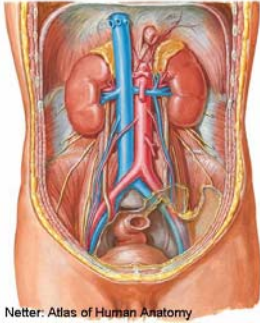


**Urinary System**  
kidneys, ureters, bladder & urethra

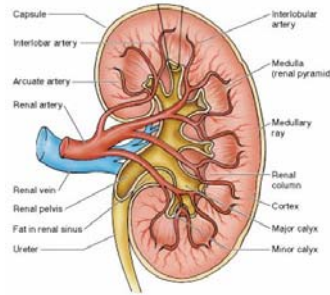


Netter: Atlas of Human Anatomy

**Kidney Function**

- Filters blood**
  - removes waste products
  - conserves salts, glucose, proteins, nutrients and water
- Produces urine**
- Endocrine functions**
  - regulates blood pressure
  - produces
    - renin
    - erythropoietin
    - prostaglandins
  - converts vitamin D to active form

**Kidney Structure**



**Capsule**

**Hilum**

- ureter → renal pelvis → major and minor calyces
- renal artery and vein → segmental arteries → interlobar arteries → arcuate arteries → interlobular arteries

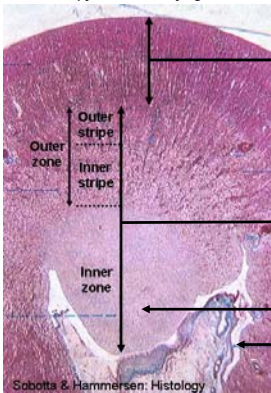
**Medulla**

- renal pyramids
- cortical/renal columns

**Cortex**

- renal corpuscles
- cortical labyrinth of tubules
- medullary rays

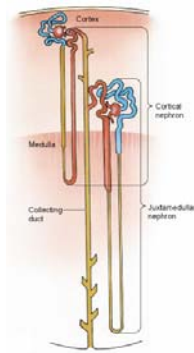
**Renal Lobe**  
= renal pyramid & overlying cortex



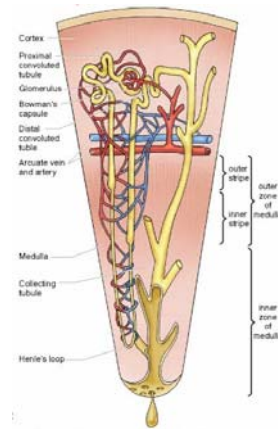
- Cortex
- Outer zone
- Outer stripe
- Inner stripe
- Medulla
- Inner zone
- Papilla
- Calyx

Sobotta & Hammersen: Histology

**Renal Lobule**  
= medullary ray & surrounding cortical labyrinth



- Cortex
- Medulla
- Collecting duct
- Juxtamedullary nephron
- Cortical nephron



- Cortex
- Proximal convoluted tubule
- Glomerulus
- Bowman's capsule
- Distal convoluted tubule
- Arcuate vein and artery
- Medulla
- Collecting tubule
- Henle's loop
- outer stripe
- outer zone of medulla
- inner stripe
- inner zone of medulla

**Uriniferous Tubule**

Nephron + Collecting tubule

**Nephron**

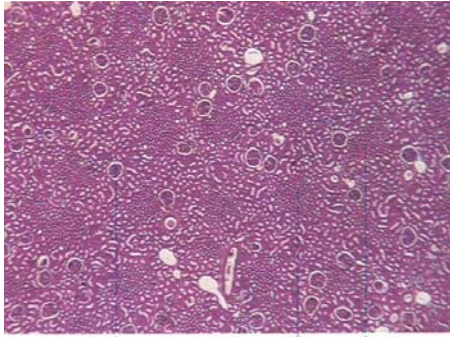
Renal corpuscle produces glomerular ultrafiltrate (180 L per day) from blood

Ultrafiltrate is concentrated

- Proximal tubule
  - convoluted
  - straight
- Henle's loop
  - thick descending
  - thin
  - thick ascending
- Distal tubule
- Collecting tubule

