Chapter 1

General Organisation of the Body

Physiology is the study of the functions of the body, its organs and the cells of which they are composed. It is often said that physiology concerns itself with maintaining the status quo or 'homeostasis' of bodily processes. However, even normal physiology is not constant, changing with development (childhood, pregnancy and ageing) and environmental stresses (altitude, diving and exercise). Physiology might be better described as maintaining an 'optimal' internal environment; many diseases are associated with the disturbance of this optimal environment.

Anaesthetists are required to adeptly manipulate this complex physiology to facilitate surgical and critical care management. Therefore, before getting started on the areas of physiology that are perhaps of greater interest, it is worth revising some of the basics – this chapter and the following four chapters have been whittled down to the absolute essentials.

How do the body's organs develop?

The body is composed of some 100 trillion cells. All life begins from a single totipotent embryonic cell, which is capable of differentiating into any cell type. This embryonic cell divides many times and, by the end of the second week, gives rise to the three germ cell layers:

- **Ectoderm**, from which the nervous system and epidermis develop.
- **Mesoderm**, which gives rise to connective tissue, blood cells, bone and marrow, cartilage, fat and muscle.
- **Endoderm**, which gives rise to the liver, pancreas and bladder, as well as the epithelial lining of the lungs and gastrointestinal (GI) tract.

Each organ is composed of many different tissues, all working together to perform a particular function. For example, the heart is composed of cardiac muscle, conducting tissue, including Purkinje fibres, and blood vessels, all working together to propel blood through the vasculature.

How do organs differ from body systems?

The organs of the body are functionally organised into 11 physiological 'systems':

- **Respiratory system**, comprising the lungs and airways.
- **Cardiovascular system**, comprising the heart and the blood vessels. The blood vessels are subclassified into arteries, arterioles, capillaries, venules and veins. The circulatory system is partitioned into systemic and pulmonary circuits.
- **Nervous system**, which comprises both neurons (cells that electrically signal) and glial cells (supporting cells). It can be further subclassified in several ways:
  - Anatomically, the nervous system is divided into the *central nervous system* (CNS), consisting of the brain and spinal cord, and the *peripheral nervous system* (PNS), consisting of peripheral nerves, ganglia and sensory receptors, which connect the limbs and organs to the brain.
  - The PNS is functionally classified into an *afferent limb*, conveying sensory impulses to the brain, and an *efferent limb*, conveying motor impulses from the brain.
  - *The somatic nervous system* refers to the components of the nervous system under conscious control.
  - *The autonomic nervous system* (ANS) regulates the functions of the viscera. It is divided into *sympathetic and parasympathetic nervous systems.*
  - *The enteric nervous system* is a semiautonomous system of nerves that control the digestive system.
- **Muscular system**, comprising the three different types of muscle: skeletal, cardiac and smooth muscle.

- **Skeletal system**, the framework of the body, comprising bone, ligaments and cartilage.
- **Integumentary system**, which is essentially the skin and its appendages: hairs, nails, sebaceous glands and sweat glands. Skin is an important barrier preventing invasion by microorganisms and loss of water (H_2O) from the body. It is also involved in thermoregulation and sensation.
- **Digestive system**, including the whole of the GI tract from mouth to anus and a number of accessory organs: salivary glands, liver, pancreas and gallbladder.
- **Urinary system**, which comprises the organs involved in the production and excretion of urine: kidneys, ureters, bladder and urethra.
- **Reproductive system**, by which new life is produced and nurtured. Many different organs are involved, including the ovaries, testes, uterus and mammary glands.
- **Endocrine system**, whose function is to produce hormones. Hormones are chemical signalling molecules carried in the blood that regulate the function of other, often distant cells.
- **Immune system**, which is involved in tissue repair and the protection of the body from microorganism invasion and cancer. The immune system is composed of the lymphoid organs (bone marrow, spleen, lymph nodes and thymus), as well as discrete collections of lymphoid tissue within other organs (for example, Peyer's patches are collections of lymphoid tissue within the small intestine). The immune system is commonly subclassified into:
  - *The innate immune system*, which produces a rapid but non-specific response to microorganism invasion.
  - *The adaptive immune system*, which produces a slower but highly specific response to microorganism invasion.

