URINARY SYSTEM: Part 1 Kidney and nephron

Dr. Larry Johnson  Texas A&M University
Objectives

Part 1 Kidney and nephron

• Describe the structure of the kidney and distinguish between cortical and medullary organization.
• Identify and differentiate between the portions of the nephron.
• Trace blood flow through the kidney.
• Describe the structural organization of the ureter, urinary bladder, and urethra.
hilum
URINARY SYSTEM - FUNCTION IN HOMEOSTASIS

RID BODY OF WASTE (UREA, URIC ACID, CREATININE, SALTS)
PRESERVES CONSTANCY OF EXTRACELLULAR FLUID IN COMPOSITION, VOLUME, AND pH

ENDOCRINE FUNCTION

a) SECRETE ERYTHROPOIETIN - RED BLOOD CELL PRODUCTION

b) PRODUCES RENIN - ALDOSTERONE RELEASE
Slide 32: Kidney (H&E)

CT adventia capsule

Renal pyramid and calyx

Simple columnar to transitional-like epithelium of pyramid

Apex of renal pyramid

Renal calyx

Cortex

Medulla

Renal pelvis
Fig. 15-1  Kidney: Cortex and Pyramid (panoramic view). Stain: hematoxylin-eosin. Low magnification.
Blood flow: Renal artery > segmental artery > interlobar artery > arcuate artery > interlobular artery > afferent arteriole > glomerulus > efferent arteriole > peritubular capillaries (assoc. with convoluted tubules) OR vasa recta (assoc. with loop of Henle) > interlobular vein > arcuate vein > interlobar vein > segmental vein > renal vein.
Slide 32: Kidney (H&E)

Cortex

Medulla

Juxtamedullary nephrons

Capsule

Cortex

Arcuate arteries

Medullary rays

Medulla
KIDNEY FUNCTION BASED ON COMBINATION OF

FILTRATION
ACTIVE SECRETION
PASSIVE DIFFUSION
SELECTIVE
ABSORPTION
Evolution – Animals escaping predators

Fresh water

Salt water
Evolution – Animals escaping predators

Fresh water

Salt water
ARTERIAL PORTAL SYSTEM

= CAPILLARY ⇔ PORTAL
ARTERIOLE ⇔ CAPILLARY

afferent ARTERIOLE,
efferent ARTERIOLE,

PERITUBULAR CAPILLARIES
ARTERIAL PORTAL SYSTEM

= CAPILLARY ⇔ PORTAL ARTERIOLE ⇔ CAPILLARY

afferent ARTERIOLE

efferent ARTERIOLE

PERITUBULAR CAPILLARIES
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PERITUBULAR CAPILLARIES
ARTERIAL PORTAL SYSTEM

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afferent ARTERIOLE efferent ARTERIOLE,

PERITUBULAR CAPILLARIES
Function of a portal system?

ARTERIAL PORTAL SYSTEM

= CAPILLARY ⇒ PORTAL ARTERIOLE ⇒ CAPILLARY

afferent ARTERIOLE
efferent ARTERIOLE,

PERITUBULAR CAPILLARIES
Function of a portal system?

Local change in blood composition whereby the first capillary modifies and second allows the change in composition to affect local cells near it.
Figure 34-3  The functional nephron.
Renal corpuscle

(a) Renal corpuscle
- Visceral layer of glomerular capsule
- Pedicels
- Filtration slits
- Podocyte cell body

(b) Histology of renal corpuscle
- PL
- CS
- MD
- DCT
- Glomerular filter
  - Fenestrated capillary endothelium
  - Glomerular basement membrane (blocks large proteins)
  - Filtration slits diaphragms between pedicels (block many small proteins)

(c) Substances filtered by filtration membrane
- Small protein
- Large protein
- Leukocyte
- Platelet
- Erythrocyte

(d) Podocytes
- Glomerular capillary
- Glomerular capillary covered by podocytes with pedicels

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Cells of the GLOMERULUS and capsule

PARIETAL EPITHELIUM
PODOCYTE
MESANGIAL CELL
ENDOTHELIAL CELL
PARIETAL EPITHELIUM
PODOCYTE

MESANGIAL CELL
ENDOTHELIAL CELL

MESANGIAL CELLS SECRETE ERYTHROPOIETIN - RED BLOOD CELL PRODUCTION
Slide 32: Kidney (H&E)

