

## Chapter 42 Water and Electrolyte Balance in Animals

- I. Challenges to Water and Electrolyte Balance in Different Environments
- A. Osmotic stress—cells can undergo osmotic stress with changes in their environment. If unopposed, osmotic stress will impair cell function and may lead to death.
    1. Water moves to the area of highest solute concentration via osmosis.
    2. If an animal's body is hypertonic (has a higher solute concentration) to its environment, the animal will take on water.
    3. If an animal's body is hypotonic (has a lower solute concentration) to its environment, the animal will lose water.
  - B. Osmotic stress may occur with either an imbalance in the water and/or electrolyte content of body fluids.
  - C. Freshwater, marine, and terrestrial habitats impose different forms of osmotic stress on the animals inhabiting them; those animals have adaptations allowing them to achieve homeostasis.
    1. Marine invertebrates . . .
      - a. Are isotonic relative to seawater
      - b. Are considered osmoconformers because they do not osmoregulate
    2. Marine fish . . .
      - a. Are hypotonic to their environment and tend to lose water and gain excess ions
      - b. Must osmoregulate by drinking water and excreting excess electrolytes
    3. Freshwater animals..
      - a. Are hypertonic to their environment and tend to gain excess water and lose electrolytes
      - b. Must osmoregulate by excreting excess water and obtaining electrolytes from their environment and food
    4. Terrestrial animals . . .
      - a. Run the risk of dehydration due to evaporation of water from their body surfaces, including respiratory organs
      - b. Must osmoregulate by drinking and excreting excess electrolytes.
- II. Osmoregulation is the ability to counteract osmotic stress and maintain homeostasis with respect to water and electrolyte balance.
- A. All organs of osmoregulation possess transport epithelium for exchange of water and electrolytes with the environment.
    1. Shark rectal gland—specialized for NaCl secretion
    2. Chloride cells—found in abundance in the gill epithelia of marine fish
    3. Nasal salt glands of marine birds and reptiles
    4. Mammalian kidney
  - B. All such organs use a common molecular mechanism for salt transport.
    1.  $\text{Na}^+/\text{K}^+$ -ATPase, located in the basolateral membrane, pumps  $\text{Na}^+$  out of epithelial cell into extracellular fluid, creating a low intracellular  $\text{Na}^+$  concentration.
    2.  $\text{Na}^+$  moves across the basolateral membrane from the extracellular to the intracellular fluid down its concentration gradient, using a  $\text{Na}^+/\text{2Cl}^-/\text{K}^+$  cotransport mechanism and bringing  $\text{Cl}^-$  and  $\text{K}^+$  into the cell.
    3.  $\text{Cl}^-$  leaves the cell through apical chloride channels, creating an electrical charge gradient for  $\text{Na}^+$  transport.
    4.  $\text{Na}^+$  moves down its concentration and electrical charge gradients from the extracellular fluid to the environment between the epithelial cells.
  - C. Migratory fishes like salmon, which move from freshwater to seawater back to freshwater during their life span, make physiological adjustments to maintain water and electrolyte balance during these transitions.
- III. The Impact of Forms of Nitrogenous Waste Products on Water Balance
- A. Deamination of amino acids generates the toxic compound ammonia.

- B. In aquatic organisms, ammonia diffuses from the extracellular fluid into the environment, thus avoiding the buildup of this toxic molecule.
- C. Terrestrial organisms convert ammonia to a less toxic compound for excretion.
  1. Uric acid has very low solubility in water, allowing birds, reptiles, and insects to excrete semisolid urine. More energy is required for synthesis of this molecule.
  2. Urea is the primary nitrogenous waste of mammals. It is more water soluble than uric acid, so more water is required to excrete this form, but its synthesis requires less energy.

#### IV. Terrestrial Invertebrates Are Subject to Dehydration

- A. The large surface area/volume ratios and the use of air as a respiratory medium present challenges to maintenance of water balance in insects.
  1. A water-impermeable waxy coating on the exoskeleton minimizes evaporation from the body surface.
  2. The openings to the insect tracheal system, used for gas exchange, are called spiracles; they can close to prevent excessive water loss from respiration.
- B. The Malpighian tubule system allows insects to produce concentrated urine, conserving water loss and maintaining water and electrolyte balance of the hemolymph.
  1. Pre-urine is formed in the Malpighian tubules.  $K^+$  is pumped into the tubule lumen; water and solutes, other electrolytes and wastes, follow.
  2. The pre-urine flows into the hindgut for processing.  $Cl^-$  and  $Na^+/K^+$ -ATPase pumps are critical for reabsorption of water and needed electrolytes, including  $K^+$ . The degree of reabsorption of these substances is based on the water and electrolyte balance of the insect and is under hormonal regulation.
  3. Malpighian tubule system allows hydrated insects to produce urine hypotonic to their hemolymph and dehydrated insects to produce hypertonic urine.

