Consists of the kidneys, ureters, bladder, and urethra

Maintains homeostasis by managing the volume and composition of fluid reservoirs, primarily blood
Regulation of blood ionic composition
Na⁺, K⁺, Cl⁻

Regulation of blood pH
H⁺, HCO₃⁻

Regulation of blood volume
H₂O

Regulation of blood pressure

Regulation of blood osmolarity

Production of hormones
Calcitrol and Erythropoietin

Excretion of metabolic wastes and foreign substances (drugs or toxins)

The kidneys are retroperitoneal, partly protected by the lower ribs.
Renal Anatomy

The indented area is called the **Hilum**.

This is the entrance for:
- Renal Artery
- Renal Vein
- Ureter
- Nerves
- Lymphatics

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External Layers

Connective Tissue, Superficial to Deep

- Renal Fascia - Anchors to other structures
- Adipose Capsule – Protects and anchors
- Renal Capsule – Continuous with Ureter

---

Internal Renal Anatomy

- Renal Cortex – Outer layer
- Renal Medulla – Inner region
- Renal Pyramids – Secreting Apparatus and Tubules
- Renal Columns – Anchor the Cortex
Papillary ducts empty urine into calyces
Calyces pass urine to the Ureter

Blood supply
Although kidneys constitute less than 0.5% of total body mass, they receive 20–25% of resting cardiac output

Nerve Supply
Renal Nerves primarily carry sympathetic outflow
They regulate blood flow through the kidneys
The Nephron

Renal corpuscle filters the blood plasma.

Renal tubule modifies the filtrate.

The Renal Corpuscle

The Renal Corpuscle consists of two parts:
The Glomerulus is a mass of capillaries.
The Glomerular (Bowman’s) Capsule has a visceral layer of podocytes which wrap around the capillaries.

The Renal Corpuscle

The Glomerulus is a mass of capillaries.
It is fed by the Afferent Arteriole and drains into the Efferent Arteriole.
Mesangial cells are contractile and help regulate glomerular filtration.
**The Glomerular (Bowman’s) Capsule**

The Glomerular (Bowman’s) Capsule has a visceral layer of podocytes which wrap around the capillaries. The filtrate is collected between the visceral and parietal layers.

**Histology of a Renal Corpuscle**

The glomerular endothelial cells have large pores (fenestrations) and are leaky. Basal lamina lies between endothelium and podocytes. Podocytes form pedicels, between which are filtration slits.
The filtrate passes from the glomerular capsule to the renal tubule

Proximal Convoluted Tubule

Nephron Loop
  Descending Loop
  Ascending Loop

Distal Convoluted Tubule

The ascending loop contacts the afferent arteriole at the macula densa.

The wall of the arteriole contains smooth muscle cells; juxtaglomerular cells.

The apparatus regulates blood pressure in the kidney in conjunction with the ANS.
Histology of a Renal Corpuscle

The Distal Collecting Tubule and Collecting Duct

Two Kinds of Nephrons

Cortical nephrons – 80-85% of nephrons
Renal corpuscle in outer portion of cortex
Short loops of Henle extend only into outer region of medulla
Create urine with osmolarity similar to blood
Renal corpuscle deep in cortex with long nephron loops
Receive blood from peritubular capillaries and vasa recta
Ascending limb has thick and thin regions
Enable kidney to secrete very concentrated urine

Cortical
Juxtamedullary

Renal Physiology - Urine Formation
Glomerular filtration
Tubular reabsorption
Tubular secretion

Excretion of a solute = glomerular filtration + secretion - reabsorption
Driven by blood pressure

Opposed by capsular hydrostatic pressure and blood colloid osmotic pressure

Water and small molecules move out of the glomerulus.

In one day, 150–180 liters of water pass out into the glomerular capsule.

Glomerular filtration rate – amount of filtrate formed by both kidneys each minute

Homeostasis requires kidneys to maintain a relatively constant GFR

Too high – substances pass too quickly and are not reabsorbed

Too low – nearly all reabsorbed and some waste products not adequately excreted
Renal Filtration Rate

GFR averages 125mL/min in males and 105mL/min in females

Controlled by:
- Renal Autoregulation
- Neural Regulation
- Hormonal Regulation

Renal Autoregulation

Myogenic Mechanism
- Smooth muscle cells in afferent arterioles contract in response to elevated blood pressure

Tubuloglomerular Feedback
- High GFR diminishes reabsorption
- Macula Densa inhibits release of nitric oxide
- Afferent arterioles constrict
Kidneys are richly supplied by sympathetic fibers.

Strong stimulation (exercise or hemorrhage)—afferent arterioles are constricted.

Urine output is reduced, and more blood is available for other organs.

Angiotensin II constricts afferents and efferents, diminishing GFR.

Atrial Natriuretic Peptide relaxes mesangial cells, increasing capillary surface area and GFR.

ANP is secreted in response to stretch of the cardiac atria.
Much of the filtrate is reabsorbed by both active and passive processes. Especially water, glucose, amino acids, and ions.

Secretion helps to manage pH and rid the body of toxic and foreign substances.

