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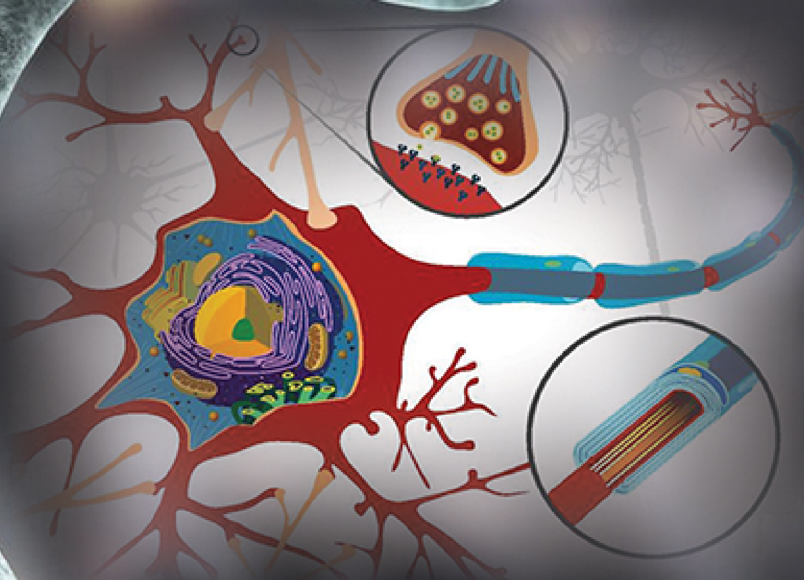


FUNDAMENTALS OF PHYSIOLOGY

A TEXTBOOK FOR STUDENTS OF NURSING, MEDICINE, DENTISTRY AND ALLIED COURSES

RL BIJLANI

JAYPEE

Contents

CHAPTER

1 Getting Introduced to Physiology

"Not in the world of light alone, Where God has built his blazing throne, Nor yet alone in earth below, With belted seas that come and go, And endless isles of sunlit green, Is all thy Maker's glory seen, Look in upon thy wondrous frame, Eternal wisdom still the same."

—OLIVER WENDELL HOLMES

Chapter Outline

- The Unicellular Organism
- Multicellular Organisms
- Principles of Regulation: Control Systems
- Physiology as the Basis of Medicine

Physiology (*physis*, nature; *logos*, discourse) literally means knowledge of nature. The term belongs to an era when physiology and philosophy were not very different from each other. But now physiology means the study of the function of living organisms. This book will concentrate on human physiology, especially from the point of view of health and disease. However, man is unmistakably similar to animals,[1] and a lot of human physiology has been learnt from animals.

The human body is made up of trillions of cells. In other words, human beings are multicellular organisms. They are very complex as compared to unicellular organisms, whose body has just one cell. But human cells have a lot of similarity with unicellular organisms. Therefore we can understand human physiology much better if we understand how a unicellular organism functions.

THE UNICELLULAR ORGANISM

An organism which consists of just one cell, such as an ameba, is a wonderful machine. It burns fuel to get energy for its various functions. When we burn fuel, e.g. wood, we use oxygen from the air. Oxygen oxidizes carbon-containing compounds (organic compounds) in the wood to produce carbon dioxide and water. Combustion produces energy because the organic compounds burnt in the process are high-energy compounds, whereas carbon dioxide and water are low-energy compounds.

High–energy organic compounds + Oxygen →
Carbon dioxide + Water + Energy

A living cell also burns fuel (we call it food) with the help of oxygen to get energy, and in the process produces carbon dioxide and water. Food also has nitrogenous organic compounds (proteins), the burning of which may produce ammonia in addition to carbon dioxide and water. Carbon dioxide,

[1]This statement is calculated to respect the pride of our species. In fact man is also an animal, although a highly evolved one. Further, he is not the final product of evolution. There is every reason to believe that still more highly evolved creatures will appear on earth in future.

JAYPEE BROTHERS

water and ammonia are thrown out of the cell. One wonderful thing about the process of combustion in a cell is that it is carried out with the help of enzymes, which carry out the process in a step-wise fashion, so that the energy obtained from the fuel is not released all at once. That is why the energy can be used for life-processes, and does not burn the cell—it just makes the cell a little warm.

A unicellular organism is totally self-reliant. It lives in sea water. When it finds in the sea a particle which may be used as food, it throws pseudopodia around it, engulfs it into a vacuole, digests it, and burns it to get energy. The oxygen required for the process is obtained from the air dissolved in the sea water. It moves into the cell by diffusion. Waste products such as carbon dioxide and ammonia formed in the cell also move out of the cell by diffusion. Hence the waste products do not accumulate in the cell. The unicellular organism uses the food not only for producing energy but also for growth and repair. In addition, it also reproduces by dividing into two identical cells. Thus the single cell of a unicellular organism is fully equipped to carry out all the functions of life (Fig. 1.1).

A living cell is a wonderful machine. It uses such simple substances from the environment to do so much. It continues to function on its own for so long, it repairs its defects, and it survives through its progeny. A comparable machine is yet to be made by man. But this wonderful machine works only under certain conditions. A few of these conditions are as follows. There should be a regular supply of food and oxygen available. The waste products such as carbon dioxide and ammonia should not accumulate in the cell. The temperature within and around the cell should be neither too cold nor too hot. If it is too cold, enzymatic activity becomes too slow to support life. If it is too hot, proteins, including enzymes, are denatured. The pH within and around the cell should be within narrow limits. The osmolarity of the fluid surrounding the cell should be the same as that within the cell. If the surrounding fluid is hypo-osmolar, water enters the cell, and the cell bursts and obviously dies. If the surrounding fluid is hyperosmolar, water leaves the cell, and the cell shrinks and eventually dies.[2]