#### V. The mammalian kidney is an important adaptation to life on land; its functional unit is the nephron.

- A. The high blood pressures of closed circulatory systems allow for the formation of pre-urine by filtration of the blood.
  1. A filtrate of blood is formed in the renal corpuscle of the nephron as water and smaller solutes, but not large proteins and cells, are forced through glomerular capillary slits into Bowman's capsule.
  2. This pre-urine is processed by remaining segments of the nephron, primarily via reabsorption. In order, these segments are proximal tubule, descending and ascending limbs of the loop of Henle, distal tubule, and collecting duct. Any substance that is filtered, but not reabsorbed, is lost in the urine.
- B. The transport activity of the proximal tubule accounts for two-thirds of the water, sodium, and chloride and all of the amino acid and glucose reabsorption.
  1. The apical membranes of the proximal tubule epithelial cells have microvilli to increase the surface area for reabsorption.
  2.  $Na^+/K^+$ -ATPase creates a driving  $Na^+$  concentration gradient for cotransport of valuable solutes. Water follows by osmosis through aquaporins.
- C. The loop of Henle creates an osmotic gradient within the renal medulla, allowing for the production of hyperosmotic urine.
  1. Kuhn hypothesized that the loop of Henle acts as a countercurrent multiplier, a model supported by other researchers.
  2. The descending limb of the loop of Henle is water permeable, but salt impermeable. The ascending limb of the loop of Henle is salt permeable, but water impermeable.
  3. Water moves out of the descending limb into the surrounding tissues, concentrating the salts that remain behind.
  4. Salts ( $Na^+$ ,  $Cl^-$ , and  $K^+$ ) move passively down their concentration gradient into the surrounding tissue in the thin ascending limb and are actively pumped out in the thick ascending limb.
  5. The presence of these salts in the medullary tissue accounts for 60% of the high osmolarity of that region.

- D. The distal tubule is the final site for adjustments to the chemical composition of the urine. Much of its activity is under hormonal regulation.
  - 1. The amount of  $\text{Na}^+$  lost in the urine is under regulation by the hormone aldosterone. If blood  $\text{Na}^+$  levels are low, aldosterone will stimulate the reabsorption of  $\text{Na}^+$ .
  - 2.  $\text{Cl}^-$  and water follow as  $\text{Na}^+$  is reabsorbed in this region.
  
- E. The water permeability of the collecting duct is under hormonal regulation by the hypothalamus.
  - 1. When blood osmolarity is high (indicating dehydration) ADH is released, increasing the water permeability of the collecting duct through the insertion of aquaporins. Water moves by osmosis into the medullary tissue and is reabsorbed. Hyperosmotic urine is formed, thus conserving water.
  - 2. When blood osmolarity indicates a well-hydrated state, the absence of ADH keeps the water permeability of the collecting duct low. Hypo-osmotic urine is produced.
  - 3. The collecting duct is responsible for depositing urea into the medulla, contributing to the high osmolarity of that region.

## Chapter Vocabulary

homeostasis

water balance  
osmolarity

osmosis  
hypertonic  
hypotonic  
isotonic  
osmotic stress  
osmoregulation  
osmoconformers  
osmoregulators

electrolytes  
electrolyte balance

diffusion

concentration gradient  
solute  
selectively permeable membrane  
equilibrium

facilitated diffusion  
channels  
carriers  
active transport  
cotransporter  
antiporter

urea  
TMAO (trimethylamine oxide)  
shark rectal gland  
lumen  
basolateral membrane  
apical membrane  
Na<sup>+</sup>/K<sup>+</sup>-ATPase (sodium-potassium pump)  
electrochemical gradient

ouabain  
chloride channel  
CFTR (cystic fibrosis transmembrane regulator)

anadromous  
chloride cells  
gill filaments  
gill lamellae  
chloride-cell-switch hypothesis

ammonia  
ammonium ion  
strong base  
pH  
nitrogenous wastes  
urea  
uric acid

tracheal system  
spiracles  
chitin  
wax  
hemolymph  
Malpighian tubules  
pre-urine  
hindgut  
reabsorption  
kidney  
nephron  
renal corpuscle  
proximal tubule  
loop of Henle  
distal tubule  
collecting duct  
cortex  
medulla  
ureter  
urethra  
renal artery  
bladder

filtration  
glomerulus  
Bowman's capsule  
filtrate  
positive feedback

microvilli  
aquaporins  
osmotic gradient  
countercurrent multiplier  
descending limb  
thin ascending limb  
thick descending limb  
vasa recta  
aldosterone  
ADH (antidiuretic hormone)  
diabetes insipidus

metabolic water  
nasal countercurrent exchange