Urine (1-2 L per day) secreted from collecting ducts into calyces

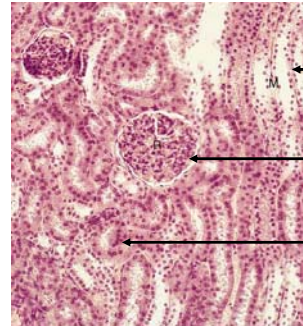
**Renal Cortex**



Glomerulus surrounded by cortical labyrinth  
Medullary rays (cross section)

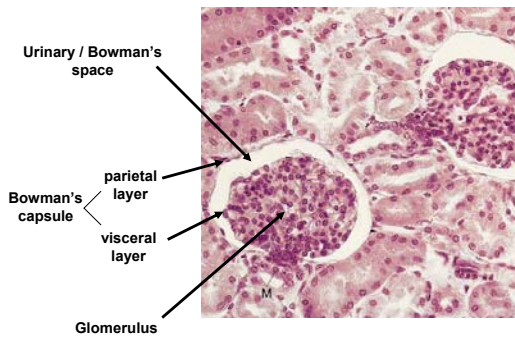
Sobotta & Hammersen: Histology

**Renal Cortex**



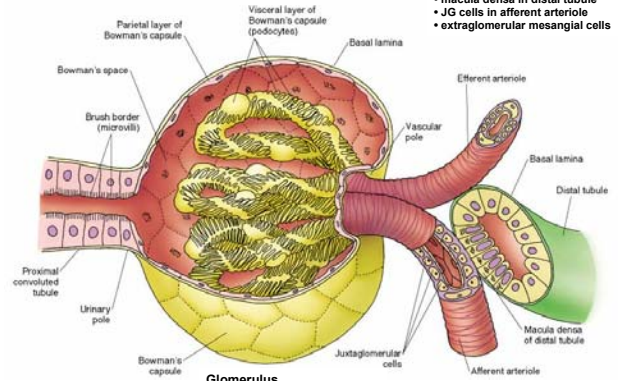
Medullary ray = collecting tubules  
Renal corpuscle = glomerulus + Bowman's capsule  
Cortical labyrinth of tubules

**Renal Corpuscle**



**Juxtaglomerular apparatus**

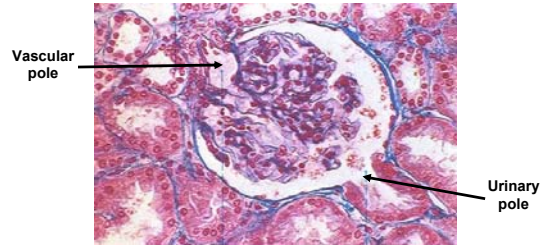
- macula densa in distal tubule
- JG cells in afferent arteriole
- extraglomerular mesangial cells



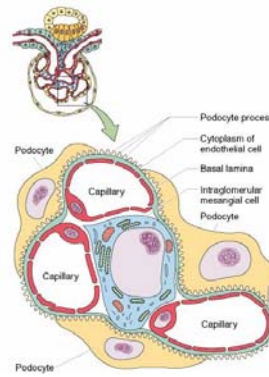
**Glomerulus**

- fenestrated capillaries
- podocytes
- intraglomerular mesangial cells

## Renal Corpuscle



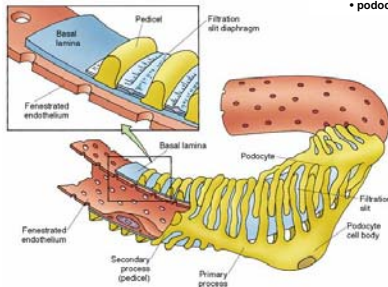
Sobotta & Hammersen: Histology



## Intraglomerular Mesangial Cells

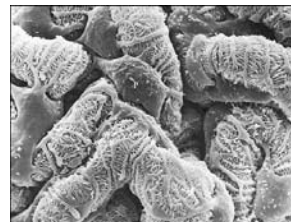
- Support capillaries
- Phagocytose basal lamina
- Vasoconstrict in response to angiotensin II

