Urinary System:

Kidneys ain’t just for pee’in

Major Functions of Urinary System:
1) Removal of organic waste products from fluids (excretion)
2) Discharge of waste products into the environment (excretion)
3) Homeostatic regulation of the volume / solute concentration of blood plasma

Blood Supply to Kidneys:
• 1/4 of cardiac output delivered to kidneys
• 0.25 x 5 L / min = 1.25 L / min (kidneys only 0.5% of total body mass)

Nerve Supply to Kidneys:
• Sympathetic nervous system
  1) Adjust rate of urine formation (change blood flow / pressure)
  2) Adjust overall blood pressure / volume (renin release)

Nephron: Functional unit of the kidney (urine formation)
• ~ 1 million / kidney
• Filter ~ 200 L of blood plasma / day
• Produce ~ 1 - 1.5 L of urine / day

Nephron Anatomy:
1) Renal Corpuscle (filtration)
   A) Glomerulus
      • Blood enters via afferent artery and exits via efferent artery
      • Fenestrated endothelium
   B) Glomerular Capsule (Bowman’s Capsule)
      • Expanded proximal end of nephron (surrounds glomerulus)
      • Outer layer = simple squamous epithelium
      • Inner layer = Podocytes (foot cells)

2) Tubule
   • Location of filtrate / urine

Peritubular Capillaries
Reabsorb materials from tubule of nephron

99% of filtrate returned to blood
Urinary System – Anatomy:
Nephron Anatomy:

1) Renal Corpuscle

- Pedicels: Podocyte processes that embrace capillary, form filtration slits

2) Proximal Convoluted Tubule (nutrient reabsorption)
   - Continuous with outer layer of glomerular capsule
   - Simple cuboidal epithelium with brush border (↑ surface area)

3) Loop of Henle (water conservation)
   - Thin segments (ascending / descending) = simple squamous epithelium
   - Thick segments (ascending / descending) = simple cuboidal epithelium

4) Distal Convoluted Tubule (secretion / selective reabsorption)
   - Simple cuboidal epithelium; no microvilli (brush border)
   - Smaller lumen / ↑ number of cells (compared to PCT)
   - Juxtaglomerular Apparatus:
     - Macula Dense cells: Line DCT near renal corpuscle
     - Juxtaglomerular cells: Modified smooth muscle cells; located in afferent artery
      - Release renin if 1) ↓ glomerular BP, 2) ↓ tubule fluid [osmotic]
      - Renin-angiotensin Mechanism (↑ blood pressure)

5) Collecting Ducts (secretion / selective reabsorption)
   - Simple cuboidal epithelium → simple columnar epithelium
Chapters 24: Urinary System

Urinary System – Anatomy:
Types of Nephrons:
1) **Cortical Nephrons** (85%):
   - Located entirely in the cortex

2) **Juxtamedullary Nephrons** (15%):
   - Bowman’s capsule in cortex; loop of Henle in medulla

Urinary System – Anatomy:
- **Bowman’s capsule**: in cortex; loop of Henle in medulla

Urinary System – Physiology:
- **Single day** → kidneys filter 60x normal blood plasma volume present
  - Consume 20 - 25 % of all oxygen at rest

Filtrate = all blood borne solutes except proteins
Urine = metabolic waste and unneeded solutes

- Major processes in urine formation:
  1) **Glomerular filtration**
  2) **Tubular reabsorption** (renal tubules)
  3) **Tubular secretion** (renal tubules)

Urinary System – Physiology:
1) **Glomerular Filtration**:
   A) Blood pressure = driving force
Glomerular Hydrostatic Pressure

Net Filtration Pressure = 55 mm Hg - (15 mm Hg + 30 mm Hg)

Colloid Osmotic Pressure
Capsular Hydrostatic Pressure

Key:
- Glomerular (blood) hydrostatic pressure (55 mm Hg)
- Blood colloid osmotic pressure (30 mm Hg)
- Capsular hydrostatic pressure (15 mm Hg)

Glomerular Filtration:
A) Blood pressure = driving force
B) Molecules Filtered < 3 nm Diameter
   - Water, glucose, amino acids, ions, nitrogenous waste (cells / proteins too large)

Glomerular filtration rate (GFR):
- Volume of fluid filtered into Bowman’s capsule / minute
  - Normal adult = 120-150 ml / min
- Factors governing filtration rate:
  1) Surface area (65 ft² / kidney)
  2) Filtration membrane permeability
  3) Net filtration pressure (40% GHP = no filtration)

