

A. N. BATYAN

V. A. KRAVCHENKO

I. V. PUHTEEVA

THE PHYSIOLOGY OF ADAPTATION PROCESSES

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А. Н. БАТЯН

В. А. КРАВЧЕНКО

И. В. ПУХТЕЕВА

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Батын, А. Н.

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В учебном пособии рассмотрены основные закономерности физиологических адаптаций, их виды, механизмы и стадии адаптации к конкретным факторам среды, характеристика и закономерности деадаптации.

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LIST OF ABBREVIATIONS

A – Adrenaline
ADP – Adenosine Diphosphate
ALV – Artificial Lung Ventilation
AMP – Adenosine Monophosphate
AOD – Antioxidant Defense
AOF – Active Oxygen Forms
APCE – Acute Poisoning of Chemical Etiology
ATP – Adenosine Triphosphate
ATPase – Adenosine Triphosphatase
BAT – Brown Adipose Tissue
cAMP – Cyclic Adenosine Monophosphate
CNS – Central Nervous System
COPD – Chronic Obstructive Pulmonary Disease
DNA – Deoxyribonucleic Acid
EBC – Expired Breath Condensate
FRC – Functional Residual Capacity
FRO – Free-Radical Oxidation
FSRS – Functional Status of Respiratory System
HHAS – Hypothalamic-Hypophysis-Adrenal System
HSP – Heat Shock Proteins
LPVC – Lung Pulmonary Vital Capacity
LPO – Lipid Peroxidation
MDA – Malondialdehyde
NA – Noradrenalin
NADP – Nicotinamide Adenine Dinucleotide Phosphate
OS – Oxidative Stress
Ph↔GA – Relationship between Function and Genetic Apparatus
RNA – Ribonucleic Acid
SAS – Sympathoadrenal System
SOD – Superoxide Dismutase
SPZ – Sanitary Protection Zone
WHO – World Health Organisation

INTRODUCTION

Thanks to the adaptive potential of the human body, the rapid development of civilisation and the exploration of aerospace, the polar regions of the planet and the world ocean are taking place. It became obvious that long-term, gradually developing and sufficiently reliable adaptation is a necessary precondition for expanding human activity in new environments, an important factor in increasing the stability of a healthy body and for preventing diseases. The directed use of long-term adaptation to manage this process requires not only the knowledge of general patterns of adaptation, the variety of its forms, but, above all, the revealing of internal adaptation mechanisms.

The term “adaptation” combines two types of adaptations. On the one hand, it is a genotypic adaptation, as a result of which modern species of animals and plants were formed on the basis of hereditary variability, mutations and natural selection. The complex of specific hereditary traits becomes the basis of the next type of adaptation, namely, phenotypic adaptation acquired during the individual life of the organism. The adaptation is formed during the interaction of an individual with the environment and is often provided by deep structural changes in the body. Such phenotypic changes acquired during life are overlapped with the hereditary characteristics of the organism – its genotype – and together with them form the individual appearance of the organism.

This assumes that the genetic programme of the organism does not provide for a pre-formed adaptation, but the possibility of its implementation under the influence of the environment, which ensures the realisation only those adaptive reactions that are vitally necessary, thereby implying an economical expenditure of energy and structural resources of the organism directed by the environment, as well as the corresponding environment formation of the entire phenotype corresponding to the environment.

Factually, the mechanism of a phenotypic adaptation is how the potential, genetically determined by the capabilities of an organism, in response to the environmental requirements, are transformed into real adaptive reactions. It has been established that environmental factors relatively quickly lead to the formation of functional systems, on the basis of which

the adaptive reactions of the body to the requirements of the environment are formed. At the same time, for perfect and complete adaptation, the emergence of a functional system is insufficient for the formation of structural changes fixing the system and increasing its physiological capacity in the cells and organs.

The textbook also discusses the issues of how the synthesis of nucleic acids and proteins is activated in the cells of the functional system responsible for the adaptation, and the formation of a systemic structural trace occurs. The architecture of systemic structural traces is compared with relatively simple and higher adaptive reactions of the body, and the role of a stress reaction in the formation of a systemic structural trace is specifically considered. This reaction ensures not only the mobilisation of energy and structural resources of the body, but the directed transfer of these resources to the dominant functional system responsible for adaptation, where a systemic structural trace is formed. Consequently, the systemic structural trace of a specific adaptation to this particular factor is formed with the participation of a non-specific stress reaction that occurs with any significant change in the environment.