## Urinary Filtration Membrane



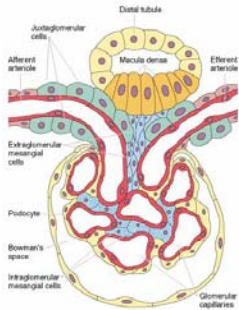
- Endothelial cell
  - 70-90 nm fenestra restrict proteins > 70kd
- Basal lamina
  - heparan sulfate is negatively charged
  - produced by endothelial cells & podocytes
  - phagocytosed by mesangial cells
- Podocytes
  - pedicels 20-40 nm apart
  - diaphragm 6 nm thick with 3-5 nm slits
  - podocalyxin in glycocalyx is negatively charged

## Podocytes



## Urinary Membrane





### Juxtaglomerular Apparatus

#### Macula densa in distal tubule

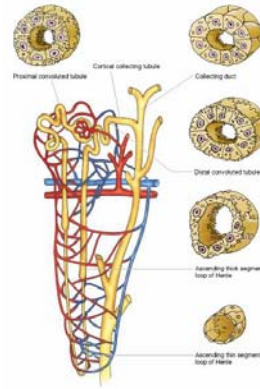
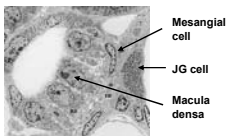
- monitor  $\text{Na}^+$  content and volume in DT
- low  $\text{Na}^+$ :
  - stimulates JG cells to secrete renin
  - stimulates JG cells to dilate afferent arteriole
- tall, narrow columnar cells
- numerous microvilli

#### JG cells

- secrete renin into circulation
  - renin converts angiotensinogen  $\rightarrow$  angiotensin I
- contain angiotensin converting enzyme (ACE)
  - lung is principal site of ACE activity
  - ACE converts angiotensin I  $\rightarrow$  II
- contain angiotensin I & II
  - angiotensin II constricts vasculature and stimulates secretion of aldosterone and ADH
- primarily in afferent arteriole
- specialized smooth muscle cells
- no basal lamina between JG cells & macula densa

#### Extraglomerular mesangial cells

- also known as Polkissen or lacis cells



#### Proximal tubule

- proximal convoluted tubule
- thick descending limb Henle's loop

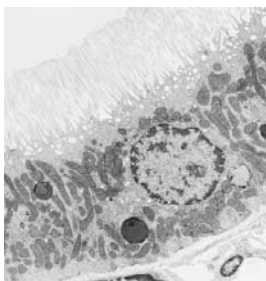
#### Henle's loop

- thin descending & ascending limbs

#### Distal tubule

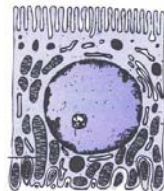
- thick ascending limb Henle's loop
- distal convoluted tubule
- macula densa in DCT

#### Collecting tubule & duct



### Proximal Convoluted Tubule

- Cuboidal (low to high) cells
- Eosinophilic granular cytoplasm
- Basal nuclei
- Elaborate brush/striated border
- Lateral interdigitations



- Resorbs 100% protein, amino acids, glucose, creatinine, and bicarbonate ions
- Resorbs 70-80% of  $\text{Na}^+$ ,  $\text{Cl}^-$ , and water
  - $\text{Na}^+/\text{K}^+$  pumps in basolateral membrane
  - $\text{Na}^+$  pumped into interstitium
  - $\text{Cl}^-$  and water follow
- Secretes waste products into lumen

### Henle's Loop (thin segments)



- Squamous cells
- slightly thicker than endothelial cells
- Few short microvilli
- Lateral interdigitations