- Urinary pole
- Urinary space
- Parietal epithelium
- Podocyte
- Visceral epithelium
- Arteriole of vascular pole
- Juxtaglomerular cells
- Macula densa

- Glomerulus
- Bowman’s capsule
- Renal corpuscle

- Renal corpuscle
19713 kidney

Proximal convoluted tubules

Glomerulus

Distal convoluted tubules
Slide 32: Kidney (H&E)

- Proximal convoluted tubules
- Distal convoluted tubules
- Microvilli
- Brush border
- Juxtaglomerular cells
- Macula densa of distal tubule
- Juxtaglomerular apparatus
- Distal convoluted tubules
- Proximal convoluted tubules
- Microvilli Brush border
0 to 8 mg/dL protein in urine is considered normal. The brush border is involved in reabsorption of protein.
Human kidney cortex

Proximal convoluted tubules

Adventia capsule with no mesothelium

Renal corpuscle
The intense eosinophilia of the cytoplasm of cells in the proximal convoluted tubules results from the glycocalyx covering the brush border staining intensely eosinophilic and the high density of membranes within the cells. These membranes and the high density of PCTs in the cortex are responsible for the PCTs absorbing most of filtered water from the renal corpuscle.
Toulidine blue kidney

Urinary pole

Proximal convoluted tubules

Glomerulus

Collecting ducts

PCT

DCT

36727
Fig. 14-12. Diagram of the renal corpuscle.
Fig. 14-12. Diagram of the renal corpuscle.
Slide 33: Kidney (PAS/Hematoxylin)

- Basement membranes are PAS positive
- Brush border of proximal tubule
- Distal tubule
Slide 33: Kidney (PAS/Hematoxylin)

- Basement membranes are PAS positive
- Brush border of proximal tubule stain PAS positive due to the rich glycocalyx covering its numerous microvilli.
- Distal tubule
CS = Capsular Space
PL = Parietal Layer Bowman’s Capsule
PO = Podocytes
Arrows = Podocyte Process
Components of the filtration barrier:
Components of the filtration barrier:
1. The fenestrations of the capillary endothelium, which blocks blood cells and platelets.
Components of the filtration barrier:
1. The fenestrations of the capillary endothelium, which blocks blood cells and platelets
2. The thick, combined basal laminae, or GBM, which restricts large proteins and some organic anions
Components of the filtration barrier:
1. The fenestrations of the capillary endothelium, which blocks blood cells and platelets
2. The thick, combined basal laminae, or GBM, which restricts large proteins and some organic anions
3. The filtration slit diaphragms between pedicels, which restrict some small proteins and organic anions
GLOMERULUS - PASSIVE ULTRAFILTRATION (ball park values)

ENDOTHELIAL CELL
>600,000 MW

BASAL LAMINA
>160,000 MW

FILTRATION SLITS
>70,000 MW
<table>
<thead>
<tr>
<th>Region of Tubule</th>
<th>Histological Features</th>
<th>Locations</th>
<th>Major Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal convoluted tubules</td>
<td>• Simple cuboidal epithelium</td>
<td>Cortex</td>
<td>• Reabsorption of all organic nutrients, all proteins, most water and electrolytes</td>
</tr>
<tr>
<td></td>
<td>• Cells well-stained with numerous mitochondria</td>
<td></td>
<td>• Secretion of organic anions and cations, H+, and NH4+</td>
</tr>
<tr>
<td></td>
<td>• Prominent basal folds and lateral interdigitations</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Long microvilli, lumens often occluded</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thin limbs of Loop of Henle</td>
<td>• Simple squamous epithelium</td>
<td>Medulla</td>
<td>Passive reabsorption of Na+ and Cl-</td>
</tr>
<tr>
<td></td>
<td>• Few mitochondria</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thick ascending limb (TAL) of Loop of Henle</td>
<td>• Simple cuboidal epithelium</td>
<td>Medulla and medullary rays</td>
<td>Active reabsorption of various electrolytes</td>
</tr>
<tr>
<td></td>
<td>• No microvilli</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distal convoluted tubules</td>
<td>• Simple cuboidal epithelium</td>
<td>Cortex</td>
<td>Reabsorption of electrolytes</td>
</tr>
<tr>
<td></td>
<td>• Cells smaller than in proximal convoluted tubules</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Short microvilli and basolateral folds</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• More empty lumens</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Principle cells of Collecting system</td>
<td>• Most abundant</td>
<td>Medullary rays and medulla</td>
<td>Regulated reabsorption of water and electrolytes</td>
</tr>
<tr>
<td></td>
<td>• Cuboidal to columnar</td>
<td></td>
<td>• Regulated secretion of K+</td>
</tr>
<tr>
<td></td>
<td>• Pale-staining</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Distinct cell membranes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercalated cells of Collecting system</td>
<td>• Few and scattered</td>
<td>Medullary rays</td>
<td>Reabsorption of K+ (low-K+ diet)</td>
</tr>
<tr>
<td></td>
<td>• Slightly darker staining</td>
<td></td>
<td>• Help maintain acid-base balance</td>
</tr>
</tbody>
</table>
Slide 32: Kidney (H&E)