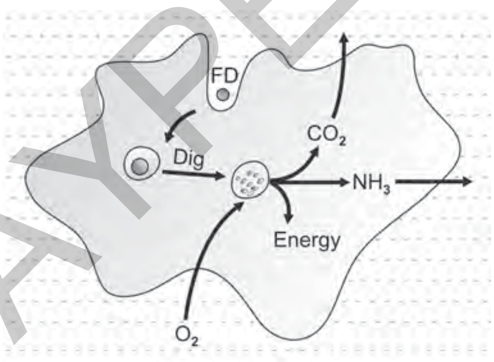


Fig. 1.1 A unicellular organism is self-reliant, and has the luxury of an extensive environment with which it can exchange nutrients and waste products. The nucleus has been omitted for convenience. FD, food; Dig, digestion

For a unicellular organism, these conditions are easy to meet. Food and oxygen are available in the surrounding sea water. A little cell cannot consume much food and oxygen. Therefore the removal of some food and water by these tiny organisms cannot finish the food and oxygen in the sea. Similarly, dumping a little carbon dioxide or ammonia by these tiny organisms in the sea cannot pollute the sea enough to make it too poisonous for the organisms to live in it.[3] The sea water is rather constant in its warmth.[4] The sea water surrounding the unicellular organisms is so huge in quantity that its pH and osmolarity are not materially affected by the life processes of the tiny organisms. You might have observed that the key to the survival of the unicellular organism resides in the sea water, which forms its immediate environment. The environment provides the optimum conditions for its survival.

[2]If you do not understand the consequences of the cell being surrounded by a hypo- or hyperosmolar fluid, revise your knowledge of osmosis (Chapter 3).

[3]These statements are about the short-term situation only. In the long-term, nutrients may be depleted, and waste might accumulate. But that does not happen because of the ecological balance achieved by a variety of organisms, including phytoplankton.

[4]High specific heat minimizes fluctuations in the temperature of a large body of water.

JAYPEE BROTHERS

MULTICELLULAR ORGANISMS

Multicellular organisms like man are very complex as compared to unicellular organisms. But they have one fundamental similarity with each other. Each cell of a multicellular organism needs exactly the same conditions for survival as a unicellular organism. Let us see how these conditions are achieved in a complex creature like man who lives not in the sea but on land.

Our cells are not surrounded by sea water, but they do have a thin layer of fluid around them (Fig. 1.2). Thus our cells may not have the luxury of the sea, but each cell at least has a private pond of its own. The fluid surrounding the cells is called the interstitial fluid. The interstitial fluid forms the immediate environment of our cells, just as the sea forms the immediate environment of organisms like the ameba. It is interesting that the composition of the interstitial fluid is very similar to that of sea water. But here we have a problem. The quantity of interstitial fluid is so small that the cell would use up all the nutrients and oxygen in it in a very short time. The waste products would also quickly build up to toxic levels. Therefore it is essential that nutrients in the interstitial fluid be replenished, and waste products removed, continually and promptly. This has been made possible by having a set of tubes, which we call capillaries (Fig. 1.3). The fluid in the capillaries exchanges these substances with the interstitial fluid, and the interstitial fluid exchanges them with the cells. Thus the fluid in the capillaries (blood) acts as an extension of the immediate environment of the cells. But the problem is still not over—now the nutrients can get depleted from the blood, and waste products can accumulate there. This does not happen because blood in the capillaries is in motion. Thus blood can bring a continuous supply of fresh nutrients to the cell, and take waste products away before they accumulate. The motive force behind the movement of blood is the heart (Fig. 1.4). However, you would realize that this 'solution' also merely postpones the problem—it does not actually solve it, because soon a time will come when all the nutrients in the blood have been used up, and waste products have accumulated to toxic levels throughout the blood. The final solution has been found in having a few points in the circulatory system where the capillaries should come in close contact with the external environment. The structure where this happens should be

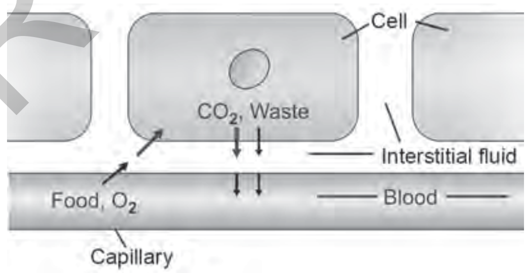


Fig. 1.3 The cells of a multicellular organism exchange nutrients and waste products with the interstitial fluid, and the interstitial fluid exchanges these with blood in the capillaries

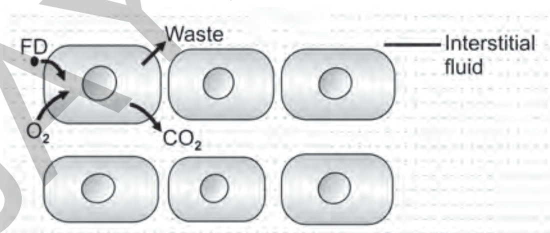


Fig. 1.2 The cells of a multicellular organism are surrounded by a small amount of interstitial fluid which provides them an environment similar to sea water. FD, food

