Urinary System
(Anatomy & Physiology)

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The Urinary System

• Functions of the urinary system
• Anatomy of the kidney
• Urine formation
  – glomerular filtration
  – tubular reabsorption
  – water conservation
• Urine and renal function tests
• Urine storage and elimination
Kidney Functions

- Blood Plasma Filtration: eliminates waste, returns useful chemicals to blood
- Blood Volume & Pressure Regulation
- Regulation of Body Fluids Osmolarity
- Secretes renin, activates angiotensin, aldosterone
  - controls BP, electrolyte balance
- Secretes erythropoietin, controls RBC count
- Regulates $P_{CO_2}$ and Acid Base Balance
- Detoxifies free radicals and drugs
- 1, 25 dihydroxycholecalciferol
- Gluconeogenesis
Excretion

Separation of wastes from body fluids & eliminating them:

- **Respiratory System**: CO₂, water

- **Integumentary System**: water, salts, lactic acid, urea

- **Digestive system**: water, salts, CO₂, lipids, bile pigments, cholesterol

- **Urinary System**: many metabolic wastes, toxins, drugs, hormones, salts, H+ and water

Nitrogenous Wastes

- **Urea**
  - proteins → amino acids → NH₂ removed → forms ammonia, liver converts to urea

- **Uric acid**
  - nucleic acid catabolism

- **Creatinine**
  - creatine phosphate catabolism

- **Renal Failure**
  - Azotemia: nitrogenous wastes in blood
  - Uremia: toxic effects as wastes accumulate
Anatomy of Kidney

- Renal cortex: outer 1 cm
- Renal medulla: renal columns, pyramids - papilla
- Lobe of kidney: pyramid + it’s overlying cortex
Lobe of Kidney

Cross-section of a human renal papilla

Blood Supply Diagram

Kidneys are 1% of body weight and use 20-25% of the oxygen.

¼ of the cardiac output is delivered to the kidneys each minute
Nephrons

- True proportions of nephron loops to convoluted tubules shown
- Cortical nephrons (85%)
  - short nephron loops
  - efferent arterioles branch off peritubular capillaries
- Juxtamedullary nephrons (15%)
  - very long nephron loops, maintain salt gradient, helps conserve water
  - efferent arterioles branch off vasa recta, blood supply for medulla

Peritubular capillaries shown only on right
Renal Corpuscle

Glomerular filtrate collects in capsular space, flows into renal tubule
Filtration Membrane

- Fenestrated endothelium
  - 70-90nm pores exclude blood cells
- Basement membrane
  - proteoglycan gel, negative charge excludes molecules > 8nm
  - blood plasma 7% protein, glomerular filtrate 0.03%
- Filtration slits
  - podocyte arms have pedicels with negatively charged filtration slits, allow particles < 3nm to pass

Filtration Membrane Diagram

- Filtration slits
- Capillary endothelium
- Pedicels
- Basement membrane
- Fenestrations
- Podocyte cell body
Filtration Barrier

A. The endothelial cells of the glomerulus; 1. pores (fenestra=40 nm).
C. Podocytes: 1. enzymatic and structural proteins (nephrin & CD2AP)
   2. filtration slit (<1.8, 1.8-4.2, >4.2 nm)
   3. diaphragma

Renal (Uriniferous) Tubule

• Proximal convoluted tubule (PCT)
  – longest, most coiled, simple cuboidal with brush border

• Nephron loop - U shaped; descending + ascending limbs
  – thick segment (simple cuboidal) initial part of descending limb and part or all of ascending limb, active transport of salts
  – thin segment (simple squamous) very water permeable

• Distal convoluted tubule (DCT)
  – cuboidal, minimal microvilli
Renal (Uriniferous) Tubule 2

- Juxtaglomerular apparatus:
  DCT, afferent/efferent arterioles

- Collecting duct: several DCT’s join

Flow of glomerular filtrate:
- glomerular capsule → PCT → nephron loop → DCT → collecting duct →
  papillary duct → minor calyx → major calyx → renal pelvis → ureter → urinary
  bladder → urethra

Urine Formation Preview

1. Glomerular filtration
   Creates a plasmalike filtrate of the blood

2. Tubular reabsorption
   Removes useful solutes from the filtrate, returns them to the blood

3. Tubular secretion
   Removes additional wastes from the blood, adds them to the filtrate

4. Water conservation
   Removes water from the urine and returns it to blood, concentrates wastes
Filtration Pressure

Glomerular Filtration Rate (GFR)

- Filtrate formed per minute
- GFR \approx NFP
- GFR = NFP \times K_f \approx 125 \text{ ml/min or 180 L/day}
- Filtration coefficient (K_f) depends on
  - Permeability
  - surface area of filtration barrier
- 99% of filtrate reabsorbed: 1 to 2 L urine excreted
Effects of GFR Abnormalities

- ↑GFR = ↑urine output → dehydration, electrolyte depletion

- ↓GFR → wastes reabsorbed (azotemia possible)

