Water is the driving force of all nature. -Leonardo Da Vinci
"What we do in this life echoes in eternity."
Urinary System

- **Primary organs** - Kidneys
- **Accessory organs**
  - bilateral tubes that carry urine from the kidneys to the bladder
  - expandable sac that serves as a reservoir for urine
  - single tube that carries urine from the bladder to the outside of the body
Urinary Functions

- water content of plasma
- ions in plasma
- pH of plasma

- Return water & solutes to the bloodstream (______________________)

- Transfers Urine Metabolites through Ureters to Urinary Bladder

- Filtrate Concentrated into Urine & Stored in the Bladder

- Nephrology - study of kidney physiology & pathology
Kidney Anatomy

• Location & External Anatomy of the Kidney
• Internal Anatomy of the Kidney
• Blood & Nerve Supply of the Kidney
• Nephrons
Urinary System Organs

Figure 25.1a
Kidney Location & External Anatomy

Figure 25.2a
Location & External Anatomy of the Kidneys

• Bean-shaped organs that lie __________________________in the superior lumbar region
• Extend from T12 to L3
• _________ kidney is slightly lower than the left because of its location under the liver
• Average adult kidney = 150 grams (about a 1/3 of a pound)
Location & External Anatomy of the Kidneys

• The medial surface is concave & has a **renal hilus** that leads into a space called the **renal sinus**, where the blood vessels, nerves & lymphatics lie

• Surrounded by a fibrous, transparent renal capsule
  – a fatty adipose capsule that cushions the organ & an outer fibrous renal fascia that anchors the kidney to surrounding structures
Internal Anatomy

- Interlobular vein
- Interlobular artery
- Arcuate vein
- Arcuate artery
- Interlobar vein
- Interlobar artery
- Lobar artery
- Segmental artery
- Renal artery
- Renal vein
- Renal pelvis
- Major calyx
- Ureter
- Renal pyramidal of medulla
- Renal capsule
- Cortex
- Papilla of pyramid
- Major calyx
- Minor calyx
- Renal column

Figure 25.3b
Internal Anatomy of the Kidney

3 distinct regions of the kidney:
• Renal Cortex
• Renal Medulla
• Renal Pelvis
Renal Cortex

• the **outer** or more **superficial** tissue layer of the kidney
  – **Lighter** in color than the deeper layers
  – Extends into the deeper Medulla to form Renal Columns
Renal Medulla

• Organized into cone-shaped areas known as ____________

• The narrow rounded end of each pyramid is known as a ____________

• There are 8 to 16 pyramids per kidney
• A **flat, funnel shaped tube** that **leads in the Ureter**
• The pelvis branches is feed from short, wide tubes known as _________________(calyx)
Renal Pelvis...

- Renal Papilla feed into the Minor Calyces branch to form the cup-shaped much larger Major Calyces that empty into the Renal Pelvis & into the Ureter, which carries urine to the Urinary Bladder
Blood Supply of the Kidney

• The kidneys receive ¼ of the total cardiac output every minute by way of the large __________________________

• Renal arteries branch repeatedly within the kidneys to form small Interlobar Arteries that extend into the cortex.
Blood Supply of the Kidney

- Within the cortex, **Afferent Arterioles** branch from the **Interlobar arteries** & carry the blood into (small filtering units) **Nephrons** where plasma becomes filtrate & filtrate is converted into urine.

- **Efferent Arterioles** drain blood out of the Nephrons & lead into **Capillary Beds** that surround each nephron.
Blood Supply of the Kidney

• From the capillary beds, the blood enters small **Interlobar Veins** which merge to form larger & larger veins

• Eventually, blood drains from the kidneys via the large _______________ which dump into the **Inferior Vena Cava**
Nephrons

• Simplest structural & functional units of the kidneys that carry out processes that form **Urine**

• Each kidney contains over 1 million nephrons

• Each nephron functions as a small “separations” plant, in which wastes & excess substances are separated from the blood & incorporated in urine
Nephrons

• Each Nephron consists of a Renal Corpuscle composed of the ____________________ (a tuft of capillaries) surrounded by the ____________________/Glomerular capsule
Nephrons continued...

