Human Physiology I
Second Year Pharmacy Students
Chapter 1: Introduction to Physiology and Homeostasis Part I

Dr. Mohammed Shbair

Faculty of Pharmacy

Al-Azhar University of Gaza

First Semester 2020/2021

Course outline

Human physiology 1 PHPT 2306

First semester 2020/2021

Second year pharmacy students

Chapter	title	Page
1	Homeostasis: the foundation of physiology	1
3	The membrane potential	75
4	Neuronal physiology	87
5	Central Nervous System (CNS)	133
6	Peripheral Nervous system “PNS” (Afferent division; special senses)	183
7	Peripheral Nervous System (Efferent division)	237
8	Muscle Physiology	257
	Reference: Lauralee Sherwood. Human Physiology: From cells to systems. Seventh “7th” edition	

Introduction

■ **Physiology is the study of the functions of living things, specifically focusing on "how the human body works".**

Physiology focuses on mechanisms of action:

There are 2 approaches to explaining events that occur • in the body:

1. Teleological approach:

■ **Emphasizing the purpose of a body process, i.e., it emphasizes "why" body processes occur?).**

2. Mechanistic approach:

■ **Emphasizing the underlying mechanism by which a body process occurs, i.e., it emphasizes "how" body processes occur?.**

Example: Shivering

■ **In response to the question "Why do I shiver when I am cold?" one answer would be "to help warm up, because shivering generates heat".**

This is the teleological approach.

Introduction

■ In response to the **question** “how does shivering occur?

A physiologist’s explanation of shivering is that when temperature-sensitive nerve cells detect a fall in body temperature, they signal the area in the brain responsible for temperature regulation. In response, this brain area activates nerve pathways that bring about involuntary, oscillating muscle contractions (that is, shivering).

This is **the mechanistic approach**.

Introduction

■ **Anatomy** (Structure of the body) **and Physiology** (Function of the body) **are inseparable:**

■ Physiological mechanisms are made possible by the structural design and relationships of the various body parts that carry out each of these functions. For example, the heart is well designed to receive and pump blood.

Levels of Organization in the Body

■ The body is structurally organized into a total functional unit, from the chemical level to the whole body. These levels of organization make possible life as we know it:

1. The chemical level: The human body is a combination of specific atoms: the most common atoms in the body are O_2, C, H and N (make up approx. about 96% of the total body chemistry).

■ These common atoms and a few others combine to form the molecules of life, such as proteins, carbohydrates, fats, and nucleic acids.

■ These important atoms and molecules are the raw ingredients from which all living things arise.

2. The cellular level: Cells are the basic units of life.

■ The mere presence of a particular collection of atoms and molecules does not confer the unique characteristics of life.

Introduction

- They must be arranged and packaged in very precise ways to form a living entity.
- The **cell,** the fundamental unit of both structure and function in a living being, is the smallest unit capable of carrying out the processes associated with life.
- Thus, the cell's interior contains a combination of atoms and molecules that differs from the mixture of chemicals in the environment surrounding the cell.

Introduction

■ Each human organism begins when an egg and sperm unite to form a single new cell, which **multiplies** and forms a growing mass through myriad cell divisions. If cell **multiplication** were the only process involved in development, all the body cells would be **identical**. However, during development of humans, each cell also **differentiates** (becomes specialized) to carry out a particular function. (human body contains 200 different specialized types of cells).

Introduction

A. Basic Cell Functions

■ All cells, whether they exist as solitary cells or as part of a multicellular organism, perform **certain basic functions** essential for their own survival:

1**.** Obtaining food (nutrients) and oxygen (O_2) from the environment surrounding the cell.

2. Performing chemical reactions that use nutrients and O_2 to provide energy for the cells, as follows:

$$\text{Food} + O_2 \rightarrow CO_2 + H_2O + \text{energy}$$

Introduction

3. Eliminating to the cell's surrounding environment CO_2 and other by-products produced during these chemical reactions.

4. Synthesizing proteins and other components needed for cell structure, growth, and carrying out particular cell functions.

5. Controlling the exchange of materials between the cell and its surrounding environment.

6. Moving materials internally from one part of the cell to another.

Introduction

7. Being sensitive and responsive to changes in the surrounding environment.

8. In the case of most cells, reproducing. Some body cells, (e.g., nerve cells and muscle cells) lose the ability to reproduce soon after they are formed.

◘ **Cells are remarkably similar in the ways they carry out these basic functions. Thus, all cells share many common characteristics.**

B. Specialized Cell Functions

■ In multicellular organisms, each cell also performs **a specialized function**, which is usually a modification or elaboration of a basic cell function. Some examples are:

1. By taking special advantage of their protein-synthesizing ability, the gland cells of the digestive system secrete digestive enzymes that break down ingested food.

Introduction

2. Certain kidney cells are able to selectively retain the substances needed by the body while eliminating unwanted substances in the urine because of their highly specialized ability to control exchange of materials between the cell and its environment.

3. Muscle contraction, which involves selective movement of internal structures to generate tension in the muscle cells, is an elaboration of the inherent ability of these cells to produce intracellular movement.

Introduction

4. Capitalizing on the basic ability of cells to respond to changes in their surrounding environment, nerve cells generate and transmit to other regions of the body **electrical impulses**. For example, nerve cells in the ear can relay information to the brain about sounds in the body's surroundings.

■ Each cell performs these specialized functions in addition to carrying on the basic functions required of all cells.

