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TEXTBOOK OF PHYSIOLOGY

生理学

Original Editors

Eric P. Widmaier
Hershel Raff
Kevin T. Strang

Chief Editors of Adaptation Edition

Yan Jianqun （闫剑群）
Wu Bowei （吴博威）

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Preface for Adaptation Edition

The world is facing increasing globalization in different areas of our lives in the 21st century. With travel and communication as accessible as they are in the world today, it is clear the tendency of internationalization of education has become more and more obvious. This has taken effect on and it will continue to influence the medical education in China, including establishing the curricula which meet the global minimum essential requirements and standards. Textbooks, which are the carrier of knowledge, play an important role in teaching and learning process as an essential tool. So, in the purpose to realize what required by the time of 21st century for the medical professional with ability, it's very meaningful to compile a bilingual teaching material or textbook with new and rich content of current medical knowledge for medical students. **Physiology** is an important branch of biology, and **Physiology** is a main basic course for medical students. Based on current popular physiological textbooks or teaching materials, we try hard to compile a new and excellent bilingual textbook book for Chinese medical students. Also we have stayed true to the overall mission of this textbook, which is to present the topic of physiology in a sophisticated way that is suitable for all medical students to help them realize what required by modern medical education system.

According to the latest edition of Vander's ***Human Physiology*** by Eric P. Widmaier, et al.: 2005. Ed: 10th, which published by McGraw-Hill as well as other physiological textbooks published by McGraw-Hill, and many domestic textbooks of physiology , we arranged this book basing on original structure of Textbook of ***Physiology (Chinese Edition)***and mainly selected or compressed the content of original content of ***Human Physiology*** in order to be suitable for physiological teaching and learning activities. In this book, there are 12 chapters in the popular order of most Chinese textbooks of physiology. Review and thought questions at the end of each chapter will help students reviewing, understanding and learning more the content of that chapter. There is a Chinese-English glossary at the end of this book.

Original edition of ***Human Physiology*** is almost the authority of physiological textbooks with very new, advanced and intensive content. One of the strengths of the textbook is its thoroughness and clarity of presentation. So the pattern we used in compiling this book can keep the original structure, content, expressing form and thought of that book. We are very pleased to have an attempt on reforming the traditional teaching idea and patterns.

This book is suitable for foreign medical students studying in China, medical undergraduate students and graduate students as well as a reference tool book for medical researchers, medical educators and physicians.

The Editorial Committee of this book is composed of many domestic physiological professors from 9 universities, who have experience of studying or working in English-spoken countries with skillful literacy in English and rich experience in teaching human physiology. For the limit of time and some insufficiency, maybe there were some errors or careless omission. So, if any errors were found, please contact us and we would revised in next edition.

We wish to acknowledge the support and professionalism of the Science Press Publishing team associated with this textbook. I also wish to express my thanks to Xu Linping, Chen Ke, Zhang Yuan and Yang Xuejuan of Xi'an Jiaotong University School of Medicine, for their hard works in proofreading, figures and tables designing, and so on.

Yan Jianqun Wu Bowei

Jan. 15, 2006

改编版前言

人类社会已经进入一个新的发展时期，社会经济和科技文化活动已从区域局部走向全球范围。伴随经济和科技发展的全球化，教育国际化的趋势日趋明显。这种趋势已经并将继续从多个方面对我国的高等医学教育产生影响。包括建立与国际先进教育水平接轨、与全球医学教育基本标准内涵一致的课程体系与教学内容。教材是知识的载体，是教与学过程得以完成的基本工具。要达到21世纪对医学人才的要求，编写体裁新颖、内容丰富、反映现代最新知识的医学生双语教材，则具有非常重要的意义。生理学是生物学的重要分支，也是一门重要的医学基础课程。借鉴和参考国内外最新的优秀教材，编写一本适用于我国医学生培养目标和要求的双语生理学教材，正是本教材编委会力图实现的目标。

