epithelium is sealed
 ← by tight junctions.

Salt and small nutrient molecules are transported to the basal aspect of the epithelium.

The basolateral plasma membrane is enriched in Na^+/K^+ -ATPase complexes, which act as sodium pumps.

The initial and the last segment of the Henle's loop is lined by a simple cuboidal epithelium

The middle segment or thin limb of Henle's loop is lined by a simple squamous epithelium.



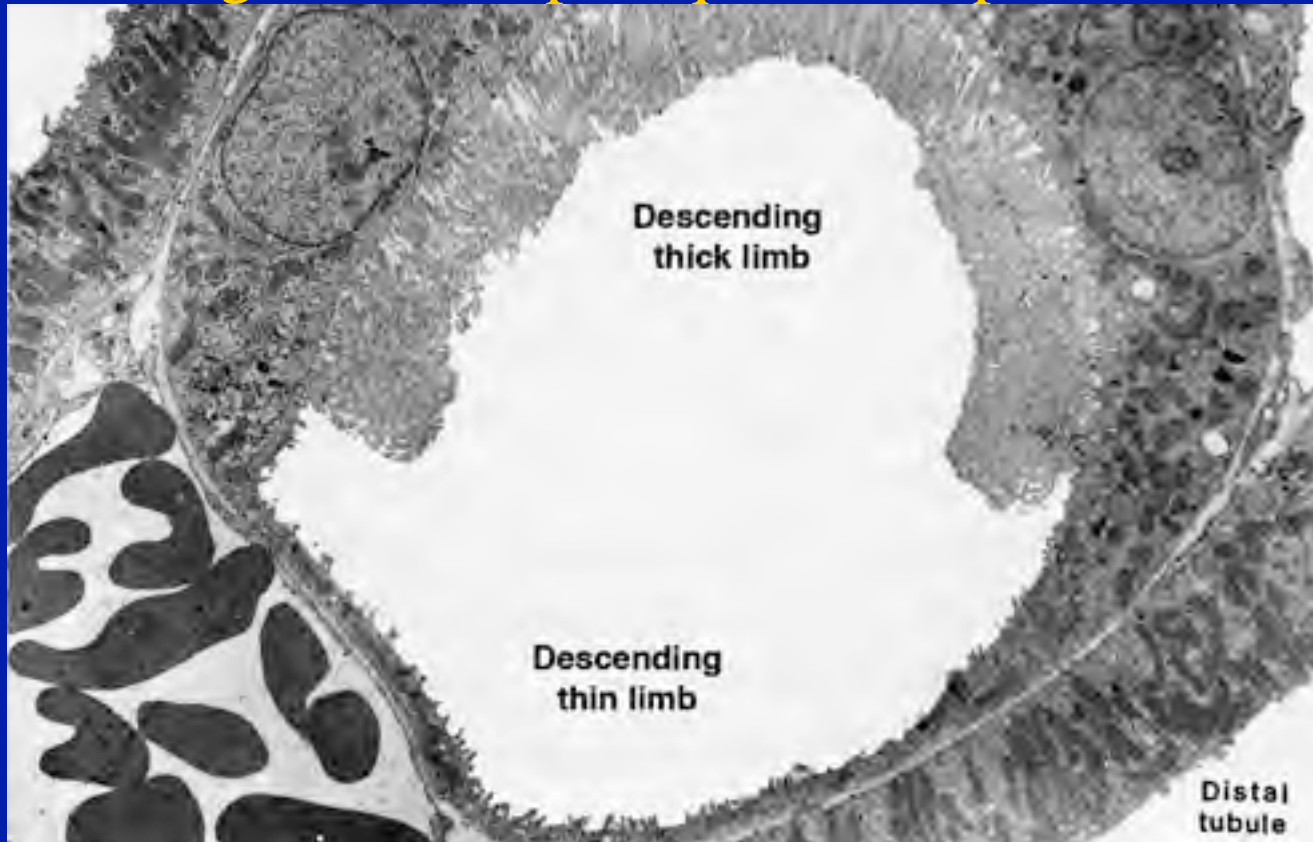
Original from Basic Histology – Text & Atlas; 10th edition, 2003; Junqueira and Carneiro, Lange McGraw-Hill Figure 19-16

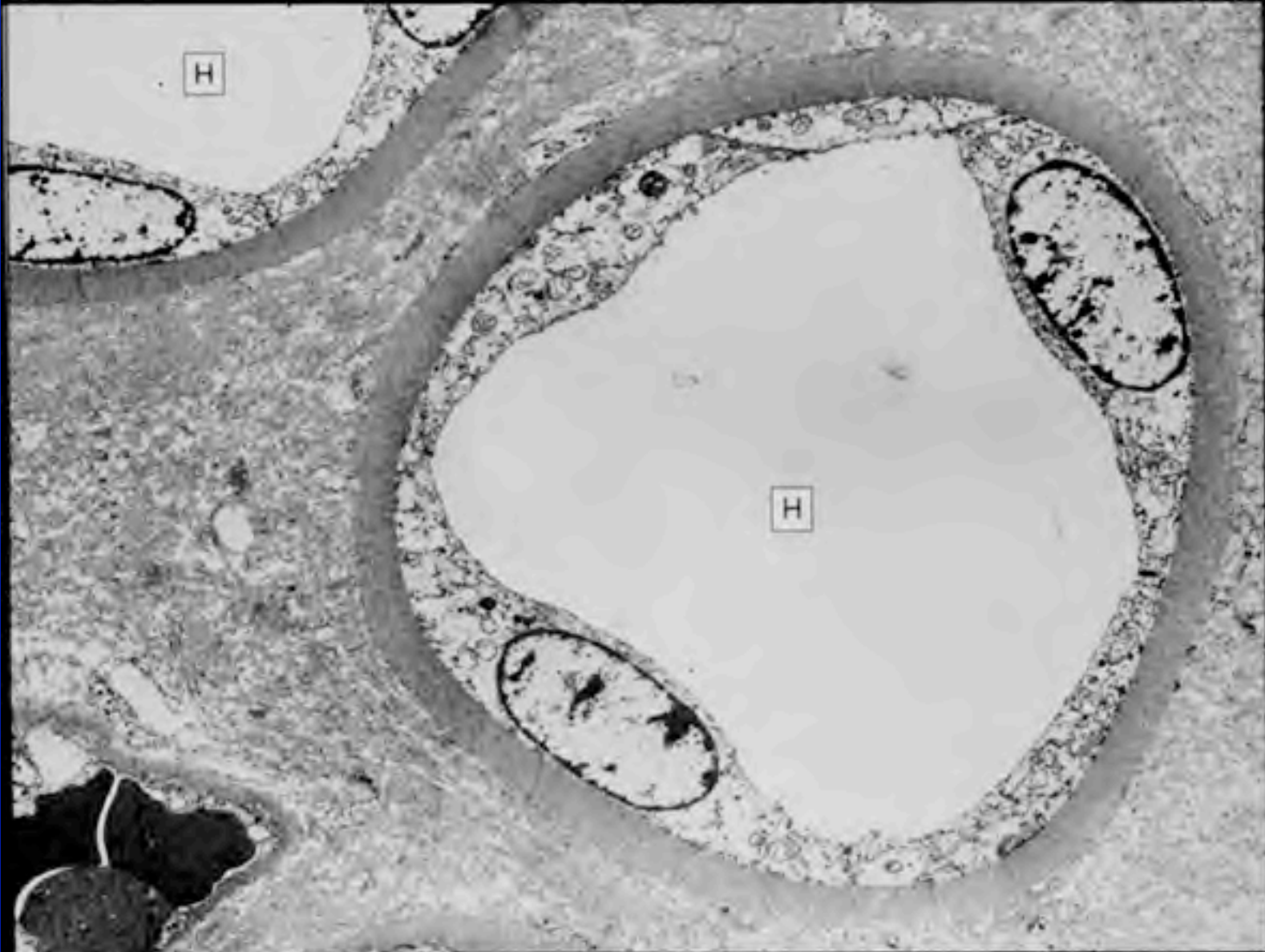


Friedrich Gustav Jacob Henle (1809-1885)

Transverse section of pyramidal substance of kidney of pig, the bloodvessels of which are injected. a. Large collecting tube, cut across, lined with cylindrical epithelium. b. Branch of collecting tube, cut across, lined with cubical epithelium. c, d. Henle's loops cut across. e. Bloodvessels cut across. D. Connective tissue ground substance.