Introduction

■ **The basic cell functions** are essential for **survival of each individual cell**, whereas the specialized functions and interactions among the cells of a multicellular organism are essential for **survival of the whole body.**

■ The cells of the body must be specifically organized to carry out the life-sustaining processes of the body as a whole, such as digestion, respiration, and circulation.

■ **Cells** are organized into **tissues, organs, body systems**, and finally the **whole body**.

Introduction

■ Each **body system** is a collection of **organs** that perform related functions and **interact** to accomplish **a common activity** that is essential for survival of the **whole body.**

■ The human body has **11 systems**: circulatory, digestive, respiratory, urinary, skeletal, muscular, integumentary, immune, nervous, endocrine, and reproductive.

■ The **whole body** of a multicellular organism consists of the various **body systems** structurally and functionally linked as an entity that is separate from its surrounding environment.

Introduction

- Thus, **the body** is made up of **living cells** organized into life-sustaining systems.
- The different body systems **do not act** in isolation from one another. Many complex body processes depend on the interplay among multiple systems. For example, regulation of blood pressure (BP) depends on coordinated responses among the circulatory, urinary, nervous, and endocrine systems.

Concepts of Homeostasis

◙ **Question:** If each cell has basic survival skills, **why** can't the body's cells live **without** performing specialized tasks and being organized according to specialization into systems that accomplish functions **essential** for the whole organism's survival?

◘ **Answer:** The cells in a multicellular organism **cannot** live and function **without** contributions from the other body cells because the vast majority of cells are **not** in direct contact with the external environment.

Concepts of Homeostasis

■ The "**external environment"** is the surrounding environment in which an organism lives.

■A single-celled organism (e.g., an amoeba) **obtains** nutrients and O_2 **directly** from its immediate external surroundings and **eliminates** wastes **back** into those surroundings.

■ Any cell in a multicellular organism (e.g., a muscle cell) has the same need for life-supporting nutrient and O_2 **uptake** and waste **elimination**.

Concepts of Homeostasis

■ But the muscle cell cannot directly make these exchanges with the external environment surrounding the body because the cell is isolated from this external environment. **How** is it a **possible** for **a muscle cell** to make **vital exchanges** with **the** "**external environment"** with which it has **no contact**???? **The key** is the presence of **a watery "internal environment"** which is the fluid that surrounds the cells (with which the body cells are in direct contact) and through which the body cells make life-sustaining exchanges.

Concepts of Homeostasis

Body cells are in contact with a privately maintained internal environment:

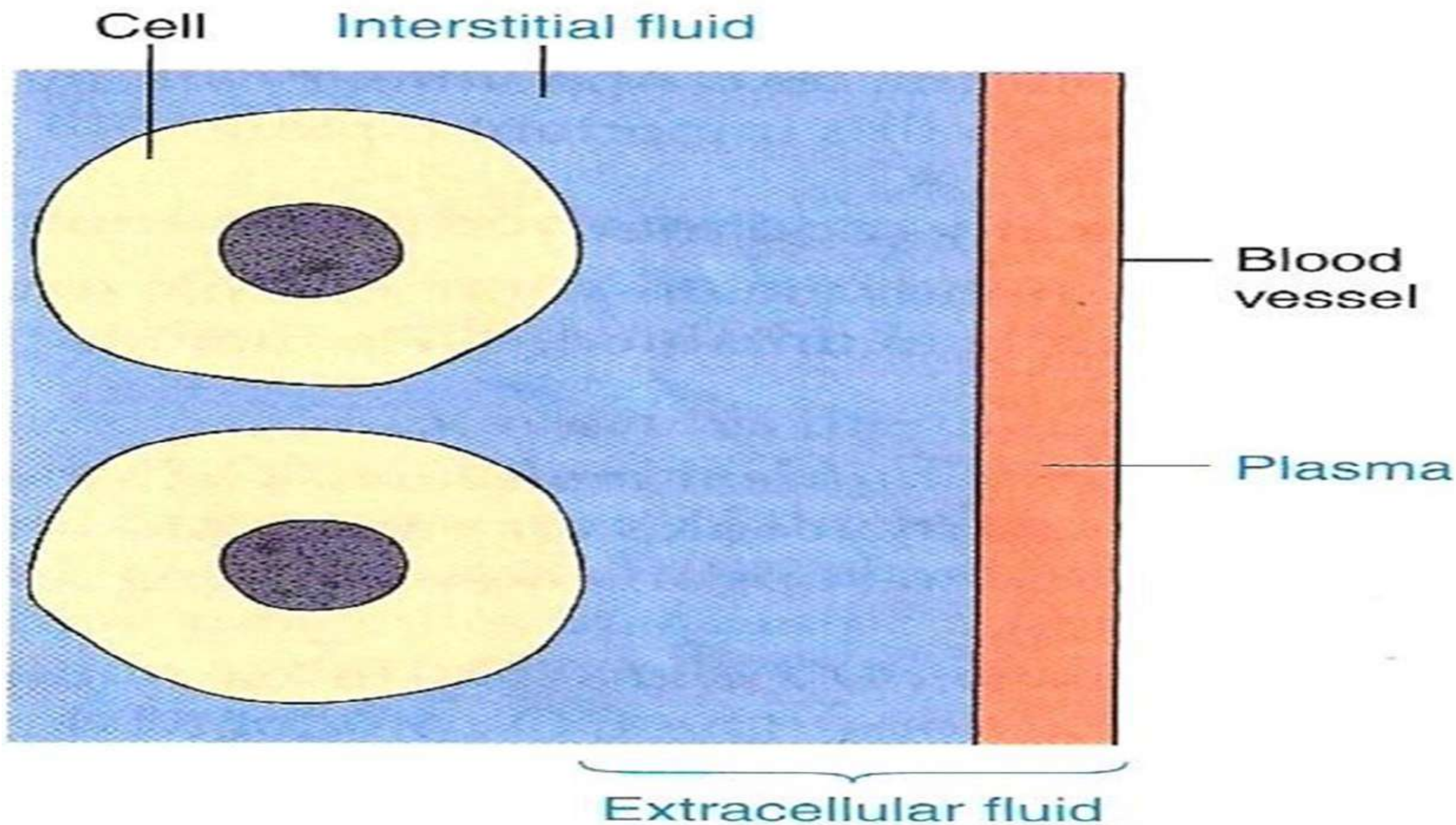
■ The **fluid collectively** contained **within** all body cells is called **intracellular fluid (ICF).**