- The Renal Tubule begins at the glomerular capsule as the Proximal Convoluted Tubule, continues through a hairpin loop, the Loop of Henle & turns into a Distal Convoluted Tubule before emptying into a Collecting Duct
Nephrons continued...

- The terms “**Proximal**” & “**Distal**” indicate the position of that part of the renal tubule relative to the renal corpuscle.
- The Loop of Henle has descending & ascending limbs.
Nephrons continued...

- The collecting ducts collect filtrate from many Nephrons, & extend through the renal pyramid to the renal papilla, where they empty into a minor calyx
Nephrons continued...

• There are 2 types of nephrons:
  • 85% **Cortical Nephrons**
    – which are located almost entirely within the cortex
  • 15% **Juxtamedullary Nephrons**
    – located near the cortex-medulla junction
Nephrons continued...

• The _______ Arteriole leading into a Glomerulus is wider than the _______ Arteriole carrying blood out of the Glomerulus.

• Because the Blood is coming into the glomerulus faster than it is leaving, pressure builds up inside the glomerular capillary bed.

• The high pressure forces Plasma & solutes out & into the Bowman’s capsule space, where it becomes known as Filtrate.
Nephrons continued...

- The **peritubular capillaries** arise from efferent arterioles draining the glomerulus & reabsorb solutes & **water** from the tubules (**99% Reabsorption**)

- Blood flow in the renal circulation is subject to high resistance in the afferent & efferent arterioles
Juxtaglomerular Apparatus

• structural arrangement between the afferent arteriole & the distal convoluted tubule

• The apparatus is composed of 2 cell types:
  • Juxtaglomerular (JG) cells
  • Macula densa cells
Juxtaglomerular (JG) cells

- Smooth muscle cells in the wall of the afferent arteriole act as mechanoreceptors that sense changes in blood pressure in the afferent arteriole.

- **The JG cells** release _________ (hormone) when the blood pressure in the afferent arteriole falls too low.

- The sequence of events following the release of **Renin** will be discussed later.
Macula Densa cells

- DCT cells that act as osmoreceptors (Chemoreceptors), responding to changes in the solute concentration of the filtrate
Nephrons

Figure 25.5b
Filtration Membrane

(a) Glomerular capillary covered by podocyte-containing visceral layer of glomerular capsule

Efferent arteriole
Afferent arteriole
Glomerular capsular space
Parietal layer of glomerular capsule
Proximal convoluted tubule
Cytoplasmic extensions of podocytes
Filtration slits
Foot processes of podocyte
Fenestrations
Glomerular capillary endothelium (podocyte covering and basement membrane removed)
Filtration Membrane

Figure 25.7c
Kidney Physiology: Mechanisms of Urine Formation

• As blood flows into the glomeruli in the kidneys, some of the plasma is forced out of the capillary bed & into the renal tubules to form filtrate (around 125 ml per minute is formed)

• The filtrate contains everything found in blood plasma except proteins
Kidney Physiology: Mechanisms of Urine Formation

• By the time it has finished traveling through all parts of the renal tubule & enters the collecting ducts, it is Urine, which contains mostly metabolic wastes & unneeded substances
Kidney Physiology: Mechanisms of Urine Formation

• There are 2 major processes involved in the formation of urine:
  • Step 1: Glomerular Filtration
  • Step 2: Tubular Reabsorption
  • Step 3: Tubular Secretion

Regulation of Urine Concentration & Volume
Step 1: Glomerular Filtration

- a passive, nonselective process in which hydrostatic pressure forces fluids out of the glomerulus & into the first part of the renal tubule (Bowman’s Capsule)
- The surface area of the glomerulus is very large & it is more permeable to solutes than other capillary beds in the body
Step 1: Glomerular Filtration

• The blood pressure in the glomerulus is much higher than in other capillary beds, so more plasma & solutes are forced out by the hydrostatic pressure