Thereby, the stress reaction, on the one hand, contributes to the formation of a new systemic structural trace and the formation of adaptation, and on the other hand, due to its catabolic effect, removes the structural traces that have lost their biological significance. In the same perspective, the mechanism of higher adaptive reactions of the body, carried out in the form of conditioned reflexes and behaviour, is considered. Next, the mechanism of adaptation of the body to extreme stressful situations is regarded. This adaptation, which develops in difficult environmental conditions when it is impossible to escape through a simple avoidance response, is essential for all types of human activities involving responsibility, risk, and the need to maintain self-control. Finally, the mechanism of compensatory processes is studied, which constitutes an important class of adaptive reactions that ensure the adaptation of the body to the resulting damage, and the preservation of not only vital functions, but often practical health despite these injuries.

A number of chapters are devoted to the mechanisms and stages of adaptation to specific environmental factors, such as physical activity, altitude hypoxia, and temperature. Considering these various adaptive reactions of the body, it is shown that their development leads to the fact that the body acquires a new quality, namely adaptation in the form of hypoxia resistance, adaptation to physical exertion, or a new skill. The role of adaptation as a preventive factor increases significantly due to the fact that long-term, structurally determined adaptive reactions have only relative specificity, i.e. they increase the body's resistance not only to the factor

to which adaptation has taken place, but also to a number of others at the same time. For example, adaptation to physical exertion increases the body's resistance to hypoxia; adaptation to toxic chemicals increases the ability to oxidise cholesterol.

The basis of the relative specificity of phenotypic adaptation is that the extensive systemic structural trace, which forms the basis of adaptation to a certain factor, often contains components that can increase the body's resistance to other factors. Thus, an increase in lung volume and the number of alveoli during adaptation to hypoxia increases endurance to physical exertion. The relative specificity of adaptation plays an important role in the natural prevention of diseases and in the active prevention of non-contagious diseases such as hypertension, atherosclerosis, and coronary heart disease. In addition, it has been shown that the adaptation of the body to repeated, short-term emotional and stressful effects naturally prevents damage to the heart, stomach, and mechanisms of immunogenesis caused by prolonged and severe stress.

Thus, rationally managed adaptation to one or more factors is a factor in increasing the resistance of a healthy organism, and this is relevant for countries with developed industrial production when the pressure on the human body of man-made factors increases every year.

There are not enough textbooks in the world literature that consistently describe the dynamics and mechanisms of individual adaptation of the body to the main environmental factors. This one should fill the gap to some extent.



BASIC PATTERNS OF PHYSIOLOGICAL ADAPTATIONS

1.1. Definition and Classification of Physiological Adaptations

Adaptation (from Latin *adaptatio*) is the adjustment of an organism to changing conditions of existence in the environment. Adaptation is manifested by the emergence of adaptive behaviour with changes in the environment. The basis of this adaptation is the changes that occur at all levels: molecular, subcellular, cellular, organ and systemic. All this leads to an increase in the body's resistance to fluctuations in external temperature, humidity, atmospheric pressure, as well as to the effects of many other environmental changes leading to the development of adaptation, and an increase in the synthesis of nucleic acids and specific proteins, which causes a long-term restructuring of the structure and function of cells, organs, tissues and systems involved in these adaptive reactions.

The concept of “adaptation” often has a different meaning. In this regard, a special commission of the International Union of Physiological Sciences, established to compile a dictionary of terms in physiology, proposed the following definitions.

Adaptation is a change that reduces the physiological stress caused by the stressful component of the environment. This change can occur within the life of an organism (phenotypic adaptation) or be the result of genetic selection of species or subspecies (genotypic adaptation).

Acclimation is a physiological change within the lifetime of an organism that reduces stress caused by stress shifts of distinctive climatic factors in experimental conditions.

Acclimatisation is a physiological change within the life of an organism that reduces stress caused by stress shifts in the natural climate (for example, seasonal or geographical).

Acclimatisation and acclimation are phenotypic adaptations to the climatic components of the environment. There are no distinct terms that

refer to genotypic adaptations to climate or distinctive climate components. All such genetically fixed properties of species or subspecies are covered by the general term “genotypic adaptation”.

