Summary: Control of Body Temperature and Water Balance

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Contents

1 Mechanisms for maintaining homeostasis in climatically volatile conditions

There exist various permutations, or implementations, if you will, of the general principle of *thermoregulation*—the mechanism through which an internal temperature can be restricted to an acceptable range conducive to the survival of a host. Two of these "implementations" may be described as such[1]:

- **Endothermic heat regulation**: body heat is derived from the metabolic systems already posessed by a host.
- **Ectothermic heat regulation**: body heat is derived from an external source.

1.1 Methods of heat exchange

As does thermoregulation, the act of *heat exchange* can occur in one of several ways:

- **Conduction**: the transfer of heat between objects that are in direct contact with each other.
- **Radiation**: the emission of electromagnetic waves, which can transfer heat between objects that are not in direct contact.
- **Convection**: the trnasfer of heat by the movement of air or liquid over a surface.
- **Evaporation**: the vaporization of molecules from the surface of a liquid.

1.2 A demonstration of heat exchange

Each of these disambiguations rely on the principle that heat flows from an object of higher temperature to one of lower temperature. Yet, they each serve unique purposes. For example, suppose an ecothermic lizard houses itself atop a warm rock. The aforementioned modes of heat exchange operate on the body temperature of the lizard in four ways:

1. *Conductively* — Heat is transfered between the surface of the rock and the scales of the lizard through the immediate contact established between the rock and the lizard.
2. *Radiatively* — Energy from the sun warms the lizard's back. Furthermore, heat is released from the lizard itself, in much the same manner, into the environment.
3. *Convectionally* — A breeze lifts heat from the lizard's tail.
4. *Evaporatively* — Moisture evaporates from the nostrils of the lizard.

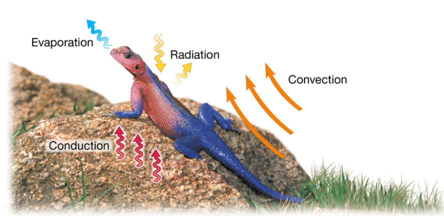

Figure 1: The lizard from our example

[1] It is not uncommon for an animal to utilize both endothermic and ectothermic heat regulation mechanisms. Take, for example, the Pygoscelis papua—a member of the Penguin family—. While these birds do regulate body temperature in a largely endothermic manner, they do warm themselves in the sun. This is an example of both endothermic and ectothermic behavior. The same is true for the ectothermic lizard.

2 Notable thermoregulation adaptations

2.1 Classifications of thermoregulation adaptations

While the aformentioned principle of temperature regulation, or *thermoregulation* can be grouped into two disambiguations: endothermism and ectothermism, five common implementations of thermoregulation can be derived from these larger categorizations. More specifically, the aforementioned five distinct categorizations are described as such:

1. **Metabolic heat production**: energy is release as heat—a byproduct of ATP synthesis processes. In humans, this results in a warm feeling while exercising. In hibernating mammals, on the other hand, ATP synthesis and warming processes are decoupled (e.g., hibernating bears).
2. **Insulation**: hair/fur, feathers, and fat reduce the radiation of heat from an animal to its environment.
3. **Circulatory adaptations**: when surface blood vesssels are constricted, the rate of heat loss through radiation is reduced as a result of a lowered volume of blood flowing to the cold surface. *Countercurrent heat exchange* is an example of a circulatory adaptation found in the limbs of many birds and mammals.[2]
4. **Evaporative cooling**: water absorbs heat from the surface of the body (e.g., as sweat evaporates, heat is lost).
5. **Behavioral responses**: an animal's internal temperature is controlled through an adjustment to the animal's behavior. For example, humans dress more heavily in colder environments.

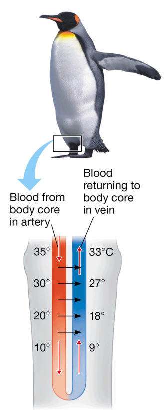

Figure 2: A penguin, countercurrently exchanging heat

2.2 Application of thermoregulation in huddles of penguins

Through a behaivoral response-mediated thermoregulation adaptation, huddles of penguins are able to converse energy otherwise lost through radiation and convection. As is the case in a single penguin, in a huddle of penguins, the largest concentration of heat is present in the core of the complex, while the least amount of heat is present in the edges of the huddle. In order to maximize the effectivity of this strategy and minimize losses to the poorly- insulated periphery, all members of the "huddle" will eventually serve as the huddle's "core." This theory was demonstrated in a 2011 German study conducted on a huddle of emperor penguins.

[2] This technique describes the tendency for warm and cold blood to flow in opposite directions in adjacent vessels, and should not be confused with *concurrent* exchange. One should recall: countercurrent exchange provides utility to an organism by conductively exchanging heat between warm blood moving towards the outer regions of the corpus and cold blood moving back to the warm core of the organism in question.