在科学出版社的指导下，本教材以McGraw-Hill出版公司最新出版的Vander's Human Physiology by Eric P. Widmaier, et al.: 2005, Ed:10th为蓝本，并参考该公司新版的其他生理学教科书及国内有关生理学教材，结合国内教学的实际和习惯，在内容编排上基本按照中文版《生理学》教材的编排顺序，在内容选择和编写方法上主要采用摘编或缩编方式，摘录的内容尽可能做到忠于英文原著，并进行有机组合和适当删改，以适合国内教学的要求。本教材共分为十二章，每章之后附有复习题和思考题，以便于学生复习、理解和进一步学习。在书末附有中英生理学名词对照，以便于检索和学习。

本教材的原版书具有高度权威性，在内容上体现了"新、精、深"。本教材的编写模式有利于保留原版教材的基本体裁、内容以及表述方式和思维方法，对于教材及教学理念的革新是一次新的尝试。

本教材可供在华留学生、国内五年制本科生及长学制医学生、研究生作为双语教材使用，亦可作为广大医学工作者的参考用书。

本教材编委由国内多所医学院校生理学专业的资深教授组成。编委均有英语国家留学或工作经历，具有良好的英语读写能力和丰富的教学经验。但由于时间

仓促和经验不足，书中难免存在错误或疏漏之处，恳请各院校的生理科学工作者和医学生给予批评指正和提出宝贵建议，以供今后修订时参考。

在本书编写过程中，西安交通大学医学院生理与病理生理学系许临平、陈坷、张源、杨雪娟等老师参与了部分文字校对、图表处理以及日常事务性工作，在此一并表示真诚的谢意。

闫剑群　吴博威

2006 年 1 月 15 日

CONTENTS

Chapter 1 Introduction

DEFINITION AND SCOPE OF PHYSIOLOGY

Physiology is the study of how living organisms work. As applied to human beings, it includes the study of individual molecules—for example, how a particular protein's shape and electrical properties allow it to function as a channel for sodium ions to move into or out of a cell. At the other end, it is concerned with complex processes that depend on the interplay of many widely separated organs in the body. For example, how the brain, heart, and several glands all work together to cause the excretion of more sodium in the urine when a person has eaten salty food. Physiologists are interested in function and integration—how parts of the body work together at various levels of organization and, most importantly, in the entire organism. Thus, even when physiologists study parts of organisms, all the way down to individual molecules, the intention is ultimately to apply the information they gain to the function of the whole body.

In this regard, a very important point must be made about the present and future status of physiology. It is easy for a student to gain the impression from a textbook that almost everything is known about the subject, but nothing could be farther from the truth for physiology. Many areas of function are still only poorly understood.

Indeed, we can predict with certainty a continuing explosion of new physiological information and understanding. One of the major reasons is related to the recent landmark sequencing of the human genome. As the functions of all the proteins encoded by the genome are uncovered, their application to the functioning of the cells and organ systems discussed in this text will provide an ever-sharper view of how our bodies work. The integration of molecular biology with physiology has, in fact, led to the need for a new term to describe this growing area of research—physiological genomics. Nowadays, physiologists use the tools of molecular biology to ask not just what changes occur in the body in response to some external or internal stimulus (as in the earlier example of a salty meal), but how the changes are produced at the level of the gene.

Finally, a word should be said about the relationship between physiology and medicine. Some disease states can be viewed as physiology "gone wrong," or pathophysiology, which makes an understanding of physiology essential for the study and practice of medicine. Indeed, many physiologists are actively engaged in research on the physiological bases of a wide range of diseases. In this text, we will give many examples of pathophysiology to illustrate the basic physiology that underlies the disease.

STRUCTURE AND FUNDAMENTAL CHARACTERISTICS OF LIVING ORGANISM

Structure of Living Organism

Cells

The Basic Units of Living Organisms. The simplest structural units into which a complex multicellular organism can be divided and still retain the functions characteristic of life are called cells. One of the unifying generalizations of biology is that certain fundamental activities are common to almost all cells and represent the minimal requirements for maintaining cell integrity and life.