Thus, in the proposed definitions of the terms there are significant limitations for their application:

a) all three terms are related to those changes in the body that are caused by environmental factors;

b) adaptive ones are considered only those shifts in the body that reduce the stress that occurs during the initial period of exposure to the stress factor of the external environment.

The term adaptation is also used in a more qualified sense. They indicate a decrease in the sensitivity of the receptors to a constantly acting adequate stimulus. This adaptation occurs due to changes in the functional state of the receptors themselves, as well as the central departments of the corresponding analyser.

I. I. Schmalhausen called adaptation or the ability to adapt to a changing environment as one of the most remarkable properties of living beings. The ability to adapt has versatility as it is inherent in any self-regulating system. The term adaptation refers, on the one hand, to the processes of hereditary variability, the occurrence of mutations and their subsequent consolidation with natural selection. This type of adaptation is called genotypic or evolutionary adaptation. On the other hand, phenotypic or individual adaptation can be defined as a process developing in the course of individual life, as a result of which the body acquires a previously not existed resistance to a certain environmental factor and, thus gets the opportunity to live in conditions previously incompatible with life and to solve problems unsolvable earlier. Recently, the idea that adaptation is a process of acquiring resistance not only to environmental factors, but also to the internal environment of the organism (for example, compensatory changes in the body in response to trauma) has been developing.

In turn, phenotypic adaptation is divided into two stages: the initial stage of immediate but imperfect adaptation and the subsequent stage of perfect, long-term adaptation.

The study of the ways and mechanisms of adaptation of the body is of particular importance nowadays in relation to human exploration of new geographical regions, the need to work in unusual climatic conditions, migration of the population to the eastern and northern regions, exploration of the Arctic and Antarctica, the need for human work in deserts and in high-altitude conditions, as well as with the development of aviation, space technology, deep water diving, exploration of ocean shelves, the emergence of new types of work, and new professions.

In modern environmental conditions, the preservation of human biological nature does not consist in protecting the body from physical and intellectual stress, but in creating some kind of “greenhouse”, “refined” conditions for it. On the contrary, only intensive comprehensive loads, intensive harmonious activity of all organs and systems can ensure the full development of the body, revealing and improving all inherent potential.

1.2. Principles and Mechanisms of Phenotypic Adaptation

Substantively, the issue of the mechanism of phenotypic adaptation is how the potential, genetically determined resources of an organism are transformed into real potential in response to the demand of the environment. Under the action of factors or a new environmental situation, functional systems are formed relatively quickly providing an adaptive response of the body to the demands of the environment. However, for perfect adaptation, the emergence of the functional system is insufficient; it is necessary that structural changes fixing the system and increasing its physiological capacity should occur in the cells and organs.

The key element in the mechanism that ensures the fixation of the functional system and, consequently, the key element in all forms of phenotypic adaptation is the relationship existing in cells between the function and the genetic apparatus. With this relationship, the functional load caused by the action of environmental factors leads to an increase in the synthesis of nucleic acids and proteins and, as a result, to the formation of a structural trace in the systems specifically responsible for adaptation to this particular environmental factor. Moreover, the mass of membrane structures responsible for the receiving control signals by the cell, ion transport, and energy supply increases to the greatest extent, i.e. precisely, those structures that limit the overall function of the cell.

The resulting systemic structural trace is a complex of structural changes that ensures the expansion of the link that limits cell function, and thereby increases the physiological capacity of the functional system responsible for adaptation. This trace forms the basis of a long-term phenotypic adaptation. After the termination of the effect of the environmental factor on the body, the activity of the genetic apparatus in the cells responsible for the adaptation of the system decreases quite sharply and the disappearance of the systemic structural trace occurs, which forms the basis of the process of de-adaptation.

1.3. Homeostasis and Its Role in the Adaptation of the Body

In the early days of evolution, life began and appeared in an aquatic environment. With the emergence of multicellular organisms, most cells lost a direct contact with the ambient environment. They existed surrounded by an internal environment – an intercellular fluid. Due to the presence of the blood and lymph circulation system, as well as the action of organs and systems that ensure the supply of various substances from the external to the internal environment of the organism (respiratory and digestive organs), and organs that ensure the excretion of metabolic products into the external environment, multicellular animals got the opportunity to maintain the constant composition of the internal environment of the body.

