Vertebrates possess kidneys:
- internal organs which are vital to ion and water balance and excretion.

The kidney has 6 roles in the maintenance of homeostasis.
6 Main Functions

1. **Ion Balance** - Especially Na\(^+\) and K\(^+\)

2. **Osmotic Balance** - Determine volume of urine produced

3. **Blood Pressure** - Controls blood volume and ECF volume

4. **pH Balance** - Retains or excretes H\(^+\) or HCO\(_3^−\)

5. **Excretion** - of nitrogenous wastes & other hydrophillic toxins

6. **Hormone Production**
Kidney Structure and Function

- Typical *mammalian* kidney is crescent shaped with 2 layers:
  - Renal Cortex
  - Renal Medulla
    - Renal Pyramids
      - *papilla*
Kidney Structure and Function

- Once urine is formed, it passes into a cavity called the **minor calyx**.

- Multiple minor calyces drain into the **major calyx**.

- The major calyx empties into **ureters** that drain the kidney.

- From there, the ureters empty into the **urinary bladder** where urine is stored.
Kidney Structure and Function

Renal pyramid
Renal cortex
Renal medulla
Renal papilla
Renal pelvis
Renal artery
Renal vein
Minor calyx
Major calyx
Ureter
Urinary bladder
Urethra

Copyright © 2009 Pearson Education, Inc., publishing as Pearson Benjamin Cummings.
Nephron

• The functional unit of the kidney is called the nephron.

• Nephrons are composed of 2 elements:
  ◦ Glomerulus
    • Twisted ball of capillaries
    • Delivers fluid to the tubule
  ◦ Renal tubule
    • Composed of a single layer of cells
The tubule is composed of epithelial cells with characteristic transport properties that allow them to reclaim specific solutes and expel others.

**Bowman’s capsule:**
- mouth of the tubule
- Cuplike expansion surrounds the glomerulus
Nephron

- Fluid in lumen moves through successive specialized regions of the tubule:
  1. Proximal Convoluted Tubule
  2. Loop of Henle
  3. Distal Convoluted Tubule

- Fluid from multiple tubules, drain into collecting ducts, several of which fuse to form papillary ducts, which empty into the minor calyx.
Nephron

- Vasculature of the nephron is central to nephron function

- Blood enters the kidney from renal artery, which branches into smaller vessels that give rise to the glomerulus.
Nephron

- After the filtered blood leaves the glomerulus, it passes into an efferent arteriole.

- Different than a normal capillary in which venous system is immediately downstream of capillary bed

- Blood passes through the efferent arteriole into one of two types of capillary beds.
Nephron

- Cortical nephrons:
  - Efferent arterioles flow into peritubular capillary beds.

- Juxtamedullary nephrons:
  - Efferent arterioles diverge into the vasa recta.

- Blood then drains into venous system:
  - carrying away recovered solutes and water from interstitial fluid that surrounds the tubule.
Urine Formation

- Hormones and neurotransmitters ensure urine composition and release are matched to the physiological needs of the animal.

- Regulatory factors affect the 4 processes involved in urine formation:
  - Filtration
  - Reabsorption
  - Secretion
  - Excretion
Filtration in the Glomerulus

- Wall of the glomerular capillary is a complex biological filter:
  - retains blood cells and large macromolecules
  - allows liquid components of blood to escape into lumen of Bowman’s capsule.
Filtration in the Glomerulus

Glomerular capillaries = fenistreted
Filtration in the Glomerulus
Reabsorption & Secretion

- As fluid passes into the lumen of the tubule, a filtrate is formed = *primary urine*

- As fluid passes through the tubule, about 99% of the volume is recovered.

- Remodeling of primary urine occurs as it passes through successive regions of tubule and results in the production of *final urine*. 
Reabsorption

- **Reabsorption** = Recovery of substances from the lumen of the tubule

- Requires both favorable electrochemical gradients and transport capacities.

- Most molecules are reabsorbed through a combination of facilitated diffusion and active transport.
Secretion

- **Secretion** = transferring solutes from the blood into the tubule lumen.

- Uses transporters found in the cells that line the lumen.

- Most important secretory products are $K^+$, $NH_4^+$, and $H^+$. 
Parts of the Nephron

- Proximal Convoluted Tubule:
  - Where most solute and water reabsorption occurs
  - Take back as much as possible:
    - all glucose
    - a lot of water
    - Na+
Parts of the Nephron

- **Loop of Henle** - establishes concentration gradient in medulla.
  - **Descending limb**: permeable to $\text{H}_2\text{O}$ not $\text{Na}^+$
  - **Ascending limb**: permeable $\text{Na}^+$ not $\text{H}_2\text{O}$

**Countercurrent Multiplier**
- Gradient maintained because vasa recta picks up water
Parts of the Nephron

- Strength of the loop of Henle depends on how long it is.