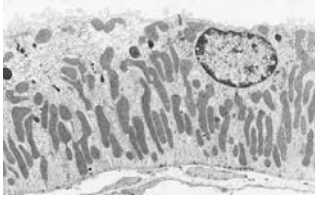
#### Descending limb

- highly permeable to water, salt and urea

#### Ascending limb

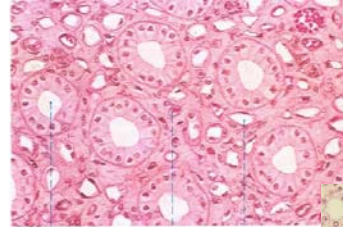
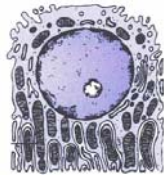
- impermeable to water
- permeable to salt which enters interstitium

**Distal Tubule**  
(DCT & thick ascending limb of Henle's loop)



- Low cuboidal cells
- Clear pale cytoplasm
- Apical nuclei (DCT)
- Central nuclei (Henle's loop)
- Numerous mitochondria
- Absent (or few short) microvilli
- Basal interdigitations
- Numerous zonula occludens

- Not permeable to water or urea
- Active Na<sup>+</sup>/K<sup>+</sup> pumps (DCT)
  - aldosterone stimulates salt resorption
  - H<sup>+</sup> and K<sup>+</sup> transported into lumen
- Active Cl<sup>-</sup> pumps (Henle's thick)
  - Cl<sup>-</sup> enters interstitium (Na<sup>+</sup> follows)

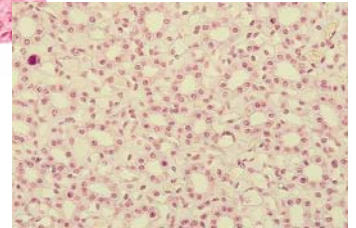


Collecting tubule      Blood capillary      Thin segment of Henle's loop

Sobotta & Hammersen: Histology

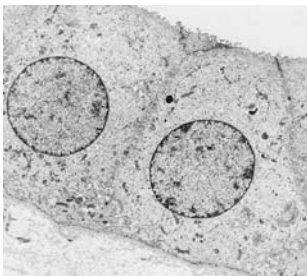
**Renal Medulla**

- Collecting tubules/ducts
- Henle's loop (thin segments)
- Capillaries of vasa recta

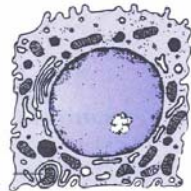


Gartner & Hiatt: Color Textbook of Histology

**Collecting Tubule & Duct**



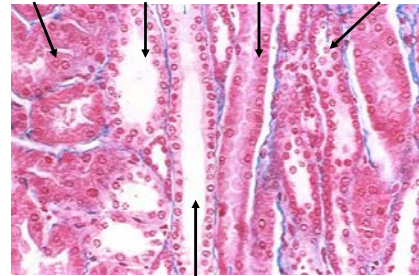
- Cuboidal to columnar cells
- Clear cytoplasm
- Central nuclei



- Permeable to urea
- In response to ADH, becomes permeable to water which enter the interstitium

**Renal Cortex**

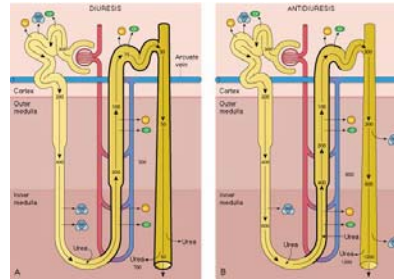
Proximal tubule (convoluted)      Distal tubule      Proximal tubule (straight)      Henle's loop (thick)



