Water Balance, Thermoregulation and Excretion

These three components of homeostasis are closely related.

Evaporative loss of water (sweating) is a key means of thermoregulation.

You can’t afford to lose too much water, since so many of the processes that go on in your body depend on maintenance of the osmolarity and composition of body fluids.

Therefore, controlling water and ion retention in excretion is critical.

A. Thermoregulation
There are 4 ways to gain or lose heat:

1. Conduction – thermal energy can be directly transferred from one object to another (always warmer to cooler) when they are in contact

2. Convection – moves heat when a current of air or water moves past an object. Heat is lost into the current when the object is warmer than the current, and vice-versa. This is the basis of “wind chill”.

3. Radiation – warm objects radiate infrared energy. The earth radiates, and trapping of the radiation is the basis of the greenhouse effect.

4. Evaporation – remember high school chemistry. There is a heat of vaporization for water of about 500 calories per gram. That heat is drawn from an animal’s body when sweat evaporates, and the energy loss helps cool the animal.
The balance between metabolic heat production, behaviour, and these 4 gains and losses is the way animals thermoregulate.

One of the key physiological mechanisms to regulate heat loss is called **countercurrent exchange**.

The shark’s pattern of circulation is somewhat different from most fish. In it, arteries run just below the skin, and are cool. Branches from these arteries extend inward into muscle. Paralleling those arterial branches are vein branches running in the opposite direction, from within muscle outward. Blood in the veins is warmer. Heat from the veins is exchanged into the arteries, warming it. Diagrammatically:

The other common example of countercurrent heat exchange is what keeps ducks and geese from freezing while they stand on ice in winter. Imagine what it would be like for you to stand barefoot on ice. Countercurrent exchange minimizes the bird’s heat loss…

Warm blood in arteries of the legs exchanges heat with cooler blood in veins before reaching the cold feet. That heat is saved.
Behaviour can also play an important role. The example of honeybees is a good one.

During the summer, workers transport liquid into the hive; workers plus drones fan. The convection driven by wing beating and the evaporative heat loss help to cool the hive.

During the winter, bees shiver, generating metabolic heat to warm the hive.

Behaviour can lead to evaporative cooling…

And many animals that live in hot or cold climates have fur that tends to trap air near the skin.

A camel uses its fur to trap cooler air, and limit exposure to the very hot daytime air temperatures in the desert.

An arctic fox or wolf adds a dense underlayer of fur for winter to prevent convective heat loss. An arctic wolf with full winter fur is thermoneutral (has to spend no extra metabolic energy to maintain body temperature) down to ~-40°C.
Then there are the physiological adaptations to get through winter by partially shutting down metabolic machinery:

Torpor – metabolic rate, respiratory rate, heart rate all slow. Recovery from torpor can be rapid. *Zapis* (jumping mice) at Ojibway will go from torpid to fully active after about a minute or two warmed in your hand.

Hibernation – a long-term torpor from which animals don’t arise quickly. Squirrels are one example; they feed heavily in fall, and live on stored fat through the winter.

There is also a summer torpor, called aestivation, that protects many desert animals from the full impact of low water availability and high temperature. They remain inactive (torpid) in burrows during the day, and become active at night.

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**Osmoregulation**

If animals use the thermal capacity and heat of vaporization of water to deal with thermoregulation, they then have to deal with the affect of water gain or loss on the osmotic pressure and composition of blood and body fluids.

How they do it varies with where they are found and their physiological abilities.

Many animals living in seawater are what are called **osmoconformers**. Their body fluids have a solute concentration equal to seawater and, over the small range of change in seawater, ‘go with the flow’
However, they still have to spend energy to maintain the appropriate ionic composition in their body fluids.

Animals that live in freshwater, on land, and even most marine vertebrates, are osmoregulators. They maintain the solute concentration of their body fluids through expenditure of energy in the digestive system, the respiratory system, and the excretory system.

Comparing a freshwater fish to a marine fish is useful to explore the problems.

The fish in salt water has fluids lower in solutes than the seawater around it.

The freshwater fish has far more solutes in its body fluids than in the water around it.

