1: HOMEOSTASIS: A FRAMEWORK FOR HUMAN PHYSIOLOGY

LECTURE OUTLINE

1.1 The Scope of Human Physiology
1.2 How Is the Body Organized?
- Muscle Cells and Tissue
- Neuron and Nervous Tissue
- Epithelial Cells and Epithelial Tissue
- Connective-Tissue Cells and Connective Tissue
- Organs and Organ Systems

1.3 Body Fluid Compartments
1.4 Homeostasis: A Defining Feature of Physiology
1.5 General Characteristics of Homeostatic Control Systems
- Feedback Systems
- Resetting of Set Points
- Feedforward Regulation

1.6 Components of Homeostatic Control Systems
- Reflexes
- Local Homeostatic Responses

1.7 The Role of Intercellular Chemical Messengers in Homeostasis
1.8 Processes Related to Homeostasis
- Adaptation and Acclimatization
- Biological Rhythms
- Balance of Chemical Substances in the Body

1.9 General Principles of Physiology

CHAPTER OVERVIEW

An understanding of homeostasis is essential to the successful mastery of physiology. It is one of the unifying concepts of physiology. Even though the systems of the body are presented in discrete chapters throughout this text, they are all inextricably linked by their role in maintaining the constant internal environment of the body. This chapter will provide the framework for understanding human physiological function by introducing general concepts related to homeostasis as well as other foundational concepts such as the levels of structural organization, body fluid compartments, and the different categories of intercellular chemical messengers.

CONTEXT FOR CHAPTER 1

The following concepts are essential for students to master in order to understand human physiological function and will appear in numerous contexts throughout the text and the study of each organ system:

1. **Levels of Organization and Tissue Types**: Students should understand the levels of organization (structural hierarchy of the human body) and that all changes in organ system/organismal function are due to the sum of changes occurring at lower levels.
2. **Body Fluid Compartments**: On average, the water content of the human body is ~55-60% of a person's body weight, or approximately 42 L for a 70 kg person. The majority of body water is located in the intracellular fluid compartment, while the remainder of water, located in the extracellular fluid compartment, is divided between what is located in the plasma volume and the interstitial fluid compartment.
3. **Homeostasis, Characteristics of Homeostasis, and Components of Homeostatic Control Systems:** It is essential for physiology students to identify the components of a homeostatic reflex arc and explain the sequence of events that occur to restore a variable under homeostatic control to its normal physiological range should it be too high/too low.
4. **Intercellular Chemical Messengers and Their Role in Promoting Homeostasis**: Communication between different areas of the body is essential for the maintenance of homeostasis. Intercellular chemical messengers can relay physiological information long distances in the body (neurotransmitters, hormones) or short distances (autocrine/paracrine agents).
5. **Processes Related to Homeostasis**: Variables under homeostatic control might operate around different set points at different times or in different situations, due to the processes of adaptation, acclimatization, and biological rhythms. Another important concept for students to understand is the balance of chemical substances in the body and the factors that can increase/decrease it, and what it means to be in positive, negative, or stable balance.
6. **General Principles of Physiology**: This is an introduction to the eight general principles of physiology to be highlighted in the study of each organ system in upcoming chapters of the text.

CONCEPTS COMMONLY FOUND TO BE CHALLENGING – TEACHING HINTS

1. When studying (human) physiology, many students equate "success" (i.e., earning the desired grade) to memorization of the outwardly-appearing effect (e.g., the amount of urine formed, which can be directly measured) rather than truly understanding how the human body functions. It is often challenging for students to think in terms of **integrated physiological function**, and that the overall outward effect is the sum of numerous intracellular changes in physiological function. For example, the amount of voided urine is dependent upon events that occur within the ~1 million nephrons (the functional units of the kidney). Nephron function is influenced by the characteristics of the epithelial layer that separates the lumen of the nephron from the interstitial space, the smooth muscle cells associated with the nephron, inputs from the sympathetic branch of the nervous system, and other inputs. All of these factors work together to determine the amount of urine formed by individual nephrons, to be transported into the collecting ducts to the renal pelvis, from the kidneys to the bladder via the ureters, and then expelled from the body via the urethra. Sometimes more urine is formed and sometimes less, depending on what is necessary for homeostatic regulation of body fluid composition and specifically the plasma volume.
2. Students frequently do not carefully review the figures associated with the text. They tend to try to memorize the specific information presented in the text rather than critically evaluating the processes described. It is helpful to remind students that if a concept is important, generally there will be a figure associated with it. Going along with that, encourage students to carefully review Fig. 1.5—it provides the framework for many flow charts and diagrams presented throughout the remainder of the text.
3. It is common for many students currently enrolled in a physiology course to have completed other basic science courses, and they frequently have a rudimentary appreciation for individual concepts related to human function. Conceptualization that many different physiological processes are occurring at the same time, or in different locations of the body, tend to be more difficult for students to understand. Likewise, one concept that many students express difficulty in understanding, at least initially, is the balance of substances in the body and specifically the concept of a "pool" of a particular substance that is available for distribution. It is helpful to review mechanisms for negative balance, positive balance, and how a substance that is part of the pool can be reversibly stored in body tissues or converted to other molecules. It is also useful to provide

a concrete example of how these processes work, for example amino acids and proteins.