Thick ascending limb of loop of Henle

Thick descending limb of loop of Henle

Thin limb of loop of Henle

Collecting duct
19713 kidney medulla
Kidney medulla (Lee’s stain) – thin portion of loop of Henle
Touloidine blue kidney

- Peritubular capillaries of the vasa recta
- Ascending loop of Henle
- Distal tubules
- Transition from ascending loop of Henle to distal tubules
- Transitional from proximal tubules to thin descending loop of Henle
- Descending loop of Henle

[Image showing the above annotations on a microscopic view of kidney tissue]
Transitions from ascending loop of Henle to distal tubules
Transitions from ascending loop of Henle to distal tubules

Infolding of the basal cell membrane line up mitochondria in cells of the distal tubule.
Descending loop of Henle

Ascending loop of Henle

Distal tubule

Blood capillaries of the vasa recta
458 kidney

Collecting duct
458 kidney

Collecting duct
Fig. 15-4  Kidney Medulla: Papilla (transverse section). Stain: hematoxylin-eosin. Medium magnification.

Fig. 15-5  Kidney Medulla: Papilla Adjacent to a Calyx (longitudinal section). Stain: hematoxylin-eosin. Medium magnification.

- 1 Straight (descending) segment (l.s.) of loops of Henle
- 2 Papillary ducts
- 3 Thin segments of loops of Henle
- 4 Capillaries and venules
- 5 Papillary ducts (l.s.)
- 6 Thin segments of loops of Henle
- 7 Straight (ascending) segment of loops of Henle
- 8 Thin segments of loops of Henle
- 9 Capillaries
- 10 Connective tissue stroma
- 11 Epithelium covering the papilla

- cortex
- medulla
- Minor calyx
Many illustrations in these VIBS Histology YouTube videos were modified from the following books and sources: Many thanks to original sources!

- Douglas P. Dohrman and TAMHSC Faculty 2012 Structure and Function of Human Organ Systems, Histology Laboratory Manual - Slide selections were largely based on this manual for first year medical students at TAMHSC
End of the Urinary System: Part 1

Next  Urinary System:  Part 2 Function and excretory ducts
Toulidine blue kidney

- Ascending loop of Henle
- Peritubular capillaries of the vasa recta
- Distal tubules
- Transition from ascending loop of Henle to distal tubules
- Transition from proximal tubules to thin descending loop of Henle

Dr. Larry Johnson  
Texas A&M University
Objectives: Part 2 Function and excretory ducts

• Describe the structure of the kidney and distinguish between cortical and medullary organization.
• Identify and differentiate between the portions of the nephron.
• Trace blood flow through the kidney.

• Describe the structural organization of the ureter, urinary bladder, and urethra.
1. Subcapsular convoluted tubules
2. Glomeruli
3. Corrugated tubules
4. Straight tubules
5. Medullary rays
6. Interlobular arteries
7. Interlobular veins
8. Glomeruli
9. Arcuate artery
10. Interlobular artery and vein
11. Base of the pyramid (with straight tubules)
12. Columnar epithelium covering a papilla
13. Transitional epithelium
14. Minor calyx: lumen and wall
15. Branches of renal artery and vein
16. Renal papilla
17. Connective tissue of the renal cortex

Cortical Nephron
Juxtamedullary Nephron
Thin Segment
Collecting Tubule
Papillary Duct
kidney thin loop of Henle in cortex
kidney thin loop of Henle in cortex
The density of the cortex is dominated by the proximal convoluted tubules.

