Learning unit 12: Regulating the internal environment

12.1 Introduction

To complete the learning unit, you will need to refer to pages 933–957 chapter 40 in Campbell et al. (2015)

Animal groups are dramatically diverse, with radically different body structures. For example, consider how different the elephant and the mice are, not only with size but also in body form and life span. Despite their differences, animal groups share many characteristics.

Over the course of its life, an elephant faces the same fundamental challenges as any other animal, whether hydra, snake or human. All animals must obtain nutrients and oxygen, and produce of offspring. Because form and function are correlated, examining anatomy often provides clues to physiology. In this learning unit, we will use the example of body temperature regulation to demonstrate how animal control their internal environment. We also look at how anatomy and physiology relate to an animal's interactions with the environment and its management of energy use.

12.2 Learning outcomes

By the end of this learning unit you should be able to

- explain how different animals regulate their internal environments and body temperature
- discuss the process of homeostasis
- explain osmoregulation
- discuss the elimination of waste products in animals

12.3 Animal form and function are correlated at all levels of organisation

Recommended reading: pages 934–940 of chapter 40 in Campbell et al. (2015)

Size and shape affect the way an animal interacts with its environment. The body plan of an animal is programmed by the genome, itself the product of millions of years of evolution.

12.3.1 Evolution of animal size and shape

Physical laws govern strength, diffusion, movement, and heat exchange. Properties of water limit possible shapes for fast swimming animals. As animals increase in size, thicker skeletons are required for support. Convergent evolution often results in similar adaptations of diverse organisms facing the same challenge.

12.3.2 Exchange with the environment

Materials such as nutrients, waste products, and gases must be exchanged across the cell membranes of animal cells. Rate of exchange is proportional to a cell's surface area while amount of exchange material is proportional to a cell's volume. A single-celled organism living in water has sufficient surface area to carry out all necessary exchange. Multicellular organisms with a saclike body plan have body walls that are only two cells thick, facilitating diffusion of materials. In flat animals such as tapeworms, most cells are in direct contact with its environment. More complex organisms are composed of compact masses of cells with complex internal organisation. Evolutionary adaptations such as specialised, extensively branched or folded structures, enable sufficient exchange with the environment. In vertebrates, the space between cells is filled with interstitial fluid, which allows for the movement of material into and out of cells. A complex body plan helps an animal living in a variable environment to maintain a relatively stable internal environment.

12.4 Feedback control maintains the internal environment in many animals

Recommended reading: pages 941–941 of chapter 40 in Campbell et al. (2015)

Faced with environmental fluctuations, animals manage their internal environment by either regulating or conforming.

12.4.1 Regulating and conforming

A regulator uses internal control mechanisms to control internal change in the face of external fluctuation. A conformer allows its internal condition to vary with certain external changes. Animals may regulate some environmental variables while conforming to others.

12.4.2 Homeostasis

Organisms use homeostasis to maintain a "steady state" or internal balance regardless of external environment. In humans, body temperature, blood pH, and glucose concentration are each maintained at a constant level. Mechanisms of homeostasis moderate changes in the internal environment. For a given variable, fluctuations above or below a set point serve as a stimulus; these are detected by a sensor and trigger a response. The response returns the variable to the set point. Homeostasis in animals relies largely on negative feedback, which helps to return a variable to a normal range. Positive feedback amplifies a stimulus and does not usually contribute to homeostasis in animals. Set points and normal ranges can change with age or show cyclic variation. In animals and plants, a circadian rhythm governs physiological changes that occur roughly every 24 hours. Homeostasis can adjust to changes in external environment, a process called acclimatisation.

12.5 Homeostatic processes for thermoregulation involve form, function, and behaviour

Recommended reading: pages 944–948 of chapter 40 in Campbell et al. (2015)

Thermoregulation is the process by which animals maintain an internal temperature within a tolerable range.

12.5.1 Endothermy and ectothermy

Endothermic animals generate heat by metabolism; birds and mammals are endotherms. Ectothermic animals gain heat from external sources; ectotherms include most invertebrates, fishes, amphibians, and nonavian reptiles. Endotherms can maintain a stable body temperature even in the face of large fluctuations in environmental temperature. Endothermy is more energetically expensive than ectothermy. In general, ectotherms tolerate greater variation in internal temperature.

12.5.2 Variation in body temperature

The body temperature of a poikilotherm varies with its environment. The body temperature of a homeotherm is relatively constant. The relationship between heat source and body temperature is not fixed (that is, not all poikilotherms are ectotherms).

12.5.3 Balancing heat loss and gain

Organisms exchange heat by four physical processes: radiation, evaporation, convection, and conduction. Heat regulation in mammals often involves the integumentary system: skin, hair, and nails. Five adaptations that help animals thermoregulate: insulation, circulatory adaptations, cooling by evaporative heat loss, behavioural responses, and adjusting metabolic heat production.

Insulation is a major thermoregulatory adaptation in mammals and birds. Skin, feathers, fur, and blubber reduce heat flow between an animal and its environment. Insulation is especially important in marine mammals such as whales and walruses.

Circulatory Adaptations

Regulation of blood flow near the body surface significantly affects thermoregulation. Many endotherms and some ectotherms can alter the amount of blood flowing between the body core and the skin. In vasodilation, blood flow in the skin increases, facilitating heat loss. In vasoconstriction, blood flow in the skin decreases, lowering heat loss. The arrangement of blood vessels in many marine mammals and birds allows for countercurrent exchange. Counter current heat exchangers transfer heat between fluids flowing in opposite directions and thereby reduce heat loss. Some bony fishes and sharks also use countercurrent heat exchanges. Many endothermic insects have countercurrent heat exchangers that help maintain a high temperature in the thorax.