### Tubular Reabsorption and Secretion

<table>
<thead>
<tr>
<th>Substance</th>
<th>Total Amount in Plasma</th>
<th>Amount in 180 L of Filtrate (l/day)</th>
<th>Amount returned to Blood (Reabsorbed)</th>
<th>Amount in Urine (l/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (passive)</td>
<td>3 L</td>
<td>180 L</td>
<td>178-179 L</td>
<td>1-2 L</td>
</tr>
<tr>
<td>Protein (active)</td>
<td>200 g</td>
<td>2 g</td>
<td>1.9 g</td>
<td>0.1 g</td>
</tr>
<tr>
<td>Glucose (active)</td>
<td>3 g</td>
<td>162 g</td>
<td>162 g</td>
<td>0 g</td>
</tr>
<tr>
<td>Urea (passive)</td>
<td>1 g</td>
<td>54 g</td>
<td>24 g (about 1/3)</td>
<td>30 g (about 1/3)</td>
</tr>
<tr>
<td>Creatinine</td>
<td>0.03 g</td>
<td>1.6 g</td>
<td>0 g (all filtered)</td>
<td>1.6 g (none reabsorbed)</td>
</tr>
</tbody>
</table>
Reabsorption Routes

Paracellular Reabsorption
Passive fluid leakage between cells

Transcellular Reabsorption
Directly through the tubule cells

Transport Mechanisms

Primary Active Transport
Uses ATP, like Na⁺/K⁺ pumps
At rest, accounts for 6% total body ATP use

Secondary Active Transport
Driven by ion’s electrochemical gradient
Symporters move substances in same direction
Antiporters move substances in opposite directions
Water Reabsorption

Obligatory Water Reabsorption – 90%
Water follows the solutes that are reabsorbed

Facultative Water Reabsorption – 10%
Regulated by ADH

Reabsorption and Secretion in PCT

Na⁺ - Glucose Symporters
Na⁺ - H⁺ Antiporters
Aquaporin - 1
Membrane protein permeable to water

Transport Mechanisms
Relatively impermeable to water, especially the ascending limb

Little obligatory water reabsorption

$\text{Na}^+ - \text{K}^+ - \text{2Cl}^- \text{ symporters}$
Reabsorption in early DCT

- $\text{Na}^+ - \text{Cl}^-$ symporters reabsorb ions
- PTH stimulates reabsorption of $\text{Ca}^{2+}$
- It also inhibits phosphate reabsorption in the PCT, enhancing its excretion

Late DCT and Collecting Duct

Principal Cells

- $\text{Na}^+ - \text{K}^+$ pumps reabsorb $\text{Na}^+$
- Aquaporin – 2 reabsorbs water
  - Stimulated by ADH

Intercalated Cells

- Reabsorb $\text{K}^+ + \text{HCO}_3^-$, secrete $\text{H}^+$

Regulation of Water Reabsorption by ADH

Facultative Reabsorption

Negative Feedback
Fluid intake is highly variable. 
Homeostasis requires maintenance of fluid volumes within specific limits. 
Urine concentration varies with ADH. 

High intake – Dilute urine of high volume 
Low intake – Concentrated urine of low volume 

Glomerular filtrate and blood have the same osmolarity – 300mOsm/Liter 
Tubular osmolarity changes due to a concentration gradient in the medulla
Formation of Dilute Urine

When dilute urine is formed, osmolarity in the tubule
1. Increases in the descending limb
2. Decreases in the ascending limb
3. Decreases more in the collecting duct

Formation of Dilute Urine

Tubule Osmolarity

↑ in descending limb
↓ in ascending limb
↓ in collecting duct

Thick Ascending Limb
Symporters actively resorb Na⁺, K⁺, Cl⁻
Low water permeability
Solutes leave, water stays in tubule

Collecting Duct
Low water permeability in absence of ADH
Formation of Dilute Urine

Tubule Osmolarity

↑ in descending limb
↓ in ascending limb
↓ in collecting duct

Formation of Concentrated Urine

Juxtamedullary Nephrons with long loops

Osmotic gradient is created by the Countercurrent Multiplier

Solutes pumped out of ascending limb, but water stays in tubule

Medulla osmolarity is increased
**Formation of Concentrated Urine**

In presence of ADH, collecting ducts become very permeable to water. Tubular fluid there becomes very concentrated. Movement of water also carries urea into the medulla, contributing to its osmolality.

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**Countercurrent Exchange**

Loop and duct cells require nutrients and oxygen from blood supply. Capillaries that feed them (vasa recta) form loops like those of nephron loops in the medulla. Incoming and outgoing blood will have similar osmolarity. This maintains medulla concentration gradient.
Routine urinalysis primarily evaluates for the presence of abnormalities in the urine:

- Albumin
- Glucose
- Red blood cells
- Ketone bodies
- Microbes
Each ureter transports urine from a renal pelvis by peristaltic waves, hydrostatic pressure, and gravity.

No anatomical valve at the opening of the ureter into bladder — when bladder fills, it compresses the opening and prevents backflow.

The bladder is a hollow, distensible, muscular organ with a capacity averaging 700–800 mL.

The discharge of urine involves voluntary and involuntary muscle contractions.

Stretch receptors trigger a spinal reflex, which we learn to control in childhood.

The urethra carries urine from the internal urethral orifice to the exterior of the body.

In males, it discharges semen as well as urine.
Male and Female Urethras

End of Chapter 26

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