However, the thin loop of Henle can be found in the cortex too.
The greatest change in flow rate occurs in the proximal tubule which reabsorbs 80% of the filtrate.
Cortical nephrons

Juxtamedullary nephrons

Loop increases temperature over straight tube with same amount of heat

Juxtamedullary nephrons
Peritubular capillaries

Capillaries of the vasa recta
PERITUBULAR CAPILLARIES

ABSORBS - 180 LITERS/DAY FROM INTERSTITIAL SPACES; THUS, ~4 TIMES REABSORPTION OF VENOUS END OF ALL OTHER CAPILLARIES OF BODY

ENDOTHELIAL CELLS - EXTREMELY POROUS

COLLOIDAL OSMOTIC PRESSURE OF PLASMA PROTEINS

LOW CAPILLARY PRESSURE PROXIMITY TO URINIFEROUS TUBULES
peritubular fenestrated endothelium

Basement lamina

Capillary lumen

fenestrated endothelium
Rich blood supply of peritubular capillaries and vasa recta

cortex

Arcuate arteries

medulla
Capillaries of the vasa recta
Countercurrent Multiplier

nephron
A diagram illustrating the reabsorption and secretion processes in the nephron. The nephron is divided into several segments: the glomerulus, proximal tubule, loop of Henle, distal tubule, and collecting duct. Key substances and ions include:

- Cl⁻, H₂O, CO₂, Urea, Protein (in the glomerulus)
- Na⁺, H₂O, Glucose, amino acids, uric acid, vitamin C, lactic acid, organic acids and bases (in the vasa recta)
- NH₃, H₂O, ADH (in the distal tubule)
- H⁺, K⁺, Na⁺, Urea, H₂O (in the collecting duct)

Aldosterone affects the reabsorption of sodium and potassium ions, influencing fluid and electrolyte balance.
Juxtaglomerular apparatus

- Glomerulus
- Juxtaglomerular cells
- Efferent arteriole
- Afferent arteriole
- Distal tubule
- Macula densa
Juxtaglomerular apparatus
Juxtaglomerular apparatus
Renin granules in JG cells of Kidney (PAS)
Renin granules in JG cells of Kidney (PAS)
Renin granules in JG cells of Kidney (PAS)
ANGIOTENSINOGEN (PLASMA GLOBULIN)

RENIN (ENZYME from JG cells)

ANGIOTENSIN 1 (PLASMA ENZYME)

ANGIOTENSIN II (MOST POTENT VASOCONSTRICTOR)
INCREASED BLOOD PRESSURE

ANGIOTENSIN II

VASOCONSTRICTION

INCREASED BLOOD PRESSURE

ALDOSTERONE RELEASE FROM ADRENALS

INCREASED SODIUM (WATER REABSORPTION BY DISTAL TUBULE)

INCREASED BLOOD VOLUME
Adrenal function

Aldosterone stimulates Na\(^+\) resorption in:

distal tubule of kidney

 gastric mucosa

 salivary glands

 sweat glands
Hypothalamus

Supraoptic nuclei

Excited by concentrated extracellular fluid

Antidiuretic hormone released by posterior pituitary gland

Excess reabsorption of water corrects excess concentration of extracellular fluid

Urine decreased but concentrated
Proteinuria

Several diseases may induce proteinuria:

- In diseases such as diabetes mellitus and glomerulonephritis, the glomerular filter is altered and becomes much more permeable to proteins, with the subsequent release of protein into the urine.
- Proteinuria is an indicator of many potential kidney disorders.

0 to 8 mg/dL protein in urine is considered normal.
458 kidney

- Cortex
- Medulla
- Minor calyx
Fluid transport and ureters
Slide 34: Ureter (upper 1/3)

1. Transitional epithelium
2. Lamina propria
3. Longitudinal smooth muscle
4. Circular smooth muscle
5. Adventia

Transitional epithelium
Ureter – transitional epithelium and smooth muscle

The shape of the urethral lumen is semi-lunar and slit-like.
Fig. 15-8  Urinary Bladder: Wall (transverse section). Stain: hematoxylineosin. Low magnification.