TEACHING/LEARNING OBJECTIVES BY SECTION

1.1 The Scope of Human Physiology

Students should be able to:

- Identify physiology as the study of the *function* of living things.
- Explain the concept of integrated physiological function and how the function of the whole body can be attributed to numerous internal processes.
- Define the term *pathophysiology*.
- Recognize that knowledge of normal physiological function is necessary for understanding and treating pathophysiologies.

1.2 How Is the Body Organized?

Students should be able to:

- Recognize that all cells have common functions that are essential for life.
- Distinguish between cell division and cell differentiation.
- List the four basic cell and tissue types.
- Describe the organizational hierarchy of humans: cells—tissues—organs—organ systems.
- Describe the locations, specialized functions, and unique structures associated with the four basic cell and tissue types.
- Describe the composition and function of the extracellular matrix.
- Recognize the eleven organ systems of the body and their primary functions.
- Define *functional unit* and provide examples.

1.3 Body Fluid Compartments

Students should be able to:

- Discuss the distribution of total body water into intracellular fluid and extracellular fluid (ECF), and the two components of the ECF.
- Explain the concept of *compartmentalization* and recognize the importance of barriers between compartments that maintain the differences in composition of the various body fluids.

1.4 Homeostasis: A Defining Feature of Physiology

Students should be able to:

- Define *homeostasis*, not as a rigidly fixed condition, but as one that fluctuates within a predictable and often narrow range.
- Provide examples of physiological processes that are under homeostatic control.
- Define *dynamic constancy* and discuss the advantage of making measurements over a 24-hour period.
- Recognize that one physiological variable may be homeostatic but others may not be.

1.5 General Characteristics of Homeostatic Control Systems

Students should be able to:

- Compare and contrast *steady state* and *equilibrium.*
- Define *set point.*
- Describe how homeostasis is achieved by balancing inputs and outputs.
- Define two types of homeostatic control systems: negative feedback and positive feedback systems.
- Contrast negative feedback mechanisms that operate to negate (undo) change—i.e., to bring a changed variable back *toward* its original set point, with positive feedback, which exacerbates change and leads to something "explosive," i.e., blood clotting.
- Recognize that the set points for regulated variables can be "reset" under different physiological conditions, such as fever.
- Discuss the adaptive value of feedforward regulation in conjunction with negative feedback for homeostatic control.

1.6 Components of Homeostatic Control Systems

Students should be able to:

- Provide a physiological definition for the term *reflex* as it refers to homeostasis and distinguish between a basic reflex and a learned (acquired) reflex.
- List the components of the reflex arc—stimulus, receptor, afferent pathway, integrating center, efferent pathway, effectors, response—and how they interact.
- Recognize that if the effect of a reflex is to change the magnitude of the original stimulus, then the reflex is a homeostatic control system.

- Relate the components of a reflex arc to the homeostatic control of body temperature.
- Describe the roles of neurons and endocrine cells as receptors and integrating centers, of hormones and nerves as afferent and efferent pathways, and of gland and muscle as effectors. (Students should appreciate that the pathway for hormones is the blood of the circulatory system that distributes the chemical messengers.)
- Differentiate between *reflexes* and *local homeostatic responses*.

1.7 The Role of Intercellular Chemical Messengers in Homeostasis

Students should be able to:

- List the four types of intercellular chemical messengers that facilitate communication between different areas of the body.
- Define and differentiate among *hormones* (endocrine agents), *neurotransmitters*, *paracrine substances*, and *autocrine substances*.
- Recognize that the same chemical messenger can be released by three different cells and act as a hormone, neurotransmitter, or paracrine/autocrine substance.
- Describe two ways in which chemical messengers do not have to enter the extracellular fluid to exert their effect.

