Urinary System Organs

- **Kidneys**
  - Major excretory organs
- **Ureters**
  - Transport urine from kidneys to bladder
- **Urinary bladder**
  - Temporary storage reservoir for urine
- **Urethra**
  - Transports urine out of the body
Urinary System Organs

- Hepatic veins (cut)
- Esophagus (cut)
- Inferior vena cava
- Adrenal gland
- Aorta
- Iliac crest
- Renal artery
- Renal hilum
- Renal vein
- Kidney
- Ureter
- Rectum (cut)
- Uterus (part of female reproductive system)
- Urinary bladder
- Urethra
Kidney Functions

- Removal of toxins, metabolic wastes, and excess ions from the blood
- Regulation of blood volume, chemical composition, and pH
- Gluconeogenesis during prolonged fasting
- Endocrine functions
  - Renin: regulates BP & kidney function
  - Erythropoietin: regulation of RBC production
- Activation of Vitamin D
Kidney Anatomy

- In superior lumbar region
- Right kidney is lower than left
- Renal hilum leads to renal sinus
  - Ureters, renal blood vessels, lymphatics, and nerves enter and exit

- Layers of support tissue
  - Renal fascia – anchor kidneys
  - Perirenal fat capsule – cushion
  - Fibrous capsule – prevents spread of infection to kidney
Internal Kidney Anatomy

- **Renal Cortex**
  - light colored, granular superficial region
    - contains the convoluted tubules and the glomeruli

- **Renal Medulla**
  - cone-shaped *medullary (renal) pyramids*, with *papilla*; separated by *renal columns*
    - Renal columns- inward extensions of the cortex that defines the boundaries of pyramids, & divides the kidney into lobes
(b) Diagrammatic view

Renal cortex
Renal medulla
Major calyx
Papilla of pyramid
Renal pelvis
Minor calyx
Ureter
Renal pyramid in renal medulla
Renal column
Fibrous capsule

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Internal Kidney Anatomy

- Renal pelvis
  - funnel shaped tube within renal sinus
  - continuous with the ureter, branches into major and minor calyces
    - Calyces: Collect urine draining from papilla; Empty urine into renal pelvis

- Urine flows through the pelvis and ureters to the bladder

- The wall of the pelvis, calyces and ureters contain smooth muscle that push urine along via peristalsis
Internal Kidney Anatomy

- Cortical radiate vein
- Cortical radiate artery
- Arcuate vein
- Arcuate artery
- Interlobar vein
- Interlobar artery
- Segmental arteries
- Renal vein
- Renal artery
- Renal pelvis
- Ureter
- Renal medulla
- Renal cortex
(b) Path of blood flow through renal blood vessels

Nephron-associated blood vessels
(see Figure 25.7)
The Nephron

- Structural and functional unit that forms urine

- Two main parts:
  - glomerulus – tuft of capillaries
  - renal tubule – begins as glomerular (Bowman’s) capsule surrounding glomerulus
    - products empty into collecting ducts

- Two types of Nephrons:
  - Cortical - typical, found in cortex
  - Juxtamedullar – in medulla- necessary for concentrated urine
Cortical vs Juxtamedullary Nephron

**Cortical nephron**
- Has short loop of Henle and glomerulus further from the corticomedullary junction
- Efferent arteriole supplies peritubular capillaries

**Juxtamedullary nephron**
- Has long loop of Henle and glomerulus closer to the corticomedullary junction
- Efferent arteriole supplies vasa recta
Glomerulus

(a) Glomerular capillaries and the visceral layer of the glomerular capsule

- Efferent arteriole
- Afferent arteriole
- Glomerular capillary covered by podocyte-containing visceral layer of glomerular capsule
- Glomerular capsular space
- Proximal convoluted tubule
- Cytoplasmic extensions of podocytes
- Filtration slits
- Parietal layer of glomerular capsule
- Podocyte cell body
- Fenestrations (pores)
- Glomerular capillary endothelium (podocyte covering and basement membrane removed)
- Foot processes of podocyte
Nephron:

Renal corpuscle

- Glomerulus: tuft of capillaries associated with a renal tubule
  - The glomerular endothelium is fenestrated
  - Filtrate passes from the capillaries to Bowman’s capsule