As a result, the body cells exist and perform their functions in relatively constant (stable) conditions. Due to the activity of a number of regulatory mechanisms, the body is able to maintain the constant internal environment with sudden changes in various characteristics of the ambient environment (high temperature, pressure, humidity or lighting changes and interruptions in the receiving nutrients).

The more precisely and reliably the constancy of the internal environment is regulated, the less the organism depends on the changes in external conditions, the wider its habitat area and the freer it is to choose one or another ambient environment for existence.

At the end of the 1860s, the French scientist Claude Bernard (Fig. 1) put forward the idea of the constancy of the internal environment of the body as a condition of its free life, thereby emphasizing the great importance of this stability.

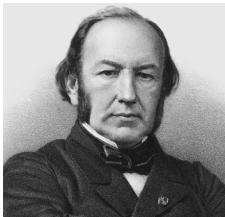


Fig. 1. Claude Bernard
(1813–1878)

The concept of homeostasis (from Greek *homeo* – like, permanent; *stasis* – state) was formulated in 1929 by the American physiologist Walter Cannon (Fig. 2). He noted that “an organism built of materials characterised by extreme impermanence and instability somehow learns the methods of maintaining constancy and maintaining the stability of physiological functions under the conditions that are quite sufficient to cause their profound violations.”

Briefly, the concept of homeostasis can be formulated as follows: **homeostasis** is the ability of an organism to maintain the constancy of the internal environment.

It is based not on static, but on dynamic processes since the constancy of the internal environment is continuously violated and is just as continuously restored.



Fig. 2. Walter Cannon
(1871–1945)

1.4. General Mechanism for Individual Adaptation

The systemic structural trace, which forms the basis of specific adaptation, and the nonspecific stress syndrome are inextricably interrelated, i.e. they are coordinated within the framework of a single adaptive response of the organism.

In the diagram (Fig. 3), it is shown that a violation of homeostasis caused by an environmental factor or a signal that such a violation is possible in the future, activates the systems that is responsible for adaptation through higher regulatory mechanisms. As a result, two phenomena arise: firstly, the mobilisation of a functional system, specifically responsible for adaptation to this factor, and secondly, a nonspecific stress syndrome. In the future, the system of specific adaptation performs an increased function and dominates the vital activity of the body.

Based on the connection between the function and the genetic apparatus, and with the potentiating effect of a stress syndrome, a structural trace is

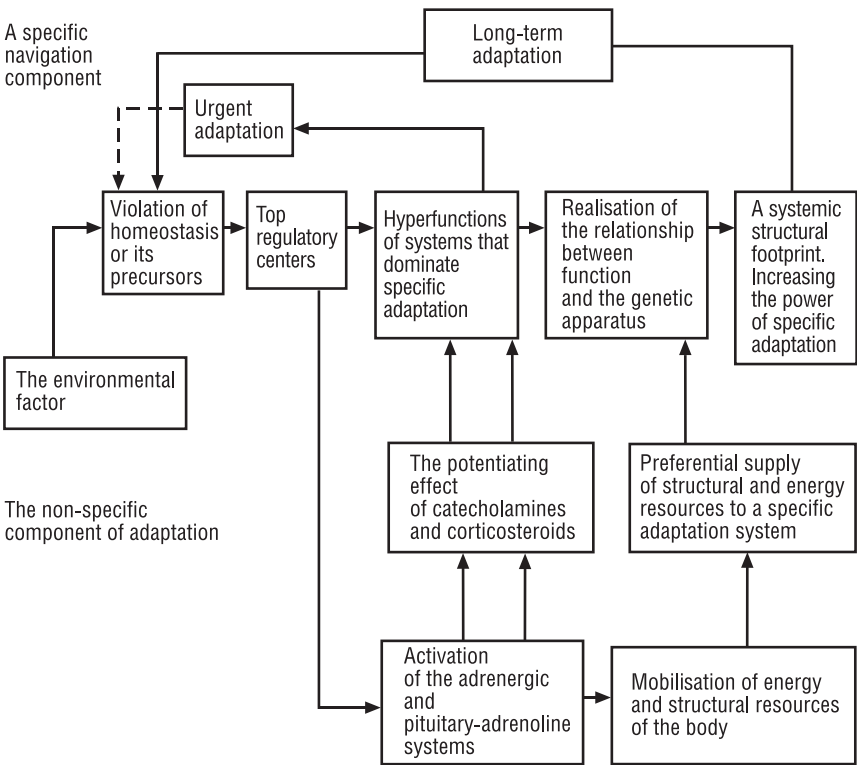


Fig. 3. General adaptation mechanism

formed in the cells of this dominant system, which significantly increases its power. Reliable and long-term adaptation is developing, which eliminates the initial violations of homeostasis and makes a stress syndrome excessive.