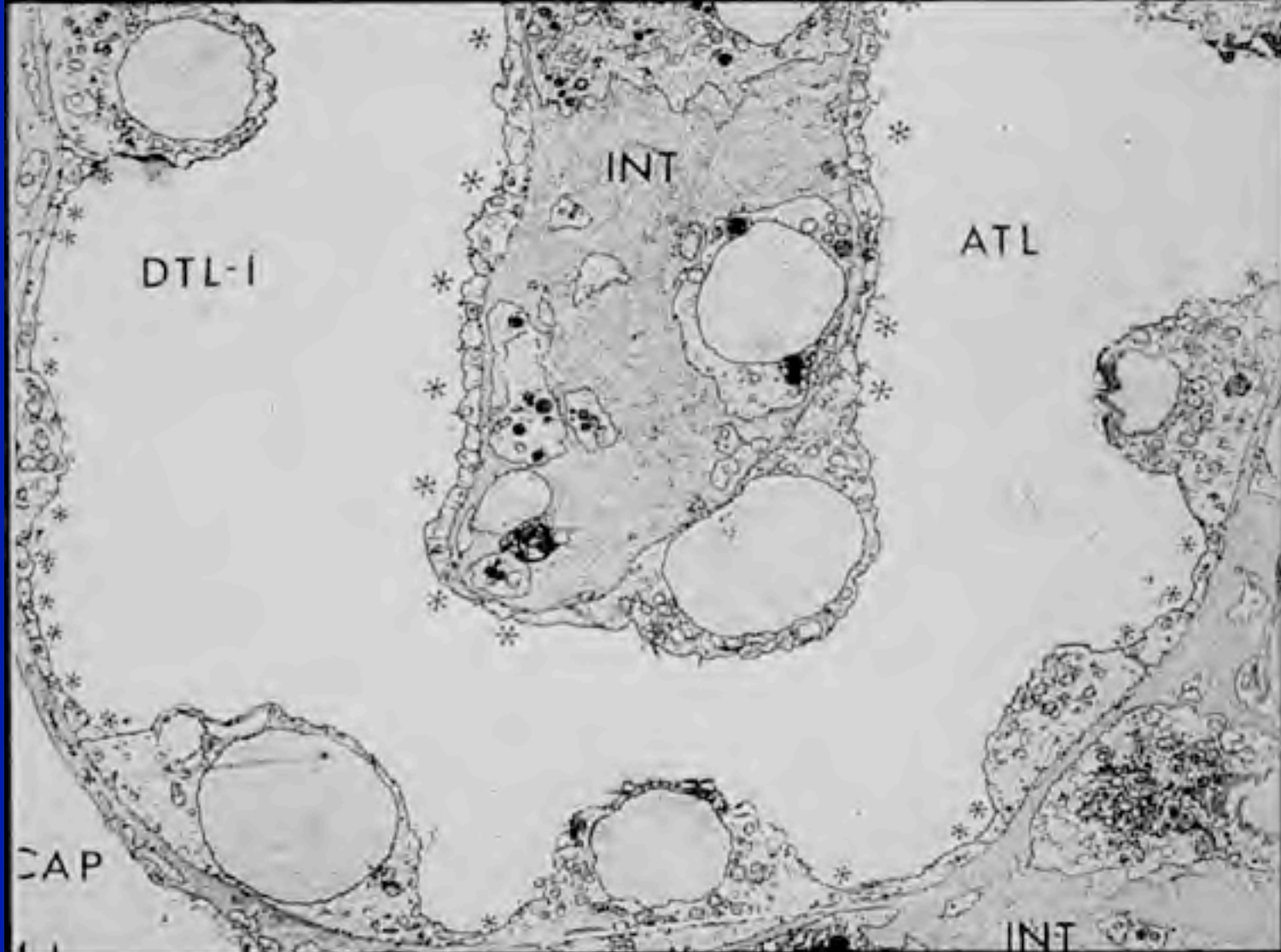
The PCT turns into the loop of Henle and continues downwards into the medulla. The initial segment is the straight descending thick limb (simple cuboidal epithelium with an apical brush border). Around the outer part of the medulla it abruptly changes into the thin descending limb, losing its brush border and turning into a simple squamous epithelium.





PD-INEL Human Histology, 2nd edition, 1997, Stevens and Lowe, Mosby Fig 15.19

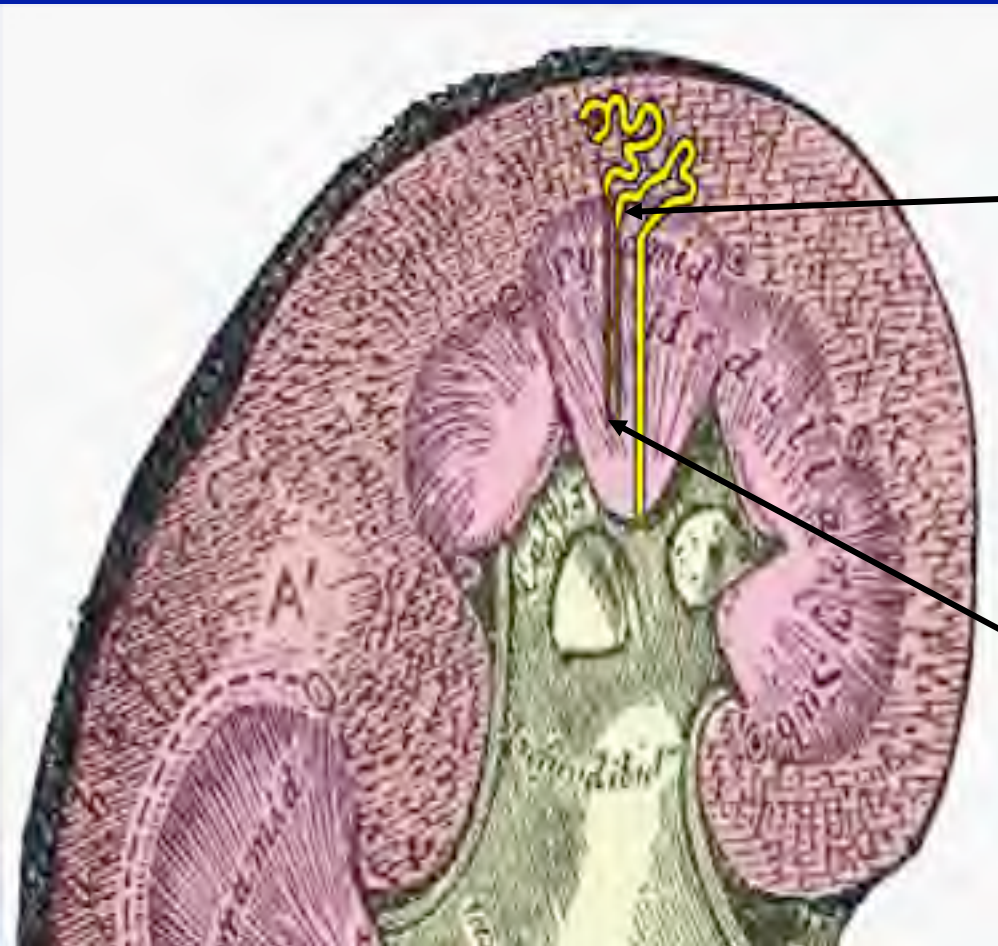
The thin limb of the loop of Henle has a similar appearance as blood capillaries.



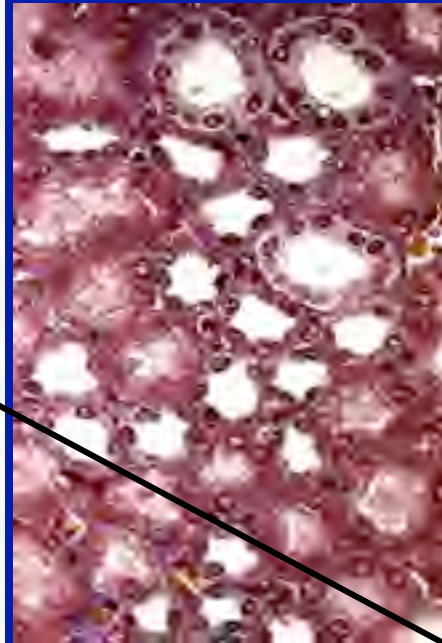
Color Atlas of Histology, 1992, Erlandsen and Magney, Mosby Book Fig 18-18

In the medulla the thin limb of the loop of Henle makes a turn back towards the renal corpuscle at the beginning of the nephron.

Histological differences between the outer and the inner (deep) medulla



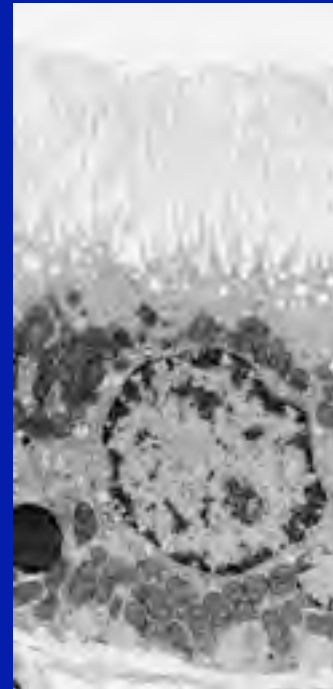
Outer medulla



Inner medulla

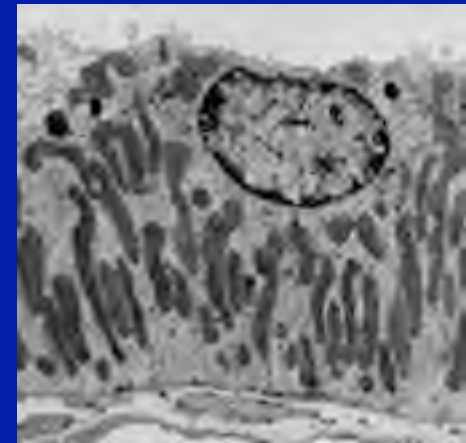
PD-INEL Japanese slide set (Humio Mizoguti, Department of Anatomy, Kobe University School of Medicine, Slides #454 and #458)

The Distal Convoluted Tubule (DCT) is shorter (about 5 mm in humans) than the PCT segment and has no apical brush border.