■ The **fluid outside** the cells is called **extracellular fluid (ECF).** The ECF is **outside** the cells but **inside** the body. Thus, the ECF is the internal environment of the body. You live in the external environment; your cells live in the body's internal environment.

Concepts of Homeostasis

- **ECF** is **made up** of **2 components**: the **plasma** (the fluid portion of the blood) and the **interstitial fluid** (which surrounds and bathes the cells). No matter **how remote** a cell is from the external environment, it can make life-sustaining exchanges with its own surrounding fluid. In turn, particular body systems accomplish the transfer of materials between the external environment and the internal environment so that the composition of the internal environment is appropriately maintained to support the life and functioning of the cells.

The Internal environment of the body



Concepts of Homeostasis

■ **For example**, the digestive system **transfers** the nutrients required by all body cells from the external environment into the plasma. Likewise, the respiratory system **transfers** O_2 from the external environment into the plasma. The circulatory system **distributes** these nutrients and O_2 throughout the body. Materials are thoroughly mixed and exchanged between the plasma and the interstitial fluid across the capillaries (the smallest and thinnest of blood vessels).

Concepts of Homeostasis

■ As a result, the nutrients and O_2 (originally obtained from the external environment) are delivered to the interstitial fluid, from which the body cells **pick up** these needed supplies.

■ Similarly, wastes (produced by the cells) are released into the interstitial fluid, **picked up** by the plasma, and **transported** to the organs that specialize in **eliminating** these wastes from the internal environment to the external environment. The lungs **remove** CO_2 from the plasma, and the kidneys **remove** other wastes for **elimination** in the urine.

Concepts of Homeostasis

- **Thus, a body cell takes in essential nutrients from its watery surroundings and eliminates wastes into these same surroundings, just as an amoeba does. The main difference is that each body cell must help maintain the composition of the internal environment so that this fluid continuously remains suitable to support the existence of all body cells. In contrast, an amoeba does nothing to regulate its surroundings.**

Concepts of Homeostasis

Negative feedback opposes an initial change and is widely used to maintain homeostasis:

■ Homeostatic control mechanisms **operate** primarily on the principle of **negative** feedback to **resist** change. In negative feedback, a change in a homeostatically controlled factor **triggers** a response that seeks to restore the factor to normal by **moving** the factor in **the opposite direction** of its initial change (a corrective adjustment opposes the original deviation from the normal desired level).

Concepts of Homeostasis

■ **A common example** of negative feedback is control of room temperature. Room temperature is a controlled variable (a factor that can vary but is held within a narrow range by a control system). In our example, the control system includes a thermostat, a furnace (a heat source that can be turned on or off), and all their electrical connectons. The room temperature is determined by the activity of the furnace.

Concepts of Homeostasis

■ To switch **on** or **off** appropriately, the control system as a whole must **“know”** what the actual room temperature is, **“compare”** it with the desired room temperature, and **“adjust”** the output of the furnace to bring the actual temperature to the desired level. A thermometer in the thermostat provides information about the actual room temperature. The thermometer is **the sensor**, which **monitors** the magnitude of the controlled variable. The sensor converts the original information about a change into a “language” that the control system can “understand”.