Collecting tubule

Sobotta & Hammersen: Histology

REGION OF URINIFEROUS TUBULE	MAJOR FUNCTIONS	MISCELLANEOUS COMMENTS
<b>Renal Corpuscle:</b> Simple squamous epithelium, fused basal laminae, podocytes	Filtration	Filtration barrier: endothelial cell, fused basal laminae, filtration slits
<b>Proximal Tubule:</b> Simple cuboidal epithelium	Resorption of 67%–100% of water, sodium, and chloride (reducing volume of ultrafiltrate); resorption of 100% of protein, amino acids, glucose, and bicarbonate	Sodium pump in basolateral membrane; ultrafiltrate is isotonic with blood
<b>Descending Thin Limb of Henle's Loop:</b> Simple squamous epithelium	Completely permeable to water and salts (reducing volume of ultrafiltrate)	Ultrafiltrate is hypertonic with respect to blood; urea enters lumen of tubule
<b>Ascending Thin Limb of Henle's Loop:</b> Simple squamous epithelium	Impermeable to water; permeable to salts, sodium and chloride leave tubule to enter renal interstitium	Ultrafiltrate is hypertonic with respect to blood; urea leaves renal interstitium and enters the lumen of tubule
<b>Ascending Thick Limb of Henle's Loop:</b> Simple cuboidal epithelium	Impermeable to water; chloride and sodium leave tubule to enter renal interstitium	Ultrafiltrate becomes hypotonic with respect to blood; chloride pump in basolateral cell membrane is responsible for the establishment of osmotic gradient in interstitium of outer medulla
<b>Macula Densa:</b> Simple columnar cells	Monitor sodium level and volume of ultrafiltrate in lumen of distal tubule	Contacts and communicates with juxtaglomerular cells
<b>Juxtaglomerular Cells:</b> Modified smooth muscle cells	Synthesize and release renin into bloodstream	Renin initiates the reaction for the eventual formation of angiotensin II (see Table 19-2)
<b>Distal Convoluted Tubule:</b> Simple cuboidal epithelium	Responds to aldosterone by reabsorbing sodium and chloride for lumen	Ultrafiltrate becomes more hypotonic in the presence of aldosterone; sodium pump in basolateral membrane; potassium is secreted into the lumen
<b>Collecting Tubule:</b> Simple cuboidal epithelium	In the presence of ADH, water and urea leave the lumen to enter the renal interstitium	Urea becomes hypertonic in the presence of ADH; urea in interstitium is responsible for gradient of concentration in interstitium of the inner medulla



## Formation of Urine

### Countercurrent Multiplier System

Increasing osmolarity gradient exists from corticomedullary junction to deep in medulla

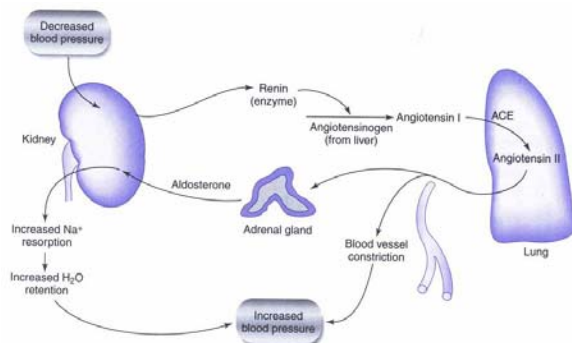
\*\* due to high urea and salt content deep in medulla

- Descending thin limb of Henle is freely permeable to water and salt
  - Due to increasing osmolarity of interstitium: luminal volume decreases and osmolarity increases
- Ascending (thin and thick) limb of Henle and DCT are not permeable to water
  - Luminal volume does not change
  - Urea enters lumen
  - Cl<sup>-</sup> pumped into interstitium (Na<sup>+</sup> follows)
    - increases salt deep in medulla
    - ultrafiltrate becomes hypotonic as it ascends
- Without ADH: collecting tubule/duct impermeable to water
  - ADH (pars nervosa of pituitary) makes collecting tubule/duct freely permeable to water and urea
    - increases water resorption, decreases urine volume, and increases urine tonicity
    - increases urea content deep in medulla to maintain interstitial osmolarity gradient

## Angiotensin II Regulation of Blood Pressure

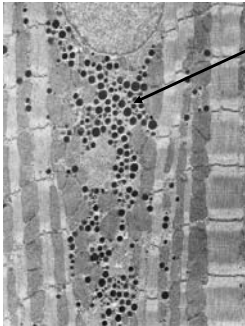
FUNCTION	RESULT
Acts as a potent vasoconstrictor	Increased blood pressure
Facilitates synthesis and release of aldosterone	Resorption of sodium and chloride from lumen of distal convoluted tubule
Facilitates release of ADH	Resorption of water from lumen of collecting tubule
Increases thirst	Increased tissue fluid volume
Inhibits renin release	Feedback inhibition
Facilitates release of prostaglandins	Vasodilation of afferent glomerular arteriole, thus maintaining glomerular filtration rate