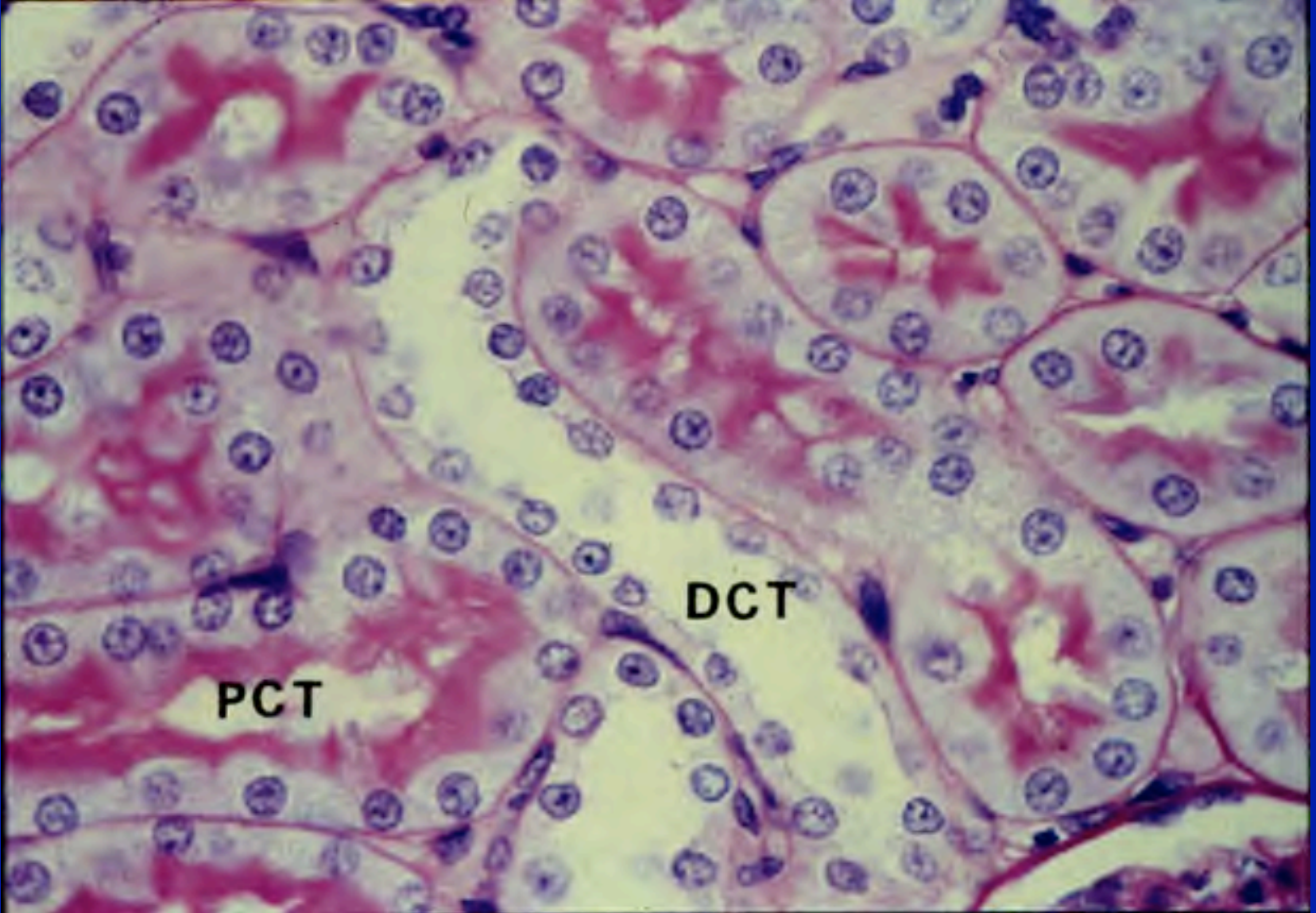



PCT

vs.



DCT



 Wheater's Functional Histology; 3rd edition, 1993, Burkitt, Young, and Heath; Churchill Livingstone, Fig 16.18b

PCT = Proximal Convoluted Tubule
DCT = Distal Convoluted Tubule

DCT from several nephrons release the processed filtrate into collecting tubules, which merge to form collecting ducts.



Transverse section of pyramidal substance of kidney of pig, the bloodvessels of which are injected. a. Large collecting tube, cut across, lined with cylindrical epithelium. b. Branch of collecting tube, cut across, lined with cubical epithelium. c, d. Henle's loops cut across. e. Bloodvessels cut across. D. Connective tissue ground substance.

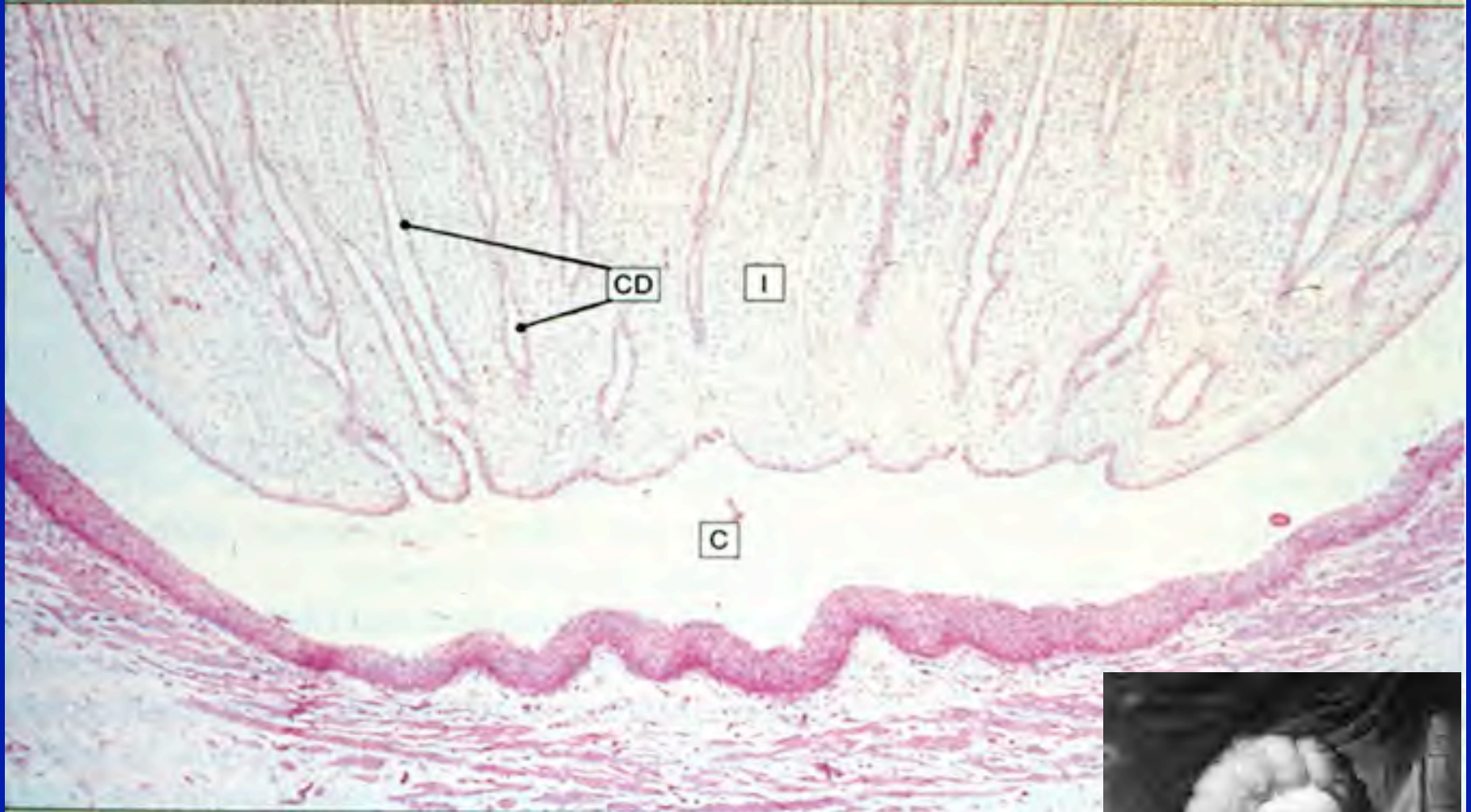


Collecting tubules can be recognized by a clear lateral demarcation between neighboring epithelial cells.

In contrast to the other tubular parts of the nephron, lateral membrane infoldings and interdigitations are missing, making the lateral cell contacts more visible.



Collecting ducts are formed by the fusion of collecting tubules and extend towards the renal papilla and the renal calyx.



Human Histology, 2nd edition, 1997, Stevens and Lowe, Mosby, Fig 15.36

The large collecting ducts at the tip of the medullary pyramid are referred to as the ducts of Bellini. The final processed filtration product is collecting in the major calyces.



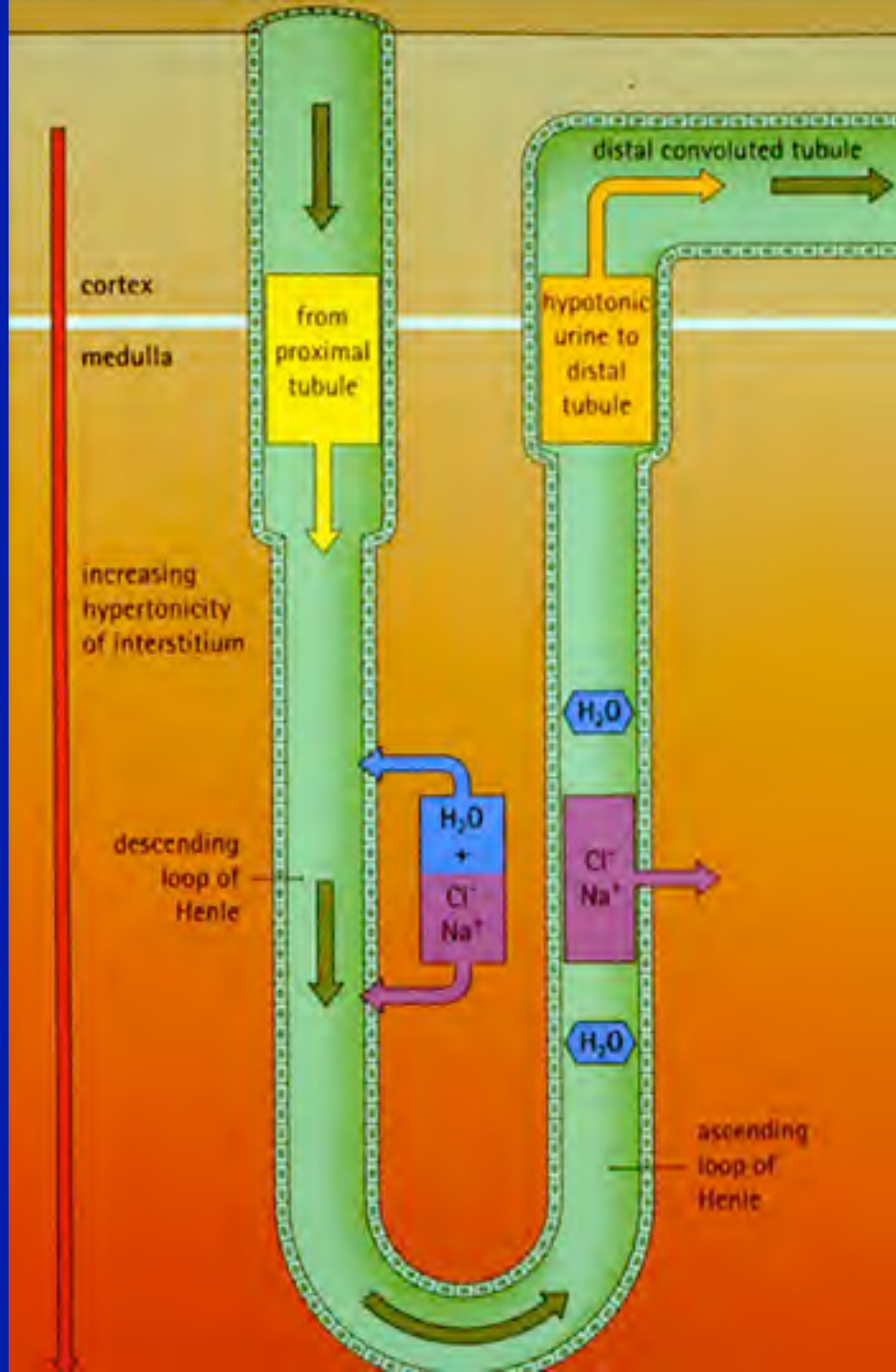
Lorenzo Bellini (1643-1704)