Concepts of Homeostasis

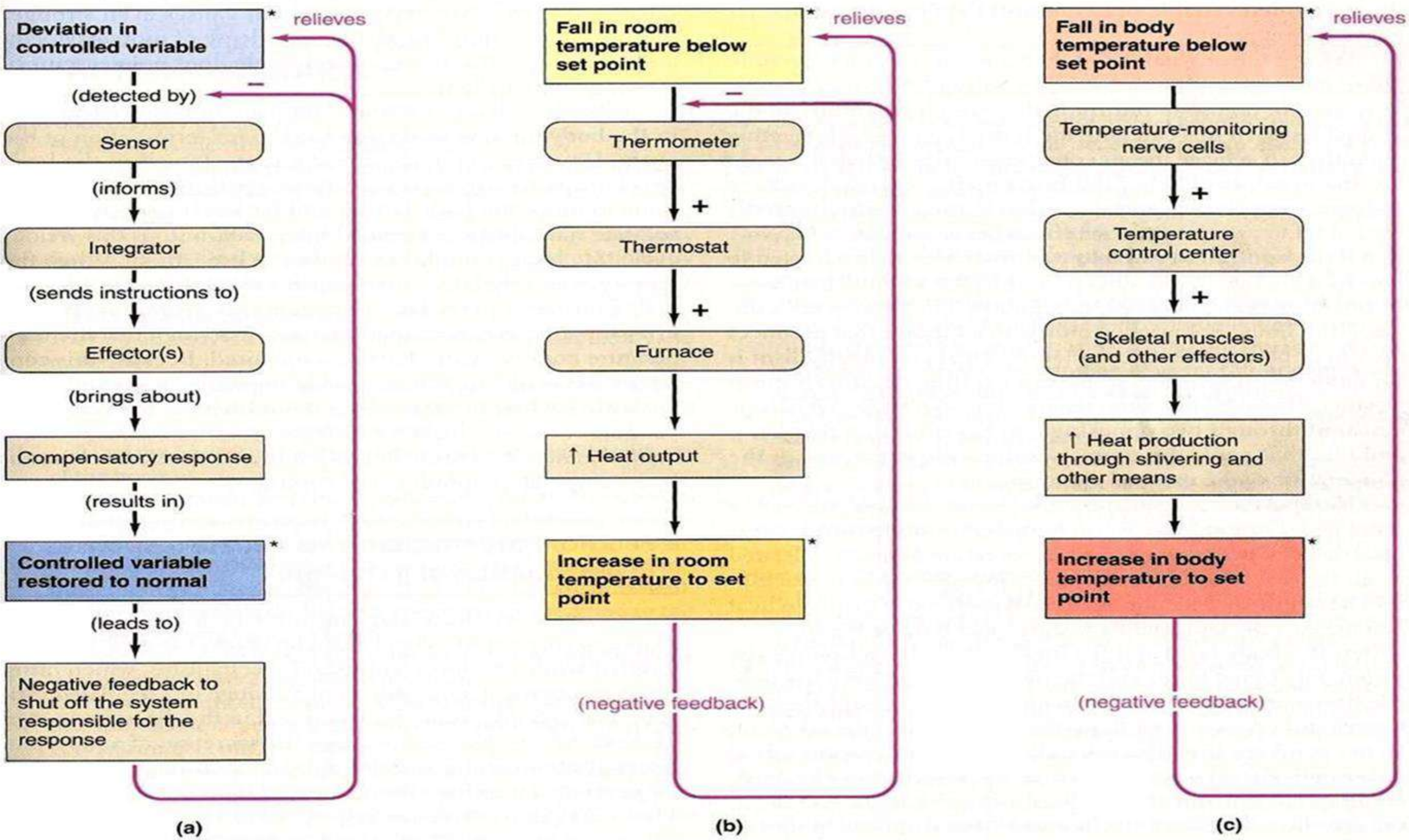
- For e.g., the thermometer converts the magnitude of the air temperature into **electrical impulses**. This message serves as the input into the control system. The thermostat setting provides the desired temperature level (or set point). The thermostat acts as an **integrator** (or control center): It **compares** the sensor's input with the set point and **adjusts** the heat output of the furnace to bring about the appropriate response to **oppose** a deviation from the set point. **The furnace** is the **effector** (the component of the control system commanded to bring about the desired effect.)

Concepts of Homeostasis

● FIGURE 1-7

Negative feedback

(a) Components of a negative-feedback control system. (b) Negative-feedback control of room temperature. (c) Negative-feedback control of body temperature.



- Let us look at a typical negative-feedback loop. For e.g., if the room temperature **falls below** the set point because it is **cold outside**, the thermostat (through connecting circuitry) **activates** the furnace, which produces heat to raise the room temperature. Once the room temperature reaches the set point, the thermometer no longer **detects** a deviation from that point. As a result, the activating mechanism in the thermostat and the furnace are switched off. Thus, the heat from the furnace **counteracts**, or is “negative” to, **the original fall** in temperature.

■ If the heat-generating pathway were **not** shut off once the target temperature was reached, heat production would continue and the room would get hotter and hotter. Overshooting the set point **does not** occur because the heat "feeds back" to shut off the thermostat that triggered its output. Thus, a negative-feedback control system **detects** a change away from the ideal value in a controlled variable, **initiates** mechanisms to correct the situation, and then shuts itself off. In this way, the controlled variable **does not** drift too far above or below the set point.

Concepts of Homeostasis

■ What if the original deviation is **a rise** in room temperature above the **set point** because it is **hot outside**? A heat-producing furnace is of **no use** in returning the room temperature to the desired level. An opposing control system involving **a cooling air conditioner** is needed to reduce the room temperature. In this case, **the thermostat**, through connecting circuitry, **activates** the **air conditioner**, which **cools** the room air (the opposite effect from that of the furnace).

Concepts of Homeostasis

■ In negative-feedback fashion, once the set point is reached, the air conditioner is turned off to prevent the room from becoming too cold. Note that if the controlled variable can be deliberately adjusted to **oppose** a change in one direction **only**, the variable can move in an uncontrolled fashion in the opposite direction. For example, if the house is equipped **only** with a furnace that produces heat to oppose a fall in room temperature, there is **no mechanism** is available to prevent the house from getting too hot in warm weather.

Concepts of Homeostasis

■ However, the room temperature can be kept relatively constant through **two opposing mechanisms**, **one** that **heats** and **one** that **cools** the room, despite wide variations in the temperature of the external environment.