- Glomerular (Bowman’s) capsule: cup-shaped end of a renal tubule that completely surrounds the glomerulus & receives filtrate

- Glomerulus + capsule = renal corpuscle
Renal tubule: Anatomy of the Glomerular Capsule

- **Parietal layer**
  - structural layer; simple squamous epithelium

- **Visceral layer**
  - consists of modified, branching epithelial podocytes and clings to the glomerulus
    - Podocytes form foot processes that intertwine to form clefts OR filtration slits
      - Allow filtrate to pass into capsule
Renal Tubule Anatomy

- From glomerular capsule, turns into a series of tubules
  - Proximal convoluted tubule
  - Loop of Henle
    - Descending & ascending limb
  - Distal convoluted tubule
- Empties into a collecting duct
  - Go through medullary pyramids > papillae > minor calyx > major calyx > renal pelvis
Renal Tubule:
Proximal convoluted tubule (PCT)

- Filtrate enters here after leaving the glomerular capsule
- Lined with cuboidal epithelial cells
- Have dense microvilli to increase surface area
  - for reabsorption of items in filtrate
    - From lumen of tubule to lumen of blood vessel
  - Can do some secretion, but mostly for reabsorption
- most H2O, Na+, and K+ will be reabsorbed here
  - NOT creatinine
Renal Tubule: Loop of Henle

- a hairpin-shaped loop of the renal tubule located in the medulla
- very important in establishing medullary osmotic gradient
  - descending limb
    - Thin segment of simple squamous epithelium
    - Freely permeable to water
  - ascending limb
    - Thick segment of cuboidal to columnar cells
Renal Tubule:

Distal convoluted tubule (DCT)

- Cuboidal cells with very few microvilli confined to cortex
- Important in **secreting** solutes into filtrate
  - From lumen of blood vessel to lumen of tubule
- Items secreted here include:
  - Drugs, creatinine, excess H+, bicarbonate, wastes, excess K+ and Na+
- Some reabsorption of Na+ under the influence of **aldosterone**
Renal Tubule

Figure 25.4b

- Parietal layer of glomerular capsule
- Distal convoluted tubule
- Basement membrane
- Podocyte of visceral layer of glomerular capsule
- Fenestrated endothelium of the glomerulus
- Proximal convoluted tubule
- Blood vessels
- Loop of Henle
  - Ascending limb
  - Descending limb
- Thick segment
- Thin segment
- Collecting duct
- Collecting duct cells
- Principal cell
- Mitochondria
- Microvilli
- Highly infolded plasma membrane
- Proximal convoluted tubule cells
- Distal convoluted tubule cells
- Loop of Henle (thin-segment) cells
- Intercalated cell
Collecting Ducts

- Receive filtrate (urine) from many nephrons
- travel through renal pyramids where they fuse into papillae that empty urine into the minor calyces
- ADH will increase H2O reabsorption here
Urine versus Filtrate

- Filtrate
  - filtered material in the renal tubules

- Called filtrate until it reaches the renal papillae (converging of the distal collecting ducts)
  - where it is then called urine
Nephron Capillary Beds

- **Glomerulus**
  - Specialized for filtration; with fenestrations
  - fed by afferent arteriole; drained by an efferent arteriole
  - BP is high because afferent diameter larger than efferent & the arterioles are high resistance vessels

- **Peritubular (or vasa recta) capillaries**
  - for reclaiming of substances from filtrate
  - arise from efferent arterioles
  - Low-pressure, porous; adapted for absorption
  - Empty into venules
  - Vasa recta in juxtamedullary nephrons; concentrate urine
Capillary Beds

Figure 25.5a
Kidney Physiology

- Filtrate: everything in plasma except proteins and cells
- Most will be reabsorbed
- Urine = what is not reabsorbed + secreted items
- Kidneys filter body’s entire plasma volume 60X each day
  - 180L of fluid /day
  - only 1% or 1.8L will leave as urine
Urine Formation

1. Glomerular filtration

2. Tubular reabsorption

3. Tubular secretion
Urine Formation:

Glomerular filtration

- Passive mechanical process driven by hydrostatic pressure

- Glomerulus is efficient filter because:
  - Permeable capillaries
  - High BP (hydrostatic pressure) in the glomerulus
  - Large surface area in the glomerulus