Source Undetermined, Wikipedia



Original from Basic Histology – Text & Atlas; 10th edition, 2003;
Junqueira and Carneiro, Lange McGraw-Hill Figure 19-16

Changes of the lining
epithelium along the
nephron and the
collecting tubules/ducts

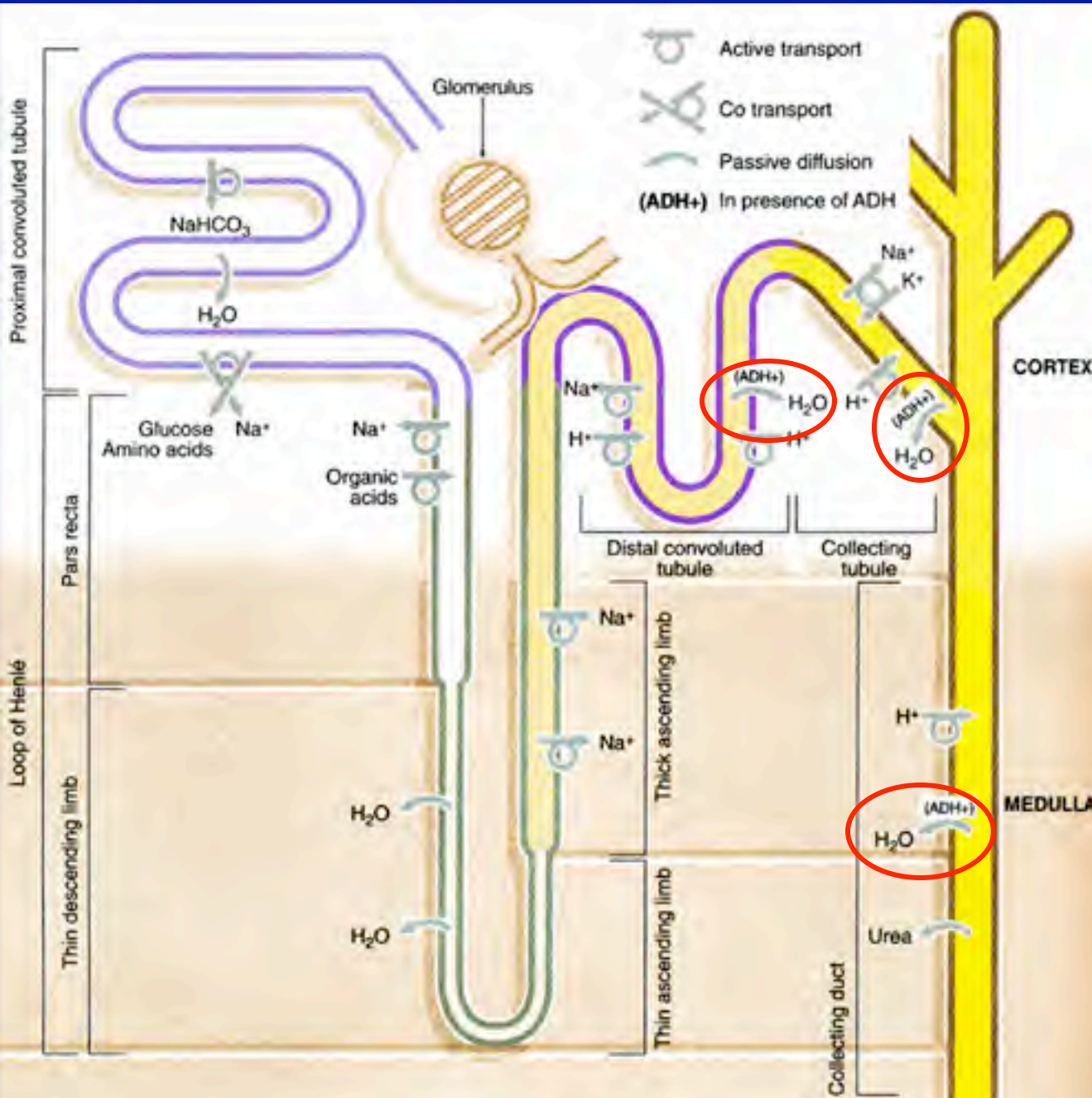


300 mOs

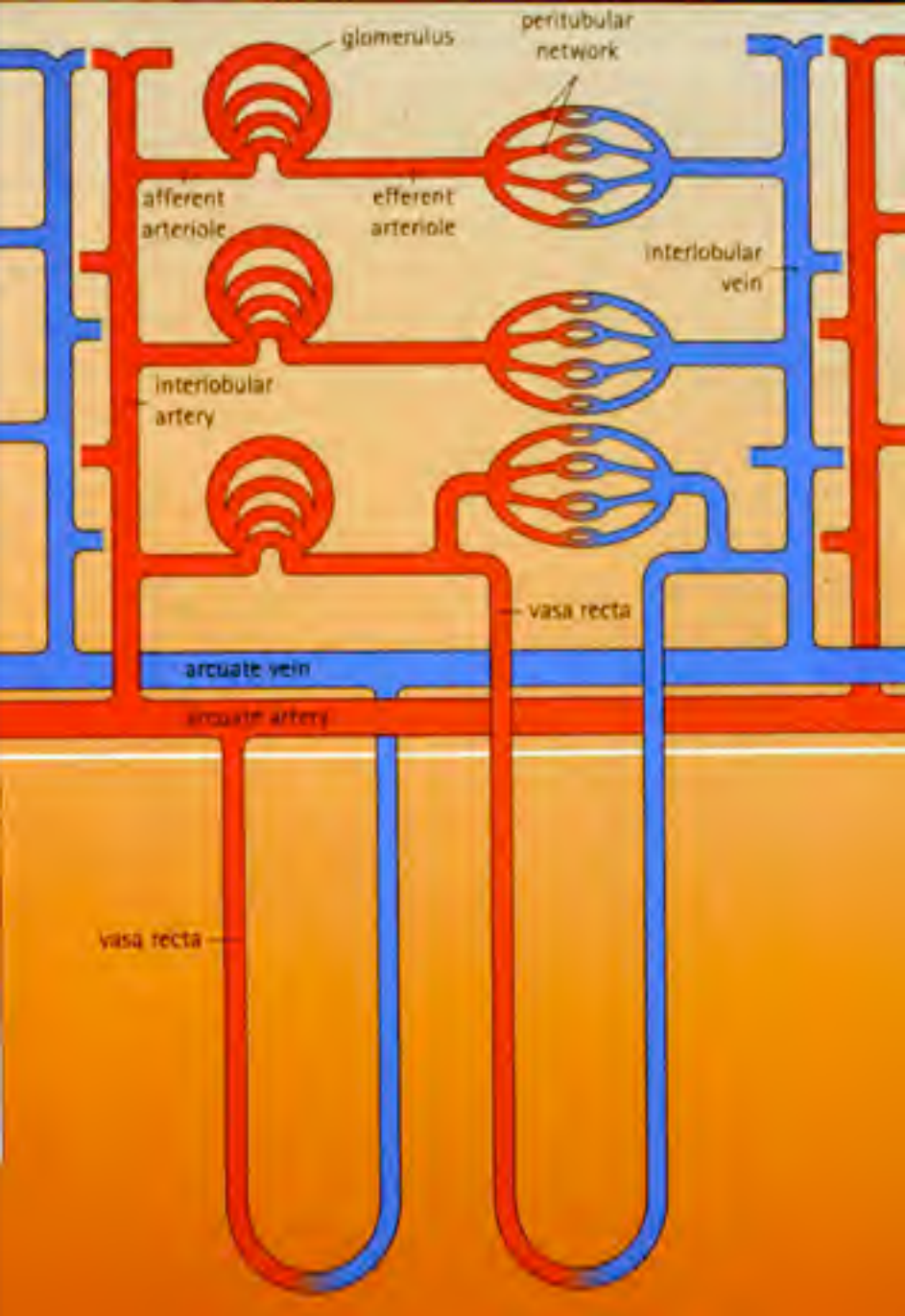
Flow of the renal filtration fluid and selective removal of salt and water creates an osmolarity gradient between cortical and medullar regions.

This is called the counter-current multiplier system.