Concepts of Homeostasis

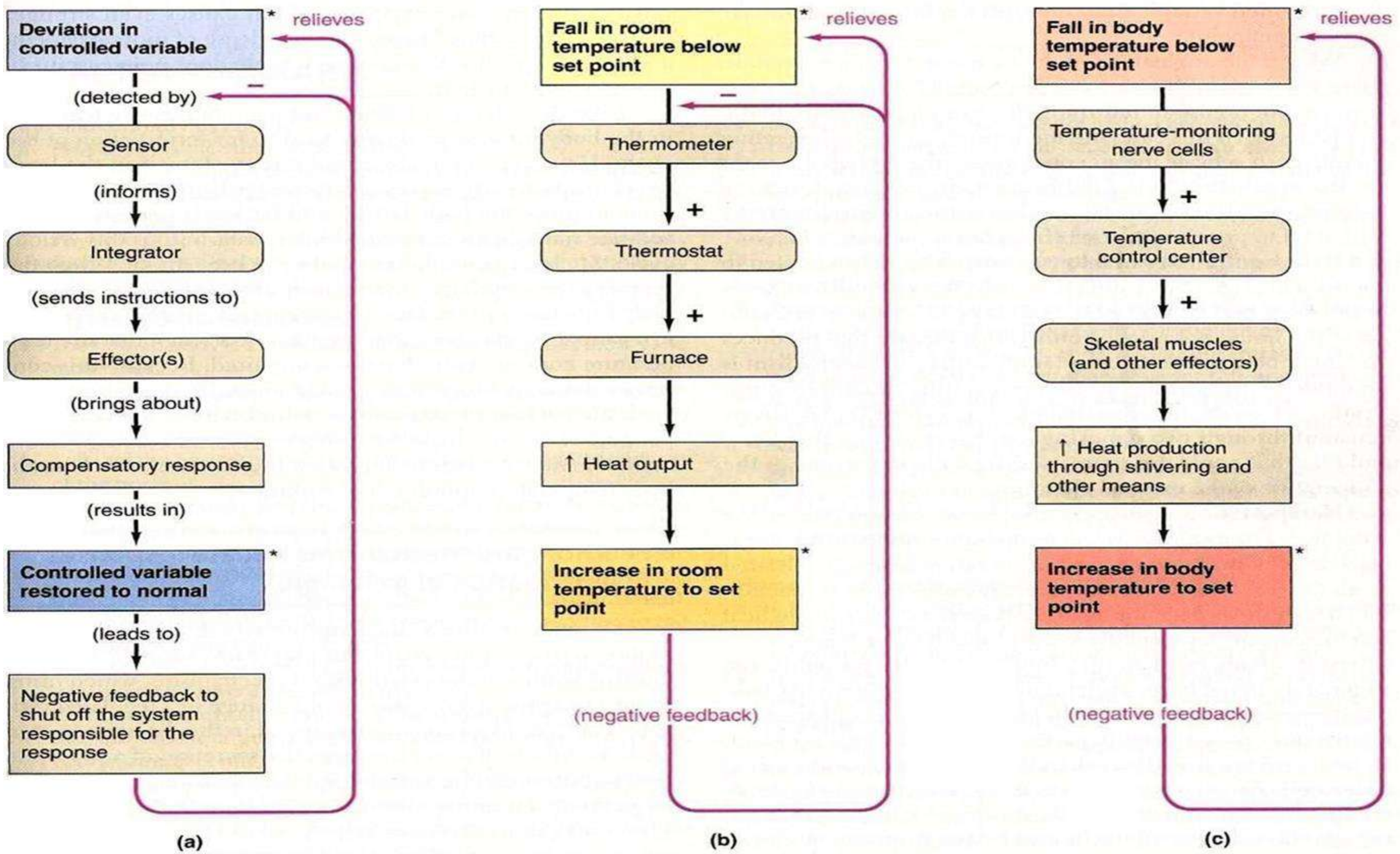


FIGURE 1-7

Negative feedback

(a) Components of a negative-feedback control system. (b) Negative-feedback control of room temperature. (c) Negative-feedback control of body temperature.