1.8 Processes Related to Homeostasis

Students should be able to:

- Compare and contrast *adaptation* and *acclimatization.*
- Recognize that biological rhythms are internal, body-controlled cycles that may be entrained by environmental cues.
- Relate circadian rhythms (*circa-*"about"; *dian-*"day") to feedforward regulatory mechanisms.
- Recognize how environmental cues modify (*entrain*) the rhythm but do not drive the rhythm.
- Define a free running rhythm as one that continues in the absence of environmental cues.
- Provide three examples of environmental cues that may influence biological rhythms.
- Describe how a *phase-shift* of the circadian rhythm accounts for jet lag.
- Name the location and function of the pacemaker (the internal time clock).
- Define the *pool* of a substance as the amount available for use and recognize that the substance can be added to or removed from the pool.

- Understand that the homeostatic *balance* of substances in the body depends upon the relative rates of net gain and loss.
- Identify mechanisms for net gain of a substance (i.e., how the amount of a substance found in the body can increase); next, identify mechanisms for net loss of a substance (i.e., how the amount of a substance can be reduced).
- Describe how changing inputs and outputs of the substances can induce negative, positive, or stable balance.

1.9 General Principles of Physiology

Students should be able to:

- Identify the eight general principles of physiology and appreciate that each one is a cornerstone to human physiological function.

CHAPTER 1 ADDITIONAL STUDENT LEARNING QUESTIONS & ANSWERS

1. Describe the levels of cellular organization and state the four major types of specialized cells and tissues.
   Cells divide and differentiate into four specialized types—muscle cells, neurons, epithelial cells, and connective tissue cells. Corresponding to the four general categories of differentiated cells, there are four general types of tissues: muscle tissue, nervous tissue, epithelial tissue, and connective tissue. The differentiated cells with similar properties aggregate to form tissues; tissues in combination form organs, many with discreet functional units. Organ systems consist of groups of organs that, in combination, perform a specific function in the body.

2. List the organ systems of the body and give one-sentence descriptions of their functions.
   Circulatory: Transports blood (and the substances carried in the blood) throughout the body.
   Digestive: Digests and absorbs nutrients and water; eliminates wastes.
   Endocrine: Regulates and coordinates many activities in the body.
   Immune: Defends the body against pathogens, returns interstitial fluid to the blood, and forms white blood cells.
   Integumentary: Protects the body against injury, dehydration, and pathogens; helps regulate body temperature.
   Lymphatic: Collects extracellular fluid for return to circulation. Participates in immune defenses.

Musculoskeletal: Supports and protects the body and allows for body movement; produces blood cells.
Nervous: Regulates and coordinates many activities of the body; detects and responds to changes in the internal and external environments; allows for states of consciousness, learning, memory, emotions, etc.
Reproductive: Produces germ cells (eggs in females, sperm in males); in females, provides a nutritive environment for the developing embryo and fetus, and nutrition for the infant after birth.
Respiratory: Exchanges oxygen from the air with carbon dioxide to and from the cells of the body by means of the blood and helps to regulate hydrogen ion concentration in the body fluids.
Urinary: Regulates the plasma concentration of minerals and water and excretes organic wastes.

3. Name the two fluids that constitute the extracellular fluid. What are their relative proportions in the body?
The extracellular fluid compartment is comprised of the interstitial fluid and blood plasma, which together account for one-third of the total-body water. The interstitial fluid volume is nearly four times greater in volume than the plasma (75-80% of ECF or 11 L vs. 20-25% of ECF or 3 L,).

4. What is one way in which the composition of intracellular and extracellular fluids differ?
The intracellular fluid contains many different proteins that help regulate cellular events such as growth and metabolism; these proteins are found intracellularly and not in the extracellular fluid compartment.

5. Describe several important generalizations about homeostatic control systems, including the difference between steady state and equilibrium.
Homeostatic control systems perform regulatory responses to preserve relatively stable conditions of the internal environment. The term steady state implies that a variable is actively maintained around a particular set point whereas the term equilibrium refers to a variable that is relatively constant but does not require the input of energy in order to maintain at that level. Important generalizations include:
(1) Stability of an internal environmental variable is achieved by the balancing of inputs and outputs. It is not the absolute magnitudes of the inputs and outputs that matter, but the balance between them. (2) In negative feedback, a change in the variable being regulated brings about responses that tend to move the variable in the direction opposite the original change—i.e., back toward the initial value or set point. (3) Homeostatic

control systems cannot maintain constancy of any given feature of the internal environment in the face of continued change in the external environment, but can only minimize changes. Therefore, any regulated variable will have a more-or-less narrow range of normal values depending upon environmental conditions. (4) The set point of some variables regulated by homeostatic control systems can be reset—i.e., physiologically raised or lowered. (5) It is not always possible for everything to be maintained within a narrow normal range by homeostatic control systems. There is a hierarchy of importance, such that certain variables may be altered markedly to maintain others within their normal range.