1200 mOs



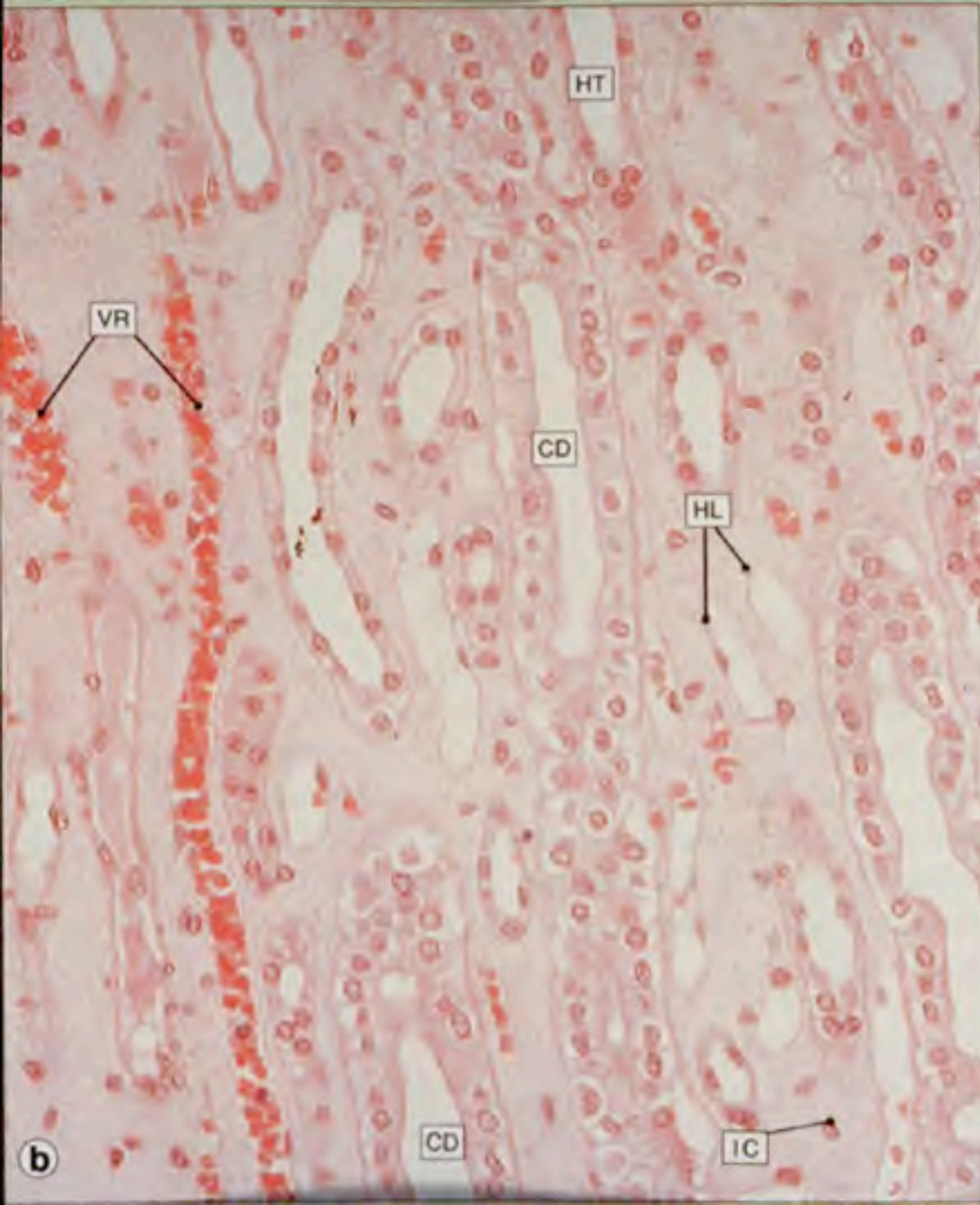
Aldosterone increases sodium uptake in the DCT. ADH (Antidiuretic hormone) regulates the water permeability of the distal part of the nephron and thereby influences the volume and concentration of the final filtration product.



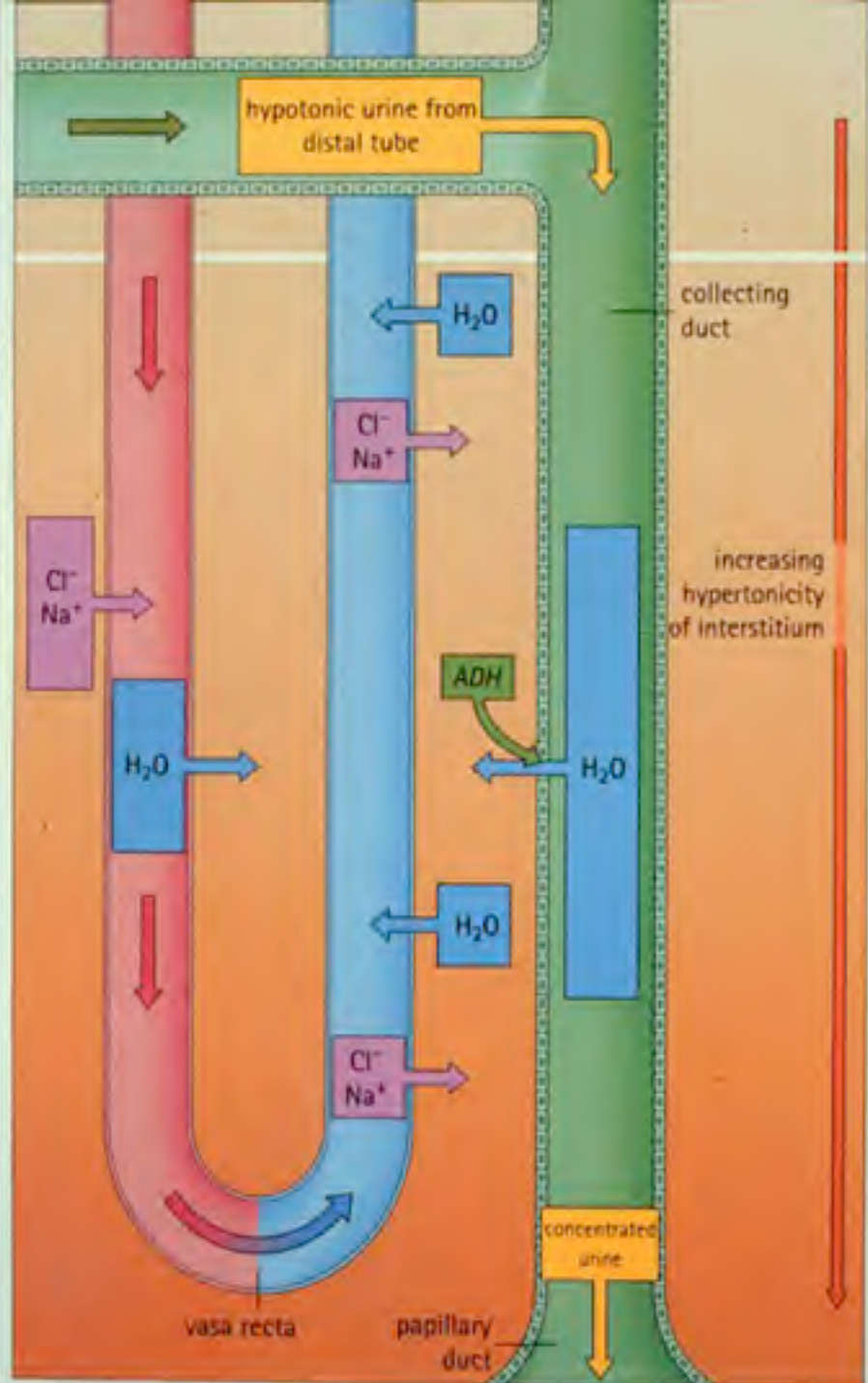
The efferent arterioles split into a second capillary system, the peritubular network, which nourishes and supplies the convoluted tubes.

The peritubular capillary endothelial cells are also a source of erythropoietin.

Cortico-medullary nephrons also extend a capillary branch deep into the medulla. These capillaries are called the vasa recta system.



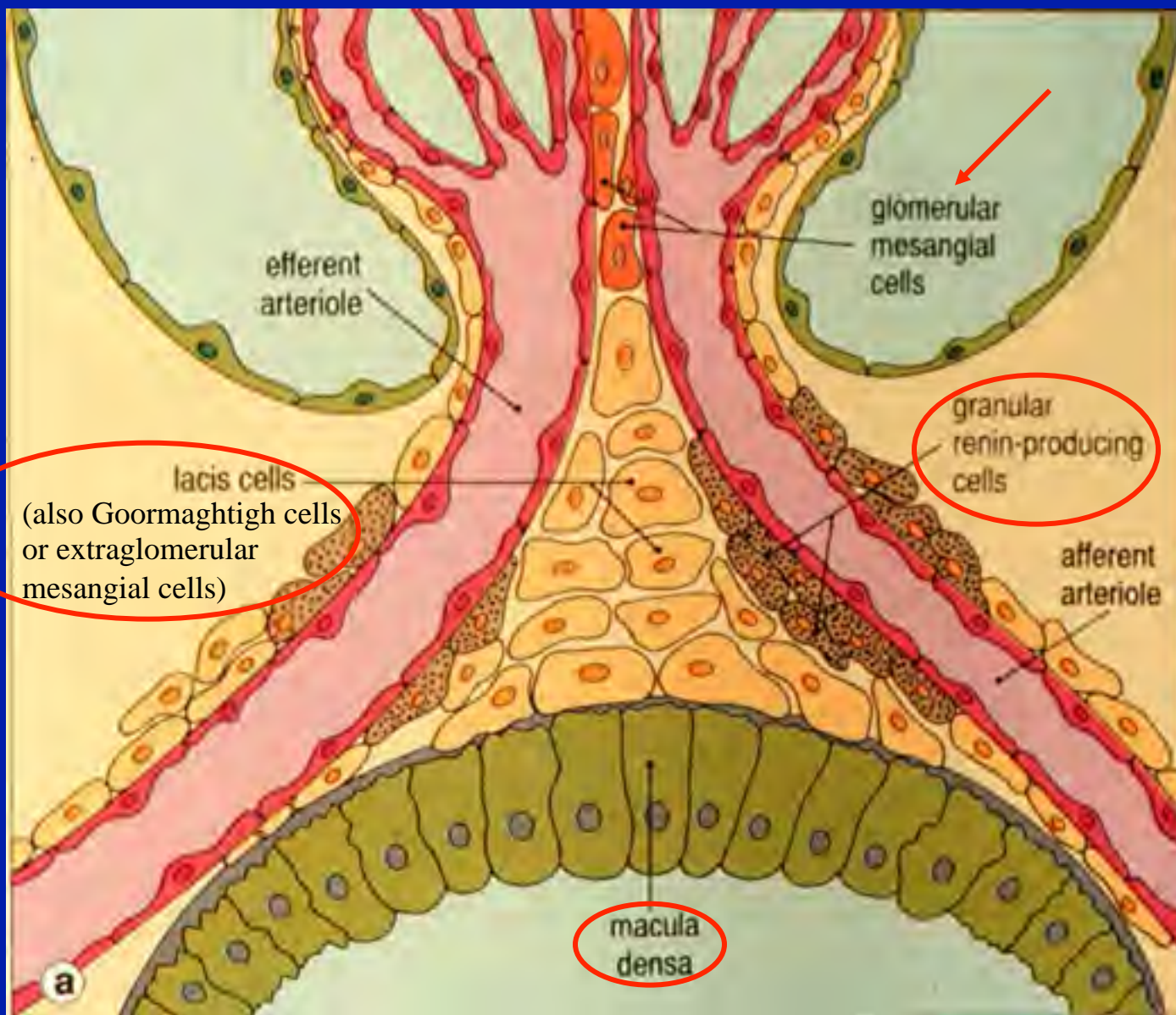
The vasa recta capillaries follow the collecting tubules/ducts into the deep medulla.