Concepts of Homeostasis

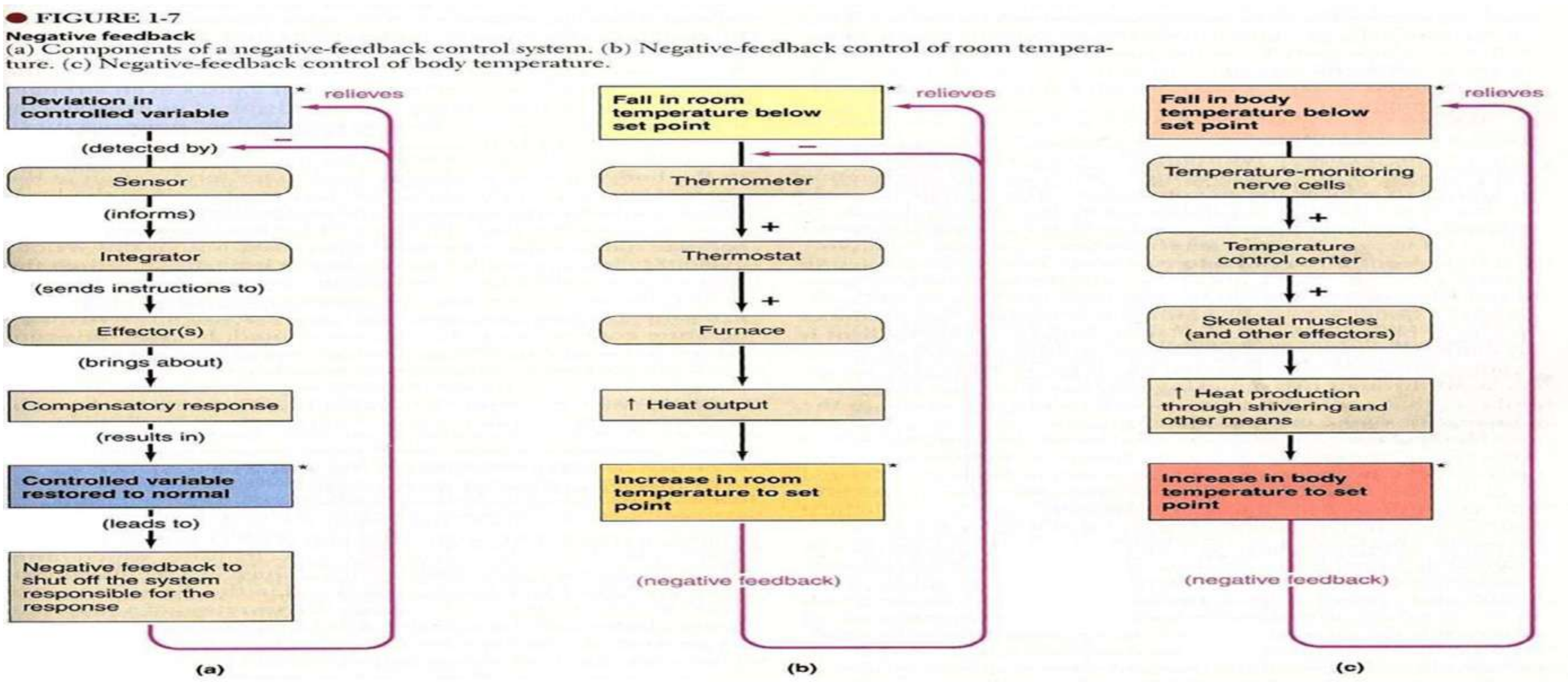
■ Homeostatic negative-feedback systems in **the human body** operate in **the same way**. For example, when temperature- monitoring nerve cells **detect a decrease** in body temperature **below** the desired level, **these sensors signal the temperature control center** in the brain, which begins a sequence of events that ends in responses, such as **shivering**, that generate heat and **raise** the temperature to the proper level.

Concepts of Homeostasis

■ When the body temperature reaches the set point, the temperature-monitoring nerve cells **turn off** the stimulatory signal to the skeletal muscles. As a result, the body temperature **does not** continue to increase **above** the set point. Conversely, when the temperature-monitoring nerve cells **detect** a rise in body temperature **above** normal, cooling mechanisms such as sweating are called into play to **lower** the temperature to normal.

Concepts of Homeostasis

- When the temperature reaches the set point, the cooling mechanisms are **shut off**. As with body temperature, opposing mechanisms can move most homeostatically controlled variables in **either** direction as needed.



Positive feedback amplifies an initial change

■ With **positive** feedback, the output **enhances** or **amplifies** a change so that the controlled variable **continues** to move in the direction of the initial change. Such action is comparable to the heat generated by a furnace triggering the thermostat to call for even more heat output from the furnace so that the room temperature would **continuously** rise. Because the major goal in the body is to maintain stable, homeostatic conditions, positive feedback **does not** occur nearly **as often as** negative feedback.

- Positive feedback plays an important role in certain instances, however, as in the birth of a baby. **The hormone oxytocin** causes powerful contractions of the uterus.
- As the contractions **push** the baby against the cervix (the exit from the uterus), the resultant stretching of the cervix triggers a sequence of events that brings about the release of even more oxytocin, which causes even stronger uterine contractions, triggering the release of more oxytocin, and so on.

■ This positive-feedback cycle **does not stop** until the baby is finally born. Likewise, all other **normal** instances of positive-feedback cycles in the body include some mechanism for stopping the cycle.

Feed-forward mechanisms initiate responses in anticipation of a change:

■**The** body **less frequently** uses **feed-forward mechanisms**, which respond in anticipation of a change in a regulated variable

Concepts of Homeostasis

■ For example, when a meal is still in the digestive tract, a feed-forward mechanism **increases** secretion of a hormone (insulin) that will promote the cellular uptake and storage of ingested nutrients after **they** have been absorbed from the digestive tract. This anticipatory response helps limit the rise in blood nutrient concentration after nutrients have been absorbed.

Concepts of Homeostasis

Disruptions in homeostasis can lead to illness and death**:** Despite control mechanisms, when one or more of the body's systems **malfunction**, **homeostasis** is **disrupted** and all cells **suffer** because they **no longer** have an optimal environment in which to live and function. Various pathophysiological states develop, depending on the type and extent of the disruption. **Pathophysiology** is the abnormal functioning of the body associated with disease. When a homeostatic disruption is **so severe** and **not** compatible with survival, death **results.**

Human Physiology I
Second Year Pharmacy Students
Chapter 1: Introduction to Physiology and Homeostasis Part II

Dr. Mohammed Shbair

Faculty of Pharmacy

Al-Azhar University of Gaza

First Semester 2020/2021

Concepts of Homeostasis

Body systems maintain **homeostasis** (a dynamic steady state in the internal environment).

