1. Kidneys
2. Ureters
3. Urinary bladder
4. Urethra
Kidney Functions

• **Primary functions:**
  – Filter and remove waste from plasma,
  – Regulate blood volume and pressure,
  – Regulate blood osmolarity.

• **Secondary functions:**
  – Produce renin,
  – Produce EPO,
  – Regulate pH,
  – Formation of calcitriol
  – Perform gluconeogenesis.
Adrenal Glands

Secrete:
- Aldosterone
- Cortisol
- Epinephrine
- Norepinephrine
- Other hormones
Renal cortex
Renal medulla
Renal column
Renal pyramid
Corticomedullary junction
Renal papilla
Renal lobe
Fibrous capsule
Renal sinus contains:
- Minor calyx
- Major calyx
- Renal pelvis
- Renal artery
- Renal vein
Ureter
Formed in the renal cortex

Travels thru the medullary pyramids

Drips out of the pyramids into the minor calyces

Flows thru major calyces

Flows thru the renal pelvis

Flows thru the ureter

Flows thru and is stored in the urinary bladder

Flows thru the urethra
Basic Pathway of Renal Blood Flow

- Renal artery
- Segmental artery
- Interlobar artery
- Arcuate artery
- Interlobular artery
- Renal vein
- Interlobar vein
- Arcuate vein
- Interlobular vein

Nephron
Basic Pathway of Renal Blood Flow

- Peritubular capillaries (associated with convoluted tubules)
  
- Arcuate vessels
  
- Interlobular vein
  
- Renal corpuscle
  
- PCT
  
- DCT
  
- Cortex
  
- Medulla
  
- Nephron loop
  
- Glomerulus
  
- Efferent arteriole
  
- Vasa recta (associated with nephron loop)
Tubular secretion
The movement of substances from the blood into the tubular fluid

Tubular reabsorption
The movement of substances from the tubular fluid back into the blood

Glomerular filtration
The movement of substances from the blood within the glomerulus into the capsular space

Efferent arteriole
Afferent arteriole
Glomerulus
Glomerular capsule
Capsular space
PCT
DCT
Nephron loop
Ascended limb
Descending limb
Peritubular capillaries
Vasa recta
Collecting tubule
Collecting duct
By regulating how much water we reabsorb, we regulate blood volume

By regulating what chemicals we reabsorb and what we secrete, we regulate blood [electrolyte] and blood pH
Renal Math

[Diagram showing renal structures and processes]

- Efferent arteriole
- Peritubular capillaries
- To renal vein
- To bladder and external environment

Diagram components labeled:
- Glomerulus
- Afferent arteriole
- Bowman's capsule
- Remainder of nephron

Table:

<table>
<thead>
<tr>
<th>Amount filtered (F)</th>
<th>Amount reabsorbed (R)</th>
<th>Amount secreted (S)</th>
<th>Amount of solute excreted (E)</th>
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Steps:
1. Amount filtered (F)
2. Amount reabsorbed (R)
3. Amount secreted (S)
4. Amount of solute excreted (E)
Nephron - sites of urine formation

• 1 million per kidney.

• 5 parts
  – Glomerulus
  – Glomerular Capsule
  – Proximal Convoluted Tubule
  – Loop of Henle
  – Distal Convoluted Tubule

• Empty into collecting ducts.
Glomerular Capsule

- 2 layers
- Encloses the glomerulus.
- Receives filtered blood (filtrate)
• Parietal layer
  – Simple squamous
  – Contains filtrate.

• Visceral layer
  – Filters
  – Made of podocytes.
Proximal Convoluted Tubule

- Primary site of R&S
- Receives filtrate from the GC
- Very twisty.
- Simple cuboidal.
- Lots of microvilli.
- Lots of mitochondria.
Loop of Henle

• Receives filtrate from the PCT

• Creates a conc. gradient in the renal medulla which allows for water reabsorption from the collecting duct
Distal Convoluted Tubule

- Receives filtrate from the loop of Henle
- Site of hormonal adjustment of water & salt secretion/reabsorption.
- Simple cuboidal
- Fewer microvilli and mitochondria.
Collecting Duct

- Receives urine from several nephrons
- Extends through the renal medulla and empties into a minor calyx
- Simple cuboidal and columnar.
- Site of hormonal adjustment of water reabsorption.
Glomerulus