300 mOs

The vasa recta capillaries pass through a region of high osmolarity. This results in an exchange of blood fluid/water. This is called the counter-current exchange system.

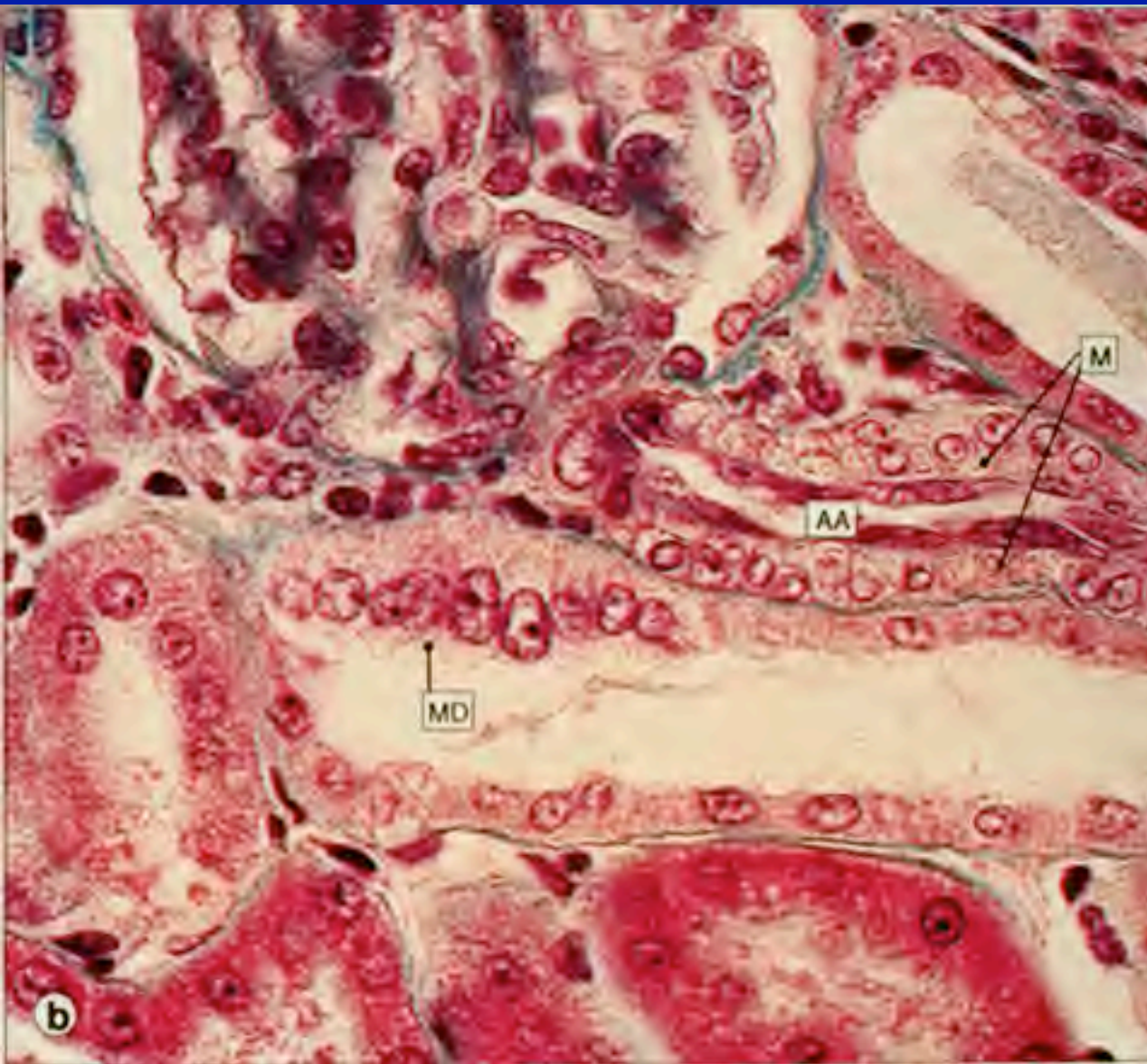
1200 mOs

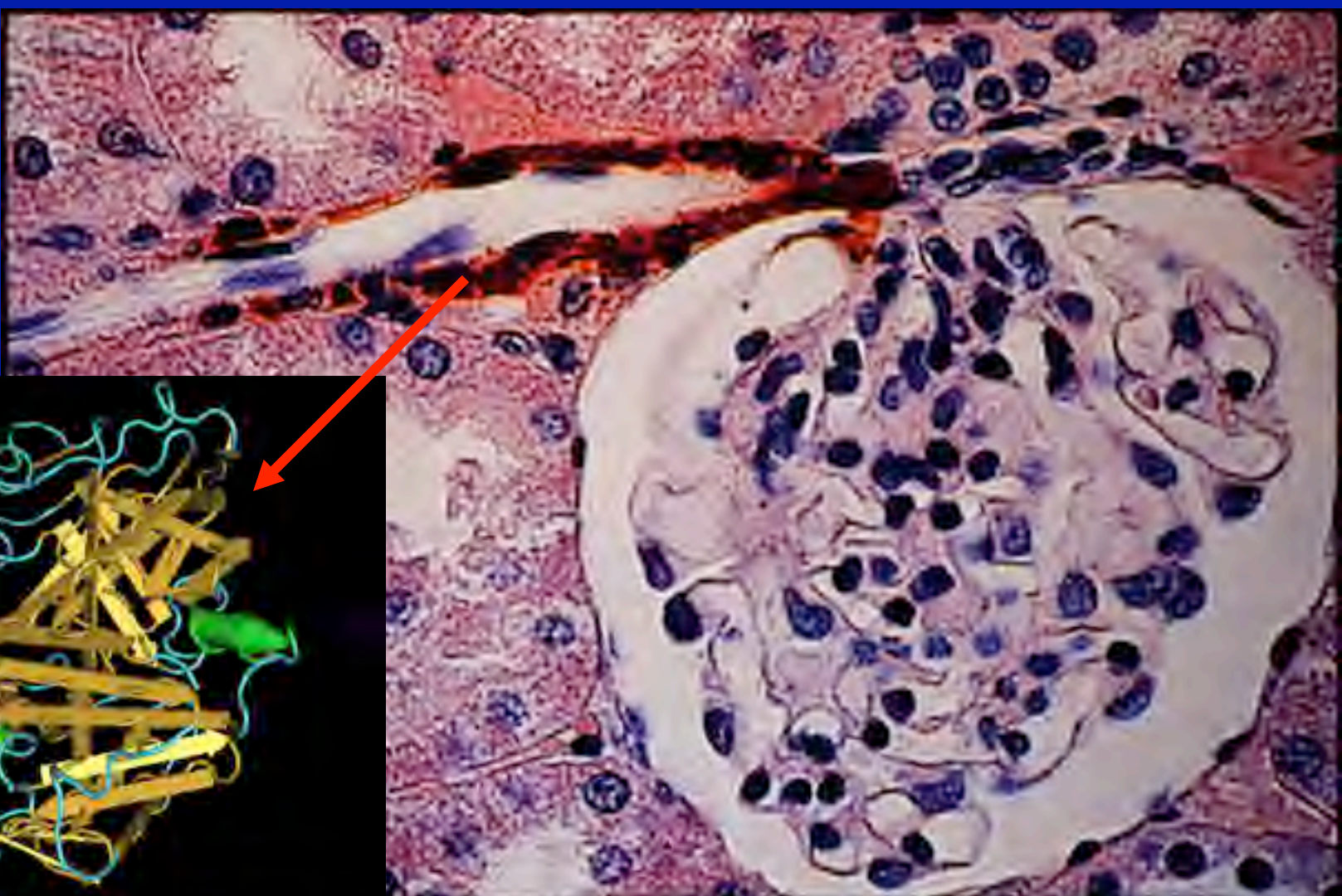


PD-INEL Human Histology, 2nd edition, 1997, Stevens and Lowe, Mosby, Modified from Fig 15.28a

The juxtaglomerular complex (shown by D) has important control and regulation functions.

The DCT passes between the afferent and efferent arteriole at the vascular pole of the renal corpuscle. A thickening in the DCT epithelium signifies the macular densa. The macula densa regulates mesangial and juxtaglomerular cells and thereby influences the blood flow through the glomerular network and the blood pressure and the renin-angiotensin system (see next slides).