## Angiotensin II Regulation of Blood Pressure



Burns & Cave: Histology & Cell Biology

## Additional Regulators of Kidney Function



### Atrial Natriuretic Peptide (ANP)

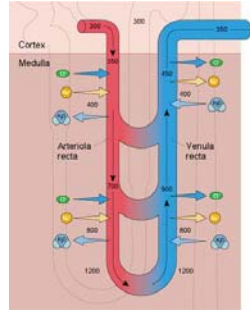
- Secreted by atrial cardiac myocytes
- Function
  - decreases renin release
  - decreases aldosterone release
  - blocks resorption salt and water
  - decreases blood pressure

### Alcohol

- decreases ADH release

### Caffeine

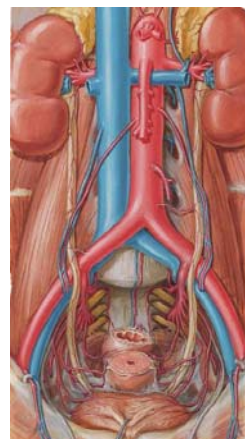
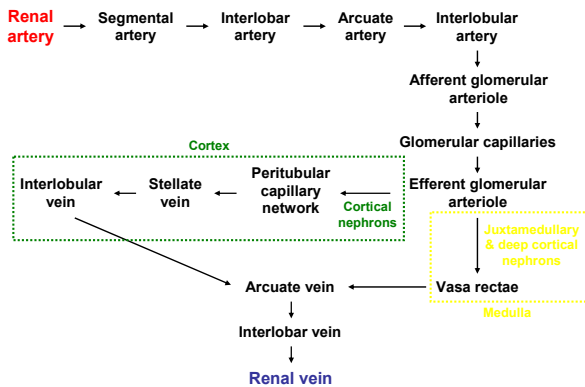
- increases salt resorption in DCT



### Vasa Rectae

- Peritubular capillary system in medulla
- Freely permeable to water and salts
- Counter current exchange system: equilibrates contents of medullary interstitium and vasculature

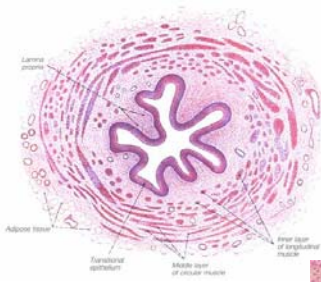
## Vasculature of Kidney



### Urine is excreted through

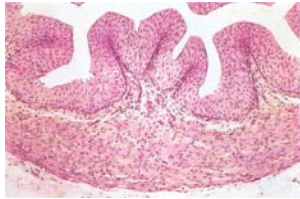
- Calyces and renal pelvis
- Ureters
- Urinary bladder (storage)
- Urethra

Netter: Atlas of Human Anatomy



### Ureter

- Mucosa - transitional epithelium
- Lamina propria
- Muscularis – smooth muscle
  - Inner longitudinal
  - Middle circular
  - Outer longitudinal (lower 1/3)

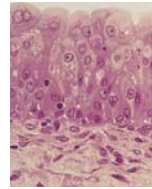


Sobotta & Hammersen: Histology



### Urinary Bladder

- Mucosa - transitional epithelium
  - provides osmotic barrier
- Lamina propria
- Muscularis – smooth muscle
  - inner longitudinal
  - middle circular (internal urethral sphincter)
  - outer longitudinal



Sobotta & Hammersen: Histology  
Gartner & Hiatt: Color Textbook of Histology



### Urethra

- Mucosa
  - varies from transitional to stratified columnar to pseudostratified columnar to stratified squamous in different regions
- Lamina propria
  - contains glands of Littre
  - highly vascularized
- External urethral sphincter of skeletal muscle
- In the male, 3 regions:
  - prostatic
  - membranous
  - penile or spongy