- Note: if capsular hydrostatic pressure increased (filtrate leaving glomerulus) then net filtration (amount filtered) would decrease
Glomerular Filtration Rate (GFR)

- Glomerular capsule
- Afferent arteriole
- Glomerular (blood) hydrostatic pressure: $HP_g = 55 \text{ mm Hg}$
- Blood colloid osmotic pressure: $OP_g = 30 \text{ mm Hg}$
- Capsular hydrostatic pressure: $HP_c = 15 \text{ mm Hg}$

Net filtration pressure
Glomerular Filtration Rate (GFR)

- Volume of filtrate formed per minute by kidneys
  - 120 – 125 ml/ min

- Very important to keep in range
  - Too low > everything, including wastes are reabsorbed
  - Too high > needed substances can not be reabsorbed fast enough > loss in urine
Regulation of GFR

- **Intrinsic controls** (locally within kidney to maintain GFR)
  - Renal autoregulation
    - By the arterioles directly (myogenic mechanism)
    - By macula densa cells (tubuloglomerular feedback)

- **Extrinsic controls** (in order to maintain systemic BP)
  - Sympathetic NS
  - Renin-Angiotensin mechanism
Intrinsic Control of GFR

- **Myogenic mechanism**
  - Constriction/dilation of afferent arterioles
    - Low BP > causes dilation of aff. arteriole > increase GFR
    - High BP > causes constriction of aff. arteriole > decrease GFR
      - Prevents too high of glomerular blood pressure

- **Tubuloglomerular feedback**
  - Via Macula densa cells in asc. LOH
    - respond to NaCl (solute) in filtrate
      - Low solute levels > indicates BP and GFR too slow > dilate afferent arteriole > inc GFR
      - High solute levels > indicates BP and GFR too fast (can’t reabsorb) > constrict afferent arteriole > dec GFR
Afferent arterioles and macula densa

- **Efferent arteriole**
- **Glomerular capsule**
- **Glomerulus**

**Juxtaglomerular apparatus**
- **Macula densa cells** of the ascending limb of loop of Henle
- **Extraglomerular mesangial cells**
- **Granular cells**

**Parietal layer of glomerular capsule**

**Foot processes of podocytes**

- **Podocyte cell body (visceral layer)**
- **Red blood cell**
- **Proximal tubule cell**

- **Capsular space**
- **Juxtaglomerular apparatus**
- **Renal corpuscle**

- **Endothelial cell of glomerular capillary**
- **Mesangial cells between capillaries**
- **Lumens of glomerular capillaries**
Extrinsic Control of GFR: Via Nervous System

- **Normal resting conditions**
  - renal blood vessels are dilated and autoregulation is dominant ("resting & digesting" parasympathetic)

- **Under extreme stress**
  - "fight or flight" response (SNS) > Epi/NE release > constriction of afferent arterioles > Filtrate formation is inhibited
    - Also causes release of renin
Extrinsic Control of GFR: Renin-Angiotensin Mechanism

- Triggered by release of Renin
- Renin converts angiotensinogen to Angiotensin I
  - Angiotensin I is converted to angiotensin II via angiotensin converting enzyme (ACE)
    - ACE inhibitors: class of drugs that inhibit ACE
      - Used to treat hypertension....act like a diuretic
  - Major effects of angiotensin II
    - Potent vasoconstrictor.....raises MAP
    - Triggers release of Aldosterone.....Na reabsorption...water follows....inc. blood volume and pressure
    - Stimulates release of ADH....water reabsorption....inc. blood volume and pressure
Renin Release

Myogenic mechanism of autoregulation

Tubuloglomerular mechanism of autoregulation

Hormonal (renin-angiotensin) mechanism

Neural controls

---

**Intrinsic mechanisms** directly regulate GFR despite moderate changes in blood pressure (between 80 and 180 mm Hg mean arterial pressure).