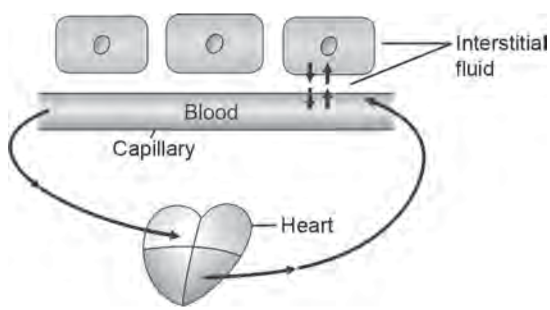
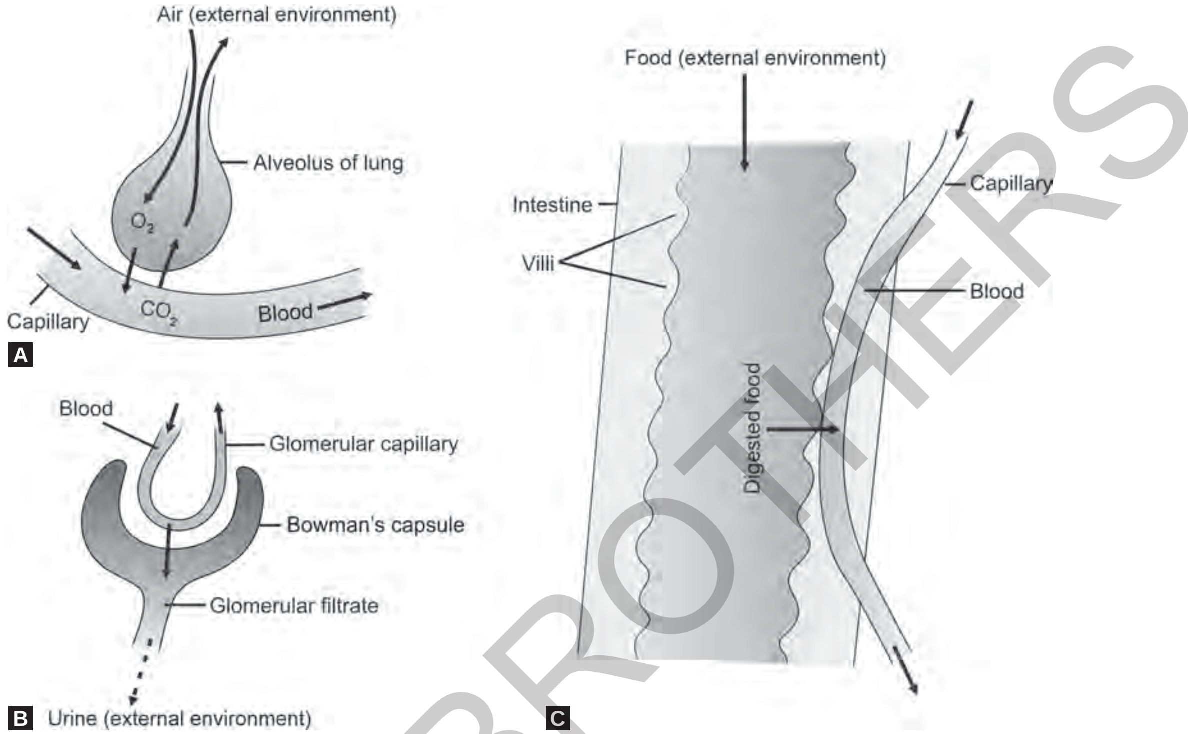


Fig. 1.4 Blood in the capillaries is in motion. As a result, fresh blood is brought in continuously, and 'used' blood taken away. The push for the motion of blood is provided by the heart

JAYPEE BROTHERS



Figs 1.5A to C The ultimate replenishment of nutrients and removal of waste products takes place as the result of an exchange with the external environment. This exchange takes place in specialized organs such as the lungs (A); the kidneys (B); the gastrointestinal tract (C); In these structures the external environment comes in intimate contact with the blood

especially built for picking up some nutrients from the external environment and passing it on to the capillaries, or for picking up some waste product from the capillaries and passing it on to the external environment. Such structures are, principally, the lungs, where oxygen is picked up and carbon dioxide is disposed of, the kidneys, where nitrogenous waste is disposed of, and the gut, where all the nutrients except oxygen are picked up (Figs 1.5A to C). In all these structures, very thin membranes and very few layers of specialized cells separate the external environment from the blood. Thus, although we live on land, eventually the external environment has to bear the burden of keeping us alive, just as in the case of unicellular organisms. Our nutrients and oxygen also come from the external environment, enter the blood, and from the blood enter the 'private pond' of every cell, making the cell 'feel like an ameba in the sea'. The waste products that our cells make also travel from the cell to the 'private pond', and from there to the blood, and are finally discharged into the external environment.

It may be noted that the heart sends blood to all parts of the body. Two important functions that the blood performs everywhere it goes are to supply nutrients and pick up waste products. But while passing through the lungs, the kidneys or the gut, it does something in addition: it picks up nutrients from, or gives up waste products to the external environment. In some of these organs (lungs and kidneys), blood discharges to the external environment waste products picked up from the internal environment of the cells (interstitial fluid) all over the body. By acting as a link between the external and the internal environment, the digestive, respiratory and excretory systems replenish the

JAYPEE BROTHERS

nutrients used up by the body, and dispose of the waste products formed. The ultimate aim of these systems is to help achieve constancy in the characteristics of the thin layer of fluid surrounding every cell of the body. This fluid, the interstitial fluid, constitutes the immediate environment of the cells, or the internal environment of the body. The importance of the constancy of the internal environment (in French, *milieu interieur*) was first stressed by Claude Bernard in 1857. Claude Bernard was not just an eminent physiologist, but is also considered the father of experimental medicine. The concepts propounded by him were further supported by the extensive experimental work of Walter Cannon in the early twentieth century. Cannon coined the term *homeostasis* to describe the constancy of the internal environment (*homoios*, similar; *stasis*, position).

You might have observed that each system of the body makes a contribution to homeostasis. In turn, it benefits from the contributions which other systems make. For example, the gut replenishes nutrients in the interstitial fluid. In turn, it benefits from the oxygen that has been added to the interstitial fluid by the lungs and also from the removal of waste products by the kidneys. Thus the body is like a society in which there is specialization and division of labor. A health professional specializes in giving health care, and in turn depends for food on the farmer, for clothes on the tailor, and for shelter on the mason. Similarly, in the body each system has specialized in doing one thing for all cells of the body. In turn, cells belonging to other systems of the body fulfill all the remaining needs of this system. Our own body is an excellent example of cooperation and interdependence.

What About the Other Systems?

We have so far seen the contribution of blood, cardiovascular system, respiratory system, gastrointestinal system and kidneys to homeostasis. But there are a few other systems also in the body. Do they also contribute to homeostasis?[5]

[5]You may try answering this question on your own before reading further.