• 180 L of filtrate are formed each day in the kidneys, compared to 3 or 4 L of interstitial fluid formed in the other capillary beds of the body
Step 1: Glomerular Filtration

• Smaller molecules such as glucose, amino acids, water, nitrogenous wastes (Urea) pass freely from the blood & into the renal tubule

• Larger molecules such as blood cells & proteins remain in the

________________________
Step 1: Glomerular Filtration

- **Glomerular Filtration Rate** (GFR) is the volume of filtrate formed each minute by all the glomeruli of the kidneys combined (120-125 ml/min in each kidney)
- An increase in blood pressure ↑ the GFR
- A decrease in blood pressure ↓ the GFR
Step 1: Glomerular Filtration

• Maintenance of a relatively constant GFR is important because reabsorption of water & solutes depends on how quickly filtrate flows through the tubules
  – If the rate of filtrate flow through the renal tubules is too fast, such as would occur with high blood pressure, then the flow of filtrate is too fast & valuable substances are lost in the urine rather than reabsorbed into the blood
  – If the rate of filtrate flow is too low, as would occur with low blood pressure, too much of the filtrate is reabsorbed, including waste products
Step 1: Glomerular Filtration

• GFR is held relatively constant through intrinsic autoregulatory mechanisms, extrinsic hormonal mechanisms & neural mechanisms

• **Intrinsic controls**

• **Extrinsic controls**
Intrinsic controls of GFR

- Increased blood pressure causes smooth muscles in afferent arterioles to constrict, thus reducing blood flow (Myogenic mechanism: mechanoreceptors)
- Decreased blood pressure causes the smooth muscles to relax, resulting in blood vessel dilation & increased blood flow
  - A reduced flow of filtrate, or decreased concentration of filtrate, in the DCT causes Macula Densa Cells to release chemicals that dilate the afferent arterioles
  - Increased flow of filtrate, to increased concentration of filtrate, in the DCT causes Macula Densa Cells to release chemicals that constrict the afferent arterioles
Extrinsic controls of GFR

• When the body is at rest, the autoregulatory mechanisms listed above are in charge.

• In times of Stress neural mechanisms take over

• Neural mechanisms are stress-induced sympathetic responses that inhibit filtrate formation by constricting the afferent arterioles & decreasing the production of filtrate

• When blood pressure in the afferent arterioles drops (due to hemorrhaging, dehydration, etc.) the JG cells release the hormone Renin, which starts the Renin-Angiotensin System
Step 1: Glomerular Filtration

• Angiotensinogen (Renin) → Angiotensin I → ACE (in lungs) Angiotensin II

• Angiotensin II has the following effects:
  • Stimulates the adrenal cortex to release aldosterone, which increases Na\(^+\) reabsorption in the renal tubules
  • **Water** follows the Na\(^+\) back into the bloodstream, so urine volume decreases
  • Stimulates vasoconstriction of systemic arterioles, leading to increased blood pressure
  • Stimulates the thirst center in the hypothalamus, leading to the sensation of thirst (+ADH)
Step 2: Tubular Reabsorption

- The total blood volume filters into the renal tubules every _____ minutes & if most it were not reabsorbed, all the plasma would be drained from the body in less than 30 minutes!
- Fortunately, most of the contents of the filtrate are reabsorbed into the bloodstream as the filtrate moves through the different parts of the nephron tubules.
- This process is known as Tubular Reabsorption.
Step 2: Tubular Reabsorption

- Tubular reabsorption begins as soon as the filtrate enters the proximal convoluted tubule & involves near total reabsorption of organic nutrients such as glucose & amino acids.
- Reabsorption of water & ions is primarily under hormonal control & is constantly adjusted.
- The most abundant cation of the filtrate is _____+ & its reabsorption is always by means of active transport.
- This accounts for 80% of the ATP energy used during the active transport processes of reabsorption.
Step 2: Tubular Reabsorption