Each human organism begins as a single cell, a fertilized egg, which divides to create two cells, each of which divides in turn to result in four cells, and so on. If cell multiplication were the only event occurring, the end result would be a spherical mass of identical cells. During development, however, each cell becomes specialized for the performance of a particular function, such as producing force and movement (muscle cells) or generating electric signals (nerve cells). The process of transforming an unspecialized cell into a specialized cell is known as cell differentiation, the study of which is one of the most exciting areas in biology today. All cells in a person have the same genes; how then is one unspecialized cell instructed to differentiate into a nerve cell, another into a muscle cell, and so on? What are the external chemical signals that constitute these "instructions," and how do they affect various cells differently? For the most part, the answers to these questions are only beginning to be understood.

In addition to differentiating, cells migrate to new locations during development and form selective adhesions with other cells to produce multicellular structures. In this manner, the cells of the body arrange themselves in various combinations to form a hierarchy of organized structures. Differentiated cells with similar properties aggregate to form tissues (nerve tissue, muscle tissue, and so on), which combine with other types of tissues to form organs (the heart, lungs, kidneys, and so on), which work together to form organ systems (Figure 1-1).

About 200 distinct kinds of cells can be identified in the body in terms of differences in structure and function. When cells are classified according to the broad types of function they perform, however, four categories emerge: (1) muscle cells, (2) nerve cells, (3) epithelial cells, and (4) connective tissue cells. In each of these functional categories, several cell types perform variations of the specialized function. For example, there are three types of muscle cells—skeletal, cardiac, and smooth—which differ from each other in shape, in the mechanisms controlling their contractile activity, and in their location in the various organs of the body.

Muscle cells are specialized to generate the mechanical forces that produce movement. They may be attached to bones and produce movements of the limbs or trunk. They may be attached to skin, as are, for example, the muscles producing facial expressions. They may also surround hollow cavities so that their contraction expels the contents of the cavity, as in the pumping of the heart muscle cells also surround many of the tubes in the body—blood vessels, for example—and their contraction changes the diameter of these tubes.

Nerve cells are specialized to initiate and conduct electrical signals, often over long distances. A signal may initiate new electrical signals in other nerve cells, or it may stimulate a gland cell to secrete or a muscle cell to contract. Thus, nerve cells provide a major means of controlling the activities of other cells. The incredible complexity of nerve-cell connections and activity underlie such phenomena as consciousness and perception.

Epithelial cells are specialized for the selective secretion and absorption of ions and organic molecules, and for protection. They are located mainly at the surfaces that (1) cover the body or individual organs or (2) line the walls of various tubular and hollow structures within the body. Epithelial cells, which rest on an extracellular protein layer called the basement membrane, form the boundaries between compartments and function as selective barriers regulating the exchange of molecules. For example, the epithelial cells at the surface of the skin form a barrier that prevents most substances in the external environment—the environment surrounding the body—from entering the body through the skin. Epithelial cells are also found in glands that form from the invagination of epithelial surfaces.

Connective tissue cells, as their name implies, connect, anchor, and support the structures of the body. Some connective tissue cells are found in the loose meshwork of cells and fibers underlying most epithelial layers; other types include fat-storing cells, bone cells, red blood cells, and white blood cells.

Tissues

Most specialized cells are associated with other cells of a similar kind to form tissues. Corresponding to the four general categories of differentiated cells, there are four general classes of tissues: (1) muscle tissue, (2) nerve tissue, (3) epithelial tissue, and (4) connective tissue.

The immediate environment that surrounds each individual cell in the body is the extracellular fluid. Actually, this fluid is interspersed within a complex extracellular matrix consisting of a mixture of protein molecules (and, in some cases, minerals) specific for any given tissue. The matrix serves two general functions: (1) It provides a scaffold for cellular attachments, and (2) it transmits information, in the form of chemical messengers, to the cells to help regulate their activity, migration, growth, and differentiation.