• High BP
  – Due to the size differential between the afferent and efferent arterioles
  – This high BP is the driving force behind the filtration
Peritubular Capillaries

- Surround renal tubules
- Receive blood from the efferent arteriole
- Sites of R&S
- Low BP and high OP
Vasa Recta

- Receive blood from the efferent arteriole
- Work with the loops of Henle to facilitate water reabsorption in the collecting duct
Three major renal processes:

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

Glomerular capillaries
Efferent arteriole
Glomerular capsule
Rest of renal tubule containing filtrate
Peritubular capillary
To interlobular vein

Urine

Interlobular artery
Afferent arteriole
To interlobular vein
Filtration Membrane

- Visceral layer of glomerular capsule
- Pedicels
- Filtration slits
- Podocyte cell body
- Capillary lumen
- Glomerular capillary
- Filtration membrane
  - Endothelium of fenestrated capillary
  - Basement membrane of capillary
  - Filtration slits of visceral layer
Endothelium (blocks formed elements)

Basement membrane (blocks large proteins)

Filtration slits of visceral layer (block small proteins)

Filtrate includes water, glucose, amino acids, ions, urea, many hormones, vitamins B and C, ketones, and very small amounts of protein

Capsular space

Capillary

Filtered

Not filtered

Erythrocyte

Platelet

Large protein

Small protein

Leukocyte
Filtration Pressure

- **Glomerular hydrostatic pressure** ($\text{HP}_g$) 60 mm Hg out
- **Blood colloid osmotic pressure** ($\text{OP}_g$) – 32 mm Hg in
- **Capsular hydrostatic pressure** ($\text{HP}_c$) – 18 mm Hg in
- **Net filtration pressure** ($\text{NFP}$) = 10 mm Hg out

Diagram: Glomerular capsule, Efferent arteriole, Afferent arteriole, Blood entering glomerulus, Capsular space, Glomerulus, PCT, NFP 10 out.
Glomerular Filtration Rate (ml/min)

- 125 mL/min
- Depends on glomerular BP
Myogenic Mechanism of Maintaining GFR

Decrease in systemic blood pressure

Efferent arteriole

Widened arteriole lumen allows more blood into glomerulus to offset a decrease in systemic blood pressure

Afferent arteriole vasodilates

Glomerulus
Myogenic Mechanism of Maintaining GFR

**Increase in systemic blood pressure**

- **Efferent arteriole**
- **Afferent arteriole**
- **Glomerulus**
- Narrowed arteriole lumen allows less blood into glomerulus to offset an increase in systemic blood pressure
Tubuloglomerular Mechanism

1. GFR increases excessively
2. Flow through tubule increases. Decreased fractional absorption of NaCl
3. Macula densa senses increased concentration of chloride within tubule.
4. Macula densa releases local mediators stimulating afferent arteriole
5. Afferent arteriole constricts
   - Resistance in afferent arteriole increases
   - Hydrostatic pressure in glomerulus decreases
   - GFR decreases back to normal level
Effect of the Sympathetic Nervous System on GFR

Increased sympathetic activity

NE and E cause afferent arteriole to constrict

GBP and thus GFR fall

What is an advantage of this process?
BP Falls

Increased sympathetic activity

JG cells release renin into the plasma

Renin converts the plasma protein Angiotensinogen into Angiotensin I

Angiotensin I is converted into Angiotensin II by ACE – the Angiotensin Converting Enzyme

Renin-Angiotensin System
Ag II causes vasoconstriction, which leads to increased TPR and increased BP. The adrenal cortex releases aldosterone, causing increased sodium reabsorption in DCT. The pituitary gland releases ADH, leading to increased water reabsorption and increased BV. Increased BV results in thirstiness.
PCT Reabsorption

- What kind of “stuff” needs to be reabsorbed?

