Chapter 44

Osmoregulation and Excretion

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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Overview: A Balancing Act

• Physiological systems of animals **operate in a fluid environment**

• Relative concentrations of water and solutes must be maintained within **fairly narrow limits**

• **Osmoregulation** regulates solute concentrations and fluid
Selectively permeable membrane

Hyperosmotic (hypertonic) side

Net water flow

Hypoosmotic (hypotonic) side

Solute

Isoosmotic (isotonic) solutions – when concentration is equal
• Most animals are **stenohaline**; they cannot tolerate substantial changes in external osmolarity

• **Euryhaline** animals can survive large fluctuations in external osmolarity
Sockeye salmon (*Oncorhynchus nerka*), euryhaline fish
Marine Animals

- Marine bony fishes are **hypoosmotic** to seawater.
- They lose water by osmosis and gain salt by diffusion and from food.
- They balance water loss by **drinking seawater and excreting salts** through gills and kidneys.
Freshwater Animals

- Freshwater animals **constantly take in water by osmosis** from their hypoosmotic environment
- They lose salts by diffusion and **maintain water balance** by **excreting large amounts of dilute urine**
- Salts lost by diffusion are replaced in foods and by uptake across the gills
Osmoregulation in marine and freshwater bony fishes: a comparison

(a) Osmoregulation in a **saltwater fish**

- Gain of water and salt ions from food
- Excretion of salt ions from gills
- Osmotic water loss through gills and other parts of body surface
- Uptake of water and some ions in food
- Uptake of salt ions by gills
- Osmotic water gain through gills and other parts of body surface
- Excretion of large amounts of water in dilute urine from kidneys

(b) Osmoregulation in a **freshwater fish**

- Gain of water and salt ions from drinking seawater
- Excretion of salt ions and small amounts of water in scanty urine from kidneys
- Excretion of salt ions and small amounts of water in scanty urine from kidneys

**Legend:**
- Light blue – water
- Dark blue - salts

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Terrestrial Animals

- Land animals manage water budgets by drinking and eating moist foods and using metabolic water.

- Desert animals get major water savings from simple anatomical features and behaviors such as a nocturnal life style.
Among the most important wastes are nitrogenous breakdown products of proteins and nucleic acids (ammonia, urea, uric acid)
Many reptiles (including birds), insects, land snails

Mammals, most amphibians, sharks, some bony fishes

Most aquatic animals, including most bony fishes

Ammonia

Urea

Uric acid
Excretory Processes

• Most excretory systems produce urine by refining a filtrate derived from body fluids

• Key functions of most excretory systems:
  – Filtration: pressure-filtering of body fluids
  – Reabsorption: reclaiming valuable solutes
  – Secretion: adding toxins and other solutes from the body fluids to the filtrate
  – Excretion: removing the filtrate from the system
Key functions of excretory systems: an overview

- Filtration
- Excretory tubule
- Reabsorption
- Secretion
- Excretion

Fig. 44-10
Survey of Excretory Systems

- Systems that perform basic excretory functions vary widely among animal groups
- They usually involve a complex network of tubules
**Protonephridia**

Protonephridia: the **flame bulb system** of a planarian

A protonephridium is a network of **dead-end** tubules connected to external openings. These tubules excrete a dilute fluid and function in osmoregulation.
Metanephridia

- Each segment of an earthworm has a pair of open-ended **metanephridia**

- **Metanephridia** consist of tubules that collect coelomic fluid and produce dilute urine for excretion
Fig. 44-12

Metanephridia of an earthworm

Components of a metanephridium:
- Capillary network
- Internal opening
- Collecting tubule
- Bladder
- External opening (nephridiopore)

Capillary network

Coelom
Malpighian Tubules

- In insects and other terrestrial arthropods, **Malpighian tubules** remove nitrogenous wastes from hemolymph and function in osmoregulation.
Digestive tract

Rectum

Intestine

Malpighian tubules

Midgut (stomach)

Hindgut

Salt, water, and nitrogenous wastes

Feces and urine

HEMOLYMPH

Reabsorption

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Structure of the Mammalian Excretory System

• The mammalian excretory system **centers on paired kidneys**, which are also the principal site of water balance and salt regulation

• Each kidney is supplied with blood by a **renal artery** and drained by a **renal vein**

• Urine exits each kidney through a duct called the **ureter**

• Both ureters drain into a common **urinary bladder**, and urine is expelled through a **urethra**
The mammalian excretory system

(a) Excretory organs and major associated blood vessels
Fig. 44-14

(a) Excretory organs and major associated blood vessels
- Posterior vena cava
- Renal artery and vein
- Aorta
- Ureter
- Urinary bladder
- Urethra