3 Osmoregulation and excretion

3.1 Why osmoregulation and excretion mechanisms are necessary

As is the case with internal temperatures, in order to maintain homeostatis, organisms must maintain a healthy balance of water and solutes. In the case of an *osmoconformer*, this is a rather straightforward task. An osmoconformer is, by specification, of an isotonic solute concentration[3]. *Osmoregulators*, on the other hand, maintain homeostatis not by construction, but by correction: through **osmoregulation**, an osmoregulator is able to prevent the loss of water or of a certain solute.

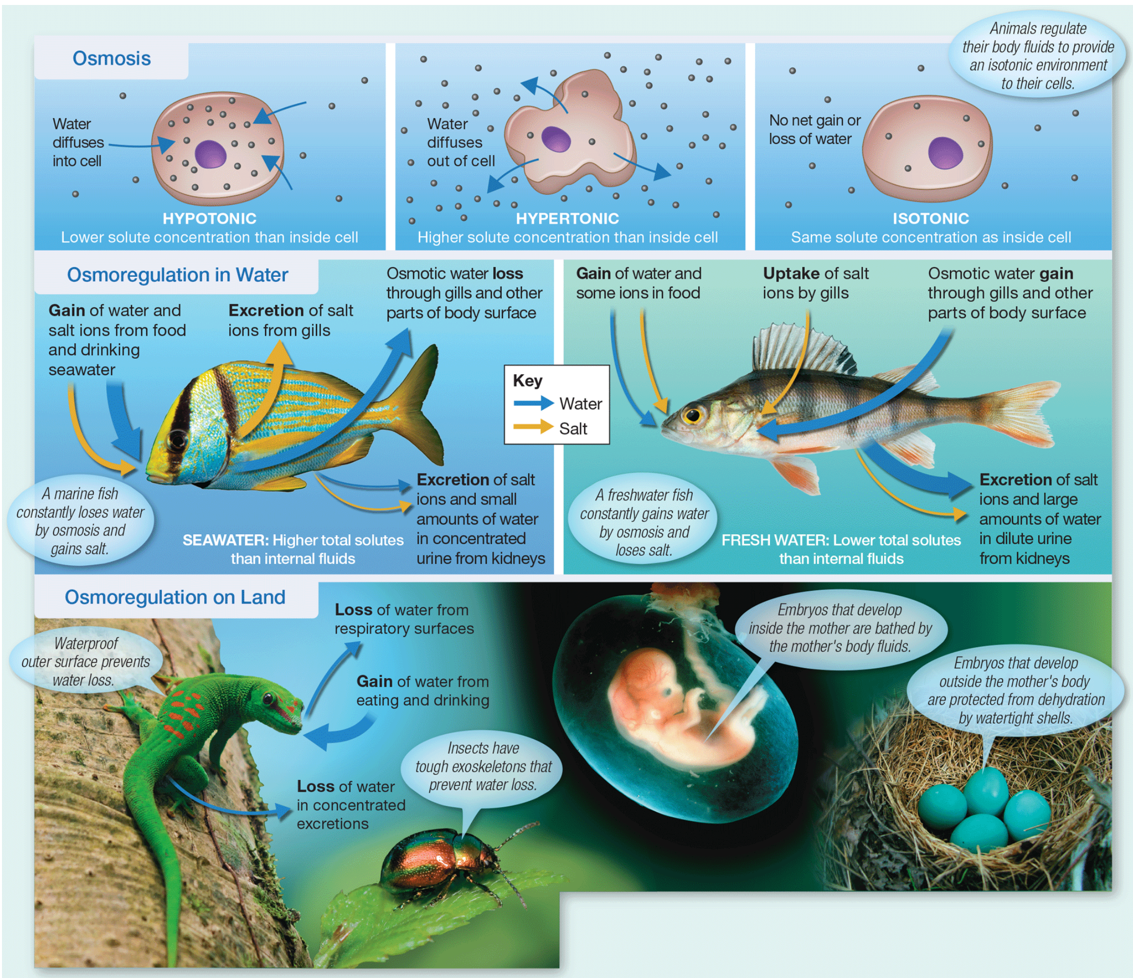

Figure 3: The various types of osmoregulating organisms, and the mechanisms on which they depend.

3.2 Excretion deals with waste disposal

Though it is objectively differentiated from the aforementioned principle of osmoregulation, excretion is tightly coupled in its implementation of waste disposal: in order to purge the body of some particular waste, such waste must be expelled to a body of water. But, more generally, **excretion** can simply be defined as the disposal of metabolic waste. Of course, the material being expelled, and how such material is expelled is a matter of developmental preference. Common metabolic wastes of animals can be defined as such:

[3]Common examples of osmoconformers are: jellies, molluscs, squids, and sea stars.