We have seen that the human body is essentially a society of cells. In a society, we also need an organizer or coordinator to see that different members of the society work in such a way that the interests of the society as a whole are well looked after. In the body, the function of co-ordination is performed by the nervous and endocrine systems. To give an example, when we take exercise, our requirement of oxygen goes up. To meet this additional demand, the heart beats faster, and the lungs work harder. How do the lungs know when to step up their activity? This is the job of the coordinating systems. These systems detect the changes resulting from exercise. These changes are contraction of muscles, movement of joints, slight fall in oxygen tension, slight increase in carbon dioxide tension, slight increase in temperature, etc. The coordinating systems process all this information, and then come up with a response. The response is to send messages to the heart and lungs to step-up their activity so that homeostasis is maintained in spite of additional oxygen requirement. Thus coordination has two basic components: communication and information processing (Fig. 1.6). First, there has to be a channel of communication with areas where changes are taking place. In the above example of exercise, the information from muscles, joints, etc. has to reach the coordinator through such a channel of communication. This information-gathering channel is called the sensory limb of the coordinator. Since information is coming from multiple sources, the coordinator has to process this information. Processing means putting together all this information, or synthesizing it, so as to understand what it means in terms of the

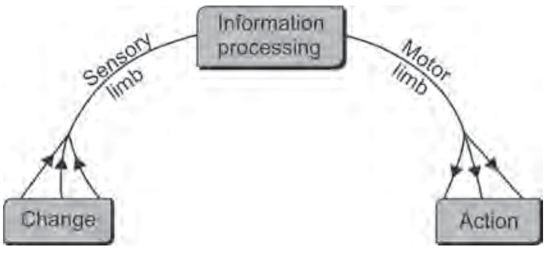


Fig. 1.6 The basic components of coordination

JAYPEE BROTHERS

disturbance in homoeostasis which it can produce. Further, processing also means deciding what needs to be done. This processing is done in the brain. The result of the information processing is the decision about what needs to be done. This decision is conveyed by the brain to the heart and respiratory muscles. Conveying the decision also needs a channel of communication. This instructional channel is called the motor limb of the coordinator. Thus the coordinator consists of the sensory limb, a processing unit, and a motor limb.

We have seen above that although the coordinating systems, i.e. the nervous and endocrine systems do not contribute directly to homeostasis, they make an indirect contribution to it. Their contribution is to make several other systems work towards homeostasis at the right time at the required level so that homeostasis is maintained in spite of changing circumstances. But there are still a few other systems to be considered. The musculoskeletal system also makes no direct contribution to homeostasis. But apart from giving a shape to the body, it enables the animal to move. Animals need to move to find food, to hunt their prey, and to escape from predators. The gut can replenish nutrients only if the animal finds food in the first place. Hence the musculoskeletal system also makes an essential, although indirect, contribution to homeostasis. Human beings may not find their food the way animals do, but move they also must to earn a living. Even highly civilized societies can support only a few paralyzed individuals and that too rather poorly. How about the skin? Apart from playing a major role in regulation of body temperature, skin is the first line of defense against a wide variety of dangerous microorganisms which our environment is full of. These microorganisms are unable to enter the body because the skin offers an effective barrier. Finally, let us have a look at the reproductive system. The reproductive system seems to contribute to homeostasis neither directly nor indirectly. But it has an important function without which homeostasis becomes meaningless. Reproduction is responsible for perpetuation of the species. No matter how effective the homeostasis, it is not perfect, and therefore every organism dies one day. Therefore, a species which cannot reproduce would soon vanish from the surface of the earth.

We have seen that every part of the body makes some contribution to the survival of the whole organism by doing something to maintain the composition, pH and temperature of the internal environment at an optimal level. The optimal level is that at which the enzyme systems function best, nutrients are available in quantity and quality commensurate with the activity of the tissue in question, and waste products remain well below toxic levels. As you go on to a detailed study of individual systems, keep in mind that the central purpose of all systems is to make a contribution to homeostasis. It is easy to get lost in details and forget this fundamental fact. But keeping this basic fact at the back of your mind will make the study of the details much easier, more interesting and more meaningful.

PRINCIPLES OF REGULATION: CONTROL SYSTEMS

Now we shall study the general mechanisms by which the coordinating systems of the body ensure constancy of the internal environment. The mode of regulation of the internal environment bears a remarkable resemblance to the way an automatic electric iron works. The setting 'cotton' or 'wool' corresponds to a temperature which the iron will maintain. When the temperature rises slightly above the set level, the iron is automatically switched off. On the other hand, when the temperature falls slightly below the set level, the iron is automatically switched on, and stays on till the temperature rises slightly above the set level. In this way, the temperature of the iron always stays close to the set level.

A similar strategy is adopted by the body to maintain homeostasis. For example, if a person loses blood by bleeding, the blood pressure falls. When this happens, the heart starts beating faster and more forcefully, and the blood vessels constrict. This raises the blood pressure towards normal. To take another example, if a person has just taken a meal, her blood glucose level starts rising. In response to the rise in blood glucose, the pancreas releases insulin. Insulin

JAYPEE BROTHERS

lowers the blood glucose level. As the blood glucose level falls slightly below the desirable level, the secretion of insulin is switched off. If the person now does not eat for the next eight hours, not only will insulin secretion remain off, glucagon secretion will be switched on. Glucagon raises blood glucose. Thus blood glucose will be maintained at a reasonable level in spite of fasting or feasting. The mechanisms which prevent the blood glucose level from rising too high or falling too low are called the control system for regulating blood glucose. The control system for a variable maintains the value of the variable within a narrow range.

A control system (Fig. 1.7) is basically designed to maintain a controlled variable close to a set point. The value of the controlled variable is continuously monitored by a sensor. The current value of the controlled variable is conveyed by the sensor to the controller in the form of a feedback signal. The feedback signal and the set point constitute the inputs for the controller. The feedback signal is naturally affected by any disturbance which alters the value of the controlled variable. The controller compares the feedback signal with the set point; the difference between the two is called the error. The output of the controller is conveyed to an effector. As a result, the effector applies a correction which takes the controlled variable towards the set point. A control system such as this one is called a negative feedback system because the effector response is negative to the initiating stimulus (disturbance). Using the terminology of control systems, the regulation of blood pressure and blood glucose have been illustrated in Figures 1.8 to 1.10.