**Extrinsic mechanisms** indirectly regulate GFR by maintaining systemic blood pressure, which drives filtration in the kidneys.
Urine Formation

1. Glomerular filtration

2. Tubular reabsorption

3. Tubular secretion
Urine formation:

Tubular Reabsorption

- Reclaiming parts of filtrate
  - Tubule lumen >>> peritubular capillary lumen
  - Begins as soon as filtrate enters PCT (and is possible throughout all tubule)
    - PCT is the most active in “reabsorption”
  - Occurs via active and passive transport

- Na+, Water, ions, Glucose, amino acids
  - Obligatory water reabsorption
    - Regardless of the needs of the body

- Transport maximum ($T_m$)
  - Dependant on the number of carriers present; when overwhelmed > extra secreted in urine
    - glucose, amino acids

- Waste products like Creatinine are NOT reabsorbed
Reabsorption by PCT Cells

1. At the basolateral membrane, Na$^+$ is pumped into the interstitial space by the Na$^+$-K$^+$ ATPase. Active Na$^+$ transport creates concentration gradients that drive:

2. “Downhill” Na$^+$ entry at the luminal membrane.

3. Reabsorption of organic nutrients and certain ions by cotransport at the luminal membrane.

4. Reabsorption of water by osmosis. Water reabsorption increases the concentration of the solutes that are left behind. These solutes can then be reabsorbed as they move down their concentration gradients:

5. Lipid-soluble substances diffuse by the transcellular route.

6. Cl$^-$ (and other anions), K$^+$, and urea diffuse by the paracellular route.
Reabsorption by Renal Tubule

- Substances are not reabsorbed if they:
  - Lack carriers
  - Are not lipid soluble
  - Are too large to pass through membrane pores

- Creatinine is not reabsorbed at all
  - other nitrogenous wastes like uric acid (nucleic acid metabolism) and urea (protein metabolism) are reabsorbed but later secreted
Urine Formation

1. Glomerular filtration
2. Tubular reabsorption
3. Tubular secretion

Three major renal processes:
1. Glomerular filtration
2. Tubular reabsorption
3. Tubular secretion
Urine formation:

Tubular Secretion

- Reabsorption in reverse!

- Peritubular capillary lumen >>> tubule lumen

- Occurs in all regions of renal tubule...DCT most active in secretion
  - Substances that were not filtered, or were filtered but reabsorbed
    - Drugs, Creatinine, Urea and uric acid, Excess H+ ions, Excess Na, or K
Hormones

- **Anti-Diuretic Hormone (ADH)**
  - Increases water permeability in collecting ducts
    - Water is reabsorbed
    - Absence of ADH = collecting ducts impermeable to H2O

- **Aldosterone**
  - Targets DCT and collecting ducts
    - Increases Na reabsorption and K secretion
      - Water will follow the Na if it can

- **Atrial Naturetic Peptide (ANP)**
  - Inhibits Na reabsorption at collecting ducts
    - Lowers Na in blood >> water follows
Loop of Henle: regulation of urine volume & concentration

- Loop of Henle has two limbs:
  - Descending limb
    - Permeable to water
    - Water moves into the renal medulla
    - Solute concentration in filtrate increases
  - Ascending limb
    - Impermeable to water
    - Na+ actively pumped out of filtrate into the renal medulla
      - Pumping Na+ results in the medullary osmotic gradient that will lead to further reabsorption of water at the DCT and collecting duct
      - Increasing ADH increases water reabsorbed at collecting duct
Formation of Dilute urine

- Filtrate is diluted in the ascending loop of Henle
- If ADH is not secreted:
  - The DCT and collecting ducts are impermeable to water — no additional water will be reabsorbed
- Produces dilute urine --- large volume
Formation of Concentrated Urine

- Antidiuretic hormone (ADH) increases the number of channels which water can pass through in the collecting ducts
  - Aquaporins – water channels
- In the presence of ADH, 99% of the water in filtrate is reabsorbed - it is critical in our ability to survive without water
- Low urine volume: very concentrated
Formation of Dilute & Concentrated Urine

(a) Absence of ADH

- Large volume of dilute urine
- Osmolality of interstitial fluid (mOsm)
- Cortex: 300 mOsm
- Outer medulla: 600 mOsm
- Inner medulla: 1200 mOsm
- Descending limb of loop of Henle: 700 mOsm

(b) Maximal ADH

- Small volume of concentrated urine
- Osmolality of interstitial fluid (mOsm)
- Cortex: 300 mOsm
- Outer medulla: 400 mOsm
- Inner medulla: 900 mOsm
- Descending limb of loop of Henle: 900 mOsm