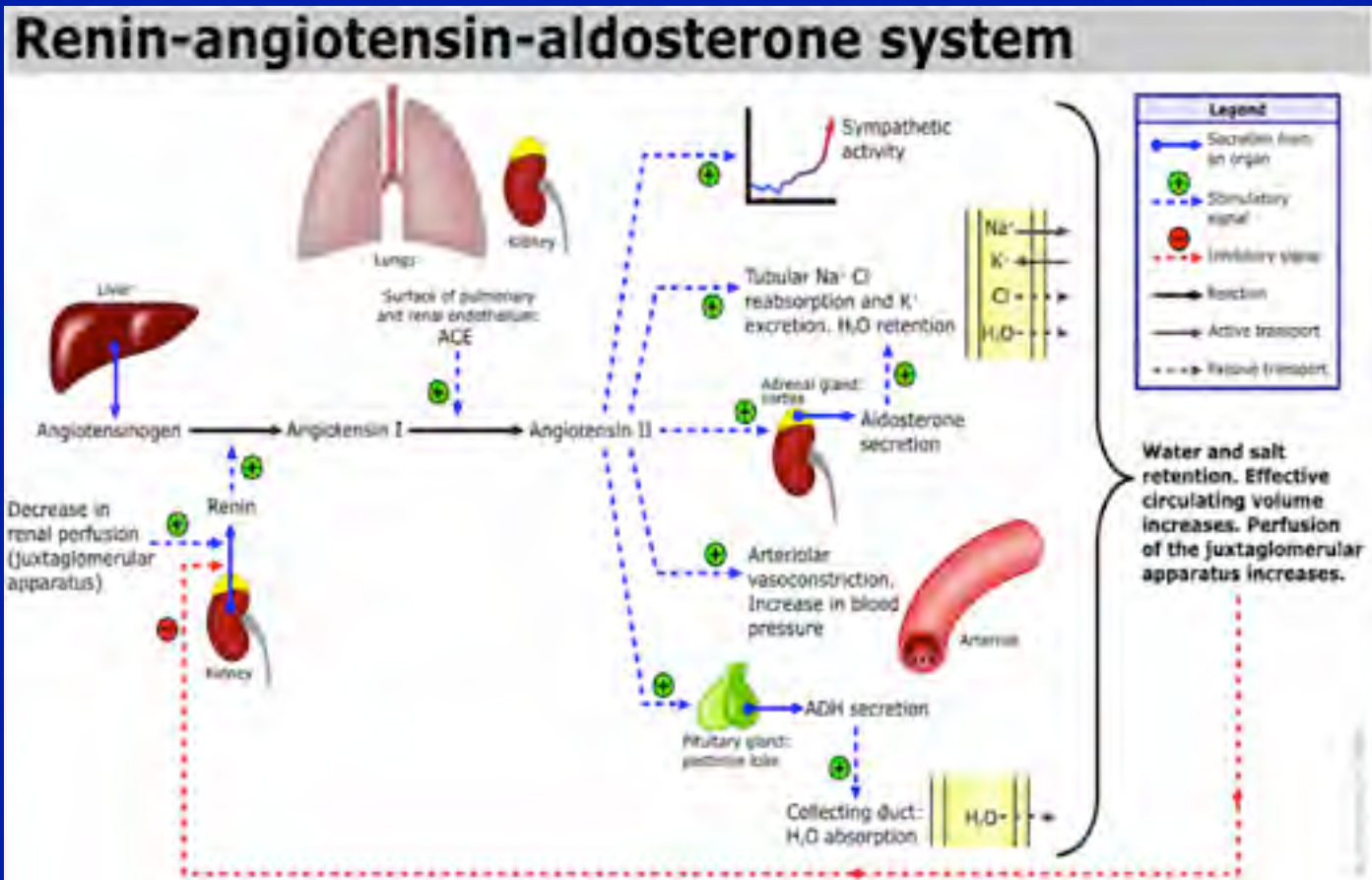


Molecular structure of human renin (406 amino acids)  Color Atlas of Histology; 1992; Erlandsen and Magney; Mosby Book Fig 18-20

 National Library of Medicine

Specialized smooth muscle cells in the afferent arteriolar wall (called juxtaglomerular cells) produce the hormone renin as shown in this immunocytochemical micrograph. Renin or angiotensinogenase is an enzyme with a proteolytic activity that cleaves angiotensinogen into angiotensin I.

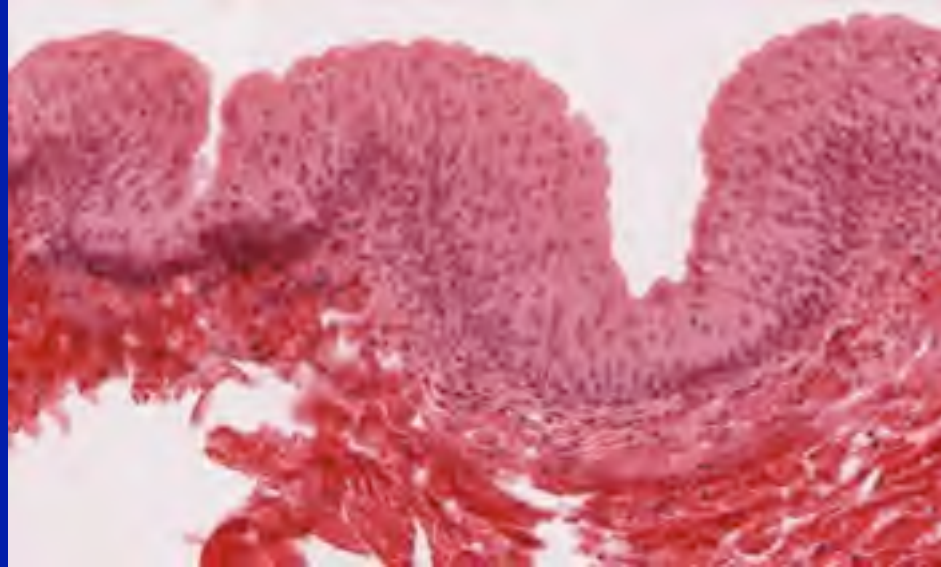
Renin secretion is triggered by ATP release from the macular densa. It induces the activation of angiotensin, which in turn induces the release of aldosterone, resulting in sodium and water retention in the kidney.



GNU-FDL A. Rad, Wikipedia

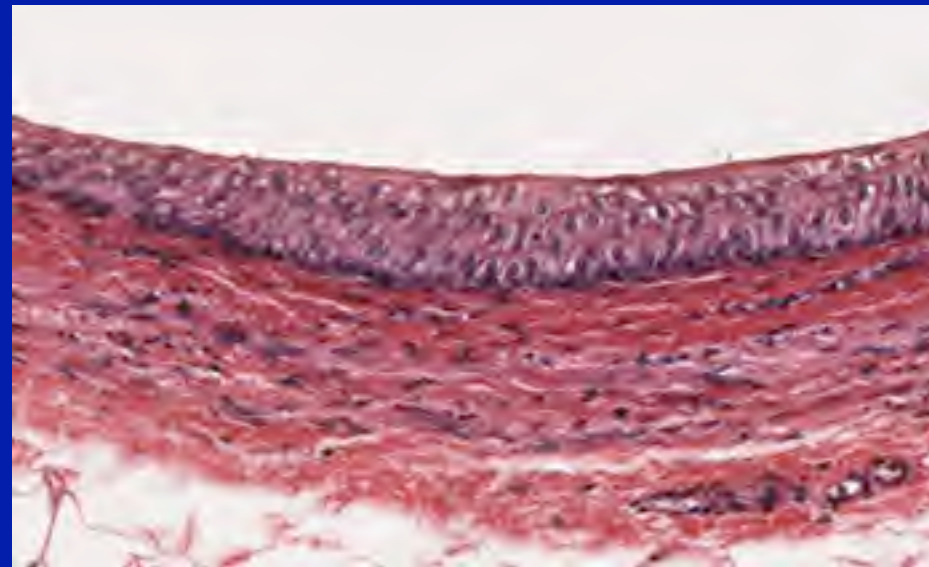


The ureter is lined by a transitional epithelium and has a rather disorganized smooth muscle layer.



PD-INEL Michigan Medical Histology Slide Collection Slide 212

Relaxed transitional epithelium



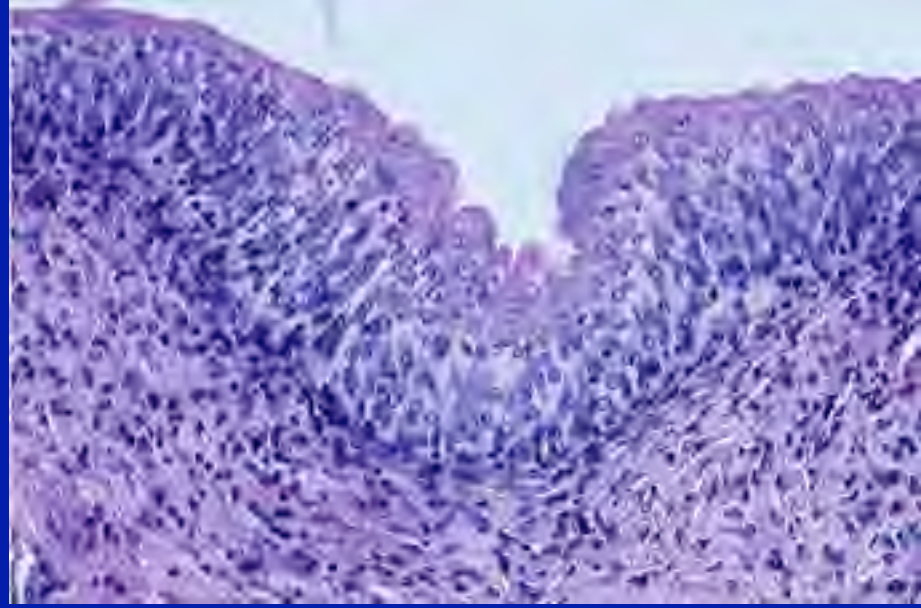
PD-INEL Michigan Medical Histology Slide Collection Slide 19-1