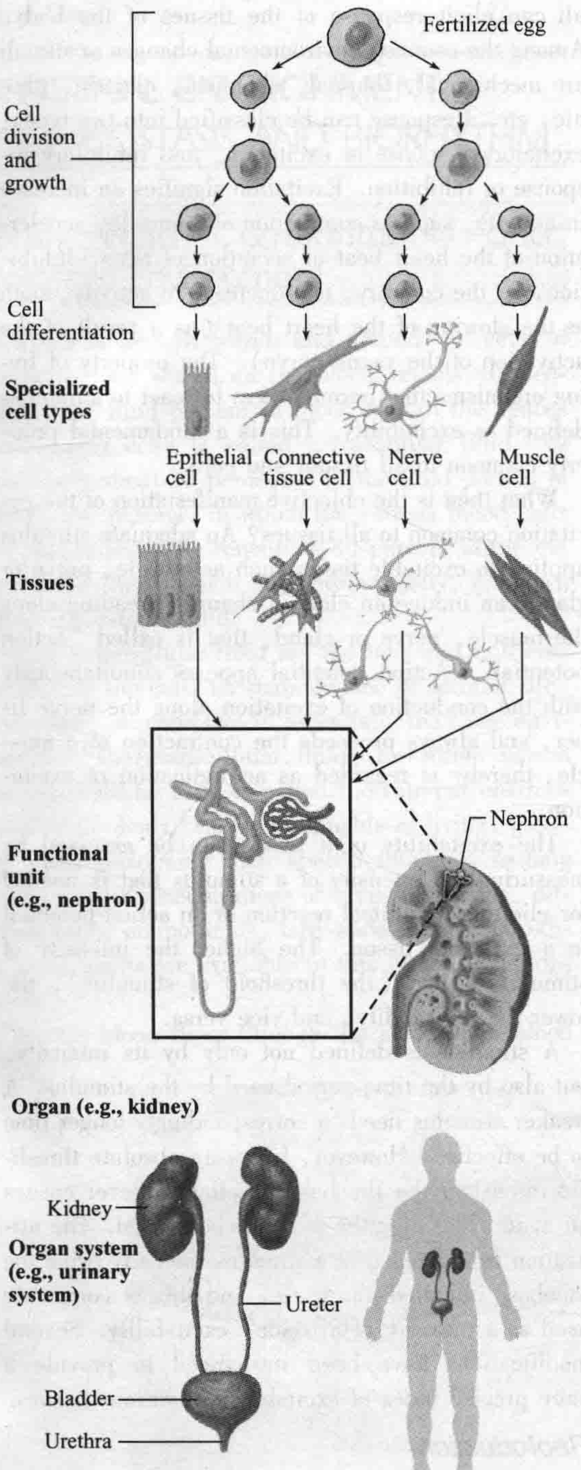

Figure 1-1 Levels of cellular organization. The nephron is not drawn to scale.

The proteins of the extracellular matrix consist of fibers—ropelike collagen fibers and rubberband like elastin fibers—and a mixture of nonfibrous proteins that contain chains of complex sugars (carbohydrates). In some ways, the extracellular matrix is analogous to reinforced concrete. The fibers of the matrix, particularly collagen, which constitutes one-third of all bodily proteins, are like the reinforcing iron mesh or rods in the concrete, and the carbohydrate-containing protein molecules are the surrounding cement. However, these latter molecules are not merely inert "packing material," as in concrete, but function as adhesion/recognition molecules between cells. Thus, they are links in the communication between extracellular messenger molecules and cells.

Organs and Organ Systems

Organs are composed of the four kinds of tissues arranged in various proportions and patterns: sheets, tubes, layers, bundles, strips, and so on. For example, the kidneys consist of (1) a series of small tubes, each composed of a single layer of epithelial cells; (2) blood vessels, whose walls contain varying quantities of smooth muscle and connective tissue; (3) nerve cell extensions that end near the muscle and epithelial cells; (4) a loose network of connective-tissue elements that are interspersed throughout the kidneys and also form enclosing capsules; and (5) extracellular fluid and matrix.

Many organs are organized into small, similar subunits often referred to as functional units, each performing the function of the organ. For example, the kidneys' functional units, nephrons, contain the small tubes mentioned in the previous paragraph, and the total production of urine by the kidneys is the sum of the amounts produced by the two million individual nephrons.