The body systems do not act in isolation; for example, arterial blood pressure is the end result of interactions between the cardiovascular, urinary, nervous and endocrine systems.

What is homeostasis?

Single-celled organisms (for example, an amoeba) are entirely dependent on the external environment for their survival. An amoeba gains its nutrients directly from and eliminates its waste products directly into the external environment. The external environment also influences the cell's temperature and pH, along with its osmotic and ionic gradients. Small fluctuations in the external environment may alter intracellular processes sufficiently to cause cell death.

Humans are multicellular organisms – the vast majority of our cells do not have any contact with the external environment. Instead, the body bathes its cells in extracellular fluid (ECF). The composition of ECF bears a striking resemblance to seawater, where distant evolutionary ancestors of humans would have lived. Homeostasis is the regulation of the internal environment of the body to maintain a stable, relatively constant and optimised environment for its component cells:

- **Nutrients** – cells need a constant supply of nutrients and oxygen (O_2) to generate energy for metabolic processes. In particular, plasma glucose concentration is tightly controlled, and many physiological mechanisms are involved in maintaining an adequate and stable partial pressure of tissue O_2.
- **Carbon dioxide (CO_2) and waste products** – as cells produce energy in the form of adenosine triphosphate (ATP), they generate waste products (for example, H^+ and urea) and CO_2. Accumulation of these waste products may hinder cellular processes; they must be transported away.
- **pH** – all proteins, including enzymes and ion channels, work efficiently only within a narrow range of pH. Extremes of pH result in denaturation, disrupting the tertiary or quaternary structure of proteins or nucleic acids.
- **Electrolytes and water** – the intracellular water volume is tightly controlled; cells do not function correctly when they are swollen or shrunken. As sodium (Na^+) is a major cell membrane impermeant and therefore an osmotically active ion, the movement of Na^+ strongly influences the movement of water. The extracellular Na^+ concentration is accordingly tightly controlled. The extracellular concentrations of other electrolytes (for example, the ions of potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+})) have other major physiological functions and are also tightly regulated.

- **Temperature** – the kinetics of enzymes and ion channels have narrow optimal temperature ranges, and the properties of other biological structures, such as the fluidity of the cell membrane, are also affected by temperature. Thermoregulation is therefore essential.

Homeostasis is a dynamic phenomenon: usually, physiological mechanisms continually make minor adjustments to the ECF environment. Following a major disturbance, large physiological changes are sometimes required.

How does the body exert control over its physiological systems?

Homeostatic control mechanisms may be intrinsic (local) or extrinsic (systemic) to the organ:

- **Intrinsic homeostatic mechanisms** occur within the organ itself through autocrine (in which a cell secretes a chemical messenger that acts on that same cell) or paracrine (in which the chemical messenger acts on neighbouring cells) signalling.

  For example, exercising muscle rapidly consumes O_2, causing the O_2 tension within the muscle to fall. The waste products of this metabolism (K^+, adenosine monophosphate (AMP) and H^+) cause vasodilatation of the blood vessels supplying the muscle, increasing blood flow and therefore O_2 delivery.
- **Extrinsic homeostatic mechanisms** occur at a distant site, involving one of the two major regulatory systems: the nervous system or the endocrine system. The advantage of extrinsic homeostasis is that it allows the coordinated regulation of many organs and feedforward control.

The vast majority of homeostatic mechanisms employed by both the nervous and endocrine systems rely on negative feedback loops (Figure 1.1). Negative feedback involves the measurement of a physiological variable that is then compared with a 'set point', and if the two are different, adjustments are made to correct the variable. Negative feedback loops require:

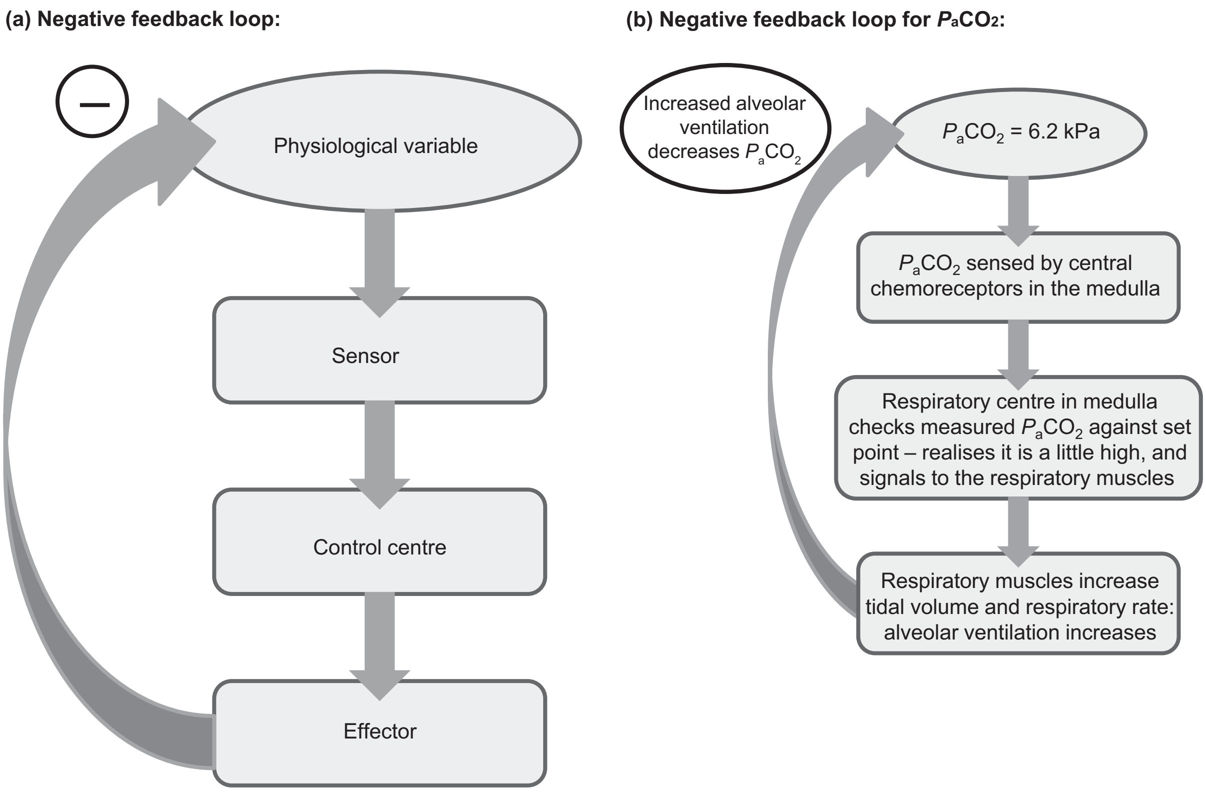

Figure 1.1 (a) Generic negative feedback loop and (b) negative feedback loop for arterial partial pressure of CO_2 (P_aCO_2).

- **Sensors**, which detect a change in the variable. For example, an increase in the arterial partial pressure of CO_2 (P_aCO_2) is sensed by the central chemoreceptors in the medulla oblongata.
- **A control centre**, which receives signals from the sensors, integrates them and issues a response to the effectors. In the case of CO_2, the control centre is the respiratory centre in the medulla oblongata.
- **Effectors**. A physiological system (or systems) is activated to bring the physiological variable back to the set point. In the case of CO_2, the effectors are the muscles of respiration: by increasing alveolar ventilation, P_aCO_2 returns to the 'set point'.

What is positive feedback?

In physiological terms, positive feedback is a means of amplifying a signal: a small increase in a physiological variable triggers a greater and greater increase in that variable (Figure 1.2). Because the body is primarily concerned with homeostasis, negative feedback loops are encountered much more frequently than positive feedback loops, but there are some important physiological examples of positive feedback:

- **Haemostasis**. Following damage to a blood vessel, exposure of a small amount of subendothelium triggers a cascade of events, resulting in the mass production of thrombin.
- **Uterine contractions in labour**. The hormone oxytocin causes uterine contractions during labour. As a result of the contractions, the baby's head descends, stretching the cervix. Cervical stretching triggers the release of more oxytocin, which further augments uterine contractions (Figure 1.2). This cycle continues until the baby is born and the cervix is no longer stretched.
- **Protein digestion in the stomach**. Small amounts of the enzyme pepsin are initially activated by decreased gastric pH. Pepsin then activates more pepsin by proteolytically cleaving its inactive precursor, pepsinogen.
- **Depolarisation phase of the action potential**. Voltage-gated Na^+ channels are opened by depolarisation, which permits Na^+ to enter the cell, which in turn causes depolarisation, opening more channels. This results in rapid membrane depolarisation.
- **Excitation–contraction coupling in the heart**. During systole, the intracellular movement of Ca^{2+} triggers the mass release of Ca^{2+} from the

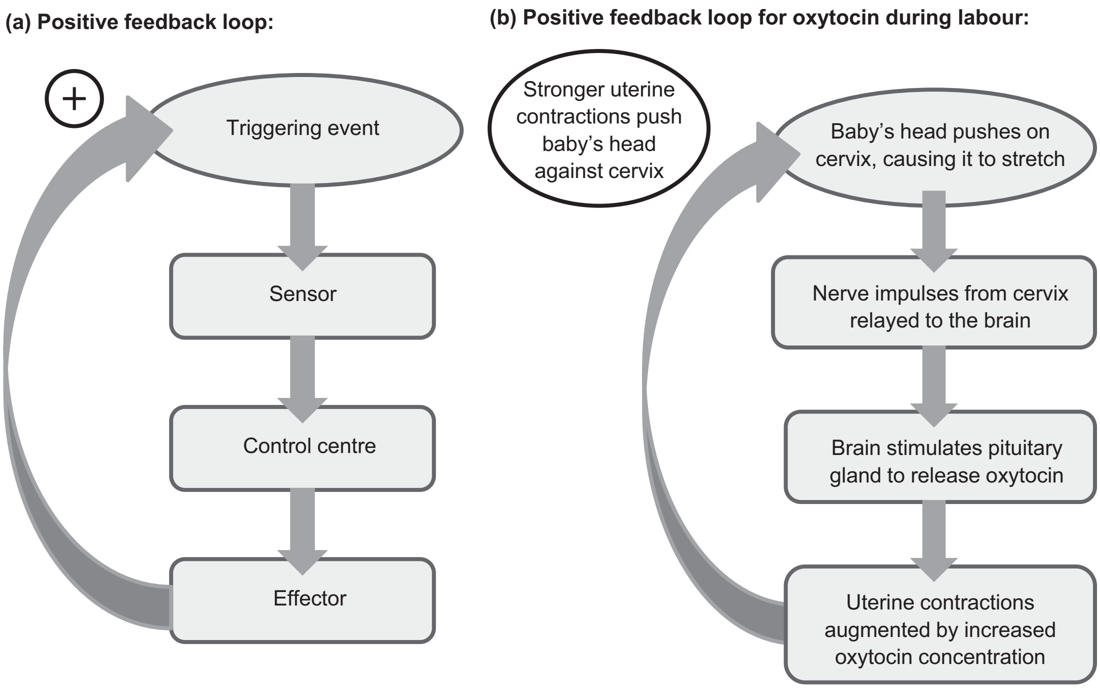

Figure 1.2 (a) Generic positive feedback loop and (b) positive feedback loop for oxytocin during labour.

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sarcoplasmic reticulum (an intracellular Ca^{2+} store). This rapidly increases the intracellular Ca^{2+} concentration, facilitating the binding of myosin to actin filaments.

Where positive feedback cycles do exist in physiology, they are usually tightly regulated by a coexisting negative feedback control. For example, in the action potential, voltage-gated Na^{+} channels inactivate after a short period of time, which prevents persistent uncontrolled depolarisation. Under certain pathological situations, positive feedback may appear as an uncontrolled phenomenon. A classic example is the control of blood pressure in decompensated haemorrhage: a fall in arterial blood pressure reduces organ blood flow, resulting in tissue hypoxia. In response, vascular beds vasodilate, resulting in a further reduction in blood pressure. The resulting vicious cycle is potentially fatal.

Further reading

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