- Reabsorbed molecules travel from the PCT to the PTC.
PCT Reabsorption

Filtrate in tubule lumen

H₂O

Luminal membrane

Transcellular

Paracellular

Solutes

Tubule cell

Interstitial fluid

Peritubular capillary

Capillary Endothelial cell

Active transport

Passive transport

Filtrate in tubule lumen

Tubule cell

Interstitial fluid

Peritubular capillary

Capillary Endothelial cell

Active transport

Passive transport
**PCT Reabsorption**

- Filtrate in tubule lumen
  - Glucose
  - Amino acids
  - Some ions
  - Vitamins

- Interstitial fluid
  - Nucleus
  - Tubule cell
  - Peritubular capillary
  - Paracellular route

- Tight junction

**Transport proteins and channels**

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  - 

- 
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- 
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  - 
  - 

**Transport mechanisms**

- Primary active transport
- Secondary active transport
- Passive transport (diffusion)

**Obligatory reabsorption**
Transport Maximum

1. Glucose molecules

2. Filtration (100 mL/min)

3. 100 mL, 100% glucose reabsorbed

4. No glucose excreted

4. Clearance of glucose = 0 mL/min
- Hormone dependent
- Fine tuning
- Aldosterone
- Parathyroid hormone
Loop of Henle Reabsorption

- Descending limb
- Ascending limb
- Urine concentration
Collecting Duct Reabsorption

- Water
- Depends on body’s hydration levels
- Antidiuretic hormone
Tubular Secretion

Filtrate composition:
- H₂O
- NaCl
- HCO₃⁻
- H⁺
- Urea
- Glucose
- Amino acids
- Some drugs

Reabsorption
- H₂O
- NaCl

Secretion
- NaCl
- Urea
- H₂O

Blood capillary to Bowman's capsule to proximal tubule to cortex to medulla to loop of Henle to distal tubule to collecting duct to urine (to renal pelvis)
Regulating Blood Concentration

- Plasma osmolarity is constantly measured by neurons in the hypothalamus.

- In response to changes in plasma osmolarity, hypothalamic neurons adjust their release of antidiuretic hormone from the posterior pituitary.

Kidney
Increased water reabsorption and concentrated urine
ADH increases the reabsorption of water from the collecting duct.
High Blood Osmolarity

- Sensed by osmoreceptors in the hypothalamus
- Posterior pituitary gland increases ADH release
- ADH increases the permeability of the collecting duct to water
- Increased water reabsorption

Blood osmolarity falls

Facultative reabsorption
What will increased ADH do to:

• Water reabsorption

• Urine output

• Urine color

• Blood volume

• Blood pressure
The diagram illustrates osmotic pressure in a semi-permeable membrane. The concentrations are as follows:

- 300 mOsM
- 600 mOsM
- 900 mOsM
- 1200 mOsM

The urine concentration is 100 mOsM.
Loop of Henle

Osmolality of interstitial fluid (mOsm)

Inner medulla

Outer medulla

Cortex

Active transport

Passive transport

Water impermeable

Medullary Osmotic Gradient

Loop of Henle
Aldosterone

- Produced by the adrenal cortex.
- Produced when:
  - Plasma $\text{Na}^+$ is too low.
  - Plasma $\text{K}^+$ is too high.
  - Stimulated by angiotensin II.

Aldosterone acts on the DCT to increase the secretion of $\text{K}^+$ and the reabsorption of $\text{Na}^+$ and water.
How would excess aldosterone affect

- Plasma sodium levels
- Plasma potassium levels
- Urine output
- Blood volume
- Blood pressure
Diuretics

• Osmotic
  – Anything that increases filtrate osmolarity increases urine output.

• Caffeine
  – Inhibits renal sodium reabsorption.

• Alcohol
  – Inhibits ADH release.
Urine

• Characteristics
  – Volume
  – pH of 4.5 - 8
  – Clear to yellow

• Components
  – 95% water
  – 5% solutes
    • Uric acid
    • Urea
    • Creatinine
    • Ions
Pelvic Diaphragm
Urethra

- Ureteral openings
- Trigone
- Urinary bladder
- Internal urethral sphincter
- External urethral sphincter
- Urogenital diaphragm
- External urethral orifice
- Labium minus
- Labium majus
Micturition

Parasympathetic fibers of pelvic nerve

Sensory
Motor

To pons
From pons

Sacral segments of spinal cord

S2
S3
S4

Parasympathetic ganglion in bladder wall

Stretch receptors

Motor fibers to detrusor muscle

Internal urethral sphincter (involuntary)

External urethral sphincter (voluntary)

Urinary bladder

Urethra

Somatic motor fiber of pudendal nerve