- Obligatory water reabsorption occurs in water-permeable regions of the tubules in response to the osmotic gradients created by active transport of Na⁺.
- Recall that “water follows salt” in the body.
- Secondary active transport is responsible for absorption of glucose, amino acids, vitamins & most cations & occurs when solutes are co-transported with Na⁺ when it moves along its concentration gradient.
- Nonreabsorbed or incompletely reabsorbed substances remain in the filtrate due to a lack of carrier molecules, lipid insolubility or large size (urea, creatinine & uric acid).
Step 2: Tubular Reabsorption

- Different areas of the tubules have different absorptive capabilities

- The ______________________________(PCT) is most active in reabsorption, with most selective reabsorption occurring there

- **All glucose & amino acids**

- 65% of the Na⁺ & **water**

- 90% of the bicarbonate

- 50% of the Cl⁻

- 55% of the K⁺
Step 2: Tubular Reabsorption

• **Loop of Henle**

• **Descending Limb of the Loop of Henle** is ________________ to water, while the

• **Ascending Limb of the Loop of Henle** is ________________ to water, but permeable to electrolytes
Step 2: Tubular Reabsorption

- **Distal Convoluted Tubule & Collecting Duct**
  reabsorption depends on body needs... \( \text{Na}^+ \) & water permeability regulated by 3 hormones:
  - **Aldosterone** – ↑ Na+ permeability & reabsorption, which ↑ water reabsorption... ↓UV, ↑BV & ↑BP
  - **Antidiuretic Hormone** – makes collecting ducts more permeable to water, ↑ water reabsorption... ↓UV, ↑BV & ↑BP
  - **Atrial Natriuretic Peptide** – inhibits \( \text{Na}^+ \) reabsorption, so more \( \text{Na}^+ \) & water remain as part of the Urine... ↑UV, ↓BV & ↓BP
Step 3: Tubular Secretion

• Some unwanted substances are eliminated in **Urine** simply because they are not reabsorbed from the filtrate

• Others must be actively secreted into the filtrate to become part of the **Urine**
Step 3: Tubular Secretion

• __________ of unwanted solutes (such as drugs)
• __________ solutes that were reabsorbed (such as urea & uric acid)
• __________ the body of excess K⁺
• ____________ blood pH
Step 3: Tubular Secretion

• Tubular secretion is **most active in the** __________________________ (PCT), but occurs in the collecting ducts & distal convoluted tubules, as well
Regulation of Urine Concentration & Volume

• **Osmolarity** \(\rightarrow\) salt in \(H_2O\)

• One of the critical functions of the kidney is to keep the solute load of body fluids constant by regulating Urine concentration & volume
Countercurrent Mechanism

- Prevents rapid removal of salt & establish water recovery
- Involves interaction between filtrate flow through the Loops of Henle of Juxtamedullary Nephrons & the flow of blood through the Vasa Recta
  - Since Water is freely absorbed from the descending limb of the loop of Henle, filtrate concentration increases as Water is reabsorbed
  - The ascending limb is permeable to solutes, but not to Water, so the filtrate is diluted as solutes are removed & Water remains
Regulation of Urine Concentration & Volume

• Since tubular filtrate is diluted as it travels through the ascending limb of the loop of Henle, production of a dilute Urine is accomplished by simply allowing filtrate to pass on to the renal pelvis.

• Formation of a concentrated Urine occurs in response to the release of ADH, which makes the collecting ducts permeable to Water & increases Water uptake from the Urine.