Active transport vs Passive transport

Collecting duct
Diuretics

- Chemicals that enhance the urinary output:
  - Any substance not reabsorbed – can cause an osmotic gradient which will draw more water into the tubules/filtrate
  - Substances that exceed the ability of the renal tubules to reabsorb it (exceed $T_m$)—same as above
    - Ex. Diabetes mellitus
  - Substances that inhibit $\text{Na}^+$ reabsorption— inhibits establishment of the medullary osmotic gradient
    - Ex. Caffeine
Diuretics

- Osmotic diuretics include:
  - High glucose levels
    - carries water out with the glucose
  - Alcohol
    - inhibits the release of ADH
  - most diuretic drugs inhibit sodium ion reabsorption
    - Lasix and Diuril – inhibit Na+-associated symporters
      - many affecting the loop of Henle “loop diuretics” alter medullary osmotic gradients
Renal Clearance

- Volume of plasma that is cleared of a particular substance in a given time – usually 1 minute
- Inulin is used as standard to compare all other substances – used to determine GFR
  - Inulin is freely filtered; not reabsorbed or secreted
  - Renal clearance tests are used to determine GFR
    - Clearance value less than inulin: Substance in partially reabsorbed
    - Clearance value higher than inulin: Tubule cells are secreting substance into filtrate
      - Possibly transport maximum exceeded
    - Clearance value of zero: reabsorption is complete (substance is NOT filtered)
- Used for determining renal clearance of drugs
- Creatinine clearance is a “quick & dirty” estimate of GFR
  - Is freely filtered but also secreted in small amounts
GFR and Renal Clearance

- Normal GFR = 120-125 ml/min
- Chronic Renal Disease: GFR < 60 ml/min
  - Filtrate formation gradually decreases; nitrogenous wastes build in blood, blood pH falls
- Renal Failure: GFR < 15 ml/min
  - Filtrate formation decreases or stops; wastes & ions in blood accumulate.....NEED HEMODIALYSIS

- Normal Inulin Clearance = GFR
- Normal Creatinine Clearance (CrCl): 140 ml/min
Summary of Nephron Function

- **(a)** Blood pH regulation
- **(b)** Water (H₂O)
- **(c)** Urea
- **(d)** Sodium (Na⁺), Chloride (Cl⁻), Potassium (K⁺)
- **(e)** Aldosterone-regulated sodium (Na⁺), calcium (Ca²⁺), and PTH-regulated chloride (Cl⁻)

**Milliosmols**
- **Cortex**
  - Glucose, amino acids, 
  - H₂O (65%), many ions (e.g., Cl⁻, K⁺), 
  - Some drugs, 
  - H⁺, HCO₃⁻, NH₄⁺ (Blood pH regulation)
- **Peritubular capillaries**
  - H₂O regulated by ADH
  - Regulated by aldosterone: Na⁺, K⁺
  - Blood pH regulation: H⁺, HCO₃⁻, NH₄⁺ (increased by ADH)
Read over the rest
Physical Characteristics of Urine

- **Urochrome**- compound containing urobilinogen (hemoglobin breakdown-bilirubin) gives urine its yellow color
- **Odor**- aromatic
- **Specific gravity**- 1.001 to 1.030—1.030 is concentrated
- **pH**- ranges 4.5-8.0; avg 6.0
- **Composition**- 95% water, urea (protein breakdown), sodium, potassium, phosphate and sulfate ions, creatinine (metabolite of creatine phosphate).
# Table 25.2 Abnormal Urinary Constituents