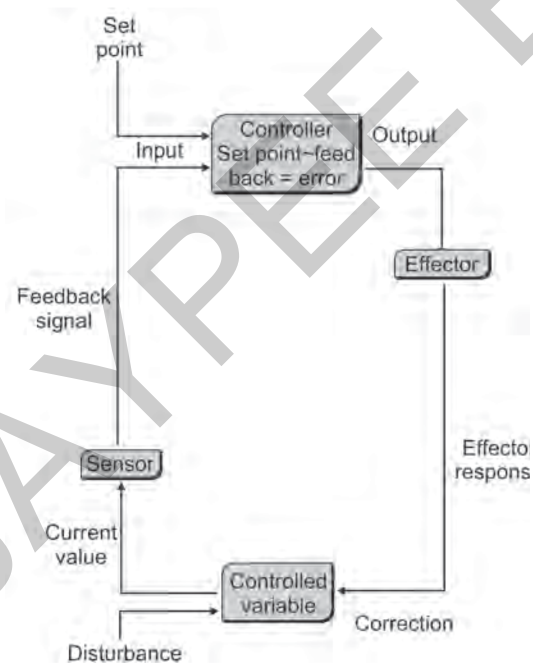


Fig. 1.7 The essential elements of a control system

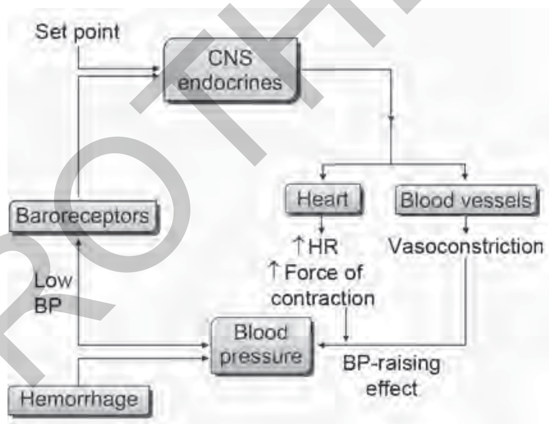


Fig. 1.8 Some basic features of the blood pressure regulatory system. The figure shows how the system responds when the blood pressure falls as a result of blood loss. BP, blood pressure; HR, heart rate; CNS, central nervous system

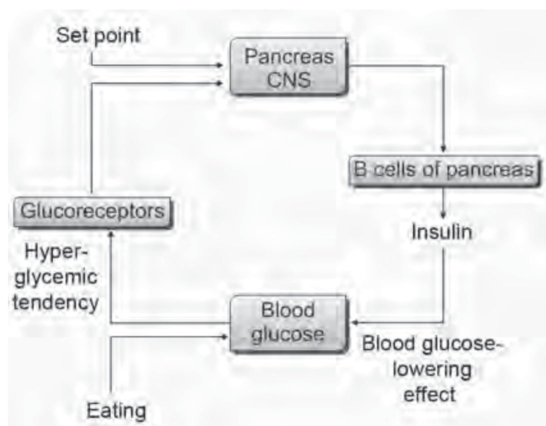


Fig. 1.9 Some basic features of the blood glucose regulatory system. The figure shows how the system responds when the blood glucose rises after a meal

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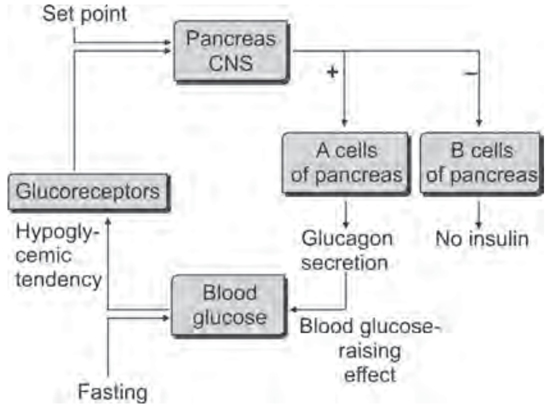


Fig. 1.10 Some basic features of the blood glucose regulatory system. The figure shows how the system responds when the blood glucose falls during fasting

Response Characteristics of a Control System

When we say that a control system maintains a controlled variable constant, we are only approximately right. First, the effect of a disturbance is not corrected immediately; there is a latency, or dead time. Secondly, the effect of a disturbance is not corrected completely; there is a residual change. The response of a control system may be represented graphically. There is a large variety of responses, some of which have been shown in Figures 1.11A and B. The accuracy and promptness of control systems varies a lot. For example, the blood pressure regulatory system is not as accurate as the systems for regulating body temperature or the pH of blood.

Additional Complexities in Control Systems

Many biological control systems are more complex than the relatively simple systems described above. Some features which introduce additional complexities have been discussed briefly below.