(b) Kidney structure
- Kidney
- Renal medulla
- Renal cortex
- Renal pelvis
- Ureter

(c) Nephron types
- Juxtamedullary nephron
- Cortical nephron
- Renal cortex
- Collecting duct
- To renal pelvis
- Renal medulla

(d) Filtrate and blood flow
- Afferent arteriole from renal artery
- Glomerulus
- Bowman's capsule
- Proximal tubule
- Efferent arteriole from glomerulus
- Peritubular capillaries
- Distal tubule
- Collecting duct
- Vasa recta
- Loop of Henle
- Descending limb
- Loop of Henle
- Ascending limb
- Branch of renal vein
The mammalian kidney has two distinct regions: an outer renal cortex and an inner renal medulla.
Fig. 44-14b

(b) Kidney structure

- Renal medulla
- Renal cortex
- Renal pelvis
- Ureter

Section of kidney from a rat

4 mm
(c) Nephron types

(cortical nephron)

(juxtamedullary nephron)

(collecting duct)

(to renal pelvis)

(renal medulla)

(renal cortex)

(afferent arteriole from renal artery)

(efferent arteriole from glomerulus)

(glomerulus)

(bowman's capsule)

(proximal tubule)

(peritubular capillaries)

(distal tubule)

(vasa recta)

(loop of henle)

(d) Filtrate and blood flow
• The **nephron**, the functional unit of the vertebrate kidney, consists of a single long tubule and a ball of capillaries called the **glomerulus**

• **Bowman’s capsule** surrounds and receives filtrate from the glomerulus
Fig. 44-14d

- Afferent arteriole from renal artery
- Efferent arteriole from glomerulus
- Glomerulus
- Bowman’s capsule
- Proximal tubule
- Peritubular capillaries
- Descending limb
- Ascending limb
- Loop of Henle
- Branch of renal vein
- Collecting duct
- Distal tubule
- Vasa recta

(d) Filtrate and blood flow
Filtration of the Blood

- **Filtration** occurs as blood pressure forces fluid from the blood in the glomerulus into the lumen of Bowman’s capsule.

- The filtrate contains salts, glucose, amino acids, vitamins, nitrogenous wastes, and other small molecules.
Blood Vessels Associated with the Nephrons

- Each nephron is supplied with blood by an **afferent arteriole**, a branch of the renal artery that divides into the capillaries.

- The capillaries converge as they leave the glomerulus, forming an **efferent arteriole**.
Pathway of the Filtrate

- From Bowman’s capsule, the filtrate passes through three regions of the nephron: the **proximal tubule**, the **loop of Henle**, and the **distal tubule**.

- Fluid from several nephrons flows into a **collecting duct**, all of which lead to the **renal pelvis**, which is drained by the ureter.
• **Reabsorption** of ions, water, and nutrients takes place in the **proximal tubule**

• Some **toxic materials** are secreted into the filtrate

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• **Tubular secretion:** movement from blood into filtrate. Tubular secretion:
  • Eliminates nonfiltered substances
  • Eliminates substances reabsorbed passively (urea)
  • The distal tubule regulates the **K^+** and **NaCl** concentrations of body fluids
  • Controls blood pH
**Key**

- **Active transport**
- **Passive transport**

**Fig. 44-15**

- **Proximal tubule**
  - NaCl, Nutrients, HCO_3^-, H_2O, K^+
  - H^+, NH_3

- **Distal tubule**
  - NaCl, HCO_3^-, K^+, H^+

- **Filtrate**

- **Loop of Henle**
  - H_2O

- **Collecting duct**
  - NaCl, Urea, H_2O
• Urine is much more concentrated than blood

• Kidneys maintain extracellular fluid osmolarity through urine concentration

• The countercurrent mechanism involving the loop of Henle and vasa recta, establishes osmotic gradient between cortex and medulla

• Mammals control the volume and osmolarity of urine
Antidiuretic Hormone and Aldosterone

- **Antidiuretic hormone (ADH)** increases water reabsorption in the distal tubules and collecting ducts of the kidney.

- An increase in osmolarity triggers the release of ADH, which helps to conserve water.

- Hormone **aldosterone** stimulates reabsorption of sodium, water follows, decreases urine output.
Thank you for your attention and participation!
You should now be able to:

1. Distinguish between the following terms: isoosmotic, hyperosmotic, and hypoosmotic; stenohaline and euryhaline animals

2. Define osmoregulation and excretion

3. Compare the osmoregulatory challenges of freshwater and marine animals

4. Describe and compare the protonephridial, metanephridial, and Malpighian tubule excretory systems
5. Using a diagram, identify and describe the function of each region of the nephron

6. Explain how the loop of Henle enhances water conservation

7. Describe the nervous and hormonal controls involved in the regulation of kidney function