■ Body cells can live and function **only** when the ECF is compatible with their survival; thus, the chemical composition and physical state of this internal environment must be **maintained** within **narrow limits.**

■ As cells **take up** nutrients and O_2 from the internal environment, these nutrients must **constantly** be replenished. Likewise, wastes must **constantly** be removed from the internal environment so that they **do not** reach toxic levels.

Concepts of Homeostasis

■ Other aspects of the internal environment **important** for maintaining life (such as temperature) also must be kept relatively constant.

■ Maintenance of a relatively stable internal environment is termed **homeostasis** (*homeo* means "similar"; *stasis* means "to stand or stay"). The functions performed by each body system **contribute** to homeostasis, thereby maintaining within the body the environment required for the survival and function of all cells. Cells, in turn, **make up** body systems.

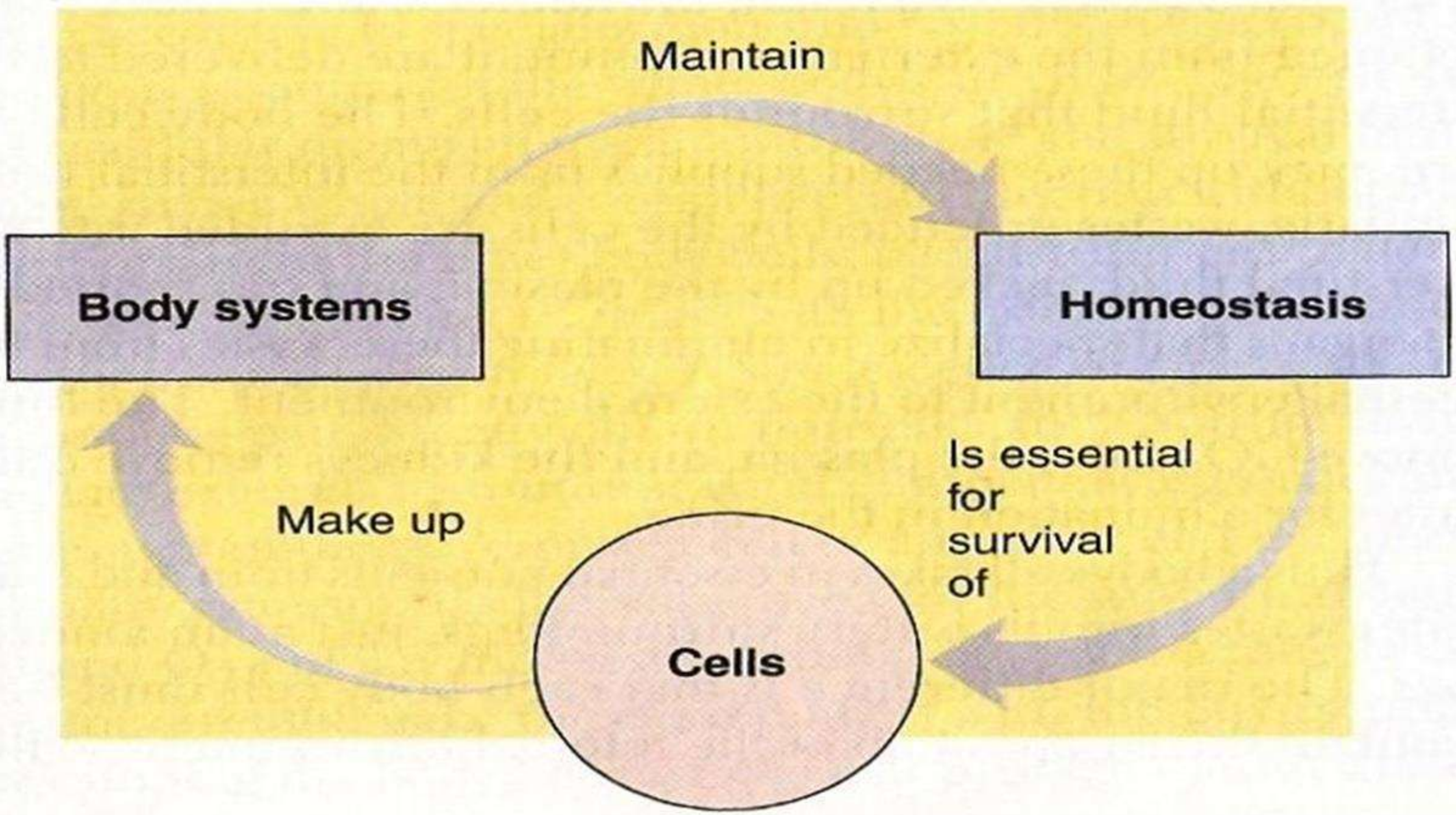
Concepts of Homeostasis

- This is the central theme of physiology: Homeostasis is essential for the survival of each cell, and each cell, through its specialized activities (as part of a body system), helps maintain the internal environment shared by all cells.

Concepts of Homeostasis

FIGURE 1-5

Interdependent relationship of cells, body systems, and homeostasis The depicted interdependent relationship serves as the foundation for modern-day physiology: *homeostasis is esssential for the survival of cells, body systems maintain homeostasis, and cells make up body systems.*



Concepts of Homeostasis

■The internal environment must be kept relatively stable, but this **does not** mean that its composition, temperature, and other characteristics are absolutely unchanging. **Both** external and internal factors continuously threaten to **disrupt** homeostasis.