Variable Set Point

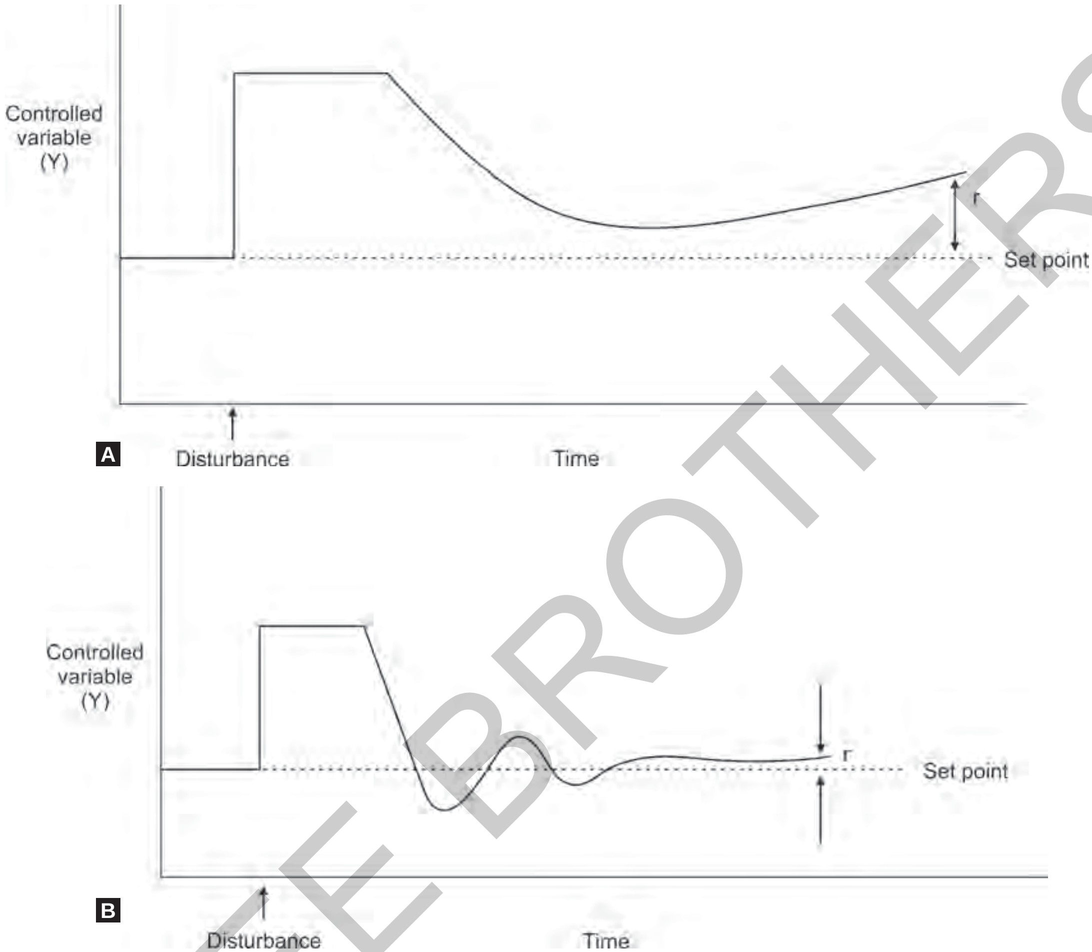
In some control systems the set point is not fixed. A control system with a variable set point is called a servomechanism. The stretch reflex which regulates muscle length is an example of a servomechanism. The resting muscle length of a skeletal muscle is not fixed–it varies with the posture. Every change of posture needs contraction and relaxation of a few muscles. After the change of posture, the muscle length in the new posture becomes the resting length of the muscles involved. Thus contraction of muscles is required mainly for changing the posture; not much contraction is needed for maintaining the posture. This is helpful. First, it saves the energy required for muscle contraction. Second, it enables us to maintain a posture for a long time without getting tired.

Anticipatory Control

In case of some variables which are regulated very efficiently, the control system starts acting in anticipation of a disturbance. The control system starts working when a disturbance is likely; it does not wait for the disturbance to actually take place. This is possible if the control system also makes use of information about factors which may lead to the disturbance. In this way, the correction can be initiated before the value of the controlled variable has deviated much from the set point. The temperature regulatory system of the body is an example of anticipatory control. When we go out in the cold, shivering begins before the temperature of the body has fallen much. The heat generated by shivering ensures that the temperature does not fall much in spite of the cold. How do you think this is achieved?[6] The temperature regulatory system makes use of information coming from the thermoreceptors in the skin. These receptors detect the coldness of the environment as soon as we step out into the cold. By being in touch with these receptors, the temperature regulatory system ‘knows’ that a fall in body temperature is likely. In anticipation of the fall, the system initiates shivering. As a result, the temperature is not allowed to fall much.

[6]You may try answering this question on your own before reading further.

JAYPEE BROTHERS



Figs 1.11A and B Response characteristics of a biological control system. The exact characteristics may vary in different systems. Two contrasting patterns of response have been shown in A and B. In B, the response is oscillatory. r, residual change

JAYPEE BROTHERS

PHYSIOLOGY AS THE BASIS OF MEDICINE

We have seen above that the aim of all parts of the body is to maintain homeostasis. It may look paradoxical that homeostasis (staying the same) needs so much of continuous activity on the part of so many organ-systems. The paradox results from the fact that life processes (e.g. oxidation of nutrients) are dynamic, and our environment poses physical (e.g. temperature), chemical (e.g. pollutants) and biological (e.g. bacteria and viruses) challenges. 'Staying the same' in spite of dynamic life processes and environmental challenges naturally needs effort. This effort is put in by various systems of the body in the form of responses to challenges arising within the body (e.g. rise in carbon dioxide levels due to oxidation of nutrients), and challenges from outside the body (e.g. hot environment). Health depends on the success of these responses. When the responses are inadequate in relation to the challenge, a person falls ill (Fig. 1.12). If the challenge is overwhelming, even a 'very healthy' person may fall sick. On the other hand, a challenge which can normally be handled quite adequately by most individuals might overwhelm a 'less healthy' person, and make him