Finally we have the organ system, a collection of organs that together perform an overall function. For example, the kidneys, the urinary bladder, the tubes leading from the kidneys to the bladder, and the tube leading from the bladder to the exterior constitute the urinary system.

To sum up, the human body can be viewed as a complex society of differentiated cells that combine structurally and functionally to carry out the functions essential to the survival of the entire organism. The individual cells constitute the basic units of this society, and almost all of these cells individually exhibit the fundamental activities common to all forms of life. Indeed, many of the cells can be removed and maintained in test tubes as free-living "organisms." (This is termed *in vitro*, literally "in glass," as opposed to *in vivo*, meaning "within the body.")

There is a paradox in this analysis: Why are the functions of the organ systems essential to the survival of the body when each cell seems capable of performing its own fundamental activities? As described in the next section, the resolution of this paradox is found in the isolation of most of the cells of the body from the external environment and in the existence of a reasonably stable internal environment (defined as the fluid surrounding all cells).

Fundmental Characteristics of Living Organism

Metabolism

The metabolism of the body means simply all the chemical reactions in all the cells of the body, that make it possible for the cells to continue living. All vital processes of the body involve myriad chemical reactions which collectively constitute the metabolism. It includes all the material and energy changes that occur in the body, and in its broadest sense is identical with the term "life". All the changes fall into two categories: catabolic and anabolic reactions. Catabolic reactions involve the breakdown of larger, more complex molecules into smaller, simpler molecules, during which energy is released for the activity of the body. Anabolic reactions involve the synthesis of complex molecules from simpler ones. Anabolism and catabolism are two opposing activities taking place simultaneously in the cell. Because of various kinds of enzymes the chemical reactions are processed smoothly and rapidly under very mild conditions, such as in the temperature range of less than 40℃ and in an almost neutral acidity of body fluid.

It is apparent from the above discussions that material and energy metabolism are two intimately related aspects of one and the same process. It is for the sake of convenience in teaching that energy metabolism is discussed in physiology, and material metabolism in biochemistry.

Excitability

Changes in the external or internal environment can induce changes in the activity of a living organism, or, in physiological terms, environmental stimuli can elicit response of the tissues of the body. Among the common environmental changes or stimuli are mechanical, thermal, chemical, electric, phonic, etc. Response can be classified into two types: excitatory response or excitation, and inhibitory response or inhibition. Excitation signifies an increase in activity, such as contraction of a muscle, acceleration of the heart beat or secretion of tears. Inhibition, on the contrary, is a decrease in activity, such as the slowing of the heart beat (as a result of the activation of the vagus nerve). The property of living organisms that permits them to react to stimuli is defined as excitability. This is a fundamental property common to all tissues and cells.

What then is the objective manifestation of the excitation common to all tissues? An adequate stimulus applied to excitable tissue such as muscle, nerve or gland can induce an electric change spreading along the muscle, nerve or gland, that is called "action potential". Action potential appears simultaneously with the conduction of excitation along the nerve fiber, and always proceeds the contraction of a muscle, thereby is regarded as an indication of excitation.

The excitability of a tissue can be assessed by measuring the intensity of a stimulus that is needed for eliciting a minimal reaction or an action potential in a excitable tissue. The higher the intensity of stimulus needed (the threshold of stimulus), the lower the excitability, and vice versa.

A stimulus is defined not only by its intensity, but also by the time period used by the stimulus. A weaker stimulus needs a correspondingly longer time to be effective. However, below an absolute threshold intensity, the rheobase, excitation never ensues no matter how long the stimulus is applied. The utilization time needed at a stimulus intensity twice the rheobase is called chronaxie, and this is commonly used as a measure of a tissue's excitability. Several modifications have been introduced to provide a more precise index of excitability in various tissues.

Reproduction

Sometimes reproduction is not considered a homeostatic function. It does, however, help to maintain static conditions by generating new beings to take the place of those that are dying. This perhaps sounds like a permissive usage of the term homeostasis, but it does illustrate that, in the final analysis, essentially all body structures are organized such