• Diuretics act to increase Urine output by either acting as an osmotic diuretic or by inhibiting Na⁺ & resulting obligatory Water reabsorption.
Renal Clearance

• the volume of plasma that is cleared of a specific substance in a given time
• __________ is used as a clearance standard to determine glomerular filtration rate since it is not reabsorbed, stored, or secreted
  – If the clearance value for a substance is less than that for inulin, then some of the substance is being reabsorbed
  – If the clearance value is greater than the inulin clearance rate, then some of the substance is being secreted
  – A clearance value of zero indicates the substance is completely reabsorbed
Glomerular Filtration Rate

Figure 25.9
Mechanisms of Urine Formation

• Urine formation & adjustment of blood composition involves 3 major processes
  – Glomerular Filtration
  – Tubular Reabsorption
  – Tubular Secretion
Formation of Dilute & Concentrated Urine

Osmolality-
Osmolarity-

Figure 25.15a, b
Formation of Dilute & Concentrated Urine

**Dilute Urine**
- Hypoosmotic
- Lack of ADH
- Low Osmolality 70 mOsm (1/4 the concentration of glomerular filtrate or plasma)

**Concentrated Urine**
- Hyperosmotic
- ADH inhibits Diuresis decreases water volume of the urine... tied to survivability w/o water
- High Osmolality 1200 mOsm
Ureters

- Bilateral tubes that actively convey *Urine* from the kidneys to the bladder
  (10” long/1/16-1/4 mm in diameter)
- Ureter walls consist of an inner mucosa continuous with the kidney pelvis & the bladder, a double-layered muscularis & a connective tissue adventitia covering the external surface
- Increased Urinary Pressure w/in the Bladder compresses ureter opening → Preventing Urine Backflow
Urinary Bladder

- A muscular sac lined with transitional epithelium that expands as Urine is produced by the kidneys
- Allows for Urine storage until voiding is convenient (& socially acceptable!)
- The bladder wall contains 3 layers:
  - An outer adventitia
  - A middle layer of Detrusor muscle
  - An inner mucosa
    - Highly folded to allow for bladder distention without a large increase in internal pressure
Urinary Bladder

- Maximum capacity is around 800 – 1000 ml/1L (1 quart)
- It can burst if overextended
- A moderately full bladder holds around 500 ml (1 pint)
- Every 200mL → Urge to Urinate
Urethra

- Muscular discharge tube that drains Urine from the body
- 2” long in females
- 9” long in males
- 2 sphincter muscles associated with the urethra:
  - the internal urinary sphincter- involuntary & formed from detrusor muscle
  - the external urinary sphincter- voluntary & formed by the skeletal muscle
- The external urethral orifice lies between the clitoris & vaginal opening in females, or occurs at the tip of the penis in males
Trigone

- Seen on the inside of the Urinary Bladder formed by the 2 Ureters & the Urethra
Lower Urinary System Structures
Urine

- **Physical Characteristics**
- Freshly voided urine is clear and pale to deep yellow due to __________________________ a pigment resulting from the destruction of hemoglobin
- The more concentrated the Urine, the deeper yellow its color
- Pink or brown Urine may be due to ingestion of certain foods or the presence of blood
- Drugs & vitamin supplements may also alter Urine color
- Cloudy Urine may indicate a urinary tract infection
Urine

• Fresh Urine is slightly aromatic, but develops an ammonia odor if allowed to stand, due to bacterial metabolism of urea

• Intake of drugs & certain vegetables can alter Urine smell

☯ Diabetes can cause Urine to smell fruity due to the presence of acetone
Urine

- **Urine** is usually slightly acidic *(around pH ___)*, but can vary from about **4.5–8.0** in response to changes in metabolism or diet.

- **Specific Gravity** - (Mass) depends on solute concentration *(1.001-1.035)*

- **Heavier than distilled water**

- Protein/Glucose _________
Urine

- **Chemical Composition**
- **Urine Volume** is about **95% water** & 5% solutes
- Pass **1-2** L/daily (depending on intake)
- The largest component of **Urine** by weight, other than water, is **Urea (formed from Amino Acids)**
- **Urea**
  formed from various substances & ammonia (a metabolic waste product that has no physiological function & must be neutralized)
- Other nitrogenous wastes include **Creatinine** (a metabolite of creatine phosphate in skeletal muscle) & **Uric acid** (an end product of nucleic acid metabolism)
- **Blood Urea Nitrogen (BUN)**
  measures renal efficiency & damage
Micturition