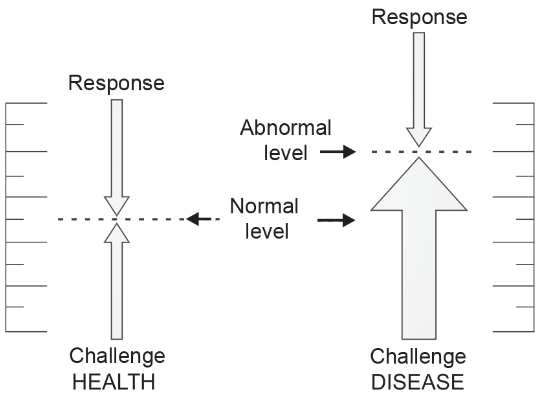
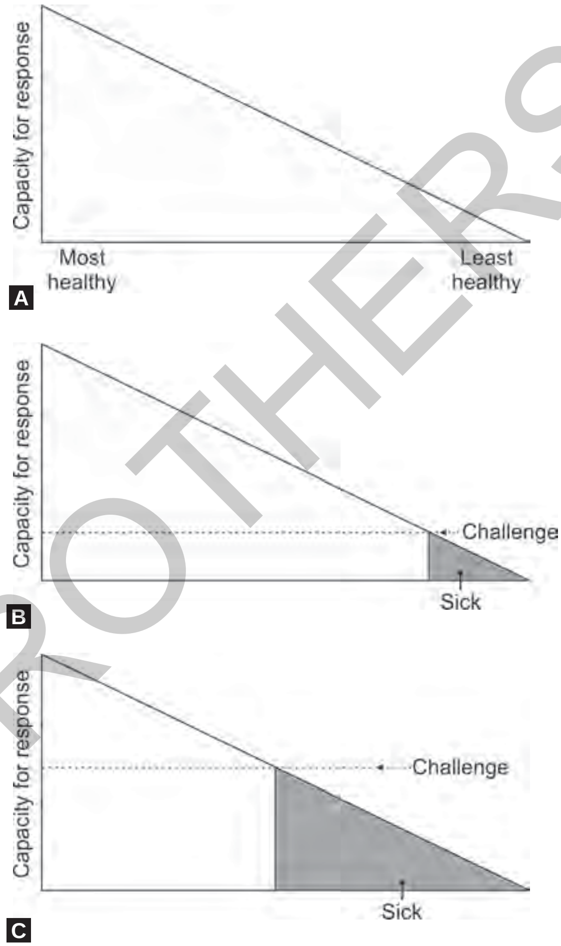


Fig. 1.12 Health and disease are a matter of balance between challenge and response. (Reproduced from Bijlani RL, Manchanda SK. The Human Machine. New Delhi: National Book Trust, 1990, Fig. 1)



Figs 1.13A to C There is no strict dividing line between health and disease (A); There is a continuous spectrum of health, which can proceed to disease under the impact of a strong enough challenge. How many persons fall sick in the face of a challenge depends on the strength of the challenge. The position of an individual within this spectrum depends on his capacity to mount a response to various challenges. The number of persons falling sick under the impact of a challenge have been shown by the stippled area (B and C). (Adapted from Bijlani RL, Manchanda SK. The Human Machine. New Delhi: National Book Trust, 1990, Fig. 2)

sick. Thus, there is no strict dividing line between health and disease. There is a continuous spectrum of health, which can proceed to disease under the impact of a threshold challenge (Figs 1.13A to C).

Once a person is sick, recovery often depends on the same type of responses which operate in good health. For example, fever may be looked upon as the resetting of the thermostat of the body.[7] Therefore when the temperature of a person starts rising towards fever, she may have shivering. This happens because the thermostat is set to a higher level (say, 40°C), and the body temperature is 37°C. Therefore the control system behaves as if the body is cold. It initiates responses which will take the body temperature towards the set point, which is now 40°C. This can be done by shivering, and therefore the person shivers. In the same way, when the person is recovering from fever, she may have sweating. Since the person has recovered, the hypothalamic thermostat is once again set at the normal level of 37°C. But the body temperature is still 40°C. The mismatch between the set point and the body temperature initiates responses for heat loss, such as sweating. As a result of sweating, the temperature is brought down to 37°C, and then sweating stops. In short, there is a lot in common between homeostatic mechanisms which operate in health, and the mechanisms which lead to recovery from disease. A variety of self-healing mechanisms

[7]The seat of the thermostat of the body is a tiny part of the brain called the hypothalamus.

JAYPEE BROTHERS

are built into the body, and these are adequate for getting well again in most situations. This fact had been recognized by Hippocrates as long ago as 400 BC when he stated that the body possesses the means for its recovery from illness.

In light of the above discussion, we can keep ourselves healthy by adopting a two-pronged strategy. First, we should improve the capacity of our body to meet challenges. Secondly, we should try to minimize the extent to which the body is challenged. Both these measures are not mutually exclusive. However, of the two, the first is more important and practical. Adequate and appropriate nutrition, regular physical exercise, and mental peace are the three most important ingredients of the lifestyle that improves the fighting capacity of the body. Ancient disciplines, such as yoga, promote a healthy lifestyle. The second part of the strategy for staying healthy is to avoid needless challenges to the body. This may be done by avoiding inhalation and ingestion of germs, harmful chemicals and pollutants. Further, one should avoid overuse, misuse or abuse of any part of the body. For example, we should not overuse our back by trying to lift a 100 kg weight, misuse our eyes by spending long hours at the computer, or abuse our lungs by smoking.

Doing all this can keep us fairly healthy but is no guarantee against illness. In case of illness, a doctor or nurse usually takes one of the following four measures. First, she reassures the patient that soon everything will be fine. The reassurance is not hollow: it is based on her knowledge of homeostatic mechanisms. Secondly, she tells the patient not to be impatient. This is because she knows that homeostatic mechanisms take time. Thirdly, she suggests some measures which assist the body in its struggle against the disease. For example, she may suggest hot fomentation of an inflamed area so that the accelerated blood flow through the area may increase further and drain away undesirable substances. Or, she may prescribe antibiotics which may kill some disease-causing germs in addition to those killed by the defence mechanisms of the body. And finally, it may be discovered that the disease was due to a deficiency. It could be a dietary deficiency, or deficiency of some physiological substance produced by the body. In that case the doctor or nurse tries to supply the deficient substance in an effort to restore physiological function. For example, in iron deficiency, she gives iron; in water and salt deficiency (as in diarrhea), she gives water and salt; and in insulin deficiency (diabetes), she gives insulin. It is worth observing that in each of the four approaches outlined above, the doctor or nurse works with nature, not against it. And, each of the four approaches needs knowledge of physiology. Truly, physiology forms the basis of medicine.