The basis for increasing the functionality of the system that is responsible for adaptation is a change in the ratio of cellular structures, namely: a selective increase in the mass and power of structures that are important for the management, ion transport, and energy supply. It is this shift, as it will be shown in detail below, provides not only high power, but also efficiency of the system responsible for adaptation, high reactivity of its links to control signals.

In the process of individual life, the body encounters a whole range of different environmental factors: as a result, not one structural trace is formed, but a complex set of systemic structural traces that form the phenotype of the organism in accordance with the requirements of the environment. At the same time, the once-formed systemic structural footprint and adaptation to a certain environmental factor are not constant. As the environment changes, the spectrum of adaptive reactions of the body changes. This happens through the process of de-adaptation, during which, by reducing the synthesis of nucleic acids and proteins and activating the process of degradation of structures, the previously formed systemic structural traces disappear and deteriorate.

A stress syndrome, which is the necessary initial component of any new adaptation, due to its catabolic effect, simultaneously potentiates the process of de-adaptation, i.e. the deterioration of old structural traces that have lost their biological significance.

1.5. The Structural “cost of adaptation”

The structural cost of adaptation is the amount of nucleic acids and protein molecules that the body must additionally synthesise in order to carry out this adaptive reaction. The structural cost, which is understood in this way, consists of:

- firstly, molecules that additionally decayed in the initial, urgent, i.e. stress; the phase of the adaptive reaction and which must be resynthesised as a stable adaptation is formed;
- secondly, from the increment in the mass of structures (i.e. essentially, a population of molecules), which is usually observed in the transitional and stable stages of the process, when organ hypertrophy develops;
- thirdly, from the accelerated updating of the structure that is responsible for the adaptation of the system, which can be maintained throughout the entire adaptation period.

Even a single stressful effect significantly shortens the life of cellular structures and makes it necessary to accelerate their resynthesis for a long time. That is why numerous stress effects have a high structural price and lead to the deterioration of the body in the ageing process.

With a prolonged and significant increase in the function of any organ or the whole system, a long-term adaptation is provided at the expense of increased break-up and even more enlarged biosynthesis of nucleic acids and proteins, i.e. it has a certain structural cost.

The amount of RNA that can be transcribed on DNA matrices of non-dividing differentiated cells is not unlimited nor is the number of protein molecules that can be translated from each matrix of informational RNA unlimited. That is why too long and strenuous long-term adaptation, achieved at too expensive structural price, can cause local wearing or local aging and the basis for the exhaustion of the adaptive capabilities of the body.

Determining the structural cost of each specific adaptation situation is of great practical importance. There are at least five situations where the structural cost of adaptation is particularly large.

The first situation, which has a huge structural cost, is a severe long-term stress.

The second situation of this kind is the initial or emergency stage of adaptation to the action of any factor. At this stage, a direct deficiency of energy-rich phosphoric compounds in cells and the catabolic effect of stress hormones lead to a significant damage to membranes and the breakdown of a number of other structures, which is manifested, for example, by enzymaemia, a negative nitrogen balance.

The third situation is most vividly realised in the transitional stage of the adaptation process, when in response to stress, hypoxia, cold or any other environmental factor causing energy deficiency, a pronounced activation of the synthesis of nucleic acids and proteins develops and an increase in the mass of cellular structures occurs in the form of hypertrophy of organs for the purposes of functional systems.

If the resulting stable adaptation is necessary for the body for a long time or for the rest of its life, a relatively economical expenditure of the structural reserve occurs. In the case when the environmental factor, to which the adaptation has taken place, subsequently ceases to act for a long period of time, and then, after the de-adaptation has managed to be realised, begins to act again, the systemic structural trace is formed again. Accordingly, the structural cost of adaptation turns out to be very high.

The fourth situation is related to the role of the dominant principle of a long-term adaptation. In this case, the formation of a pronounced systemic structural trace in the dominant functional system responsible for

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