Urinary System
kidneys, ureters, bladder & urethra

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 calyxes
  - 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

Renal Lobule
- medullary ray & surrounding cortical labyrinth

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 calyxes
Renal Cortex

Sobotta & Hammersen: Histology

Renal Cortex

Renal corpuscle

= glomerulus + Bowman’s capsule

Medullary ray = collecting tubules

Cortical labyrinth of tubules

Renal Corpuscle

Glomerulus

• fenestrated capillaries
• podocytes
• intraglomerular mesangial cells

Juxtaglomerular apparatus
• macula densa in distal tubule
• JG cells in afferent arteriole
• extraglomerular mesangial cells

Urinary / Bowman’s space

Bowman’s capsule

visceral layer

parietal layer

Glomerulus
Renal Corpuscle

Vascular pole

Urinary pole

Sobotta & Hammersen: Histology

Intraglomerular Mesangial Cells

• Support capillaries
• Phagocytose basal lamina
• Vasconstrict 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 Na⁺ content and volume in DT
- Low Na⁺:
  - Stimulates JG cells to secrete renin
  - Stimulates JG cells to dilate afferent arteriole
  - Tall, narrow columnar cells
  - Numerous microvilli

JG cells
- Secret renin into circulation
  - Renin converts angiotensinogen → angiotensin I
  - Lung is principal site of ACE activity
- Contain angiotensin converting enzyme (ACE)
- ACE converts angiotensin I → 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
- Thin descending & ascending limbs

Distal tubule
- Thick ascending limb

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 Na⁺, Cl⁻, and water
- Na⁺/K⁺ pumps in basolateral membrane
- Na⁺ pumped into interstitium
- 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+/K+ pumps (DCT)
  - Aldosterone stimulates salt resorption
  - H+ and K+ transported into lumen
- Active Cl− pumps (Henle’s thick)
  - Cl− enters interstitium (Na+ follows)

Renal Medulla

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

Collecting Tubule & Duct

- Cuboidal to columnar cells
- Clear cytoplasm
- Central nuclei
- Permeable to urea
- In response to ADH, becomes permeable to water which enters the interstitium

Renal Cortex

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

Collecting tubule
Formation of Urine

**Countercurrent Multiplier System**

Increasing osmolality gradient exists from corticomedullary junction to deep in medulla

- **Descending thin limb of Henle** is freely permeable to water and salt
  - Due to increasing osmolality of interstitium: lumenal volume decreases and osmolarity increases
  - Ascending (thin and thick) limb of Henle and DCT are **not** permeable to water
    - Urea enters lumen
      - Cl⁻ pumped into interstitium (Na⁺ follows)
        - Increases salt deep in medulla
        - Urea becomes hypertonic 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

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Angiotensin II Regulation of Blood Pressure

**TABLE 19-2 Effects of Angiotensin II**

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acts as a potent vasopressor</td>
<td>Increased blood pressure</td>
</tr>
</tbody>
</table>
| Facilitates synthesis and release of aldosterone | Resorption of sodium and chloride from luminal fluid
| 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 | Vascularization of afferent glomerular arterioles, thus maintaining glomerular filtration rate |
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

Additional Regulators of Kidney Function

Vasculation of Kidney

Urine is excreted through
- Calyces and renal pelvis
- Ureters
- Urinary bladder (storage)
- Urethra

Netter: Atlas of Human Anatomy
Ureter
- Muscosa - transitional epithelium
- Lamina propria
- Muscularis – smooth muscle
  - Inner longitudinal
  - Middle circular
  - Outer longitudinal (lower 1/3)

Urinary Bladder
- Muscosa - transitional epithelium
- Lamina propria
- Muscularis – smooth muscle
  - Inner longitudinal
  - Middle circular
  - Outer longitudinal

Empty

Distended

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