QUESTIONS

1. a. What constitutes the internal environment?
   b. Why is it called so?
   c. Why is its constancy important?
   d. List the variables which should be maintained constant in the internal environment.
2. Why is negative feedback called so?
3. Give an example of negative feedback.
4. Why do people get high blood pressure if there is a control system for regulating blood pressure?
5. What is positive feedback? Does it have a place in physiological systems?

ANSWERS

1. a. The internal environment consists of the fluid which surrounds the cells. This fluid is called the interstitial fluid (since the interstitial fluid engages in a constant exchange with the plasma, the plasma is also often considered to be a part of the internal environment).
   b. It is called environment because it surrounds the cells (environment means the surroundings). The interstitial fluid forms the surroundings of the cells. Therefore, this fluid is the environment of the cells.
   It is called internal because it is inside the body.
   A common error made by the students is to say that it is called internal because it is

JAYPEE BROTHERS

inside the cells. This is wrong. The internal environment, or the interstitial fluid, is outside the cells, but inside the body. It is an environment because it is outside the cells; it is internal because it is inside the body.

c. Cells get their nutrition from the fluid which surrounds them. Cells also throw their waste products into the fluid which surrounds them. For the cells to function properly, this fluid (the internal environment) should always be able to provide nourishment, and should not have too much of waste products. Further, the temperature, pH and osmolarity of this fluid should also be constantly at a level which is appropriate for the cell. That is why constancy of the internal environment is important.

d. A partial list is as follows:
   - Temperature
   - pH
   - Osmolarity
   - The concentration of glucose, electrolytes, oxygen and carbon dioxide.

2. The product of a control system is its output. The output is ultimately in the form of a certain value for the controlled variable. The value of the controlled variable itself guides the activity of the control system. Thus the output of the control system goes back (feeds back) to the control system to tell it what to do. This feedback results in the control system working in such a way as to negate, or oppose, the disturbance which takes the controlled variable away from the set point. Since the feedback leads to a response from the control system which is opposite (or negative in direction) to the disturbance, it is called a negative feedback system.

   A common error made by the students is to say that it is called negative feedback because it lowers variables, e.g. if the blood glucose rises, the negative feedback system lowers it. This is a wrong answer because the same system also raises blood glucose when it has fallen. When a disturbance raises blood glucose, the system lowers it. When a disturbance lowers blood glucose, the system raises it. The system in both cases is a negative feedback system. 'Negative' only refers to the fact that the response is opposite in direction to the disturbance. Thus the word negative has been used here in an algebraic sense. Fall is negative to a rise; rise is negative to a fall. The negative feedback system can do both—it can lower a variable if it has gone up, and it can raise a variable if it has gone down.

3. The most common example of negative feedback given by students is that of product inhibition. In a chemical reaction,

$$A + B \rightarrow C,$$

   As the concentration of C rises, the reaction slows down. This is a correct example. But this is not the only example of negative feedback in the body. Regulation of blood glucose, blood pressure, blood pH or body temperature is also achieved by negative feedback mechanisms.

4. The conventional explanation for this phenomenon is as follows:

   In high blood pressure, there is initially a narrowing of blood vessels by fatty deposits. This reduces the lumen of blood vessels. Reduction in lumen raises the peripheral resistance. Rise in peripheral resistance raises the blood pressure. Since the rise in blood pressure takes place gradually over a period of years, the receptors for sensing blood pressure (baroreceptors) adapt to the change, i.e. the receptors do not respond any more by activating the mechanisms for lowering the blood pressure. This is in keeping with the traditional assumption that baroreceptors are equipped for responding to acute changes in blood pressure, not to chronic changes. Hence, the baroreceptors have been generally considered useful for short-term regulation of blood pressure, not for long-term regulation.

   But recent work indicates that:

   a. Baroreceptors do have a role in long-term regulation of blood pressure, and

JAYPEE BROTHERS

b. The sensitivity of baroreceptors is reduced in those having high blood pressure.

Thus while it is true that there is a narrowing of arteriolar lumen in high blood pressure, and possibly contributes to high blood pressure, there may be another factor also involved. The reduced sensitivity of baroreceptors might itself contribute to the hypertension directly, and also indirectly by not responding adequately to the effect of the rise in peripheral resistance. Some support for this explanation is available from studies showing that yogic postures which restore baroreceptor sensitivity also help in bringing down the blood pressure of hypertensive patients.

5. In a positive feedback system, the response is in the same direction as the disturbance. A little reflection would show that the effects of positive feedback could be disastrous (try to answer why before you read further). For example, if a person is exposed to heat, a small increase in body temperature above the set point would raise the temperature still further in a positive feedback system. Now this bigger rise above the set point would have a still stronger effect of raising the body temperature. The result eventually would be a runaway increase in the body temperature which keeps rising till the person is dead. Thus only negative feedback systems can bring a variable back towards the set point after the variable has deviated from it. That is why most physiological systems are of the negative feedback type.

However, there are a few situations in the body where positive feedback operates, and serves a useful purpose. For example, uterine contractions during labor push the fetus down towards the cervix. The downward movement of the fetus stretches the cervix. Stretching of the cervix stimulates uterine contraction. Uterine contraction pushes the fetus down. The fetus going down stretches the cervix. Stretching of the cervix stimulates uterine contraction, and so on. The sequence continues till the baby has been delivered. Here the downward movement of the fetus is a change from a 'set position' which has been brought about by uterine contraction (the disturbance). A negative feedback system would inhibit further uterine contraction, and would try to restore the fetus to the set position. But instead, here the response of the system is to stimulate contraction of the uterus, which in turn moves the fetus further away from its set position in the uterus. Therefore, this is a positive feedback system. But here it serves a purpose. The purpose of labor is to move the fetus towards the vaginal opening so that it can be delivered.

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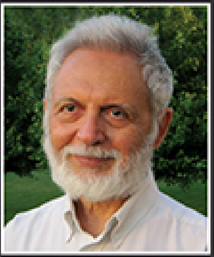

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