Fig. 15-9  Urinary Bladder: Mucosa (transverse section). Stain: hematoxylineosin. Medium magnification.
Slide 35: Urinary bladder

1. Transitional epithelium
2. Lamina propria
3. Inner longitudinal smooth muscle
4. Middle circular smooth muscle
5. Outer longitudinal smooth muscle
6. Serosa

Transitional epithelium

6. Serosa
5. Outer longitudinal smooth muscle
4. Middle circular smooth muscle
3. Inner longitudinal smooth muscle
2. Lamina propria
1. Transitional epithelium
Urinary bladder, monkey
Urinary bladder

- Nerve and mesothelium

- Transitional epithelium

- Smooth muscle
Fig. 17-13  Penis (transverse section). Stain: hematoxylin-eosin. Low magnification.

Fig. 17-14  Cavernous Urethra (transverse section). Stain: hematoxylin-eosin. Low magnification.
Human Penis – transitional epithelium and surrounding spongy cavernous of penal urethra
Slide 98: Penile urethra (monkey)

Urethra

Transitional epithelium
## Study Guide

<table>
<thead>
<tr>
<th>DIFFERENTIATING BETWEEN TUBULES IN THE CORTEX</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximal convoluted tubules</strong></td>
</tr>
<tr>
<td>• most numerous around the renal corpuscle</td>
</tr>
<tr>
<td>• taller cuboidal cells</td>
</tr>
<tr>
<td>• brush border with small lumen</td>
</tr>
<tr>
<td>• intensely eosinophilic</td>
</tr>
<tr>
<td><strong>Distal convoluted tubules</strong></td>
</tr>
<tr>
<td>• smaller cuboidal cells</td>
</tr>
<tr>
<td>• proportionally larger lumen</td>
</tr>
<tr>
<td>• less intensely eosinophilic</td>
</tr>
<tr>
<td>• macula densa</td>
</tr>
</tbody>
</table>
### DIFFERENTIATING BETWEEN TUBULES IN THE MEDULLA

<table>
<thead>
<tr>
<th>Tubule Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thick descending limb</td>
<td>- Intensely eosinophilic (resembles proximal convoluted tubule)</td>
</tr>
<tr>
<td></td>
<td>- More cuboidal than proximal convoluted tubule</td>
</tr>
<tr>
<td>Thick ascending limbs</td>
<td>- Cuboidal</td>
</tr>
<tr>
<td></td>
<td>- Less intensely eosinophilic (resembled distal convoluted tubule)</td>
</tr>
<tr>
<td></td>
<td>- Confused with collecting duct, but no distinct cell boundaries, no scalloped appearance</td>
</tr>
<tr>
<td>Thin limb</td>
<td>- Simple squamous epithelium</td>
</tr>
<tr>
<td></td>
<td>- Nuclei often bulge into the lumen</td>
</tr>
<tr>
<td>Capillaries</td>
<td>- Simple squamous epithelium</td>
</tr>
<tr>
<td></td>
<td>- Nuclei do not bulge into the lumen</td>
</tr>
<tr>
<td></td>
<td>- Blood cells sometimes present</td>
</tr>
<tr>
<td>Collecting ducts</td>
<td>- Tall cuboidal to columnar epithelium</td>
</tr>
<tr>
<td></td>
<td>- Light staining similar to distal convoluted tubule</td>
</tr>
<tr>
<td></td>
<td>- Apical surface often appears “scalloped”</td>
</tr>
<tr>
<td></td>
<td>- Distinct lateral cell boundaries</td>
</tr>
</tbody>
</table>
Cortical nephrons

Juxtamedullary nephrons
Loop increases temperature over straight tube with same amount of heat

Cortical nephrons

Juxtamedullary nephrons
Functions of the Urinary system

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End of the Urinary System: Part 2

URINARY SYSTEM: Part 2 Function and excretory ducts

Toulidine blue kidney

Dr. Larry Johnson  Texas A&M University
The End!

My wife’s horse
Sam