Homeostasis, thermoregulation and the kidney

Negative and positive feedback, homeostasis and temperature control, the structure of the kidney, urea and ultrafiltration, reabsorption and the loop of Henle, ADH, and gene control by hormones.

Feedback and homeostasis

Homeostasis is the maintenance of a **stable internal environment** (temperature, blood glucose, water potential, pH) within narrow limits, in a state of **dynamic equilibrium**. It is important because **enzymes** and cell processes work best at certain conditions, and it allows organisms to be independent of the external environment.

Negative feedback

A **negative feedback** system **reverses** a change, returning the factor to its **set point**.

1. A **receptor** detects a change from the set point.
2. A **coordinator** (e.g. the hypothalamus) processes the information.
3. **Effectors** (muscles or glands) bring about a response that **opposes the change**.

Having **separate mechanisms** to raise and lower the level gives **greater control**.

Positive feedback

A change causes a response that **increases** the change. It is not used for homeostasis, but for events that need to be completed quickly: **blood clotting**, the **action potential** (the opening of sodium channels), **contractions in labour** (oxytocin) and **atherosclerosis**.

Thermoregulation

The **hypothalamus** contains the **thermoregulatory centre**, which detects the blood temperature, and receives information from **thermoreceptors** in the skin.

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If temperature is too **high**	If temperature is too **low**
Vasodilation: arterioles in the skin widen, so more blood flows near the surface and more heat is lost by radiation	**Vasoconstriction**: arterioles narrow, so less blood flows near the surface
Sweating: evaporation of water removes heat (latent heat)	**Shivering**: rapid muscle contractions release heat
Hairs lie flat (in mammals)	**Hair erector muscles** raise hairs, trapping a layer of insulating air
Behaviour: seek shade	Behaviour: seek warmth; **raised metabolic rate** (hormones, e.g. thyroxine)

In **exercise**, heat from muscle contraction is lost by these mechanisms to prevent overheating.

The kidney

Structure

- The **cortex** (outer): contains the **glomeruli**, **Bowman's capsules** and **convoluted tubules**.
- The **medulla** (inner): contains the **loops of Henle** and **collecting ducts**.
- The **pelvis**: collects urine, which leaves through the **ureter**.
- A **nephron** is the functional unit: Bowman's capsule with a **glomerulus** (a knot of capillaries), the **proximal convoluted tubule**, the **loop of Henle**, the **distal convoluted tubule** and the **collecting duct**.

Urea

Excess amino acids cannot be stored. In the **liver** they are **deaminated** (the amino group is removed), producing **ammonia**, which is converted to the less toxic **urea**. Urea is carried in the blood to the kidneys, where it is removed.

Ultrafiltration

In the **glomerulus**, the **afferent arteriole** is wider than the **efferent arteriole**, which produces **high hydrostatic pressure**. Water and small molecules (glucose, amino acids, urea, ions) are forced out of the capillary into the **Bowman's capsule**, as the **glomerular filtrate**. Blood cells and large proteins stay in the blood.

The filtration barrier has three layers: the **capillary endothelium** (with gaps or fenestrations), the **basement membrane** (which acts as a filter that retains large proteins) and the **podocytes** (cells of the Bowman's capsule with slits between them).

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Selective reabsorption in the proximal tubule

The cells of the **proximal convoluted tubule** have **microvilli** (large surface area) and many **mitochondria**. They reabsorb:

- **All glucose** and **amino acids**, by **active transport** (co-transport with sodium ions) and facilitated diffusion,
- **Sodium** ions (active transport),
- Most of the **water** (by osmosis), and some **urea**.

About 80% of the filtrate is reabsorbed here.

The loop of Henle: countercurrent multiplier

The loop of Henle creates a **high solute concentration** in the medulla, allowing the production of **concentrated urine**.

1. In the **ascending limb** (impermeable to water), **sodium and chloride ions** are **actively pumped out** into the medulla, making the tissue fluid at a **low water potential**.
2. In the **descending limb** (permeable to water), **water leaves by osmosis** into the medulla, so the filtrate becomes more concentrated towards the bottom.
3. The two limbs run in opposite directions (a **countercurrent**), which **multiplies** the concentration gradient up and down the medulla, keeping a **steep water potential gradient** for the full length of the collecting duct.
4. In the **collecting duct**, water is **reabsorbed by osmosis** into the medulla, if the duct is permeable, so the urine is concentrated.

Animals that live in dry environments (e.g. a desert rat) have a **longer loop of Henle**, so that they can produce more concentrated urine and save water.

Control of water: ADH

If the blood has **too little water** (a low water potential):

1. **Osmoreceptors** in the **hypothalamus** detect the low water potential, and send signals to the **posterior pituitary gland**.
2. The pituitary releases **antidiuretic hormone (ADH)** into the blood.
3. ADH makes the **cells of the distal tubule and collecting duct** more **permeable to water** (more **aquaporins** in the membrane).
4. **More water** is **reabsorbed** by osmosis, so a **small volume of concentrated urine** is produced.
5. The blood water potential **rises**, osmoreceptors are no longer stimulated, and **less ADH** is released. (**Negative feedback**.)

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If the blood has **too much water**, less ADH is released, so the collecting duct becomes less permeable, and a **large volume of dilute urine** is produced.

> **ADH acts on the collecting duct and distal tubule, and it increases permeability to water. It does not change the amount of salt excreted.**

Genes switched on and off by hormones

Hormones can control **transcription** of genes through **transcription factors**.

- **Peptide hormones** (insulin, ADH) cannot cross the membrane. They bind to **receptors on the cell surface** and trigger a **second messenger** inside the cell that activates a transcription factor.
- **Steroid hormones** (oestrogen, testosterone) are **lipid-soluble**, so they cross the membrane, bind to **receptors in the cytoplasm or nucleus**, and the **hormone–receptor complex acts as a transcription factor**, binding to DNA and **switching on** (or off) a specific gene.

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