- GFR controlled by adjusting glomerular blood pressure
  - autoregulation
  - sympathetic control
  - hormonal mechanism: renin and angiotensin

Juxtaglomerular Apparatus

- Podocytes
- Mesangial cells
- Efferent arteriole
- Distal tubule
- Juxtaglomerular cells
  - vasomotion
- Afferent arteriole
- Smooth muscle cells
- Macula densa
  - monitor salinity

Sympathetic nerve fiber
Renal Autoregulation of GFR

- $\uparrow$ BP $\rightarrow$ constrict afferent arteriole, dilate efferent
- $\downarrow$ BP $\rightarrow$ dilate afferent arteriole, constrict efferent
- Stable for BP range of 80 to 170 mmHg (systolic)
- Cannot compensate for extreme BP

Negative Feedback Control of GFR

- Reduced GFR
  - Constriction of afferent arteriole
  - Unidentified paracrine secretion
  - Macula densa senses high NaCl concentration

- High GFR
  - Rapid flow of filtrate in renal tubules
  - Less reabsorption
Sympathetic Control of GFR

- Strenuous exercise or acute conditions (circulatory shock) stimulate afferent arterioles to constrict

- $\downarrow$ GFR and urine production, redirecting blood flow to heart, brain and skeletal muscles

Hormonal Control of GFR
Effects of Angiotensin II

- Causes constriction of efferent arteriole
- Increases glomerular blood pressure and filtration and reduces blood pressure in peritubular capillary
- Reduces resistance to tubular reabsorption
- Tubular reabsorption increases
- Urine volume is less but concentration is high

Tubular Reabsorption and Secretion

1. **Glomerular filtration**
   - Creates a plasmalike filtrate of the blood

2. **Tubular reabsorption**
   - Removes useful solutes from the filtrate, returns them to the blood

3. **Tubular secretion**
   - Removes additional wastes from the blood, adds them to the filtrate

4. **Water conservation**
   - Removes water from the urine and returns it to blood, concentrates wastes
Peritubular Capillaries

- Blood has unusually high COP here, and BHP is only 8 mm Hg (or lower when constricted by angiotensin II); this favors reabsorption

- Water absorbed by osmosis and carries other solutes with it (solvent drag)

Proximal Convoluted Tubules (PCT)

- Reabsorbs 65% of GF to peritubular capillaries

- Great length, prominent microvilli and abundant mitochondria for active transport

- Reabsorbs greater variety of chemicals than other parts of nephron
  - transcellular route - through epithelial cells of PCT
  - paracellular route - between epithelial cells of PCT

- Transport maximum: when transport proteins of plasma membrane are saturated; glucose > 220 mg/dL remains in urine (glycosuria)
Tubular Secretion of PCT and Nephron Loop

- Waste removal
  - urea, uric acid, bile salts, ammonia, catecholamines, many drugs
- Acid-base balance
  - secretion of hydrogen and bicarbonate ions regulates pH of body fluids
- Primary function of nephron loop
  - water conservation, also involved in electrolyte reabsorption
DCT and Collecting Duct

- Effect of aldosterone
  - ↓ BP causes angiotensin II formation
  - angiotensin II stimulates adrenal cortex
  - adrenal cortex secretes aldosterone
  - aldosterone promotes Na\(^+\) reabsorption
  - Na\(^+\) reabsorption promotes water reabsorption
  - water reabsorption ↓ urine volume
  - BP drops less rapidly

Renin-Angiotensin-Aldosterone System
DCT and Collecting Duct 2

- Effect of Atrial Natriuretic Factor (ANF)
  - ↑ BP stimulates right atrium
  - atrium secretes ANF
  - ANF promotes Na\(^+\) and water excretion
  - BP drops
- Effect of ADH
  - dehydration stimulates hypothalamus
  - hypothalamus stimulates posterior pituitary
  - posterior pituitary releases ADH
  - ADH ↑ water reabsorption
  - urine volume ↓

Collecting Duct Concentrates Urine

- Osmolarity 4x as high deep in medulla
- Medullary portion of CD is permeable to water but not to NaCl
Control of Water Loss

- Producing hypertonic urine
  - GFR drops
  - tubular reabsorption ↑
  - less NaCl remains in CD
  - ADH ↑ CD’s water permeability
  - more water is reabsorbed
  - urine is more concentrated

Normal urine output = 0.5ml/kg body weight/hr
30 to 40 ml per hour for an adult

Countercurrent Multiplier of Nephron Loop Diagram

- Recaptures NaCl and returns it to renal medulla
- Descending limb
  - reabsorbs water but not salt
  - concentrates tubular fluid
- Ascending limb
  - reabsorbs Na⁺, K⁺, and Cl⁻
  - maintains high osmolarity of renal medulla
  - impermeable to water
  - tubular fluid becomes hypotonic
- Recycling of urea: collecting duct-medulla
  - urea accounts for 40% of high osmolarity of medulla
Maintenance of Osmolarity in Renal Medulla

Summary of Tubular Reabsorption and Secretion