- **Ammonia** (NH_3): highly soluble and diffuses rapidly. In acquatic animals, this property is rather appealing, as it allows for the passive disposal of this toxic chemical into the surrounding environment. In order to be transported actively, Ammonia must be heavily diluted, due to its toxic nature. This amount of unused water is often unattainable in terrestrial animals. As such, Ammonia is often converted, rather than transported in terrestrial animals.
- **Urea** (CH_4N_2O): a major waste product excreted by mammals, adult amphibians, sharks, and bony fishes. Urea is produced in the liver through the combination of NH_3 with CO_2, and can be substituted for Ammonia in excretion.
- **Uric Acid** ($C_5H_4N_4O_3$): a target for Ammonia conversion in various repitiles, birds and insects. The conversion of Ammonia to uric acid is often appealing, as it can offset water loss almost completely, and is relatively nontoxic. However, the excretion of this waste in its "semisolid paste" form consumes a fair amount of energy, but is still appealing considering the water savings with respect to the alternative: urea.

3.3 Excretion, filtration, and osmoregulation in humans

3.3.1 The role of the kidneys in homeostasis

In order to preserve the greatest amount of both water and nutrients possible, humans refrain from excreting all of the **filtrates**—a combination of water, nutrient solutes and urea—present in our blood[4]. Instead of simply purging the body of all filtrates, filtrates are first collected by the kidneys, which return water and nutrients back to the blood. About 1.5 L of **urine**, a refined, more heavily concentrated form of urea, is produced by the kidneys each day.

3.3.2 The pathway of filtrate and urine

In order for urine to be filtered by the kidneys, blood must first enter the kidney through the **renal artery**. As is implied by its name, blood will eventually exit the kidney through the **renal vein**. Generally, the pathway taken by blood from the bloodstream, into the kidney, and back is as follows:

1. Blood enters the kidney via the renal artery.
2. Filtrate is forced into a capillary wall, and into a kidney tube by the pressure of moving blood.
3. Urine leaves the kidney through the **ureter**.
4. Blood leaves the kidney through the renal vein.
5. Urine is drained from the ureter into the **urinary bladder**
6. Urine is expelled from the bladder through the **urethra**, where the **sphincter** controls the flow of urine.

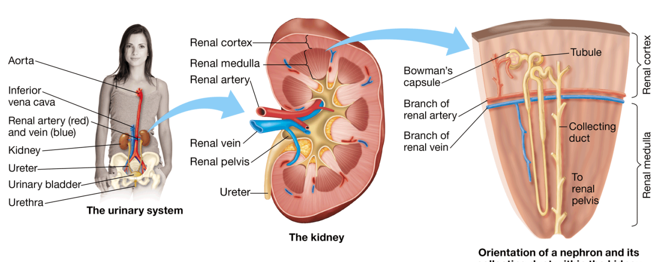

Figure 4: The human urinary system

[4] About 180 L of filtrate is collected by the kidneys each day.

4 The kidney as a means of preservation of homeostatis

4.1 The structural composition of the kidneys

The highest level components of the kidney lie in the organ's division into two main compartments: the **renal cortex** and the inner **renal medula**. Inside the renal medula, millions of **nephrons** process filtrate in parallel. A nephron consists of:

- A single folded tubule
- Associated blood vessels

These two components of the nephron can be further described in terms of their position with respect to the kidney and their function. For example, the **bowman's capsule** is a term used to refer to the cup-shaped blood-filtering end of the nephron. The function of a nephron has been carried out once it disposes of its refined filtrate into the **collecting duct** of the cortex, which carries urine to the renal pelvis.

Before one analyzes the flow of blood and filtrates in the nephron, one must first recognize the three sections of the nephron in which filtrate processing occurs:

1. The **promixal tubule**: conveys and helps refine filtrate.
2. The **Loop of Henle**: helps concentrate the filtrate conveying it between a proximal tubule and a distal tubule
3. The **Distal tubule**: helps refine filtrate and empties it into a collecting duct

Inside of the nephron, blood and filtrate will take the following path:

- Both enter renal artery
  - Both enter glomerulus
    - Blood remains in capillaries
      - Blood exits Bowman's capsule via arteriole
        - Various capillaries
          - Renal vein
    - Filtrate enters nephron tube
      - Proximal tubule
        - Loop of Henle
          - Distal tubule
            - Collecting duct

Even after filtrates are processed in the nephrons, the process of **reabsorption** serves to further process the products of the aforementioned process by returning nutrients to the blood through capillary walls. **Secretion**, on the other hand, can be used to remove unwanted minerals from the bloodstream via the filtrate products of the nephron processes.