- 15-20% of human nephrons have long loops.
  - Can increase urine osmolarity 4x plasma

- Kangaroo rats:
  - all long loops – 12x plasma

- Freshwater fish:
  - all short loops – dilute urine
Parts of the Nephron

- **Distal Convoluted Tubule:**
  - Specialized secretion and reabsorption:
    - hormone mediated regulation of uptake of solutes and water
  - Reabsorb Na\(^+\) in response to *aldosterone*
  - Secretes excess K\(^+\)
Parts of the Nephron

- **Collecting Duct**: main site of hormone regulated H₂O reabsorption
  - Responds to **anti-diuretic hormone (ADH)**
    - Also known as Vasopressin
    - High levels of ADH increase reabsorption of H₂O by the collecting duct.
    - If ADH not present, impermeable to H₂O
Role in Acid-Base Balance

- Nephron regulates pH of urine by transport of $\text{H}^+$, $\text{HCO}_3^-$, and ammonia.
  - $\text{Na}^+/\text{H}^+$ exchangers recover $\text{Na}^+$ and extrude $\text{H}^+$, acidifying the urine
  - $\text{Cl}^-/\text{HCO}_3^-$ exchangers recover $\text{Cl}^-$, while alkalinizing primary urine

- Exchangers occur throughout different parts of tubule.
Role in Acid-Base Balance
Bladder

- Urine leaves kidney and enters urinary bladder for storage.
- Exits via urethra: sphincters of smooth muscle control flow.
- Opening and closing of sphincter influenced by voluntary and involuntary controls.
Regulation of Renal Function

- 3 main forces determine net glomerular filtration pressure:
  - Glomerular capillary hydrostatic pressure
  - Bowman’s capsule hydrostatic pressure
  - Net oncotic pressure
Regulation of Renal Function

- Typical mammalian kidney: Net glomerular filtration pressure is about 15 mmHg

Blood pressure: 60 mmHg
Lumen hydrostatic pressure: 15 mmHg
Oncotic pressure: 30 mmHg
Intrinsic Regulators

3 intrinsic pathways maintain GFR despite changing blood pressures:

- **Myogenic Regulation**
- **Tubuloglomerular Feedback**
- **Mesangial Control**
Myogenic Regulation

- Smooth muscle cells of the vasculature both interpret and respond to changes in blood pressure to maintain GFR
Tubuloglomerular Feedback

- Alters arteriole resistance

- Cells in region of distal tubule called the **macula densa**, contact specialized **juxtaglomerular cells** in the walls of the afferent arterioles:
  - ↑ Blood flow
  - cells signal afferent arteriole,
  - vasoconstriction,
  - ↓ hydrostatic pressure
  - ↓ GFR back to normal levels
Tubuloglomerular Feedback
Mesangial Control

- **Mesangial cells** =
  - control dimensions of filter

- ↑blood pressure
- Blood vessels swell in response
- Mesangial cells stretch
- Increasing GFR
ADH

- **Antidiuretic hormone (ADH), also known as vasopressin:**
  - main hormone responsible for the recovery of water from the tubule.
  - ADH alters uptake by affecting the number of aquaporins within collecting duct.
  - High ADH levels increase reabsorption of water by the collecting duct.
Aldosterone

- Regulates sodium and potassium balance

- Stimulates expression of genes coding transport proteins (ie Na+/K+ ATPase)

- Stimulates Na+ reabsorption and enhances K+ excretion
RAAS regulates low blood pressure

- Renin-angiotensin-aldosterone system (RAAS) regulates low blood pressure
- Aldosterone production is regulated by the hormone **angiotensin II**
- Juxtaglomerular cells in the afferent and efferent arterioles secrete the enzyme renin
RAAS regulates low blood pressure
ANP regulates high blood pressure

- **Atrial natriuretic peptide (ANP):**
  - Hormone secreted by cardiac atrial cells in response to excessive stretch
    - Ie ↑blood volume /↑blood pressure

- When released it travels to the kidney:
  - ↑ filtration rate at glomerulus
  - ↓ aldosterone release
  - ↓ Na\(^+\) reabsorption at DCT
  - ↓ renin release
  - ↓ ADH production and release
Environmental Adaptations
Adaptations to Environmental Conditions

- The potential to produce concentrated urine is best expressed as **relative medullary thickness**:  
  - Width of medulla relative to total width of kidney

- **Amount** of long loops of Henle important  
  - Mammals can produce urine with an osmolarity 5x greater than plasma osmolarity
Adaptations to Environmental Conditions

- **Reniculate kidney**: multi-lobed kidney found in marine mammals.

- Kidneys of this morphology have increased surface area for concentrating urine and removing toxins from the body more efficiently than a non-lobed kidney.