6. Contrast feedforward, positive feedback, and negative feedback.
   Feedforward regulation initiates an adaptive response in the body in anticipation of a change in the environment. Feedforward regulation happens before homeostasis has been disrupted and helps to minimize fluctuations and speed up the response. Positive feedback also occurs in response to a change in a controlled variable; the original change initiates a cascade of physiological events that increase the magnitude of the variable away from its set point. Over time, the events associated with positive feedback will contribute to the restoration of normal physiological function. Negative feedback occurs only after there has been a change in the internal or external environment so that the controlled variable is outside of its normal physiological range. Negative feedback mechanisms come into play to elicit a response that restores the variable toward its original set point.

7. List the components of a reflex arc.
   Stimulus, receptor, afferent pathway, integrating center (compare to set point), efferent pathway, effectors

8. What is the basic difference between a local homeostatic response and a reflex?
   In a reflex, nerves or hormones act as the afferent and efferent pathways and facilitate communication between different areas of the body. These long-distance communication mechanisms are unnecessary for local homeostatic responses.

9. List the general categories of intercellular messengers and briefly describe how they differ.
   N*eurotransmitters, hormones, and autocrine/paracrine substances. Neurotransmitters and hormones both promote communication between areas of the body that may not be in close proximity. Autocrine and paracrine substances act locally; they are released by one cell (or groups of cells) and will cause changes in cellular function in the same cell from which they are secreted or in adjacent cells, respectively.*

10. Describe the conditions under which acclimatization occurs. Are acclimatizations passed on to a person's offspring?
Acclimatization is an improved ability to respond to an environmental stress and is induced by prolonged exposure to the stress. If it occurs early in life, it may be irreversible, and thus is known as a developmental acclimatization. Acclimatizations are not inheritable.

11. Define circadian rhythm. Under what conditions do circadian rhythms become free running?
Brain pacemakers internally drive circadian rhythms but they are entrained by environmental cues. In the absence of such cues they become free-running. For example, circadian rhythms run free when a person is maintained in constant darkness or constant light.

12. How do phase-shifts occur?
Phase-shifts are brought about by changes in environmental cues, such as experiencing a change in light-dark cycles because of a jet flight to a different time zone.

13. What is the most important environmental cue for entrainment of body rhythms?
The light-dark cycle

14. Draw a figure illustrating the balance concept in homeostasis.

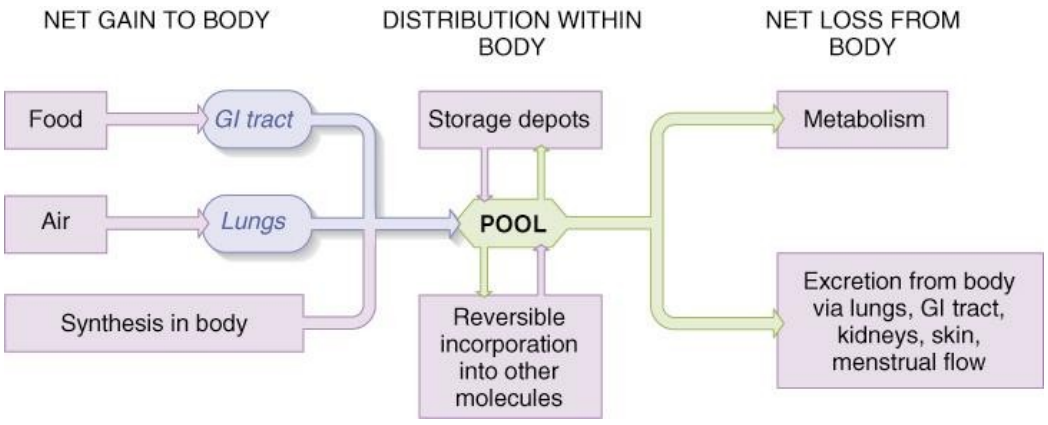

Fig. 1.12

15. Make and keep a list of the general principles of physiology. See if you can explain what is meant by each principle. To really see how well you've learned physiology at the end of your course, remember to return to the list you've made and try this exercise again at that time.

1. Homeostasis is essential for health and survival.

2. The functions of organ systems are coordinated with each other.

3. Most physiological functions are controlled by multiple regulatory systems, often working in opposition.

4. Information flow between cells, tissues, and organs is an essential feature of homeostasis and allows for integration of physiological processes.

5. Controlled exchange of materials occurs between compartments and across cellular membranes.

6. Physiological processes are dictated by the laws of chemistry and physics.

7. Physiological processes require the transfer and balance of matter and energy.

8. Structure is a determinant of—and has evolved with—function.