How do they osmoregulate?

The saltwater fish loses water by osmosis through its body surfaces (it is hypotonic to seawater). It drinks seawater to take in water, but gets rid of excess salts from the seawater by pumping them out through its gills. It also gets rid of salts but only a little water in its small amounts of urine.

The freshwater fish has opposite problems. It is hypertonic to the water around it. Osmosis through body surface and gills, as well as water taken in with food, all would tend to dilute its body fluids. It excretes a copious urine that is dilute, and resorbs ions both in its gut and kidneys. Even the gills take up some specific ions.
Fish have continuous access to water. Terrestrial animals are frequently found in environments where water must be conserved. There are various ways to achieve that conservation:

1. Have an impermeable surface through which water can’t be lost – the waxy, hard chitinous exoskeleton of arthropods is a widespread example.
2. Avoid exposure in times of evaporative stress – desert rodents spend their days in burrows and come out at night.
3. Produce a very concentrated urine – birds excrete a paste of uric acid.

Where lots of water is available, e.g. for fish, the way nitrogenous wastes are removed is as ammonia (NH\textsubscript{3}). Ammonia is very toxic, but also very soluble. It will diffuse out of small animals, and fish excrete some through their gills, but also as a dilute urine.

Terrestrial animals use energy to convert ammonia into urea in the liver. It is relatively non-toxic and highly soluble. It is concentrated in the kidneys to produce urine with limited water loss.

Where even the water loss in a concentrated urine could be a problem (in insects and birds, for example), uric acid (non-toxic but relatively insoluble) is made at higher cost and excreted.
Urine is made in the kidneys of vertebrates. Human kidney structure shows us the structure and function…

Blood to be filtered enters the kidneys in the renal artery.
Filtered blood leaves the kidneys in the renal vein.
The kidney is divided into two main functional regions: the cortex and the medulla.

The functional units of the kidney are the nephrons. There are about 1 million of them in each of your kidneys. Here’s what a single nephron looks like:

Initially, filtrate is passed from a dense ball of capillaries (a glomerulus) into Bowman’s capsule in the renal cortex. The filtrate passes through the proximal tubule into the loop of Henle, then into the distal tubule and the collecting duct. The loops of Henle, collecting ducts and blood vessels of juxtamedullary nephrons form the medulla.

Only birds and mammals have the juxtamedullary nephrons. Other vertebrates have only the cortical nephrons. Here’s a more detailed view of a single juxtamedullary nephron, showing the intimate association of blood vessels in the nephron:
The filtration process

Blood pressure in the capillaries within Bowman’s capsule forces water and small solute molecules (salts, glucose, vitamins, amino acids, urea) out of capillaries, into interstitial fluid, and finally the capsule.

What happens to this initial filtrate is **reabsorption** and **secretion**. Valuable materials (water, salts, nutrients, amino acids) are reabsorbed from the tubules into adjacent blood vessels. Excess K\(^+\) and/or H\(^+\) in the blood are secreted (**active transport**) into the filtrate from the blood. Ammonia moves passively into the proximal tubule.

Here’s the filtration process diagram. Part of the explanation for the movement of materials is difference in the osmolarity (concentration of solutes) between the cortex and medullary regions.

The kidney is regulated by key interactions with the rest of the body. If you’ve been sweating a lot, you want the kidneys to reabsorb more water. That’s achieved using **ADH (AntiDiuretic Hormone)**. It causes the distal tubules and collecting ducts to be more leaky, so that more water is reabsorbed.

Obviously, the opposite can also happen. The amount of ADH in circulation is decreased when the osmolarity of your blood drops (more water than the set ‘normal’ level).
There are other control interactions. When blood pressure drops, the RAAL (renin-angiotensin-aldosterone) system causes increased reabsorption of water and salts, which increases blood volume and pressure.

There is a check and balance to the RAAL system. The walls of the atria of the heart release a hormone called ANF (atrial natriuretic factor) when blood volume and pressure increase. ANF inhibits release of renin, and thus the steps of the RAAL system.

There are checks and balances like this on most human processes/systems. Hormones (next lecture) are the mechanisms underlying many.