■ When any factor starts to **move** the internal environment **away** from optimal conditions, the body systems **initiate** appropriate counter-reactions to **minimize** the change

Concepts of Homeostasis

■ For example, exposure to a cold environmental temperature (an external factor) tends to **reduce** the body's internal temperature. In response, the temperature control center in the brain **initiates** compensatory measures (such as **shivering**) to **raise** body temperature to normal. By contrast, production of extra heat by working muscles during exercise (an internal factor) tends to **raise** the body's internal temperature. In response, the temperature control center brings about **sweating** and other compensatory measures to **reduce** body temperature to normal.

Concepts of Homeostasis

- Thus, homeostasis is **not** a **rigid, fixed state** but **a dynamic steady state** in which the changes that occur are **minimized** by compensatory physiological responses.
- The term **dynamic** refers to each homeostatically regulated factor being marked by continuous change, whereas steady state implies that these changes **do not** deviate **far** from a constant, (or steady) level. Small fluctuations around the optimal level for each factor in the internal environment are normally kept within the narrow limits compatible with life.

Concepts of Homeostasis

■ **Some** compensatory mechanisms are immediate, transient responses to a situation that **moves** a regulated factor in the internal environment **away** from the desired level, whereas **other** compensatory mechanisms are **more long-term adaptations** that take place in response to prolonged or repeated exposure to a situation that **disrupts** homeostasis. Long-term adaptations make the body **more efficient** in responding to an ongoing or repetitive challenge.

Homeostatically Regulated Factors

■ Many factors of the internal environment must be homeostatically maintained. They include the following:

1. Concentration of nutrients: Cells need a constant supply of nutrients for energy production that is needed to **support** basic and specialized cell activities.

2. Concentration of O_2 and CO_2: Cells need O_2 to produce energy, and the CO_2 produced must be removed, so that the acidity of the internal environment **does not increased.**

Concepts of Homeostasis

3. Concentration of waste products: Some waste products have a toxic effect on body cells if they accumulate.

4. pH: Changes in the pH of the ECF **adversely** affecting nerve cell function and the enzyme activity of all cells.

5. Concentrations of water, salt, and other electrolytes: Because the concentrations of salt and water in ECF influence how much water **enters** or **leaves** the cells, these concentrations are carefully regulated to **maintain** the proper volume of the cells.

Concepts of Homeostasis

■ Cells **do not** function **normally** when they are swollen or shrunken. Other electrolytes perform a variety of vital functions (e.g., the rhythmic beating of the heart depends on a relatively constant concentration of K^+ in the ECF).

6. Volume and pressure: The circulating component of the internal environment (the plasma) must be maintained at adequate volume and blood pressure to ensure body-wide distribution of this important link between the external environment and the cells.

Concepts of Homeostasis

7. Temperature: Body cells function best within a narrow temperature range. If cells are **too cold**, their functions **slow down** too much; if they get **too hot,** their structural and enzymatic proteins are impaired or destroyed.

Homeostatic Control Systems

■ A homeostatic control system is a functionally interconnected network of body components that operate to maintain a given factor in the internal environment **relatively constant** around an optimal level.

■To maintain homeostasis, the control system must be able to:

(1) **detect** deviations from normal in the internal environmental factor that needs to be remain within narrow limits.

Concepts of Homeostasis

(2) **integrate** this information with any other relevant information; and

(3) **make** appropriate adjustments in the activity of the body parts responsible for **restoring** this factor to its desired value.

■ **Homeostatic control systems may operate locally or body wide:** Homeostatic control systems can be grouped into 2 classes: **intrinsic** (local) and **extrinsic** controls.

1. Intrinsic controls are built into or are inherent in an organ. For e.g., as an exercising skeletal muscle rapidly **uses up O_2** to generate energy to support its contractile activity, the **O_2 concentration within** the muscle **falls**. This local chemical change **acts** directly on the smooth muscle in the walls of the blood vessels supplying the exercising muscle, causing the smooth muscle to **relax** so that the vessels **dilate** (or open widely). As a result, increased blood **flows** through the dilated vessels into the exercising muscle, **bringing in more O_2**.

Concepts of Homeostasis

■ This local mechanism helps maintain an optimal level of $\mathbf{O_2}$ in the fluid **immediately** around the exercising muscle's cells.

2. However, **most** factors in the internal environment are maintained by **extrinsic** (or systemic) controls, which are regulatory mechanisms **initiated** outside **an organ** to alter the organ's activity. Extrinsic control of the organs and body systems is accomplished by the nervous and endocrine systems (the two major regulatory systems).

Concepts of Homeostasis

■ **Extrinsic** control permits coordinated regulation of several organs **toward** a common goal; in contrast, **intrinsic** controls **serve only** the organ in which they occur. Coordinated, overall regulatory mechanisms are crucial for **maintaining** the dynamic steady state in the internal environment as a whole. For example, to **restore** blood pressure to the proper level when it **falls** too low, the nervous system acts simultaneously on the heart and blood vessels throughout the body to **increase** blood pressure to normal.

Concepts of Homeostasis

- To **stabilize** the physiological factor being regulated, homeostatic control systems must be **able** to **detect** and **resist** change.
- The term **feedback** refers to **responses** made **after** a change has been detected.
- the term **feed forward** refers to **responses** made in **anticipation** of a change.