- **Urination**
- the act of voiding or emptying the bladder
- As *Urine* accumulates, distention of the bladder activates stretch receptors, which trigger spinal reflexes, resulting in contraction of the internal & external sphincters & inhibition of the detrusor muscle of the bladder
- This results in storage of *Urine*
- When *Urine* levels reach around 200 ml in the bladder, afferent impulses from stretch receptors are transmitted to the brain, creating the “urge” to void
- Reflex contractions of the bladder become more & more frequent & urgent
Micturition

- Voluntary initiation of voiding reflexes results in activation of the micturition center of the pons, which signals **parasympathetic motor neurons** that stimulate contraction of the detrusor muscle & relaxation of the urinary sphincters.
- Choosing not to void (“holding it”) causes the reflex bladder contractions to subside temporarily & the external sphincter can remain voluntarily closed through Cortical Inhibition.
Micturition

- The urge to void becomes irresistible when the urine volume in the bladder reaches 500–600 ml, at which point micturition will occur (regardless of circumstances!)
- Internal sphincter (**involuntary**)
- External sphincter (**voluntary**)
- **Micturition Reflex** (Pons) every 200 mL
- After micturition, only about 10 ml of Urine remain in the bladder
Micturition (Voiding or Urination)

Figure 25.20a, b
Renal Hormones

• ANP (Atrial Natriuretic Peptide)
• ADH (Vasopressin)
• Renin-Angiotensin
• Aldosterone
Atrial Natriuretic Peptide

- High Na or BV $\rightarrow$ ANP Released by the Heart $\rightarrow$ $\uparrow$ GFR/inhibit Na+ reabsorption & inhibits Renin secretion
- Natriuresis $\uparrow$ Na+ excretion & $\uparrow$ Urine output $\rightarrow$ by $\uparrow$ water volume in urine... $\downarrow$ BV & $\downarrow$ BP
- Diuresis (urine output)- $\uparrow$ urine $\rightarrow$ $\downarrow$ BV & BP
- Inhibit Na+ reabsorption Water follows out collecting duct $\uparrow$ urine volume
Antidiuretic Hormone

• **Vasopressin** released by the?

• ________________

• Alcohol & Caffeine reduce ADH → higher **Urine** output
• Inhibits diuresis
• ↑ **Water** reabsorption by action on the Collecting Duct
• Osmoreceptor in Hypothalamus- Neurohypophysis monitor an increase BV & regulate **Water** reabsorption accordingly
• **High ADH** → Highly concentrated **Urine** 500 mL/day
• **Low ADH** → dilute **Urine** 2 L
**Renin~Angiotensin~Aldosterone**

- Angiotensinogen $\rightarrow$ Angiotensin I (Renin)
- **ACE** (Angiotensin Converting Enzyme) converts Angiotensin I $\rightarrow$ Angiotensin II
- $\downarrow$ GFR by vasoconstriction of afferent arterioles
- Enhance $\text{Na}^+$, $\text{Cl}^-$ & **water** reabsorption $\rightarrow$ $\uparrow$ BV
- Stimulates Adrenal Cortex to release Aldosterone
Aldosterone

- released by ________________
- reabsorb Na⁺, secrete K⁺
- Water follows Na⁺ → ↑BV & ↑BP
- Renin → Angiotensin → Aldosterone
- ↓BV & ↓BP less stretch JG cells → release of Renin or Symp ↑BP & BV
- (Hepatocyte) Angiotensinogen → (Renin) Angiotensin I (ACE) → Angiotensin II (vasoconstrictor) → Aldosterone
Urinary System Objectives

• Correlate Nephron Structure to Urine Formation
• Describe Urine Formation
• Examine the Role of Hormonal Control in Kidney Function
• Explain the Role of the Kidney’s Vascular System in Urine Formation
Urinary System Objectives

- Explain the Normal & Abnormal Constituents of Urine & their Significance
- Examine the role of Hormonal Control in Kidney Function
- Understand the role of Filtration & Reabsorption in Urine Formation
- Homeostatic Imbalances & Urinary Pathologies