Distended transitional epithelium

Relaxed ureter



PD-INEL Source Undetermined



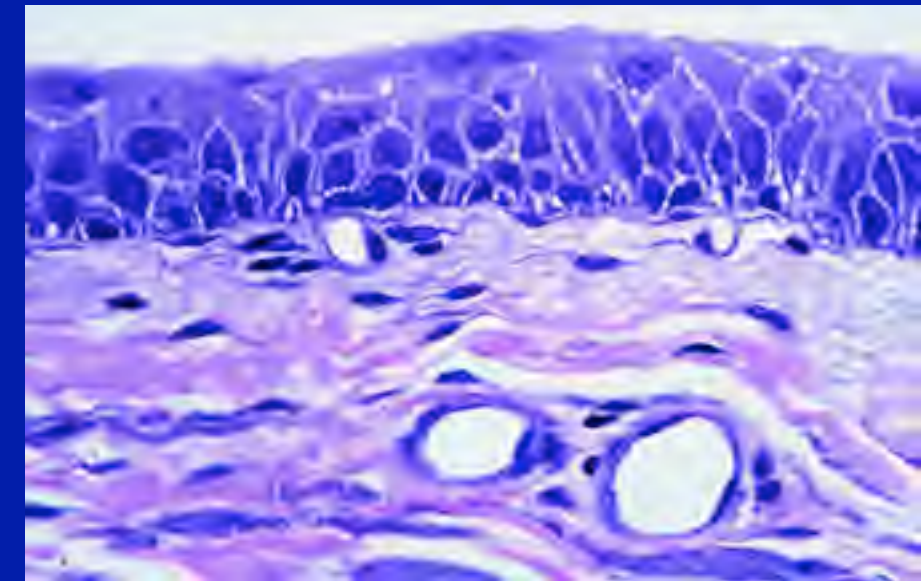
PD-INEL Source Undetermined

Relaxed transitional epithelium

Distended ureter

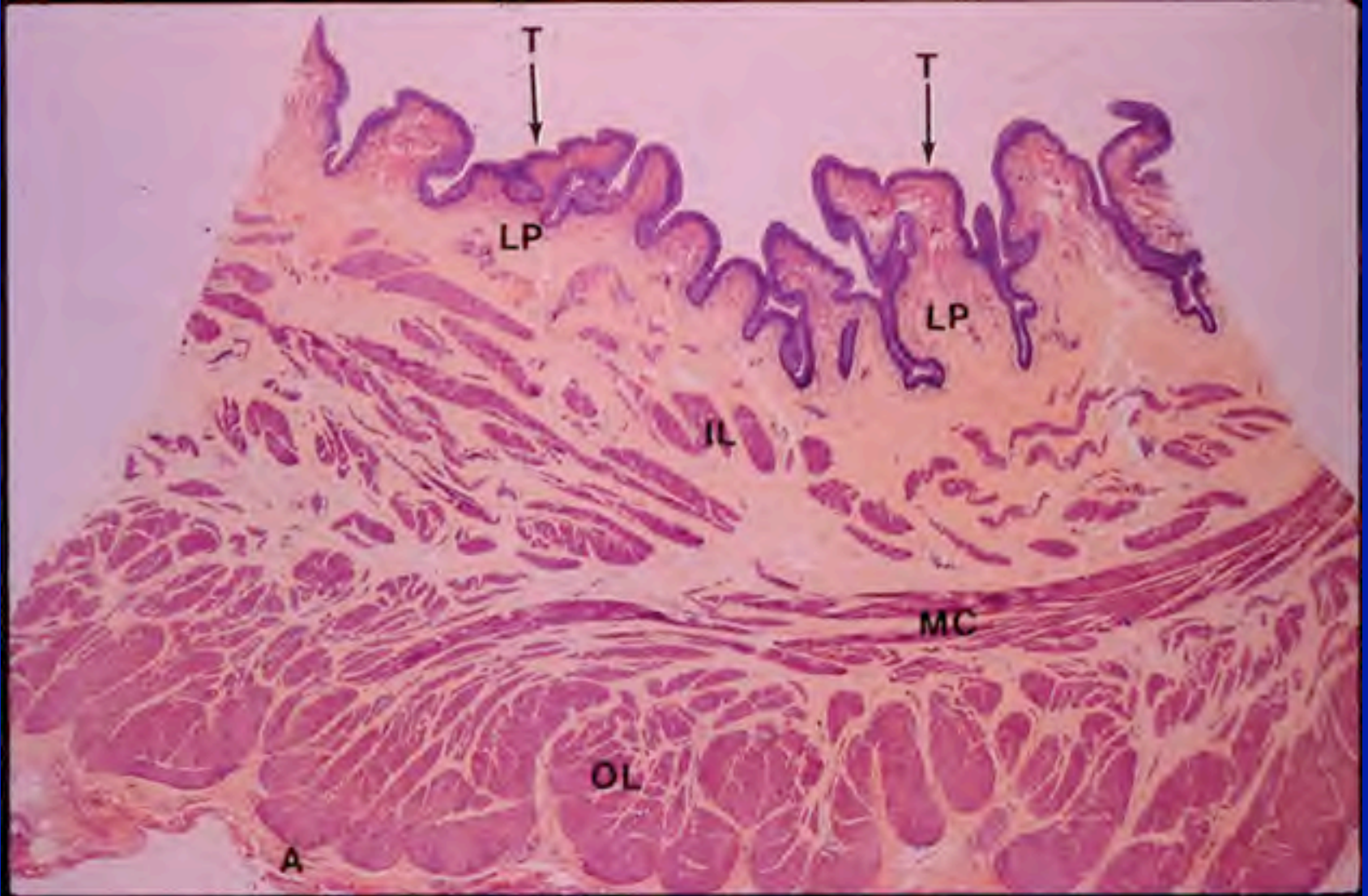


PD-INEL Source Undetermined



PD-INEL Source Undetermined

Distended transitional epithelium



PD-INEL Color Atlas of Basic Histology; 1993; Berman; Appelton and Lange, Fig 16-18

Similarly, the bladder is lined by a transitional epithelium and has three rather unorganized smooth muscle layers.

Additional Source Information

for more information see: <http://open.umich.edu/wiki/CitationPolicy>

Slide 4: National Library of Medicine

Slide 7: “Kidney”, U.S Federal Government, “Histology Image”, Wheater’s Functional Histology, 4th edition, 2000, Young and Heath, Churchill Livingstone Elsevier Fig.16.3

Slide 8: Wheater’s Functional Histology, 4th edition, 2000, Young and Heath, Churchill Livingstone Elsevier Fig 16.5

Slide 9: “Marcello Malpighi”, Source Undetermined; “Nephron”, Gray’s Anatomy

Slide 10: “Kidney”, U.S Federal Government, “Histology Image”, A Text and Atlas, 5th edition, 2006, Ross and Pawlina, Lippincott Williams and Wilkins Fig 20.6; “Kidney Sketch”, Gray’s Anatomy

Slide 11: Histology – A Text and Atlas, 5th edition, 2006, Ross and Pawlina, Lippincott Williams and Wilkins Fig 20.6

Slide 12: “Piotr Michał Jaworski”, Wikipedia, http://commons.wikimedia.org/wiki/File:KidneyStructures_PioM.svg, CC: BY-SA 3.0
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Slide 13: Gray’s Anatomy

Slide 14: Vectorized in CorelDraw by Mysid, <http://en.wikipedia.org/wiki/User:Mysid>, from the online edition of Gray's Anatomy, Wikipedia, <http://en.wikipedia.org/wiki/File:Gray1130.svg>

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Slide 23: A Text and Atlas, 5th edition, 2006, Ross and Pawlina, Lippincott Williams and Wilkins Fig 20.10

Slide 24: Cell and Tissue Ultrastructure – A Functional Perspective, 1993, Cross and Mercer, Freeman and Co. Fig. page 325

Slide 25: “Bowman’s Capsule”, Modified by M. Hortsch from Wheater’s Functional Histology, 3rd edition, 1993, Burkitt, Young, and Heath, Churchill Livingstone Fig. 16.19; “William Bowman”, National Library of Medicine, http://en.wikipedia.org/wiki/File:William_Bowman.jpg

Slide 26: Color Atlas of Basic Histology, 1993, Berman, Appelton and Lange Fig 16-8

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Slide 30: Source Undetermined

Slide 31: “Jacob Henle”, Source Undetermined, Wikipedia, http://en.wikipedia.org/wiki/Jacob_Henle; “Henle’s Loop” Basic Histology – Text & Atlas, 10th edition, 2003, Junqueira and Carneiro, Lange McGraw-Hill Figure 19-16

Slide 32: “Concise Histology” by Fawcett and Jensch, 1997, Chapman & Hall Fig 21-12 Originally Osvaldo and Latta J. of Ultrastructure Research 15: 144, 1966

Slide 33: Human Histology, 2nd edition, 1997, Stevens and Lowe, Mosby Fig 15.19

Slide 34: Color Atlas of Histology, 1992, Erlandsen and Magney, Mosby Book Fig 18-18

Slide 35: Gray’s Anatomy; Japanese slide set (Humio Mizoguti, Department of Anatomy, Kobe University School of Medicine, Slides #454 and #458

Slide 36: Color Textbook of Histology, 3rd edition, 2007, Gartner and Hiatt, Elsevier Figures 19-12 and 19-13

Slide 37: Wheater’s Functional Histology, 3rd edition, 1993, Burkitt, Young, and Heath, Churchill Livingstone, Fig 16.18b

Slide 39: Color Atlas of Basic Histology, 1993, Berman, Appelton and Lange, Fig 16-13

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Slide 41: Human Histology, 2nd edition, 1997, Stevens and Lowe, Mosby, Fig 15.36; “Bellini” Source Undetermined, Wikipedia

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Slide 44: Wheater’s Functional Histology; 4th edition, 2000, Young and Heath; Churchill Livingstone Elsevier Fig. 16.21

Slide 45: Human Histology, 2nd edition, 1997, Stevens and Lowe, Mosby Fig 15.4a

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Slide 50: National Library of Medicine, Color Atlas of Histology, 1992, Erlandsen and Magney, Mosby Book Fig 18-20

Slide 51: A. Rad, Wikipedia, http://commons.wikimedia.org/wiki/File:Renin-angiotensin-aldosterone_system.png, GNU FDL 1.2, <http://www.gnu.org/licenses/fdl-1.2.html#TOC1>

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