<table>
<thead>
<tr>
<th>SUBSTANCE</th>
<th>NAME OF CONDITION</th>
<th>POSSIBLE CAUSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose</td>
<td>Glycosuria</td>
<td>Diabetes mellitus</td>
</tr>
<tr>
<td>Proteins</td>
<td>Proteinuria, or albuminuria</td>
<td>Nonpathological: excessive physical exertion, pregnancy, high-protein diet</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pathological (over 250 mg/day): heart failure, severe hypertension, glomerulonephritis, often initial sign of asymptomatic renal disease</td>
</tr>
<tr>
<td>Ketone bodies</td>
<td>Ketonuria</td>
<td>Excessive formation and accumulation of ketone bodies, as in starvation and untreated diabetes mellitus</td>
</tr>
<tr>
<td>Hemoglobin</td>
<td>Hemoglobinuria</td>
<td>Various: transfusion reaction, hemolytic anemia, severe burns, etc.</td>
</tr>
<tr>
<td>Bile pigments</td>
<td>Bilirubinuria</td>
<td>Liver disease (hepatitis, cirrhosis) or obstruction of bile ducts from liver or gallbladder</td>
</tr>
<tr>
<td>Erythrocytes</td>
<td>Hematuria</td>
<td>Bleeding urinary tract (due to trauma, kidney stones, infection, or neoplasm)</td>
</tr>
<tr>
<td>Leukocytes (pus)</td>
<td>Pyuria</td>
<td>Urinary tract infection</td>
</tr>
</tbody>
</table>
Ureters

- urine from the kidneys to the bladder
- Ureters enter the base of the bladder through the posterior wall
  - This closes their distal ends as bladder pressure increases and prevents backflow of urine into the ureters
- Ureters actively propel urine to the bladder via peristaltic waves and is controlled by smooth muscle stretch reflexes
Kidney stones and the ureters

- High concentrations of Ca+, Uric acid (gout), can lead to crystallization in the pelvis called renal calculi or kidney stones
- If kidney stones obstruct the ureters they will need to be removed
  - Removal of calculi is usually preformed via shock wave lithotripsy – ultrasonic shock waves are used to shatter the calculi. The smaller pieces can be passed.
  - Drink lots of water and acidic drinks may help
Urinary Bladder

- Smooth, collapsible, muscular sac that stores urine
- It lies retroperitoneally on the pelvic floor posterior to the pubic symphysis
  - Males – prostate gland surrounds the neck inferiorly
  - Females – anterior to the vagina and uterus
- Trigone common opening for the ureters and the urethra
  - Clinically important because infections tend to persist in this region
- The bladder is distensible and collapses when empty has folded ridges = rugae
- As urine accumulates, the bladder expands- can hold up to 2.5L
Urinary Bladder

Figure 25.18a, b
Urethra

- Muscular tube that:
  - Drains urine from the bladder
  - Conveys it out of the body

- Sphincters keep the urethra closed when urine is not being passed
  - Internal urethral sphincter – involuntary sphincter at the bladder-urethra junction
  - External urethral sphincter – voluntary sphincter surrounding the urethra a bit below the bladder
Urethra

- The female urethra is 3-4 cm long and opens into the external urethral orifice (opening to the outside) anterior to the vagina.
- The male urethra is 20 cm long and has three named regions:
  - Prostatic urethra – runs within the prostate gland
  - Membranous urethra – part in the middle
  - Spongy (penile) urethra – passes through the penis and opens via the external urethral orifice
- In males the urethra carries urine and semen.
The difference in length of the urethra has much to do with the greater # of UTI (urinary tract infections) in women versus men.
Micturition (Voiding or Urination)

- The act of emptying the bladder

- Requires 3 processes:
  - Contraction of bladder detrusor muscle
  - Opening of internal urethral sphincter (involuntary)
  - Opening of external urethral sphincter (voluntary)

- Requires increased activity of the parasympathetic nervous system...and decreased activity of the sympathetic nervous system
Urinary bladder filling stretches bladder wall → Afferent impulses from stretch receptors → Simple spinal reflex → Parasympathetic activity ↑ → Detrusor muscle contracts; internal urethral sphincter opens → Micturition

Brain → Higher brain centers allow or inhibit micturition as appropriate

Pontine micturition center promotes micturition by acting on all three spinal efferents

Pontine storage center inhibits micturition by acting on all three spinal efferents

Spinal cord

↓ Parasympathetic activity

↓ Sympathetic activity

↓ Somatic motor nerve activity

External urethral sphincter opens

Inhibits
Problems with urination

- **Incontinence:** inability to control voiding (urination)
  - Most incontinence after the toddler years is due to emotional problems, physical pressure or nervous system problems

- **Urinary retention:** the inability to void
  - In men it is often the result of enlarged prostate
  - Must insert a drainage tube—catheter—though the urethra
  - Do not do catheter unless necessary—increases UTI chances