Cooling by Evaporative Heat Loss

Many types of animals lose heat through evaporation of water from their skin. Sweating or bathing moistens the skin, helping to cool an animal down. Panting increases the cooling effect in birds and many mammals.

Behavioural Responses

Both endotherms and ectotherms use behavioural responses to control body temperature. Some terrestrial invertebrates have postures that minimise or maximize absorption of solar heat. Honeybees huddle together during cold weather to retain heat.

Adjusting Metabolic Heat Production

Thermogenesis is the adjustment of metabolic heat production to maintain body temperature. Thermogenesis is increased by muscle activity such as moving or shivering. Non-shivering thermogenesis takes place when hormones cause mitochondria to increase their metabolic activity. Some ectotherms can also shiver to increase body temperature.

12.5.4 Acclimatisation in thermoregulation

Birds and mammals can vary their insulation to acclimatise to seasonal temperature changes. When temperatures are subzero, some ectotherms produce “antifreeze” compounds to prevent ice formation in their cells.

12.5.5 Physiological thermostats and fever

Thermoregulation in mammals is controlled by a region of the brain called the hypothalamus. The hypothalamus triggers heat loss or heat generating mechanisms. Fever, a response to some infections, reflects an increase in the normal range for the biological thermostat. Some ectothermic organisms seek warmer environments to increase their body temperature in response to certain infections.

12.6 Energy requirements are related to animal size, activity, and environment

Recommended reading: pages 949–952 of chapter 40 in Campbell et al. (2015)

Bioenergetics is the overall flow and transformation of energy in an animal. It determines how much food an animal needs and it relates to an animal’s size, activity, and environment.

12.6.1 Energy allocation and use

Organisms can be classified by how they obtain chemical energy. Autotrophs, such as plants, harness light energy to build energy-rich molecules. Heterotrophs, such as animals, harvest chemical energy from food. Energy-containing molecules from food are usually used to make ATP, which powers cellular work. After the needs of staying alive are met, remaining food molecules can be used in biosynthesis. Biosynthesis includes body growth and repair, synthesis of storage material such as fat, and production of gametes.

12.6.2 Quantifying energy use

Metabolic rate is the amount of energy an animal uses in a unit of time. Metabolic rate can be determined by

-an animal’s heat loss.

-the amount of oxygen consumed or carbon dioxide produced.

-measuring energy content of food consumed and energy lost in waste products.

12.6.3 Minimum metabolic rate and thermoregulation

Basal metabolic rate (BMR) is the metabolic rate of an endotherm at rest at a “comfortable” temperature. Standard metabolic rate (SMR) is the metabolic rate of an ectotherm at rest at a specific temperature. Both rates assume a non-growing, fasting, and non-stressed animal. Ectotherms have much lower metabolic rates than endotherms of a comparable size.

12.6.4 Influence on metabolic rate

Metabolic rates are affected by many factors besides whether an animal is an endotherm or ectotherm. Some key factors are age, sex, size, activity, temperature, and nutrition.

12.6.5 Torpor and energy conservation

Torpor is a physiological state in which activity is low and metabolism decreases. Torpor enables animals to save energy while avoiding difficult and dangerous conditions. Hibernation is long-term torpor that is an adaptation to winter cold and food scarcity. Summer torpor, called estivation, enables animals to survive long periods of high temperatures and scarce water. Daily torpor is exhibited by many small mammals and birds and seems adapted to feeding patterns. There are many aspects to the relationship between structure and function in animals. There are also some fundamental similarities in the evolutionary adaptations of plants and animals.

12.7 Activity 12.1

Do this activity and add it to your portfolio.

Refer to your textbook and answer the following questions:

b. Differentiate between ectotherms and endotherms.
d. How do humans and iguanas differ in body temperature regulation?
f. What are some physiological and behavioural adaptations to extreme cold and extreme heat?
h. How do land animals gain and lose water?

12.8 Feedback on activity 2.1

b. Iguanas are ectotherms; they lack an internal temperature-regulating mechanism so they must move to areas where they can gain or lose heat. Humans are endotherms; we regulate body temperature internally to maintain a relatively constant body temperature.
d. Ectotherms use the environment, not their own internal mechanisms, to regulate their body temperature. Endotherms regulate their body temperature through internal mechanisms.
f. Some physiological adaptations to extreme cold include countercurrent exchange systems, shunting of blood from extremities, and shivering. Behavioural adaptations to extreme cold include fluffing fur or feathers, huddling, and hibernating. Some physiological adaptations to extreme heat include evaporative cooling, dilating surface blood vessels near the skin, and rerouting skin-cooled blood to towards the brain. Behavioural adaptations to extreme heat include hiding in shade, digging burrows, swimming, shedding clothes, and consuming cold drinks.
h. Land animals take in water through food, drink and metabolism. They lose it through their lungs, skin, feces, and urine.

12.9 Summary

The forms of signaling between animal cells differ in the type of secreting cell and the route taken by the signal to its target. Endocrine signals, or hormones, are secreted into the extracellular fluid by endocrine cells or ductless glands and reach target cells via circulatory fluids. Pheromones are released into the surrounding environment for communication between animals of the same species.

Hormone pathways may be regulated by negative feedback, which dampens the stimulus, or positive feedback, which amplifies the stimulus and drives the response to competition. Invertebrates, neurosecretory cells in the hypothalamus produce two hormones that are secreted by posterior pituitary and that act directly on non-endocrine tissues: oxytocin, which induces uterine contractions and release of milk from mammary glands.