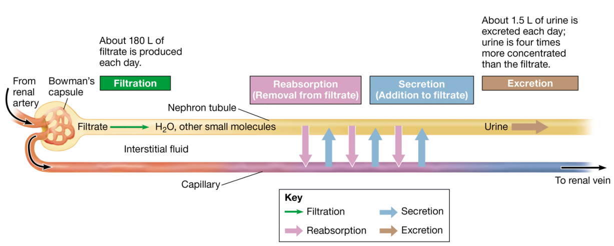

Figure 5: The relationship between the nephron and secretion/reabsorption

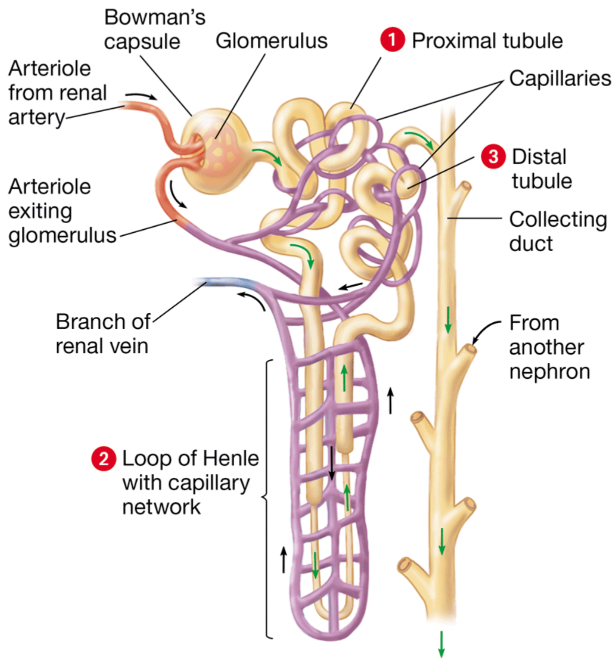

Figure 6: The pathway of blood and filtrates through the nephron

Once initial processing and secretion/reabsorption have completed, urine is excreted from the body via the ureters, urinary bladder, and urethra.

4.2 Preservation of water and valuable solutes through reabsorption and filtrate movement

Reabsorption is largely a responsibility of the proximal tubes. 65% of the water contained in filtrates is reabsorbed in this region of the nephron. Beyond the proxmial tubule, water may be reabsorbed through the natural concentration gradient present in the rest of the nephron and collecting duct. In the loop of Henle, for example, water is moved out of the filtrate and into nearby blood capillaries throguh **aquaporins**—passive water transport proteins. Until the filtrate reaches the diastal tube, water ceases to exit, as the section of the loop of Henle past its lower turning point lacks aquaporins necessary to facilitate the transport of water out of the tube. In the meantime, NaCl continues to exit up until the filtrate reaches the collecting duct.

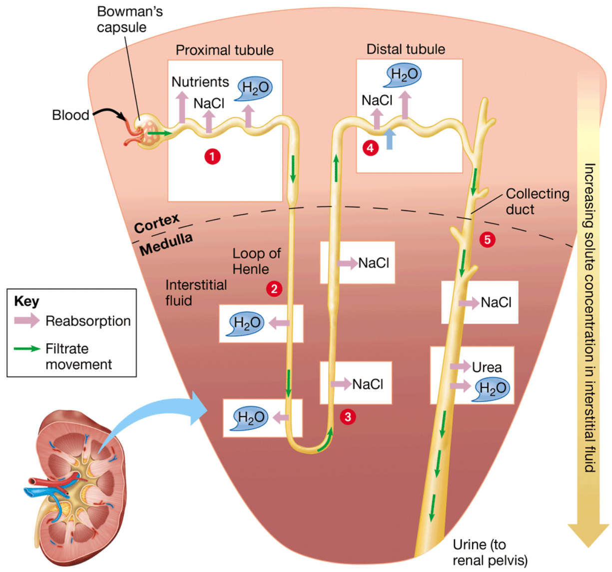

Figure 7: The reabsorption of mineral and H_2O

4.3 The role of hormones in regulating the urinary system

The secretion of antidiuretic hormone from the pituitary gland can allow for a temporary increase in water reabsorption by binding to collecting duct receptor molecules where additional aquaporin channels can be formed, allowing for water to exit the collecting duct. This decreased concentration of water in the filtrate may result in darker-colored urine, as the filtrate resulting from kidney filtration lacks its usual dilution.

This same ADH-powered aquaporin management process is just as useful when water concentration is too high: ADH level fall, and less aquaporin channels are opened in the nephron.

However, antidiuretic hormone isn't necessarily the only force at play in terms of the concentration of collecting duct aquaporin channels: alcohol, for example, is a diuretic that inhibits the release of the aforementioned hormone. This inhibiting factor results in decreased water reabsorption, and, as a result, more frequent urination.