Creatinine Clearance Test
- Metabolite of creatine phosphate
- Eliminated in urine (not reabsorbed…)
- Amount cleared in urine (mg / h)
- Amount in blood (mg / dl)
- Rate (ml / min)

Control of GFR:
1) Autoregulation: Local changes in afferent / efferent arteriole diameters
   - Reduced blood flow (40% GHP) = Dilation of afferent arteriole
   - Relaxation of glomerular capillaries
   - Constriction of efferent arteriole

Increased blood flow (140% GHP)
**Urinary System – Physiology:**

1) **Glomerular Filtration:**
   A) Blood pressure = driving force
   B) Molecules Filtered < 3 nm Diameter
      - Water, glucose, amino acids, ions, nitrogenous waste (cells / proteins too large)
   C) Glomerular filtration rate (GFR):
      - Volume of fluid filtered into Bowman’s capsule / minute
      - Normal adult = 120-150 ml / min
      - Factors governing filtration rate:
         1) Surface area (ft² / kidney)
         2) Filtration membrane permeability
         3) Net filtration pressure (↓ 20% GHP = no filtration)

   • **Control of GFR**
     1) Autoregulation: Local changes in afferent / efferent arteriole diameters
     2) Hormonal Regulation: Renin-angiotensin mechanism…

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### Creatinine Clearance Test

- Metabolite of creatine phosphate
- Eliminated in urine (not reabsorbed…)

\[
\text{Amount cleared in urine (mg/h)} = \frac{\text{Amount in blood (mg/dl)}}{\text{Rate (ml/min)}}
\]

**Relatively fixed…** (65 ft² / kidney)

### Control of GFR

1) Autoregulation: Local changes in afferent / efferent arteriole diameters
2) Hormonal Regulation: Renin-angiotensin mechanism…
3) Autonomic Regulation: Sympathetic innervation
   - Associated with vasoconstriction of afferent arteriole (over-rides local control)

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### Tubular Reabsorption

1) **Active processes:**
   - Chemicals moved against gradient
     - Requires ATP (pumps in epithelial cell membranes)

2) **Passive processes:**
   - Chemicals move down gradients

---

**Assisting movement into blood:**
- Highly permeable basement membrane
- Low blood pressure and high [protein] in capillary

**Transport Maximums (Tm):**
- Diabetes

**Key:**
- Primary active transport
- Secondary active transport
- Passive transport (diffusion)
- Protein carrier
- Ion channel

**Obligatory water reabsorption**

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**Urinary System – Physiology:**

2) **Tubular Reabsorption:**

   - Return of fluid from renal tubules to blood
   - ~ 80% of water & solutes reabsorbed at proximal convoluted tubule

   A) **Active processes:**
      - Chemicals moved against gradient
      - Requires ATP (pumps in epithelial cell membranes)

   B) **Passive processes:**
      - Chemicals move down gradients

---

### Transport of Solutes and Ions

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Solutes and Ions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal Convoluted Tubule</td>
<td>Glucose (100%)</td>
</tr>
<tr>
<td>Loop of Henle</td>
<td>Na⁺ (~ 70%)</td>
</tr>
<tr>
<td>Distal Convoluted Tubule &amp; Collecting Duct</td>
<td>Na⁺ (hormone dependent)</td>
</tr>
</tbody>
</table>
Urinary System – Physiology:

2) Tubular Reabsorption:
   - Non-reabsorbed substances:
     1) Urea (~ 21 g / day)
        • Result of amino acid breakdown
     2) Creatinine (~ 1.8 g / day)
        • Result of creatine phosphate breakdown
     3) Uric Acid (~ 480 mg / day)
        • Result of nucleotide breakdown
   - Not reabsorbed because:
     A) Lack protein carriers
     B) Not lipid soluble
     C) Too large to pass through membrane pores

3) Tubular Secretion:
   - Movement of material from capillary / tubule cells to filtrate
   - Functions:
     A) Eliminating substances not in filtrate (e.g., antibiotics)
     B) Eliminating substances reabsorbed (e.g., urea)
     C) Eliminating excess K⁺ (exchanged for Na⁺)
     D) Balancing pH
        \( \text{H}^+ / \text{HCO}_3^- \); dependent on pH of peritubular blood

Urinary System – Physiology:

Regulation of Urine Volume / Concentration:

Osmolality: \( \text{Osm} \)

# of solute particles dissolved in 1 L of water

Units:

\( \text{Osm} = 1 \text{ mole of non-ionizing substance in 1 L of water} \)

\( 1 \text{ mole glucose dissolved in 1 L water} = 1 \text{ Osmol} \)

\( 1 \text{ mole of NaCl dissolved in 1 L water} = 2 \text{ Osmol} \)

\( m\text{Osm} = 0.001 \text{ Osmol} \)

Hyper-osmotic \((^{+}\text{Osm})\)

Hypo-osmotic \((-\text{Osm})\)

Water

Regulation of Urine Volume / Concentration:

Osmolarity of interstitial fluid \((m\text{Osm})\)

Cortex

Water

Outer medulla

1) Descending limb of loop of Henle
    permeable to water but not solutes

300

400

600

800

1000

1200

1200
Urinary System – Physiology:
Regulation of Urine Volume / Concentration:

**Formation of Dilute Urine (~ 100 mOsm/l):**
- 15 – 19 ml fluid / min produced (~ 22.5 L urine / day)
- Collecting ducts impermeable to water
- Diuretics = Chemicals that enhance urinary output
  - Used to treat various medical conditions (e.g., hypertension)

**Formation of Concentrated Urine (~ 1200 mOsm/l):**
- 1.0 ml fluid / min produced (~ 1.5 L urine / day)
- Hormonally controlled (facultative water reabsorption)
  1) Antidiuretic Hormone (ADH)
  2) Aldosterone

Water channels open in distal tubule and collecting duct

Activation of osmoreceptors in hypothalamus

↑ osmolarity of blood
Urinary System – Physiology:
Regulation of Urine Volume / Concentration:

- ↑ Aldosterone (adrenal cortex)
- ↓ blood volume (∼ BP)
- ↑ [K⁺]
- ↑ reabsorption of Na⁺
- ↑ secretion of K⁺

Angiotensinogen

converted to

Angiotensin II

Renin released

Blood volume

K⁺

Na⁺

Water

peritubular capillary

Chapters 24: Urinary System

Urinary System – Physiology:

Composition of Urine:

- 95% water
- 5% solutes
  - Nitrogenous wastes (urea > creatinine > uric acid)
  - Ions (Na⁺, K⁺, phosphates, sulfates)

Physical Characteristics of Urine:
1) Color & Transparency
   - Dilute = clear / pale yellow; Conc. = deep yellow (urobilin)
2) Odor
   - Fresh = slight odor; Old = ammonia odor (bacterial metabolism)
3) pH
   - Acidic (pH ~ 6)

Produced by flora in large intestine (absorbed in colon)

Urinary System – Physiology:

Urine Transport, Storage, and Elimination:
1) Ureters: Convey urine from kidney to bladder
   - Movement = Peristalsis
     - Histology:
       - Mucosa (Transitional epithelium)
       - Smooth muscle layer (longitudinal / circular)
       - Adventitia
     - Kidney Stones

2) Bladder: Collapsible, muscular sack → urine storage
   - Retroperitoneal (maximum capacity ~ 1 L)
   - Histology:
     - Mucosa (Transitional epithelium)
     - Smooth muscle layer (Detrusor muscle)
     - Adventitia / serosa

3) Urethra: Opening to external environment
   - Distinct between sexes
   - Histology:
     - Mucosa (Stratified epithelium – transitional / columnar / squamous)
     - Mucin-secreting cells present
     - Lamina propria anchors to surrounding structures
Urinary System – Physiology:
Urine Transport, Storage, and Elimination:

Micturition (urination):

Incontinence:
Inability to control urination voluntarily (e.g., spinal cord injury)

If not acknowledged, relaxation for ~ 1 hr.

Incontinence:
Postganglionic neuron in intramural ganglion stimulates detrusor muscle contraction

Sensory fiber in pelvic nerve

Urinary bladder

Stretch receptor

1. Voluntary relaxation of external urethral sphincter causes relaxation of internal urethral sphincter

2. Afferent

3. Spinal cord

4. Postganglionic neuron in intramural ganglion stimulates detrusor muscle contraction

5. Voluntary relaxation of external urethral sphincter causes relaxation of internal urethral sphincter

6. Interneuron relays sensation to thalamus

7. Thalamus delivers sensation to cerebral cortex

8. Projection fibers from thalamus deliver sensation to cerebral cortex

9. Sensory fiber in pelvic nerve

10. Postganglionic neuron in intramural ganglion stimulates detrusor muscle contraction

Chapters

24: Urinary System